| **US Radiocommunication Sector** **FACT SHEET** |
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| **Study Group:** USWP 7C | **Document No:** 7C/27-036NC |
| **Reference:**  | **Date: 12 February 2025** |
| **Document Title:** Preliminary draft new Report ITU-R RS series - Evaluation of co-frequency sharing between NGSO FSS and EESS passive in 18.6-18.8 GHz band |
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| **Purpose/Objective**: Technical studies evaluating the interference that could be received by EESS (passive) sensors in the 18.6-18.8 GHz band  |
| **Abstract**: Surface water reflections may potentially cause downlink satellite signals to be reflected towards space and inadvertently received by EESS (passive) sensors operating in the 18.6-18.8 GHz band. Technical studies are necessary to determine the significance of this reflection phenomenon and using modern non-GSO systems and operational characteristics of EESS (passive) sensors |
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| **Radiocommunication Study Groups** |  |
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| Received: Date References: Documents Source: Document  | **Document 4A/X** |
| **Date**  |
| **English only** |
| United States of America |
| Proposed Working document towards a preliminary draft new Report ITU-R S.[NGSO-18-GHz] |
| Evaluation of co-frequency sharing between NGSO FSS and EESS passive in 18.6-18.8 GHz band |

This document presents example studies of the feasibility of utilizing the 18.6-18.8 GHz frequencies for non-GSO FSS service, as attached.

**Attachment:** 1

Attachment

WORKING DOCUMENT towards a draft new
report ITU-R S.[ NGSO-18.6-18.8-GHz]

**Evaluation of co-frequency sharing between NGSO FSS and EESS passive in 18.6-18.8 GHz band**

# Introduction

The 18.6-18.8 GHz band serves critical scientific purposes, particularly for Earth Exploration-Satellite Service (EESS) passive operations. These operations enable the measurement of various atmospheric and oceanic parameters, including water vapour profiles, precipitation, cloud formations, snow and ice coverage, melting layer characteristics, and sea surface properties such as wind, temperature, and topography. Recommendation ITU-R RS.2017 outlines the performance and interference criteria for these remote sensing systems. However, a comprehensive technical assessment of these criteria has not been conducted for a considerable time. This situation may necessitate a review, especially in light of recent developments such as Recommendation ITU-R P.2146, which provides a method for predicting signal reflection from sea surfaces.

In this band, FSS systems are co-primary with EESS (passive) but are limited by RR No. 5.522B to geostationary systems and non-geostationary systems with an orbit of apogee greater than 20,000 km. It has been many years since any technical assessment of co-frequency non-GSO FSS downlinks on EESS (passive) operations in this band has been performed.

This report analyses the EESS (passive) protection criteria in 18.6-18.8 GHz and presents updated studies on the impact of non-GSO FSS systems orbiting at or above 20,000 km on EESS (passive) sensors sharing the same band. For comparison, it also includes studies assessing the theoretical impact of non-GSO FSS systems with apogee of orbit lower than 20,000 km. The focus is on potential interference into EESS (passive) sensors caused by emission reflections off bodies of water on the Earth's surface.

This report aims to evaluate the technical feasibility of modern non-GSO FSS downlink operations in the 18.6-18.8 GHz frequency band while considering the concurrent operation and protection of EESS (passive) services.

# Definitions

e.i.r.p.: Equivalent isotropically radiated power

epfd: Equivalent power flux-density

FOV: Field of view

FSS: Fixed-satellite service

GSO: Geostationary satellite orbit

HTS: High throughput satellite

I/N: Interference-to-thermal-noise ratio

non-GSO: Non-geostationary satellite orbit

EESS: Earth exploration satellite-service

# Discussion on EESS (passive) operation in 18.6-18.8 GHz

The EESS (passive) allocation in the 18.6-18.8 GHz band was upgraded from secondary to primary in Regions 1 and 3 at WRC-2000. Following WRC-2000, the EESS (passive) operated worldwide under the assumption that networks in the primary FSS would be operating in the same band at the maximum allowable power flux-density (pfd) limits prescribed in RR Article **21**, Table **21-4**, No. **21.16.2**.

The FSS allocation in 18.6-18.8 GHz is limited by RR No. **5.522B** to GSO networks and non-GSO systems with an orbit apogee greater than 20 000 km. Both the FSS and the fixed service (FS) are subject to band-specific emission limits in RR Article **21**. For Region 2, the 18.6-18.8 GHz FSS (space-to-Earth) band is part of an identification for the use by high-density FSS applications in RR No. **5.516B**.

The 18.6-18.8 GHz band is extensively used for scientific purposes, and it is essential for all land and ocean surface data products generated from radiometer data. EESS (passive) operations in this band allow measurements of the water vapour profile, precipitation, clouds, snow, ice, melting layer and sea surface wind, temperature and topography. These measurements enable multiple applications, including climate and environmental applications, weather forecasting, and sea surface characterisation. Many passive remote sensing instruments operate in this band, and more are planned for future deployment. It is, therefore, of vital interest to minimize harmful interference in this portion of the spectrum.

EESS (passive) sensors operating in 18.6-18.8 GHz currently face an increased interference environment. The source and mechanism of this interference are still under investigation, noting that part of it might be due to the operations of FSS downlinks operating in-band and in adjacent bands in conjunction with sea surface reflectivity phenomena.

Therefore, it may be useful to study the impact on the EESS interference environment of non-GSO FSS stations allowed under No. **5.552B**, and, for comparison, to study the impact of non-GSO FSS stations with an orbit apogee less than 20 000 km if they were to transmit in the frequency band 18.6-18.8 GHz.

# Characteristics of EESS (passive) operation in 18.6-18.8 GHz

EESS (passive) sensors operating in 18.6-18.8 GHz are expected to tolerate and operate in an interference environment that includes emissions from FSS systems operating in-band as well as adjacent bands in accordance with the pfd limits specified in RR No. **21.16.2**. Recognizing that these operations are not co-directional, the actual source and mechanism of this interference is not fully known and is still under investigation. As per RR No. **5.522B,** the use of FSS systems in the 18.6-18.8 GHz band is limited to GSO systems and systems with an orbit of apogee greater than 20 000 km. GSO ESIMs are currently authorized for operation in the band 18.6-18.8 GHz according to Resolution **169 (Rev. WRC-23)**.

# Analysis of EESS (passive) characteristics and protection criteria in 18.6-18.8 GHz

TBD

# Existing information on characteristics of EESS (passive) operation in 18.6-18.8 GHz

The typical technical and operational characteristics of EESS (passive) sensors are captured in Recommendation ITU‑R [RS.1861](https://www.itu.int/rec/R-REC-RS.1861-0-201001-I/en)-1. Tables 1 to 3 contain the characteristics of EESS (passive) sensors in the 18.6-18.8 GHz as included in the Recommendation ITU‑R RS.1861-1. The protection criteria for EESS (passive) systems are contained in Recommendation ITU-R [RS.2017](https://www.itu.int/rec/R-REC-RS.2017-0-201208-I/en)-0 and is defined over a square measurement area of 10 000 000 km².

TABLE 1

EESS (passive) sensor characteristics in the 18.6-18.8 GHz band

|  |  |  |  |
| --- | --- | --- | --- |
|  | Sensor D3 | Sensor D4 | Sensor D5 |
| Sensor type | Conical scan | Conical scan | Conical scan |
| Orbit parameters |  |  |  |
| Altitude | 865.6 km | 835 km | 699.6 km |
| Inclination | 20 | 98.85° | 98.186° |
| Eccentricity | 0 | 0 | 0.002 |
| Number of beams |  | 1 | 1 |
| Antenna size | 0.65 m | 0.65 m | 2.0 m |
| Maximum beam gain |  | 38.7 dBi | 49.4 dBi |
| Polarization | V, H | V, H | V, H |
| Off-nadir pointing angle | 44.5 | 53.3 | 47.5 |
| Incidence angle at Earth | 52.3 | 65° | 55.0° |
| Antenna efficiency |  |  | 0.567 9 |
| Beam dynamics | 20 rpm | 2.5 s scan period, clockwise | 40 rpm |
| Sensor antenna pattern | See Rec. [ITU‑R RS.1813](http://www.itu.int/rec/R-REC-RS.1813/en) | See Rec. ITU‑R RS.1813 | See Rec. ITU‑R RS.1813 |
| Channel bandwidth | N/A | 200 MHz centred at 18.7 GHz | 200 MHz centred at 18.7 GHz |

TABLE 2

**EESS (passive) sensor characteristics in the 18.6-18.8 GHz band**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Sensor D6 | Sensor D7 | Sensor D8 | Sensor D9 | Sensor D10 |
| Sensor type | Conical scan | Conical scan | Conical scan | Conical scan | Nadir |
| Orbit parameters |  |  |  |  |  |
| Altitude | 830 km | 407 km | 820 km | 407 km | 1 336 km890.6 km\* |
| Inclination | 98.85° | 50° | 98.702° | 65° | 66°77.6°\* |
| Eccentricity | 0 | 0.003 | 0.001 144 1 | 0 | 0 |
| Number of beams | 1 | 1 | 8 | 1 | 12\* |
| Antenna size | 1.0 m | 1.1 m | 7.5 m | 1.22 m | Effectively 0.61 m;physical reflector is 1 m, but beam is intentionally de-focused |
| Maximum beam gain | 43.6 dBi | 44.4 dBi | 59.6 dBi | 45.6 dBi | 40.5 dBi |
| Polarization | V, H, V+45, V-45 | V, H | H, V | H/V | Dual Linear |
| Off-nadir pointing angle | 53.3 | 48.6 | 46.5° | 48.5° | 0°±2.65° cross-track\* |
| Incidence angle at Earth | 65 | 53 | 55° | 52.8° | 0°3.0°\* |
| Antenna efficiency | 0.5974 | 0.594 | TBD |  | 0.79 |
| Beam dynamics | 2.5 s scan period, counter clockwise | 30 rpm | 7.8 rpm | 32 rpm | N/A |
| Sensor antenna pattern | See Rec. [ITU‑R RS.1813](http://www.itu.int/rec/R-REC-RS.1813/en) | See Rec. ITU‑R RS.1813 | TBD | Rec. ITU-R RS.1813 | See Rec. ITU‑R RS.1813 |
| Channel bandwidth | 200 MHz centred at 18.7 GHz | 200 MHz centred at 18.7 GHz | 200 MHz centred at 18.7 GHz | 200 MHz centred at 18.7 GHz | 200 MHz centredat 18.7 GHz |

TABLE 3

EESS (passive) sensor characteristics in the 18.6-18.8 GHz band

|  | Sensor D11 | Sensor D12 | Sensor D13 | Sensor D14 |
| --- | --- | --- | --- | --- |
| Sensor type | Conical scan | Fixed-pointing | Conical scan | Conical scan |
| **Orbit parameters** |
| Altitude | 970 | 970 | 665.96 km | 833 km |
| Inclination | 99.3° | 99.3° | 98.06° | 98.6° |
| Eccentricity | 0.001 17 | 0.001 17 | 0.001 5 | 0 |
| Number of beams | 1 | 3 | 1 | 1 |
| Antenna size | 1.0 m | 0.92 m | 2.0 m |  |
| Maximum beam gain | 43 dBi | 43 dB | 49.4 dB | 41.5 dBi |
| Polarization | V, H | V, H | V, H |  |
| Off-nadir pointing angle | 44° | −2.4° | 47.7° |  |
| Incidence angle at Earth | 53° | −2.4° | 55.0° |  |
| Antenna efficiency | 96% | 93.1% | 0.5679 |  |
| Beam dynamics | 3.57 s |  | 40 rpm |  |
| Sensor antenna pattern |  |  | See Rec. [ITU‑R RS.1813](http://www.itu.int/rec/R-REC-RS.1813/en) | See Rec. ITU-R RS.1813 |
| Channel bandwidth | 200 MHz | ±250 MHz | 200 MHz centred at 18.7 GHz | 200 MHz centred at 18.7 GHz |

The model to estimate the power reflected by the water surface is Recommendation ITU‑R P.2146. Related information on ocean surface wind speed is provided by Recommendation ITU-R P.2148.

Step-by-step algorithm for a single time step in the simulation

Step 1: When the beam center of the EESS sensor is inside the measurement area

Step 2: Repeat Step 3 to Step 11 for all visible space stations of the non-GSO system

Step 3: Repeat Step 4 to Step 11 for all beams allocated to a cell on the surface of the Earth

Step 4: Calculate the off-axis angle between the point of boresight of the beam of the non-GSO space station and the point of boresight of the EESS sensor

Step 5: Calculate the off-axis discrimination of the non-GSO space station beam towards the point of boresight of the EESS sensor using Rec. ITU-R S.1528 Recommends 1.4

Step 6: Calculate pfd from the non-GSO system at the point of boresight of the considered beam from the pfd mask associated with the respective non-GSO system

Step 7: Calculate the pfd at the point of boresight of the EESS sensor

Step 8: Calculate the zenith and azimuth angle of the incidence wave at the reflection point

Step 9: Calculate the zenith and azimuth angle of the scattering wave at the reflection point towards the EESS space station using the off-nadir pointing of the sensor

Step 10: Calculate the sea surface scattering components according to Rec. ITU-R P.2146 using fixed values for U10 = 7 m/s, T = 20° C, S = 35 g/kg.

Step 11: Calculate the coherent and diffuse received power at the EESS receiver

Step 12: Add all interference contributions to an aggregate interference power

The scattering is the sum of two components:

– the coherent component, which occurs only for completely the specular reflection, requires determining at each time step the specular reflection point on the Earth, the distances and antenna gain towards this specular point for both the FSS and EESS satellites. At 18 GHz the coherent component is negligible, so only the incoherent component is taken into account;

– the incoherent component, which does not necessarily correspond to specular conditions, is applied over the EESS sensor footprint. In that case the EESS sensor antenna gain is approximated by the maximum antenna gain and the FSS antenna gain is calculated in the direction of the EESS sensor footprint.

# Analysis

Simulations were performed to assess the percentage of a measurement area that would be impacted by such interference due to sea surface reflection of NGSO FSS satellites operating within the band 18.6‑18.8 GHz. The following subsections describe the assumptions and methodology.

## Definition of a reference/measurement area

Concerning EESS (passive) services in the band 18.6-18.8 GHz, the Recommendation ITU-R RS.2017 protection criterion of −163 dB(W/(200 MHz*))* not to be exceeded more than 0.1% of the time is associated with a square measurement area of 10 000 000 km2. This means that only the time events when the EESS sensor footprint is within this measurement area are to be retained for interference calculation and derived statistics.

The measurement areas chosen are square in longitude/latitude and cantered over the Pacific at 15° North (N) latitude and at –134.5° East (E).

Equation (Eq.) (1) provides a metric to verify the correct measurement area size on the Earth's surface based on the latitudes and longitudes of the four points in the square, considering that the perpendicular sides of the square are parallel to the latitudes and meridians.

$A=r\_{E}^{2}\left(\sin(\left(φ\_{1}\right))-\sin(\left(φ\_{2}\right))\right)\left|θ\_{1}-θ\_{2}\right|$ (1)

In Eq. (1), $r\_{E}$ = 6 378.145 km is the radius of the Earth, $φ\_{1}, φ\_{2}$ are the two latitudes associated to the square in degrees North and $θ\_{1}, θ\_{2}$ are the respective two longitudes in degrees East.

The reference areas are chosen so that when limiting the emission of non-GSO FSS systems to land areas, they cover the adjacent sea surface, i.e., coastal areas and sea surface.

Table 3

Points of the square measurement area over the West Pacific (Region 2)

|  |  |  |
| --- | --- | --- |
| Point No. | Latitude | Longitude |
| 1 | 15° N | –150° E |
| 2 | 46° N | –150° E |
| 3 | 46° N | –119° E |
| 4 | 15° N | –119° E |

\* The measurement area is intentionally made slightly bigger to compensate for the included land. Land was included to cover potential high interference events in the coastal areas.

## Technical and operational characteristics of non-GSO FSS systems

The technical and operational characteristics of the non-GSO FSS systems, which are considered to operate co-frequency with the EESS systems in the 18.6-18.8 GHz frequency range are listed below.

## 7.1 Operational characteristics of non-GSO FSS systems with orbits above 20 000 km

The FSS parameters assumed for the HEO systems in this study are composed of eight HEO satellites in eight orbital planes with an orbital period of 11 hours 58 minutes.

For this study, the minimum elevation angle for the HEO systems was chosen to be 10 degrees. Orbital parameters of the FSS systems are given in Table 2.

Table 7.1-1

HEO Orbital Parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
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|  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Orbit** |  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| # of sats per plane |  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Apogee | km | 39 400 | 39 400 | 39 400 | 39 400 | 39 400 | 39 400 | 39 400 | 39 400 |
| Perigee | km | 1 000 | 1 000 | 1 000 | 1 000 | 1 000 | 1 000 | 1 000 | 1 000 |
| RAN | deg. | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 0 |
| Inclination | deg. | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 63 |
| Argument of Perigee | deg. | 270 | 270 | 270 | 270 | 270 | 270 | 270 | 270 |
| Min. operational altitude | km | 20 000 | 20 000 | 20 000 | 20 000 | 20 000 | 20 000 | 20 000 | 20 000 |
| True anomaly | deg. | 90 | 225 | 180 | 315 | 270 | 450 | 0 | 135 |

Link parameters for the HEO systems are shown in Table 7.1-2.

Table 7.1-2

HEO FSS Link Parameters

|  |  |  |
| --- | --- | --- |
| Min Operational Altitude | km | 20 000 |
| Power | dBW | 15 |
| Power in 100 MHz | dBW | -1.1 |
| Polarization | RHCP |  |
| Antenna Gain | dBi | 51.0 |
|  Max. PSD | dBW/Hz | -69 |
|  |  |  |
| Antenna Gain | dBi | 51 |
| 3 dB beamwidth | degrees | 0.47 |
| Antenna pattern |  | Rec. ITU-R S.672 (Ls=-20 |
| Satellite selection |  | Random |

## 7.2 Operational characteristics of other non-GSO FSS systems

Table 7.2-1

Technical and operational characteristics of the non-GSO systems

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | System 1 | System 2 | System 3 | System 4 |
| Apogee (km) | 630, 610, 590 |  |  |  |
| Perigee (km) | 630, 610, 590 |  |  |  |
| Eccentricity | 0, 0, 0 |  |  |  |
| Inclinations (deg.) | 51.9, 42, 33 |  |  |  |
| Space stations per plane | 34, 36, 28 |  |  |  |
| Planes per shell | 34, 36, 28 |  |  |  |
| GSO exclusion angle (deg.) | 18 |  |  |  |
| Number of co-frequency space stations serving one point on the Earth | 1 |  |  |  |
| Min. operational elevation (deg.) | 35 |  |  |  |
| Antenna gain (dBi) | 41 |  |  |  |
| Antenna reference Pattern | Rec. ITU-R S.1528 Recommends 1.4 |  |  |  |
| Antenna beam width (deg.) |  |  |  |  |
| *L*N (dB) | N/A |  |  |  |
| *L*r (m) | 0.25 |  |  |  |
| *L*r (m) | 0.25 |  |  |  |
| SLR (dB) | 25 |  |  |  |
| *ϕ* (deg.) | 0 |  |  |  |
| Tx max PFD (dB(W/1 MHz)) | -117 |  |  |  |
| Polarization  | RHCP |  |  |  |
| Beam pointing | Equidistant grid |  |  |  |
| Frequency reuse factor | 3 |  |  |  |
| Number of co-frequency beams per satellite | 9 |  |  |  |
| Satellite Selection | Random |  |  |  |
| Average distance co-frequency beams on the surface of the Earth | 103.94 km1 |  |  |  |

Note 1: The distribution of co-frequency cells on the surface of the Earth is based on an equidistant grid with fixed points of boresight (PoBs). The amount and separation of the PoBs are based on the cell diameter, the assumed spectrum used within the cells, and the activity ratio of the non-GSO systems. It is assumed that not all cells are active and loaded 100% of the time, depending on geographical coverage, population density, daytime, and licensing. To cope with these differences, it is assumed that the application of these boundary conditions and operations constraints are reflected best by larger equidistant separation of co-frequency cells within the considered service area adjacent to the reference area.

## Simulation data setup

The model is based on a linear time-variant simulation with a dual time step to improve computation time. A fine time step is when the EESS sensor is inside the reference area, and a larger time step is outside the reference area. The fine time step depends on the selected EESS sensor, all having different beam dynamics, as provided in Tables 1 to 3. To cover a detailed simulation result with the same number of samples per beam, different time steps for each sensor are proposed in Table 6, all of them (primarily conical sensors) having the same number of samples (64 samples corresponding to 1 sample every 5.625 degrees) within one round.

Table 6

Points of the square measurement area over the Pacific

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | Unit | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 | D11 | D12 | D13 | D14 |
| Rounds per minute |  | 20 | - | 40 | - | 30 | 7.8 | 32 | - | - | - | 40 | - |
| Seconds per round | s | 3 | 2.5 | 1.5 | 2.5 | 2 | 7.69 | 1.875 |  | 3.75 |  | 1.5 |  |
| Samples per round |  | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| Time step inside the reference area | s | 0.05 | 0.04 | 0.02 | 0.04 | 0.03 | 0.1 | 0.03 |  | 0.06 |  | 0.02 |  |
| Time step outside the reference area | s | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Total simulation time | h | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |

[Note: The simulation time in this table is a proposal for the interested parties to use when conducting studies. The simulation in this study was conducted over 10 days, but due to the long computation time, a shorter time frame was proposed. A longer simulation time than the proposed table may be agreed on, if deemed necessary]

Interreference samples are collected anytime that the beam footprint is inside the measurement area. This is independent of the location of the EESS passive satellite.

## Study #1: NGSO HEO and EESS (passive) coexistence

Figure 9-1

Results study #1



Figure 9-2

Spatial distribution of max interference levels in the reference area



1. Results study #2

### Sensor D8 non-GSO system 1

Two figures are presented as a result of study #1. The first one is Figure 1, showing the complementary cumulative distribution function (ccdf) of the interference power in 200 MHz concerning the protection criterion of Rec. ITU-R RS.2017-0.

Figure 10.1-1

Results study #2



The second plot in Figure 10.1-2 shows the maximum interference power per sample in the reference area (red square) collected over the total simulation time as a function of the spatial coordinates. The beams of the non-GSO system are distributed according to the characteristics described in Table 5 within the square highlighted by the dotted lines on the landmasses only, which in Figure 2 are the West Coast of the United States and parts of Canada and Mexico.

Figure 10.1-2

Spatial distribution of max interference levels in the reference area



Detail of the computation is provoided here for more information.



### Sensor D4 non-GSO system 1

[TBD]

# Summary

# The result of the studies conducted in section 9 and 10 indicates that non-GSO systems in orbits above and below 20,000 km may operate in the frequency band 18.6-18.8 GHz without causing unacceptable interference into EESS passive operation in 18.6-18.8 GHz.

This study is conducted using a set of conservative assumptions to reflect the worst-case interference scenario. However, it only covers one aspect of the technical considerations needed to ensure coexistence of non-GSO FSS systems below 20,000 km with EESS passive in 18.6-18.8 GHz. Further analysis is required to comprehensively address all the technical factors that may impact the compatibility between these systems.