ONEWEB NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT A
Technical Information to Supplement Schedule S

A.1   SCOPE AND PURPOSE

This attachment contains the information required by §25.114(d), §25.146 and other sections of the FCC's Part 25 rules that cannot be captured by the Schedule S software.

A.2   OVERALL DESCRIPTION OF SYSTEM FACILITIES, OPERATIONS AND SERVICES AND EXPLANATION OF HOW UPLINK FREQUENCY BANDS ARE CONNECTED TO DOWNLINK FREQUENCY BANDS (§25.114(d)(1))

The OneWeb non-geostationary orbit ("NGSO") satellite system (the "OneWeb system") consists of a constellation of 720 Low Earth Orbit ("LEO") satellites, plus in-orbit spares, in near-polar circular orbits of altitude 1,200 km, as well as associated ground control facilities, gateway earth stations and end user earth stations ("user terminals").[1] The OneWeb system will provide high-quality, broadband Internet access to small low-cost user terminals located anywhere on the Earth. The service provided will be comparable to the broadband terrestrial

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[1]   The OneWeb satellite system has been designed such that more satellites beyond 720 can be added to the constellation at a future time to increase capacity while still protecting GSO satellite networks through compliance with EPFD limits. Technical design features necessary to achieve this evolutionary approach are inherent in all the satellites to be launched as part of the initial OneWeb system.

services available in densely populated areas of developed countries today. In addition, because the OneWeb satellites are at a much lower altitude than GSO satellites, users on OneWeb's system experience round trip latency of less than 50 milliseconds, which is 1/13th of the latency of GSO satellites, and consistent with terrestrial technologies.[2]

The OneWeb system will extend the networks of mobile operators and ISPs to serve new coverage areas bringing voice and data access to consumers, businesses, schools, and other community locations that cannot technically or economically be served through terrestrial means. The OneWeb user terminal can also function as a small cell with integrated backhaul to extend the networks of mobile operators by acting as a low cost base station to which mobile users can connect. OneWeb will partner with mobile operators so all of their customers will have the high speed (up to 50 Mbps) and low latency (less than 50 ms) benefits of the OneWeb infrastructure in areas such as "not spots" where their mobile services are either not deployed or the quality of service is very low. Through roaming agreements, other operators' customers can also access the OneWeb infrastructure.

OneWeb's system is also designed to support the work of the public protection and disaster relief (PPDR) emergency services during the most demanding crises, which can strike unexpectedly, leaving communities suddenly without infrastructure. When the OneWeb user terminals are attached to any vehicle, they create a cell network around the vehicle for first responders that is capable of working with any mobile operator, including potentially with FirstNet.[3] OneWeb's vehicle cell network will provide 4G quality Internet and voice directly to emergency vehicles to

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[2]   According to the FCC's 2014 "Report on Consumer Wireline Broadband Performance in the U.S.", the average latency on all terrestrial networks during peak period was 34.9 ms, whereas on geostationary satellites it was 671 ms. Available at https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-broadband-america-2014#block-menu-block-4.

[3]   First Responder Network Authority ("FirstNet") is an independent authority within NTIA to provide emergency responders with the first nationwide, high-speed, broadband network dedicated to public safety.

ensure connectivity for first responders, humanitarian workers, and medical personnel globally where and when it is needed.[4] Through this application, OneWeb is not seeking licensing of any terrestrial mobile frequencies, as it will rely on spectrum already available to its partner operators, where they have been authorized. The Vehicle Cell Network terminals will only activate when the proper terrestrial spectrum is available, augmenting and extending the coverage of its partner operators to reach 100% of the United States geography including Alaska, Hawaii and the US Territories.

The OneWeb system uses Ku-band for the RF links between the satellites and user terminals and Ka-band for the RF links between the satellites and gateway earth stations, with the latter providing the interconnection to the global internet. The OneWeb Ku-band user terminals consist of small and inexpensive antennas (typically in the 30 cm to 75 cm range). Implementation of these antennas may involve mechanically steered parabolic reflectors and/or low-cost phased array designs, or other beam steering technology already under development. An optional built-in solar array panel can be added to battery powered terminals. The user terminals will therefore be quick and easy to deploy and can easily be used for transportable applications. Larger user terminals may also be employed in some situations such as for business applications with different service requirements. The Ka-band gateway earth stations will typically utilize 2.4 m or larger antennas, depending on their location and the associated propagation characteristics and service requirements.

The frequency ranges used by the OneWeb system are summarized in Table A.2-1 below, and also shown in Figures A.2-1 and A.2-2 together with an indication of the FCC frequency

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[4] The vehicle-mounted base station could also operate on the FirstNet frequencies if that is permitted by regulators and the agency, thus avoiding the need to build expensive infrastructure where there is little population or non-existent cellular coverage.

allocations that exists in these bands. The detailed channelized frequency plan is given in the associated Schedule S.

**Table A.2-1: Frequency bands used by the OneWeb non-GSO satellite system**

Type of Link and Transmission Direction	Frequency Ranges
Gateway-to-Satellite	27.5 – 29.1 GHz 29.5 – 30.0 GHz
Satellite-to-Gateway	17.8 – 18.6 GHz 18.8 – 19.3 GHz 19.7 – 20.2 GHz (Note 1)
User Terminal-to-Satellite	12.75 – 13.25 GHz (Note 1) 14.0 – 14.5 GHz
Satellite-to-User Terminal	10.7 – 12.7 GHz

Note 1: Although the OneWeb satellites have the capability to operate in the Earth-to-space direction in the 12.75-13.25 GHz band, and the space-to-Earth direction in the 19.7-20.2 GHz band, FCC authorization is not being requested for these bands at this time and they will not be used from any US territories.

Figure A.2-1: Frequency plan for OneWeb showing the FCC Ku-band frequency allocations
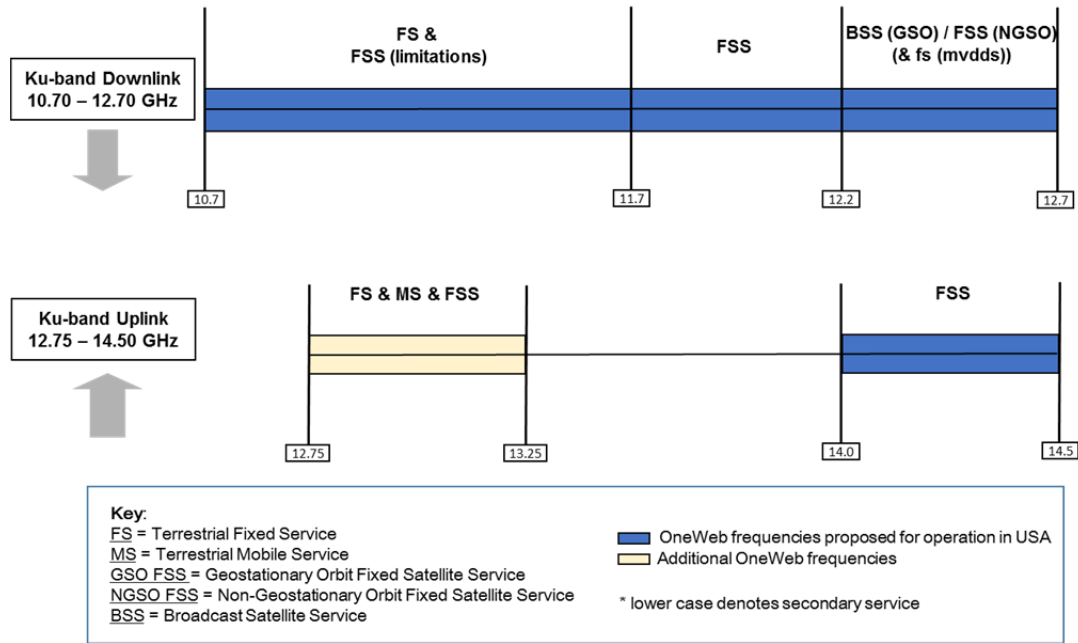
Figure A.2-2: Frequency plan for OneWeb showing the FCC Ka-band frequency allocations
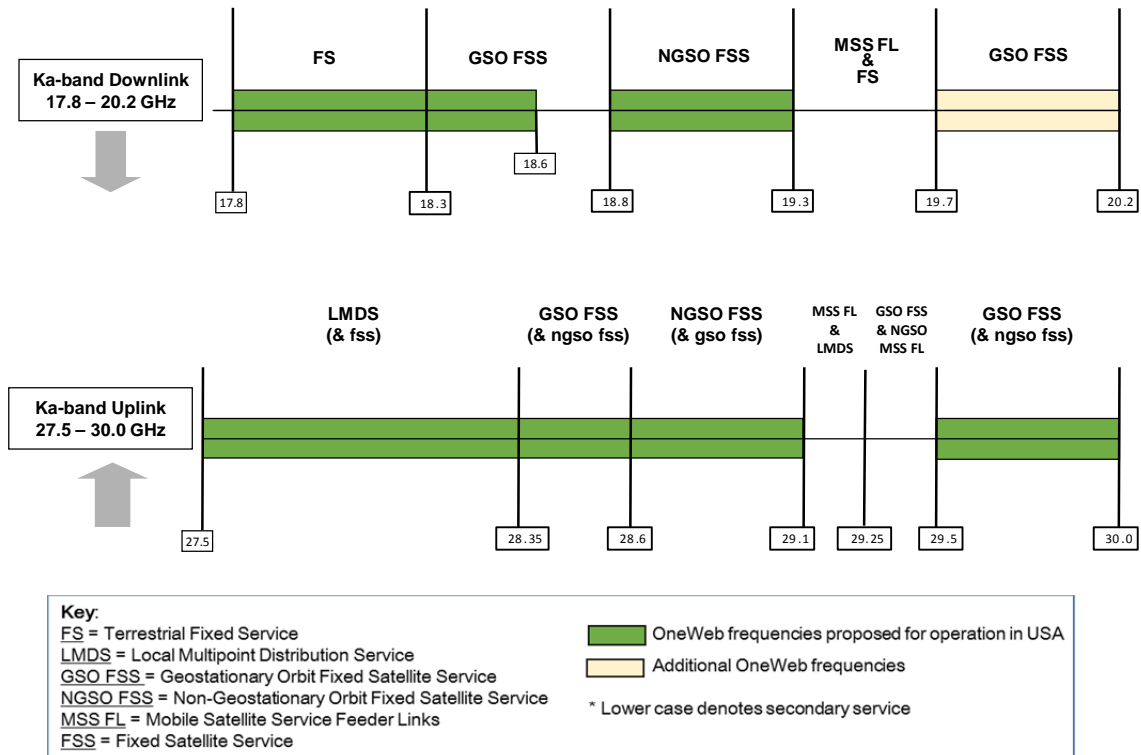
The constellation of OneWeb satellites will be deployed as follows. OneWeb will initially launch a small number of satellites for evaluation and proof-of-concept. Subsequently 32 satellites will be launched on each of 18 Soyuz launch vehicles, one launch for each of the 18 orbital planes, and then Soyuz vehicles will increase the constellation size on a continuing basis with demand. The Soyuz vehicles will be launched from both Baikonur, Kazakhstan and Kourou, French Guiana locations, which provide schedule robustness in the event of launch delays at one particular site. OneWeb will launch every three to four weeks, so the initial phase of launches should be completed in less than 18 months. Additional satellites will then be launched, using remaining Soyuz and/or Virgin Galactic launch vehicles, to increase the number of satellites per orbital plane to 40 plus any additional in-orbit spares. OneWeb will notify the Commission, consistent with §25.118(f), of the spare and active satellite configuration nearer the time of deployment.

The OneWeb system provides broadband communications services between the user terminals and the gateway earth stations located on the global fiber network. Typically, up to ten or in some cases more, gateway earth station antennas will be collocated at a gateway site in order to access a number of visible OneWeb satellites simultaneously from that location. It is expected that approximately 50 or more gateway earth station sites will be deployed over time – the exact number will depend on the markets and services in various different parts of the world. At least four gateway earth station sites are expected to be deployed in the USA, including gateway earth stations in Hawaii and Alaska, and likely additional sites in some US territories. The exact locations of the gateway earth stations have yet to be determined. The gateway earth stations will also transmit and receive control channels for purposes of satellite payload control and gateway link power control. A subset of the gateway sites in high latitude regions of the world will also act as TT&C earth stations. None of the TT&C stations are currently planned to be located in US territory.

OneWeb will operate at least two separate satellite control centers each backing up the other. The centers will likely be located in Virginia, USA and the United Kingdom. Network operations will be primarily controlled from facilities in the United Kingdom and Melbourne, FL. Connectivity

between these control centers and the TT&C and gateway earth stations will be implemented using terrestrial leased circuits and secure Internet virtual private networks (VPN).

Each OneWeb satellite will have 16 nominally identical *user beams*, operating in Ku-band, each consisting of a non-steerable highly-elliptical spot beam[5]. There are also two identical steerable *gateway beam* antennas, operating in Ka-band, on each OneWeb satellite, and each of these antennas creates an independently steerable circular spot beam. The 16 Ka-band uplink channels in one gateway receive beam (the one tracking the servicing gateway) are converted to 16 Ku-band downlink channels, each one routed to one of the 16 user beams ("forward links"), nominally at 250 MHz bandwidth. Additionally, 16 different Ku-band uplink channels from the same 16 user beams are converted to 16 Ka-band downlink channels and sent back to the same gateway transmit beam ("return links"), each having a nominal channel bandwidth of 125 MHz.[6] The second gateway beam is tracking the next gateway earth station for handover procedures.

For TT&C purposes, including the control of the OneWeb satellite payloads, there are dedicated channels in portions of Ka-band.[7]

The total aggregate footprint of the Ku-band beams of the entire OneWeb satellite constellation provides coverage over all of the Earth's surface. The movement of the satellites in their orbits means that a user will be progressively handed over from beam to beam within a OneWeb

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[5]   While the Ku-band user beams cannot be steered, through the use of OneWeb's patent pending Progressive Pitch technology, the entire Ku-band footprint of any satellite can be moved up or down in latitude from the sub-satellite point.

[6]   The associated Schedule S defines Ka-band downlink channel bandwidths for communications carriers of 155 MHz to allow for on-board frequency translation and associated filter implementations.

[7]   The associated Schedule S provides details of the payload control transmissions that will be used to and from the gateway earth stations located in US territory. No TT&C earth stations are currently foreseen to be located in US territory.

satellite and then handed off to the beams of the next satellite in the same orbital plane, or as required to a satellite in the adjacent orbital plane. This regular handover will occur seamlessly so the user experiences continuous service, much like cell phones get handed off from one cell tower to another.

Handover of the OneWeb satellite gateway link from one gateway earth station to another will also occur as the satellites move in their orbits. The second gateway antenna on each satellite is used to enable this handover so the gateway link alternates between the first gateway beam and the second gateway beam.

Each forward channel downlink in a user beam operates in Ku-band with one channel per solid state power amplifier ("SSPA") for a total of 16 active forward link SSPAs. For the gateway downlinks in the return channel there are a total of four Ka-band satellite SSPAs. Two of these SSPAs are connected to each satellite gateway antenna, with each of these SSPAs transmitting the eight channels in one of the two orthogonal circular polarizations. These 16 return channels are downlinked to the active gateway. Gateway beam handover from one gateway earth station to another is achieved seamlessly by ensuring simultaneous transmission to both gateways for a very short period of time during handover.

In the forward direction, the OneWeb system uses the 27.5 – 29.1 GHz and 29.5 – 30 GHz uplink bands and the 10.7 – 12.7 GHz downlink band. In the return direction, the OneWeb system uses the 14.0 – 14.5 GHz uplink band and the 17.8 – 18.6 GHz and 18.8 – 19.3 GHz downlink bands for US service. In addition, the 12.75 – 13.25 GHz uplink band and 19.7 – 20.2 GHz band can also be used for service in territories outside of the USA. Payload control

transmissions to and from the US gateway earth stations will take place in the band edges just below 19.3 GHz (downlink) and just above 27.5 GHz (uplink).[8]

For each OneWeb satellite the frequency re-use achieved will be as follows:

(1) In Ku-band, at least two-times spatial frequency re-use is achieved per satellite by re-using the same Ku-band frequencies between geographically separated beams of the same satellite;

(2) In Ka-band, two-times frequency re-use is achieved on each satellite by the use of orthogonal circular polarization for the transmissions to the active gateway earth station.

Each forward channel supports a single wideband carrier. Narrower return channels employ a number of medium bandwidth carriers, supporting a variable information data rate, depending on the instantaneous modulation and coding scheme employed. Adaptive coding and modulation (ACM) is used to ensure the optimum data throughput as a function of the link margin available at the time, which varies as a function of rain fade as well as the time varying geometry of the link due to the moving OneWeb satellite. The ACM is adapted for each transmission burst to/from a user terminal based on the specific link quality available.

Each user beam supports services to multiple user terminals. In the forward direction (gateway-to-user) there is a TDM transmission scheme in operation whereby the user beam supports a single 250 MHz wideband carrier. Each user terminal in the beam receives and demodulates this carrier and extracts only the data that is destined for it, which is determined by the data headers. In the return direction (user-to-gateway) there is a Single Carrier TDMA/FDMA (SC-TDMA/FDMA) transmission scheme where each user terminal transmits time bursts of data on a

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[8]   See Section A.5 for more information regarding TT&C and payload control.

relatively narrow-band carrier (typically 1.25 MHz to 20 MHz wide) to minimize the peak RF transmit power requirements of the user terminal. Multiple user terminals can access the same uplink carrier based on allocated time slots from the network control center. They can also access different uplink carriers that occupy the FDMA channel arrangement in the satellite. The multiple return carriers are then received by the gateway station. The control information between the user terminals and the network control center is carried over the same RF channels used for communications information.

The channel frequencies and bandwidths as well as the connectivity between the uplink and downlink beams in each OneWeb satellite are defined in tabs S9 and S10 of the associated Schedule S.

There are three broad categories of earth stations in the OneWeb system – the TT&C stations, the gateway stations and the user terminals. At TT&C sites, which will be located only at high latitudes, there will be multiple active tracking antennas and associated electronics, with each typically being 2.4 meters or larger in reflector diameter. The gateway sites will also employ multiple active tracking antennas, each typically of 2.4 meters in reflector diameter. Some TT&C stations may also act as gateway stations. The user terminals, which will be deployed in large numbers, are typically in the range 30 cm to 75 cm in equivalent antenna diameter and will include fixed and transportable ground-based terminals as well as mobile terminals on board aircraft, maritime vessels and land vehicles.[9] The user terminals will employ mechanically steerable parabolic reflector antennas, electronically steerable phased array antennas or other beam steering technology. User terminals will be capable of providing continuous service, allowing for handovers between active satellites. For the mechanically steered antennas, this

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[9]   OneWeb will separately seek authorization for its earth stations, including gateway and user terminals, operating in US territories.

will be achieved by the use of two independently steerable apertures or, for certain applications, with a single antenna aperture that can quickly switch pointing direction between the active satellites, using data buffering to ensure no loss of transmitted information. For the phased array implementation of the user terminal, the electronically steerable beam will instantaneously switch between active satellites using a single fixed antenna aperture.

The OneWeb satellite constellation will operate under a UK registration at the ITU (network name "L5"). Further details of this are provided in Section A.9 below.

A.3   PREDICTED SPACE STATION ANTENNA GAIN CONTOURS (§25.114(c)(4)(vi)(B))

For the links between the OneWeb satellites and the users, each satellite has 16 identical Ku-band receive and transmit spot beams fixed to the spacecraft body. Each of these spot beams is highly elliptical with its major axis in the east-west direction and minor axis in the north-south direction. The 16 beams are arranged in a single row in the north-south direction to create an almost square footprint on the Earth. The overall beam pattern from a single OneWeb satellite on the Earth's surface is shown in Figure A.3-1 below, where the -3 dB relative gain contours of all 16 beams are shown. These beams are as viewed from the satellite. The Ku-band satellite antennas are fixed to the Earth pointing face of the satellites and therefore their pointing directions are fixed relative to the pointing direction of the satellite. However, the attitude control system of the OneWeb satellite allows the pointing of the satellite to be adjusted so the beam pattern can be moved in the pitch direction (i.e., north-south), relative to the nominal nadir pointing direction. This feature is used to control the power levels generated in certain directions by the OneWeb system so as to be compliant with the EPFD limits in the FCC rules and ITU Radio Regulations, as explained in Section A.8.1 below.

Figure A.3-1: Ku-band beam array for normal mode (no pitch bias)

for a single OneWeb satellite

(nominally identical for receive and transmit)
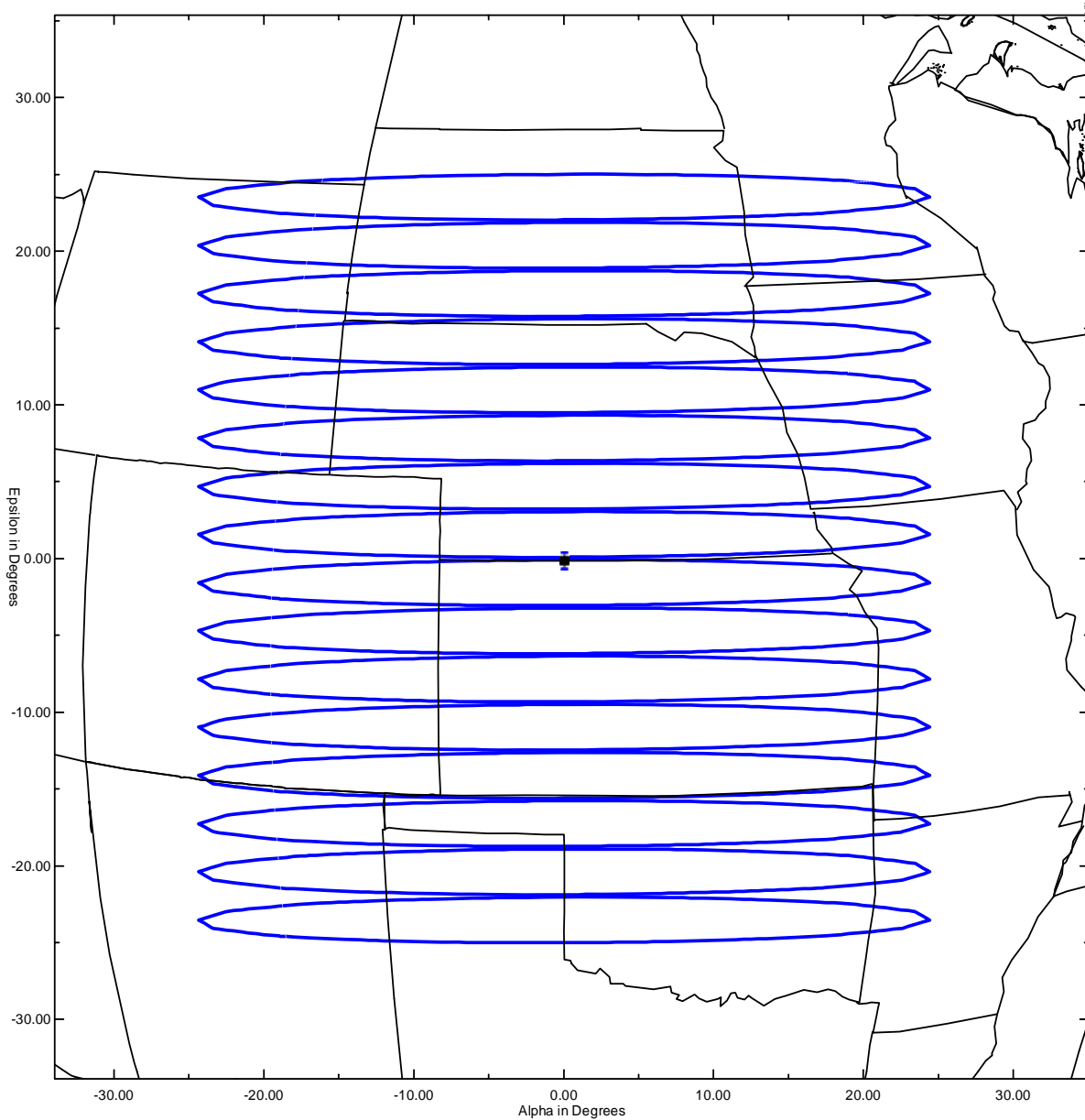
For the links between the OneWeb satellites and the gateway stations, each satellite has two identical circular Ka-band spot beams which are independently steerable over the full field of view of the Earth, where the arrival angle is at least 15 degrees.

Data for the Ku-band and Ka-band beam contours are embedded in the associated Schedule S submission. This data is provided in the form of the required contours plotted on a flat-Earth projection and with the beam peak pointed to nadir, as required by (§25.114(c)(4)(vi)(B).

A.4   GEOGRAPHIC COVERAGE
(§25.145(c) and §25.146(i))

Because of the use of near-polar orbits, the OneWeb satellites essentially pass over all parts of the Earth's surface and therefore, in principle, have the ability to provide service to all Earth locations as shown in Figure A.4-1 below. Every point on the Earth's surface will see, at all times, a OneWeb satellite at an elevation no less than 55º, with increasing minimum elevation angles with latitude. For instance, users in Alaska will experience elevation angles significantly higher than 55º at all times.

Figure A.4-1: OneWeb satellites cover the entire Earth's surface

(showing simplified circular footprints for each satellite)
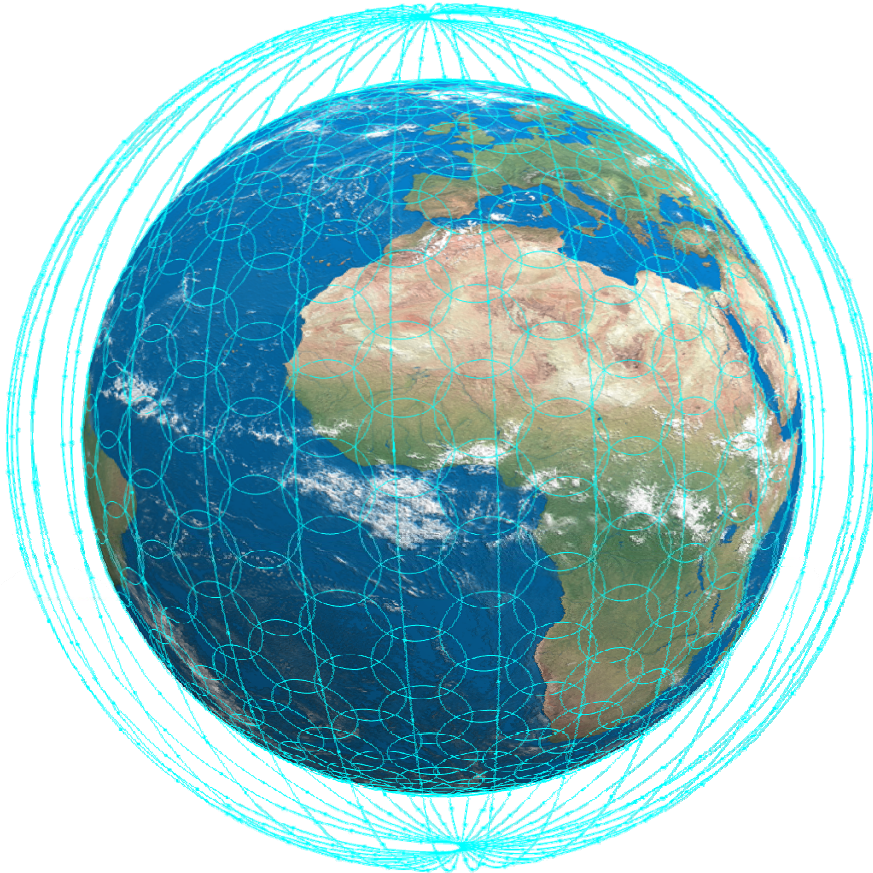
The Commission's geographic coverage requirements are set forth in §25.145(c)(1) and (2) for Ka-band and §25.146(i)(1) and (2) for Ku-band. They are essentially the same for both frequency bands and are stated as follows:

(1) A demonstration that the proposed system is capable of providing fixed-satellite services on a continuous basis throughout the fifty states, Puerto Rico and the U.S. Virgin Islands, U.S.; and

(2) A demonstration that the proposed system is capable of providing Fixed-Satellite Services to all locations as far north as 70° North Latitude and as far south as 55° South Latitude for at least 75 percent of every 24-hour period.

§25.145(c)(1) above clearly relates to service in geographic territories that the FCC should be concerned about when granting the authorization requested in this application. The genesis of §25.145(c)(2) above was in the context of the Big-LEO rulemaking where it was related to having "at least one satellite … visible above the horizon at an elevation angle of at least 5 degrees for at least 18 hours each day within the described geographic region …". The OneWeb system with 720 operational satellites meets this more precisely defined requirement as explained below.

Ku-Band Geographic Coverage

For the Ku-band service links, the combination of the geographic coverage achievable from each satellite plus the number and proximity of the satellites in their orbits, ensures that blanket global Ku-band coverage is provided by the OneWeb constellation. Figure A.4-2 gives a snapshot of the beams from five OneWeb satellites, both within the same orbit plane and between adjacent orbit planes, and how they overlap to provide continuous Ku-band coverage. In Figure A.4-2 three consecutive satellites are shown in the plane on the right (yellow, blue and turquoise beams) with two consecutive satellites in the adjacent plane to the left (pink and green beams). The variation in the size and shape of the beams in Figure A.4-2 is because of the flat Earth projection used. The -3 dB relative gain contours are shown, although service is provided to lower gain contour levels when necessary. The overlapping beams between adjacent satellites in the same plane are necessary to enable the progressive pitch technique to be used as explained below and further in Section A.8.1.1.

Figure A.4-2: Snapshot of OneWeb Ku-band satellite beam coverage from five adjacent satellites
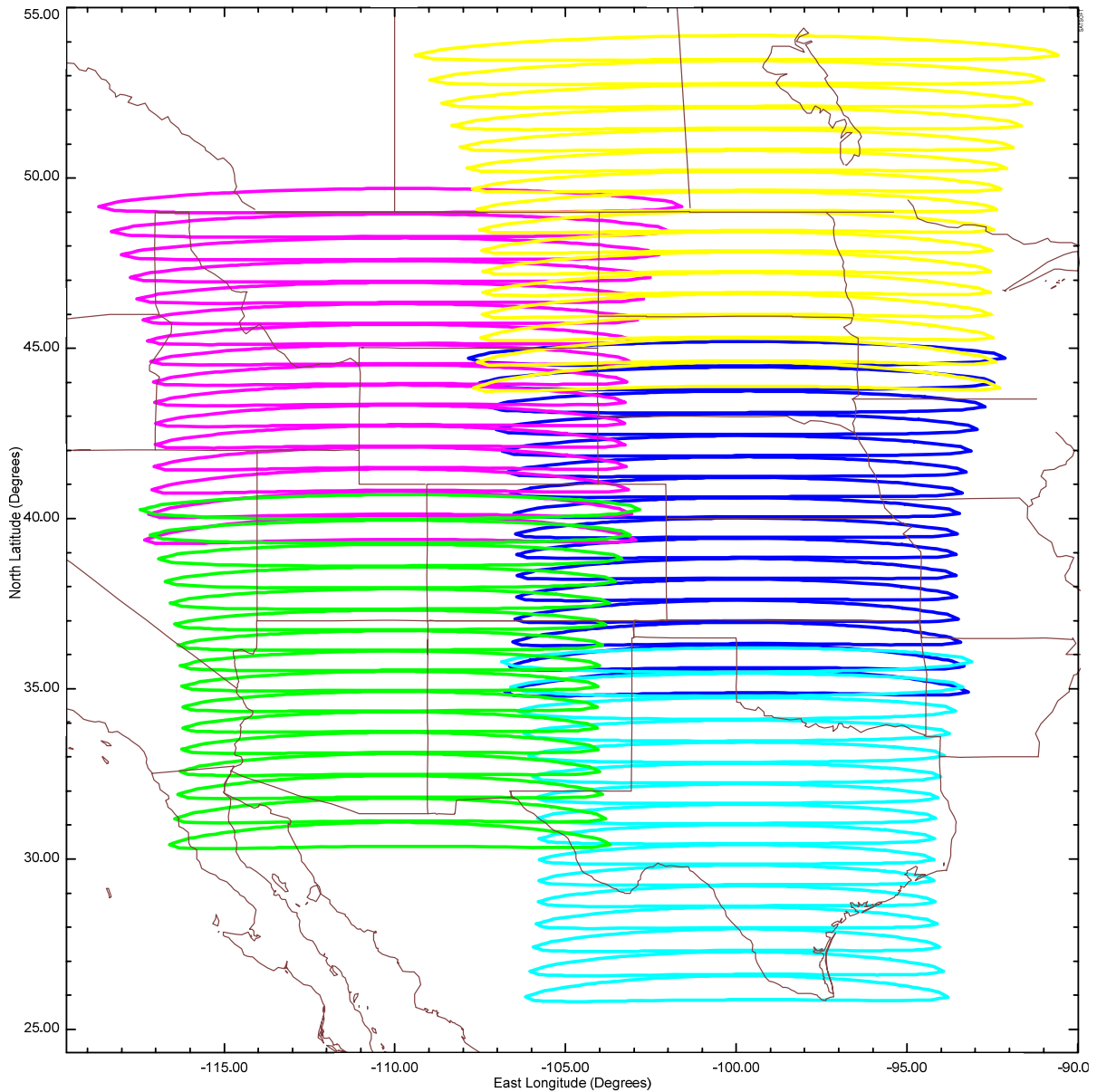
In order to comply with the EPFD limits and thereby protect GSO satellite networks from interference, the pointing directions of the Ku-band beams are adjusted from the nominal nadir direction as the OneWeb satellites move away from the poles and towards the equator. Eventually, when the pointing direction adjustment alone is not sufficient to comply with EPFD

limits, certain Ku-band beams are turned off. This technique also protects the OneWeb system from interference caused by GSO networks.[10]

Ka-Band Geographic Coverage

The gateway links of the OneWeb system provide the necessary communications links back from the OneWeb satellites to the global internet. It is the intention of OneWeb to install sufficient gateway sites around the world (currently expected to be 50 or more) to ensure that the OneWeb satellites have a visible gateway earth station with which they can communicate from all parts of their orbits. Therefore, the OneWeb Ka-band gateway links will be sufficient to serve OneWeb satellites at all latitudes, which meets the requirements of §25.145(c)(1) and (2) as far as these rules can be applied to such types of links.

A.5 TT&C AND PAYLOAD CONTROL CHARACTERISTICS (§25.202(g))

Gateway earth stations capable of receiving and transmitting payload control transmissions will be located in the USA, but no TT&C earth stations are foreseen in the USA at present. This application therefore requests authorization from the Commission for the payload control transmissions to and from these gateway earth stations only. Authorization is not being sought for the TT&C transmissions to and from the TT&C earth stations which use alternative downlink frequencies and which are located outside of the USA and in high latitude regions. The basic parameters of the overall TT&C and payload control system are described in this section and complements that which is provided in the associated Schedule S submission.

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[10] By these means, when there are 720 satellites in the constellation, the full OneWeb service is provided to latitudes that encompass the territories of the fifty U.S. states, Puerto Rico and the U.S. Virgin Islands so compliance with §25.146(i)(1) is achieved.

The OneWeb TT&C system provides for communications during pre-launch, transfer orbit and on-station operations, as well as during spacecraft emergencies. The TT&C system operates at the edges of the Ka-band frequency allocations in the communications uplink and downlink frequency ranges during all phases of the mission.

The TT&C and payload control system controls and monitors all aspects of the spacecraft necessary for onboard equipment configuration, safe operations and health monitoring. Some control data is required in real-time (e.g., certain payload control functions), but other data is not as time-sensitive because the spacecraft are sufficiently autonomous for periods of time without receiving continuous telecommand signals. The time-sensitive payload control information is transmitted to and from the OneWeb satellites using the gateway earth stations. All payload control transmissions to and from these gateway earth stations are at EIRP density levels no higher than the gateway communications carriers because they access the high gain satellite antennas on-board the OneWeb satellites. Because these transmissions may take place from US gateway earth stations their technical parameters are included in the associated Schedule S.

The TT&C earth stations will be located only in the high northerly latitudes where maximum simultaneous visibility of large numbers of satellites is possible. These high-latitude TT&C earth stations can also communicate with the OneWeb satellites via the low-gain near-omnidirectional TT&C antennas on the OneWeb satellites.

A summary of the TT&C and payload control subsystem characteristics is given in Table A.5-1. The frequency ranges specified for the TT&C transmissions may be reduced further as the final operational TT&C frequencies are selected, and OneWeb will inform the Commission of this at that time.

Table A.5-1: TT&C and Payload Control Characteristics

Uplink Control Signal Modulation	BPSK
Uplink Control Frequencies	27500 - 27550 MHz
Downlink Control Signal Modulation	QPSK
Downlink Control Frequencies	TT&C: 19700 - 19770 MHz to high-latitude TT&C stations (outside of USA)
	Payload Control: 19265 – 19300 MHz for gateway earth stations (including ones in the USA)
Polarization of Satellite Rx/Tx Antennas	Rx: LHCP & RHCP Tx: LHCP & RHCP

A.6 CESSATION OF EMISSIONS
(§25.207)

Each active satellite transmission chain (channel amplifiers and associated solid state power amplifier) can be individually turned on and off by ground telecommand, thereby causing cessation of emissions from the satellite, as required by §25.207 of the Commission's rules.

A.7 COMPLIANCE WITH PFD LIMITS
(§25.208(b), §25.208(c), §25.208(e) and §25.208(o))

The OneWeb system complies with all applicable FCC and ITU Power Flux Density ("PFD") limits, which are designed to protect the terrestrial Fixed Service ("FS") from downlink interference due to the satellite transmissions.

<u>Downlink PFD Limits in Ku-band</u>

The FCC's Ku-band downlink PFD limits which apply to each satellite of the OneWeb system, and which apply across the 10.7-11.7 GHz band, are given in §25.208(b) and are as follows:

- -150 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

- -150+(δ-5)/2 dB(W/m^2) in any 4 kHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and

- -140 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

Incidentally, the ITU PFD limits applicable to NGSO systems in the 10.7-11.7 GHz band, which are given in Table 21-4 of the ITU Radio Regulations, are effectively the same as the FCC PFD limits mentioned above.[11]

Compliance with the FCC's PFD limits is demonstrated below. The maximum Ku-band downlink EIRP density for the OneWeb satellites is -13.4 dBW/4kHz.[12] The shortest distance from the OneWeb satellite to the Earth's surface (1,200 km) gives a worst case (i.e., smallest) spreading loss of 132.6 dB (i.e., $10*\log(4.\pi.(1200 \times 10^3)^2)$. Using these worst-case values, the highest PFD at the Earth's surface, for the nadir situation and for the worst case EIRP density of -13.4 dBW/4kHz, is -146.0 dBW/m^2/4kHz, which is 6.0 dB below the PFD limit that applies for elevation angles

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[11] The ITU PFD limits applicable to NGSO systems in the 10.7-11.7 GHz and 11.7-12.7 GHz bands are defined in a 1 MHz reference bandwidth, rather than the 4 kHz reference bandwidth of the FCC limits (in the 10.7-11.7 GHz band). However, the PFD levels in the ITU limits are 24 dB higher than the values in the FCC limits, in proportion to the difference in reference bandwidth. Therefore, the ITU limits are essentially the same as the FCC limits for flat digital spectrum transmissions.

[12] See also Section A.12 of this document and S13 of the associated Schedule S.

greater than 25 degrees. Figure A.7-1 below shows the PFD levels that would result at the Earth's surface for all elevation angles, using this worst-case methodology, if the EIRP was maintained at -13.4 dBW/4kHz, for all directions away from beam peak while taking account of the increased spreading loss for lower elevation angles. In reality, the satellite EIRP is less than this assumed value for angles of arrival below about 45 degrees due to the shaped beams shown in Figure A.3-1 and the associated Schedule S. For simplicity's sake, we nevertheless calculate PFD based on this maximum EIRP density for all angles of arrival. From this it can be seen that the OneWeb Ku-band downlink transmissions are compliant with the PFD limit in §25.208(b) with at least 5 dB margin, even for the hypothetical case with the maximum transmitted EIRP density in all directions.

**Figure A.7-1: Compliance of the maximum Ku-band PFD levels
of the OneWeb NGSO FSS system with the FCC PFD mask
for the 10.7-11.7 GHz band
(assuming constant EIRP density over all visible area)**
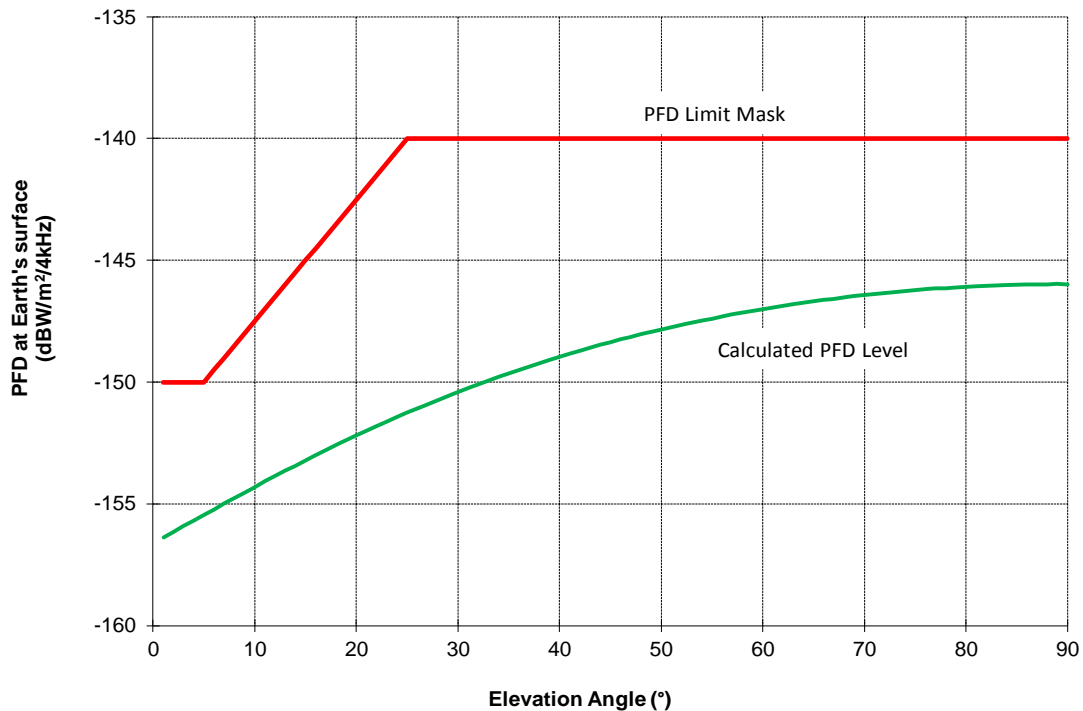
Incidentally, in the 11.7-12.2 GHz downlink frequency band there are no FCC PFD limits. There are, however, ITU PFD limits in the 11.7-12.7 GHz band which are effectively 2 dB higher than the FCC PFD limits in the 10.7-11.7 GHz band.[13] The OneWeb system will therefore also be compliant with these ITU PFD limits across the entire 11.7-12.7 GHz band.

The FCC has specific low elevation PFD limits in §25.208(o) which apply in the 12.2-12.7 GHz band in order to protect the MVDDS service. These limits, which relate to the PFD into an actual operational MVDDS receiver, are defined as follows:

- -158 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 2 degrees above the horizontal plane;

- -158+3.33(δ-2) dB(W/m^2) in any 4 kHz band for angles of arrival δ (in degrees) between 2 and 5 degrees above the horizontal plane.

Figure A.7-2 below shows compliance with the FCC's low elevation PFD limits of §25.208(o) to protect the MVDDS service in the 12.2-12.7 GHz band can be achieved assuming only a 3 dB reduction in the EIRP density transmitted towards low elevation directions, which is clearly a worst-case assumption when considering the gain contours in Figure A-3.1. In fact, the satellite beam roll-off is at least 15 dB below peak for elevation angles of 5 degrees and less, and this only occurs in the east-west directions due to the high ellipticity of the beam.   Therefore, in practice the OneWeb satellite downlinks will achieve compliance with these FCC low elevation PFD limits with ample margin, much higher than shown in this figure.

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[13]   *Id.*

**Figure A.7-2: Compliance of the maximum low-elevation Ku-band PFD levels
of the OneWeb NGSO FSS system with the FCC PFD mask
for the 12.2-12.7 GHz band
(assuming a satellite EIRP density of -16.4 dBW/4kHz in these directions)**
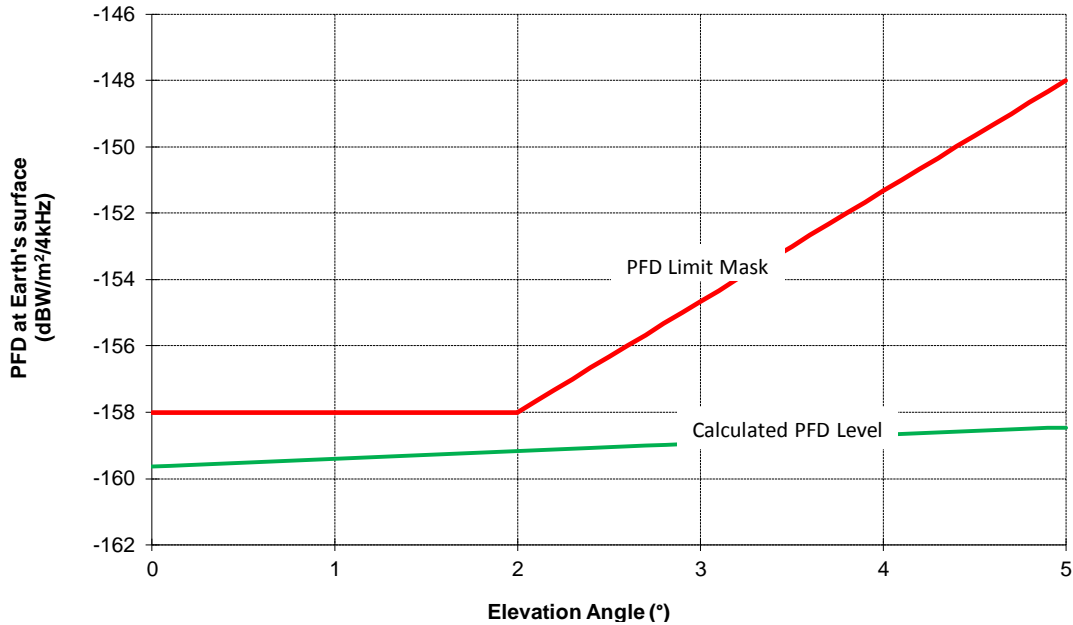
Therefore, all the Ku-band downlink transmissions from the OneWeb satellites comply with all the FCC and ITU PFD limits.[14]

Downlink PFD Limits in Ka-band

The FCC's Ka-band downlink PFD limits in §25.208(c) and §25.208(e) apply in different parts of the Ka-band downlink frequency bands used by OneWeb. §25.208(c) applies in the 17.7-17.8 and 18.3-18.6 GHz bands where GSO is primary, and §25.208(e) applies in the 18.8-19.3 GHz band, where NGSO is primary, according to the FCC's Ka band plan. By comparison, a single set of

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[14]   The maximum PFD levels given in S8 of the associated Schedule S are derived from accurate analysis of the beam contours versus elevation angle and are therefore lower than those calculated here which are based on a simple worst-case methodology.

PFD limits in Article 21 of the ITU Radio Regulations applies to NGSO systems across the entire band 17.7-19.3 GHz which encompasses most of the Ka-band downlink band used by OneWeb. In the 19.7-20.2 GHz band there are no PFD limits in the FCC rules nor in the Radio Regulations.[15] The PFD limits in §25.208(e) are identical to these limits in Article 21 of the ITU Radio Regulations, and they are expressed as a function of the number of satellites in the NGSO system. Because of the dependency on the number of NGSO satellites, the limits in §25.208(e) and in Article 21 of the ITU Radio Regulations are effectively more constraining than those in §25.208(c). The more constraining NGSO PFD limits of §25.208(e) and Article 21 of the Radio Regulations are therefore assumed to apply to the OneWeb system across the entire 17.7-19.3 GHz band, and are as follows:

- $-115-X$ dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

- $-115-X+((10+X)/20)(\delta-5)$ dB(W/m^2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and

- -105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

   Where X is defined as a function of the number of satellites in the non-GSO FSS constellation, n, as follows:

   - $X = 0$ dB   for $n \leq 50$

   - $X = (5/119)(n - 50)$ dB   for $50 < n \leq 288$

   - $X = (1/69)(n + 402)$ dB   for $n > 288$

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[15]   See Table 21-4 of Article 21 of the ITU Radio Regulations.

These PFD limits apply to each satellite in the OneWeb system. The value of "n" is 720 and therefore X is equal to 16.26 dB according to the above formulae. This results in the PFD mask shown in Figure A.7-3 below.

The maximum Ka-band downlink EIRP density for the OneWeb satellites is +8.0 dBW/MHz.[16] This value is used to calculate the PFD at the surface of the Earth assuming the maximum satellite downlink EIRP density occurs in all directions, and taking account of the actual spreading loss from the satellite to the surface of the Earth.[17] This is shown in Figure A.7-3 together with the PFD mask. Compliance with the PFD limit is achieved with a minimum margin of almost 3 dB at 5-degree elevation, and much greater margin at higher elevation angles. In practice the operational minimum elevation angle for the gateway links is 15 degrees, which means that the EIRP below this arrival angle would be less than the one used in these calculations, thus resulting in more margin.[18]

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[16]   See also Section A.12 of this document and S13 of the associated Schedule S.

[17]   Note that this way of estimating the PFD at the Earth's surface is overly pessimistic because the maximum downlink EIRP density is only used in operation for pointing directions involving the maximum path length to the Earth's surface. For pointing directions where the path length is less, downlink power control is used to maintain a near-constant PFD at the Earth's surface, so at nadir (i.e., 90° angle of arrival), the PFD would be about 7 dB lower than shown in this figure. See also Annex 2.

[18]   The maximum PFD levels given in S8 of the associated Schedule S are derived from accurate analysis of the beam contours versus elevation angle and are therefore lower than those calculated here which are based on a simple worst-case methodology.

**Figure A.7-3: Compliance of the maximum Ka-band PFD levels
of the 720-satellite OneWeb NGSO FSS system with the PFD mask
(assuming a constant 8 dBW/MHz EIRP density)**
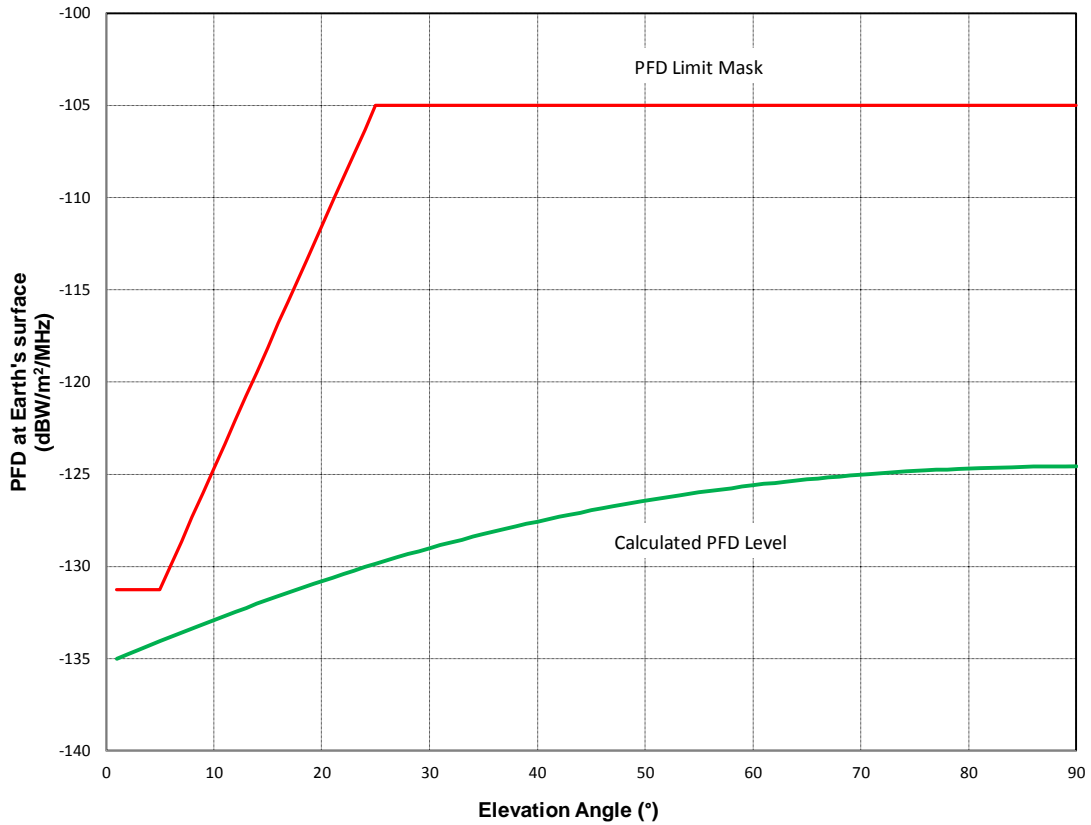
A.8   INTERFERENCE ANALYSES

Figures A.8-1 and A.8-2 below give the frequency ranges proposed to be used in Ku-band and Ka-band, respectively, showing also the designations that exist in these bands in the FCC table of frequency allocations. This is being provided to accompany the more detailed explanations of each sharing / interference scenario described in the sub-sections below.

Figure A.8-1: Frequency plan for OneWeb showing the FCC Ku-band frequency allocations
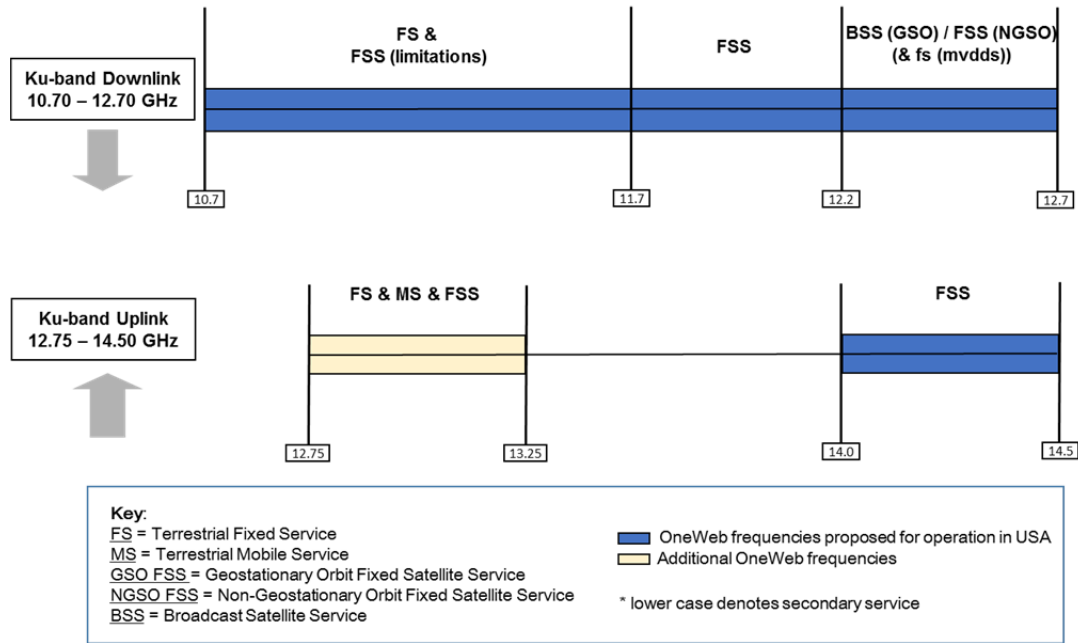
Figure A.8-2: Frequency plan for OneWeb showing the FCC Ka-band frequency allocations
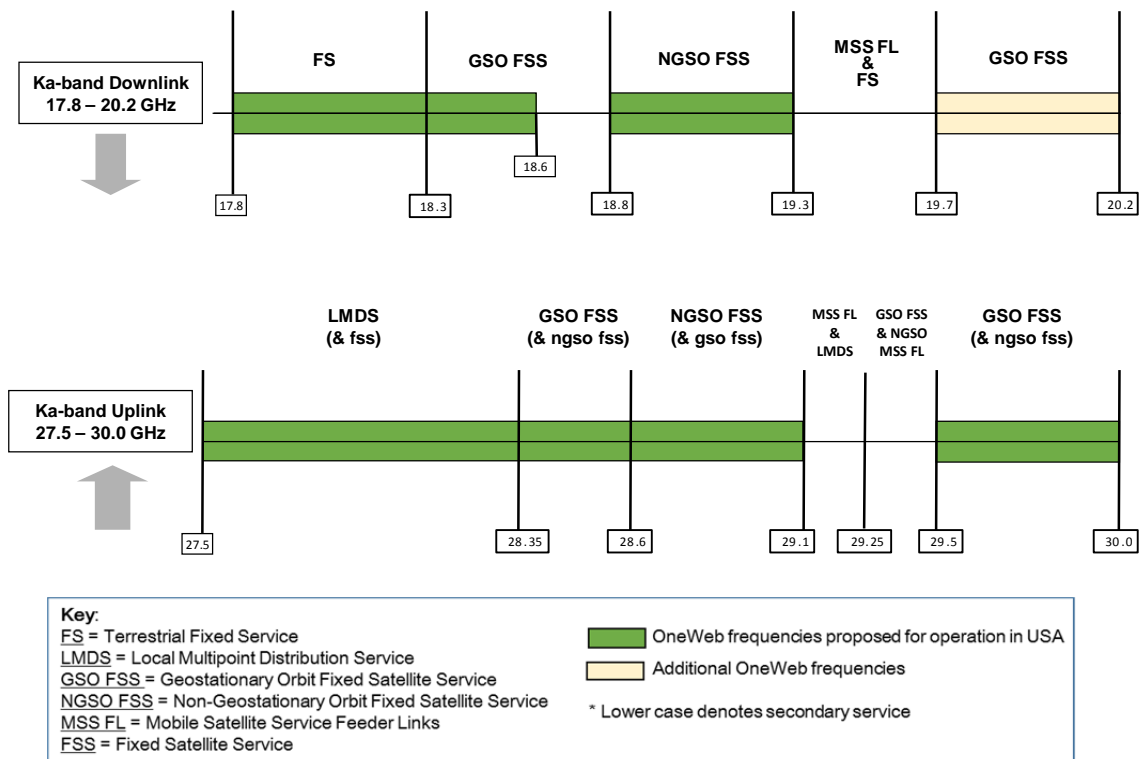
A.8.1 Interference Protection for GSO Satellite Networks
(§25.146 and §25.208)

The OneWeb NGSO satellite system has been designed to provide the necessary interference protection to GSO satellite networks in both Ku-band and Ka-band as required under Article 22 of the ITU Radio Regulations. In addition, in the Ku-band, the OneWeb system will fully comply with the similar requirements in §25.146 of the Commission's rules.[19] In the following sections, we will therefore demonstrate compliance with Article 22 of the ITU Radio Regulations for the Ka-band and with §25.146 for the Ku-band. In addition, we will demonstrate compliance with the $EPFD_{is}$ limits for Ku-band and parts of Ka-band that exist in the ITU Radio Regulations but which are not referenced in §25.146.

Specifically, No. 22.5C and 22.5I of the Radio Regulations defines Equivalent Power Flux Density ("EPFD") limits for the downlink transmissions from an NGSO satellite system in certain Ku and Ka-band downlink frequency ranges that must be met in order to not cause unacceptable interference to GSO satellite networks.[20] The Ku-band EPFD↓ limits of the ITU are also reflected in §25.146, §25.208(g), §25.208(i), §25.208(j) and §25.208(l) of the Commission's rules for Ku-band. In addition, the Commission defines in §25.208(h) and §25.208(m) aggregate EPFD↓ limits arising from multiple co-frequency NGSO systems in Ku-band.

Similarly, No. 22.5D of the Radio Regulations defines corresponding EPFD limits applicable to the uplinks from an NGSO satellite system, in certain Ku and Ka-band uplink frequency ranges.

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[19]   The Commission does not have rules similar to §25.146 for the Ka-band.

[20]   These limits are referred to in the Radio Regulations as "epfd↓" limits.

These Ku-band EPFD$\uparrow$ limits of the ITU are also reflected in §25.146 and §25.208(k) of the Commission's rules for Ku-band.[21]

Finally, there are also EPFD limits in No. 22.5F of the Radio Regulations, applicable to certain parts of the Ku and Ka-band frequency ranges, that are designed to protect GSO satellites using these frequency ranges in the opposite transmission direction.[22] These EPFD$_{is}$ limits are not reflected in the Commission's rules for NGSO systems in Ku-band.

OneWeb will meet all the EPFD limits that apply within the frequency ranges used by OneWeb, and all other obligations of the ITU Radio Regulations and the Commission's Part 25 rules in this regard within the frequency ranges where such limits apply. The frequency ranges used by OneWeb and in which EPFD limits apply (either in the ITU Radio Regulations or the Commission's Part 25 rules) are:

- Ku-band:
  - Uplink: 12.75-13.25 GHz and 14.0-14.5 GHz
  - Downlink: 10.7-12.7 GHz
- Ka-band:
  - Uplink: 27.5-28.6 GHz and 29.5-30.0 GHz
  - Downlink: 17.8-18.6 GHz and 19.7-20.2 GHz

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[21]   These limits are referred to in the Radio Regulations as "epfd$\uparrow$" limits.

[22]   These limits are referred to in the Radio Regulations as "epfd$_{is}$" limits. They relate to the potential interference path from transmitting NGSO satellites to receiving GSO satellites.

The explanation of OneWeb's techniques for complying with the EPFD limits is given separately for Ku-band and Ka-band in the following subsections. Note that these techniques are used to protect GSO satellite networks from interference from the OneWeb NGSO system and have the effect also of protecting the OneWeb system from GSO interference, as they are based on the principle of avoiding inline and near-inline events.

A.8.1.1   EPFD Compliance in Ku-Band

Annex 1 provides a detailed explanation of the EPFD levels produced by the OneWeb system in Ku-band, and how they comply with the single-entry EPFD validation limits in §25.146(a)(1) and (2). Annex 1 also addresses other related aspects of §25.146. These EPFD limits exist across both the FSS and BSS portions of the Ku-band, which vary in frequency allocation across the three ITU Regions of the world. For example, in the USA (Region 2) the FSS limits apply across the band 10.7-12.2 GHz and the BSS limits across the band 12.2-12.7 GHz. OneWeb complies with both the FSS and BSS EPFD limits.

Below we will explain the principles by which the OneWeb system protects GSO satellite networks from interference in Ku-band.

Compliance with the EPFD limits for the protection of GSO satellite networks by an NGSO satellite system, for both uplink and downlink, involves ensuring that there is the necessary amount of angular separation between the transmissions from the NGSO satellites (in the downlink bands) and user earth stations (in the uplink bands) relative to the potential victim GSO earth stations (in the downlink bands) and satellites (in the uplink bands), respectively. This is a complex geometrical problem to solve in the general case, but when the specifics of the OneWeb system are considered, the solution is simple and elegant.

A key factor to protecting GSO networks from interference is the number of OneWeb satellites in the constellation relative to the service areas being covered. The OneWeb constellation has sufficient satellites to ensure that there is always a OneWeb satellite visible from any point in the service area at a high elevation angle – typically greater than 50º.[23] Therefore each OneWeb satellite's Ku-band beam coverage (Rx and Tx) only needs to be over a narrow range of angles relative to the nadir pointing direction. Each OneWeb satellite is effectively providing service only to the area of the Earth directly beneath it, at a high look angle and at a relatively short distance, with the Ku-band beams centered on the sub-satellite point when no pitch bias is applied.   This means that there is an inherent interference isolation due to the angular separation from GSO networks for all OneWeb satellites at higher latitudes, as shown in Figure A.8.1-1(a) below where the GSO earth station being protected is at 50ºN latitude and the OneWeb satellite is passing through the boresight of the GSO receiving earth station. Therefore, in these situations, GSO earth stations would only potentially receive (i) low-power signals from the far-out sidelobes of the OneWeb satellites that are in the main beam of the GSO earth station, and (ii) maximum power signals only from the OneWeb satellites that appear in the far-out sidelobes of the GSO earth station. Similarly, uplink protection of the receiving GSO satellites is afforded because the transmitting OneWeb earth stations point well away from the GSO arc when communicating with OneWeb satellites.

Only as the OneWeb satellites approach lower latitudes would there be a situation where interference could potentially occur to GSO networks because the OneWeb satellites serving areas near the GSO earth station start to move closer to the line of sight between the GSO earth stations and their corresponding GSO satellites. Interference in these situations is avoided by pitching the OneWeb satellite (by less than 10 degrees) in a direction towards the equator to

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[23]   The minimum elevation angle varies with latitude because of the use of a near-polar orbit. At low latitudes the geographic density of the OneWeb satellites is lower, resulting in a lower minimum elevation angle.

reduce the antenna gain towards latitudes where GSO earth stations would be in a near-alignment situation with the OneWeb satellite, as shown in Figure A.8.1-1(b) below. In this case the GSO earth station being protected is at 30ºN latitude and the beams of the OneWeb satellite are biased to the south to move them further away from the GSO earth station. In addition, the RF link power density in each of the OneWeb satellite beams can be reduced to further protect GSO satellite networks.

As the OneWeb satellites pass over the equator they are temporarily turned off while they adjust their pitch to the opposite direction. The adjustment in the pitch of the OneWeb satellite will take place gradually as the satellite passes through mid-latitudes to the lower latitudes. This patent pending "progressive pitch" technology is the key to the interference protection of Ku-band GSO satellite networks by the OneWeb system.

Figure A.8.1-1: Ku-band interference protection of the GSO using progressive pitch technology

(a) GSO earth station at 50ºN (<u>no</u> pitch bias)
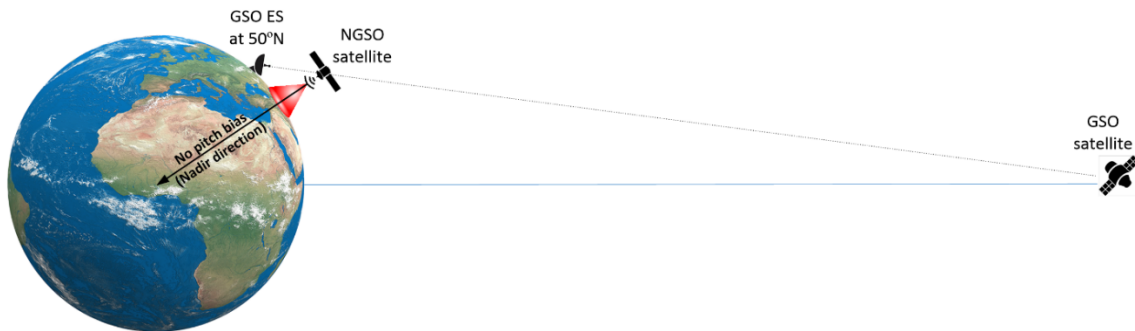
(b) GSO earth station at 30ºN (<u>with</u> pitch bias)
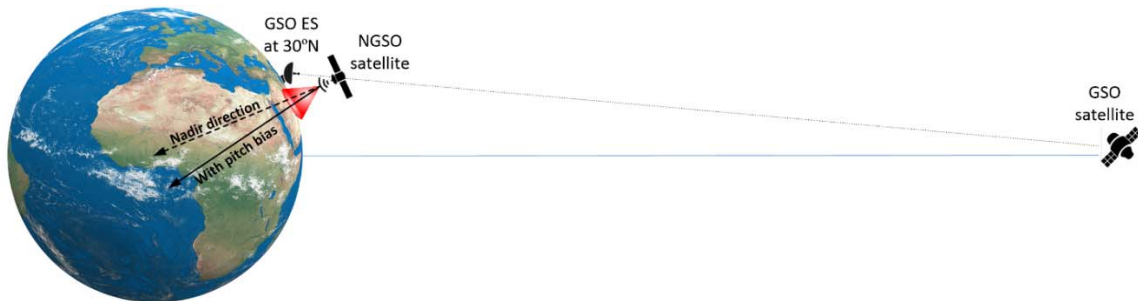
The progressive pitch technique explained above is used as the basis for the generation of the PFD masks used to demonstrate EPFD compliance in Annex 1.

A.8.1.2   EPFD Compliance in Ka-Band

Annex 2 provides a detailed explanation of the EPFD levels produced by the OneWeb system in Ka-band, and how they comply with the single-entry EPFD validation limits in Article 22 of the ITU Radio Regulations.

Below we will explain the principles by which the OneWeb system protects GSO satellite networks from interference in Ka-band.

As explained above in relation to Ku-band, compliance with the Ka-band EPFD limits for the protection of GSO satellite networks by an NGSO satellite system, for both uplink and downlink, involves ensuring that there is the necessary amount of angular separation between the transmissions from the NGSO satellites and gateway earth stations and the direction towards the potential victim GSO earth stations and satellites, respectively.

The gateway antennas on the OneWeb satellites create relatively narrow beams (less than 0.5° half-power beamwidth) capable of being steered over almost the entire visible part of the Earth's surface, in order to minimize the number of gateway sites needed. Each OneWeb gateway site is therefore equipped with multiple antennas so that it can track a number of visible OneWeb satellites down to a much lower elevation angle than is used for the Ku-band service links. Typically, the minimum elevation angle for the gateway links is 15º, although this may vary depending on the situation of the gateway station. The gateway links at Ka-band use earth station antennas that are at least 2.4 m in diameter (much larger than those used for the service links). The beamwidth of the gateway earth stations is therefore very small (typically < 0.5º) and their gain is relatively high (typically 55 dBi transmit and 51.5 dBi receive). All these factors contribute to a situation where interference to Ka-band GSO satellite networks can be prevented without significant burden on the OneWeb design or operations, as explained below.

The principle used to protect GSO satellite networks from Ka-band interference from OneWeb is the simple GSO arc avoidance approach. By careful choice of the OneWeb gateway sites, and by placing modest constraints on the possible positions of OneWeb satellites with which each gateway site can communicate, the GSO arc avoidance scheme can be implemented. Because of the relatively low power used on the OneWeb gateway links (both uplink and downlink) the necessary GSO arc avoidance angle is only 6º. This angle is used as the basis of the EPFD compliance analysis given in Annex 2.

The use of GSO arc avoidance by the Ka-band gateway links of the OneWeb system results in a modest increase in the number of gateway sites needed compared to the theoretical situation where no such GSO arc avoidance was used. However, more gateway sites provide additional link geometry diversity which can also improve performance of the gateway links in cases of extreme rain fade events.

A.8.1.3   Ka-Band Frequency Ranges Where No EPFD Limits Exist

Note that the OneWeb system frequency plan includes some portions of Ka-band spectrum where no EPFD limits exist in the ITU Radio Regulations. These are the 28.6-29.1 GHz uplink and 18.8-19.3 GHz downlink frequency bands, which are allocated to NGSO satellites on a primary basis according to the FCC's Ka-band frequency plan, with GSO satellite networks operating on a secondary basis in the 28.6-29.1 GHz range and on a non-conforming basis in the 18.8-19.3 GHz range. According to ITU procedures applicable to these frequency ranges (RR 9.11A), coordination between NGSO and GSO networks is on a first-come, first-served basis, depending on the ITU date priority of the relevant ITU filings. OneWeb has started coordination with GSO satellite networks in these frequency ranges, and is confident that compatibility with all GSO satellite networks in this band can be achieved using a similar GSO arc avoidance methodology as is adopted in the parts of Ka-band where EPFD limits apply.

A.8.2   Interference with Respect to Other NGSO Satellite Systems

According to ITU procedures (RR 9.12), for all of the Ku-band and Ka-band frequency ranges to be used by OneWeb, coordination amongst NGSO systems is on a first-come, first-served basis, depending on the ITU date priority of the relevant ITU filings.

Under FCC rules (§25.261), sharing between NGSO satellite systems in the 28.6-29.1 GHz uplink and 18.8-19.3 GHz downlink bands should be achievable, using whatever means can be coordinated between the operators to avoid in-line interference events, or by resorting to band segmentation in the absence of any such coordination agreement.[24]

OneWeb is confident that it can achieve the necessary coordination with other NGSO satellite systems, as necessary. OneWeb has already started the coordination process with some other NGSO operators.

Currently, there are no other NGSO satellite systems licensed by the Commission, or granted market access in the USA, that operate within the Ku-band frequency ranges to be used by OneWeb.[25]

In the Ka-band frequency ranges to be used by OneWeb, there is currently only one NGSO satellite system licensed by the Commission, or granted market access in the USA.[26]   That

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[24]   The Commission further clarified in its Public Notice entitled "International Bureau provides guidance concerning avoidance of in-line interference events among Ku-band NGSO FSS systems", dated October 20, 2015, that the requirements of §25.261 (b)-(d), which relate to parts of Ka-band only, will also be used as a condition for authorization of any Ku-band NGSO FSS system.

[25]   Although not licensed by the Commission, there is a US government NGSO satellite system with which coordination is required under FCC footnote 334. This is addressed in Section A.10.

system is the 12-satellite O3b MEO system, which operates in an equatorial orbit of altitude 8,062 km. OneWeb has initiated early informal coordination discussions with O3b and is confident that mutually agreeable conditions can be agreed with O3b to allow interference-free coexistence of these two NGSO systems, such as by making use of the inherent gateway diversity that exists in the OneWeb system, as explained in Section A.8.1.2 above. The GSO orbit avoidance scheme employed by OneWeb to meet EPFD limits, will inherently also serve to facilitate coordination with the O3b network as it also operates in the equatorial plane.

A.8.3 Interference with Respect to Terrestrial Networks in the 10.7-11.7 GHz Band

The only part of the Ku-band downlink spectrum to be used by OneWeb that is shared with terrestrial fixed services in the USA is the 10.7-11.7 GHz band. In this band, which is shared on a co-primary basis between the FSS and FS, the FCC has restricted the earth stations in an NGSO system to be gateway earth stations only. The rationale for this was to limit the number of earth stations that would need interference protection from the FS, thereby avoiding constraints on future deployment of the FS in this band.[27,28]

To the extent necessary, OneWeb seeks a waiver of the above-mentioned FCC restriction on earth stations operating in the 10.7-11.7 GHz band based on the fact that OneWeb proposes to

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[26] In addition there is the US government's non-GSO satellite system which is addressed in Section A.10 of this document.

[27] See FCC Order and Authorization for SkyBridge, L.L.C., July 18, 2005, paragraph 21.

[28] See also note 12 to §25.202(a) in pre-2012 versions of the FCC rules. The current FCC rules do not have this limitation but this may not be intentional on the part of the Commission.

operate its user terminal earth stations on a non-interference, non-protected basis.[29] This will be achieved as follows:

(a) The satellite downlink transmissions in the 10.7-11.7 GHz band to these earth stations will comply with the existing FCC PFD limits as demonstrated in Section A.7 above. These PFD limits are intended to protect the FS from interference from the satellite downlinks, and the FCC has determined that such limits are sufficient for this purpose.[30]

(b) The receiving earth stations will not seek any interference protection from the FS and so their operation will not constrain the further development of the FS in this band.

There are sound technical reasons to support the use of OneWeb user terminals in the 10.7-11.7 GHz band on a non-protected basis with respect to the FS, as follows:

(i) The potentially interfering FS transmitters are radiating in a horizontal or near-horizontal direction using narrowbeam antennas, and the OneWeb receiving user terminal earth stations have low gain towards the horizon. This is because the OneWeb system is designed to provide service to user terminals at high elevation angles (typically in excess of 50º) so the user terminals only have significant gain in these high elevation directions. The effect of this is that the required separation distance of a OneWeb user terminal from an FS transmitter is manageable, given the highly directional nature of the FS transmit antennas in this frequency band. In addition, FS

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[29] The Commission has granted a similar waiver in the past to EchoStar KuX Corporation. See FCC Order and Authorization "In the Matter of EchoStar KuX Corporation Application for Authority to Construct, Launch and Operate a Geostationary Satellite Using the Extended Ku-band Frequencies in the Fixed-Satellite Service at the 121° W.L. Orbital Location", September 30, 2004.

[30] *Id.*

links tend to be located on towers or relatively tall buildings, such that their "local" horizon is tens or hundreds of feet above the ground, whereas the OneWeb user terminals are much more likely to be located on or near the ground, so that there is further geometrical angular separation at the transmit FS site between its main pointing direction to the receiving FS site, and the victim OneWeb user terminal.

(ii) The OneWeb user terminals receive wideband downlink transmissions from the OneWeb satellites (typically 250 MHz bandwidth). This is a much wider bandwidth than any likely interfering signal from an FS transmitter, where the widest bandwidth carrier is typically 40 MHz. This will further reduce the effect of the interfering FS carrier in proportion to the ratio of the bandwidths of the transmissions, which is approximately 8 dB.

(iii) The OneWeb link to the user terminal can also use the 11.7-12.7 GHz band which is not shared with the FS. So in the unlikely event of a case where the FS interference in the 10.7-11.7 GHz band is problematic, for that specific location one option may instead be to use mostly the 11.7-12.7 GHz band for service to the user terminal.

(iv) Interference mitigation of an affected user terminal can be achieved by rotating or repositioning the user terminal to provide more rejection in the direction of the interfering signal. Rotating the antenna may increase the rejection towards the interferer because the gain pattern of the user terminal antenna in certain cases can be rotationally asymmetric at low elevation angles. Additional rejection would also be achievable by repositioning the terminal to the other side of natural or man-made obstacles (e.g., a building) so that it blocks the interfering FS signal.[31]

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[31] In addition, further developments in the user terminal design will permit adaptive nulling techniques to be implemented so as to null out the interfering signal.

A.8.4 Interference with Respect to Terrestrial Networks in the 12.2-12.7 GHz Band

There are currently 46 grandfathered FS links in the 12.2-12.7 GHz band that have legacy licenses under old FCC allocations. No new FS links will be authorized by the Commission in this band. OneWeb will accept any interference from these 46 legacy FS links. As for the 10.7-11.7 GHz band mentioned above, the OneWeb downlink transmissions in the 12.2-12.7 GHz band will comply with the ITU PFD limits as demonstrated in Section A.7 above. These PFD limits are intended to protect the FS from interference from the satellite downlinks and so will ensure there is no downlink interference into these 46 legacy FS links.

The Commission has authorized the Multichannel Video Distribution and Data Service (MVDDS) in the 12.2-12.7 GHz band, and this was auctioned by the Commission in 2006. The FCC established technical and service rules for MVDDS in the 12 GHz band in the *Second Report and Order (Second R&O)* of FCC-02-116A1, which specifically states that the MVDDS providers will share the 12 GHz band with new NGSO FSS operators on a co-primary basis.

To account for the particular interference mechanisms between MVDDS and NGSO systems the Commission adopted the following operating requirements for both systems.

MVDDS Operating Requirements:

(i) PFD at a distance: To promote MVDDS and NGSO FSS band sharing, the PFD of an MVDDS transmitting system shall not exceed -135 dBW/m^2/4 kHz measured and/or calculated at the surface of the earth at distances greater than 3 km from the MVDDS transmitting site.

(ii) The maximum MVDDS EIRP shall not exceed 14 dBm per 24 MHz, but there is no restriction on the polarization of the MVDDS transmission.

(iii) The MVDDS transmitting antenna may not be installed within 10 km of any pre-existing NGSO FSS receiver unless the affected licensees agree to a closer separation.

NGSO FSS Operating Requirements:

> (iv) Later-in-time NGSO FSS receivers must accept any interference resulting from pre-existing MVDDS transmitting antennas.

> (v) Low angle PFD limits on NGSO FSS downlinks in 12.2-12.7 GHz band: For elevation angles from 0º to 2º above the horizontal plane, NGSO FSS downlinks must meet a reduced PFD level of -158 dBW/m^2/4kHz, and for elevation angles from 2º to 5º degrees above the horizontal plane, a reduced PFD level of -158 + 3.33 (δ-2) dBW/m^2/4kHz, where δ is the elevation angle in degrees.

To allow the sharing mechanisms of (i), (iii) and (iv) above to be implemented the MVDDS and NGSO FSS operators must maintain and share databases of their respective transmitters and receivers, as required by the MVDDS *Second Report and Order* cited above. OneWeb is committed to this sharing arrangement and will comply with the requirements of this Order.

OneWeb will also comply with the requirements of (v) above concerning the low elevation angle PFD limits in the 12.2-12.7 GHz band, as demonstrated in Section A.7 above.

A.8.5   Interference with Respect to Terrestrial Networks in the 17.8-18.3 GHz Band

Part of the Ka-band spectrum to be used by the OneWeb system for its gateway operations is the 17.8-18.3 GHz band, which is allocated on a primary or co-primary basis, according to the US table of frequency allocations, to terrestrial fixed service ("FS") systems in the USA.[32]   These

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[32]   From 18.3-18.58 GHz, according to §101.85(b)(1) of the FCC rules, terrestrial licensees were transitioned out of this band as of November 19, 2012. From 18.58-19.3 GHz, according to §101.85(b)(2), terrestrial licensees were transitioned out as of June 8, 2010 or October 31, 2011, depending on the type and frequency of operation of the FS system.

systems are individually site licensed by the FCC under Parts 74F, 78 and 101 of the FCC's rules. OneWeb is seeking authority to use this band on a non-conforming basis, as described in the legal narrative portion of the application.

In the 17.8-18.3 GHz band, which OneWeb uses in the space-to-Earth direction and only for links to a relatively small number of gateway earth stations in the USA, the only potential interference path from the FS is from the transmitting FS station into the sidelobes of the OneWeb receiving gateway earth station antenna. In the unlikely event that potential interference would be caused to the OneWeb gateway earth station by FS activity in the area, OneWeb will accept any such interference and take the necessary measures to prevent it from impacting the earth station operations. Such necessary technical measures may include adjusting the minimum operational elevation angles, frequency avoidance, power level adjustment, earth station shielding or some combination thereof.

Existing PFD limits in §25.208, which apply to the frequency range 18.3-18.8 GHz and to which the OneWeb satellites conform as demonstrated in Section A.7 of this document, are intended to adequately protect FS receivers in this band from harmful interference from satellite downlinks. As explained in Section A.7 above, the same ITU PFD limits extend across the entire 17.8-18.8 GHz band with the objective of protecting terrestrial FS receivers, and therefore OneWeb's compliance with these limits will protect FS receivers from OneWeb satellite downlink interference across the entire 17.8-18.3 GHz band.

A.8.6   Interference with Respect to Terrestrial Networks in the 27.5-28.35 GHz Band

The OneWeb system also uses the 27.5-28.35 GHz band which is allocated by the Commission's 28 GHz First Report and Order, to the terrestrial LMDS (Local Multipoint Distribution System)

service on a primary basis and to the fixed-satellite service on a secondary basis in the USA.[33] These systems are licensed by the FCC on a geographic area basis. As OneWeb uses this frequency band in the Earth-to-space direction for gateway links only with a minimum uplink elevation of 15°, the only potential interference path from OneWeb is from the sidelobes of the transmitting OneWeb gateway earth station into the LMDS receivers.

Regarding §2.105(c)(2)(i), uplinks from gateway earth stations that are located in the United States must be operated in a manner such that they do not cause harmful interference to any current or future licensed LMDS station. OneWeb will put in place procedures to protect LMDS operations in the 27.5-28.35 GHz frequency band. These will involve careful coordination with any LMDS operators in the area where gateway earth stations are proposed. Since there will be few OneWeb gateway sites in the US and considering that the LMDS deployments are likely only to occur in urban areas, due to the severe propagation conditions in this band, it should be relatively easy to locate OneWeb gateways outside the main commercial target areas of the LMDS proponents.

OneWeb's future gateway earth station applications to the FCC that propose to transmit in the uplink direction to OneWeb's satellites in the 27.5-28.35 GHz band will include a showing addressing LMDS protection. In the unlikely event that an LMDS link could be interfered with, OneWeb will work cooperatively with the LMDS licensee to ensure that the LMDS link is protected. OneWeb is prepared to take necessary technical measures to avoid harmful interference such as adjusting the minimum transmit elevation angles, frequency avoidance, uplink power adjustment, earth station shielding, or some combination thereof.

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[33] *See* Rulemaking to Amend Parts 1, 2, 21, and 25 of the Commission's Rules to Redesignate the 27.5-29.5 GHz Frequency Band, to Reallocate the 29.5-30.0 GHz Frequency Band, to Establish Rules and Policies for Local Multipoint Distribution Service and for Fixed Satellite Service, *First Report and Order and Fourth Notice of Proposed Rulemaking*, CC Docket No. 92-297, 11 FCC Rcd 19005 (1996) (*28 GHz First Report and Order*).

§2.105(c)(2)(ii) requires OneWeb, as a secondary user, to accept incoming interference from a primary user. Transmitting LMDS stations cannot cause harmful interference into the OneWeb receiving earth station since the earth station does not receive transmissions in the 27.5-28.35 GHz band. Harmful interference occurring from the aggregation of transmitting LMDS stations into a receiving spot beam of the OneWeb satellites is considered to be very unlikely, for similar reasons to those explained above in the context of the potential interference from OneWeb gateways into LMDS; nevertheless, OneWeb undertakes to accept this risk and will not seek protection from such interference in the event it occurs.

A.8.7   Interference with Respect to TDRSS Receiving Ground Stations in the 14.0-14.2 GHz Band

OneWeb will coordinate with NASA concerning the protection of the designated TDRSS receiving ground stations in the USA from transmissions of the OneWeb user terminals operating in the 14.0-14.2 GHz band, consistent with §25.226(c) and §25.227(c).

A.8.8   Interference with Respect to the Radio Astronomy Service

Several footnotes to the FCC's table of frequency allocations address the need for satellite downlink transmissions to adequately protect the Radio Astronomy Service ("RAS") at specific sites in the USA. These are addressed below.

Footnote US131 directly addresses NGSO systems operating in the 10.7-11.7 GHz band and the need to coordinate with and protect the RAS observatories listed in this footnote, which operate in the 10.6-10.7 GHz band. OneWeb has started the process of coordinating with the RAS community in the USA and will pursue this to ensure all necessary coordination is completed.

Footnote US211 addresses the more general matter of taking all practical steps to protect RAS observatories in the USA which operate in the RAS frequency ranges listed in this footnote. This footnote also makes reference to footnote US74 regarding the extent of the protection needed. Footnote US74 makes further reference to footnote US385 which lists the geographic

locations at which such RAS observations are performed. OneWeb will take this into account in determining the specifications of its satellite transmitters and, as necessary, its operations with respect to these specific geographic locations.

OneWeb will also coordinate with the National Science Foundation regarding transmissions from its user terminal earth stations in the 14.47-14.5 GHz band, consistent with §25.226(d) and §25.227(d).

A.9   ITU FILINGS FOR ONEWEB

The OneWeb satellite system is registered with the ITU by the United Kingdom administration under the satellite network name "L5". A summary of the related ITU publications to date for L5 is given in Table A.9-1 below. These encompass all the frequencies to be used by OneWeb that are the subject of this application to the Commission.

Table A.9-1: Current ITU Publications for L5 System

Publication Reference					Date of receipt	IFIC #	IFIC Date
API/A	/	8111			27-Nov-12	2738	19-Feb-13
API/A	/	8111	MOD -	1	14-Mar-13	2745	28-May-13
CR/C	/	3413			27-Jun-13	2757	12-Nov-13
CR/C	/	3413	MOD -	1	14-Sep-13	2761	21-Jan-14
API/A	/	8111	MOD -	2	27-Jun-13	2763	18-Feb-14
CR/C	/	3413	MOD -	2	6-Dec-13	2767	15-Apr-14
CR/D	/	2541			6-Dec-13	2771	10-Jun-14
API/B	/	413			27-Jun-13	2774	22-Jul-14
CR/D	/	2575			6-Dec-13	2775	5-Aug-14
API/A	/	8111	MOD -	3	18-Jul-14	2778	16-Sep-14
CR/C	/	3413	MOD -	3	27-Jun-14	2782	11-Nov-14
API/A	/	8111	MOD -	4	24-Sep-14	2783	25-Nov-14
CR/D	/	2644			27-Jun-14	2783	25-Nov-14
API/A	/	8111	MOD -	5	27-Nov-14	2787	3-Feb-15
CR/C	/	3413	MOD -	4	6-Dec-13	2790	17-Mar-15
CR/C	/	3413	MOD -	5	25-Nov-14	2797	23-Jun-15
CR/C	/	3413	MOD -	6	18-Jan-15	2800	4-Aug-15
CR/C	/	3413	MOD -	7	1-Apr-15	2809	8-Dec-15

A.10   COORDINATION WITH THE US GOVERNMENT SATELLITE NETWORKS
(Footnote US334 in the FCC Table of Frequency Allocations)

US334 requires coordination of the OneWeb system with US government satellite networks, both GSO and NGSO, in portions of the Ka-band spectrum.

OneWeb has initiated this coordination process and is optimistic that it can be concluded in a mutually acceptable manner. OneWeb will inform the Commission when this has been completed.

A.11   ORBITAL DEBRIS
(§25.114(d)(14))

This matter is addressed in the main legal narrative part of this application.

A.12   SATELLITE EIRP DENSITY VALUES

§25.114(c)(4)(ii) requires the value of the maximum EIRP density for each space station transmit antenna. This data is not part of the Schedule S and so is provided in Table A.12-1 below, using the reference bandwidths required by the rule. The transmit beam designations are those used in S7 of the associated Schedule S.

Table A.12-1: Maximum EIRP density values

for each space station transmit antenna and frequency band

Satellite Transmit Beam	Frequency Ranges	Value	Units
UD	10.7 – 12.7 GHz	-13.4	dBW/4kHz
GD	17.8 – 18.6 GHz 18.8 – 19.3 GHz	+8.0	dBW/MHz

A.13   SATELLITE G/T AND SFD RANGE VALUES

§25.114(c)(4)(v) requires the beam peak G/T values and both the minimum and maximum saturation flux density ("SFD") values for each space station receive antenna that is connected to transponders.   Although the minimum SFD values are in S7p of the Schedule S there is no provision in the Schedule S for the maximum SFD values. Therefore, the maximum SFD values as well as the beam peak G/T values are provided in Table A.13-1 below.   The receive beam designations are those used in S7 of the associated Schedule S.

Table A.13-1: Maximum SFD values for each space station receive antenna

Satellite Receive Beam	G/T at beam peak (dB/K)	SFD at beam peak (dBW/m^2)	
		Minimum	Maximum
UU	-1.0	-77.5	-77.5
GU	+11.4	-101.5	-77.5

A.14 ADDITIONAL INFORMATION CONCERNING DATA IN THE ASSOCIATED SCHEDULE S
(§25.114(c))

The data provided in the associated Schedule S is consistent with the latest available FCC instructions.[34] Table A.14-1 below lists the data items from the Schedule S that are required to be provided in current applications (specifically for an NGSO system) and those data items no longer required.

Table A.14-1: Identification of Schedule S data items
required by current FCC rules

	Required	<u>NOT</u> Required
S1: General Information	S1a, S1f, S1i, and S1l	S1b, S1c, S1d1, S1d2, S1e, S1g, S1h, S1j and S1k
S2: Operating Frequency Bands	S2a, S2b, S2c, S2d, S2e and S2f	
S4: Orbital Information for Non-Geostationary Satellites	S4a, S4b, S4c, S4d, S4e, S4f, S4g, S4h, S4i, S4j, S4k, S4l, S4m and S4n	S4o (if service arc is not defined in S4m and S4n)
S5: Initial Satellite Phase Angle	S5a, S5b and S5c	
S6: Service Area Characteristics	S6a, S6b, and S6c or S6d	

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[34] See SPECIFIC INSTRUCTIONS FOR SCHEDULE S, Technical and Operational Description of Space Station(s), Revised March, 2014 Pursuant to Changes in 47 C.F.R. §25.114 adopted by the Commission on August 9, 2013, Rev. 6k, May 14, 2014.

S7: Antenna Beam	S7a, S7b, S7e, S7f, S7g, S7j, S7m, S7o, and S7p (as appropriate for Tx/Rx)	S7c, S7d, S7h, S7i, S7k, S7l, S7n, S7q and S7r
S8: Antenna Beam Diagrams	S8a, S8b, S8c, S8e or S8f, S8g, S8h, S8i, S8j, S8k and S8l	S8d
S9: Space Station Channels	S9a, S9b, S9c, S9d, S9e, S9f	
S10: Space Station Transponders	S10a, S10c and S10d, and/or S10e and S10f	S10b
S11: Digital Modulation Parameters	S11a, S11b and S11c (for highest EIRP density)	S11d, S11e, S11f, S11g, S11h and S11i
S12: Analog Modulation Parameters	S12a, S12b and S12c (for highest EIRP density)	S12d, S12e, S12f, S12g, S12h, S12i, S12j, S12k, S12l, S12m, S12n and S12o
S13: Typical Emissions	S13a, S13b, S13c and/or S13d as appropriate, and S13m	S13e, S13f, S13g, S13h, S13i, S13j, S13k, S13l, S13n, S13o and S13p

The following notes are provided related to the data provided in the accompanying Schedule S for the OneWeb system:

1. Uplink transponders are listed separately from downlink transponders in S10 of the Schedule S, consistent with the FCC requirements.

2. S13 of the Schedule S lists only the satellite downlink transponders as the Schedule S is no longer required to capture the characteristics of the associated transmitting earth stations.

3. The values given in S7m (satellite transmit maximum EIRP) are the maximum EIRP levels from each satellite high power amplifier. For Ku-band this value is the maximum

EIRP in a 250 MHz bandwidth channel, and for Ka-band this is the aggregate of the downlink channels that share a common satellite amplifier.

A.15 COORDINATION WITH VERY LARGE ANTENNAS (VLA) IN THE 10.7-12.5 GHZ BAND
(§25.146(f))

OneWeb has initiated this coordination process and is optimistic that it can be concluded in a mutually acceptable manner. OneWeb will inform the Commission when this has been completed.

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ANNEX 1

Demonstration of EPFD Compliance in Ku-Band

This annex provides a detailed explanation of the EPFD levels produced by the OneWeb system in Ku-band, and how they comply with the single-entry EPFD validation limits in §25.146(a)(1) and (2).

Because of the complexity of the rules in §25.146 the relevant rule sections are repeated below together with the response to the rule requests. The rule texts are shown in italicized text.

§25.146 Licensing and operating rules for the non-geostationary orbit Fixed-Satellite Service in the 10.7 GHz-14.5 GHz bands.

(a) A comprehensive technical showing shall be submitted for the proposed non-geostationary satellite orbit Fixed-Satellite Service (NGSO FSS) system in the 10.7-14.5 GHz bands. The technical information shall demonstrate that the proposed NGSO FSS system would not exceed the validation equivalent power flux-density (EPFD) limits as specified in §25.208 (g), (k), and (l) for EPFD$_{down}$, and EPFD$_{up}$. If the technical demonstration exceeds the validation EPFD limits at any test points within the U.S. for domestic service and at any points outside of the U.S. for international service or at any points in the geostationary satellite orbit, as appropriate, the application would be unacceptable for filing and will be returned to the applicant with a brief statement identifying the non-compliance technical demonstration. The technical showing consists of the following:

The comprehensive technical showing presented below demonstrates that the OneWeb system will not exceed the validation equivalent power flux-density (EPFD) limits in Ku-band as specified in §25.208 (g), (k), and (l) for EPFD$_{down}$ and EPFD$_{up}$.

(1) Single-entry validation equivalent power flux-density, in the space-to-Earth direction, (EPFD$_{down}$) limits. (i) Provide a set of power flux-density (PFD) masks, on the surface of the Earth, for each space station in the NGSO FSS system. The PFD masks shall be generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503, "Functional Description to be used in Developing Software Tools for Determining Conformity of Non-GSO FSS Networks with Limits Contained in Article 22 of the Radio Regulations." In particular, the PFD masks must encompass the power flux-density radiated by the space station regardless of the satellite transmitter power resource allocation and traffic/beam switching strategy that are used at different periods of a NGSO FSS system's life. The PFD masks shall also be in an electronic form that can be accessed by the computer program specified in paragraph (a)(1)(iii) of this section.

<u>EPFD_{down}</u>:

In order to demonstrate compliance with the single-entry validation equivalent power flux-density ($EPFD_{down}$) limits, in the space-to-Earth direction, OneWeb is providing the Commission, with this application, the computer files that contain the sets of Ku-band power flux-density (PFD) masks, on the surface of the Earth, for each space station in the OneWeb system. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The PFD masks are one of the data inputs to the EPFD validation software program required to calculate the $EPFD_{down}$ levels in Ku-band.

The PFD masks define the maximum satellite downlink PFD in Ku-band over the surface of the Earth that is visible to the satellite and may, according to ITU-R Recommendation S.1503-2, be constant or variable as a function of the sub-satellite latitude. The PFD masks can be expressed in two ways. The first is as a function of the azimuth ("Az") and elevation ("El") angles as viewed from the satellite towards the Earth relative to nadir direction. Azimuth is in the east-west direction and elevation is in the north-south direction, as seen at the sub-satellite point. The second is as a function of two different variables: the α angle, which is defined in the recommendation as the separation angle, measured at the surface of the Earth, between the line to the NGSO satellite and the nearest point on the GSO orbit, and the ΔL angle which is the difference in longitude between the NGSO sub-satellite point and the point on the GSO arc where the α angle is minimized.

(ii) Identify and describe in detail the assumptions and conditions used in generating the power flux-density masks.

OneWeb uses the Az/El option described above for the definition of its satellite Ku-band PFD masks that are provided with this application. These masks have been generated using the following methodology and assumptions related to the actual design and real-world operation of the OneWeb system:

(a) The starting point is the two dimensional (as a function of Az/El) EIRP density mask for a single OneWeb Ku-band satellite transmit beam at the maximum operational transmit EIRP level (for all conditions of modulation and traffic patterns). This will vary for each of the beams on the satellite because of their slightly different pointing directions.

(b) The different spatial frequency re-use patterns used within each OneWeb satellite are then taken into account to derive a set of different aggregate EIRP density masks, one for each combination of co-frequency beams that is used. These satellite-aggregate EIRP masks will be different for each re-use pattern because of the relative pointing directions of the different beams.

(c) At latitudes close to the equator, the downlink EIRP is progressively reduced in certain beams in order to ensure compliance with the EPFD limits at these latitudes. In addition, certain beams are eventually turned off to achieve the EPFD objective. These beams are the ones closest to the GSO alignment geometry, which means they are the ones in the satellite footprint which are furthest away from the equator. These measures are reflected in the EIRP masks that apply to low latitude positions of the satellites.

(d) The different EIRP masks are then converted to PFD masks (also as a function of Az/El) by taking account of the pitch bias, which varies with latitude, and the resulting spreading loss from the satellite to the surface of the Earth.

(e) The resulting PFD masks for each set of satellites are therefore a function of Az/El and sub-satellite latitude.

(f) As OneWeb will vary the re-use pattern on a satellite-to-satellite basis, each of the different PFD masks are assigned to an equal number of satellites within the constellation.

(iii) If a computer program that has been approved by the ITU for determining compliance with the single-entry EPFD$_{down}$ validation limits is not yet available, the applicant shall provide a computer program for the single-entry EPFD$_{down}$ validation computation, including both the source code and the executable file. This computer program shall be developed in accordance with the specification stipulated in the most recent

version of Recommendation ITU-R S.1503. If the applicant uses the ITU approved software, the applicant shall indicate the program name and the version used.

The ITU has not yet approved a computer program for determining compliance with the single-entry $EPFD_{down}$ (and $EPFD_{up}$ and $EPFD_{is}$) validation limits, although it is in the process of developing such a program in accordance with the specification stipulated in the most recent version of Recommendation ITU-R S.1503. It is understood that the ITU-BR is in the process of final testing of this program. OneWeb is making available to the FCC, as part of this application, an executable copy of the latest version of this computer program. This software is likely to be very close to the final version that the ITU will approve as the software developer is one of the companies that has been working with the ITU in the development of the code.[35] This is the most accurate and reliable way for the EPFD levels to be evaluated based on the PFD and EIRP masks being provided.

OneWeb is prepared to provide all necessary assistance to the FCC in running this computer program.

(iv) Identify and describe in detail the necessary input parameters for the execution of the computer program identified in paragraph (a)(1)(iii) of this section.

Although not specifically requested in §25.146(a)(1), OneWeb is providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation program to validate the $EPFD_{down}$ levels. This replicates part of the ITU's SRS database file and

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[35] Due to software licensing restrictions, OneWeb does not have access to, nor is able to provide the Commission with, the source code for this computer program. However, this computer program is close to being the final one that the ITU will approve. Indeed, the ITU recently held a NGSO workshop highlighting that this software is now fully developed and tested. See generally http://www.itu.int/en/ITU-R/space/workshops/2016-NGSO/Pages/default.aspx; presentation available at http://www.itu.int/en/ITU-R/space/workshops/2016-NGSO/SiteAssets/Pages/programme2/Workshop%20Software%20Slides.pdf.

contains the orbital parameters and other data concerning the OneWeb constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

(a) The orbital parameters of the OneWeb constellation, consistent with the associated Schedule S submission;

(b) The parameter entitled "nbr_op_sat" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.6.a). This is defined as "the maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location in various latitude ranges." Although the number of satellites transmitting with the *intention* of providing service to the given location is at maximum two, a much higher value needs to be used when running the EPFD validation software in order to capture the contributions to the $EPFD_{down}$ from all the visible satellites, whether they are intentionally transmitting to this location or not. A value of 40 is proposed for all latitude ranges, as the EPFD validation software will determine from the orbit geometry the maximum number of visible satellites up to the number provided;

(c) The parameter entitled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as "the minimum elevation angle at which any associated non-geostationary satellite earth station can transmit to a non-geostationary satellite." A value of 45° is used for both uplink and downlink for this parameter.

(v) Provide the result, the cumulative probability distribution function of EPFD, of the execution of the computer program described in paragraph (a)(1)(iii) of this section by using only the input parameters contained in paragraphs (a)(1)(i) and (a)(1)(iv) of this section.

The Ku-band $EPFD_{down}$ results from the EPFD validation computer program using the input data explained above are shown below. Each plot corresponds to one of the GSO reference earth station antenna sizes from the EPFD limits. The labeling of each diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the size of the GSO reference earth station antenna (in meters), and whether this is a BSS or FSS EPFD limit.[36] Also shown for each EPFD plot is the worst-case geometry defined by the latitude of the GSO reference receiving earth station location and the Δ_{long} (difference in longitude between the GSO reference receiving earth station location and its corresponding GSO satellite). This worst-case geometry has been determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. On each diagram the resulting EPFD level is shown by the blue curve and the EPFD mask that applies is shown by the red lines. The determination by the EPFD validation software of the worst-case $EPFD_{down}$ results, as shown below, also takes into account the high latitude EPFD limits given in Table 2G of §25.208(g) for the GSO FSS and Table 2L of §25.208(l) for the GSO BSS. Therefore, compliance with these limits is also assured.

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[36]   The frequency used for the analysis is determined by the EPFD validation software and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency is 10.7 GHz for the FSS and 11.7 GHz for the BSS.

Worst-case geometry:
GSO ES latitude = 17.888°N, Δ_{long} = 3.828°

EPFD Down, 11.700, 40.000, 0.300, BSS
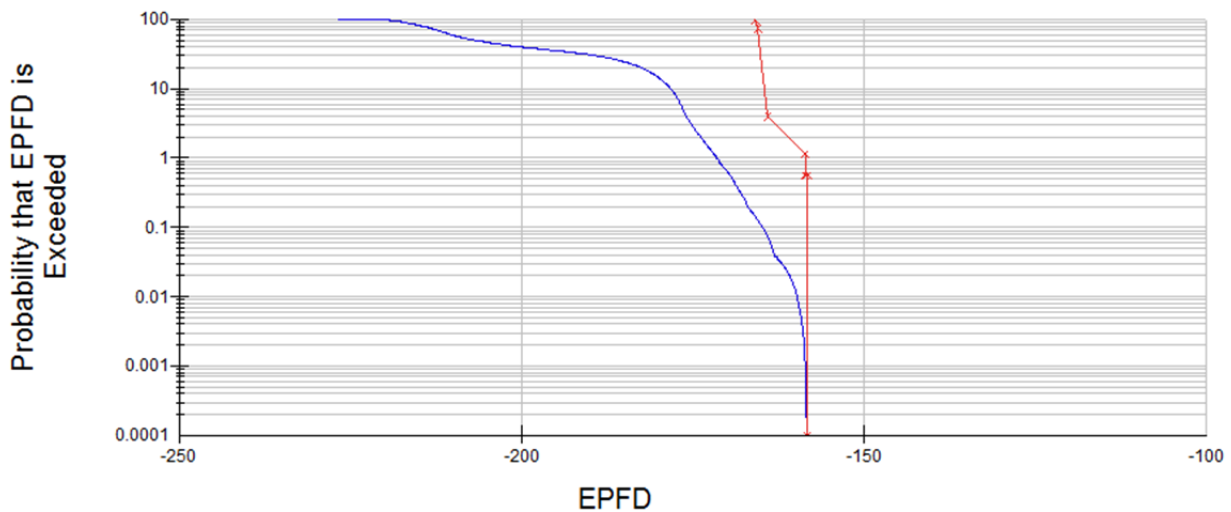
Worst-case geometry:
GSO ES latitude = 17.689°N, Δ_{long} = 3.332°
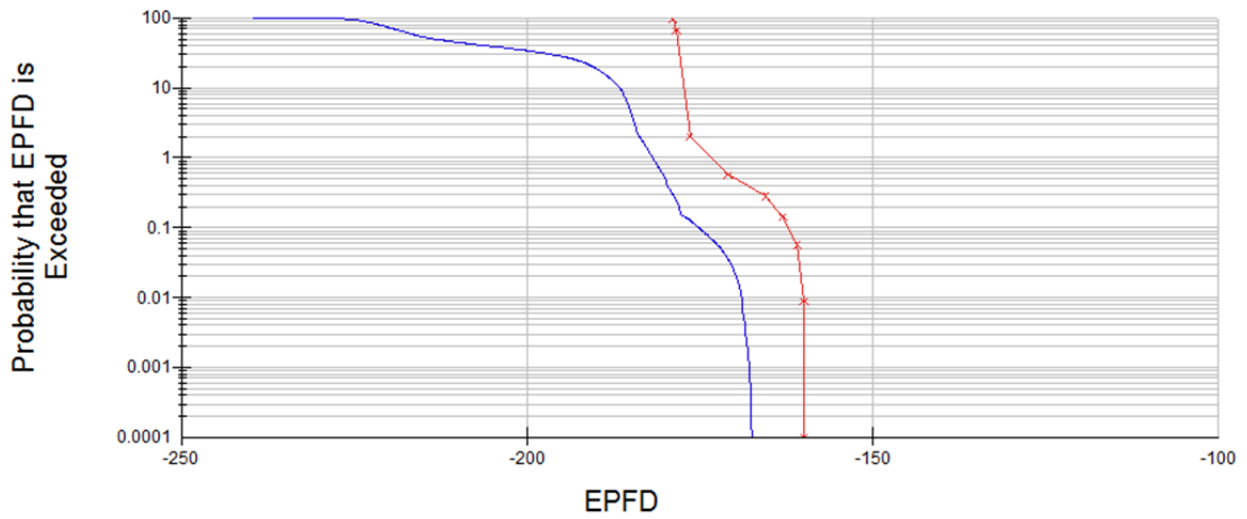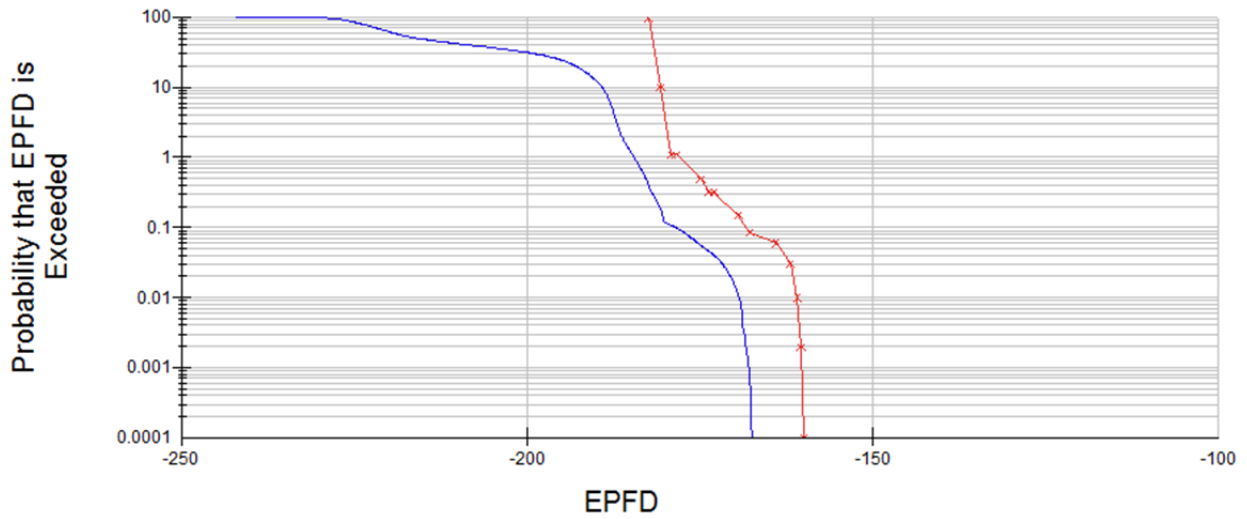
EPFD Down, 11.700, 40.000, 0.450, BSS
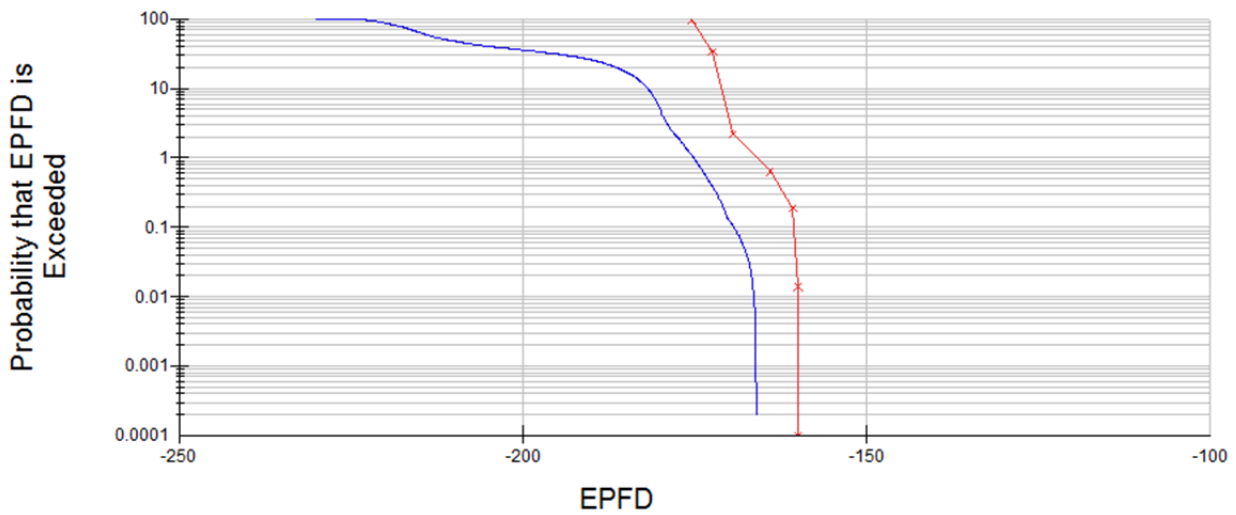
Worst-case geometry:
GSO ES latitude = 24.984°N, Δ_{long} = 2.575°
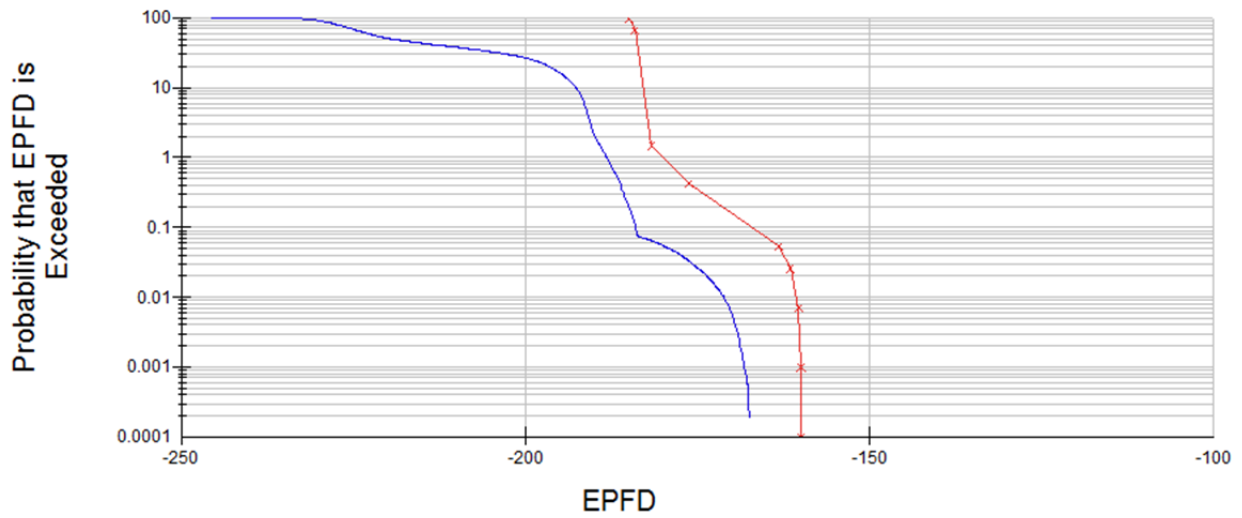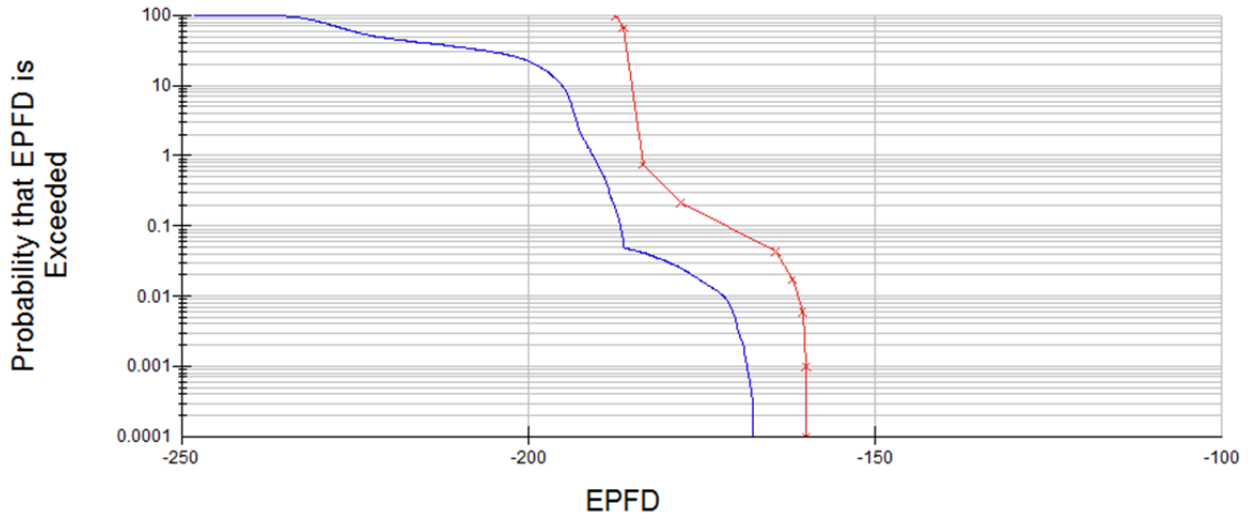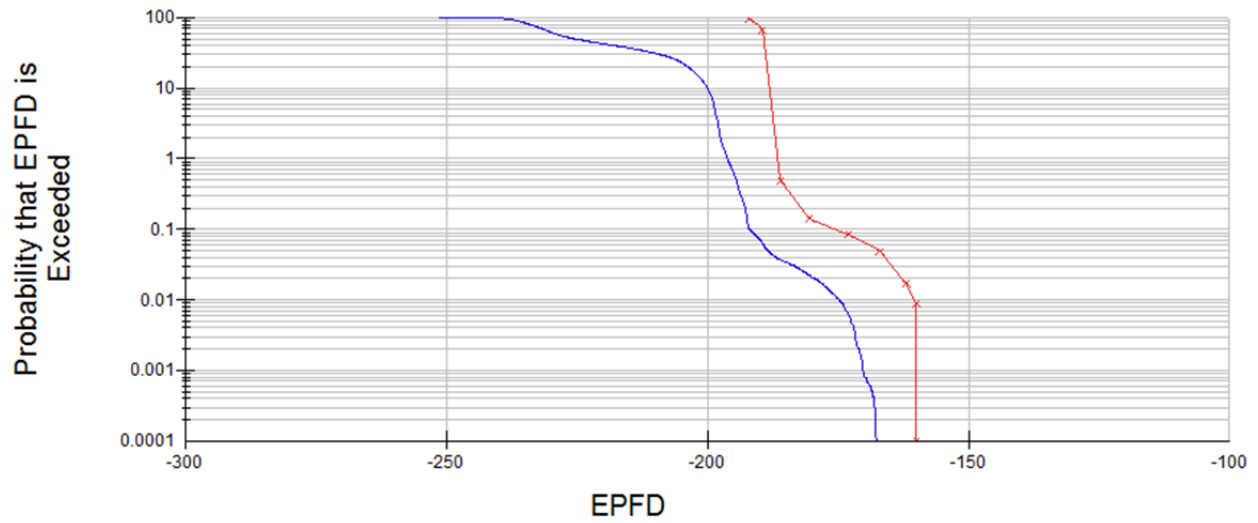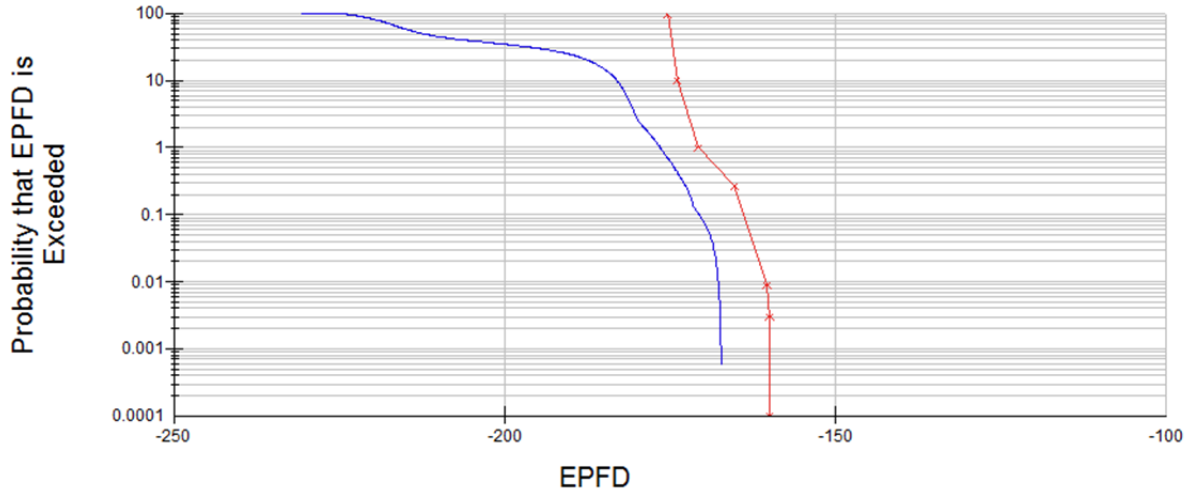
EPFD Down, 11.700, 40.000, 0.600, BSS
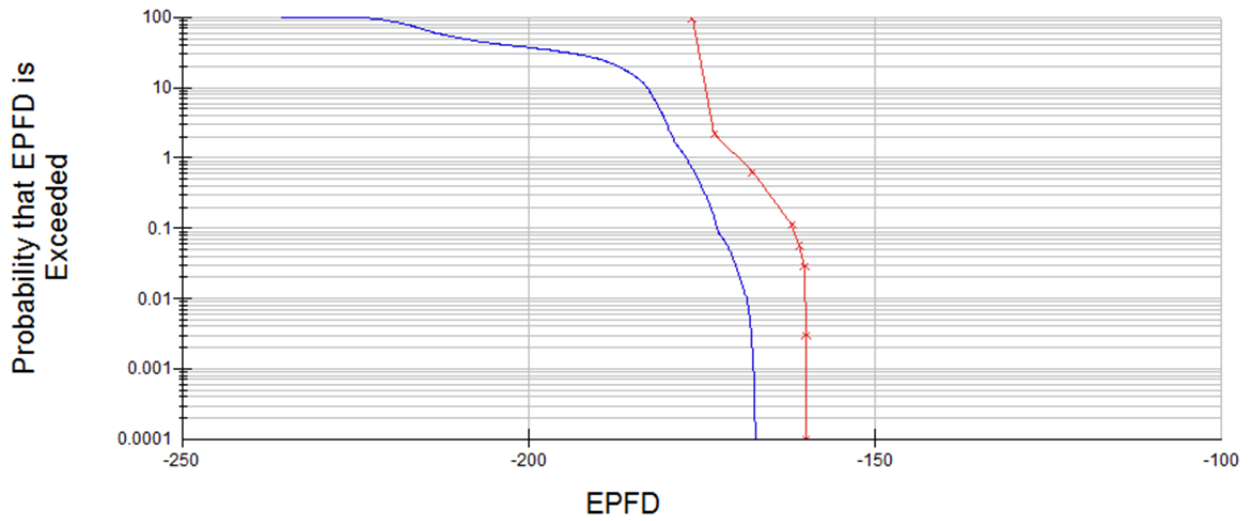
Worst-case geometry:
GSO ES latitude = 28.029°N, Δ_{long} = 2.595°

EPFD Down, 11.700, 40.000, 0.900, BSS

Worst-case geometry:
GSO ES latitude = 28.028°N, Δ_{long} = 2.647°

EPFD Down, 11.700, 40.000, 1.200, BSS

Worst-case geometry:
GSO ES latitude = 28.028°N, Δ_{long} = 2.648°

EPFD Down, 11.700, 40.000, 1.800, BSS

Worst-case geometry:
GSO ES latitude = 28.026°N, Δ_{long} = 2.751°

EPFD Down, 11.700, 40.000, 2.400, BSS

Worst-case geometry:
GSO ES latitude = 32.527°N, Δ_{long} = 4.583°
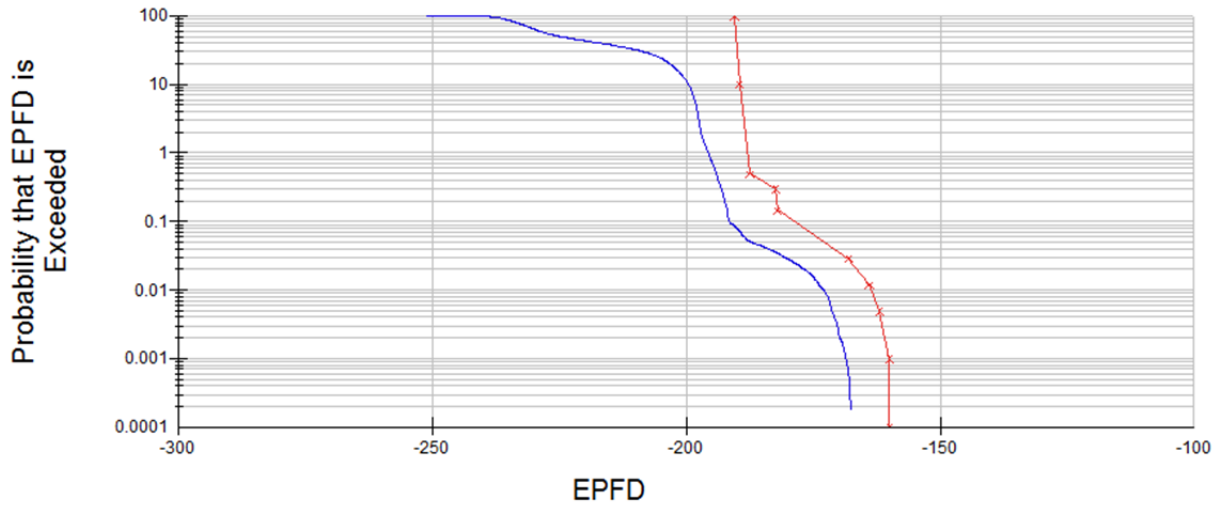
EPFD Down, 11.700, 40.000, 3.000, BSS

Worst-case geometry:
GSO ES latitude = 17.687°N, Δ_{long} = 2.539°

EPFD Down, 10.700, 40.000, 0.600, FSS

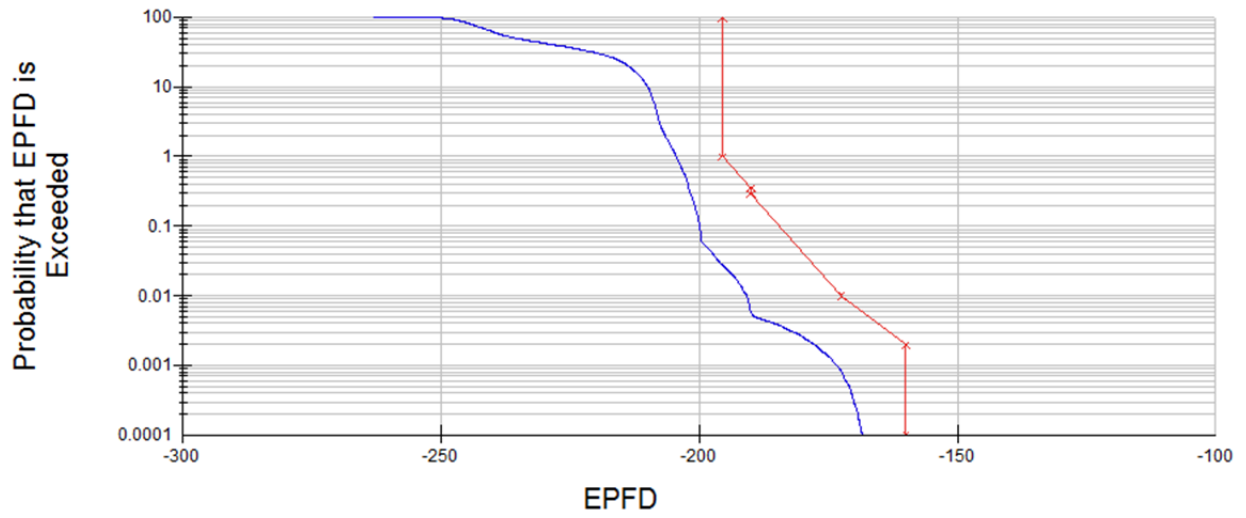Worst-case geometry:
GSO ES latitude = 28.029°N, Δ_{long} = 2.596°

EPFD Down, 10.700, 40.000, 1.200, FSS
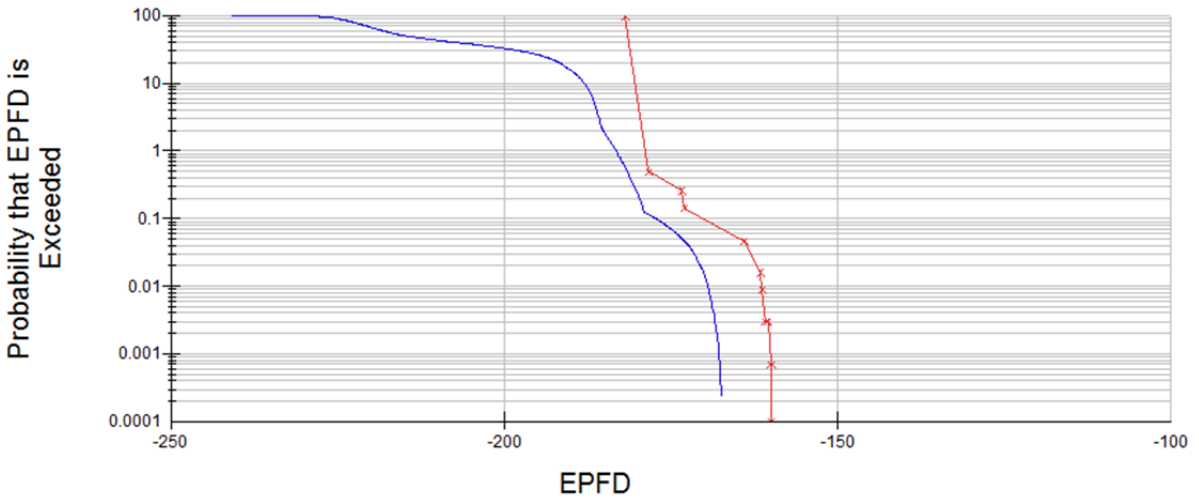
Worst-case geometry:
GSO ES latitude = 32.527°N, Δ_{long} = 4.582°

EPFD Down, 10.700, 40.000, 3.000, FSS

Worst-case geometry:
GSO ES latitude = 28.039°N, Δ_{long} = 4.251°

EPFD Down, 10.700, 40.000, 10.000, FSS

(2) Single-entry additional operational equivalent power flux-density, in the space-to-Earth direction, (additional operational EPFD$_{down}$) limits. (i) Provide a set of NGSO FSS earth station maximum equivalent isotropically radiated power (EIRP) masks as a function of the off-axis angle generated by an NGSO FSS earth station. The maximum EIRP mask shall be generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503. In particular, the results of calculations encompass what would be radiated regardless of the earth station transmitter power resource allocation and traffic/beam switching strategy are used at different periods of an NGSO FSS system's life. The EIRP masks shall be in an electronic form that can be accessed by the computer program specified in paragraph (a)(2)(iii) of this section.

OneWeb understands that the first sentence in the rule section above contains a typographical error and that it should in fact refer to "Single-entry validation equivalent power flux-density, in the Earth-to-space direction, (EPFD$_{up}$) limits." That would be consistent with the remaining sentences above which relate to the parameters required for determining the EPFD$_{up}$ rather than the EPFD$_{down}$ levels. Also, the EPFD$_{down}$ assessment was dealt with in §25.146(a)(1) and so should not be repeated here.

EPFD$_{up}$:

In order to demonstrate compliance with the single-entry validation equivalent power flux-density (EPFD$_{up}$) limits, in the Earth-to-space direction, OneWeb is providing the Commission, with this application, the computer files that contain the Ku-band earth station maximum off-axis EIRP masks for the earth stations in the OneWeb system. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the EPFD$_{up}$ levels in Ku-band.

The EIRP masks define the off-axis EIRP density of the Ku-band transmitting earth stations as a function of off-axis angle. They were derived using a composite antenna pattern taking into account, for each angle off-boresight, the highest off-axis gain in all directions around that boresight. The masks then assume the off-axis gain is rotationally symmetric around the boresight of the antenna, and therefore represent a worst-case situation. They may, according to ITU-R Recommendation S.1503-2, be constant or variable as a function of the earth station latitude, but the simulations assume the same EIRP mask at all latitudes.

(ii) Identify and describe in detail the assumptions and conditions used in generating the maximum earth station e.i.r.p. mask.

These masks have been generated using the following methodology and assumptions related to the actual design and real-world operation of the OneWeb system:

A single EIRP mask is created that represents the highest on-axis and off-axis EIRP density levels (per 40 kHz) for any of the Ku-band transmitting user terminal earth stations, which is not earth station latitude dependent, but inclusive of all conditions of modulation and traffic patterns;

(iii) If a computer program that has been approved by the ITU for determining compliance with the single-entry EPFD$_{up}$ validation limits is not yet available, the applicant shall provide a computer program for the single-entry EPFD$_{up}$ validation computation, including both the source code and the executable file. This computer program shall be developed in accordance with the specification stipulated in the most recent version of Recommendation ITU-R S.1503. If the applicant uses the ITU approved software, the applicant shall indicate the program name and the version used.

See comments above in response to §25.146(a)(1)(iii) concerning the computer program for determining compliance with the EPFD$_{down}$ validation limits. This same computer program can be used for determining compliance with the EPFD$_{up}$ validation limits.

(iv) Identify and describe in detail the necessary input parameters for the execution of the computer program identified in paragraph (a)(2)(iii) of this section.

Although not specifically requested in §25.146(a)(2), OneWeb is providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation program to validate the EPFD$_{up}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the OneWeb constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

The orbital parameters of the OneWeb constellation, consistent with the associated Schedule S submission;

(a) The parameter entitled "nbr_sat_td" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.a). This is defined as "the maximum number of non-geostationary satellites receiving simultaneously with overlapping frequencies from the associated earth stations within a given cell." The value of this parameter should be two which is a worst-case value based on the rare situation when operational satellites have overlapping service areas and overlapping frequencies.

(b) The parameter entitled "density" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.b). This is defined as "the average number of associated earth stations with overlapping frequencies per square kilometre within a cell." The value of this parameter is related directly to the size of the aggregate beam coverage area from each OneWeb satellite, which is approximately 1140 km by 1140 km, and the maximum number of times an uplink frequency can be spatially re-used within this area, which is four times. Therefore, the average density will be four times for every $1140*1140$ km^2 (=1,299,600 km^2), or once per 324,900 km^2. This gives a density value of (1÷324,900) or 0.00000308 earth stations per km^2.

(c) The parameter entitled "avg_dist" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.c). This is defined as "the average distance, in kilometres, between co-frequency cells." The value of this parameter is directly related to the "density" value described above, and is in fact the square root of the inverse of the density value. This gives a value of 570 km as the average distance between co-frequency transmitting earth stations.

(d) The parameter entitled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as "the minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite. For the OneWeb Ku-band user terminals this parameter is set to 45º.

(e) The parameter entitled "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.d.2). This is the minimum GSO avoidance angle measured at the surface of the Earth. For the OneWeb Ku-band user terminals this parameter is set to 5.9º as this reflects the way the OneWeb system will be operated.

(v) Provide the result of the execution of the computer program described in paragraph (a)(2)(iii) of this section by using only the input parameters contained in paragraphs (a)(2)(i) and (a)(2)(iv) of this section.

The Ku-band EPFD$_{up}$ results from the EPFD validation computer program using the input data explained above are shown below. The labeling of the diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the beamwidth of the reference GSO satellite receiving antenna beam (4.0 degrees) and the fact that this is a FSS EPFD limit.[37] Also stated is the worst-case geometry defined by the latitude of the pointing direction of the reference GSO satellite receiving beam and the Δ_{long} (difference in longitude between this pointing direction and the corresponding GSO satellite). This worst-case geometry has been determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. The resulting EPFD level is shown by the blue curve and the EPFD mask is shown by the red line.

Worst-case geometry:
GSO satellite pointing direction latitude = 42.552°N, Δ_{long} = 0.0°

EPFD Up, 14.000, 40.000, 4.000, FSS

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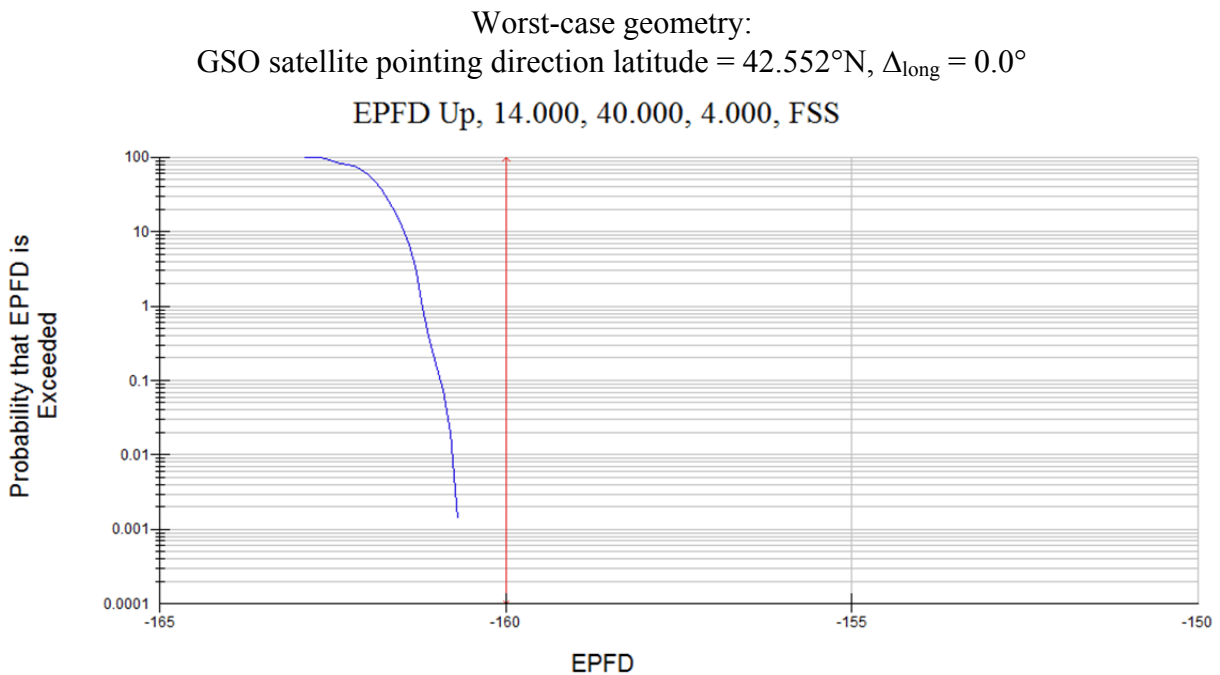
[37] The frequency used for the analysis is determined by the EPFD validation software and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency is 14.0 GHz for the FSS frequency range of 14.0-14.5 GHz.

The results above demonstrate that the OneWeb system complies with the Commission's and the ITU's EPFD$_{down}$ and EPFD$_{up}$ limits.

EPFD$_{is}$:

The FCC rules applicable to Ku-band NGSO FSS systems do not include any reference to the EPFD$_{is}$ limits that exist in No. 22.5F of the ITU Radio Regulations. Compliance with these EPFD$_{is}$ limits for both Ku-band and Ka-band is provided in Annex 3 of this document.

Other general EPFD rules:

OneWeb will comply at the appropriate time with the rule sections §25.146(b) and §25.146(g) which require additional submissions on the part of OneWeb ninety days prior to the initiation of service to the public.

OneWeb confirms, consistent with §25.146(e), that it is not claiming interference protection from GSO FSS and BSS networks operating in accordance with the FCC Part 25 rules and the ITU Radio Regulations.

OneWeb confirms it will coordinate with the very large GSO FSS earth stations in the 10.7-12.75 GHz band under the conditions described in §25.146(f).

ANNEX 2

Demonstration of EPFD Compliance in Ka-Band

This annex provides a detailed explanation of the EPFD levels produced by the OneWeb system in Ka-band, and how they comply with the single-entry EPFD validation limits in No. 22.5C, 22.5D and 22.5F of the ITU Radio Regulations.[38]

EPFD$_{down}$:

In order to demonstrate compliance with the single-entry validation equivalent power flux-density (EPFD$_{down}$) limits in Ka-band, in the space-to-Earth direction, OneWeb is providing the Commission, with this application, the computer files that contain the set of Ka-band power flux-density (PFD) masks, on the surface of the Earth, for each space station in the OneWeb system. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The PFD masks are one of the data inputs to the EPFD validation software program required to calculate the EPFD$_{down}$ levels in Ka-band.

The PFD masks define the maximum satellite downlink PFD in Ka-band over the surface of the Earth that is visible to the satellite and may, according to ITU-R Recommendation S.1503-2, be constant or variable as a function of the sub-satellite latitude. The PFD masks can be expressed in one of two ways. The first is as a function of the azimuth ("Az") and elevation ("El") angles as viewed from the satellite towards the Earth. Azimuth is in the east-west direction and

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[38] There are no EPFD limits for Ka-band in the FCC Part 25 rules.

elevation is in the north-south direction, as viewed at the sub-satellite point. The second is as a function of two different variables: the α angle, which is defined in the recommendation as the separation angle, measured at the surface of the Earth, between the line to the NGSO satellite and the nearest point on the GSO orbit, and the ΔL angle which is the difference in longitude between the NGSO sub-satellite point and the point on the GSO arc where the α angle is minimized.

Note that the OneWeb satellite Ka-band antennas are narrow beamwidth steerable antennas that point towards the gateway earth stations, and there are only two such antennas on each OneWeb satellite.

For the definition of its satellite Ka-band PFD masks that are provided with this application OneWeb uses the option described above where the PFD masks are defined as a function of the α angle. The definition of the α angle is shown in Figure Annex.2-1 below.

Figure Annex.2-1: Definition of the α angle
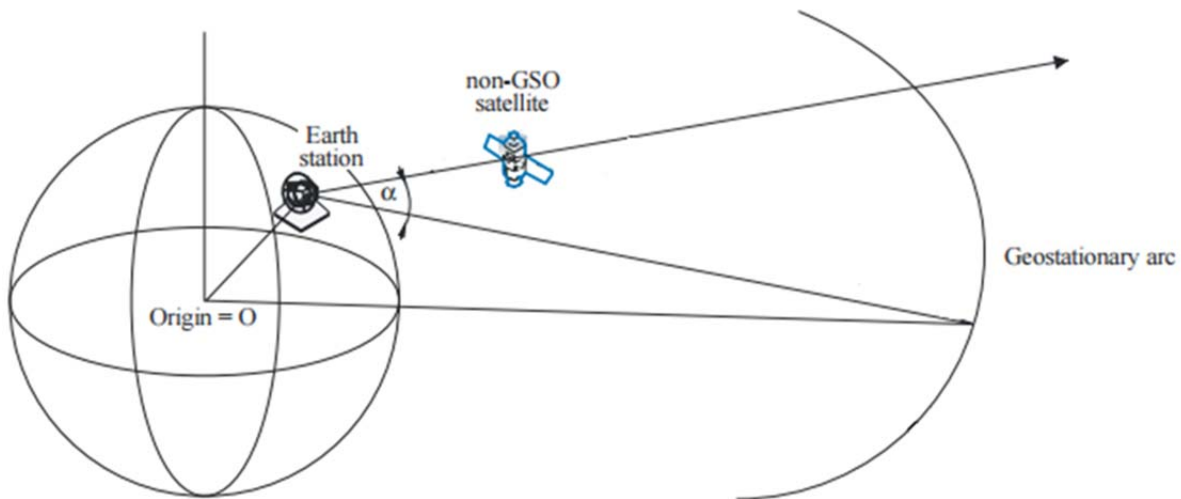
The PFD masks have been generated using the following methodology and assumptions related to the actual design and real-world operation of the OneWeb system:

(a) The starting point is the generation of a simple off-axis EIRP density mask (i.e., EIRP density per 40 kHz versus off-axis angle) based on the actual performance of the OneWeb Ka-band satellite transmit beam at the maximum operational transmit EIRP level. Because the off-axis gain performance is not rotationally symmetric about the boresight, the worst-case direction from boresight is assumed (i.e., highest off-axis gain) and used for the generation of this mask.

(b) In Ka-band the OneWeb system will maintain a GSO arc avoidance angle (α) of 6º. For the Ka-band downlink this means the angle, as viewed from any GSO earth station, between its boresight and the location of any OneWeb satellite that is transmitting towards that GSO earth station, will never be less than 6º. When the NGSO satellite is directly in-line between the GSO earth station and the GSO arc, or within 6º of this line, the NGSO satellite can only transmit sidelobe energy towards that location. The PFD mask therefore captures the maximum PFD on the surface of the Earth that could be generated by a OneWeb satellite, given this GSO arc avoidance constraint. The PFD mask also takes account of the fact that downlink power control is used on these links to maintain a constant PFD at the Earth's surface down to the minimum elevation angle of 15°, since the satellite beam can be pointed anywhere in this area. The resulting PFD mask is shown by the red curve in Figure Annex.2-2 below. The dotted curve over which the red curve is overlaid shows the shape of the antenna off-axis gain characteristic. The PFD level is constant beyond $\alpha = 6$º because the satellite EIRP density is adjusted to compensate for path length differences in order to ensure a constant PFD at the surface of the Earth beyond the GSO exclusion zone. This also explains why the OneWeb satellite PFD mask is independent of the ΔL variable provided in the ITU-R Recommendation S.1503-2.

Figure Annex.2-2: PFD mask for Ka-band downlink
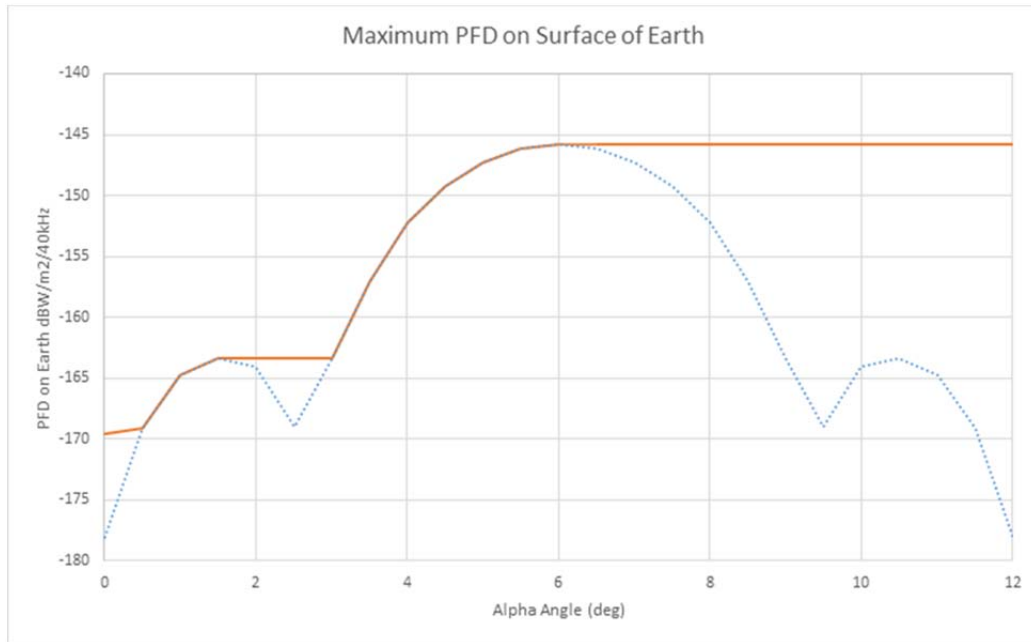
The ITU has not yet approved a computer program for determining compliance with the single-entry $EPFD_{down}$ (and $EPFD_{up}$ and $EPFD_{is}$) validation limits, although it is in the process of developing such a program in accordance with the specification stipulated in the most recent version of Recommendation ITU-R S.1503. It is understood that the ITU-BR is in the process of final testing of this program. OneWeb is making available to the FCC, as part of this application, an executable copy of the latest version of this computer program. This software is likely to be very close to the final version that the ITU will approve.[39] This is the most accurate and reliable way for the EPFD levels to be evaluated based on the PFD and EIRP masks being provided.

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[39]   Due to software licensing restrictions, OneWeb does not have access to, nor is able to provide the Commission with, the source code for this computer program. However, this computer program is close to being the final one that the ITU will approve. Indeed, the ITU recently held a NGSO workshop highlighting that this software is now fully developed and tested. See generally http://www.itu.int/en/ITU-R/space/workshops/2016-

OneWeb is prepared to provide all necessary assistance to the FCC in running this computer program.

OneWeb is also providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation program to validate the $EPFD_{down}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the OneWeb constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

(a) The orbital parameters of the OneWeb constellation, consistent with the associated Schedule S submission;

(b) The parameter entitled "nbr_op_sat" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.6.a). This is defined as "the maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location in various latitude ranges." For the OneWeb Ka-band gateway downlinks this should be set equal to the maximum number of satellites that may be served by a gateway station, which is typically 20 or less, but nevertheless set as 50 in the EPFD analysis to ensure worst case analysis;

(c) The parameter entitled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as "the minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite." The minimum elevation angle of 15º used for the gateway links is used for this parameter.


The Ka-band EPFD$_{down}$ results from the EPFD validation computer program using the input data explained above are shown below. Each plot shows one of the GSO reference earth station cases from the EPFD limits. The labeling of each diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the size of the GSO reference earth station antenna (in meters), and the fact that this is a FSS EPFD limit.[40] Also shown for each EPFD plot is the worst-case geometry defined by the latitude of the GSO reference receiving earth station location and the Δ_{long} (difference in longitude between the GSO reference receiving earth station location and its corresponding GSO satellite). This worst-case geometry has been determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. On each diagram the resulting EPFD level is shown by the blue curve and the EPFD mask that applies is shown by the red lines.

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[40] The frequency used for the analysis is determined by the EPFD validation software and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency is 17.8 GHz for the frequency range 17.8 – 18.6 GHz, over which the EPFD$_{down}$ limit applies.
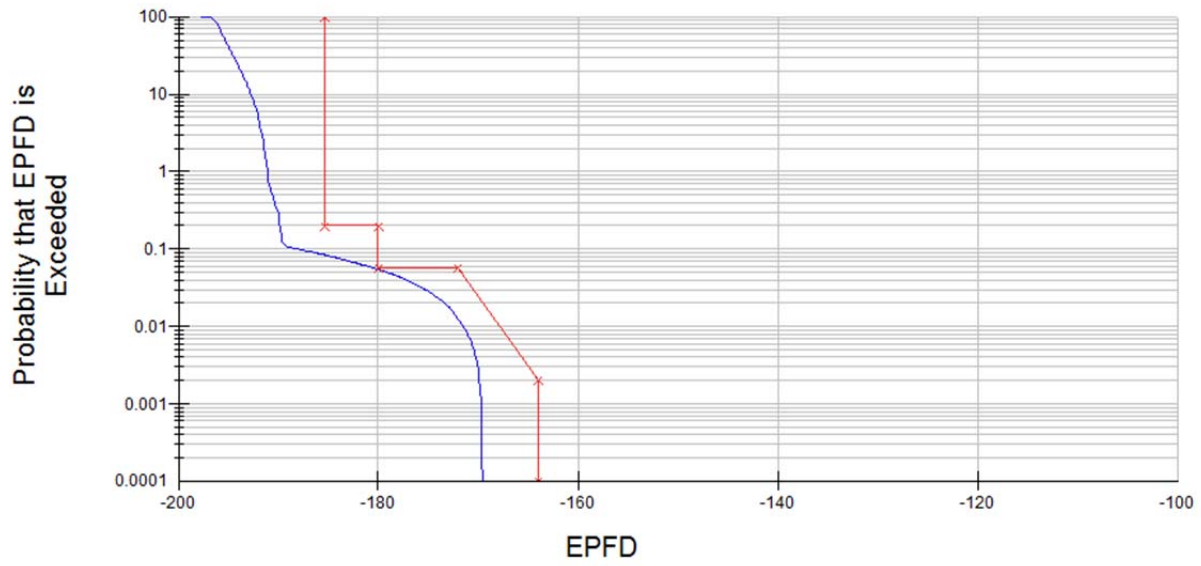
Worst-case geometry:
GSO ES latitude = 66.551°N, Δ_{long} = 2.107°

EPFD Down, 17.800, 40.000, 1.000, FSS
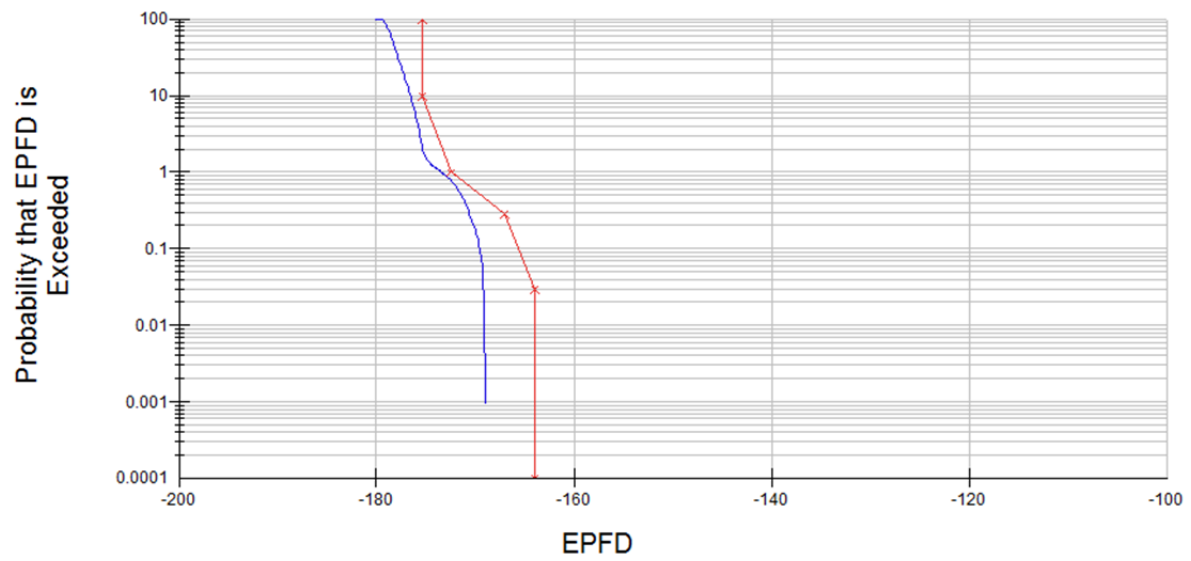
Worst-case geometry:
GSO ES latitude = 66.551°N, Δ_{long} = 2.107°

EPFD Down, 17.800, 40.000, 2.000, FSS
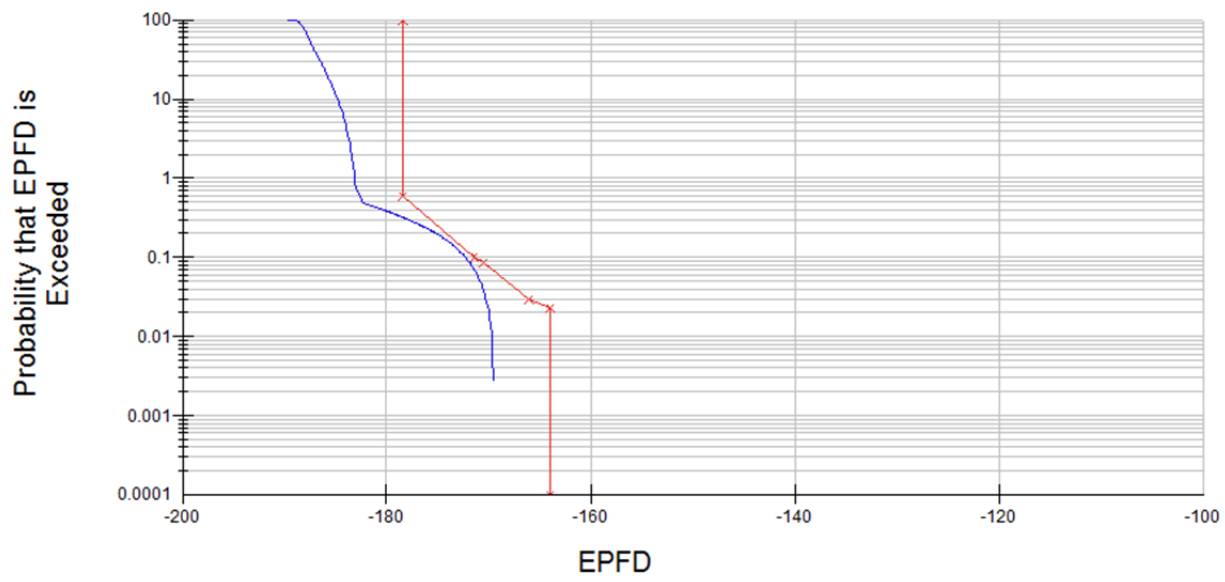
Worst-case geometry:
GSO ES latitude = 66.530°N, Δ_{long} = 3.790°

EPFD Down, 17.800, 40.000, 5.000, FSS

<u>EPFD_{up}:</u>

In order to demonstrate compliance with the single-entry validation equivalent power flux-density (EPFD$_{up}$) limits, in the Earth-to-space direction, OneWeb is providing the Commission, with this application, the computer files that contain the set of Ka-band earth station maximum off-axis EIRP masks, for the earth stations in the OneWeb system. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the EPFD$_{up}$ levels in Ka-band.

The EIRP masks define the off-axis EIRP density of the Ka-band transmitting earth stations as a function of off-axis angle. They assume the off-axis gain is rotationally symmetric around the boresight of the antenna. They may, according to ITU-R Recommendation S.1503-2, be constant or variable as a function of the sub-satellite latitude.

These masks have been generated using the following methodology and assumptions related to the actual design and real-world operation of the OneWeb system:

A single EIRP mask is provided that represents the highest on-axis and off-axis EIRP density levels (per 40 kHz) for the Ka-band transmitting gateway earth stations. The worst case would be for the gateway earth station with the smallest antenna diameter which is 2.4m;

OneWeb is also providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation program to validate the EPFD$_{up}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the OneWeb constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

(a) The orbital parameters of the OneWeb constellation, consistent with the associated Schedule S submission;

(b) The parameter entitled "nbr_sat_td" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.a). This is defined as "the maximum number of non-geostationary satellites receiving simultaneously with overlapping frequencies from the associated earth stations within a given cell." The value of this parameter is set to 50 to ensure a worst-case analysis.

(c) The parameter entitled "density" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.b). This is defined as "the average number of associated earth stations with overlapping frequencies per square kilometre within a cell." The value of this parameter is therefore the assumed maximum number of OneWeb gateway sites worldwide (using 100 gateway stations for a worst-case analysis) divided by the land area of the Earth (1.48326×10^8 km^2). This gives a value of 0.00000067.

(d) The parameter entitled "avg_dist" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.c). This is defined as "the average distance, in kilometres, between co-frequency cells." The value of this parameter is determined by the average geographic density of the OneWeb gateways (see above). Therefore, the value for avg_dist is 1217 km.

(e) The parameter entitled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as "the minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite. For the OneWeb Ka-band gateway earth stations this parameter is set to 15º.

(f) The parameter entitled "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.d.2). This is the minimum GSO avoidance angle measured at the surface of the Earth. For the OneWeb Ka-band gateway earth stations this parameter is set to 6º.

The Ka-band EPFD$_{up}$ results from the EPFD validation computer program using the input data explained above are shown below. The labeling of the diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the beamwidth of the reference GSO satellite receiving antenna beam (1.55 degrees) and the fact that this is a FSS EPFD limit.[41] Also stated is the worst-case geometry defined by the latitude of the pointing direction of the reference GSO satellite receiving beam and the Δ_{long} (difference in longitude between this pointing direction and the corresponding GSO satellite). This worst-case geometry has been determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. The resulting EPFD level is shown by the blue curve and the EPFD mask is shown by the red line.

Worst-case geometry:
GSO ES latitude = 50.934°N, Δ_{long} = 0°

EPFD Up, 27.500, 40.000, 1.550, FSS

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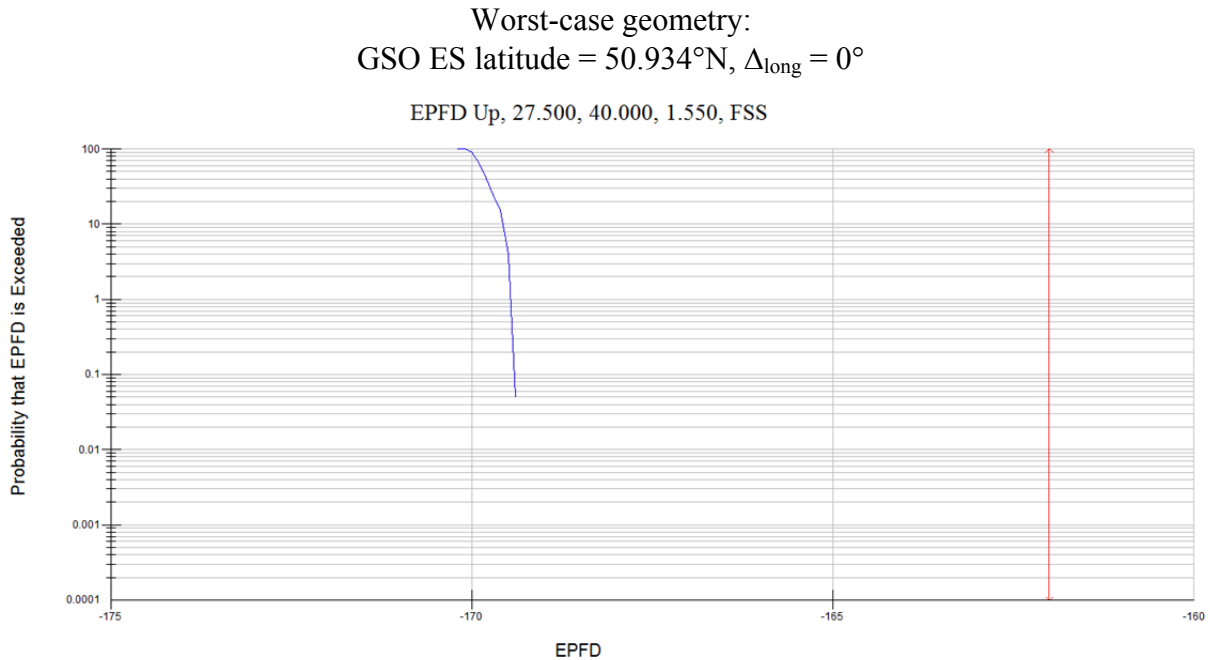
[41] The frequency used for the analysis is determined by the EPFD validation software and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency is 27.5 GHz for the FSS frequency ranges of 27.5-28.6 GHz and 29.5-30.0 GHz.

The results above demonstrate that the OneWeb system complies with the ITU's $EPFD_{down}$ and $EPFD_{up}$ limits and therefore will not cause unacceptable interference to GSO satellite networks.

$EPFD_{is}$:

Compliance with the $EPFD_{is}$ limits that exist in No. 22.5F of the ITU Radio Regulations for both Ku-band and Ka-band is provided in Annex 3 of this document.

Other general EPFD rules:

OneWeb confirms that it is not claiming interference protection from GSO FSS and BSS networks operating in accordance with the Commission's part 25 rules and the ITU Radio Regulations.

OneWeb confirms it will coordinate with the very large GSO FSS earth stations in the 17.8-18.6 GHz and 19.7-20.2 GHz bands according to 9.7A and 9.7B of Table 5-1 of Appendix 5 of the ITU Radio Regulations.

ANNEX 3

EPFD$_{is}$ Analysis for OneWeb

The EPFD$_{is}$ limits in the ITU Radio Regulations are intended to protect frequency ranges that are allocated bi-directionally (i.e., for both uplinks and downlink). They essentially protect receiving GSO satellites from interference from the unintended emissions of an NGSO transmitting satellite. In Ku-band, such bidirectional allocations exist in the 10.7-11.7 GHz and 12.5-12.75 GHz bands, depending on the ITU Region.[42] In Ka-band, the bidirectional allocations exist in the 17.8-18.4 GHz band in all ITU Regions.

In this annex, we demonstrate that the OneWeb system complies with the EPFD$_{is}$ limits in the ITU Radio Regulations which apply to some of the Ku and Ka-band frequencies used by OneWeb. These limits are contained in No. 22.5F, Table 22-3 of the Radio Regulations, which has been copied below. The EPFD$_{is}$ limits are similar to the EPFD↑ limits in that they consist of a single, never to be exceeded, EPFD level at the GSO, defined as follows:

22.5F   4)   The equivalent power flux-density[18], epfd$_{is}$, produced at any point in the geostationary-satellite orbit by emissions from all the space stations in a non-geostationary-satellite system in the fixed-satellite service in the frequency bands listed in Table **22-3**, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, shall not exceed the limits given in Table **22-3** 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 **22-3**, for all pointing directions towards the Earth's surface visible from any given location in the geostationary-satellite orbit.   (WRC-2000)

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[42]   Specifically, 10.7-11.7 GHz and 12.5-12.75 GHz in Region 1, and 12.7-12.75 GHz in Region 2.

TABLE **22-3** (WRC-2000)

Limits to the epfd$_{ik}$ radiated by non-geostationary-satellite systems in the fixed-satellite service in certain frequency bands[19]
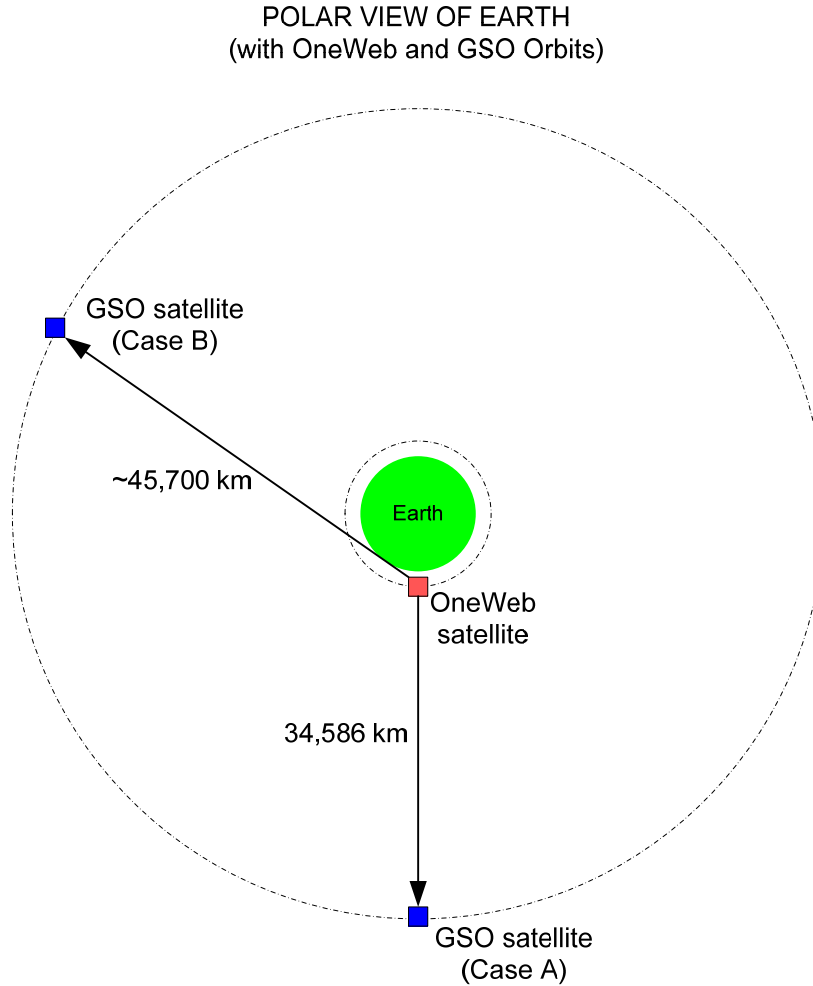
Frequency band (GHz)	epfd$_{is}$ (dB(W/m^2))	Percentage of time during which epfd$_{is}$ level may not be exceeded	Reference bandwidth (kHz)	Reference antenna beamwidth and reference radiation pattern[20]
10.7-11.7 (Region 1) 12.5-12.75 (Region 1) 12.7-12.75 (Region 2)	−160	100	40	4° Recommendation ITU-R S.672-4, $Ls = -20$
17.8-18.4	−160	100	40	4° Recommendation ITU-R S.672-4, $Ls = -20$

These limits apply to the OneWeb system in the 10.7-11.7 GHz, 12.5-12.7 GHz and 17.8-18.4 GHz bands used by OneWeb.

Because of the relatively low orbit altitude used by OneWeb, the visible path length from the OneWeb satellites to the GSO orbit varies only from 34,586 km immediately below the GSO (i.e., 35,786 km – 1,200 km) to approximately 45,700 km at the Earth's limb, when measured in the equatorial plane. This is shown in Figure Annex.3-1 below where Case A and Case B show the two extreme geometries. The difference in these two path lengths amounts to a difference of approximately 2.4 dB in spreading loss.

Figure Annex.3-1: Difference in path lengths from OneWeb orbit to GSO

POLAR VIEW OF EARTH
(with OneWeb and GSO Orbits)

GSO satellite
(Case B)

~45,700 km

Earth

OneWeb
satellite

34,586 km

GSO satellite
(Case A)

From this we can conclude that the highest levels of potential $EPFD_{is}$ would occur from the sidelobes of the OneWeb satellites across the Earth limb to the GSO satellite (Case B), because the path length difference is so small compared to the difference between sidelobes and backlobes.

The analysis methodology adopted below is to calculate initially the $EPFD_{is}$ levels at the GSO caused by a single OneWeb satellite at the minimum distance from the GSO and to establish the margin against the $EPFD_{is}$ limit for that case. Then we determine how many such satellites would aggregate into the GSO satellite reference beam to provide a true measure of compliance with the aggregate $EPFD_{is}$ limit.

For the Case A distance (see Figure Annex.3-1) of 34,586 km the free space spreading loss is 161.8 dB, while for Case B it is 164.2 dB.

Ku-band analysis

For Ku-band the maximum downlink EIRP density for the OneWeb satellites is -13.4 dBW/4kHz which is equal to -3.4 dBW/40kHz. The Ku-band beams are pointed relatively close to nadir and the reduction in antenna gain towards the Earth's horizon at the equator is at least 10 dB in the worst case and greater than 20 dB in more than 95% of directions, due to the extreme asymmetry of the Ku-band shaped beams. The resulting maximum EIRP density toward the GSO is therefore -13.4 dBW/40kHz in the worst case, and less than -23.4 dBW/40kHz in 95% of directions.

So, for Case A, where the backlobes of the NGSO satellites can enter into the GSO main beam pointing at nadir, which results in minimal spreading loss, the PFD is given by -23.4 – 161.8 dB, or -185.2 dBW/m^2/40kHz in the worst case. This is 25.2 dB below the limit, so even if almost one half of the satellites in the OneWeb constellation were located within the GSO receive mainbeam and all transmitting maximum power simultaneously on two beams (frequency reuse) there would still be margin compared to the EPFD$_{is}$ limit. Clearly, this is impossible as only a few satellites would be located within even the -10 dB footprint of the GSO satellite, as can be seen from the Figure Annex.3-2 below.

Figure Annex.3-2: GSO satellite reference beam for EPFD$_{is}$ calculation

(4º beamwidth at Equator)
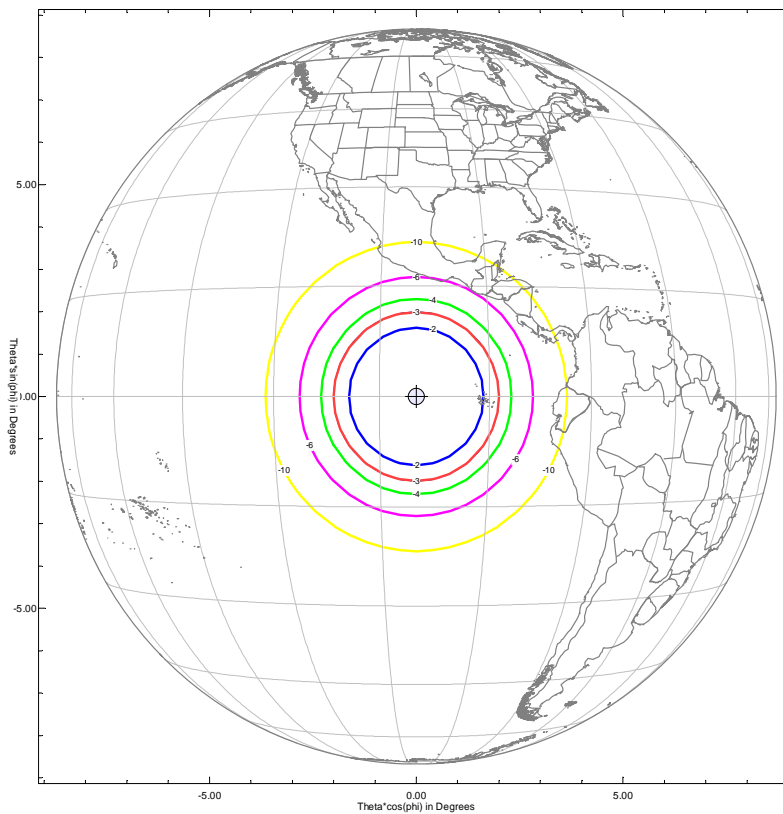
For the case B, where near sidelobes (-10 dB) of the OneWeb satellites can be pointed on the Earth's limb towards the GSO arc, the single entry PFD level at the GSO could be -13.4 − 164.2 = -177.6 dBW/m^2/40kHz in the worst case. For other beams or satellites, the resulting PFD is less than -187.6 dBW/m^2/40kHz in 95% of cases. These PFD levels are 17.6 dB and 27.6 dB, respectively, below the EPFD$_{is}$ limit.

To convert from the PFD level arising from a single OneWeb satellite to EPFD$_{is}$ we have to determine the maximum number of co-frequency interferers from the OneWeb constellation. The definition of EPFD$_{is}$ involves an assumed GSO satellite receive antenna with a beamwidth of 4° pointed towards any part of the Earth's surface visible from any given location in the GSO. The relative gain contours of this GSO reference antenna are shown in Figure Annex.3-3 below,

illustrating that such a small antenna beamwidth will only receive interference over a small proportion of the visible Earth's surface, or the region in space just beyond the Earth's horizon.

Figure Annex.3-3: GSO satellite reference beam for EPFD$_{is}$ calculation
(4º beamwidth near the Pole)
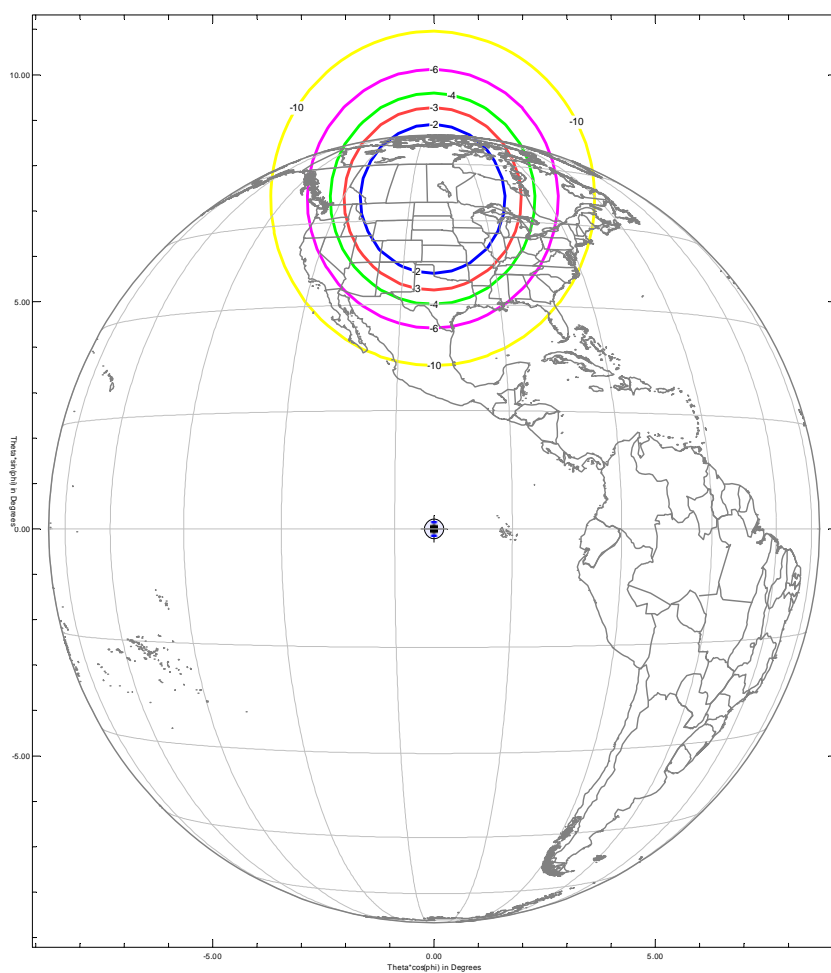
The margin of 17.6 dB / 27.6 dB calculated above would allow for up to 28 OneWeb satellites with one of their beams pointed close to the GSO arc or 280 OneWeb satellites, each with two times frequency reuse, with their far sidelobes contributing equally to the EPFD$_{is}$ level. In reality, it is impossible that more than a few satellites, almost certainly less than 5, that could have their near sidelobes pointed at a single point on the GSO arc while also being located within the main beam of the GSO satellite, even in the worst-case when it is pointed at the North Pole.

As there is a total of 720 OneWeb satellites in the constellation it would clearly be impossible to aggregate sidelobe interference from 280 satellites into the reference GSO receive beam shown in Figure Annex.3-3 above. Therefore, compliance with the Ku-band $EPFD_{is}$ limits in Article 22 of the ITU Radio Regulations is assured.

Ka-band analysis

For Ka-band the peak OneWeb satellite transmit EIRP density is +8.0 dBW/MHz (consistent with the Schedule S data), which is -6.0 dBW/40kHz.

As for the Ku-band analysis above, it can be concluded that the worst case situation in practice would be when the OneWeb satellite beam is pointed close to the Earth limb. Because the minimum operating elevation angle for the Ka-band gateway links is 15º, there is additional beam roll-off to be taken into account, which amounts to at least 3 dB, making the worst case EIRP density of the OneWeb satellite downlink no greater than (-6.0 – 3 =) -9.0 dBW/40kHz. For this Earth limb scenario, the distance from the OneWeb satellite to the GSO is 45,700 km (see the Case B distance in Figure Annex.3-1) resulting in a free space spreading loss of 164.2 dB. This results in a maximum PFD at the GSO from a single OneWeb satellite gateway downlink beam of (-9.0 – 164.2 =) -173.2 dBW/m^2/40kHz. This PFD level, resulting from a worst-case analysis of a single OneWeb satellite, is 13.2 dB below the $EPFD_{is}$ limit.

Figure Annex.3-4: GSO satellite reference beam for EPFD$_{is}$ calculation

(4° beamwidth near the Earth's limb)
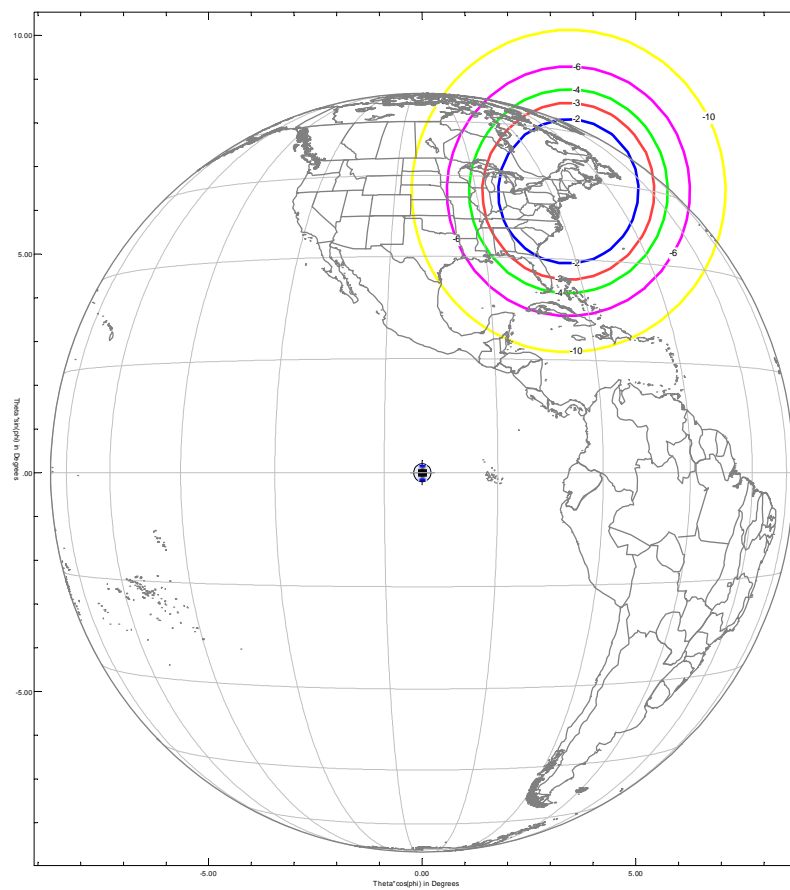
The 13.2 dB margin derived above would permit up to 20 such simultaneous worst-case interference contributions to occur to get to the aggregate EPFD$_{is}$ limit, which is clearly not possible given the GSO reference receive beam shown in Figure Annex.3-4 above. Therefore, compliance with the Ka-band EPFD$_{is}$ limits in Article 22 of the ITU Radio Regulations is assured.

CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application and that it is complete and accurate to the best of my knowledge and belief.

_____/s/_____

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