Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
SPACE NORWAY AS	)	Call Sign: S2978
Petition for a Declaratory Ruling Granting Access to the U.S. Market for the Arctic Satellite Broadband Mission	)	File No. SAT-PDR-20161115-00111

COMMENTS OF SPACE EXPLORATION TECHNOLOGIES CORP.

Space Exploration Technologies Corp. ("SpaceX") hereby comments on the application filed by Space Norway AS for authority to serve the U.S. market with its non-geostationary satellite orbit ("NGSO") system providing Fixed-Satellite Service ("FSS") in the Ku and Ka bands. The proposed system would consist of two satellites in highly elliptical orbit ("HEO"), orbiting at altitudes ranging from approximately 8,000 km to 43,500 km.[1] The Space Norway system would use downlink beams that, taking into account the significant spreading that would occur from Space Norway's high operational altitude would result in very large spot sizes on the surface of the Earth—approximately 1.6 million square miles—and from the perspective of low-Earth orbit ("LEO")

[1] *See* Space Norway AS, *Schedule S*, IBFS File No. SAT-PDR-20161115-00111 (Apr. 2016). Space Norway indicates that the minimum height at which its satellites are active is 28,454 km. *See Petition for Declaratory Ruling Granting Access to the U.S. Market for the Arctic Satellite Broadband Mission*, IBFS File No. SAT-PDR-20161115-00111, Appendix A at 19-20 (Nov. 15, 2016) ("Space Norway Application")

satellites.[2] Indeed, Space Norway proposes to cover the entire arctic with only seven beams.[3]

As an initial matter, this pattern of coverage will result in poor spectral efficiency—*i.e.*, kilobits per second, per square kilometer, per MHz—for the Space Norway system itself with, optimistically, only 4.8 Gbps available for the entire 1.6 million square miles covered by each satellite. But it will also reduce the efficiency of all other NGSO systems in the band by increasing the frequency of in-line events through the use of inflexible beams and very large spots. Certainly the Commission should not reward such an inflexible system design with the unique, and inappropriate, interference protections that Space Norway has requested.[4]

In addition, due to Space Norway's proposed operational altitude, Space Norway's uplink beams are likely to cause significant interference to LEO satellites whenever a LEO satellite passes through a Space Norway earth station's main beam or sidelobe. This would effectively prevent a LEO system with steerable beams (like SpaceX's) from working around the in-line event, forcing the default arrangement of band segmentation. The Commission should ensure that operators of system types under consideration in this processing round will be able to coexist with one another while making equitable and efficient use of scarce spectral resources. And, if necessary, the Commission should impose license conditions to ensure that operators have the proper incentives to coordinate fairly and effectively with every other NGSO system.

---

2 Space Norway notes that these beams will be steerable. Steerable beams may theoretically increase flexibility and ease spectrum sharing challenges. But it appears unlikely that this will be a viable strategy for Space Norway's system with such large beams, and a limited number of satellites.

3 *Id.*

4 *See* Letter from Lafayette Greenfield, Counsel to Space Norway AS, to Marlene Dortch, Secretary, FCC, IB Docket No. 16-408 (filed June 1, 2017) ("June 1 Letter").

I. LARGE BEAMS AND HIGH OPERATIONAL ALTITUDES EXACERBATE SPECTRUM SHARING CHALLENGES

When the Commission adopted its current avoidance of in-line interference approach, it anticipated that in-line events would be relatively infrequent.[5] But these analyses were made in the context of a limited number of first-generation NGSO/FSS systems with constellations of just tens of satellites apiece.[6] However, due to Space Norway's very large spot sizes, there will virtually always be at least one, and often more LEO satellites within Space Norway's beam, greatly increasing the frequency of in-line events. In fact, in-line events involving three or more operators may not be uncommon. In this environment, it is essential that operators design their systems with technical characteristics that will enable them to minimize the impact of these events.

Unfortunately, as SpaceX has previously explained,[7] large spot sizes—resulting from a combination of beamwidth and altitude—not only reduce spectral efficiency by precluding intensive frequency reuse, they also limit the proposed system's ability to share spectrum with other NGSO/FSS constellations, increasing the incidence of band segmentation. Large beams limit an operator's ability to provide satellite diversity, which would enable it to serve customers from an alternate satellite when there would otherwise have been an in-line event. As the Commission has recognized, "[w]ith

---

5 *Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ka-Band*, Report and Order, 18 FCC Rcd. 14708, ¶ 19 (2003) ("*Ka-band NGSO Sharing Order*").

6 *See, e.g.*, *Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ku-Band*, Notice of Proposed Rulemaking, 16 FCC Rcd. 9680, Appendix D (2001) (discussing seven proposed Ku-band NGSO systems with 13 to 80 satellites in the constellation); *Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ka-Band*, Notice of Proposed Rulemaking, 17 FCC Rcd. 2807, Appendix D (2002) (discussing five proposed Ka-band NGSO systems with 15 to 96 satellites in the constellation).

7 Comments of Space Exploration Technologies Corp. at 12-14, 15-17, IBFS File No. SAT-LOI-20160428-00041 (Aug. 15, 2016).

satellite diversity, NGSO FSS systems can avoid an in-line interference event by selecting another visible satellite within their system constellation (performing a hand-over process) whenever the current satellite approaches the in-line event with a satellite operating in another NGSO FSS system constellation."[8] But Space Norway does not appear to provide any significant degree of satellite diversity.[9] This means that it has no way to limit the incidence of in-line events with the numerous satellites likely to fall within its beams at lower orbital altitudes, or those at higher altitudes seeking to serve users within Space Norway's footprint. Other operators of more sophisticated systems will therefore be required to shoulder the burden of avoiding these in-line events, or the affected operators will be required to split the available spectrum, in the absence of another agreement.

Furthermore, large beam size increases the number of in-line events that a Space Norway satellite is likely to experience with other systems, increases the duration of those in-line events, and increases the odds that a given satellite will experience in-line events with multiple operators at one time. Instead of a fleeting event, an in-line event with a Space Norway satellite will last a significant period of time, during which affected satellites will remain in either a band-splitting or other spectrally inefficient coordination regime. For other systems with large inflexible beams, each individual satellite may experience long-duration in-line events with Space Norway satellites. In systems with larger numbers of satellites and narrower beams, each satellite may only be briefly affected, but a number of satellites may be affected simultaneously. In either case, other operators must shoulder the burden of long periods of in-line coexistence with Space

---

8 *Ka-band NGSO Sharing Order* ¶ 44.

9 Space Norway Application, Appendix A at 5-6 (illustrating the configuration of operational satellites in the Space Norway system).

Norway's satellites, due to its inflexible system design. This will significantly reduce the spectrum available to the Space Norway system itself, and will further reduce the spectrum available to other systems, especially in cases of in-line events with more than one operator, unless those other operators take on the burden of finding ways to mitigate the impact of in-line events.

In fact, Space Norway itself makes these points explicitly.[10] It concedes that, due to its chosen altitude and beamwidth, it will experience a "continuous stream" of in-line events,[11] and explicitly asks the Commission to shift the spectrum sharing burden to other NGSO operators. Space Norway suggests that it would be "relatively easy"[12] for other NGSO systems to accommodate the Space Norway system through "spectrum reuse techniques." But this premise does not withstand scrutiny, and would not warrant the extraordinary relief that Space Norway requests even if true.

It is true that LEO NGSO systems such as SpaceX's have superior coexistence capabilities due to, *inter alia*, spectral reuse techniques, satellite diversity, narrow spot beams, and other attributes, but these capabilities do not make it "easy" to share spectrum equitably and efficiently with Space Norway. Space Norway's beams are so large that, for many operators, numerous satellites would be within Space Norway's beam at one time, multiplying the burdens well beyond a single satellite, and limiting the benefits of satellite diversity. Indeed, Space Norway's proposal would affect any NGSO satellite operating in the arctic in this band, significantly impairing every operators' ability to serve this region, except for Space Norway.

---

[10] *See* June 1 Letter.

[11] *Id*., attachment at 9.

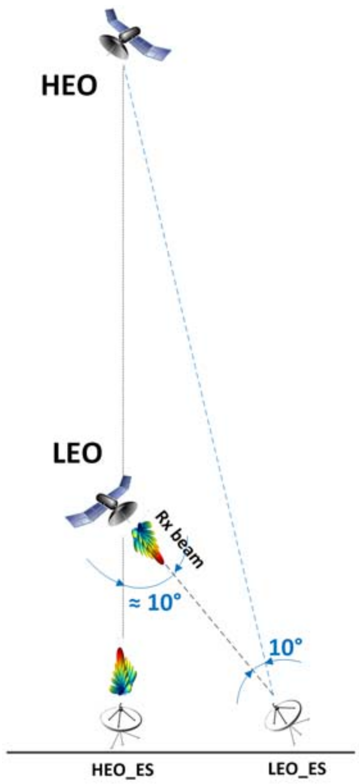
[12] *Id*., attachment at 11.

More fundamentally, Space Norway's proposal would unfairly transfer the benefits of the sharing capabilities of more flexible systems, in which SpaceX and other operators have invested heavily, from those operators to Space Norway. The Commission should decline to do so. Instead, it should remain focused on developing a system of baseline rules for NGSO operators that encourage flexibility and spectral efficiency. Operators should be encouraged to negotiate amongst themselves in this market environment to reach private coordination agreements that take into account the particular capabilities of each system. The regulatory approach Space Norway proposes would achieve the opposite. It would reduce investment in flexibility and efficiency by transferring the benefits of those capabilities away from the operator that developed them.

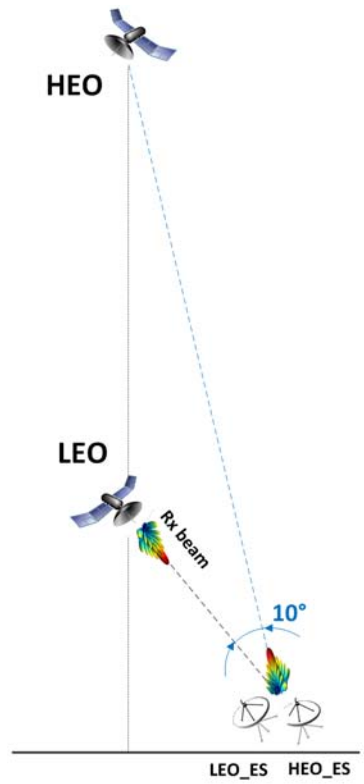
II. HIGHLY-ELLIPTICAL ORBIT SYSTEMS MAY CAUSE INTERFERENCE TO ANY LEO SATELLITE WITHIN OR NEAR THEIR BEAMS, EVEN WITHOUT AN IN-LINE EVENT

The Space Norway system, and other systems with high operational altitudes, are likely to cause interference to LEO systems due to the very high EIRP of these systems' earth station uplink beams. For example, in order to communicate with satellites at altitudes of 45,300 km, Space Norway's uplink beams will transmit at EIRP levels from 30 dB to 50 dB higher than SpaceX's. This means that they will also be approximately 30-50 dB stronger than a LEO's desired uplink signal at the satellite as the LEO satellite crosses through the Space Norway uplink beam. With such an extreme EIRP disparity, the Space Norway uplink beam would likely degrade the ability of SpaceX or any other LEO satellite's to receive an uplink signal in the affected band from *any* location on the Earth, whether or not it is near the transmitting Space Norway earth station.

To illustrate this point, consider two in-line scenarios involving the NGSO systems proposed by Space Norway and SpaceX. As depicted below, in Scenario 1, the SpaceX LEO satellite is in the main beam of the Space Norway earth station uplink to a Space Norway HEO satellite.[13] In Scenario 2, the SpaceX and Space Norway earth stations are essentially collocated while their satellites have an apparent angular separation of 10 degrees.



Scenario 1



Scenario 2

Using operational parameters from the SpaceX and Space Norway applications, we can determine the impact (measured as ΔT/T) of these in-line events.

For example, Table 1 below sets forth the analysis of the impact that the Ka-band uplink beams from a Space Norway gateway earth station would have on SpaceX in

[13] Note that, given the extreme difference between the operating altitudes of the two systems, the separation angle between HEO_ES and LEO_ES from the LEO satellite perspective is essentially the same as the angle between HEO and LEO from the LEO_ES perspective.

Scenario 1, yielding ΔT/T of 14,469%, assuming 10 degrees of angular separation.[14] A similar analysis applies for interference from Space Norway Ku-band user terminals, with ΔT/T of 7,544%. As this analysis demonstrates, both Space Norway user terminals and gateway uplinks could cause a dramatic increase in noise temperature relative to the desired signal at the receive antenna on SpaceX satellites.

SpaceX SAT Rx antenna gain at nadir [dB]	41.00	
SpaceX SAT Rx antenna G/T at nadir [dB/K]	13.70	*see SpaceX FCC filing*
SpaceX SAT Rx antenna G/T at 10º [dB/K]	-20.30	*32-25log(φ) at 10° separation*
Space Norway ES EIRP [dBW/40kHz]	41.92	*ES EIRP masks in EPFD DB show 41.92, 43.36, 51.66, and 65.14 dBW/40kHz*
Space Norway ES EIRP [dBW/Hz]	-4.10	*note lowest ES EIRP used here*
I/N [dB]	**21.60**	*at 10° separation*
ΔT/T [%]	**14,469%**	*at 10° separation*

Table 1. Impact of Space Norway Gateway Earth Station in Scenario 1

SpaceX SAT Rx antenna gain at nadir [dB]	37.00	
SpaceX SAT Rx antenna G/T at nadir [dB/K]	9.80	*See SpaceX FCC filing*
SpaceX SAT Rx antenna G/T at 10º [dB/K]	-20.20	*32-25log(φ) at 10° separation*
Space Norway ES EIRP [dBW/40kHz]	32.82	*ES EIRP masks in EPFD DB show 32.82, 34.26, and 34.56 dBW/40kHz*
Space Norway ES EIRP [dBW/Hz]	-13.20	*note lowest ES EIRP used here*
I/N [dB]	**18.78**	*at 10° separation*
ΔT/T [%]	**7,544%**	*at 10° separation*

Table 2. Impact of Space Norway User Terminals in Scenario 1

An analysis of Scenario 2 yields similar results, although here it is the sidelobes of the Space Norway earth station[15] that interfere with the main beam of the SpaceX earth station's uplink transmissions. Tables 3 and 4 below show the increase in noise

---

[14] For purposes of this analysis, SpaceX used representative frequencies (29 GHz for Ka-band and 14.25 GHz for Ku-band) and representative orbital altitude for its system (1,110 km), and EIRP values for Space Norway earth stations taken from the EPFD_up analysis submitted with its application. I/N is calculated using this equation (where k = Boltzmann constant):

$$\frac{I}{N} = EIRP - 10\log(4\pi d^2) - 10\log\left(\frac{4\pi}{\lambda^2}\right) + \frac{G}{T} - 10\log(k)$$

[15] For this analysis, SpaceX determined off-axis gain of Space Norway earth stations using the formula 32-25log(ϕ) from Recommendation ITU-R S.465-6, *available at* https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.465-6-201001-I!!PDF-E.pdf.

temperature expected in the SpaceX uplink due to operations of a Space Norway gateway and user terminal, respectively, when the separation angle between a SpaceX satellite and a Space Norway satellite is 10 degrees from the earth station's point of view.

Ka-band (29 GHz)		
SpaceX SAT Rx antenna G/T at nadir [dB/K]	13.70	*See SpaceX FCC filing*
Space Norway ES Diameter D [m]	0.35	
Space Norway ES Gmax [dB]	38.29	
Space Norway ES Gain @ 10º [dB]	7.00	*32-25log(φ), per Rec. ITU-R S.465-6*
Space Norway ES EIRP @ 10º [dBW/40kHz]	10.63	
Space Norway ES EIRP @ 10º [dBW/Hz]	-35.39	
I/N [dB]	**24.32**	*at 10° separation*
ΔT/T [%]	**27,024%**	*at 10° separation*

Table 3. Impact of Space Norway Gateway in Scenario 2

Ku-band (14.25 GHz)		
SpaceX SAT Rx antenna G/T at nadir [dB/K]	9.80	*See SpaceX FCC filing*
Space Norway ES Diameter D [m]	0.60	
Space Norway ES Gmax [dB]	36.80	
Space Norway ES Gain @ 10º [dB]	7.00	*32-25log(φ), per Rec. ITU-R S.465-6*
Space Norway ES EIRP @ 10º [dBW/40kHz]	3.02	
Space Norway ES EIRP @ 10º [dBW/Hz]	-43.00	
I/N [dB]	**18.98**	*at 10° separation*
ΔT/T [%]	**7,905%**	*at 10° separation*

Table 4. Impact of Space Norway User Terminal in Scenario 2

As these tables demonstrate, the high EIRP of the Space Norway earth stations will make efficient and equitable spectrum sharing with a LEO system difficult or impossible. In Scenario 1, interference is so strong that it would prevent the SpaceX satellite from using its steerable beams to service other users (even outside the area subject to the in-line event) using spectrum shared with Space Norway, and thus essentially prevents SpaceX from using those frequencies anywhere during the in-line event. In Scenario 2, because SpaceX will experience an unacceptable level of interference without a separation angle much larger than 10 degrees, the operators would have to expand the in-line event zone which would negatively impact spectral efficiency and usable capacity for both systems. Moreover, Space Norway's proposal for protection of its HEO operations would exacerbate the problem. Even at larger separation angles, Space Norway's earth stations would cause significant interference to SpaceX uplinks and prevent SpaceX from using spectrum even in areas outside the scope of an in-line event.

Without effective coordination, this pervasive HEO-to-LEO interference will significantly reduce the overall utility of NGSO operations throughout the band. The Commission is currently considering whether to adopt default limits for EIRP density of NGSO uplink transmissions in order to facilitate spectrum sharing among systems,[16] and SpaceX believes that such limits will be critical to coexistence among non-homogeneous NGSO systems. At a minimum, any grant of Space Norway's application should be conditioned upon compliance with the outcome of that rulemaking proceeding. The Commission should also consider whether it would be appropriate to impose additional conditions to address this potential interference and enhance the potential for efficient spectrum sharing.

III. CONCLUSION

In effect, systems with very large, inflexible beams shift the burden of designing a flexible system, capable of effective and efficient spectrum sharing, onto other operators. They require other operators to either shoulder the burden of designing a highly flexible system, as SpaceX has done, or the burden of inefficiently splitting spectrum during a large portion of its satellites' time on orbit. High-altitude systems such as Space

[16] *See Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 31 FCC Rcd. 13651, ¶¶ 28-30 (2016).

Norway's compound these challenges by posing an asymmetric interference risk to lower-altitude operators whenever they pass through the main beam or sidelobe of a Space Norway uplink transmission. The Commission should carefully consider whether the public interest would be served by authorizing systems that are only workable if other, more adaptable systems take a disproportionate burden of sharing, as the compromises required would reduce the overall capacity available to serve consumers, and also evaluate how it can foster spectrally efficient coexistence between LEO and HEO systems.

Respectfully submitted,

SPACE EXPLORATION TECHNOLOGIES CORP.

By: */s/ Tim Hughes*
Tim Hughes
Senior Vice President, Global Business and Government Affairs

Patricia Cooper
Vice President, Satellite Government Affairs
SPACE EXPLORATION TECHNOLOGIES CORP.
1030 15th Street, N.W.
Suite 220E
Washington, DC 20005
202-649-2700 tel
202-649-2701 fax

William M. Wiltshire
Paul Caritj
HARRIS, WILTSHIRE & GRANNIS LLP
1919 M Street, N.W.
Suite 800
Washington, DC 20036
202-730-1300 tel
202-730-1301 fax

Counsel to SpaceX

June 26, 2017

ENGINEERING CERTIFICATION

The undersigned hereby certifies to the Federal Communications Commission as follows:

(i) I am the technically qualified person responsible for the engineering information contained in the foregoing Comments,

(ii) I am familiar with Part 25 of the Commission's Rules, and

(iii) I have either prepared or reviewed the engineering information contained in the foregoing Comments, and it is complete and accurate to the best of my knowledge and belief.

Signed:

/s/ Mihai Albulet

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

June 26, 2017

Date

CERTIFICATE OF SERVICE

I hereby certify that, on this 26th day of June, 2017, a copy of the foregoing Comments was served by electronic mail upon:

Phillip L. Spector
Dara A. Panahy
Lafayette Greenfield
Milbank, Tweed, Hadley & McCloy LLP
1850 K Street, N.W.
Suite 1100
Washington, DC 20036
PSpector@milbank.com

/s/ *Sabrina McMillin*
Sabrina McMillin