ONEWEB NON-GEOSTATIONARY SATELLITE SYSTEM (LEO)

ATTACHMENT A
Technical Information to Supplement Schedule S

A.1 SCOPE AND PURPOSE

On April 28, 2016 OneWeb requested authorization from the Federal Communications Commission ("Commission" or "FCC") to operate 720 non-geostationary ("NGSO") satellites in low Earth orbit ("LEO") in the Ku- and Ka-bands. On June 23, 2017 the Commission granted OneWeb's request.[1] OneWeb is now seeking to modify this LEO NGSO constellation (the "LEO Component") to add more satellites in light of the new FCC rules pertaining to NGSO systems, which permit longer time periods in which an operator can implement its entire NGSO system.[2]

This modification to the LEO Component consists of an increase in the number of active satellites to be deployed (from 720 to 1,980). There are no other technical changes to the LEO Component being requested at this time. The additional satellites will be technically identical to the original OneWeb satellites, as far as this application is concerned.

This attachment contains the information required for this modification request by §25.117(d), §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 complete Schedule S, using the new online Schedule S software, is being

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1 *In the Matter of 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 (2017) ("OneWeb Market Access Grant").

2 *See In the Matter of 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, 7830-31, ¶ 67 (2017) ("*NGSO R&O*").

submitted with this modification request. This new Schedule S contains identical information to that submitted with OneWeb's original April 28, 2016 submission ("Original Petition") except insofar as the number of satellites (and the corresponding orbit data resulting from the increased number of satellites) is concerned.

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))

This information is available in Attachment A ("Technical Information to Supplement Schedule S") to the Original Petition. The only change here is that the total number of LEO satellites to be deployed has increased from 720 to 1,980. The orbit altitude and orbit inclination remains the same. The satellites are now distributed between 36 (rather than 18) evenly spaced orbital planes, and there would now be a maximum of 55 (rather than 40) satellites per orbital plane.

The LEO Component will be deployed as stated in the Original Petition. The additional satellites beyond 720 will be deployed using multiple satellites per launch vehicle.

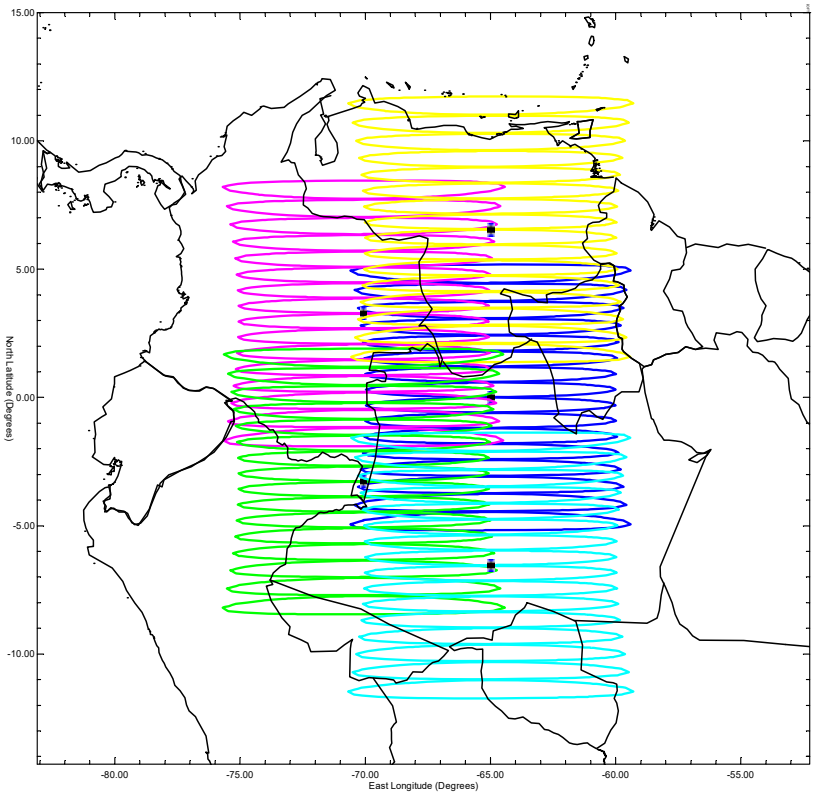
The use of a larger number of satellites in the LEO Component will require additional gateway earth stations per gateway site, typically up to 50 per site, as well as the possible use of more gateway sites. The current plan is still to have at least four gateway sites in the U.S., with the exact geographic locations still to be determined. None of the high-latitude TT&C stations are currently planned to be located in U.S. territory.

The use of additional satellites in the LEO Component, while maintaining the same beam coverage per satellite, will generally increase the elevation angle from the users to the satellites and provide overlapping Ku-band user beam coverage between adjacent OneWeb satellites in both the east-west and north-south directions. This will provide improved service quality and increased capacity to the OneWeb users as well as creating additional opportunities to use limited satellite diversity. Any user terminal, regardless of latitude, will have several OneWeb satellites in view that are simultaneously providing beam coverage to it, including the availability of somewhat higher

elevation satellites at all times. All of these factors will contribute towards improving service quality to the OneWeb users and providing additional spectrum sharing opportunities.

To illustrate the effect on the Ku-band beam coverage of having more satellites in the LEO Component, Figure A.2-1 gives a snapshot of the beams from five adjacent OneWeb LEO satellites, located close to the equator, both within the same orbit plane and between adjacent orbit planes. This shows the extent of the beam overlap between adjacent satellites and how it provides Ku-band satellite diversity to all user locations. In Figure A.2-1, three consecutive satellites are shown in the plane on the right (yellow, blue and cyan beams) with two consecutive satellites in the adjacent plane to the left (magenta and green beams). The variation in the size and shape of the beams in Figure A.2-1 is because of the flat Earth projection used. The -3 dB relative gain contours are shown, although service can also be provided to lower gain contour levels when necessary.

Figure A.2-1: Snapshot of OneWeb Ku-band satellite beam coverage from five adjacent satellites (close to the equator)



The LEO Component will operate under UK and French registrations at the ITU. The Ku-band operates using the UK L5 network recently amended by the ITU Radiocommunication Bureau.[3] The Ka-band can be operated using a combination of UK (L5, THEO) and French (MCSAT-LEO) filings.

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

This information is available in Attachment A to the Original Petition. There is no change to the beam information which has been incorporated into the associated new Schedule S.

A.4 GEOGRAPHIC COVERAGE (§25.146(b))

This information is available in Attachment A to the Original Petition. With more satellites in the LEO Component, OneWeb's ability to meet the Commission's geographic coverage requirements is even better assured than with the original 720 satellites.

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

This information is available in Attachment A to the Original Petition.

A.6 CESSATION OF EMISSIONS (§25.207)

This information is available in Attachment A to the Original Petition.

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[3] See ITU IFIC 2862 CR/C/3413 MOD-8 published on January 23, 2018.

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

The FCC and ITU power flux density ("PFD") limits are defined per-satellite, and there are no changes to the maximum downlink EIRP densities from each satellite of the LEO Component. Therefore, the same demonstration of compliance that was provided in the Original Petition still holds for the modified LEO Component with 1,980 satellites. The only exception to this relates to the Ka-band PFD limit, which is dependent on the total number of satellites in the constellation. This matter is addressed in detail below.

Downlink PFD Limits in Ka-band

The FCC's Ka-band downlink PFD limits applicable to NGSO systems according to the current FCC rules are stated in §25.146(a)(1). This rule adopts the ITU PFD limits that are stated in Article 21 of the ITU Radio Regulations across the entire band 17.7-19.3 GHz, which encompasses most of the Ka-band downlink frequencies 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.[4] The applicable PFD limits in the 17.7-19.3 GHz band are expressed as a function of the number of satellites in the NGSO system 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.

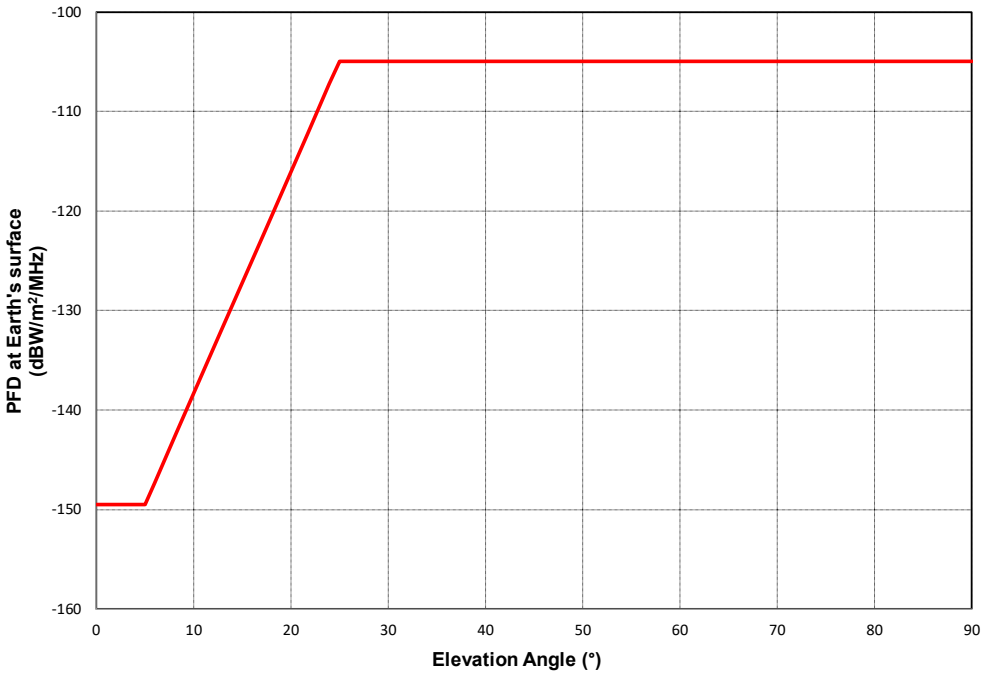
  Where X is defined as a function of the number of satellites in the non-GSO FSS constellation, n, as follows:

  - $X = 0$ dB for $n \leq 50$
  - $X = (5/119)(n - 50)$ dB for $50 < n \leq 288$
  - $X = (1/69)(n + 402)$ dB for $n > 288$

These PFD limits apply to each satellite in the LEO Component. The value of "n" is 1980, and therefore X is equal to 34.52 dB according to the above formulae. This results in the PFD mask shown in Figure A.7-1 below.

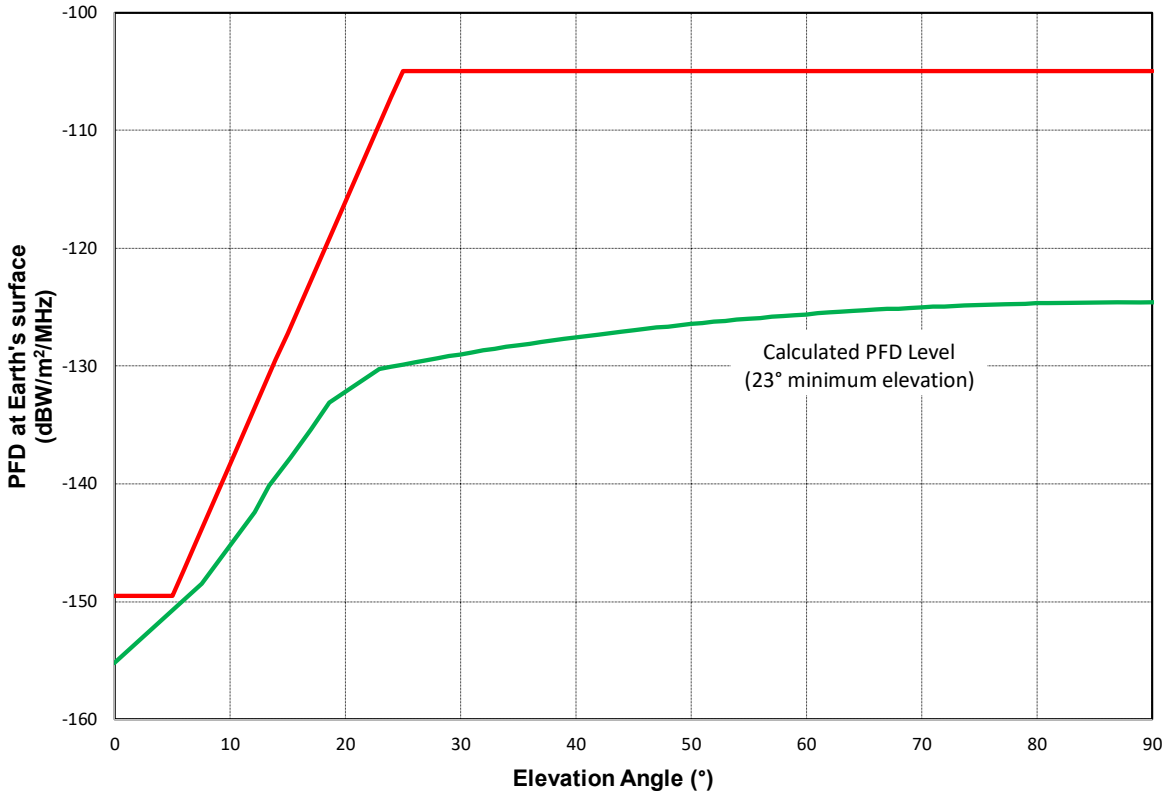
[4] See Table 21-4 of Article 21 of the ITU Radio Regulations.

Figure A.7-1: Ka-band PFD limit for NGSO systems applicable to the 17.7-19.3 GHz band (for N = 1980 satellites)



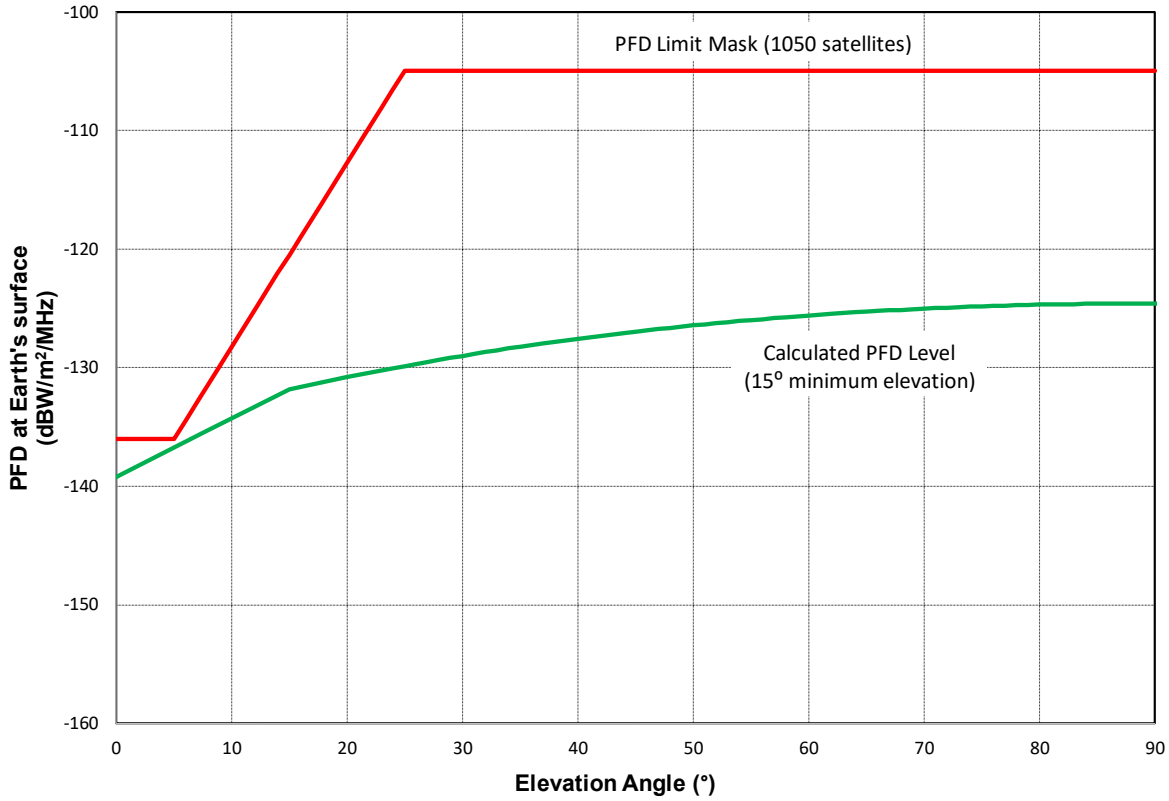
In order to meet this PFD limit when all 1,980 LEO satellites are in operation, the minimum elevation angle of the boresight of the Ka-band satellite transmit antenna will be maintained above 23°. Under this condition compliance with the PFD limits is assured as demonstrated in Figure A.7-2 below. The calculated PFD level shown in green takes into account the beam roll-off of the satellite transmit antenna at the elevation angles lower than the boresight minimum.

Figure A.7-2: Compliance with the PFD mask of the maximum Ka-band PFD levels of the OneWeb NGSO FSS system when 1,980-satellites are deployed (23° minimum boresight elevation)



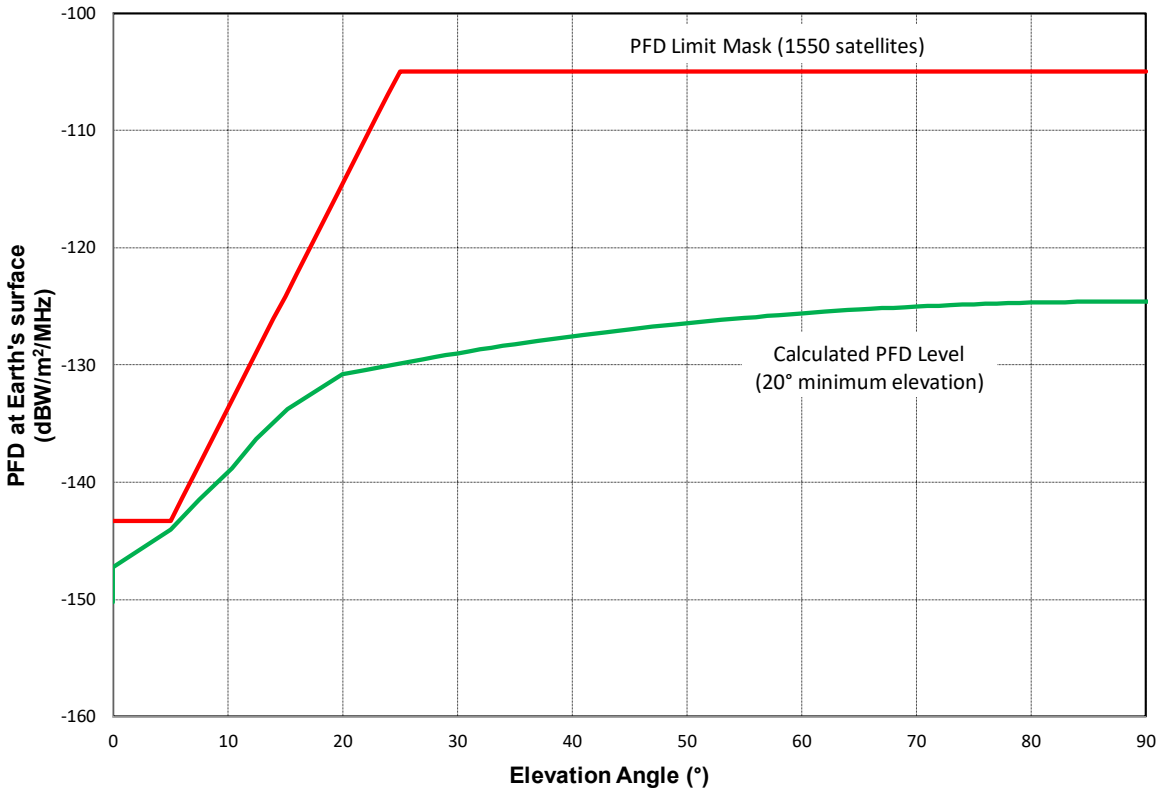
In the earlier phases of operation of the LEO Component, when there will be fewer operational satellites, this constraint on the minimum elevation angle of the boresight of the Ka-band satellite transmit antenna can be relaxed. Figure A.7-3 below shows the case when there are up to 1,050 satellites in operation, where the same minimum elevation of 15° is used as stated in the Original Petition, where 720 satellites were assumed. Compliance with the PFD limit is achieved in this case.

Figure A.7-3: Compliance with the PFD mask of the maximum Ka-band PFD levels of the OneWeb NGSO FSS system when 1,050-satellites are deployed (15° minimum boresight elevation)



The further example in Figure A.7-4 below shows an intermediate case where there are up to 1,550 satellites in operation, and the minimum boresight elevation is 20°, demonstrating compliance with the PFD limit.

Figure A.7-4: Compliance with the PFD mask of the maximum Ka-band PFD levels of the OneWeb NGSO FSS system when 1,550-satellites are deployed (20° minimum boresight elevation)



The ability to operate the gateway links at progressively higher minimum elevation angles over time is compatible with the natural evolution of the LEO Component of the OneWeb system. Additional gateway sites will become available as the deployment of the system progresses.

A.8 INTERFERENCE ANALYSES

Only the interference assessments that might be different for the larger 1,980-satellite LEO Component are addressed here. Refer to Attachment A to the Original Petition for any information not addressed below.

A.8.1 Interference Protection for GSO Satellite Networks (§25.146 and §25.208)

OneWeb will ensure that the 1,980-satellite LEO Component still provides the necessary interference protection to GSO satellite networks in both the Ku- and Ka-bands as required by §25.146 of the Commission's rules and Article 22 of the ITU Radio Regulations.

Consistent with the current FCC rules,[5] OneWeb hereby certifies as part of this modification application that it will comply with applicable equivalent power flux-density ("EPFD") levels in Article 22, Section II and Resolution 76 of the ITU Radio Regulations. These EPFD levels apply in the following frequency ranges to be used by the OneWeb LEO Component in the U.S.:

- Ku-band:
  - Uplink: 14.0-14.5 GHz
  - Downlink: 10.7-12.7 GHz
- Ka-band:
  - Uplink: 27.5-29.1 GHz and 29.5-30.0 GHz
  - Downlink: 17.8-18.6 GHz and 18.8-19.3 GHz

The techniques by which compliance with the EPFD limits will be met are the same in principle for the larger 1,980-satellite LEO Component as for the original 720-satellite constellation. Minor adjustments to the "progressive pitch" algorithm used in Ku-band are required to account for the increased number of satellites and therefore the increased amount of overlapping beam coverage between consecutive satellites in the same orbital plane. In Ka-band, the GSO avoidance angle will also be adjusted accordingly. The net result is that the 1,980-satellite LEO Component is able to meet the EPFD limits as required to protect GSO satellite networks, both in the Ku-band and the Ka-band.

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[5] *See NGSO R&O* at ¶ 41.

A.8.2 Interference with Respect to Other NGSO Satellite Systems

The increase in the number of satellites in the LEO Component does not mean increased interference issues with respect to other NGSO systems. With more OneWeb LEO satellites in operation there will be more scope to exploit limited satellite diversity in Ku-band due to the increased beam overlap between adjacent OneWeb satellites. This will increase the possibility of reaching mutually beneficial coordination agreements with other NGSO system operators. In Ka-band the ability to use gateway earth station diversity in the OneWeb system is unchanged by the increase in the number of OneWeb LEO satellites. OneWeb is therefore confident that it can achieve the necessary coordination with other NGSO satellite systems with the increased number of satellites in its LEO Component.

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

This information is available in Attachment A to the Original Petition. The interference situation is unaffected by the increase in the number of LEO satellites.

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

This information is available in Attachment A to the Original Petition. The interference situation is unaffected by the increase in the number of LEO satellites. The legacy fixed service links in the 12.2-12.7 GHz band, as well as any multichannel video distribution and data service links in this band, will be protected with 1,980 OneWeb LEO satellites in operation in exactly the same way as they are protected with 720 OneWeb LEO satellites in operation.

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

This information is available in Attachment A to the Original Petition. The interference situation is unaffected by the increase in the number of OneWeb LEO satellites. In the 17.8-18.3 GHz band, the only significant interference interaction between the LEO Component and terrestrial networks relates to the OneWeb gateway earth stations and the potential interference that might be received from terrestrial transmitters. As there will likely be no additional U.S. gateway sites when 1,980

OneWeb satellites are in operation compared to when 720 OneWeb satellites are in operation, there will be no additional issues in this frequency band.

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

This information is available in Attachment A to the Original Petition. The interference situation is unaffected by the increase in the number of OneWeb LEO satellites. In the 27.5-28.35 GHz band, the only significant interference interaction between the LEO Component and terrestrial networks relates to the OneWeb gateway earth stations and the potential interference that they might cause to terrestrial receivers. As there will likely be no additional U.S. gateway sites when 1,980 OneWeb satellites are in operation compared to when 720 OneWeb satellites are in operation, there will be no additional issues in this frequency band. The range of earth station antenna pointing directions considered in the coordination process with terrestrial services covers all possible OneWeb LEO satellite positions above a certain minimum elevation angle, and this range is the same for the case of either 720 or 1,980 satellites in the LEO Component. When seeking earth station licenses for its gateway earth stations, OneWeb will consider the aggregate PFD around each site to ensure that it complies with the UMFUS rules.[6]

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 its designated tracking and data relay satellite system receiving ground stations in the U.S. 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) of the Commission's rules. This coordination process is unaffected by the increase in the number of OneWeb LEO satellites from 720 to 1,980.

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[6] *See* 47 C.F.R. § 25.136.

A.8.8 Interference with Respect to the Radio Astronomy Service

OneWeb will address with the Radio Astronomy Service ("RAS") community the protection of RAS sites in the U.S. and how it is impacted by the addition of satellites to the LEO Component. Based on the analysis already performed for the 720-satellite constellation, and the planned operational measures to be used to protect the RAS, OneWeb can confidently assert that it will protect the RAS to the required interference levels when the 1,980-satellite LEO Component is in operation.

A.9 COORDINATION WITH THE US GOVERNMENT SATELLITE NETWORKS (Footnote US334 in the FCC Table of Frequency Allocations)

OneWeb will continue to coordinate its LEO Component with U.S. government satellite networks, both GSO and NGSO, in portions of the Ka-band spectrum according to US334.

OneWeb has initiated this coordination process for the 720-satellite constellation and will expand it to encompass the 1,980-satellite LEO Component. OneWeb is optimistic that coordination can be concluded in a mutually acceptable manner and will inform the Commission when it has been completed.

A.10 ORBITAL DEBRIS (§25.114(d)(14))

This matter is addressed in the Legal Narrative included with the modification application.

A.11 SATELLITE EIRP DENSITY VALUES

The satellite EIRP density values are not changed from the Original Petition. Refer to Attachment A to the Original Petition for this information. This data is now also entered into the new Schedule S.

A.12 SATELLITE G/T AND SFD RANGE VALUES

The satellite beam peak G/T values (for both the minimum and maximum saturation flux density values for each space station receive antenna) are not changed from the Original Petition. Refer to Attachment A to the Original Petition for this information. This data is also entered into the new Schedule S.

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

The associated Schedule S information for the modified OneWeb LEO Component was prepared using the FCC's new online Schedule S software.[7] The data provided in the Schedule S is consistent with the latest available FCC instructions.[8]

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

1. Orbit adjustments of the LEO Component 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 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.

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

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

3. The Schedule S software does not correctly print out 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 and the new online version of the software:

    a. Only half the number of designated channels are required with the new 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 new 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 new 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.

A.14 COORDINATION WITH VERY LARGE ANTENNAS (VLA) IN THE 10.7-12.5 GHZ BAND (§25.146)

OneWeb has initiated this coordination process for the 720-satellite constellation and is optimistic that it can be concluded in a mutually acceptable manner for the 1,980-satellite LEO Component. OneWeb will inform the Commission when this coordination has been completed.

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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