TELESAT LOW EARTH ORBIT NON-GEOSTATIONARY SATELLITE SYSTEM

TECHNICAL INFORMATION SUPPLEMENT TO SCHEDULE S

A.1 SCOPE AND PURPOSE

On August 4, 2021, the satellite division of the FCC invited applications and petitions for declaratory ruling for NGSO satellite operations in the 37.5-40.0 GHz, 40.0-42.0 GHz, 47.2-50.2 GHz and 50.4-51.4 GHz bands (referred to herein as the "V-band").

This document is the technical appendix to Telesat's petition for a declaratory ruling authorizing a second round V-band non-geostationary low-earth orbit (LEO) satellite network. The network will be deployed in two main stages: the first stage, referred to as the "Global Constellation", will consist of 298 satellites; the second stage, referred to as the "Augmented Constellation", will add 1373 satellites. This brings the total number of satellites to 1671, and is generally referred to as "the Second Round V-band LEO Constellation", or simply "the Constellation" in this document.

The technical information of the Constellation, as required by paragraph (d) of Section 25.114[1] of the FCC's rules, is included in this document. The information specified in paragraph (c) of that section has been provided in Schedule S and is not repeated here.

[1] 47 C.F.R. §25.114

A.2 OVERALL DESCRIPTION

The design concept for the Constellation is consistent with the design for the Telesat Lightspeed Ka-band system.[2] The Constellation provides 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 (OISLs) and connects to the terrestrial internet through strategically located gateways. Gateways will have access to every satellite in the Constellation at all times either directly or through other satellites via OISLs. The OISL parameters are shown in Table A.2-1 below.

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[2] *Telesat Canada Petition for Declaratory Ruling to Grant Access to the U.S. Market for Telesat's NGSO Constellation, IBFS File No. SAT-PDR-20161115-00108,* Order and Declaratory Ruling, 32 FCC Rcd 9663 (2017). *See also Telesat LEO Inc., Application for Modification of Market Access Authorization*, IBFS File No. SAT-MPL-20200526-00053 (filed May 26, 2020), *as amended* IBFS File No. SAT-APL-20210104-00002.

Table A.2-1 – OISL terminal parameters

Parameter	Channel	
	Communication	Beacon
Wavelength	1536.61 nm / 1553.33 nm	976 nm +/- 5 nm
Laser radiated average power	1.6 W	0.3 W (nominal) / 0.5 W (long range)
Duty cycle	100 % (always on)	100 % (always on)
Beam diameter at emitter	13 cm	1 cm
Beam divergence (1 sigma +/-)	11 μrad	87 μrad
Power margin at the receiver at maximum operating distance of 5500 km for a nominal mode	2.5 dB	1.6 dB
Power margin at the receiver at maximum operating distance of 7800 km for a long range	3 dB	1.6 dB

Selected gateways will also provide the necessary telemetry, tracking and command (TT&C) links to ensure redundant and reliable control of the Constellation. Each satellite has four steerable spot beams to communicate with the gateways, and a set of Direct Radiating Array ("DRA") antennas providing up to 48 fully independent, shapeable and steerable user beams. One of the user beams is dedicated to the network entry process for users. A Network Entry User Beam is activated periodically and steered to cover the field of view of a satellite over a certain period of time. An integrated Constellation Network Operating System ("CNOS") allocates resources (power, bandwidth, beam size, etc.).

Deployment will occur in phases. The first phase will provide global coverage with 298 satellites (the "Global Constellation"); while the second phase will be deployed to meet capacity demand, and over time will add 1373 satellites to the Global

Constellation to bring the total to 1671 satellites (the "Augmented Constellation"). The Second Round V-band LEO Constellation is designed to provide additional communications capacity to Telesat's NGSO services through new satellites that will be separate from the Ka-band satellites, hence the V-band constellation will be separate from the Ka-band constellation. Table A.2-2 provides a summary of the orbital parameters of the Global Constellation and the Augmented Constellation.

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

Parameter		Global Constellation (298)	Augmented Constellation (1671)
Polar Sub-Constellation	Orbital planes	6	27
	Satellites per plane	13	13
	Inclination (deg)	98.98	98.98
	Altitude (km)	1015	1015
	Total satellites	78	351
Inclined Sub-Constellation	Orbital planes	20	40
	Satellites per plane	11	33
	Inclination (deg)	50.88	50.88
	Altitude (km)	1325	1325
	Total satellites	220	1320
Total satellites		298	1671

This application is for V-band frequencies, as indicated in Table A.2-3 below, for gateway links, user links and TT&C links. The specific TT&C frequencies are provided in the Schedule-S that accompanies this technical narrative.

Table A.2-3: Frequency bands

Gateway and User Links		
Direction	Lower Frequency Limit (GHz)	Upper Frequency Limit (GHz)
Downlink	37.5	40.0
	40.0	42.0
Uplink	47.2	50.2
	50.4	51.4

<u>37.5-40 GHz frequency band</u>

According to footnote NG63 of the FCC Table of Frequency Allocations, in the band 37.5-40 GHz earth station operations in the fixed-satellite service (space-to-Earth) shall not claim protection from stations in the fixed and mobile services, except where individually licensed earth stations are authorized. Section 25.202[3] of the Commission's Rules states that use of the band 37.5-40 GHz by the fixed-satellite service is limited to individually licensed earth stations and that satellite earth station facilities in this band may not be ubiquitously deployed.

Telesat's use of the band 37.5-40 GHz for the Constellation in the U.S. will comply with footnote NG63 and Section 25.202. In addition, the FCC allocated the frequency band 37.5-40 GHz to Upper Microwave Flexible Use Services (UMFUS) while

[3] 47 C.F.R. §25.202(a)(1)(ii).

still allowing fixed-satellite services to share this band with the UMFUS through several mechanisms. Telesat's use of the frequency band 37.5-40 GHz in the U.S. will comply with the FCC mechanisms for sharing with the UMFUS,[4] including Section 25.136.[5]

40.0-42.0 GHz frequency band

Telesat's use of the 40.5 – 42.5 GHz band will comply with footnote US211. Radio Astronomy observations in the 42.5 – 43.5 GHz band will be protected from harmful interference through stringent control of out-of-band interference from the satellite transmitters.

47.2-50.2 GHz frequency band

Telesat's use of the 47.2 – 50.2 GHz band will comply with footnote US342. Radio Astronomy observations will be protected from harmful interference from earth station transmitters consistent with the relevant provisions of the ITU *Radio Regulations*.

50.4-51.4 GHz frequency band

The frequency band 50.4-51.4 GHz is allocated to fixed-satellite service (Earth-to-space) in the FCC Table of Frequency Allocations. Telesat's operation of the Constellation will be in compliance with the footnote US156 of the FCC Table of Frequency Allocations which states that "In the bands 49.7-50.2 GHz and 50.4-50.9 GHz, for earth stations in the fixed-satellite service (Earth-to-space), the unwanted emissions

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[4] *See Use of Spectrum Bands Above 24 GHz for Mobile Radio Services*, Report and Order and Further Notice of Proposed Rulemaking, 31 FCC Rcd 8014 (2016).

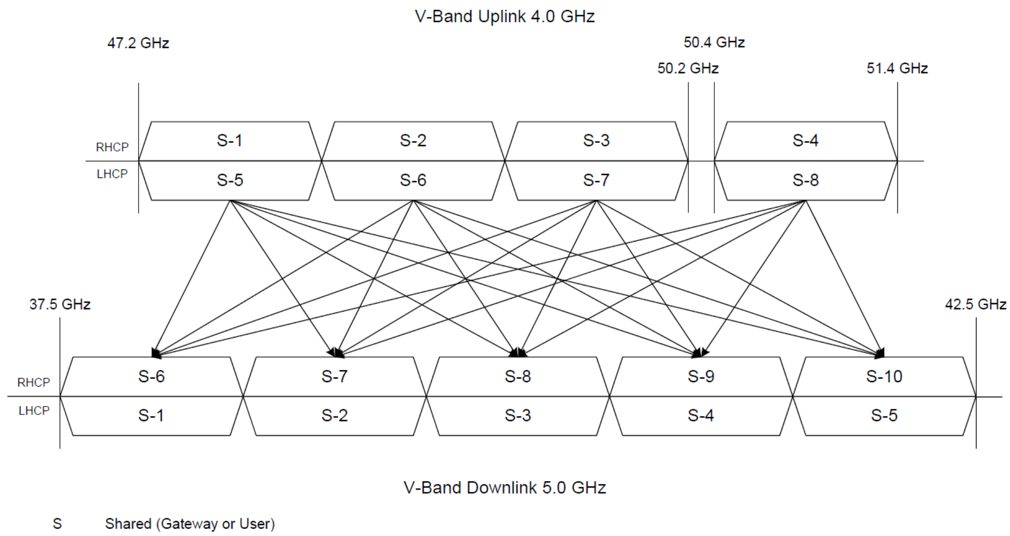
[5] 47 C.F.R. §25.136

power in the band 50.2-50.4 GHz shall not exceed -20 dBW/ 200 MHz (measured at the input of the antenna), except that the maximum unwanted emissions power may be increased to -10 dBW/200 MHz for earth stations having an antenna gain greater than or equal to 57 dBi. These limits apply under clear-sky conditions. During fading conditions, the limits may be exceeded by earth stations when using uplink power control."

Section 25.114(d)(1) of the Commission's Rules requires an explanation of how the uplink frequency bands are connected to the downlink frequency bands. The frequency bands of the Constellation are listed in Table A.2-3. The Constellation satellites will use on-board processing and, as part of the on-board processing, any uplink frequency band segment will be able to be connected to any downlink frequency band segment, as shown in Figure A.2-1. Each satellite will have an IP network router and optical inter-satellite link terminals so that any user or any gateway can be connected to any other user or gateway. Thus, any uplink frequency band received from any user or any gateway can be connected to any downlink frequency band and transmitted to any user or any gateway.

The polarization used for all signals will be circular. Frequency reuse will be exploited through the use of orthogonal polarization and geographical isolation of the beams.

Figure A.2-1: Frequency bands



A.3 SPACE STATION ANTENNA GAIN CONTOURS

Space station antenna gain information applicable to the Constellation is provided in a GIMS database attached to Schedule S. This section supplements Schedule S, in accordance with Section 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.3-1: Linkage between beams in the GIMS database and Schedule S

Orbit type	Beam type	Direction	GIMS	Schedule S
Polar	Gateway	Uplink	GWPOLRX	G1P1, G1P2, G2P1, G2P2
Inclined	Gateway	Uplink	GWINCRX	G1P1, G1P2, G2P1, G2P2
Polar	Gateway	Downlink	GWPOLTX	N1P1, N1P2
Inclined	Gateway	Downlink	GWINCTX	N1P1, N1P2
Polar	User Station	Uplink	USRPOLRX	F1P1, F1P2, F2P1, F2P2
Inclined	User Station	Uplink	USRINCRX	F1P1, F1P2, F2P1, F2P2
Polar	User Station	Downlink	USRPOLTX	M1P1, M1P2
Inclined	User Station	Downlink	USRINCTX	M1P1, M1P2

Table A.3-2 provides a description of the gateway and user beams specified in Schedule S. Since all gateway beams have identical technical capabilities, as do all user beams, only one beam of each type is provided in Schedule S.

Table A.3-2 also shows how the gain contours of the GIMS database (attached to the Schedule S) are related to the satellite beams. The GIMS database includes the antenna gain contours when the peak antenna gain is pointed at nadir for one polar orbit satellite location and one inclined orbit satellite location. The satellite beams are steerable; therefore, as required by Section 25.114(c)(4)(vi), the contours that would result from moving the beam peak around the limit of the effective beam peak area and the 0 dB relative antenna gain isoline have also been included in the GIMS database. Since the user beams are also shapeable, in the downlink direction the gain contours for the beam configuration that results in the highest EIRP have been provided, and in the uplink direction the gain contours of the configuration that results in the smallest gain-to-temperature ratio have been provided, as required by Section 25.114(c)(4)(vi).

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

Beam Description	Beam ID	Notes
Uplink Gateway RHCP polarization	G1P1 and G2P1	Beam ID G1P1 and G2P1, for 47.2-50.2 and 50.4-51.4 GHz, respectively
Uplink Gateway LHCP polarization	G1P2 and G2P2	Beam ID G1P2 and G2P2, for 47.2-50.2 and 50.4-51.4 GHz, respectively
Downlink Gateway RHCP polarization	N1P1	Beam ID N1P1 for 37.5- 42.0 GHz
Downlink Gateway LHCP polarization	N1P2	Beam ID N1P2 for 37.5- 42.0 GHz
Uplink User Station RHCP polarization	F1P1 and F2P1	Beam ID F1P1 and F2P1, for 47.2-50.2 and 50.4-51.4 GHz, respectively
Uplink User Station LHCP polarization	F1P2 and F2P2	Beam ID F1P2 and F2P2, for 47.2-50.2 and 50.4-51.4 GHz, respectively
Downlink User Station RHCP polarization	M1P1	Beam ID M1P1 for 37.5- 42.0 GHz
Downlink User Station LHCP polarization	M1P2	Beam ID M1P2 for 37.5- 42.0 GHz

A.4 INTERFERENCE ANALYSIS

This section addresses the compliance of the Second Round V-band LEO Constellation with the ITU Radio Regulations (RR) Article **21** and RR Article **22**.

A.4.1 Compliance with Article 21 and Section 25.208 PFD limits

The downlink frequency bands of the Constellation are in the 37.5-42 GHz band. Different portions of this band are subject to different PFD limits. The Constellation will comply with applicable PFD limits in Article **21**[6] of the ITU Radio Regulations, as

[6] Table **21-4** of the ITU *Radio Regulations*

well as those in Section 25.208 of the FCC's rules.[7] Paragraph (r) of Section 25.208 includes two sets of PFD limits for NGSO satellites in the band 37.5-40 GHz, one set under assumed free space conditions and one set under rain-fade conditions. Paragraphs (s) and (t) of Section 25.208 include a third set of PFD limits for all conditions, for the 40.0-40.5 GHz and 40.5–42 GHz bands, respectively.

The applicable ITU and FCC limits are summarized in Tables A.4.1-1 and A.4.1-2, respectively.[8]

Table A.4.1-1: Article 21 Applicable PFD limits

Frequency band	Limit in dB (W/m²) for angles of arrival (δ) above the horizontal plane			Reference bandwidth
	0°-5°	5°-25°	25°-90°	
37.5-40 GHz	−120[10, 16]	−120 + 0.75(δ − 5)[10,16]	−105[10, 16]	1 MHz
40-40.5 GHz	-115	-115 + 0.5(δ − 5)	−105	1 MHz
40.5-42 GHz	-115[10, 16]	-115 + 0.5(δ − 5)[10,16]	−105[10, 16]	1 MHz

[10] **21.16.4**: The values given in this table entry shall apply to emissions of space stations of non-geostationary satellites in systems operating with 99 or fewer satellites. Further study concerning the applicability of these values is necessary in order to apply them to systems operating with 100 or more satellites. (WRC-2000)
[16] **21.16.14**: When addressing the sharing conditions between the fixed service and the fixed-satellite service in the bands 37.5-40 GHz and 40.5-42.5 GHz, the power flux-density at the Earth's surface from any FSS satellite should be no greater than the level(s) required to meet the FSS link availability and performance objectives of the subject applications, taking into account the technical and operational requirements of the overall design of the satellite network. In any case, the levels shall not exceed the applicable power flux-density limits in Table **21-4**. (WRC-03)

Table A.4.1-2: Section 25.208 Applicable PFD limits

Type of PFD limit	Frequency band	Limit in dB (W/m²) for angles of arrival (δ) above the horizontal plane			Reference bandwidth
		0°-5°	5°-25°	25°-90°	
Clear-sky	37.5 – 40 GHz	−132	−132 + 0.75(δ − 5)	−117	1 MHz
Rain-fade	37.5 - 40 GHz	−120	−120 + 0.75(δ − 5)	−105	1 MHz
Clear-sky	40 – 40.5 GHz	-115	-115 + 0.5(δ − 5)	−105	1 MHz
Clear-sky	40.5 – 42 GHz	-115	-115 + 0.5(δ − 5)	−105	1 MHz

[7] 47 C.F.R. §25.208.

[8] Telesat notes that although the ITU *Radio Regulations* at **21.16.4** limits applicability to 99 or fewer satellites, no such limitation pertains in §25.208 of the Commission's Rules.

Comparing the values in Tables A.4.1-1 and A.4.1-2 above, overall the limits in Table A.4.1-2 reflect the more stringent PFD limits with which the Constellation must comply.

The minimum elevation angle at which both user and gateway links will operate is 10 degrees. This means that for any angle of arrival smaller than 10 degrees, any given point on the ground will be radiated with power emitted by the satellite antenna off-axis with respect to its boresight. The minimum satellite antenna gain discrimination values for angles of arrival smaller than 10 degrees for the polar and inclined sub-constellations are summarized in Table A.4.1-3.

Table A.4.1-3: Satellite antenna gain discrimination for the polar and inclined sub-constellations, for angles of arrivals at 10 deg and below

Ground elevation angle (deg)		10	9	8	7	6	5	4	3	2	1	0
Satellite antenna gain discrimination from peak (dB)	(Polar sub-constellation)	0.0	-0.3	-1.2	-2.4	-4.0	-5.6	-7.3	-8.8	-10.0	-10.7	-11.0
	(Inclined sub-constellation)	0.0	-0.3	-0.9	-1.9	-3.0	-4.2	-5.3	-6.4	-7.2	-7.7	-7.9

<u>**The Polar Sub-Constellation**</u>

Frequency band 37.5-40 GHz

Under assumed clear sky conditions, the Polar Sub-Constellation's maximum EIRP density is -48.7 dB(W/Hz). Considering the minimum satellite antenna gain discrimination values indicated in Table A.4.1-3, the applicable PFD limits and the calculated PFD levels at select angles of arrival are shown in Table A.4.1-4. Under rain-fade conditions, the maximum EIRP will be increased to compensate for rain-fade, but the downlink EIRP density will not exceed -36.7 dB(W/Hz). The applicable PFD limits and the calculated PFD at select angles of arrival limits are shown in Table A.4.1-5.

Table A.4.1-4 Polar Sub-Constellation PFD, Clear Sky Conditions, 37.5-40 GHz

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)	Antenna gain discrimination (dBc)	Net Calculated PFD dB(W/m^2/MHz)
5	-132	-129.7	-5.6	-135.3
10	-128.3	-128.5	0	-128.5
15	-124.5	-127.3	0	-127.3
20	-120.8	-126.2	0	-126.2
25	-117	-125.2	0	-125.2
90	-117	-119.7	0	-119.7

Table A.4.1-5: Polar Sub-Constellation PFD, Rain-Fade Conditions, 37.5-40 GHz

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)	Antenna gain discrimination (dBc)	Net Calculated PFD dB(W/m^2/MHz)
5	-120	-117.7	-5.6	-123.3
10	-116.3	-116.5	0	-116.5
15	-112.5	-115.3	0	-115.3
20	-108.8	-114.2	0	-114.2
25	-105	-113.2	0	-113.2
90	-105	-107.7	0	-107.7

Frequency band 40-42 GHz

When operating in this frequency band the Polar Sub-Constellation's maximum EIRP density will be -32.8 dB(W/Hz). The applicable PFD limits, which are applicable under all conditions, and the calculated PFD at select angles of arrival, considering the minimum satellite antenna gain discrimination values indicated in Table A.4.1-3, are shown in Table A.4.1-6.

Table A.4.1-6 Polar Sub-Constellation PFD, All Conditions, in 40-42 GHz

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)	Antenna gain discrimination (dBc)	Net Calculated PFD dB(W/m^2/MHz)
5	-115	-113.9	-5.6	-119.5
10	-112.5	-112.7	0	-112.7
15	-110	-111.5	0	-111.5
20	-107.5	-110.4	0	-110.4
25	-105	-109.4	0	-109.4
90	-105	-103.9	0	-103.9

In all cases, the calculated PFD is lower than the applicable PFD limit. Therefore, the Polar Sub-Constellation is compliant with the limits stated in Section 25.208 of the Commission's rules.

<u>**The Inclined Sub-Constellation**</u>

Frequency band 37.5-40 GHz

Under assumed clear sky conditions, the Inclined Sub-Constellation's maximum EIRP density is -47.2 dB(W/Hz). Considering the minimum satellite antenna gain discrimination values indicated in Table A.4.1-3, the applicable PFD limits and the calculated PFD at select angles of arrival using are shown in Table A.4.1-7. Under rain-fade conditions, the maximum EIRP will be increased to compensate for rain-fade, but the downlink EIRP density will not exceed -35.2 dB(W/Hz). The applicable PFD limits and the calculated PFD at select angles of arrival limits are shown in Table A.4.1-8.

Table A.4.1-7: Inclined Sub-Constellation PFD, Clear Sky Conditions, 37.5-40 GHz

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)	Antenna gain discrimination (dBc)	Net Calculated PFD dB(W/m^2/MHz)
5	-132	-129.8	-4.2	-134.0
10	-128.3	-128.7	0	-128.7
15	-124.5	-127.7	0	-127.7
20	-120.8	-126.7	0	-126.7
25	-117	-125.8	0	-125.8
90	-117	-120.6	0	-120.6

Table A.4.1-8: Inclined Sub-Constellation PFD, Rain Fade Conditions, 37.5 -40 GHz

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)	Antenna gain discrimination (dBc)	Net Calculated PFD dB(W/m^2/MHz)
5	-120	-117.8	-4.1	-121.9
10	-116.3	-116.7	0	-116.7
15	-112.5	-115.7	0	-115.7
20	-108.8	-114.7	0	-114.7
25	-105	-113.8	0	-113.8
90	-105	-108.6	0	-108.6

Frequency band 40-42 GHz

When operating in this frequency band, and considering the minimum satellite antenna gain discrimination values indicated in Table A.4.1-3, the Inclined Sub-Constellation's maximum EIRP density will be -31.2 dB(W/Hz). The applicable PFD limits and the calculated PFD at select angles of arrival are shown in Table A.4.1-9.

Table A.4.1-9 Inclined Sub-Constellation PFD, All Conditions, in 40-42 GHz

Angle of Arrival (deg)	PFD limit in dB(W/m²/MHz)	Calculated PFD dB(W/m²/MHz)	Antenna gain discrimination (dBc)	Net Calculated PFD dB(W/m²/MHz)
5	-115	-113.8	-4.2	-118.0
10	-112.5	-112.7	0	-112.7
15	-110	-111.7	0	-111.7
20	-107.5	-110.7	0	-110.7
25	-105	-109.8	0	-109.8
90	-105	-104.6	0	-104.6

In all cases, the calculated PFD is lower than the applicable PFD limits. Therefore, the Inclined Sub-Constellation is compliant with the limits stated in Section 25.208 of the Commission's rules.

A.4.2 Compliance with Article 22 limits

The limits in the bands within which Telesat is applying to operate, were developed during WRC-19 following the studies carried out under WRC-19 Agenda Item 1.6. As a result, Articles **22.5L** and **22.5M** were adopted in the Radio Regulations. Telesat will comply with the ITU single-entry limits included in Article **22.5L**[9] and will engage in the coordination process associated with ensuring that the aggregate limits in Article **22.5M**[10] are met. Telesat also will comply with Section 25.289 of the

[9] To comply with Article **22.5L**, the Constellation will be operated such that it shall not exceed a single-entry increase of 3% of the time allowance for the C/N value associated with the shortest percentage of time specified in the short-term performance objective of the generic geostationary-satellite orbit reference links; and a single-entry permissible allowance of at most 3% reduction in time-weighted average spectral efficiency calculated on an annual basis for the generic geostationary-satellite orbit reference links using adaptive coding and modulation.

[10] To comply with Article **22.5M**, the Constellation will be operated such that it shall not exceed the aggregate increase of 10% of the time allowances for the appropriate C/N values as specified in the article; and a reduction of 8% in a calculated annual time-weighted average spectral efficiency for the specified geostationary-satellite orbit links using adaptive coding and modulation, taking into account that the methodology ensures that the degradation of time-weighted average spectral efficiency on each link is lower than the maximum permissible reduction.

Commission's rules,[11] which implements Article **22.2** of the Radio Regulations and addresses requirements for NGSO systems to avoid unacceptable interference to, and to refrain from claiming protection from, GSO networks.

A.5. SECTION 25.114(d)(6): PUBLIC INTEREST CONSIDERATIONS IN SUPPORT OF GRANT

The Constellation will provide secure, high speed, and low latency communications in the United States as well as the rest of the globe. Due to its efficient design, the Constellation will provide extensive flexibility in satisfying customer requirements that may not be well satisfied by other services such as GSO or terrestrial services. Therefore, the grant of this application will be in the public interest.

A more comprehensive discussion of public interest considerations is provided in the legal narrative portion of this application.

A.6. LINK BUDGETS

The Constellation will use on-board processing and therefore uplink and downlink link budgets are analyzed independently. To make efficient use of the spectrum, the Constellation will use adaptive modulation and coding based on the signal-to-noise-plus-interference ratio. Example clear-sky uplink and downlink budgets for the Constellation are provided in Table A.6.1-1 and

Table A.6.1-2. It should be noted that the link budgets of Table A.6.1-1 and

Table A.6.1-2 are sample link budgets and in practice the Constellation Network Operating System (CNOS) will select the proper modulation and coding scheme for

[11] 47 C.F.R. §25.289

each of the downlink and uplink communication links based on the actual levels of the signal-to-noise-plus-interference ratio for the link. No adjacent satellite interference (ASI) has been considered from other satellite networks in the sample link budgets due to the time varying nature of ASI in the V-band NGSO environment.

Table A.6.1-1: Sample clear-sky uplink link budgets

	Forward Link		Return Link	
Orbit type	Polar Orbit	Inclined Orbit	Polar Orbit	Inclined Orbit
TX Earth Station Location	Inuvik, NT, Canada (68.4N,133.7W)	Allan Park, ON, Canada (44.2N,80.9W)	Shishmaref, AK, USA (66.2N, 166.1W)	Bismarck, ND, USA (46.8N, 100.8W)
Emission Bandwidth [kHz]	10000	10000	10000	10000
Modulation	256APSK 3/4	256APSK 31/45	256APSK 31/45	64APSK 4/5
Information (bit) rate [kbps]	57700	53000	53000	46300
Frequency [GHz]	49	49	49	49
Earth Station antenna diameter [m]	1.8	1.8	0.6	0.6
Earth Station antenna gain [dBi]	57.1	57.1	47.5	47.5
Antenna feed flange power density [dB(W/Hz)]	-76.5	-76.0	-72.0	-69.5
Antenna feed flange power [dBW]	-6.5	-6.0	-2.0	0.5
Earth Station antenna elevation angle [deg]	37	28	41	26
Earth Station to Satellite Distance [km]	1525	2254	1429	2341
Free-Space Loss [dB]	189.9	193.3	189.3	193.6
Satellite RX antenna gain towards the TX Earth Station [dBi]	41.38	40	40	40
Satellite Rx system noise temperature [K]	1200.0	1200.0	1200.0	1200.0
Attenuation due to Atmospheric Gases [dB]	2.50	3.17	2.29	3.40
Noise temperature increase due to Atmospheric Gases [K]	127.1	150.4	118.9	157.5
Thermal C/N [dB]	26.9	21.9	21.3	18.3
C/I (Xpol) [dB]	25.0	25.0	25.0	25.0
C/I (IM) [dB]	25.0	25.0	25.0	25.0
C/(N+I) [dB]	20.8	18.9	18.6	16.7
Required C/(N+I) [dB]	19.6	18.1	18.1	15.9
Margin [dB]	1.2	0.8	0.5	0.9

Table A.6.1-2: Sample clear-sky downlink link budgets

	Forward Link		Return Link	
Orbit type	Polar Orbit	Inclined Orbit	Polar Orbit	Inclined Orbit
RX Earth Station Location	Shishmaref, AK, USA (66.2N, 166.1W)	Bismarck, ND, USA (46.8N, 100.8W)	Inuvik, NT, Canada (68.4N,133.7W)	Allan Park, ON, Canada (44.2N,80.9W)
Emission Bandwidth [kHz]	10000	10000	10000	10000
Modulation	32APSK 3/4	16APSK 25/36	64APSK 5/6	64APSK 4/5
Information (bit) rate [kbps]	36200	26800	48200	46300
Frequency [GHz]	41	41	41	41
Downlink EIRP density [dB(W/Hz)]	-46.0	-45.5	-46.5	-45.5
Downlink EIRP [dBW]	24.0	24.5	23.5	24.5
Earth Station antenna elevation angle [deg]	40.9	26.2	37.6	28.2
Earth Station to Satellite Distance [km]	1429.0	2341.0	1505.0	2254.0
Free-Space Loss [dB]	187.8	192.1	188.2	191.8
RX Earth Station antenna diameter [m]	0.6	0.6	1.8	1.8
RX Earth Station antenna gain [dBi]	46.0	46.0	55.5	55.5
RX Earth Station system noise temperature [K]	300	300	300	300
Attenuation due to Atmospheric Gases [dB]	0.69	1.02	0.74	0.95
Noise temperature increase due to Atmospheric Gases [K]	42.4	60.7	45.3	57.1
Thermal C/N [dB]	14.8	10.4	23.3	20.4
C/I (Xpol) [dB]	25.0	25.0	25.0	25
C/I (IM) [dB]	20.0	20.0	20.0	20
C/(N+I) [dB]	13.3	9.8	17.5	16.5
Required C/(N+I) [dB]	12.7	9.3	16.6	15.9
Margin [dB]	0.6	0.6	0.9	0.7

A.7. ITU FILINGS AND SHARING WITH OTHER SERVICES

The Constellation is licensed through the Canadian administration. The relevant ITU filings are CANSAT-LEO-V, TELSTAR-LEO-V-1 and TELSTAR-LEO-V-2. Telesat may submit to the ITU through Canada additional networks as necessary.

A.8. COMPLIANCE WITH SECTION 25.202(g)

The frequency and bandwidth of the telemetry, tracking, and command (TT&C) signals of the V-band LEO Constellation have been provided in the Schedule S. The on-axis and off-axis EIRP density levels of TT&C signals will not be more than the on-axis and off-axis EIRP density levels of the signals of the service links, in both the uplink and downlink directions. The methodology that is used for protecting other services applies identically to both the user communication signals and the TT&C signals. Therefore, the interference from the TT&C signals into other services will be at the same level as, or less than, the interference from the communication traffic, and neither the TT&C nor the communication links will cause any harmful interference into other services. The TT&C signals of the V-band LEO Constellation also require no greater protection from interference than the communications traffic. The operation of all frequency bands of the V-band LEO Constellation satellite network, including the communication traffic and the TT&C, will be coordinated in accordance with applicable FCC and international requirements.

A.9. SECTION 25.114(d)(14): DESCRIPTION OF THE DESIGN AND OPERATIONAL STRATEGIES THAT WILL BE USED TO MITIGATE ORBITAL DEBRIS

Telesat has been operating satellites for decades and has a proven record of responsible spacecraft operation. Telesat is subject to direct regulatory oversight by the Canadian licensing authority, Innovation, Science and Economic Development (ISED) Canada. The applicable Canadian regulation is contained in CPC-2-6-02, Issue 4, Licensing of Space stations, issued June 2017[12]. Specifically, the regulation states that for non-geostationary satellites licensing applicants must submit a plan for de-orbiting their satellites(s) in accordance with best industry practices, noting specifically the United Nations' space debris mitigation guidelines at www.unoosa.org. Further to the ISED requirements, the Constellation will be launched and operated in full compliance with the Commission's rules[13], as elaborated upon below.

Section 25.114(d)(14)(i), Debris release during normal operations, and probability of becoming source of debris due to collisions with small objects

The Constellation satellites will be designed so that during normal operation they will release no debris. The appendage deployment release mechanisms will be designed so as to contain all debris within the mechanism. The materials on the outside will be chosen to be tolerant of radiation and thermal cycling/mechanical fatigue to minimize the risk of release of extraneous material. Items that will not be located within the spacecraft nor shielded (e.g., antennas) will be able to withstand impacts by small debris and meteoroids. All critical components (e.g., computers and control devices) will be located within the structure and shielded from external influences to ensure the spacecraft remains fully controllable from the ground.

[12] https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html

[13] In this document, Telesat addresses the current version of Section 25.114(d)(14) of the Commission's Rules. Telesat notes that revisions to portions of Section 25.114(d)(14) have been adopted but will not be effective until OMB approves them.

Section 25.114(d)(14)(ii), Probability of accidental explosions

Telesat will review failure modes for all equipment to assess the possibility of an accidental explosion onboard the spacecraft. To pre-empt accidental explosion in orbit, Telesat will take specific precautions such as: all pressure vessels (pressurized propellant tanks, heat pipes, Lithium ion batteries etc.) on board will have the appropriate structural margins to failure in accordance with the MIL-Spec requirements used in the industry; all batteries and fuel tanks will be monitored for pressure or temperature variations; the batteries will be operated utilizing a redundant automatic recharging scheme, thereby ensuring that charging terminates normally without building up additional heat and pressure; and alarms in the Telesat Satellite Control Centre (SCC) in Ottawa, ON, Canada, will inform controllers of any anomalous variations. Additionally, long-term trending analysis will be performed to monitor for any unexpected trends.

Once the satellite is moved to the final passive disposal orbit described in section (iv), all stored energy sources onboard the satellite will be removed by venting the remaining propellant and the remaining helium pressurant. All propulsion lines and latch valves will be vented and left open. All battery chargers will be turned off and batteries will be left in a permanent discharge state. All momentum storage devices will be switched off. These steps will ensure that no buildup of energy can occur and eliminate the risk of explosion after the satellite has stopped operating.

Section 25.114(d)(14)(iii), Probability of becoming source of debris due to collisions with large objects

Telesat has a long history of operating from its SCC a fleet of geostationary satellites, and non-geostationary satellites including the Radarsat satellites and Telesat's LEO-1 satellite. As with all the satellites in its fleet, Telesat has assessed and limited the probability of any satellite in the Constellation becoming a source of debris by collisions with large debris or other operational space stations. To protect against collision with other orbiting objects, Telesat shares ephemeris data with the Canadian Space Agency (CSA), the United States 18th Space Control Squadron (18 SPCS) and the Space Data Center (SDC). The Canadian Space Agency provides Probability of Collision (PoC) analysis to determine the need for collision avoidance maneuvers. Collectively, 18 SPCS and the CSA provide notifications to Telesat for any object they see approaching a Telesat satellite, together with assessments of whether avoidance maneuvers are required. With this information Telesat effects maneuvers as required.

Similarly, Telesat will coordinate with other non-geostationary satellite networks to minimize the risk of collision associated with the Constellation satellites. During orbit raise and disposal operations, Telesat will ascertain high probability contacts with active operators through publicly available sources (space-track.org, union of concerned scientists, etc.) and directly contact those operators for co-ordination and reliable notification channels, well in advance of the planned orbit transits. In conjunction with planned elliptical orbit raise and deorbit operations, there is a high likelihood of successful coordination of physical operations with other systems.

The risk of collision with debris of diameter ≥10 cm calculations per NASA DAS model indicates a single failed spacecraft probability of collision of 0.0012 and 0.0002, respectively, over a 12-year period, for the polar and inclined constellations.

It should be noted, moreover, that while this addresses the Commission's hypothetical condition of uncontrolled orbit failures, Telesat fully expects the actual probability of a failed satellite, especially a failure that results in a loss of any maneuver control, to be substantially less. Such reliability will be produced, among other ways, in the redundancy of critical subsystems; including in propulsion, mechanisms, sensors, spacecraft computer and power subsystems; as well as best practices in satellite operation by experienced and well-trained engineering personnel. Telesat has been operating spacecraft for almost 50 years and successfully maneuvered every spacecraft from the operational orbit to the disposal orbit at the end of life.

With regard to other Telesat satellites that are still be in service, given the maneuver capability and other means that Telesat has to identify and avoid collisions with large space objects, based upon Telesat's operational experience, Telesat regards any additional risk as negligible.

A collision probability analysis of satellite injection orbit failures will be carried out once the mission design requirements have matured. More specific analyses will be carried out as part of the final mission design.

All the satellites of the Constellation will have a propulsion system to maintain their orbit. The propulsion system on each satellite will also enable the satellite to make necessary maneuvers to avoid collision with any approaching object. Avoidance of other space objects will be achieved by the satellite firing its thrusters to adjust its position within its control box in order to avoid the other object. The clearance required between space objects is typically about 2 km, and this is significantly smaller than the allowable control box, so that the impact to the mission is minimal or non-existent.

For orbit insertion, the spacecraft will be phased into the final orbits after release from the launcher, with due regard to the debris environment in the transition orbits. The maneuvers will be planned after appropriate conjunction analyses to ensure safe delivery into the operational orbit. By design, the Constellation will have a minimum close approach of 10 km with other satellites. The orbits will be propagated a few days ahead and compared with the data from debris monitoring agencies so that appropriate collision avoidance maneuvers will be undertaken as necessary.

The space station orbit parameters will be maintained as follows:

- Apogee or Perigee Altitude ±300 meters
  - This value is in relation to the target apogee and target perigee, not the mean altitude.
- Inclination ±0.04 degrees
  - This value is in relation to the target mean inclination, not the osculating inclination.
- Right Ascension of the Ascending Node (RAAN) ±1 deg
  - This value is in relation to the target ascending node. For a Walker constellation this is referenced to the key satellite, and not to a particular RAAN (0-360 deg).

- Target values are determined by Walker orbit design and phasing for the inclined constellation.
- Target values are determined by initial polar orbit deployment and phasing for the polar constellation.

The spacecraft will be designed with redundancy so that individual unit faults will not cause the loss of control of the spacecraft. On-board fault protection will ensure isolation between the affected unit(s) and the replacement back-up hardware/systems. As this process will occur within the spacecraft, it will also afford additional protection from command link failures.

Section 25.114(d)(14)(iv), Post-mission disposal plans

At the end of life, each satellite will be de-orbited by re-entering the satellite into the Earth's atmosphere and burning. The de-orbiting has two phases:

In the first phase, the satellite will be moved from its operational orbit to a planned lower orbit, the "Decaying Lower Orbit". The Decaying Lower Orbit will be an orbit with an apogee of less than 1015 km and a perigee of not more than 550 km. Within this range, Telesat has studied highly elliptical orbits of approximately 750 km x 150 km for end-of-life disposal. Telesat notes that the use of a highly elliptical orbit for end of life disposal reflects a design to reduce fuel usage, time in the disposal orbit and risk of debris generation.

In the second phase, the satellite will be left fully passivated as described in section (ii) in the Decaying Lower Orbit which, within 25 years, will result in the re-entry of the satellite into the Earth's atmosphere and burning of the satellite. The design will be consistent with the requirement 4.7.-1 of NASA-STD 8719.14- Process for Limiting Orbit Debris. For each of Telesat's Ka-band and V-band constellations, using the NASA DAS (Debris Assessment Software) for the probability of collision with an object of greater than 10 cm, the collision risk, per satellite for the Telesat studied highly elliptical orbits, rounded to five decimals, is 0.00000. Given that the probability of collision is less than the resolution of the DAS software, the aggregate risk for the constellation would be near zero.

At the time of entry into disposal and passive disposal phase, Telesat will custom design disposal orbit parameters that minimize the probability of collision with all known high value assets in the lower orbits. Telesat is experienced in eccentricity and inclination collocation and probability of collision avoidance strategies. At the planned eccentricity, even a passive disposal strategy, with properly chosen argument of perigee and orbital parameters, will create significant separation. Telesat continues to review and assess other de-orbit strategies as part of its system level engineering trades.

Currently, ISS debris avoidance maneuvers occur once or twice per year with more than 100 catalogued debris objects within a +/- 20 km altitude range. It is expected that the decommissioned satellites from the Constellation, which will have fast decaying orbits during the passive phase of the deorbit, will have an insignificant impact on the ISS collision avoidance activities.

Sufficient (worst case 3-sigma) propellant will be budgeted for the de-orbit maneuvers to insert the spacecraft into the Decaying Lower Orbit, which will ensure re-entry into the Earth's atmosphere and burning up of the satellite.

One of the critical requirements for the satellite design is to ensure the materials, processes and assemblies are selected, designed, and integrated such that the probability of survival of spacecraft components through the re-entry into the Earth's atmosphere is extremely limited. The design will be assessed using NASA DAS (Debris Assessment Software) and modified as required to ensure that the human casualty risk resulting from the de-orbiting of the satellites is less than 1 in 10,000, in accordance with the applicable guidelines.

A.10. LIMITS ON EMISSIONS INTO THE 50.2-50.4 GHz BAND

Earth station emissions into the 50.2-50.4 GHz band will comport with the limits contained in Resolution 750 (Rev. WRC-19) of the ITU Radio Regulations.

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/ *Mohamed Moussa*

Mohamed Moussa
Senior Systems Engineer

4 November 2021