ONEWEB NON-GEOSTATIONARY SATELLITE SYSTEM (LEO)

PHASE 2: MODIFICATION TO AUTHORIZED SYSTEM

ATTACHMENT B

Technical Information to Supplement Schedule S

B.1 Scope and Purpose

This attachment contains the information required by §§25.114, 25.117(d), 25.146 and other sections of the FCC's Part 25 rules that cannot be captured by the Schedule S software. It is meant to detail the proposed Phase 2 deployment of the OneWeb System, which will build on the proposed 716-satellite configuration[1] to one that compromises up to 47,844 satellites. Phase 2 of the OneWeb System will allow OneWeb to greatly increase the capacity offered to its customers by launching additional satellites in the 1,200 km orbital shell.

Table B.1-1 below shows the proposed configuration of the Phase 2 OneWeb System which would consist of a number of planes of 87.9° inclined satellites combined with several planes of inclined satellites at 40° and 55° inclined satellites. The actual number of satellites will vary over time, and the numbers provided in the table are maximum values as requested in this application.

[1] *See* Attachment A to this application.

Table B.1-1: Orbital Characteristics of the OneWeb Phase 2 non-GSO satellite system

Max. Number of Planes	Max. Number of satellites per plane	Inclination	Maximum total for orbit shell
36	49	87.9°	1764
32	720	40°	23 040
32	720	55°	23 040

The Schedule S associated with this application also includes data related to the Phase 1 implementation of the OneWeb System, which is described in Attachment A. Certain data in the Schedule S is common to both Phase 1 and Phase 2, with the exception of the following:

- Orbit details in the Schedule S relate only to Phase 1 as it is not feasible to enter manually the large number of satellite phase angles required for Phase 2 into the online Schedule S software. The required orbit details for Phase 2 is being provided to the Commission in the form of a separate Excel spreadsheet that is attached to this application which is structured in the same way as the Schedule S format for orbit data;
- Certain satellite beams contained in the Schedule S are associated only with satellites in Phase 1 or Phase 2. This is clarified in Section A.3 of Attachment A and Section B.3 of Attachment B.

B.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 Phase 2 OneWeb System consists of a constellation of up to 47,844 low-Earth orbit ("LEO") satellites, plus in-orbit spares, in a combination of three circular orbits of altitude around 1,200 km, as well as associated ground control facilities, gateway earth stations and end user earth stations ("user terminals"). The Phase 2 OneWeb System will enhance the capability to provide high-quality, broadband Internet access to small low-cost user terminals located anywhere on Earth with greatly increased overall system capacity. The services that will be provided by the Phase 2 configuration will be comparable to the broadband terrestrial services available in densely populated areas in the United States today. In addition, because the OneWeb satellites are at a much lower altitude than GSO satellites, users of the OneWeb System will experience round trip latency of less than 50 milliseconds, which is approximately $1/13^{th}$ of the latency of GSO satellites, and comparable to terrestrial networks.

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 backbone. The OneWeb Ku-band user terminals consist of small and inexpensive antennas (typically in the 30 cm to 1-m range). The Phase 2 deployment will be comprised of low-cost phased array designs, or other beam steering technology which are 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 and mobile applications. Larger user terminals may also be employed in some situations such as for enterprise applications with different service requirements. The Ka-band gateway earth stations in the OneWeb System will typically utilize antennas in the 2.4 m to 3.5 m range,[2] depending on their location and the associated propagation characteristics and service requirements. Each satellite will be equipped with at least two gateway servicing antennas, which can simultaneously communicate with the servicing gateway site(s), and an additional antenna for handovers.

The frequency ranges used by the OneWeb system are summarized in Table B.2-1 below, as previously shown in relevant figures of the OneWeb Market Access Petition together with an indication of the FCC frequency allocations that exists in these bands.[3] The detailed channelized frequency plan is given in the associated Schedule S.

Table B.2-1: Frequency bands used by the OneWeb Phase 2 Deployment

Type of Link and Transmission Direction	Frequency Ranges
Gateway-to-Satellite	27.5 – 29.1 GHz 29.1 – 29.5 GHz (Note 1) 29.5 – 30.0 GHz
Satellite-to-Gateway	17.8 – 18.6 GHz 18.8 – 19.3 GHz 19.3 – 19.7 GHz (Note 1) 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 and the 29.1-29.5 GHz bands, and the space-to-Earth direction in the 19.3-19.7 and 19.7-20.2 GHz bands, FCC authorization is not being requested for these bands at this time.

[2] The Phase 1 OneWeb System operates with Gateway antennas that are 3.5 m in size, but the Phase 2 system with its reconfigurable beam technology could accommodate smaller gateway antennas.

[3] *See* IBFS File No. SAT-LOI-20160428-00041 (Call Sign S2963).

The constellation of OneWeb satellites will be deployed as follows. Shortly after, or even during the completion of the OneWeb Phase 1 deployment, OneWeb will start to launch a small number of Phase 2 satellites for evaluation and proof-of-concept. OneWeb plans to launch subsequent satellites for each orbital plane in one orbit inclination,[4] and subsequently additional launches in the same plane and/or adjacent planes until the desired coverage is attained. There is currently no predetermined schedule for the actual number of planes in one orbital shell, nor for the number of satellites per plane that would be deployed before proceeding with the next orbital shell. The reason is that service can be improved or migrated from Phase 1 constellation to the Phase 2 deployment over time, as the Phase 2 satellites become available. Depending on commercial requirements at the time, OneWeb could select any of the three proposed orbital inclinations and any of the plane RAAN and satellite spacing that would best accommodate its requirements. OneWeb will notify the Commission, consistent with §25.118(f), of the spare and active satellite configuration as deployment progresses.

The OneWeb System provides broadband communications services between the user terminals and the gateway earth stations connected to the global Internet backbone. Similar, to the Phase 1 configuration, several 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 the full deployment would require additional antennas at each gateway earth station site to be deployed over time worldwide – the exact number will depend on service characteristics and market conditions in various areas of the world. At least five gateway earth station sites are expected to be deployed in the USA, including gateway earth stations in Hawaii and Alaska, and

[4] Depending on the health of the Phase 1 satellites, OneWeb may choose to start Phase 2 by populating the 87.9° orbital shell, or any of the other two shells (40° or 55°), however, this will ultimately depend on market requirements.

other gateway locations that have been subject of license applications in the past few years.[5] The exact locations of any additional gateway earth stations have yet to be determined, but will build on the initial network of existing earth stations. 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 United States.

OneWeb will continue to operate at least two separate satellite control centers each backing up the other. The centers, along with network operation centers, are located in Tysons, Virginia and the United Kingdom. Connectivity between these control centers and the TT&C and gateway earth stations has been implemented using terrestrial leased circuits and secure Internet virtual private networks.

Each OneWeb satellite will have 32 nominally identical *user beams*, operating in Ku-band, each consisting of a steerable spot beam. There are at least 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. There is at least one beam providing connectivity with a gateway earth station and one additional gateway beam 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.

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[5] *See, e.g.,* IBFS File Nos. SES-LIC-20180604-01082 (Talkeetna, AK gateway earth station granted Nov. 8, 2019); SES-LIC-20180727-02075 (Clewiston, FL gateway earth station granted Nov. 8 2019); SES-LIC-20180727-02076 (application for Southbury, CT gateway earth station); SEC-LIC-20190422-00538 (application for Santa Paula, CA gateway earth station).

The total aggregate footprint of the Ku-band beams of the OneWeb System covers all of the Earth's surface, with the ability to relocate the beams to areas with the highest demand. The movement of the satellites in their orbits means that a user will be progressively handed over from a OneWeb satellite to the beams of the next satellite in either the same orbital plane or to a satellite in the adjacent orbital planes. This regular handover will occur seamlessly so the user experiences continuous service, much like cell phone traffic gets handed off from one cell tower to another.

Handover of the OneWeb satellite gateway links between different sets of gateway earth stations will also occur as the satellites move in their orbits. The multiple gateway antennas on each satellite are used to enable this 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 United States. 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 in the United States. In addition, the 12.75 – 13.25 GHz and 29.1 – 29.5 GHz uplink bands and the 19.3 – 20.2 GHz downlink band may also be used for service in territories outside of the United States. 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).[6]

Each Phase 2 satellite will be capable of beam forming up to 32 user beams, each capable of transmitting or receiving on one or multiple RF channels, and on one or both polarizations. The satellites have on-board processing and, at some point in the deployment of the system, may make use of optical inter-satellite links such that user traffic packets can be routed through various satellites, for most effective and quick routing. User signals are demodulated by the on-board

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[6] *See* Section B.5 for more information regarding TT&C and payload control.

processor and routed either to one of the gateway beams if the traffic terminates within the satellite footprint, or can be routed via optical intersatellite links to other satellites for a more direct path to the intended recipient. Such user packets can also be routed to a user beam for direct links between OneWeb customers where permitted by law. Return traffic either from another user in direct connection scenario, or from the Gateway site for Internet access, follows a similar path.

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

(1) In Ku-band, at least four-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 combined with the use of orthogonal polarizations;

(2) In Ka-band, two-times frequency re-use is achieved on each satellite using orthogonal circular polarizations for the transmissions to the active gateway earth station; and this can also be further increased by adding more gateway antennas, and hence spatial frequency re-use, to increase satellite capacity.

Each gateway uplink and user downlink channel supports a single wideband carrier. Narrower channels on the user uplink and gateway downlinks allow for 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 relatively narrow-band carrier (typically 1.25 MHz to 50 MHz wide) to minimize the peak RF transmit power requirements of the user terminal, but which can extend to 125 MHz for terminals that are more capable or those transmitting to very high G/T satellite receive beams. 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.

There are three broad categories of earth stations in the OneWeb system –TT&C stations, gateway stations and 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 3.5 meters or larger in reflector diameter. The gateway sites will also employ multiple active tracking antennas, each typically of 2.4 to 3.5 meters in reflector diameter. Some TT&C stations may also act as gateway stations. The user terminals, which will be deployed in large numbers, will include fixed and transportable ground-based terminals as well as mobile terminals on board aircraft, maritime vessels and land vehicles.[7] The user terminals will employ 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, as the electronically steerable beam will instantaneously switch between active satellites using a single fixed antenna aperture.

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[7] *See* n.5 above. OneWeb has already been authorized for two gateway earth stations and has applied for blanket authority to deploy 1.9 million user terminals, and will separately seek authorization for additional earth stations, including gateway and user terminals, operating in the United States, as required. *See* IBFS File Nos. SES-LIC-2019030-01237 (filed Sept. 30, 2019) and SES-LIC-20190930-01217 (filed Sept. 30, 2019).

The Phase 2 satellite constellation will operate under a U.K. registration at the ITU (network name "THEO"), as well as modifications to these existing networks and additional networks. Further details of this are provided in Section B.11 below.

B.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 32 independently steerable and re-configurable Ku-band receive and transmit spot beams that can be moved anywhere in the visible portion of the Earth's surface where the elevation angle, at beam center, exceeds 25 degrees. The transmit power into each of these beams is independently adjusted using automatic downlink power control to nominally maintain the PFD constant as the beam is moved from nadir direction towards edge-of-coverage, and then a slight reduction in PFD near the 25° elevation contour, as necessary, depending on the size of the transmitting beam and its sidelobe roll-off. This feature is used to control the power levels generated in certain directions by the OneWeb System so as to be compliant with the PFD and EPFD limits in the FCC rules and ITU Radio Regulations, as explained in Sections B.7 and B.8 below. These beams can also be adjusted in terms of their size, and hence gain, over a wide range of values. To account for this adjustability in gain, the Schedule S includes both maximum and minimum gain values for these Ku-band beams.

For the links between the OneWeb satellites and the gateway stations, each satellite has at least two identical circular Ka-band spot beams which are independently steerable over the full field of view of the Earth. Downlink power control is used to maintain the PFD at a nominal value over the range of angles of arrival between 15° and 90°. Exceptionally, the beams could steer down to 5° elevation angles, for instance when satellites fly over oceans and need to reach far-away land areas, but in this case the downlink power density will not increase beyond the value used at 15° elevation point resulting in a further reduction in PFD at the Earth's surface for elevation angles below 15°.

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).

As mentioned above, the associated Schedule S contains the beams used for both Phase 1 and Phase 2 implementations of the OneWeb System. Only the following beams from the Schedule S are used in the Phase 2 implementation:

- Satellite receive beams:
  - Ku-band:
    UUBR, UUCR, UUBL, UUCL
  - Ka-band:
    GUAR, GUBR, GUAL, GUBL
- Satellite transmit beams:
  - Ku-band:
    UDDR, UDER, UDDL, UDEL
  - Ka-band:
    GDAR, GDBR, GDAL, GDBL

B.4 GEOGRAPHIC COVERAGE (§25.146(b))

Because of the use of combined 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. 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 always experience elevation angles significantly higher than 55 º.

The Commission's current geographic coverage requirements are set forth in §25.146(b) and require 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.[8]

The OneWeb system with up to 47,844 operational satellites meets this requirement as explained below.

Ku-Band Geographic Coverage

For the Ku-band service links, the combination of the geographic coverage achievable from each satellite, based on 32 individually steerable and re-sizeable user beams, plus the number and proximity of the satellites in their orbits, ensures that blanket global Ku-band coverage is provided by the OneWeb System.

In order to comply with the EPFD limits and thereby protect GSO satellite networks from interference, the pointing directions of the Ku-band beams avoid the direction vectors between the GSO arc and all points on the Earth's surface where there could be an in-line event with the OneWeb satellites. This technique also protects the OneWeb system from interference caused by GSO networks.[9]

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[8] OneWeb notes the Commission has proposed to remove these domestic coverage requirements. *See Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, Report and Order and Further Notice of Proposed Rulemaking, 32 FCC Rcd. 7809, 7833 ¶ 76 (2017).

[9] By these means, even when there are as few as 716 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.

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 for Phase 1) to ensure that the OneWeb satellites have a visible gateway earth station with which they can communicate from all parts of their orbits. The on-board processor, potentially augmented by optical intersatellite links on the Phase 2 satellites, will allow traffic to be routed from any user to any other user, or to the terrestrial infrastructure. Additional gateway antennas per site, and additional sites, will be deployed to support the greatly expanded capacity offered by the Phase 2 deployment. Therefore, the OneWeb Ka-band gateway links will be sufficient to serve OneWeb satellites at all latitudes, which meets the requirements of §25.146(b).

B.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 United States, but no TT&C earth stations are foreseen in the United States at present. This application therefore requests authorization from the Commission for the payload control transmissions to and from the 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 United States 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.

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 (around 27.5 GHz and just above 19.7 GHz) 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 taken account in the associated Schedule S.

A summary of the TT&C and payload control subsystem characteristics is given in Table B.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 B.5-1: TT&C and Payload Control Characteristics

<table>
<tr><td>Uplink Control Signal Modulation</td><td>BPSK</td></tr>
<tr><td>Uplink Control Frequencies</td><td>27500 - 27600 MHz</td></tr>
<tr><td>Downlink Control Signal Modulation</td><td>QPSK</td></tr>
<tr><td rowspan="2">Downlink Control Frequencies</td><td>TT&C: 19700 - 19770 MHz to high-latitude
TT&C stations
(outside of USA)</td></tr>
<tr><td>Payload Control: 19265 – 19300 MHz
for gateway earth stations
(including ones in the USA)</td></tr>
<tr><td>Polarization of Satellite Rx/Tx Antennas</td><td>Rx: LHCP & RHCP

Tx: LHCP & RHCP</td></tr>
</table>

B.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.

B.7 COMPLIANCE WITH PFD LIMITS (§25.146(a)(1)

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.

Downlink PFD Limits in Ku-band

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)(1) 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.

In addition, there are ITU PFD limits applicable to NGSO systems which also apply to the OneWeb System consistent with §25.146(a)(1). These ITU PFD limits are the same as those in §25.208(b)(1) across the 10.7-11.7 GHz band, but are 2 dB higher across the 11.7-12.7 GHz band.[10]

The FCC also 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.

Downlink power control is used on the OneWeb satellite downlink transmissions to maintain constant PFD throughout the range of pointing angles, while ensuring compliance with all of the above-mentioned PFD limits. For non-nadir directions the path length to the Earth increases thereby permitting a higher EIRP density to be used while still complying with the PFD limits.

The maximum EIRP density for a nadir pointed beam, regardless of beam size, is -7.9 dBW/4kHz, which results in a PFD at the Earth's surface of -140.5 dBW/m^2/4kHz (i.e., where the spreading loss

[10] 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.

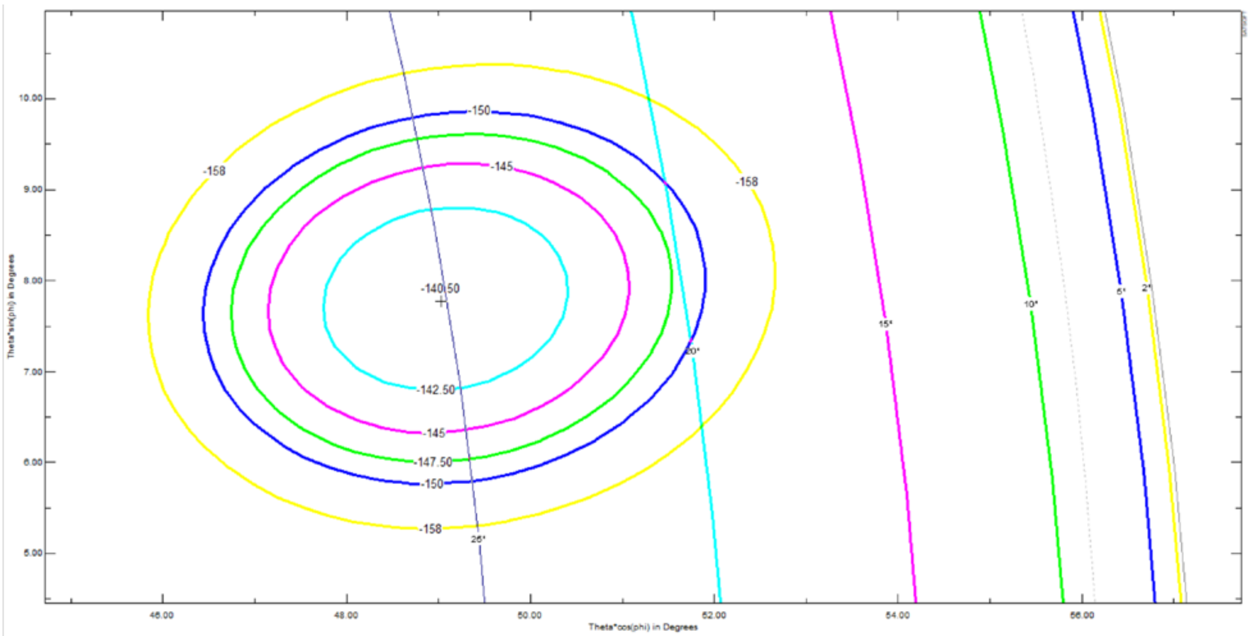
for the 1,200 km path length is 132.6 dB). This PFD value is 0.5 dB below the PFD limit applicable to the 10.7-11.7 GHz band and 2.5 dB below the PFD limit for the 11.7-12.7 GHz band.

Demonstration of the amount that the EIRP density can be increased above the nadir value (-7.9 dBW/4kHz), while still complying with all PFD limits, is provided below for both the smallest and largest Ku-band downlink beams. In all cases the tighter PFD limit from the 10.7-11.7 GHz band is referred to, rather than the one for the 11.7-12.7 GHz band.

Initially, for the smallest Ku-band beam (37.0 dBi peak gain), the PFD contours are plotted in Figure B.7-1 below when the beam is pointed directly at the 25° elevation contour, and operating with the power spectral density into the antenna increased to its maximum value corresponding to a peak EIRP density of -2.7 dBW/4kHz, the value given in the associated Schedule S. The color-coded PFD contour levels shown are those that correspond to the PFD limits at the elevation contour designated by the same color, namely:

- -158 dBW/m^2/4kHz (yellow) applicable at 2° elevation
- -150 dBW/m^2/4kHz (blue) applicable at 5° elevation
- -147.5 dBW/m^2/4kHz (green) applicable at 10° elevation
- -145 dBW/m^2/4kHz (magenta) applicable at 15° elevation
- -142.5 dBW/m^2/4kHz (cyan) applicable at 20° elevation
- -140 dBW/m^2/4kHz (value at center of beam) applicable at >25° elevation

Figure B.7-1: PFD contours for the smallest OneWeb satellite transmit beam operating at maximum EIRP density of -2.7 dBW/4kHz when directed towards the 25° elevation contour



From Figure B.7-1 above it is clear that compliance with all PFD limits is achieved for this beam using a maximum downlink EIRP of -2.7 dBW/4kHz when the beam is pointed towards the minimum elevation angle contour of 25°. The most critical PFD limit in this case is the value of -140 dBW/m^2/4kHz which applies for elevation angles of 25° and greater, at which there is a margin of 0.5 dB.

PFD compliance for the largest Ku-band downlink beam (24.5 dBi peak gain) is demonstrated in Figure B.7-2 below when that beam is operating at the maximum EIRP density of -4.6 dBW/4kHz, the value given in the associated Schedule S. In this case, however, this maximum EIRP density is only possible when the beam is directed towards an elevation contour of 38° or slightly lower. In Figure B.7-2 the maximum PFD level is -140.5 dBW/m^2/4kHz, which is compliant with the PFD limit for elevation angles greater than 25° with a 0.5 dB margin. The next most critical PFD limit is the -158 dBW/m^2/4kHz one that applies at 2° (shown in yellow), which limits how much lower in elevation this beam can be pointed with this same maximum EIRP density.

Figure B.7-2: PFD contours for the largest OneWeb satellite transmit beam operating at maximum EIRP density of -4.6 dBW/4kHz when directed towards the 38° elevation contour

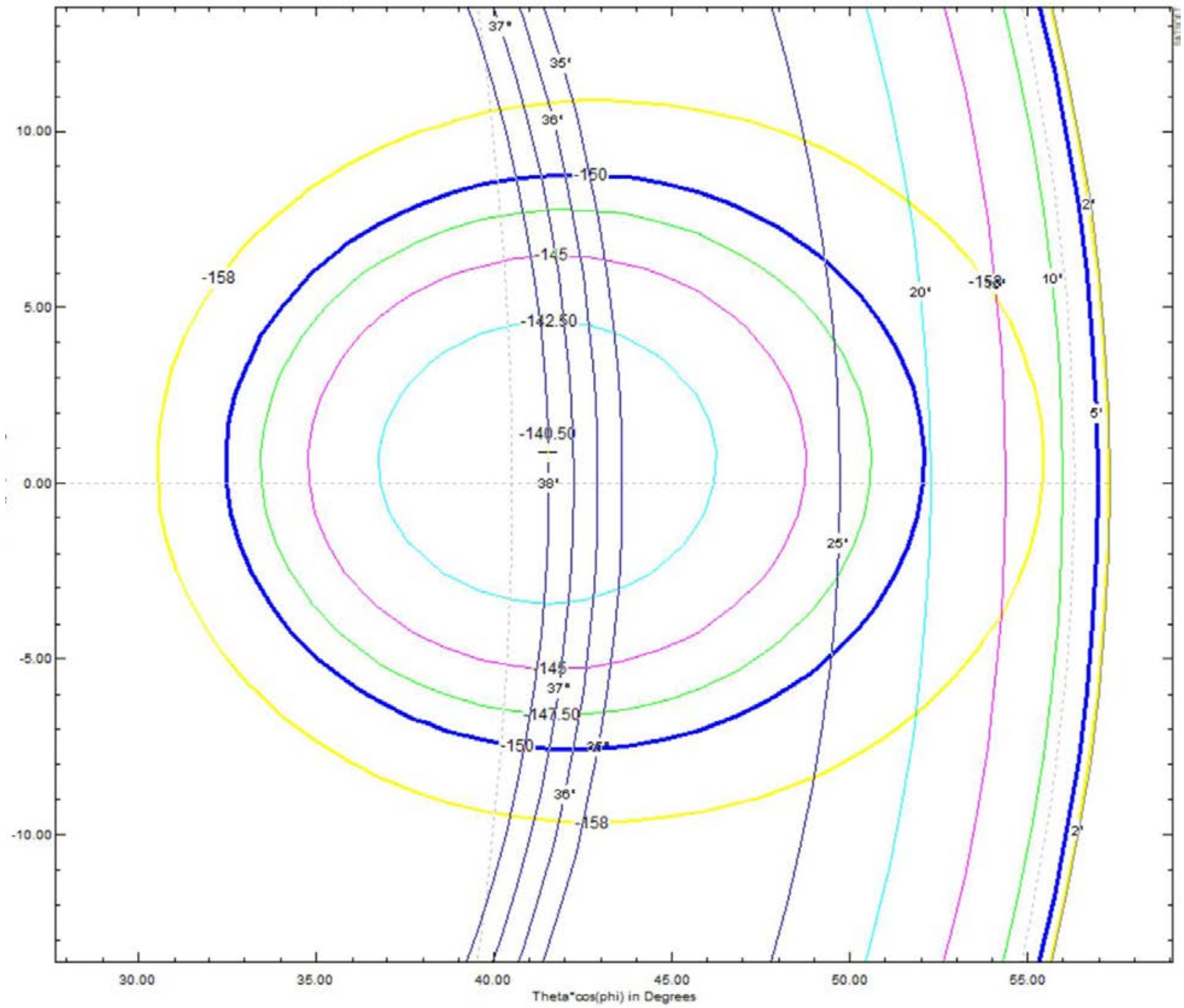


Table B.7-3 below summarizes the maximum EIRP density permissible for the two Ku-band beam sizes as a function of the pointing direction, which is given in terms of the elevation angle from the Earth.

Table B.7-3: PFD calculations for two beam sizes and various pointing directions

Beam Type	Pointing direction of the beam in terms of elevation angle (°)	Maximum EIRP Spectral Density (dBW/4kHz)	ΔEIRPsd rel. to Value at Nadir (dB)	Peak PFD (dBW/m2/4kHz)
Large Beam (24.5 dBi)	90	-7.9	0.0	-140.5
	60	-6.9	1.0	-140.5
	50	-5.9	2.0	-140.5
	45	-5.5	2.4	-140.5
	40	-4.9	3.0	-140.5
	38	**-4.6**	3.3	-140.5
	35	-5.9	2.0	-142.3
	30	-11.5	-3.6	-148.7
	25	-14.5	-6.6	-152.0
Small Beam (37 dBi)	90	-7.9	0.0	-140.5
	60	-6.9	1.0	-140.5
	50	-5.9	2.0	-140.5
	45	-5.5	2.4	-140.5
	40	-4.9	3.0	-140.5
	35	-4.2	3.7	-140.5
	30	-3.5	4.4	-140.5
	25	**-2.7**	5.2	-140.5

Therefore, all the Ku-band downlink transmissions from the OneWeb satellites comply with all the FCC and ITU PFD limits.

Downlink PFD Limits in Ka-band

The FCC's Ka-band downlink PFD limits in §25.146(a)(1) which refers to provision in §25.108 apply the ITU PFD limits of Article 21 to NGSO systems in different parts of the Ka-band downlink frequency bands used by OneWeb. A single set of 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.[11] The PFD limits in Article 21 of the ITU Radio Regulations are expressed as a function of the number of satellites in the NGSO system. The NGSO PFD limits of Article 21 of the Radio Regulations 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)(δ-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 $n > 288$

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

Compliance for angles of arrival above 25 degrees above the horizontal plane

The maximum Ka-band downlink EIRP density for the OneWeb satellites is +8.0 dBW/MHz. 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 on the 15° elevation angle contour and taking account of the actual spreading loss from the satellite to the surface of the Earth. Since the OneWeb System uses downlink power control, the PFD is constant within the angular range from 15º to 90º in elevation on the Earth's surface. The calculated PFD levels are then -131.8 dBW/m^2 per 1 MHz for that entire range.

Therefore, compliance with the PFD limit in §25.146(a)(1) for angles above 25º is achieved with a minimum margin of almost 27 dB.

Compliance of angles of arrival below 25 degrees above the horizontal plane

These PFD limits in §25.146(a)(1) apply to each satellite in the OneWeb system. The value of "n" for the Phase 2 deployment is 47,844 and therefore X would be calculated to be equal to 699 dB according to the above formulae. This clearly demonstrates that this formula is not feasible for large NGSO constellations. This methodology was recognized by the Commission as being impractical,[12] and by ITU WRC-19 which decided that:[13]

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[12] *See*, *Space Exploration Holdings, LLC*, *Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, Memorandum Opinion, Order, and Authorization, 33 FCC Rcd. 3391, 3404 ¶ 34-35 (2018) ("We agree with several of the points raised by SpaceX, in particular that the ITU limits were derived for constellations up to 840 satellites and under worst case assumptions.").

[13] *See* ITU Circular Letter CIR-015 (at https://www.itu.int/md/R00-CR-CIR-0456/en)

"In considering section 3.1.7.2 on 'Scaling factor in the definition of RR Article 21 pfd limits applicable to non-GSO satellite systems in the fixed-satellite service in the frequency band 17.7-19.3 GHz', WRC-19 invites ITU-R to study the appropriateness of the equations contained in RR No. 21.16.6 for large non-GSO satellite systems (e.g. such as those having more than 1 000 satellites). The results of the studies can be considered by WRC-23 under standing agenda item 7 if an Issue under this agenda item has been included in the CPM-23 report. WRC-19 also instructs the Radiocommunication Bureau to issue qualified favorable findings under RR Nos. 9.35/11.31 when examining compliance of frequency assignments to non-GSO FSS satellite systems with RR Article 21 pfd limits applicable in the frequency band 17.7-19.3 GHz if the notifying administration requests it to do so. Such practice shall apply to non-GSO FSS satellite systems for which coordination requests have been received from 23 November 2019 until the last day of WRC-23."

In order to assess the potential for interference of its Phase 2 constellation into the Fixed Service OneWeb performed the following analysis:

For the long-term, the interference-to-noise ratio is determined by the PFD for angles of arrival between 15º and 90º as received through the victim Fixed Service station antenna sidelobes. Assuming a conservative 5 co-frequency (Nco) satellites having maximum PFD towards a given location, the I/N can be calculated as:

$$I/N = PFD + 10 \log Nco - 10 \log (4 \pi (f /.3)^2) + Grx - (kT_0B + NF)$$

Grx is the gain (dBi) of the Fixed Station antenna
f is the frequency (in GHz)
kT_0B is the noise level of an ideal receiver
NF is the receiver noise factor

The long-term I/N[14] would therefore be -25.8 dB which corresponds to an imperceptible increase in the terrestrial system noise level, and which is almost 16 dB below the -10 dB long-term criterion of Recommendation ITU-R F.1495.

For the short-term, the interference-to-noise ratio is determined by the PFD for low angles of arrival as received through the main lobe of the Fixed Service station. The PFD produced by a OneWeb satellite would never exceed a level that is 3.4 dB lower at the horizon (0º in elevation) than for high elevation angles, and only for those rare instances when the satellite beam is pointed directly at the 5º elevation contour, i.e. -135.2 dBW/m^2 per 1 MHz. The I/N can be calculated as:

$$I/N = PFD - 10 \log (4 \pi (f /.3)^2) + Grx - (kT_0B + NF)$$

The I/N would therefore be no greater than 4.7 dB, and this is 9.3 dB and 13.3 dB below the two short-term criteria in this Recommendation.[15]

The above assessments clearly show the overly restrictive requirements of the ITU low arrival angle PFD limits for large NGSO FSS constellations and the challenges for operators of such systems to demonstrate compliance with the ITU PFD limits. OneWeb expects that when the methodology used to assess PFD compliance more accurately reflect large constellation operations, it will become clear that the OneWeb System will not be a source of interference to terrestrial deployments in the Ka-band. Thus, OneWeb respectfully submits that its systems will adequately protect terrestrial operations in the relevant portions of the Ka-band. However, to the extent necessary and pursuant

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[14] Based on an FS receiver with 5dB Noise Figure and 5 co-frequency satellites that are at least 10 degrees off-axis to the FS station main pointing direction resulting in Grx of 4 dBi.

[15] Assuming an FS receiver with 48 dBi peak gain, pointed at 0º elevation with 5 dB noise figure, and a single NGSO satellite at its boresight and transmitting a PFD of -135.2 dBW/m^2 per 1 MHz.

to Section 1.3 of the Commission's rules, OneWeb requests a waiver of Section 25.146(a)(1) requiring certification of compliance with ITU PFD limits in the 17.7-19.3 GHz band for geometries below 25 degrees above the horizontal plane.

B.8 INTERFERENCE ANALYSES

Referring to Table B.2-1 presented earlier giving the frequency ranges proposed to be used in Ku-band and Ka-band, respectively, and further considering the designations that exist in these bands in the FCC table of frequency allocations allows to better understand the more detailed explanations of each sharing / interference scenario described in the sub-sections below.

B.8.1 Interference Protection for GSO Satellite Networks (§25.146)

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 and §25.146(a)(2) of the Commission's rules.[16] The OneWeb System fully complies with these limits as will be evaluated by the ITU.

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 covered by this application and in which EPFD limits apply (either in the ITU Radio Regulations or the Commission's Part 25 rules) are:

[16] The Commission requirements in §25.146 incorporate by reference the ITU Article 22 limits under §25.108.

- Ku-band:
  - Uplink: 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

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.

B.8.1.1 EPFD Compliance in Ku-Band

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.

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 System 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. Therefore, each OneWeb satellite's Ku-band beam coverage (Rx and Tx) typically only needs to be over a narrow range of angles relative to the nadir pointing direction when the full constellation is deployed. This means that there is an inherent interference isolation due to the angular separation from GSO networks for all OneWeb satellites at higher latitudes, when the OneWeb satellite is passing through the boresight of the GSO receiving earth station. When there is a need to steer a Ku-band user beam to lower elevation angles, the OneWeb System will ensure to maintain sufficient GSO arc avoidance. 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.

As the OneWeb satellites approach lower latitudes there is a higher probability 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 ensuring that the User Beams are pointed away from the "GSO exclusion zone," the area that a OneWeb satellite is not allowed to serve so as to reduce the antenna gain towards latitudes where GSO earth stations would be in a near-alignment situation with the OneWeb satellite. In addition, the RF link power density in each of the OneWeb satellite beams can be reduced to further protect GSO satellite networks.

B.8.1.2 EPFD Compliance 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 (about 2° receive and 3° transmit half-power beam width) 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 beam width 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.

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 minimized.

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.

B.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 completed coordination with many GSO satellite networks in these frequency ranges for its current authorization 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.

B.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.

Pursuant to Section 25.261 of the FCC's rules, sharing between NGSO satellite systems should be achievable, using good faith efforts during inter-operation coordination to avoid in-line interference events, or by resorting to band segmentation in the absence of any such coordination agreement.

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 with regards to its currently authorized system.

B.8.3 Interference with Respect to Terrestrial Networks in 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 originally 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. Recently the Commission allowed blanket licensing of user terminals.[17]

OneWeb proposes to operate its user terminal earth stations on a non-interference, non-protected basis. 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 B.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.

(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.

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

There are currently some 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 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 B.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 legacy FS links.

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[17] *See* §25.115(f)(2) of the FCC rules, allowing blanket licensing of earth stations on an unprotected basis.

The Commission has authorized the Multichannel Video Distribution and Data Service ("MVDDS") in the 12.2-12.7 GHz band and established technical and service rules for MVDDS which specifically states that the MVDDS providers will share the 12 GHz band with NGSO FSS operators on a co-primary basis.[18]

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

<u>MVDDS Operating Requirements</u>:

(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.

<u>NGSO FSS Operating Requirements</u>:

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

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[18] *See Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, Memorandum Opinion and Order and Second Report and Order, 17 FCC Rcd. 9614 (2002) ("Second Report and Order").

(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 acknowledges this sharing arrangement and will comply with the Commission's required sharing arrangements.

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 B.7 above.

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

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 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.

As explained in Section B.7 above, the ITU PFD limits extend across the entire 17.8-18.8 GHz band with the objective of protecting terrestrial FS receivers worldwide, and therefore OneWeb's compliance with these limits would protect FS receivers from OneWeb satellite downlink interference across the entire 17.8-18.3 GHz band. The OneWeb satellites meet the downlink PFD limits for high angles of arrival, but the limits are unreasonable for low angles. Nevertheless, Nevertheless, as demonstrated above in Section B.7, the FS stations will not receive harmful interference from the OneWeb System.

B.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 for its gateway earth stations in the United States.

OneWeb acknowledges that FSS is secondary to the Upper Microwave Flexible Use Service ("UMFUS") in this band. OneWeb's operations in this band will adequately protect UMFUS operations and otherwise will be consistent with Section 25.136(a) of the Commission's rules, as described in its license applications for gateway earth stations in the United States.[19]

OneWeb's past and current 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 have included a full showing to demonstrate UMFUS protection. In the unlikely event that a future UMFUS link could be interfered with, OneWeb will work cooperatively with the licensee to ensure that the link is protected. OneWeb is prepared to take necessary technical measures to ensure that its calculated coordination contour is not exceeded thus avoiding harmful interference into UMFUS, such as adjusting the minimum transmit elevation angles, frequency avoidance, uplink power adjustment, earth station shielding, or some combination thereof.

§2.105(c)(2)(ii) requires OneWeb, as a secondary user, to accept incoming interference from a primary user. Transmitting UMFUS stations cannot cause harmful interference into the OneWeb

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[19] *See* n.9 above.

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 UMFUS 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 UMFUS; nevertheless, the Commission has opened a docket allowing FSS operators to bring to its attention noticeable degradation to their Earth-to-space links due to aggregate interference from UMFUS.[20]

B.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 the OneWeb Market Access Grant.[21] While these coordination efforts have focused on OneWeb's currently authorized system, there is no reason to believe that the coordination would be more difficult with Phase 2 given that this phase would consist of satellites that are more flexible and frequency/spatially agile than their predecessors.

B.8.8 Interference with Respect to the Radio Astronomy Service

OneWeb has been involved in coordination discussions with the National Science Foundation (NSF) and the Heads of various Radio Astronomy Service ("RAS") sites concerning the protection

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[20] *See International Bureau Seeks Comment On Implementing Earth Station Siting Methodologies,* Public Notice, 32 FCC Rcd. 5044 (IB 2017).

[21] *WorldVu Satellites Limited Petition for a Declaratory Ruling Granting Access to the U.S. Market for the OneWeb NGSO FSS System*, Order and Declaratory Ruling, 32 FCC Rcd. 5366, ¶ 20 (2017) ("OneWeb Market Access Grant").

of the RAS sites in the USA and worldwide. These protection requirements have been factored into the design of the OneWeb satellites and are equally applicable to the proposed Phase 2 OneWeb System. Agreement has been reached in principle with regards to satellite unwanted emissions in the 10.6-10.7 GHz band and significant progress has been made to address the potential interference from transmit earth stations (gateways and user terminals) to ensure protection of RAS sites for the currently authorized system. The coordination discussions are also addressing the possibility of perturbations to optical astronomy and work continues to avoid reflections from the OneWeb satellites into optical telescopes.

B.9 COORDINATION WITH VERY LARGE ANTENNAS (VLA) IN THE 10.7-12.5 GHZ BAND (§25.146(d))

OneWeb is in the process of coordinating with the representative of the operators of VLAs in the Ku-band in various countries around the world based on the characteristics in its initial application. OneWeb is optimistic that coordination can also be concluded taking into account the characteristics of the Phase 2 as detailed in this petition. OneWeb will inform the Commission when this coordination has been completed.

B.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 held detailed coordination discussions with the US government representative for the currently authorized system, has made substantial progress and is optimistic that it can be concluded in a mutually acceptable manner that can then be extended to cover the Phase 2 deployment. OneWeb will inform the Commission when this has been completed.

B.11 ITU FILINGS FOR ONEWEB

The Phase 2 OneWeb satellite system is registered with the ITU by the United Kingdom administration under the satellite network name "THEO", which will be augmented to reflect the planned Phase 2 deployment. A summary of the related ITU publications to date for THEO is given in Table B.11-1 below. These encompass all the frequencies to be used by OneWeb that are the subject of this application to the Commission.

Table B.11-1: Current ITU Publications for THEO System

Publication reference	Date of receipt	IFIC number	IFIC publication date
API/A/11802	22.06.2016	2823	05.07.2016
CR/C/4301	22.12.2016	2846	30.05.2017
CR/D/3401	22.12.2016	2860	12.12.2017
CR/C/4301 MOD-1	26.09.2017	2901	06.08.2019

B.12 ORBITAL DEBRIS (§25.114(d)(14))

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

B.13 ADDITIONAL INFORMATION CONCERNING DATA IN THE ASSOCIATED SCHEDULE S (§25.114(c))

The Schedule S associated with this Phase 2 of the OneWeb System also includes data relevant to Phase 1. In addition, as part of this submission there is an associated Excel spreadsheet containing orbit data for Phase 2. A detailed explanation concerning which data in the Schedule S (and the accompanying Excel spreadsheet) is common to both phases, and which is unique to one, is given in the appropriate sections of this document, as follows:

- Orbit data: See Section B.1
- Beam data: See Section B.3

The associated Schedule S information for the OneWeb System was prepared using the FCC's online Schedule S software.[22] The data provided in the Schedule S is consistent with the latest available FCC instructions.[23]

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

1. Orbit adjustments of OneWeb System will be made to the orbit altitudes of the various orbital planes to ensure safe operation.

2. For satellite transmitting and receiving beams circular polarization is used, and therefore there is no polarization alignment angle. However, the Schedule S online software defaults

[22] Schedule S software is available at https://enterpriseefiling.fcc.gov/schedules/

[23] *See* SPECIFIC INSTRUCTIONS FOR SCHEDULE S, April 2016, Available at https://enterpriseefiling.fcc.gov/schedules//resources/Instructions%20for%20Schedule%20S%20vApr2016.pdf

to a value of 45° for the polarization angle when circular polarization is selected, and this value cannot be changed, so it should be ignored.

3. The Schedule S PDF printout software does not correctly list the satellite numbering and phase information that has been entered into the online system.

4. Because of differences between the old Schedule S offline software (used for OneWeb's FCC application that resulted in the existing Market Access Grant) and the current online version of the software:

    a. Only half the number of designated channels are required with the current software, as the channel designation does not take into account the polarization used by that channel. The old software had duplicated channel designations to account for the use of dual polarization.

    b. The current software only permits channel designations with up to four characters. For this reason, the channels previously designated as PCU1 to PCU10 are now named PU1 to PU10. Similarly, channels previously designated as PCD1 to PCD10 are now named PD1 to PD10.

    c. The current software requires a separate beam designation for each contiguous frequency range and each polarization. Therefore, the single type of Ka-band beam as defined in the original application has to be duplicated firstly to account for the fact that the beam is used over two non-contiguous frequency ranges, and then duplicated again to allow for the use of dual polarization. Therefore, the Ka-band receive beam GU has become beams GUAL, GUAR, GUBL and GUBR. Similarly, the Ka-band transmit beam GD has become GDAL, GDAR, GDBL and GDBR.

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/ *Philippe Secher*

Philippe Secher
Vice President, Spectrum Engineering
OneWeb