

August 17, 2017

BY ELECTRONIC FILING

Marlene H. Dortch
Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

Re: *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters, IB Docket No. 16-408*

Dear Ms. Dortch:

This is to inform you that, on August 15, 2017, representatives of Space Exploration Technologies Corp. (“SpaceX”) met with staff of the Commission’s International Bureau to discuss certain proposals for revision of the rules and policies governing non-geostationary satellite orbit (“NGSO”), Fixed-Satellite Service (“FSS”) systems.¹ In its filings in this proceeding, SpaceX has consistently supported proposals to enhance the regulatory framework for a robust and competitive NGSO environment. SpaceX has endorsed reinstating prior allocation or designation decisions in order to increase spectrum available for FSS operations and opposed any presumption that NGSO systems must protect geostationary orbit (“GSO”) systems in bands that lack sharing rules. SpaceX has further encouraged a more flexible build-out regime for NGSO systems, allowing constellations to adapt to their evolving user demands, and noted that geographic coverage requirements are unnecessary given broad NGSO coverage capabilities.² During this meeting, SpaceX presented certain additional proposals designed to yield even more efficient and equitable NGSO operations. As discussed more fully below and in the presentation attached hereto (which was distributed at the meeting), SpaceX argued that:

- SpaceX supports the Commission’s current in-line events spectrum sharing regime and urged that this approach be applied to additional bands. Further, in order to avoid false in-line events that unnecessarily reduce spectrum efficiency, the Commission should require NGSO system operators to share real-time beam pointing information. This could be accomplished through a neutral third-party clearinghouse.

¹ See *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 31 FCC Rcd. 13651 (2016) (“NPRM”). Attendees at the meeting are listed in Exhibit 1 hereto.

² See generally Comments of Space Exploration Technologies Corp., IB Docket No. 16-408 (Feb. 27, 2017); Reply Comments of Space Exploration Technologies Corp., IB Docket No. 16-408 (Apr. 10, 2017).

- In order to facilitate spectrum sharing among NGSO systems operating at very different altitudes, the Commission should adopt on-axis and off-axis EIRP limits for uplink transmissions from all NGSO earth stations.
- In light of the stated intention of some NGSO applicants to expand their constellations in the future, the Commission should clarify how it will process such modification requests.

We discuss each of these proposals below.

I. In Order to Enhance Spectrum Sharing, the Commission Should Require NGSO Operators to Share Real-Time Beam Pointing Information

SpaceX supports the Commission's current spectrum sharing regime based on avoidance of in-line events, which applies when satellites of different NGSO systems appear to an earth station to be physically aligned at a specified trigger angle. In such situations, operators must either agree in coordination to a spectrum sharing strategy or employ the default approach of spectrum splitting. At present, this regime applies by rule only in the Ku-band. SpaceX believes that it should be applied to additional bands used by NGSO systems, and that the 10 degree trigger angle used for the Ku-band would also be appropriate for the Ka-band as well. The 10 degree trigger angle balances the need to ensure efficient use of spectrum with the potential to deploy low cost, low gain user terminals for direct-to-consumer services.

SpaceX also discussed ways in which the public interest benefits of in-line events regime could be further enhanced. Most importantly, SpaceX noted that NGSO systems with large footprints but small beam sizes present a wasted opportunity for spectral efficiency in the absence of real-time information sharing. The coverage footprints of a satellite operating at mid-Earth orbit ("MEO") or highly-elliptical orbit ("HEO") altitude tends to be very large – often larger than the contiguous United States. Even for those MEO or HEO systems employing narrow, steerable spot beams, other satellite systems have no way of knowing whether they are involved in an actual in-line event with one of these active spot beams or whether they are simply within that MEO/HEO satellite's overall footprint, with no active beam. This results in wasteful band splitting or other interference avoidance measures as both satellite systems act to avoid presumed interference that, unbeknownst to them, would never have occurred.

Figures 1 and 2 below illustrate the problem vividly as it relates to the ViaSat MEO system. Without beam pointing information (Figure 1), SpaceX must assume that its spacecraft are involved in an in-line event with a ViaSat MEO satellite in a large portion of its footprint. With information on where ViaSat's beams are actually operating (Figure 2), the number of actual in-line events that must be managed is dramatically reduced. Information sharing means the difference between false inline events across most of North America and potential in-line events in a small number of very targeted areas. This dramatically reduces the number of instances in which *both* operators must reach agreement for spectrum sharing or default to band splitting.

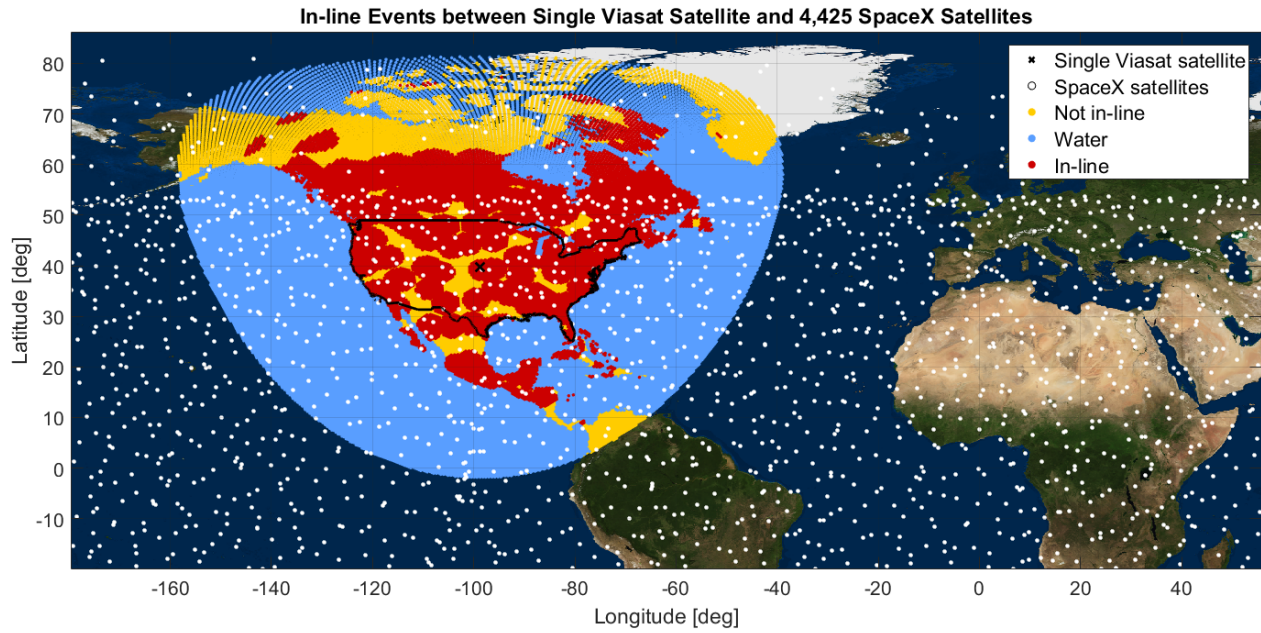


Figure 1. Potential In-Line Events Between ViaSat and SpaceX Satellites Without Information Sharing

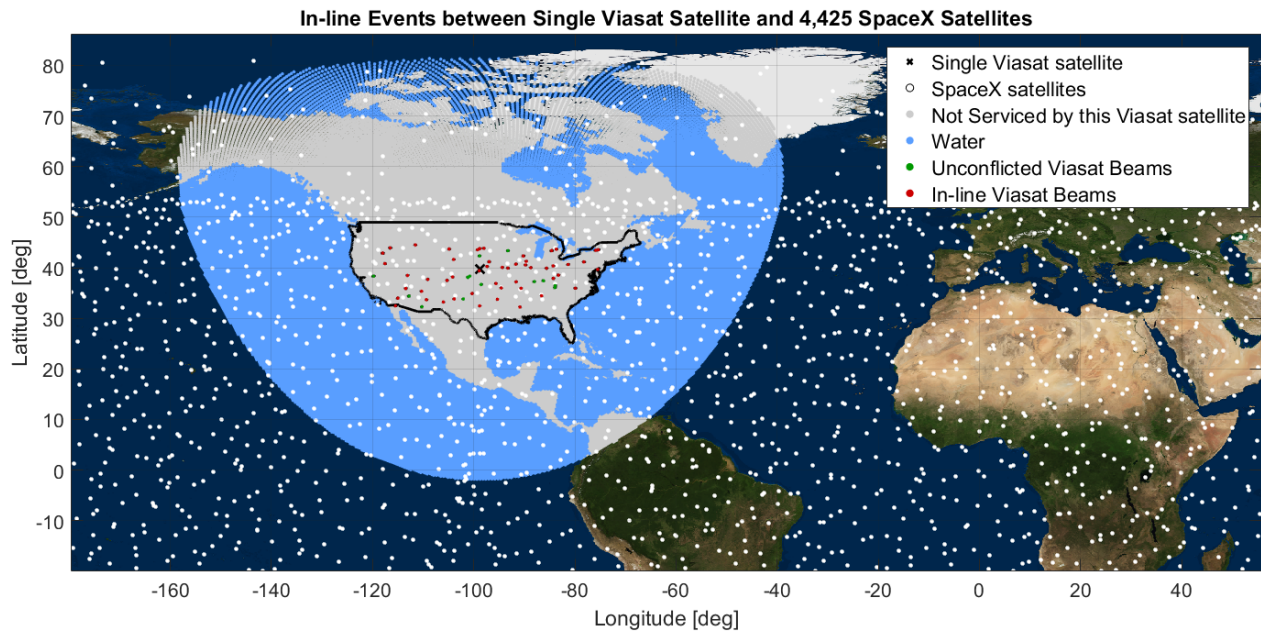


Figure 2. Potential In-Line Events Between ViaSat and SpaceX Satellites With Information Sharing

To address this issue and radically increase spectral efficiency, SpaceX recommended that the Commission require operators of NGSO systems to share beam pointing data with other NGSO operators. Sharing such data just a few minutes in advance should present minimal technical challenges, given that each operator is aware of the steering angle of its own satellites' beams. Information on beam steering decisions could then be shared with other NGSO operators at the same time that this information is determined by control facilities on Earth and then communicated to the satellite via TT&C links. To maximize the utility of this system, the operator would also transmit the length of time for which the operator anticipates maintaining that steering configuration. This information may be more challenging to estimate with full precision, but even a significant overestimate of beam pointing duration would promote far more efficient use of spectrum by all satellite operators than no information sharing at all.

SpaceX outlined one possible method to facilitate sharing of this information while protecting proprietary data by using a neutral, third-party clearinghouse organization. NGSO operators could then query this clearinghouse as needed to determine whether a given beam on a given satellite is or soon will be involved in an in-line event with another operator, and how long that event is likely to last. The use of a third-party clearinghouse, which would not share the actual beam pointing data with anyone else, would address any competitive concerns associated with the sharing of potentially sensitive operational data. An advanced version of this clearinghouse could also serve as a repository of agreed-upon coordination behaviors and beam splitting rules such that, instead of merely reporting whether a satellite will experience an in-line event, it can determine which frequencies a satellite may use at a given location and steering angle, consistent with industry agreements.

II. The Commission Should Adopt Uplink EIRP Limits to Prevent Pervasive Interference Between HEO/MEO Uplink Beams and LEO Spacecraft Receivers

As SpaceX explained in its comments on Ku/Ka-band HEO and MEO systems,³ interference from these systems' uplink beams poses a serious interference challenge that would best be addressed by establishing EIRP limits for earth stations for all NGSO systems – LEO, MEO, and HEO alike. As illustrated in the attached presentation, the received power of HEO/MEO uplink beams at a LEO satellite will be significantly higher than the desired signal from a LEO earth station. As a result, the LEO satellite will experience severe harmful interference on its uplink beam whenever it is within the HEO/MEO uplink beam or sidelobe. This will occur regardless of whether these beams are closely aligned, and is likely to extend into adjacent channels, frustrating any attempts to prevent this interference through beam splitting. With such an extreme power disparity, the HEO/MEO uplink beam would likely degrade a LEO satellite's ability to receive any uplink signal in the affected band from *any* location on the Earth, whether or not it is near the transmitting HEO/MEO earth station. Thus, this form of interference will also frustrate any attempts to avoid this in-line event through the use of steerable beams – the LEO satellite's uplink beams will experience harmful interference regardless of their steering angle to the affected satellite.

³ See, e.g., Comments of Space Exploration Technologies Corp., IBFS File No. SAT-PDR-20161115-00120, at 4-9 (June 26, 2017) (discussing interaction with ViaSat's MEO system) ("SpaceX Comments on ViaSat").

This problem stems from the dramatic differences in uplink EIRP used by LEO, MEO, and HEO earth stations to compensate for the varying altitudes at which their satellites operate.⁴ Beyond additional power, another solution would include MEO and HEO systems deploying better performing satellite receive antennas to compensate – a viable strategy given that MEO/HEO systems typically use fewer and larger satellites than do LEO systems. To illustrate this point, SpaceX presented two scenarios.⁵

In Scenario 1, the LEO satellite is directly in the center of the MEO uplink beam, but the LEO satellite is separated by an apparent angle of 10 degrees from the MEO satellite from the perspective of the LEO-system earth station. In such a case, using relatively conservative assumptions, SpaceX calculates that the LEO satellite would experience $\Delta T/T$ of 2,624%. If the LEO system were designed to target a typical $\Delta T/T$ of 6%, the LEO uplink would need 26 dB of additional received power to function without harmful interference.⁶ In Scenario 2, the MEO- and LEO-system earth stations are in close geographic proximity to one another while their satellites have an apparent angular separation of 10 degrees. In this case, the LEO satellite experiences interference from the sidelobe of the MEO earth station uplink beam. Yet here again, under relatively conservative assumptions, the results are similar to Scenario 1: $\Delta T/T$ of 1,789%, which equates to a LEO link budget deficit of approximately 25 dB. Moreover, the interference levels discussed above are likely to understate the problem with respect to a HEO system (using higher power to communicate to a higher altitude) or a LEO system operating at a lower altitude.

SpaceX recommended that the Commission solve this problem and enhance spectrum sharing by limiting the uplink EIRP of all NGSO earth stations. In order to address the interference in Scenario 1, SpaceX proposed on-axis uplink EIRP limits of -35 dBW/Hz and -30 dBW/Hz for Ku-band and Ka-band operations, respectively. In order to address the interference in Scenario 2, SpaceX proposed an off-axis uplink EIRP limit of -65 dBW/Hz for both Ku- and Ka-band operations. (SpaceX did not propose similar limits for V-band operations, as that band will require further study.) In all cases, the proposed levels will be more than enough power to permit NGSO systems operating at both low and high altitudes in the same frequency bands to make efficient use of spectrum, but would also prevent the spectrum sharing difficulties associated with significant

4 For example, compared to a SpaceX LEO satellite, uplink beams to a ViaSat MEO satellite or Space Norway HEO satellite will experience 17 and 31.5 dB greater path loss, respectively.

5 The specific calculations underlying the analysis of these two scenarios involving a 60 cm ViaSat earth station can be found at SpaceX Comments on ViaSat at 4-9.

6 These calculations assume an MEO uplink beam operating at full power, which may occur only to compensate for rain fade. But even under clear sky conditions, it is unlikely that uplink EIRP will be sufficiently reduced to prevent harmful interference. EIRP increases to account for rain fade are unlikely to exceed 8-10 dB, leaving earth station EIRP still well above the highest levels that can be tolerated at a LEO receiver.

power disparities.⁷ Accordingly, as suggested by the Commission, SpaceX supports prescribing default limits on NGSO uplink emissions.⁸

III. The Commission Should Clarify How It Will Process Requests to Modify NGSO Systems Authorized Through a Processing Round

Some applicants in the recent Ku/Ka- and V-band processing rounds have informally indicated that they intend to launch additional satellites beyond those reflected in their applications.⁹ As a general matter, SpaceX believes that NGSO operators should have the flexibility to adapt their constellations to both market demand and evolving technological capabilities over time. At present, however, there is simply no regulatory precedent for the considerable constellation enlargements that some operators have described for NGSO systems authorized through a processing round.

The Commission's past guidance indicated that a proposed modification to an NGSO system that does not present any significant interference problems and is otherwise consistent with Commission policies will generally be granted.¹⁰ However, if the proposed modification presents significant interference problems, the Commission would treat it as a newly filed application – and in the context of an NGSO system, that means that the Commission will consider the modification application in a subsequent satellite processing round.¹¹ This guidance is now over 15 years old, and arose in the context of a request to decrease the number of satellites in a constellation rather than to increase them. Moreover, the discussion did not reach key issues that have taken on additional prominence in recent years, such as orbital debris mitigation and spectrum sharing. Accordingly, SpaceX urged the Commission to take this opportunity to clarify the standard for evaluating a proposed modification to an NGSO authorization issued through a processing round.

Specifically, assuming the application of an in-line events sharing regime, SpaceX recommended that the Commission clarify that it will focus on key criteria related to spectral

⁷ Angular separations greater than 10 degrees could reduce the severity of the harmful interference somewhat. However, the discrimination of most antennas is much greater within 10 degrees of boresight and rolls off fairly slowly thereafter, so it is doubtful that any degree of additional apparent angular separation, without other measures, would be sufficient to reduce harmful interference sufficiently. More importantly, increasing the separation angle would reduce spectral efficiency, to the detriment of all NGSO operators.

⁸ See *NPRM* ¶ 28. The Commission also asks whether it should impose similar limitations on downlink transmissions. *Id.* ¶ 30. Fortunately, downlink EPFD and PFD limitations applicable in many bands yield roughly comparable transmission levels for all NGSO systems.

⁹ See, e.g., Tereza Pultarova, *OneWeb Weighing 2,000 More Satellites*, SPACENEWS (Feb. 24, 2017), available at <http://spacenews.com/oneweb-weighing-2000-more-satellites/>. Note that as part of the current Ku/Ka-band processing round, O3b Limited has requested authority to serve the U.S. using additional satellites to augment its existing NGSO constellation, which was authorized outside a processing round. Such a situation falls outside the context at issue here.

¹⁰ See *Teledesic LLC*, 14 FCC Rcd. 2261, ¶ 5 (Int'l Bur. 1999).

¹¹ *Id.*

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efficiency and orbital safety. In particular, proposed system modifications should not result in warehousing of either spectrum or orbital resources, should ensure that the system remains compliant with applicable EPFD protection rules, and should not create material additional risk to the safety of operations in space for all interested parties. By clarifying the factors relevant to consideration of such modification applications now, the Commission can provide greater certainty to those who receive authorizations through the ongoing processing rounds as they move forward in developing and deploying their systems.

Respectfully submitted,



William M. Wiltshire
Counsel to SpaceX

Attachments

cc: Attached list

EXHIBIT 1
MEETING ATTENDEES

International Bureau

Jose Albuquerque
Clay DeCell
Jennifer Gilsenan
Kathryn Medley
Sankar Persaud

SpaceX

Mihai Albulet
Matt Botwin
Paul Caritj
Patricia Cooper
Rod Fleck
Jonathan Herman (by phone)
Mark Krebs
David Pattillo
Bill Wiltshire



SPACEX VIEWS ON FCC NGSO NPRM

August 15, 2017



Summary of SpaceX Views on NGSO NPRM Items

PREVIOUS COMMENTS:

- SpaceX supports proposals to increase spectrum available for FSS and allow blanket licensing in 17.8-18.3GHz
- SpaceX opposes any presumption that NGSO systems must protect GSO systems in bands that lack sharing rules
- SpaceX supports additional milestone and PFD flexibility to accommodate larger and more complex constellations
- SpaceX supports proposals to eliminate geographic coverage requirements as unnecessary, given competition among multiple NGSO systems

NEW DISCUSSION:

- Avoidance of In-line Interference
 - SpaceX supports the default mechanism adopted by the Commission, with a 10° trigger angle for Ku/Ka-band operations and application to all other bands as appropriate
 - SpaceX supports sharing beam pointing information among NGSO system operators
 - SpaceX supports creation of a clearinghouse to aggregate beam-pointing information
- Earth Station EIRP Limits
 - SpaceX supports the adoption of on- and off-axis earth station EIRP limits for NGSO systems
- Approach to Modification of Authorized NGSO Systems
 - SpaceX supports modifications/expansions of NGSO constellations that meet protection rules and do not threaten space safety



Avoidance of In-line Interference

- **SpaceX supports extension of the current default mechanism adopted by the Commission for NGSO in-line events to additional bands**
 - When satellites of different NGSO FSS systems appear to an earth station to be physically aligned at a specified trigger angle, operators split spectrum
 - *ITU priority-based mechanism does not make sense for NGSOs; it does not encourage competition and good use of spectrum, and does not serve the public interest*
- **SpaceX supports a 10° trigger angle for Ku/Ka band in-line events**
 - Offers a good compromise between efficient use of spectrum and low cost/low gain user terminals that can be widely deployed
 - Smaller separation angles require high-gain earth stations, not affordable to home users
 - Larger separation angles reduce spectral efficiency
 - Proposals to use $\Delta T/T$ or I/N criteria to define trigger angles are not workable
 - Think of the 10° trigger angle as a “not to be exceeded” value
 - Parties can agree in coordination to use smaller separation angles
- **V-band will likely require higher gain earth stations, may allow smaller trigger angles**
 - Systems with poor antenna rejection or transmitting large on-axis/off-axis EIRPs could require (and also force other systems to use) large separation angles
- **Spectrum splitting during in-line events should be fair, reflecting different rules applied to different bands (BSS/FSS, GSO/NGSO bands, Radio Astronomy, etc.)**



Defining In-line Interference Events

Is the following instance an in-line event?

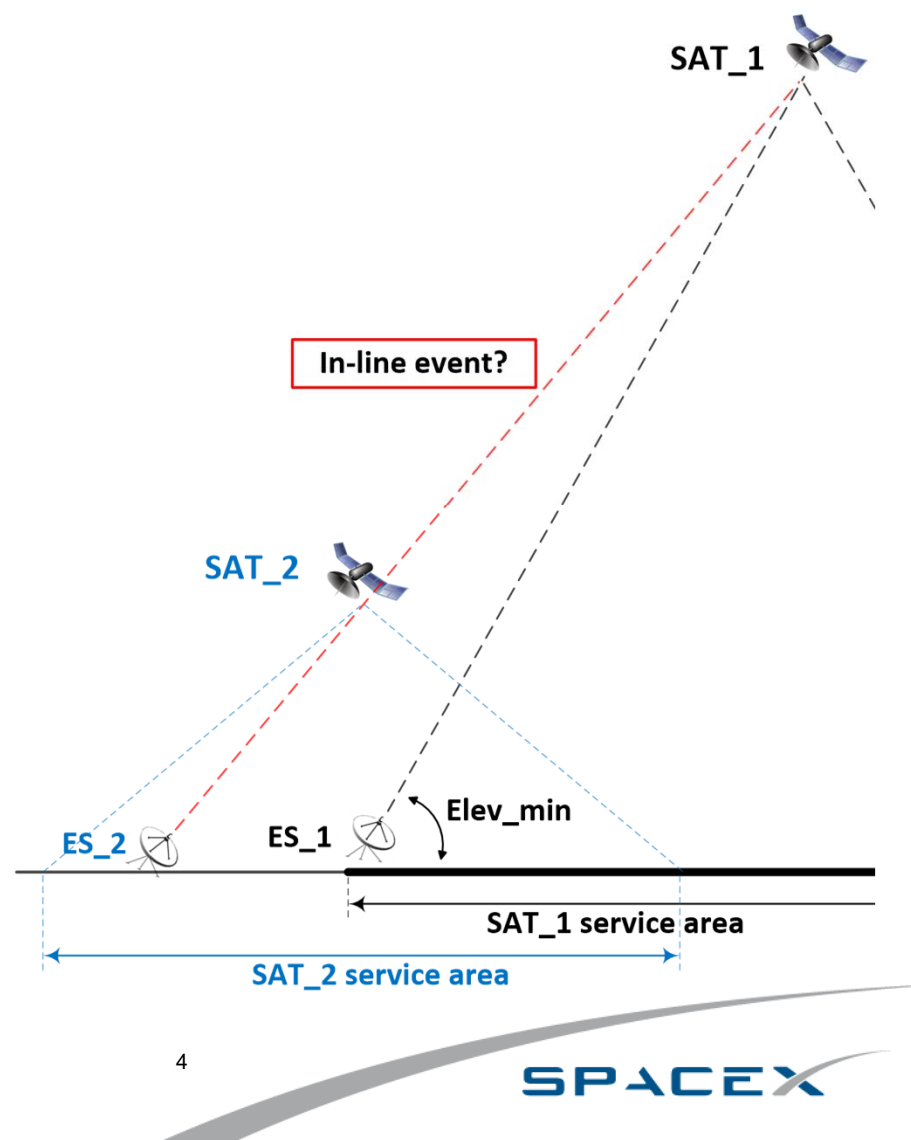
- ES_1 min elevation sets the satellite service area (footprint) for SAT_1
- ES_2 is outside SAT_1 service area

If YES:

- Significant RF penalty on SAT_2
- No impact on SAT_1

SpaceX proposes to clarify that:

- This should **NOT** be considered an in-line event
- SAT_1 expected to generate negligible interference outside its service area
- SAT_1 expected to cope with reasonable interference from outside its service area
- Could establish a reasonably small “buffer zone” right outside the service area ($< 4^\circ$)



False In-line Events

- Sharing of beam-pointing information among all NGSO system operators would significantly identify and reduce false in-line events
- Result would expand spectral efficiency significantly
- Example: MEO/HEOs with very large coverage footprints, but relatively few beams
 - At any given time, a single MEO/HEO satellite only serves a very small fraction of its total coverage area (much larger than CONUS)
 - Absent actual beam pointing knowledge, NGSOs must consider any location on the ground as an in-line event (if separation angle is $< 10^\circ$), regardless of “genuine” beam conflict
 - The actual number of “genuine” in-line events is extremely small
 - Sharing beam-pointing information would permit discarding false events, more usage of the band

Illustration: In-line events without beam knowledge
(between single Viasat satellite and SpaceX)

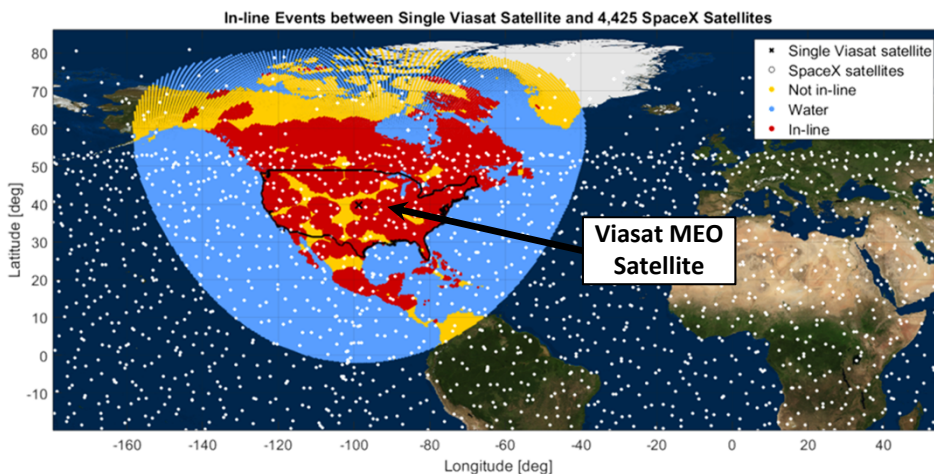
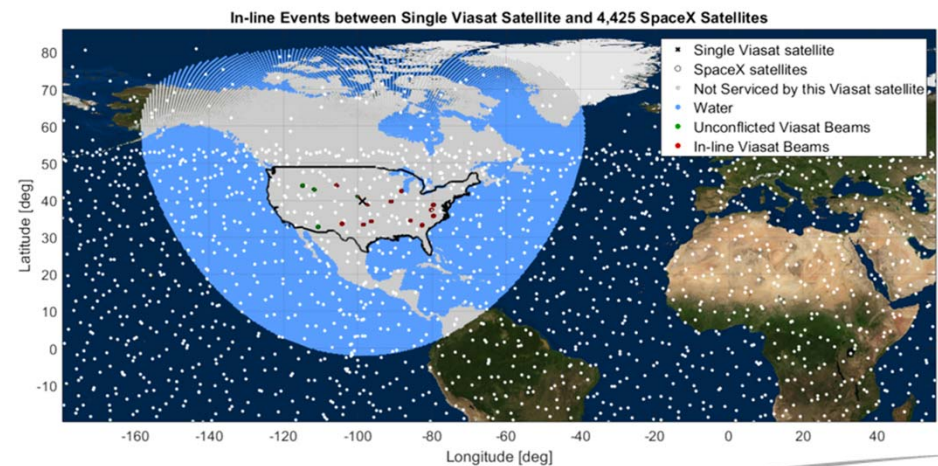
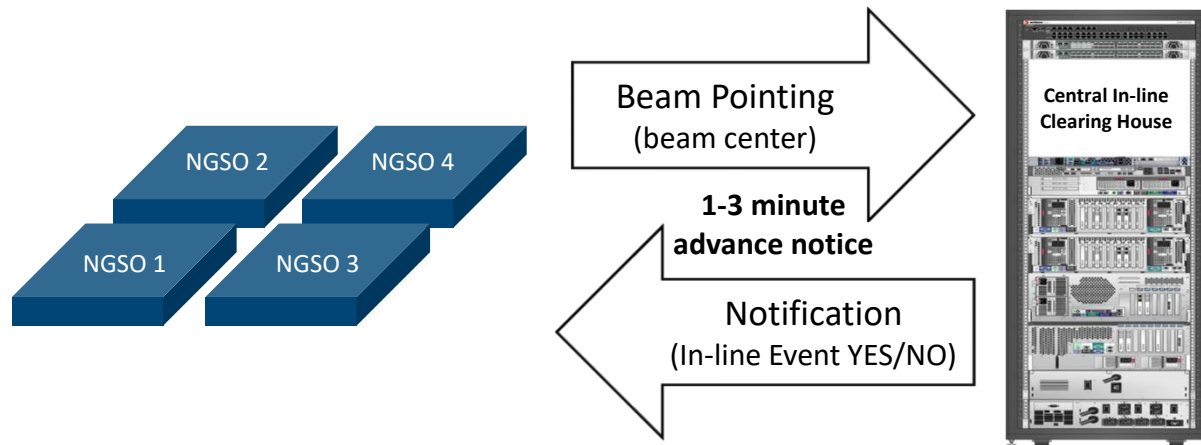


Illustration: In-line events with beam knowledge
(between single Viasat satellite and SpaceX)



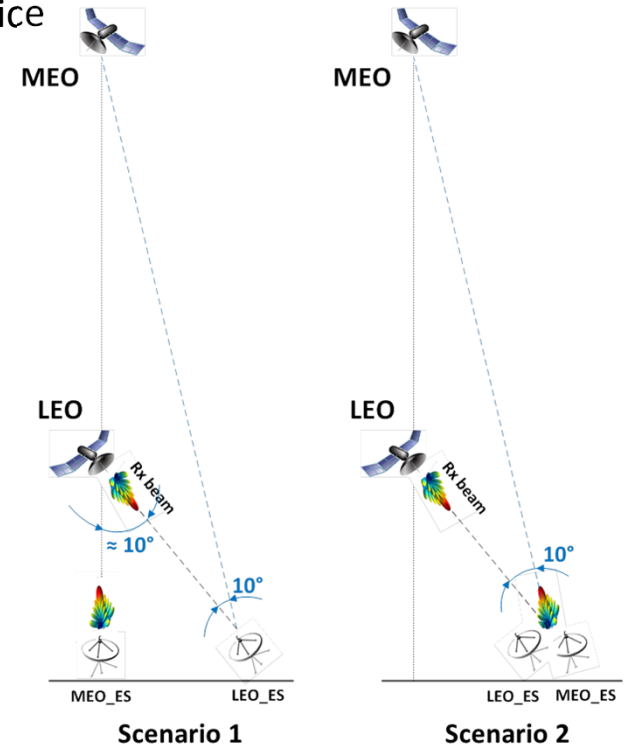
SpaceX Proposal for In-line Event Coordination

- SpaceX encourages the FCC to require licensed HEO/MEO system operators to submit beam pointing information to resolve in-line events and reduce false in-line events
- SpaceX recommends creating a neutral central “clearinghouse” for in-line events to aggregate and protect confidentiality of proprietary beam-pointing data (similar to JSpOC approach for orbital conjunctions)
 - No beam pointing information will ever be shared with a competitor
 - Clearinghouse would notify operators whether in-line event occurs or not, and identify portion of spectrum that should be used by each party during in-line events (spectrum splitting)
 - Improved method to address 3-way (or more) in-line events
 - NGSO operators pay fee for information from clearinghouse
- **Quick, automated service would not place any undue burden on NGSOs**
 - Operators should be able to provide this information 1-3 mins in advance
- **Opportunity for HEO/MEO systems with a small number of beams to have LEO systems route around their beams for a significant portion of time**



Earth Station EIRP Limits

- **SpaceX supports the adoption of earth station EIRP limits for NGSO systems**
 - Limits are necessary to ensure that interference at the “not to be exceeded” trigger angle is acceptable
 - SpaceX has provided several examples in its comments in Ku/Ka processing round showing that MEO and HEO earth stations can cause significant interference to LEO systems
 - MEO/HEO systems with limited/use-specific capabilities could impede the operation of LEO systems operating with far greater capacity and potential service
 - Increased separation angles would likely provide diminished returns
 - In some cases, the LEO satellite may not be able to use a frequency anywhere in its field of view; even other channels may be severely impacted
 - Generally, HEO earth stations generate more interference than MEO earth stations and LEOs at low altitudes are more susceptible to interference
 - Less of a problem for feeder links (known locations / pointing), but significant for ubiquitously deployed user terminals



Proposed On-Axis EIRP limits

- In Scenario 1, the only rejection is provided by the LEO satellite Rx antenna
- EIRP limits depend on LEO altitude, SAT Rx antenna gain, G/T, sidelobe rejection
- EIRP limits are different in Ku / Ka / V bands

Ideally:

- **All earth stations (LEO/MEO/HEO) radiate equal (or at least comparable) on-axis EIRPs**
- **MEO/HEO satellites compensate for the additional path loss via Rx antenna gain**
 - A side benefit: spot size equalization

SpaceX suggested on-axis EIRP limits:

Ku-band: less than -35dBW/Hz

Ka-band: less than -30dBW/Hz

V-band: TBD



Proposed Off-Axis EIRP limits

- In Scenario 2, the only rejection is provided by the interfering MEO/HEO earth station Tx antenna
- EIRP limits will be different in Ku / Ka / V bands

Ideally:

- **All earth stations (LEO/MEO/HEO) should radiate equal (or at least comparable) off-axis EIRPs**
 - If all earth stations (LEO/MEO/HEO) radiate equal or comparable on-axis EIRPs, then this should not be an issue
- **If MEO/HEO earth stations are allowed to use higher on-axis EIRPs, then they should use the same Tx power (as LEO earth stations) and higher antenna gain**

SpaceX suggested off-axis EIRP limits:

Ku-band: less than -65dBW/Hz

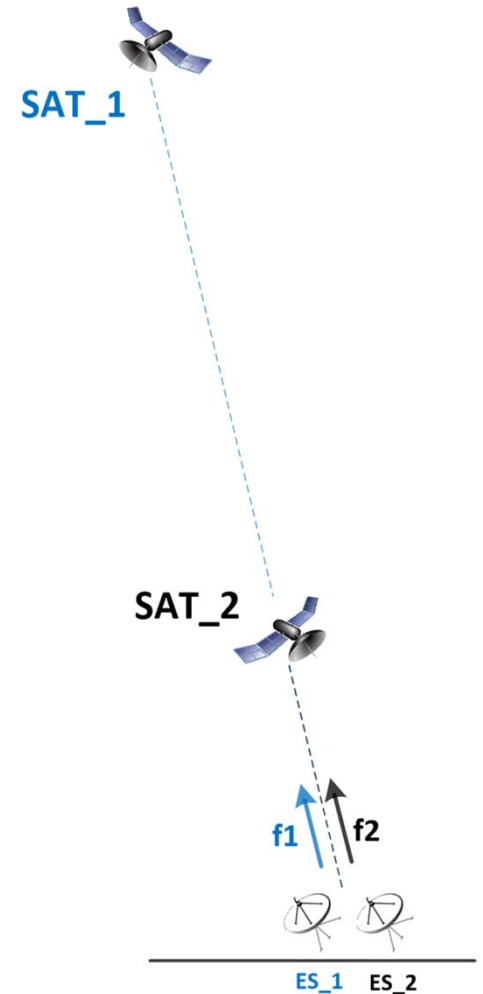
Ka-band: less than -65dBW/Hz

V-band: TBD



Out-of-Band Emissions

- Section 25.202(f) emission mask is defined based on “authorized bandwidth” (*i.e.*, the contiguous spectrum a system is authorized to use)
- SpaceX recommends clarifying that in case of spectrum-splitting during an in-line event, the authorized bandwidth is ***the fraction of the assigned bandwidth in which the system may transmit during the in-line event***
- This should ensure that, in general, interference in the adjacent channels is acceptable
 - Assumes comparable signal levels of desired and interferer
 - Generally true for downlink (due to PFD/EPFD limits), but not for uplink (with no EIRP limits)
 - A high EIRP MEO/HEO can completely jam a LEO in the adjacent channel
 - Additional ACLR requirements may be needed



Flexibility for Authorized NGSO Systems

- Some NGSO systems have indicated interest in further expanding their constellations, beyond the number originally requested
- SpaceX supports enabling NGSO operators with the flexibility to adapt their constellations to both market demand and evolving technological capabilities over time
- The Commission should clarify its approach to considering such modifications to expand the number of spacecraft in an NGSO constellation
- In the presence of in-line rule, SpaceX recommends focusing on key criteria of spectral efficiency and orbital safety impact
 - No warehousing of either spectrum or orbital resources
 - Remain compliant with EPFD protection rules
 - No material additional orbital safety risk





THANK YOU