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January 16, 2018

VIA IBFS

Jose Albuquerque
Chief, Satellite Division
International Bureau
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Astro Digital US, Inc.
File No. SAT-LOA-20170508-00071, Call Sign S3014

Dear Mr. Albuquerque:

As required by the Astro Digital US, Inc. ("Astro Digital") license grant, the company submits the attached technical document showing how its operations in the 29.9-30.0 GHz band will comply with the equivalent power flux density ("EPFD") limits specified in Article 22 of the International Telecommunication Union ("ITU") Radio Regulations ("RR").[1] To the extent necessary, because the Astro Digital license specifies that that this compliance showing must be completed using certain ITU EPFD software,[2] Astro Digital requests a waiver of the method by which it must show compliance.[3]

The ITU EPFD software is an elaborate PFD statistical analysis program designed to be used for large non-geostationary orbit ("NGSO") satellite constellations with many satellites and multiple ground stations.[4] The software determines EPFD compliance by simulating long-duration orbit propagation runs to determine under what geometric conditions alignments of NGSO satellites and earth station would occur. The Commission itself has acknowledged that this compliance showing is complex and labor-intensive, and just reviewing the showing can take months.[5] Use of this software to demonstrate EPFD compliance, however, is not necessary for Astro Digital's less complex system.

Astro Digital will uplink data to its thirty satellite system from only a single site located in Svalbard, Norway. As explained in detail in the attached technical showing, that location in the North Pole has extremely limited visibility to the geostationary orbit ("GSO") arc, and in the vast majority of cases the

[1] *See* ITU RR Article 22.
[2] *See* Stamp Grant, File No. SAT-LOA-20170508-00071, at ¶ 5 (granted Dec. 14, 2017, as corrected).
[3] In the event this waiver request is denied, Astro Digital requests additional time to provide the showing requested in paragraph 5 of its license.
[4] *See, e.g.*, *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 (proposing 720 satellites and 50 ground stations); *SpaceX Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System Supplement*, IBFS File No. SAT-LOA-20161115-00118 (proposing 4,425 satellites).
[5] *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, Rule and Order and Notice of Proposed Rulemaking, 32 FCC Rcd 7809 ¶ 41 (2017) ("*NGSO FSS Service Rules R&O*").

mountains due south of the station effectively block all transmissions to the GSO arc. In the few instances where such transmissions may not be blocked, Astro Digital will take certain simple operational steps (*e.g.*, not transmitting at angles of elevation less than 7°) to ensure that its uplink transmissions in the Ka-band frequencies do not exceed the limits specified in Article 22 of the ITU RR. Under such circumstances, Astro Digital submits that demonstration of compliance using the resource- and labor-intensive ITU software is unnecessary.

To the extent necessary, Astro Digital requests that the Commission accept the attached technical analysis as a substitute for the compliance demonstration using the ITU EPFD software or, in the alternative, waive the method of the compliance showing specified in the license grant.[6] The Commission is authorized to grant a waiver under Section 1.3 of the Commission's rules if the requesting party demonstrates good cause for such action.[7] Good cause may be found "where particular facts would make strict compliance inconsistent with the public interest."[8] To make this public interest determination, the waiver cannot undermine the purpose of the rule, and there must be a stronger public interest benefit in granting the waiver than in applying the rule.[9]

The EPFD limits in the ITU Radio Regulations and the Commission license condition requiring a demonstration of compliance with those limits are intended to protect receiving GSO satellites from interference caused by unintended emissions of an NGSO system's earth station.[10] Because Astro Digital demonstrates via an alternative showing that it satisfies the Article 22 limits and protects co-frequency GSO satellites, the purpose of the ITU Radio Regulations and the Astro Digital license condition would not be undermined. Additionally, requiring Astro Digital to divert resources from the development and deployment of its system, when it has demonstrated compliance with the ITU-established EPFD limits, is contrary to the Commission's policy goal "to encourage the rapid deployment of new spacecraft and the optimal utilization of scarce orbital and spectrum resources."[11] For these reasons, Astro Digital submits that good cause exists for waiver of the method for showing compliance with ITU RR Article 22.

Respectfully submitted,

/s/ Tony Lin

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Attachment
cc: Stephen Duall (with attachment)

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[6] *See supra* note 1.

[7] *See* 47 C.F.R. § 1.3.

[8] *See Northeast Cellular Telephone Co. v. FCC,* 897 F.2d 1164, 1166 (D.C. Cir. 1990).

[9] *See WAIT Radio v. FCC,* 418 F.2d 1153, 1157 (D.C. Cir. 1969).

[10] *See NGSO FSS Service Rules R&O* at ¶ 41.

[11] *See, e.g., Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Further Notice of Proposed Rulemaking, 29 FCC Rcd 12116 ¶ 19 (2014); *see also Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Second Report and Order, 30 FCC Rcd 14713 ¶ 53 (2015).

Demonstration of Compliance with
Article 22 of the International Telecommunication Union Radio Regulations

On December 14, 2017, the Federal Communications Commission ("FCC" or the "Commission") granted, in part, a license to Astro Digital U.S., Inc. ("Astro Digital") to operate a non-geostationary satellite orbit ("NGSO") Earth Exploration Satellite Service constellation.[1] The partial grant, *inter alia*, requested that Astro Digital demonstrate compliance with Article 22 of the International Telecommunication Union ("ITU") Radio Regulations ("RR"). Specifically, paragraph 5 of the license grant states:

> Within 30 days of grant of this authorization, Astro Digital must submit to the Commission its input parameters and the simulation output results, using approved ITU EPFD simulation software, demonstrating EPFD compliance with the same ITU Article 22 limits applicable to NGSO FSS operations in the 29.9-30.0 GHz band.[2]

The effective power flux density ("EPFD") limits in the ITU RR Article 22 are intended to protect receiving GSO satellites from interference from the emissions of an NGSO system's earth station. The software is an elaborate PFD statistical analysis program intended to be used for large NGSO satellite constellations with many satellites and multiple ground stations. The software uses long-duration orbit propagation runs, which can take many months to complete, to determine geometric conditions where NGSO satellites and earth station alignments occur, effectively identifying how radiated earth station emissions could arrive at the GSO arc. The Commission itself has acknowledged that this compliance showing is complex and labor-intensive, and just reviewing the showing can take months.[3] Accordingly, demonstrating

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[1] *See* Stamp Grant, IBFS File No. SAT-LOA-20170508-00071 (granted Dec. 14, 2017, as corrected).
[2] *Id*. at ¶ 5.
[3] *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, Rule and Order and Notice of Proposed Rulemaking, 32 FCC Rcd 7809 ¶ 41 (2017).

compliance through use of the ITU-approved software is a resource and time-intensive endeavor.[4]

Astro Digital submits that the circumstances regarding Astro Digital's use of the 29.9-30.0 GHz frequencies are much different than in the case of typical NGSO-FSS systems and do not require the use of ITU simulation software to demonstrate compliance with the ITU established EPFD limits. Astro Digital will uplink data to only thirty spacecraft from a single site at Svalbard, Norway. That location in the North Pole has extremely limited visibility to the geostationary orbit ("GSO") arc, and Astro Digital will take certain simple mitigation steps to further reduce the possibility of causing harmful interference to GSO satellites. For all of these reasons, Astro Digital requests that the Commission accept the following analysis as a demonstration of compliance with the EPFD limits specified in ITU RR Article 22.

I. Factors to be Considered in Protecting the GSO Arc from Potential Interference Caused by the Landmapper System

The Landmapper System has several special constraining characteristics that eliminate the need for statistical, Monte Carlo-like simulations to be carried out. These are:

1) There are only thirty (30) space stations in the constellation.

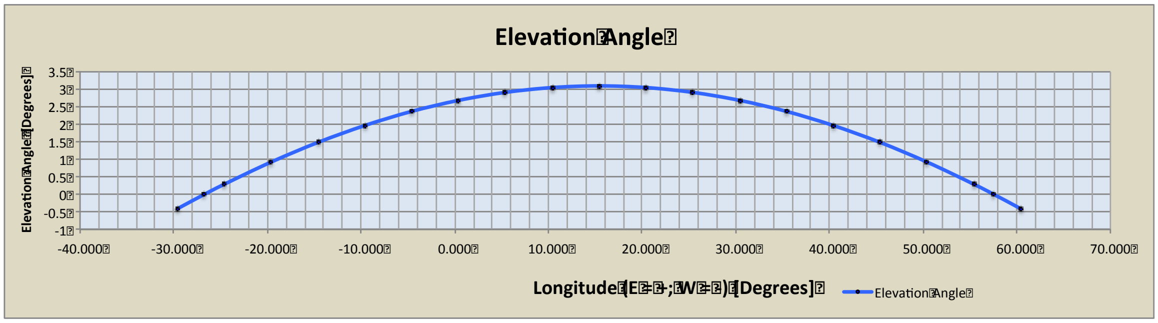
2) There is only one Ka-band earth station location associated with the Landmapper constellation, and it is located at Svalbard, Norway, 78.23° N, 15.41° E.

3) Data is only transmitted to and from the Landmapper satellites from Svalbard during fly-over periods of the satellites, when there are line-of-sight conditions existing between the satellites and this single earth station location. During all other periods throughout the orbits of all satellites the transmitters used in the band 25.5-27.0 GHz and the receivers used in the band 29.9-30.0 GHz will be off.

4) Due to the very high latitude of this earth station, the GSO arc (the locus of all locations where geostationary satellites could be seen from our earth station) is visible only at very low elevation angles and only over a limited range of azimuth angles. This is demonstrated in Figure 1 and Table 1.

[4] Astro Digital understands that more advanced ITU-approved software can be used but at a significant financial cost.

Figure 1: Range of GSO Arc Locations Visible from Svalbard (KSAT) Earth Station



The portion of the arc visible from Svalbard ranges from 26.7° W to 57.5° E longitude. This span of the GSO arc, in longitude, is 84.2°. The maximum elevation angle seen from Svalbard (in the due-south direction) is 3.082°. This elevation angle, of course, is the elevation above the mean earth surface value, not considering local terrain.

Table 1: Range and Angle Characteristics of Geostationary Arc from Svalbard, Norway

	Δlong. from Sat. Stn.: (degrees)	*GEO Arc Longitude: (degrees)*	*E.S. Antenna Elevation: (degrees)*	*E.S. Antenna Azimuth to GEO Arc (degrees)*	*E.S. Antenna Azimuth to NGSO Sat. (degrees)*	*Range (GEO Arc to Svalbard): (kilometers)*
	-45.0	-29.590	-0.407	225.609	45.609	41724.3
	-42.1	-26.725	0.000	222.741	42.741	41679.0
	-40.0	-24.590	0.290	220.601	40.601	41646.7
	-35.0	-19.590	0.920	215.574	35.574	41576.7
	-30.0	-14.590	1.477	210.573	30.573	41514.8
	-25.0	-9.590	1.958	205.470	25.47	41461.6
	-20.0	-4.590	2.358	200.394	20.394	41417.4
	-15.0	0.410	2.673	195.307	15.307	41382.6
	-10.0	5.410	2.899	190.210	10.21	41357.6
	-5.0	10.410	3.036	185.107	5.107	41342.5
Nominal Vector South to GEO Arc	0.0	15.410	3.082	180.000	0.000	41337.4
	5.0	20.410	3.036	174.893	354.893	41342.5
	10.0	25.410	2.899	169.790	349.79	41357.6
	15.0	30.410	2.673	164.693	344.693	41382.6
	20.0	35.410	2.358	159.606	339.606	41417.4
	25.0	40.410	1.958	154.530	334.53	41461.6
	30.0	45.410	1.477	149.470	329.47	41514.8
	35.0	50.410	0.920	144.426	324.426	41576.7
	40.0	55.410	0.290	139.399	319.399	41646.7
	42.1	57.545	0.000	137.259	317.259	41679.0
	45.0	60.410	-0.407	134.391	314.391	41724.3

5) Due to radiofrequency health and safety standards practiced at the KSAT site, the minimum allowable elevation angle at which a transmitting earth station may operate is 5.0°. This means that at Acquisition of Signal ("AOS") or Loss of Signal ("LOS") times, when RF transmissions will initiate or cease, the off-boresight angle between the GSO arc and the Landmapper earth station 5° elevation mask is 1.918°. This occurs when the earth antenna beam heading is 180°, a worst-case scenario. We note, coincidentally, that this is almost exactly the minimum worst-case spacing between two GSO satellites as seen by any FSS earth station. Our earth station -3dB beamwidth is 0.28° and the roll-off of our beam is -31.6 degrees at the arc.

6) The effects of such low elevation angles at this high latitude location are:

a) Blockage of the potentially visible portion of the GSO arc by local terrain features, and
b) Significant excess attenuation of signals radiated toward the arc due to atmospheric gas and water vapor attenuation.

Regarding 6a) above, from the Astro Digital site on Svalbard in the directions subtending the GSO arc, there is a mountain range with peaks that range to more than 5° elevation angles. These geographic features occult the line-of-sight to the arc. Terrain data has been obtained from our ground station operator, Kongsberg Satellite Services AS ("KSAT") which demonstrates that 73% of the potentially visible GSO arc, as seen from the site, is blocked by a mountain range. This blockage means that only 6% of the potential azimuth range (of 360°) at the earth station can see the GSO arc. The total visible arc can be divided into a set of "gaps" where it is possible to have a line-of-sight to a geostationary satellite slot from the KSAT facility.

7) The only times when any energy from the Astro Digital station could reach the GSO arc is when the earth station beam direction is at approximately 5° elevation and at azimuth values associated with the mountain gaps at Svalbard.

Astro Digital believes that these seven constraints limit the potential for interference to GSO satellites operating in Ka-band (assuming they are co-channel and co-polarization) from the Landmapper System. Thus, a straight-forward non-stochastic analysis can be performed. That analysis follows.

II. Landmapper Earth Station PFD Limits

Article 22 of the ITU Radio Regulations at Section 22.5D addresses interference from NGSO earth stations directed toward GSO satellites operating in the fixed satellite service (FSS):[5]

22.5D 3) The equivalent power flux-density[14], epfd↑, produced at any point in the geostationary-satellite orbit by emissions from all the earth stations in a non-geostationary-satellite system in the fixed-satellite service in the frequency bands listed in Table **22-2**, for all conditions and for all methods of modulation, shall not exceed the limits given in Table **22-2** for the specified percentages of time. These limits relate to the equivalent power flux-density which would be obtained under free-space propagation conditions, into a reference antenna and in the reference bandwidth specified in Table **22-2**, for all pointing directions towards the Earth's surface visible from any given location in the geostationary-satellite orbit. (WRC-2000)

Highlighted below is the relevant frequency band in which the Landmapper System will operate.

[5] ITU-RR § 22.5D.

TABLE 22-2 (WRC-03)

Limits to the epfd↑ radiated by non-geostationary-satellite systems in the fixed-satellite service in certain frequency bands[15]

Frequency band	epfd↑ (dB(W/m^2))	Percentage of time epfd↑ level may not be exceeded	Reference bandwidth (kHz)	Reference antenna beamwidth and reference radiation pattern[16]
5 925-6 725 MHz	−183.0	100	4	1.5° Recommendation ITU-R S.672-4, *Ls* = −20
12.5-12.75 GHz 12.75-13.25 GHz 13.75-14.5 GHz	−160	100	40	4° Recommendation ITU-R S.672-4, *Ls* = −20
17.3-18.1 GHz (Regions 1 and 3) 17.8-18.1 GHz (Region 2)[17]	−160	100	40	4° Recommendation ITU-R S.672-4, *Ls* = −20
27.5-28.6 GHz	−162	100	40	1.55° Recommendation ITU-R S.672-4, *Ls* = −10
29.5-30 GHz	−162	100	40	1.55° Recommendation ITU-R S.672-4, *Ls* = −10

The EPFD within the band is limited to -162.0 dBW/m^2/40 kHz and that this EPFD level may not be exceeded 100% of the time. Since we are not using a statistical method of analysis, we've chosen to adopt a worst-case approach and are, accordingly, computing the PFD by traditional means. We assume that our ground station transmits at constant power output at all times our satellites are visible from Svalbard and during periods where the satellites are at 5° or higher elevation angles. This is a worst-case assumption.

II.1 Landmapper Phases

As presented in our application,[6] the Landmapper System will be carried out in three phases based on advances in technology and occupied bandwidth. In Phase 2 of our program, which is expected to start in 2018, we will begin to utilize a Ka-band Earth-to-space link in order

[6] Application of Astro Digital U.S., Inc. for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in the Earth-Exploration Satellite Service, IBFS File No. SAT-LOA-20170508-00071 (filed May 8, 2017).

to provide feedback to our spacecraft in order to adjust the transmitted data rate and then control the resending of missed data packets when they do occur. The necessary bandwidth of this emission during Phase 2 is 15 MHz. Phase 3 of our program is expected to begin in 2019. When Astro Digital advances to this phase in technology, we will increase our necessary bandwidth to 30 MHz. This is summarized in Table 2. These uplinks employ DVB-S2 operating in ACM mode.

Table 2: Data Flow Control Channel Characteristics

Landmapper Phase	Necessary Bandwidth	Symbol Rate	Peak Data Rate
Phase 2	15 MHz	12.5 Msps	55.663 Mbps
Phase 3	30 MHz	25 Msps	111.326 Mbps

The data rate of the control channel can itself be controlled by a feedback path associated with the high-speed downlink data stream. Regardless of modulation type or coding type, which, in combination, control the data rate, the occupied channel bandwidth and power density within the channel remains constant.

II.2 Power Flux Density Calculations

PFD calculations have been carried out by Astro Digital[7] at the minimum distance to the GSO arc for both Program Phases 2 and 3. They were carried out using a 40 kHz bandwidth. The range used to the GSO arc is a worst-case value in that it is the shortest distance from Svalbard to the GSO arc location, which is due south of Svalbard (180° true bearing). Table 3 Summarizes the PFD values calculated. The earth station uplink transmitter power for both Phase 2 and 3 of the program is set at 10 watts (10 dBW).

[7] PFD calculations are available upon request.

Table 3: Power Flux Density Calculations from Svalbard to Closest GSO Arc Location

Program Phase	Utilized Bandwidth (-3 dB)	Antenna Boresight PFD	Reference PFD Bandwidth
Phase 2	12.5 MHz	-124.47 dBW/m^2	40 kHz
Phase 3	25.0 MHz	-127.48 dBW/m^2	40 kHz

The earth station antenna is a 2.8 m diameter parabola, which has a boresight gain of 56.4 dBi. Table 4 is based on vendor measured data for the antenna. The roll-off is fully compliant with a gain envelope given by $G(\theta) = 32 - 25 \log(\theta)$. Hence, this envelope equation is used in Table 4 to calculate the beam roll-off values. The elevation angle of the antenna at its roll-off value is also shown. Our analysis assumes the antenna is parked at its lowest transmitting position, which is 5.0° elevation. The azimuth value, in this case, is always the independent variable (the direction along the arc being investigated).

Table 4: Ka-band Earth Station Antenna Roll-Off Characteristics

Roll-Off:	Gain:	Angle from Boresight:	Angle from Horizon:
0.00 dB	56.35 dB	0.0 (degrees)	5.0 (degrees)
3.00 dB	53.35 dB	0.14	4.860
7.41 dB	48.94 dB	0.21	4.790
10.00 dB	46.35 dB	0.2668	4.7332
11.28 dB	45.07 dB	0.3	4.700
12.95 dB	43.40 dB	0.35	4.650
14.40 dB	41.95 dB	0.4	4.600
16.82 dB	39.53 dB	0.5	4.500
17.86 dB	38.49 dB	0.55	4.450
18.80 dB	37.55 dB	0.6	4.400
20.00 dB	36.35 dB	0.67	4.33
21.93 dB	34.42 dB	0.8	4.200
23.21 dB	33.14 dB	0.9	4.100
24.35 dB	32.00 dB	1	4.000
25.38 dB	30.97 dB	1.1	3.900
26.33 dB	30.02 dB	1.2	3.800
27.20 dB	29.15 dB	1.3	3.700
28.00 dB	28.35 dB	1.4	3.600
28.75 dB	27.60 dB	1.5	3.500
29.45 dB	26.90 dB	1.6	3.400
30.00 dB	26.35 dB	1.682	3.318
30.73 dB	25.62 dB	1.8	3.200
31.32 dB	25.03 dB	1.9	3.100
31.88 dB	24.47 dB	2	3.000
32.41 dB	23.94 dB	2.1	2.900
32.91 dB	23.44 dB	2.2	2.800
34.30 dB	22.05 dB	2.5	2.500
35.33 dB	21.02 dB	2.75	2.250
36.28 dB	20.07 dB	3	2.000
37.15 dB	19.20 dB	3.25	1.750
37.95 dB	18.40 dB	3.5	1.500
38.70 dB	17.65 dB	3.75	1.250
39.40 dB	16.95 dB	4	1.000
40.00 dB	16.35 dB	4.225	0.775
40.68 dB	15.67 dB	4.5	0.500
41.27 dB	15.08 dB	4.75	0.250
41.82 dB	14.53 dB	5	0.000
42.35 dB	14.00 dB	5.25	-0.250
42.86 dB	13.49 dB	5.5	-0.500
43.34 dB	13.01 dB	5.75	-0.750
43.80 dB	12.55 dB	6	-1.000

II.3 Excess Path Loss; Atmospheric Gases and Water Vapor/Rain

ITU RR Article 22 specifies that a measurement is to be obtained using free-space propagation conditions. This implies the inclusion of excess path losses due to meteorological phenomena are not to be considered in such an analysis. While this may be just a conservative assumption in cases where the GSO arc could be located at moderate-to-high elevation angles with respect to an earth station, in our case where the maximum elevation angle is only 3° and the frequency is approximately 30 GHz, not using this excess loss in the PFD analysis results in a significant overestimation of the PFD. Meteorological losses are composed of components that vary statistically (such as losses caused by rain and clouds), while atmospheric gaseous losses are nearly constant with time. They, however, vary sharply as a function of elevation angle.

Excess path losses, even in very dry locations like Svalbard, are as high as -3.4 dB at 5° elevation angle, and such losses are static for the atmospheric gases involved. Table 5 shows how the non-statistical excess losses change as a function of elevation angle at Svalbard at 29.95 GHz.[8] Note again, we are not using losses associated with water (clouds, suspended water droplets, rain, or snow) nor are we considering scintillation effects. The conditions we propose be considered can be characterized as "clear sky" conditions for purposes of link analysis. As such, these excess losses would have to be considered as conservative as they do not yet include the effects of water. To be clear, ITU regulations do not consider excess path losses in the analysis.

Table 5: Excess Path Loss Values for Atmospheric Gas Losses at Svalbard

Elevation Angle at Svalbard Earth Station	Excess Path Loss Due to Atmospheric Gases at Svalbard
5°	**-3.4 dB**
4°	**-4.2 dB**
3°	**-5.6 dB**
2°	**-8.4 dB**
1°	**-16.8 dB**
0.5°	**-33.6 dB**

Accordingly, even if we did not take mitigation measures, which we are, we would still satisfy the ITU EPFD limits, as a practical matter. Astro Digital encourages the Commission

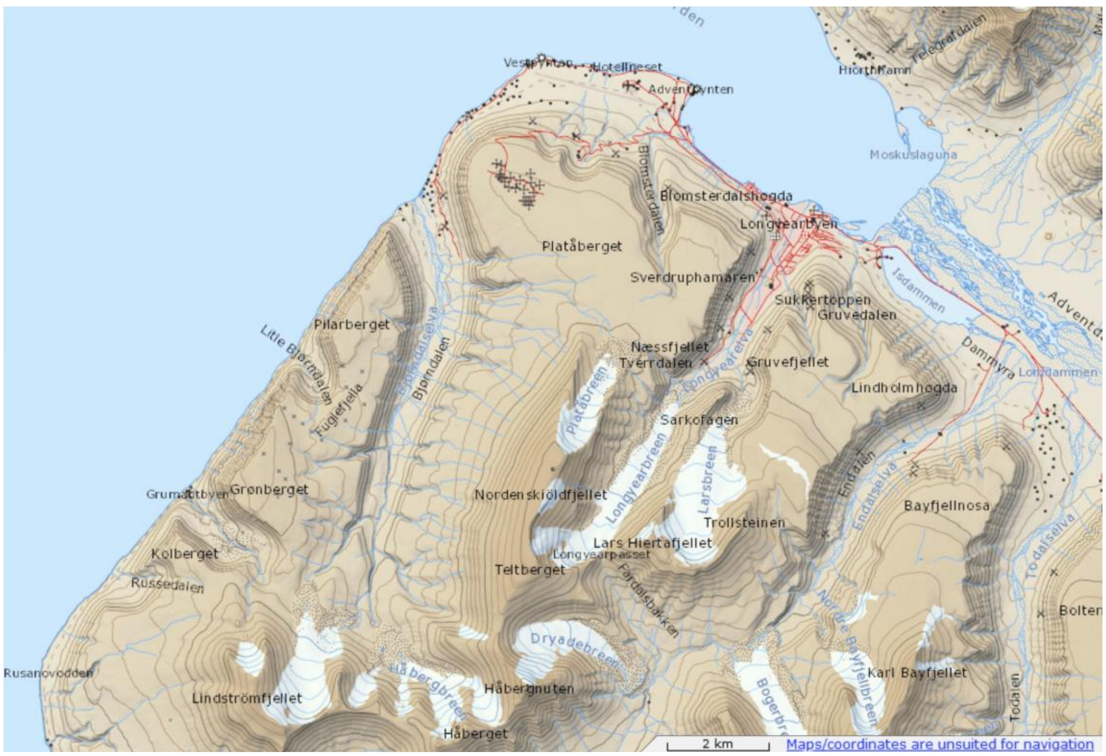
[8] ITU-R Recommendation P.618-6.

(and ITU) to consider the inclusion of excess path loss as a factor in PFD analysis at mmW frequencies and low-elevation angles to facilitate more accurate calculations.

II.4 Mountain Occultation Effects and Relationship to the Antenna Pattern at the Earth Station

There is significant mountain topography in the vicinity of the earth station site at the KSAT facility on Svalbard, primarily to the south of the station. As such, there is very significant blockage in the direction of the GSO arc. Figure 2 is a topographic map of the area that illustrates the close proximity between the mountains and the KSAT facility.

Figure 2: Topographic Map of Svalbard in the Vicinity of the KSAT Facility

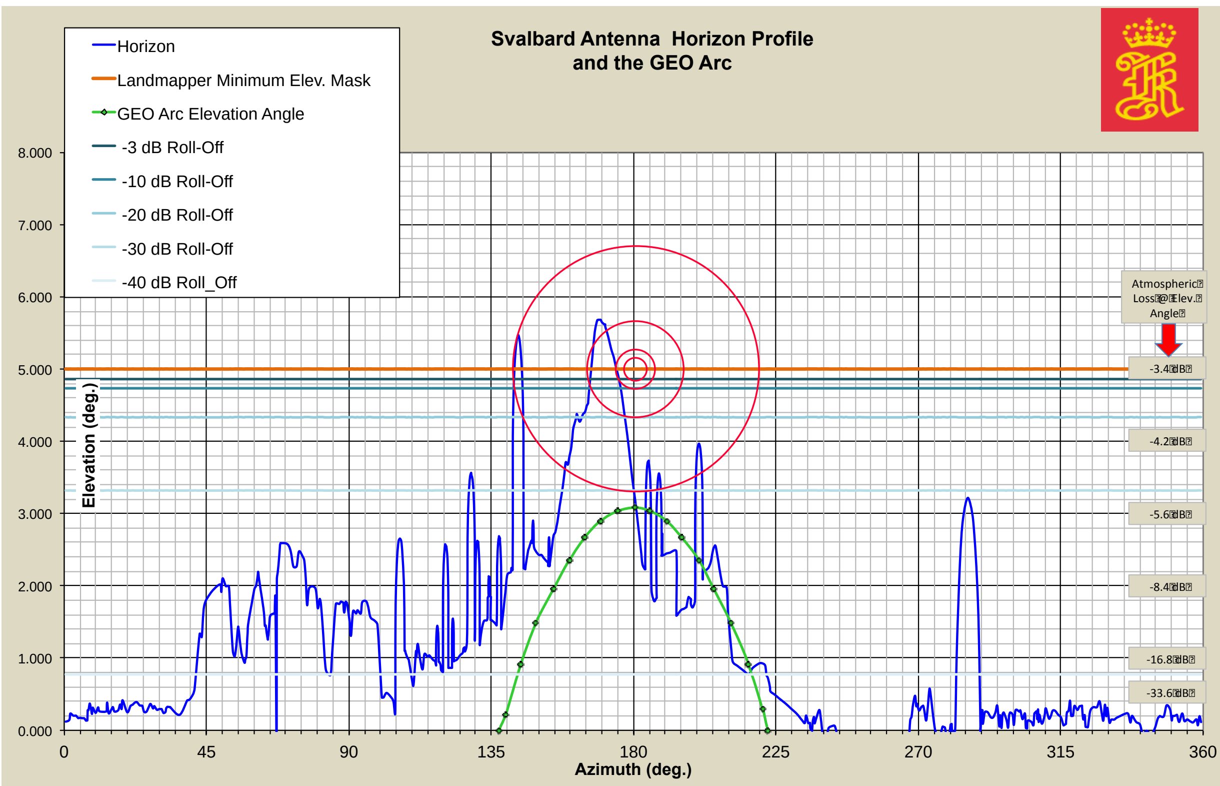


Note: The KSAT antennas are located in the upper central portion of the figure.

The combined effects of path loss, antenna roll-off due to off-pointing of the earth station antenna, excess path loss as a function of elevation angle of the TX antenna, and blockage due to mountains, are represented in Figure 3. The outline of the mountains to the south of Svalbard is represented by the blue outline in the figure. The range just east of south peaks at 5.7° elevation.

The GSO arc is shown by the green line and the arc can be seen to peak at just above 3° elevation. The red circles are the roll-off contours of the Ka-band earth station antenna. Contour rings are shown at -3 dB, -10 dB, -20 dB, and -30 dB. The -40 dB contour line is just visible at approximately 0.8° elevation. The -40 dB contour ring is eliminated for clarity. If the beam is swept in azimuth, the light blue contour "lines" are generated (constant roll-off at constant elevation). The red beam contours are for the dish, when parked at 5° Elevation angle and 180° azimuth angle.

Figure 3: Antenna Roll-Off Pattern, Svalbard Horizon and the GSO Arc



Upon careful inspection, it can be seen that at the KSAT site, there are four (4) small "gaps" in the mountain range were the earth station antenna has a direct line-of-sight view to the GSO arc. These are at azimuth values of:

- **Gap 1: 180.0° to 183.5° azimuth**
- **Gap 2: 185.0° to 186.5° azimuth**
- **Gap 3: 189.0° to 200.0° azimuth**
- **Gap 4: 210.0° to 217.0° azimuth**

We now assess the PFD from the KSAT earth station to the GSO arc within these four gaps.

II.5 Net Power Flux Density Summary

If the effects of free space path loss, antenna off-pointing, mountain blockages, and excess path loss (gases only) are combined as depicted in Figure 3, the net PFD of a victim satellite positioned at a slot on the arc within each gap can be determined. Table 6 presents an overall summary of the PFD results obtained from our analysis. The PFD results are shown for Phase 2 (2018) and Phase 3 (2019) of the Landmapper program. Phase 3 uses twice the bandwidth of Phase 2 of the program. Both system phases use the same ground station equivalent isotropic radiated power ("EIRP"), hence the PFD for Phase 2 has twice the power density and 3.01 dB higher flux density per unit of bandwidth compared with Phase 3.

We observe that for both Phases 2 and 3 of the program, the PFD margins (with respect to Article 22, Table 22-2) are negative for Gaps 1 through 3 and positive for Gap 4. This is the result if we conclude that excess path losses due to atmosphere cannot be used in the PFD calculation. However, if we include these losses, only Gaps 1 and 2 of the Phase 2 program have negative margin (of less than 0.5 dB). By Phase 3 of the program (using the increased bandwidth), within all Gaps the interference signals are less than -162 $dBW/m^2/40$ kHz.

Table 6: Summary PFD Calculations in Svalbard Mountain "Gaps"

KSAT/Svalbard: Visibility Gaps in Svalbard Mountains in the Direction of the GSO Arc.									
Gap No:	Azimuth Range of Visibility Gap	Width in Azimuth of Visibility Gap	Elevation Angle to GSO Arc Within Visibility Gap	Ground Station Antenna Roll-Off [Dish at Min Elev. Angle (5°)]	ITU Rain Model (P618-V6) Gaseous Attenuation	PFD @ GSO Arc (No Gas Losses)	Margin w.r.t.ITU Article 22; Table 22-2; 29.9-30 GHz **	PFD @ GSO Arc (Including Gas Losses)	Margin w.r.t. ITU Article 22; Table 22-2; 29.9-30 GHz **
Phase 2:	(degrees)	(degrees)	(degrees)	(dB)	(dB)	dBW/m^2/40 kHz	(dB)	dBW/m^2/40 kHz	(dB)
1	180.0 - 183.5	3.50	3.05 - 3.04	-31.60	-5.50	-156.07	-5.93	-161.52	-0.48
2	185.0 - 186.5	1.50	3.02 - 3.00	-31.80	-5.55	-156.27	-5.73	-161.82	-0.18
3	189.0 - 200.0	11.0	2.95 - 2.45	-32.15	-5.80	-156.62	-5.38	-162.42	0.42
4	210.0 - 217.0	7.0	1.50 - 0.85	-37.95	-12.5	-162.41	0.42	-174.92	12.92
Phase 3:	(degrees)	(degrees)	(degrees)	(dB)	(dB)	dBW/m^2/40 kHz	(dB)	dBW/m^2/40 kHz	(dB)
1	180.0 - 183.5	3.50	3.05 - 3.04	-31.60	-5.50	-159.08	-2.92	-164.58	2.58
2	185.0 - 186.5	1.50	3.02 - 3.00	-31.80	-5.55	-159.28	-2.72	-164.83	2.83
3	189.0 - 200.0	11.0	2.95 - 2.45	-32.15	-5.80	-159.63	-2.37	-165.43	3.43
4	210.0 - 217.0	7.0	1.50 - 0.85	-37.95	-12.5	-165.43	3.43	-177.93	15.93

Total Subtended Angle of Visibility Gaps:	23.0 deg
Total of GSO Arc Above 0° from Svalbard Earth Station:	85.5 deg
Azimuth Range Possible for Landmapper NGSO Satellites in Constellation:	360.0 deg
% of Arc Visible Through Mountain Gaps:	27%
% of all Azimuth Angles where Arc is Visible:	6%

Frequency band	epfd↑ (dB(W/m²))	Percentage of time epfd↑ level may not be exceeded	Reference bandwidth (kHz)	Reference antenna beamwidth and reference radiation pattern[16]
29.5-30 GHz	−162	100	40	1.55° Recommendation ITU-R S.672-4, $L_s = -10$

** ITU, Article 22; Table 22-2 Entry for Ka-Band at 29.5 to 30 GHz

Antenna Boresight PFD	**Phase 2** System Earth Station Boresight PFD/EPFD at Worst-Case GSO Distance (41,679.0 km):	-124.47	dBW/m^2/40 kHz
Antenna Boresight PFD	**Phase 3** System Earth Station Boresight PFD/EPFD at Worst-Case GSO Distance (41,679.0 km):	-127.48	dBW/m^2/40 kHz

III. Mitigation of Interference to the GSO Arc from the Landmapper System

Using the conventional rules of the ITU and while not considering excess path losses in mmW link interference budgets, we can conclude that under worst case conditions Gaps 1, 2 and 3 require that the Landmapper EIRP toward the arc must be decreased by approximately 6 dB (in practical terms). For signals arriving via Gap 4 (at elevation angles below 1.5 degrees), the antenna roll-off contribution alone is capable, in both Phases 2 and 3 of the program, of reducing the interference PFD to a level below -162 dBW/m^2. Hence, Gap 4 is of no concern.

There are two simple means to further reduce the Landmapper uplink signal EIRP in the direction of the arc:

> *Procedure a)* When Landmapper satellites have an AOS or LOS event within the azimuth range from 180° to 200° at Svalbard, switch off the Ka-band TX power to the transmitter at elevation angles below 7° (instead of using the facility required value of 5°); or

Procedure b) When Landmapper satellites have an AOS or LOS event within the azimuth range from 180° to 200° at Svalbard, do not allow the antenna system elevation to go below 7°. The additional roll-off of the antenna, if it is constrained to stay at 7°, within this azimuth window, will decrease the PFD by more than the required 6 dB in PFD at the arc.

Astro Digital will implement these strategies, where necessary to ensure that it meets ITU RR Article 22 limits. Procedure a) above is somewhat preferable as the dish will be operated in full duplex and the downlink signal can continue to be tracked even while the uplink signal is terminated, hence there is a net reduction in the loss of data to the program by using this procedure.

IV. Conclusion

With this analysis, Astro Digital demonstrates that the circumstances associated with our system and our earth station location at Svalbard, Norway essentially prevent any visibility of the GSO arc. There are only four visibility zones within which the GSO arc is visible from our Ka-band uplinking station, and we calculate there is a small negative PFD margin in three of the "gaps" when our system is operating in conformance with our filed application. Astro Digital has identified multiple simple mitigation techniques (operational adjustments to our earth station) that will prevent any interference to the GSO arc under any set of conditions. PFD levels in the fourth gap comply with the PFD level limits. For these reasons, Astro Digital submits that the use of the advanced statistical methods in the ITU software are not necessary or warranted for Astro Digital and that this technical analysis demonstrates compliance of the Astro Digital system with ITU RR Article 22.

Technical Certification

I, Jan A. King, hereby certify, under penalty of perjury, that I am the technically qualified person responsible for the preparation of the engineering information contained in the technical portions of this compliance demonstration, that I am familiar with Part 25 of the Commission's rules and Article 22 of the ITU Radio Regulations, and that the technical information is complete and accurate to the best of my knowledge and belief.

/s/

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Dated: January 16, 2018