AST&Science LLC
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BLUEWALKER 3 NON-GEOSTATIONARY SATELLITE
Technical Annex

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A.1 SCOPE AND PURPOSE

This Technical Statement has been prepared in support of AST&Science LLC ("AST's") application for a conventional experimental license for the BlueWalker 3 ("BW3") satellite. It supplements the technical information provided in the Schedule S prepared in accordance with the requirements of 47 C.F.R. § 25.114 and other relevant sections of the Federal Communications Commission's ("FCC" or "Commission") rules. In its application, AST is seeking authority to test the BW3 for a period of two years from the time that the satellite is operational.[1/] Testing from the United States will occur at two fixed earth station locations and,

[1/] AST addresses orbital debris mitigation and end-of-life disposal matters for the spacecraft in a separate attachment.

for testing with mobile handsets, in four select geographic areas on frequencies licensed to wireless licensees.

A.2 BASIC TECHNICAL INFORMATION

The BW3 is a non-geostationary satellite ("NGSO") that will be used to test a novel phased array satellite technology to provide direct connectivity to off-the-shelf mobile handsets. During the testing, satellite forward link uplink will occur on the V band frequencies, and then each carrier will be transmitted on the service link frequency to the user equipment *via* a space station spot beam. Testing will also occur in reverse (return link), where the user equipment will transmit on the service link frequency up to the satellite, which will then be transmitted back down to earth on the V band frequencies.

A.2.1 Space Segment

The BW3 will operate at an inclination angle of between 97.4 and 97.8 degrees, at an altitude of between 500 and 600 km.[2/] The attached Schedule S provides additional information regarding the spacecraft, including illustrations of the coverage footprint of the satellite.

A.2.2 Spectrum

AST's application seeks authority to allow the BW3 to operate in the following frequency bands:

a) For service links in the Earth-to-space direction
846.5-849 MHz
845-846.5 MHz
788-798 MHz

b) For service links in the space-to-Earth direction
891.5-894 MHz
890-891.5 MHz
758-768 MHz

c) For gateway/feeder links in the Earth-to-space direction
47.2-50.2 and 50.4-51.4 GHz

d) For gateway/feeder links in the space-to-Earth direction
37.5-42.0 and 42.0-42.5 GHz

e) For TT&C operations (space-to-Earth and Earth-to-space)

[2/] *See* Section A.2.4. below

400.15-401 MHz
437-438 MHz

A.2.3 Channelization Plan and Spectrum Use

Each user beam will have a dedicated channel, using any combination of channel bandwidths of 10 MHz, 5 MHz, 3 MHz, or 1.4 MHz. The satellite will transmit all of its active user beams on the same frequency or different frequencies. Each active user beam will track a fixed cell on the ground within its FoV without steering the boresight of the planar phased array antenna. All of the active beams can be distributed flexibly within the FoV. The same cell on the ground can be tested by a single beam or by multiple beams from the satellite. The beam-to-beam handover uses the similar approach to the terrestrial system and the gateway handover is based on schedules and uses a “break-then-make” approach.

A.2.4 Additional Information Regarding the Orbital Plane

To more clearly define the orbital plane for the BW3 mission, AST must supplement the information in Schedule S considering the nature of sun-synchronous orbits (SSO). In this orbit, the satellite passes over a designated location on the surface of the Earth at the same local time, known as the local time of the ascending node (LTAN). In this orientation, the right ascension of the ascending node (RAAN) of the satellite will precess approximately one degree each day due to the oblateness of the Earth, repeating each year. Since this is not a fixed parameter, it is more appropriate to use the satellite’s LTAN to characterize the precession of the RAAN. The inclination is then selected according to the orbital altitude such that this precession occurs at the rate necessary to maintain the same orientation with respect to the sun.

The BW3 mission consists of a single satellite in a circular (equal apogee and perigee), SSO orbit between the altitudes of 500 and 600 km. For these altitudes, the orbital period is expected to be between 5677 and 5801 seconds. In order to maintain the SSO orbit, the inclination shall be between 97.4 and 97.8 degrees, depending on the operational altitude. Given that the RAAN precesses approximately one degree per day, it is more appropriate to define the LTAN for satellites in SSO. For BW3, the LTAN is defined as 10:30 to 11:00. The active service arc angle with respect to the ascending node shall begin at -90 degrees and end at 90 degrees. Within the orbital plane, the sole satellite for the BW3 mission shall have a mean anomaly of 0 degrees at the orbit epoch date.

A.3 PREDICTED SPACE STATION ANTENNA GAIN CONTOURS

Service Links: The BW3 will transmit and receive in the service link frequency bands using independently and electrically steerable beams with 36 dBi maximum gain and sidelobe patterns conforming to ITU-R Recommendation S.672-4 with L_N better than -20 dB.

Gateway Beams: All gateway link spot beams from the satellite will be independently and mechanically steerable over the view of Earth at a 10 degrees ground elevation angle. For the feeder links, BW3 will use receive steerable beams of 45.5 dBi gain and transmit steerable beams of 45.1dBi gain, with sidelobe patterns conforming to ITU-R Recommendation S.672-4 with L_N equal to -20 dB.

TT&C Beams: The space operation receive and transmit beams in the 437-438 MHz band will be fixed, omnidirectional, with 0 dBi gain. The BW3 additionally will use the requested V band frequencies for TT&C, under operations discussed in the preceding paragraph. The space operation receive and transmit beams in the S band – *used only outside of the U.S.* – will be fixed, with 6 dBi gain and sidelobe patterns conforming to ITU-R Recommendation S.672-4 with L_N equal to -10 dB. Communication to and from the TT&C earth stations will operate at an elevation above the local horizon of 10 degrees or higher. Each TT&C beam will support one command channel and one telemetry channel with the channel bandwidth of between 10 kHz and 100 kHz for 437-438 MHz band and 10 MHz for the V band.

A.4 OVERALL DESCRIPTION OF SYSTEM FACILITIES, OPERATIONS AND SERVICES

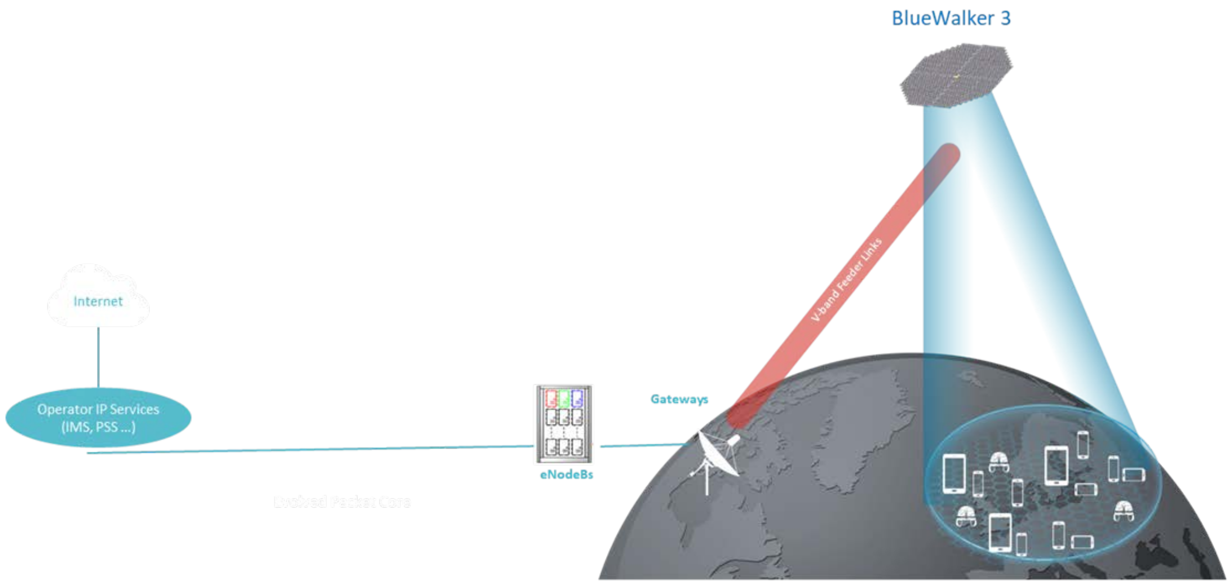
Testing on the service link bands will use off-the-shelf equipment, such as smartphones, for communicating with the BW3. All user equipment will operate on frequencies already licensed to parties that will agree to allow AST to conduct its requested testing.

The gateway uplink carriers in the V band accommodate and uplink the wireless downlink signals for each active cell to the BW3 satellite. The satellite payload processer demultiplexes the V band uplink signals and maps them to the downlink beams covering the cells from the phased array antenna in the assigned wireless network channel frequencies. At the return link side, the user equipment uplink signals from different cells in the assigned wireless network channels are received from the phased array antenna on the BW3 satellite. The received signals are multiplexed in frequency domain, up-converted to the V band downlink frequencies, and transmitted to the gateway station.

The V band gateway earth stations will use 2.4 m antennas. Multiple gateway stations may be collocated at each gateway site.

AST's TT&C operations for the BW3 will be conducted worldwide pursuant to an agreement with a third party provider to use its S band and UHF band services. On-orbit nominal operation will be conducted through the in-band channel in the V band frequencies *via* the V band gateway station. AST will monitor TT&C operations from its system control center located in Midland, Texas.[3/] The control center and the earth station connections are via a dedicated Ethernet.

Transmissions will be conducted through simple frequency translation transponders on board the satellite. Figure 2 below shows the architecture of the system in its final phase:



[3/] AST's facility in College Park, MD will serve as a secondary control center, though no antennas will be located at this site, which will receive links via fiber from the Midland facility.

Figure 2: System Architecture

A.5 CESSATION OF EMISSIONS

Pursuant to Section 25.207,[4/] AST will ensure that the BW3 is capable of ceasing radio emissions by use of ground commands that will ensure definite cessation of emissions. As noted above, AST will have the ability to control the satellite *via* locations outside of the United States.

A.6 SPECTRUM SHARING

The frequency ranges that AST proposes to use in the U.S. for user terminals will be those licensed to mobile service providers that have informed AST of availability of frequencies for its requested testing. Through precise control of the satellite's beams, AST will maintain all transmissions within the licensee's channels and service area.[5/] Consequently, unacceptable interference within these frequency bands is not an issue for this application.

Regarding the gateway stations, these will be located in Midland, TX and Kapolei, HI, locations already previously authorized for ground station transmission. For downlink transmissions, any licensed users may be protected through use of a narrow and controlled beams and adjustments to power levels as necessary.

A.7 POWER FLUX DENSITY AT THE EARTH'S SURFACE

The Schedule S that is provided with this application reflects the satellite's worst case operations. However, the BW3 will operate when testing with the more stringent power flux density limits that are required under the FCC rules for particular V band frequencies, meeting those rules in all instances.

Section § 25.208(r) contains PFD limits that apply in the 37.5-40 GHz frequency band.[6/] The PFD limits when no allowance is made for propagation impairments are as follows:

- -132 dB(W/m2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

4/ 47 C.F.R. § 25.207.

5/ *See also* Section A.10 below.

6/ 47 C.F.R. § 25.208(r).

- -132 + 0.75 (δ-5) dB(W/m2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and
- -117 dB(W/m2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane,
- and during periods when FSS system raises power to compensate for rain-fade conditions they are:
- -120 dB(W/m2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
- -120 + 0.75 (δ-5) dB(W/m2) 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/m2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

Sections § 25.208(s) and (t) also contain PFD limits that apply in the 40-42 GHz frequency band.[7/] The PFD limits when no allowance is made for propagation impairments are as follows:

- -115 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
- -115 + 0.5 (δ-5) dB(W/m2) 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/m2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.
- Moreover, Table 21-4 of the Radio Regulations (RR) contains PFD limits that apply to non-GSO FSS satellite systems in the 42-42.5 GHz frequency band, which are:
- -120 dB(W/m2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

7/ 47 C.F.R. § 25.208(s) and (t).

- -120 + 0.75 (δ-5) dB(W/m2) 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/m2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

The maximum downlink EIRP density that the BW3 can transmit in the frequency band 40-42 GHz is -40.9 dBW/Hz. The worst case PFD levels will occur for the shortest distance from the satellite to the Earth, *i.e.*, 500 km, and were reproduced in the Schedule S, although the actual PFD levels for frequency bands other than 40-42 GHz will be lower, as explained below.

Table 1 below shows the corresponding PFD levels on the Earth's surface and the margins with respect to the Part 25 masks applicable to the frequency band 40-42 GHz, assuming the satellite beam can be pointed to a minimum elevation angle of 5°. The margins are always equal to or greater than 0 dB.

Table 1: Demonstration of Compliance with 47 C.F.R. § 25.208(s) and (t)

Elevation Angle (°)	Range (km)	Spreading Loss (dB)	Pfd (dBW/m^2/MHz)	§25.208 Mask (dBW/m^2/MHz)	Margin (dB)
5	2077.9	137.3	-118.2	-115.0	3.2
10	1695.1	135.6	-116.5	-112.5	4.0
15	1407.5	134.0	-114.8	-110.0	4.8
20	1193.0	132.5	-113.4	-107.5	5.9
25	1031.9	131.3	-112.1	-105.0	7.1
90	500.0	125.0	-105.9	-105.0	0.9

The maximum downlink EIRP density that the BW3 can transmit in the frequency band 37.5-40 GHz under faded conditions and in the band 42-42.5 GHz is -42.7 dBW/Hz. The worst case PFD levels will occur for the shortest distance from the satellite to the Earth, *i.e.*, 500 km.

Table 2 below shows the corresponding PFD levels on the Earth's surface and the margins with respect to the Part 25 mask applicable to the 37.5-40 GHz frequency band under faded conditions and the RR Article 21 PFD limits applicable to the frequency band 42-42.5 GHz, assuming the satellite beam can be pointed to a minimum elevation angle of 5°. The margins are always equal to or greater than 0 dB.Table 2: Demonstration of Compliance with 47 C.F.R. § 25.208(r) and Table 21-4 of the Radio Regulations

Elevation Angle (°)	Range (km)	Spreading Loss (dB)	Pfd (dBW/m^2/MHz)	§25.208/RR Mask (dBW/m^2/MHz)	Margin (dB)
5	2077.9	137.3	-120.0	-120.0	0.0
10	1695.1	135.6	-118.3	-116.25	2.05
15	1407.5	134.0	-116.6	-112.5	4.1
20	1193.0	132.5	-115.2	-108.75	6.45
25	1031.9	131.3	-113.9	-105.0	8.9
90	500.0	125.0	-107.7	-105.0	2.7

When there is no need to raise power to compensate for rain-fade conditions at the FSS earth station, the maximum downlink EIRP transmitted by BW3 in the frequency band 37.5-40 GHz will be -54.7 dBW/Hz.

Consequently, compliance with the applicable PFD limits in Section 25.208 will always be assured.

Finally, there are no variations in antenna gain over the steerable range. And the spacecraft will maintain the constant EIRP spectrum density which is set to ensure compliance to the PFD requirement in the worst case condition.

A.8 CARRIER FREQUENCY OF SPACE STATION TRANSMITTERS

BW3 will comply with 47 C.F.R. § 25.202(e).

A.9 EMISSION LIMITATIONS

BW3 will comply with 47 C.F.R. § 25.202(f)(1), (2) and (3).

A.10 INTERFERENCE ANALYSIS

The BW3 has been engineered to co-exist with other systems. With regard to the V band gateway beams, the following attributes will allow AST to successfully share with other users:

- Steerable antennas with narrow beamwidth (no more than 0.75 degrees 3 dB beamwidth) and no performance degradation over the steerable range;
- Low sidelobe levels that minimize the potential interference outside of the antenna main beam; and
- Any gateway beam can be independently switched off per polarization.

With regard to sharing with terrestrial networks in the V band downlink frequencies, compliance with the FCC rules and Article 21 PFD limits will be sufficient to protect terrestrial services. As to sharing with other NGSO systems operating in the same bands, Section A.7 above addresses how AST will successfully share with other NGSOs.

In the service links using the LTE frequencies, successful frequency sharing may be accomplished due to:

- Narrow beamwidth beams that can be individually turned off when they near a geographic area where AST has not been provided authorization to use the frequency;
- Low beam sidelobes and fast rolloff because of the use of large aperture phased array antenna;
- Dynamically controlled beam center and beam EIRP level; and
- Adjacent Channel Leakage Ratio (“ACLR”) that is minimized and compliance with applicable terrestrial standards improvements in the formed beams with large number of elements and multiple formed beams.

A.11 ITU FILINGS FOR BW3

The BW3 satellite will operate under network filings made on behalf of AST with the ITU by the Papua New Guinea administration under the name MICRONSAT.

AST&Science LLC
File No. 1059-EX-CN-2020

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 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.

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