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FCC License Application Technical Attachment

For UmbraSAR (Umbra-2001)

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Revisions

Revision	**Date**	**Changes**
01	5/11/2020	Initial Revision
02	5/12/2020	Rev to include additional RF detail

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1.0 Ownership Operation and Construction

Umbra Lab Inc. ("Umbra") is a Delaware C-corporation headquartered in Santa Barbara, California, which will provide space-based commercial remote sensing services. Space-based radar imaging data will be made available commercially for defense, intelligence and analytics solutions. Umbra Lab's synthetic aperture radar (SAR) microsatellites will deliver sub-meter imagery as a service through an integrated web platform. SAR can capture images day and night regardless of weather conditions and natural illumination.

Construction of the proposed experimental satellite ("Satellite") and associated facilities has begun prior to the Commission's grant of an authorization. This is necessary given the nature of satellite construction and technical requirements over long lead times. Space Station information is listed in Table 1.

Table 1. Space Station Information

Space Station Name	UMBRA-2001
Licensed Commercial Remote Sensing System	UmbraSAR
Estimated Launch Date	4th Quarter 2020
Purpose	Experimental
Orbital Type	NGSO

2.0 Satellite Orbital Elements

This is an experimental application to cover one (1) satellite. Launch will occur via ride-share and the initial LTDN is unknown at this time. The initial orbit will be circular sun-synchronous at an altitude between 500 and 600 km. Anticipated final orbital elements are shown in Table 2.

Table 2. Space Station Orbital Elements

Apogee	583-km
Perigee	583-km
Inclination	97 – 98 deg
Eccentricity	0.
Orbital Period	1.61 hours
LTDN	TBD
Orbital Type	NGSO

3.0 Purpose of Experiment

Umbra plans a constellation of SAR satellites (Umbra SAR) and is initially seeking approval from the FCC for an experimental license for operation of the first satellite to be launched in late 2020. If applicable, Umbra plans to submit for approval for the full constellation once the design is validated.

The purpose of the first satellite will be to test technologies and designs, validate performance, and progress into a fully operational architecture. Technology developments being tested include but are not limited to:

- Deployable high gain mesh antenna developed by Umbra
- Radar and radio electronics developed by Umbra
- Novel thermal management systems
- Electrical and power systems
- Mission Concept-of-Operations
- Function of integrated space-ground system
- Radar image formation utilizing full ITU bandwidth allocation of 1,200 MHz

Mission control of Umbra SAR satellites will be located at Umbra Lab's headquarters located in Santa Barbara, CA with a mobile back-up. Tasking will be generated, encrypted, and passed to the Satellite utilizing a commercial ground station (earth station) service. This uplink occurs over S-Band as described in

Mission Data and Telemetry will be packetized and encrypted onboard and sent to ground through the commercial ground station service. Cloud services are utilized for storage and distribution of data through Umbra's web portal following raw data processing.

To collect radar imagery Umbra has developed a proprietary antenna technology allowing for relatively low power operation to achieve high quality SAR images. The antenna provides high gain with industry leading mass and compaction ratio and is designed for the rideshare form factor.

The radar configuration including bandwidth, pulse repetition frequency and duty cycle may be varied as required for operation.

With the modifications approved by the ITU, usage of the band 9.2 – 10.4 GHz is now possible in accordance with the associated notes and is requested for this experimental license. However, we are requesting the use of two action frequencies. For low-bandwidth SAR using the 600-MHz

band centered on 9.6 GHz, and for high-bandwidth SAR using the 1200-MHz band centered at 9.8 GHz. The spacecraft can be commanded to collect images utilizing either action frequency. The following are justifications we have identified for operation over this proposed spectrum.

- ITU Modifications include Earth exploration-satellite (active) on a non-interference basis for bands (in accordance with 5.474A, 5.474B, 5.474C, 5.474D, 5.479, 5.480)[1]:
  - 9.2 – 9.3 GHz
  - 9.9 - 10.0 GHz
  - 10.0 – 10.4 GHz
- Allocations for Earth exploration-satellite (active) exist on a non-interference basis for bands (in accordance with associated notes 5.427, 5.474, 5.475A, 5.475B, US67, US71, US476A):
  - 9.3 - 9.5 GHz
  - 9.5 – 9.9 GHz

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1. *See* Final Acts WRC-15, World Radiocommunication Conference, Geneva, 2015

4.0 Ground Station Locations

Umbra has contracted with Kongsberg Satellite Services ("KSAT") for ground-based telemetry, tracking, and command ("TT&C") and mission data downlink services for the Satellite.

KSAT works with Umbra, national regulatory authorities, and international regulatory authorities to obtain all necessary licenses for station operations and transmission approval

The sites listed in Table 3 are part of the KSAT-lite ground network and will be utilized by the Satellite for both S-Band uplink and downlink as well as X-Band downlink. Utilization of all these sites is preferred, subject to restrictions of availability as managed by KSAT and higher priority needs as dictated by the government agencies.

Requested Stations (US): None

Requested Stations (Foreign): Locations are listed in Table 3 and associated antenna information is listed in Table 4 and Table 5.

Table 3. International Ground Sites Requested

Site	Antenna Size / Band	Lat	Lon	Elevation (m)
Svalbard, Norway	3.7-m / S 3.7-m / X	78.2 N	15.3 E	484
Inuvik, Canada	3.7-m / S 3.7-m / X	68.2 N	133.3 W	127
Punta Arenas, Chile	3.7-m / S 3.7-m / X	53 S	70 W	186
Awarua, New Zealand	3.7-m / S 3.7-m / X	46.5 S	168.4 E	186

Table 4. S-Band Ground Antenna Specification

Size	3.7-m Diameter
Radiation Pattern	ITU-R S.465-6
EIRP	44.8 dBW
Maximum Gain	35.4 dBi
Minimum Elevation	5 deg
Azimuthal Range	360 deg
Polarization	RHCP

Table 5. X-Band Ground Antenna Specification

Size	**3.7-m Diameter**
Half Power Beamwidth	0.8 degrees
Minimum Output Power	0 W
EIRP	NA
Maximum Gain	47 dBi
Minimum Elevation	5 deg
Azimuthal Range	360 deg
Polarization	RHCP

5.0 Space Station Action Frequencies

As shown in Figure 1 and Table 6 Umbra seeks the use of the following frequency bands for the space station:

1. 2200-2290 MHz as a means for downlinking of mission telemetry. (US303)[1]
    a. 2254 MHz proposed center frequency with 100-kHz bandwidth (100KG7D)

2. 8025-8400 MHz for the downlink of mission data and telemetry. (US258)[2]
    a. 8150 MHz proposed center frequency with 220-MHz bandwidth (250MG7D)

3. 9200-10400 MHz for SAR imaging. (allocated per the above justification)
    a. 9600 MHz proposed center 600-MHz bandwidth (600MF3N)
    b. 9800 MHz proposed center 1200-MHz bandwidth (1G20F3N)

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1. *See* U.S. Table of Frequency Allocations, FN US303, *available at* https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf (allocating the 2200-2290 MHz band for non-Federal space-to-Earth transmissions on a case-by-case, non-interference basis).
2. *See* FN US258 (allocating the 8025-8400 MHz band on a primary basis for non-Federal EESS use).

Figure 1. RF Payloads Diagram

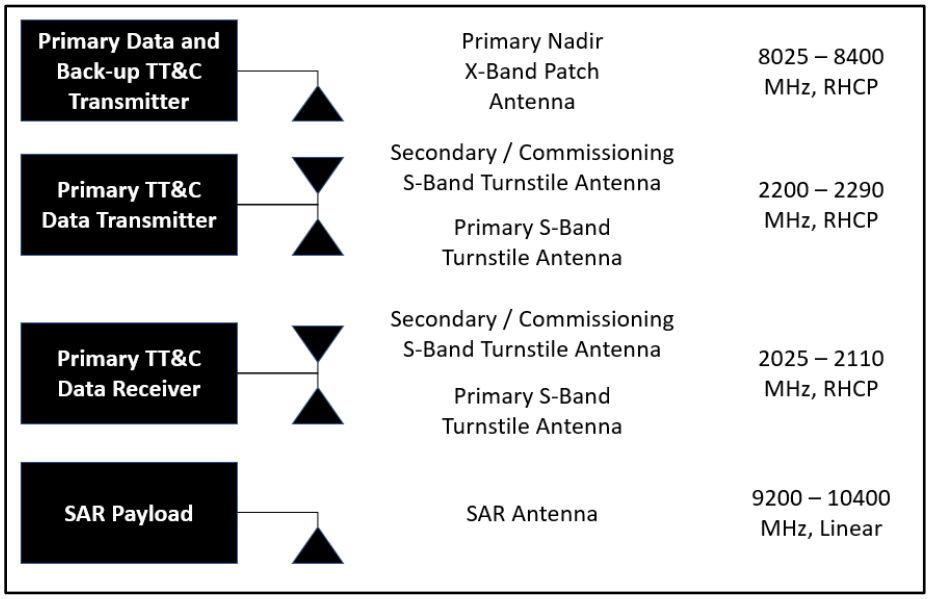


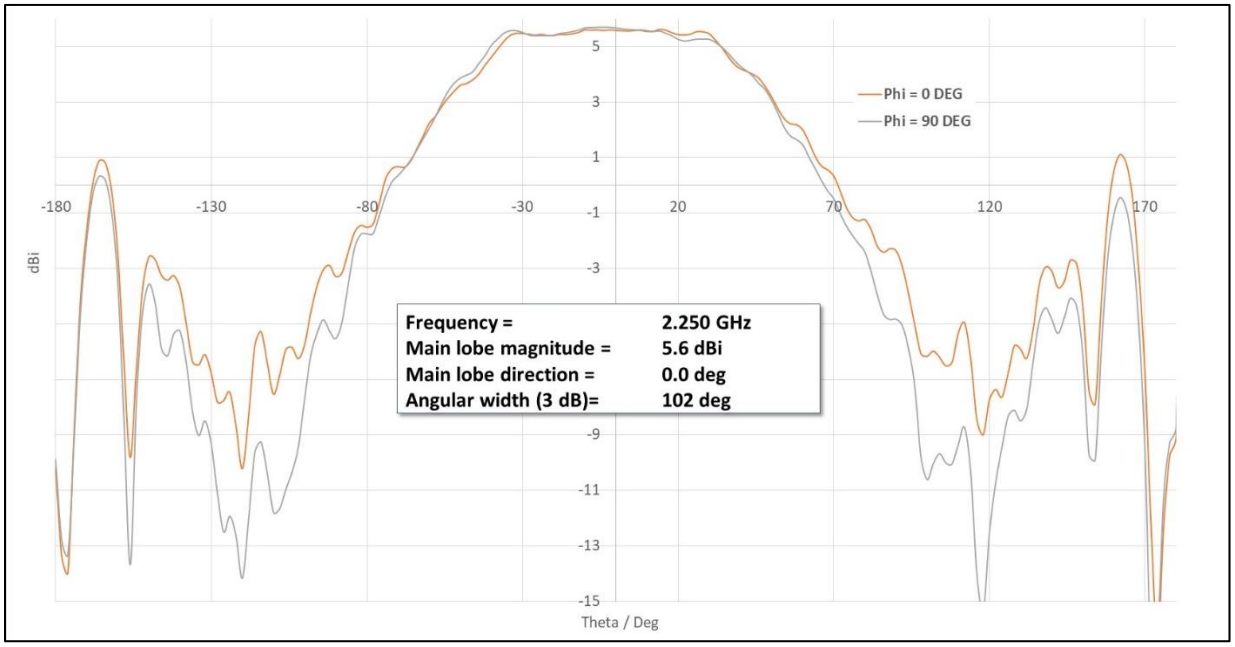
Table 6. Frequency Utilization

Function	Band	Description
Mission Data Downlink Telemetry Downlink	8025 – 8275 MHz	PSK Modulation 250 MHz Bandwidth Polarization: RHCP
EESS(Active) Band 1	9300 – 9900 MHz	Linear Frequency Modulation Polarization: Linear
EESS(Active) Band 2	9200 – 10400 MHz	Linear Frequency Modulation Polarization: Linear
Telemetry Downlink	2200 – 2290 MHz	PSK Modulation 100 kHz Bandwidth Polarization: RHCP
Telemetry Uplink	2025 – 2110 MHz	PSK Modulation 100 kHz Bandwidth Polarization: RHCP

5.1 S-Band Downlink (2200-2290 MHz)

The antenna beam profile is shown in Figure 2.

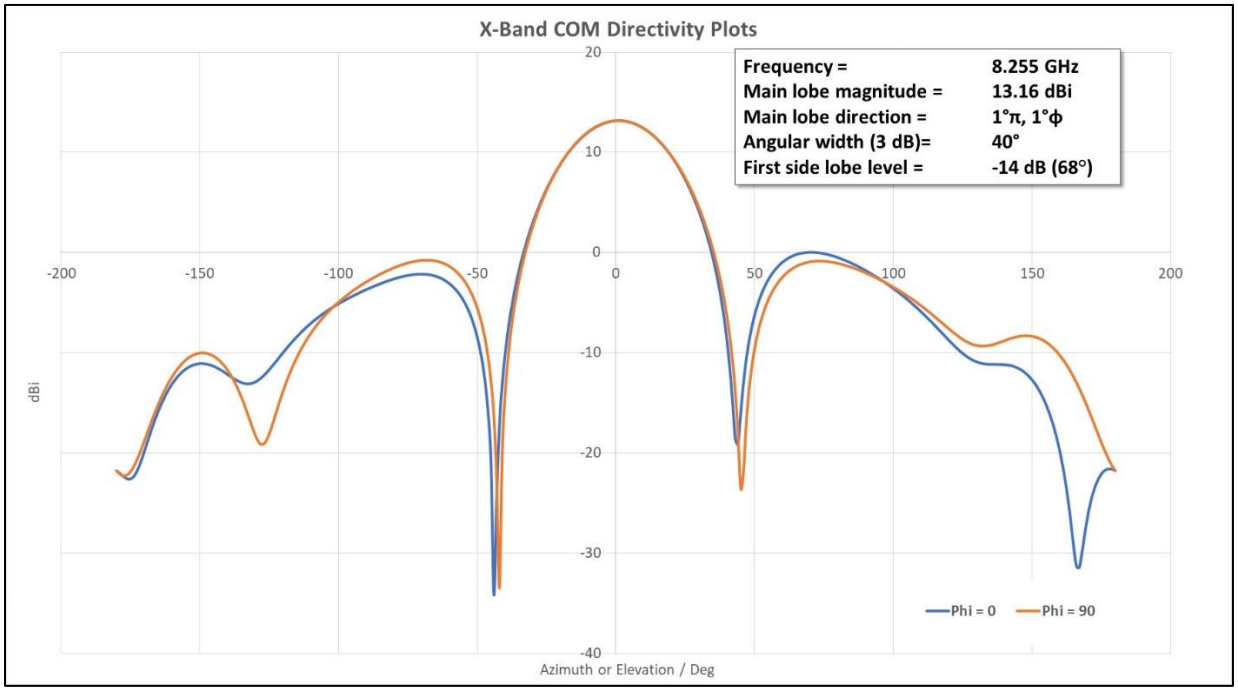
Figure 2. Antenna Profile for S-Band (2200-2290 MHz)



5.2 X-Band Downlink (8025-8275 MHz)

The antenna beam profile is shown in Figure 3.

Figure 3. Antenna Beam Profile for X-Band (8025-8275 MHz)

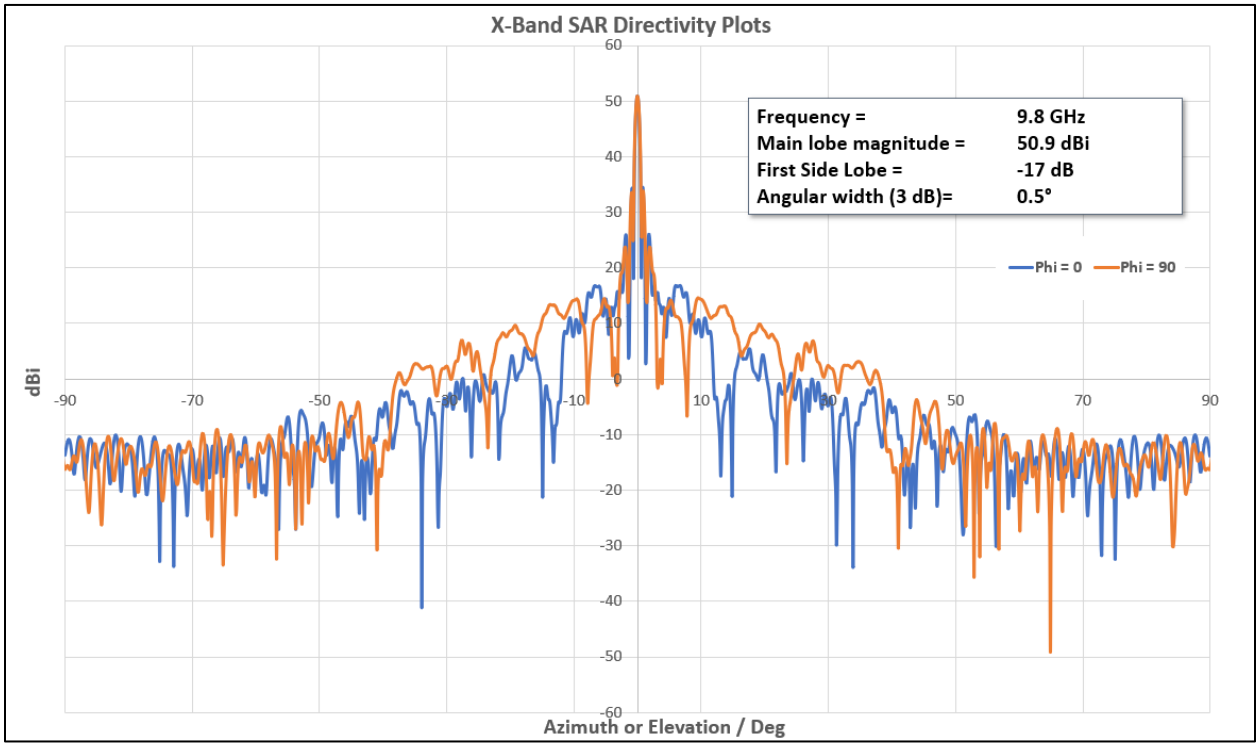


1. Planned frequency of operation is 8025 – 8275 MHz

5.3 X-Band Radar (9200-10400 MHz)

The antenna beam profile for this band is shown in Figure 4.

Figure 4. Antenna Profile for Radar (9200 – 10400 MHz)



6.0 Power Flux Density Analysis

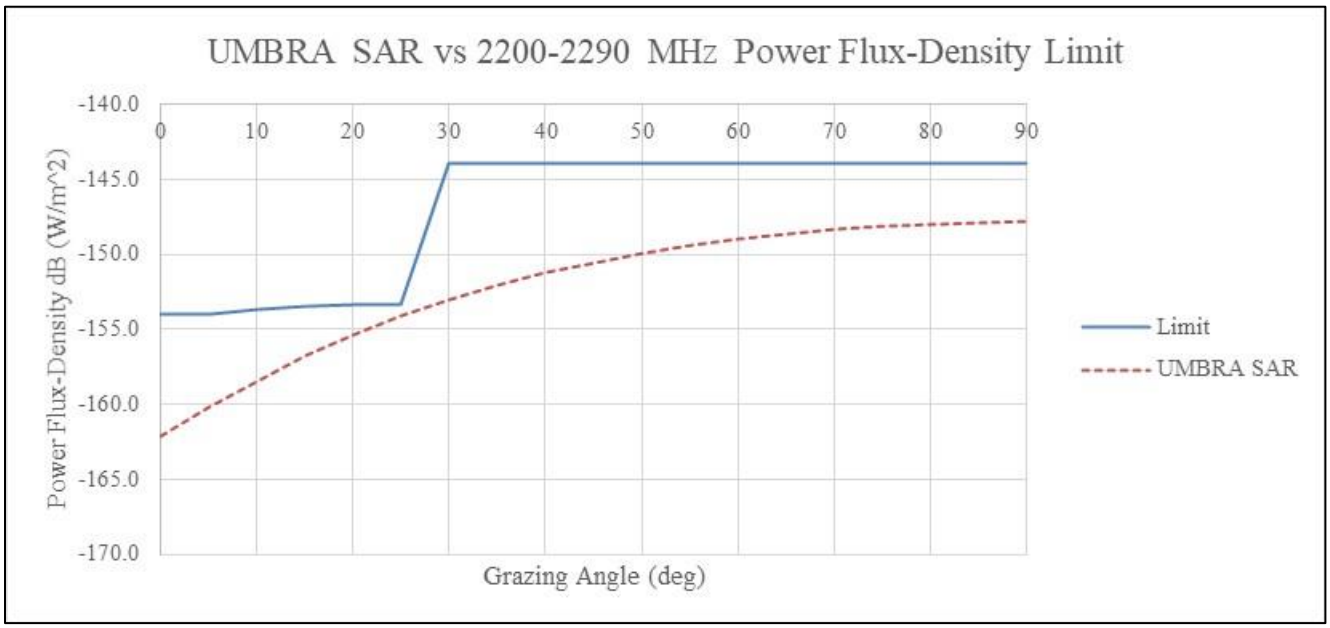
This section demonstrates the Satellite will operate with power flux-density (PFD) below specified limits. For each band shown a worst-case approach was taken to show compliance in even the most outlying case. These settings include the worst-case operational altitude of 500-km.

6.1 Power Flux Density in the band 2200 – 2290 MHz

In accordance with note US303 within the FCC Table of Frequency Allocations the power flux-density at Earth-s surface from non-Federal stations shall not exceed -144 to -155 dBw/m^2/kHz, depending on the angle of arrival, in accordance with ITU Radio Regulation 21.16.

Figure 5 shows the Satellite complies with the power flux-density of ITU radio Regulation 21.16 at all angles of arrival. This analysis assumes peak antenna gain and is thus valid for all vehicle attitude states. Further, the onboard radio power may be adjusted to further reduce power as required to mitigate interference.

Figure 5. Power Flux Density for S-Band (2200-2290 MHz)

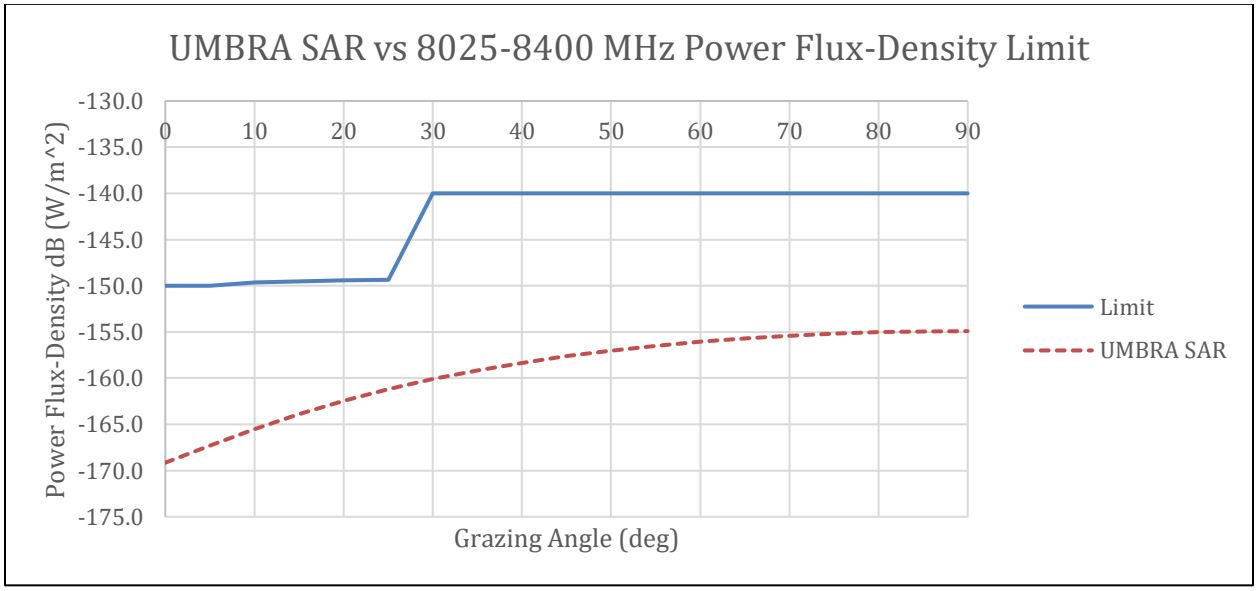


1. plotted against ITU Limits set forth in Section V, Table 21-4

6.2 Power Flux Density in the band 8025 – 8400 MHz

To ensure that interference with any Deep Space Research communications within the adjacent frequency spectrum at 8400-8450 MHz remains below -221 dB(W/(m^2 Hz)), per ITU-R SA.1157-1, Umbra plans to operate such that the highest band edge within the operating frequency (8250 MHz) is more than 125-MHz below the lower edge of the DSN band.

Figure 6: Power Flux Density for X-Band (8025-8275 MHz)



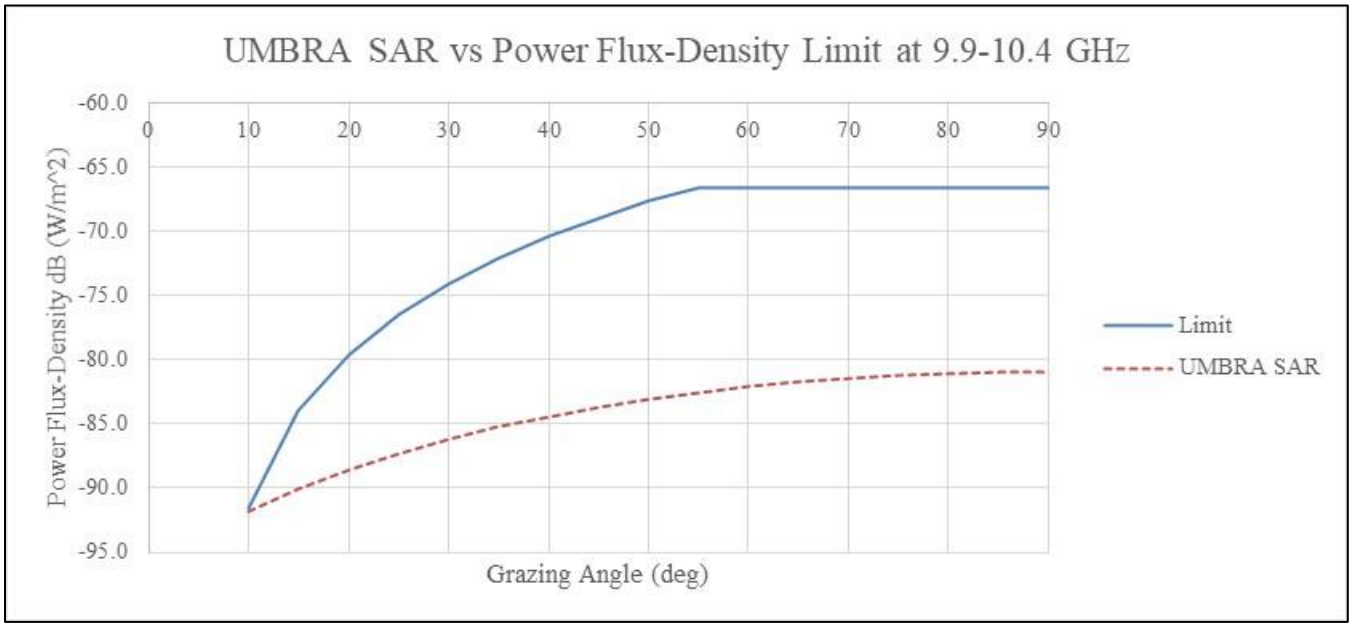
1. Power Flux Density is plotted against ITU limit

6.3 Power Flux Density in the band 9900 – 10400 MHz

PFD limits between 9900 - 10400 MHz were identified within ITU Radio Regulation 21.16 and WRC-15 Table 21-4. Figure 7 shows the simulated worst-case power flux density compared to the allowable limits.

Radar peak output power is controllable through software and may be reduced. Umbra plans to operate at grazing angles greater than or equal to 10 degrees.

Figure 7. Power Flux Density for X-Band (9.9-10.4 GHz)



1. ITU limits per Section 5, Table 21.47

6.4 Power Flux Density at the Geostationary Satellite Orbit

No. 22.5 of the ITU Radio Regulations specifies that in the frequency band 8025-8400 MHz, which the EESS (using non-geostationary satellites) shares with the fixed-satellite service (Earth-to-space) and the meteorological-satellite service (Earth-to-space), the maximum power flux-density produced at the geostationary satellite orbit ("GSO") by any EESS space station shall not exceed –174 dBW/m^2 in any 4 kHz band.

The calculation below shows that the PFD produced by the transmissions from the proposed Umbra SAR satellites does not exceed the limit in No. 22.5, even in the worst possible hypothetical case.

The PFD at the GSO produced by the Satellite transmission is:

$$PFD\ [dBW/m^2\ /4\ kHz] = EIRP\ (dBW) - 71 - 20\log10(D) - 10\log10(BW) – 24$$

Where:

- EIRP is the Maximum EIRP of the transmission, in dBW;
- D is distance between the Satellite and GSO, in km;
- BW is the symbol bandwidth of the transmission, in MHz.

The minimum possible distance between the Satellite and the GSO is 35,786 - 600 = 35,186 km.

Under a hypothetical assumption that the Satellite antenna is radiating at its peak EIRP toward the GSO, with the peak EIRP = 18 dBW and BW = 250 MHz produces a PFD at the GSO of:

$$-192\ dBW/m^2/4\ kHz$$

Even in this unlikely scenario the PFD is 17 dB below the specified maximum.

7.0 Interference Analysis

S-Band Downlink (2200-2290 MHz)

The 2200-2290 MHz band is allocated for Federal use for EESS (Earth-to-space) subject to such conditions as may be applied on a case-by-case basis. Further, transmissions from the satellites operating in this band shall not cause harmful interference to Federal and non-Federal stations operating in accordance with the U.S. Table of Frequency Allocations.

Umbra understands that use and coordination of this band may not be possible for its earth station locations within the United States. It is not seeking approval for such earth stations.

Umbra selected this band after a review of alternatives due to operational needs, available hardware, and compatibility with third-party commercial earth station operators.

Interference between the Satellite and other systems is unlikely because EESS systems operating in the 2200-2290 MHz band normally transmit only in short periods of time while visible from the dedicated receiving earth stations (typically less than 10 minutes for a single pass). Further, the earth station beam required to intercept the transmitted signal is highly directive. Further, the Satellite will only 100 kHz of bandwidth. Further, the Satellite will be configured so as not to exceed the PFD limit for non-federal space stations.

The Satellite is designed to be a non-broadcast. For interference to happen, satellites belonging to different systems would have to travel through the antenna beam of the receiving earth station and transmit at the same time and at same frequency. In such a very unlikely event, interference can be still be avoided by coordinating the satellite transmissions so that they do not occur simultaneously. This frequency coordination is managed by the commercial operator that controls the earth stations.

In addition, orbital parameters can also be adjusted such that phasing of the contacts can be offset over time. The satellite is equipped with a propulsion system which will allow additional maneuverability and phasing throughout their life.

S-Band Uplink (2025-2110 MHz)

The 2025-2110 MHz band is allocated for Federal/non-Federal use for EESS (Earth-tospace) subject to such conditions as may be applied on a case-by-case basis. Further, transmissions from the satellites operating in this band shall not cause harmful interference to Federal and non-Federal stations operating in accordance with the U.S. Table of Frequency Allocations. Data uplink for Umbra TT&C data is coordinated by our ground station vendors per their approved

procedures already in place. This has been coordinated with Federal and non-Federal operators in this band to ensure compliance with this requirement.

X-Band Downlink (8025-8275 MHz)

The 8025-8400 MHz band is allocated for several uses including non-Federal use for EESS (Earth-to-space) subject to such conditions as may be applied on a case-by-case basis. Further, transmissions from the satellites operating in this band shall not cause harmful interference to Federal and non-Federal stations operating in accordance with the U.S. Table of Frequency Allocations. Umbra will coordinate with Federal and non-Federal operators in this band to ensure compliance with this requirement.

Umbra has taken time to understand and include mitigation techniques outlined in the ECC Report 155, for operating its satellite downlink in the 8025 - 8400 MHz band. Below are the key steps taken to minimize risk of interference.

- Satellite will operate in a non-broadcast mode, only radiating when transmitting data to one or more of our planned earth stations
- Satellite will employ a directional antenna
- Satellite will operate well within the power flux density limits
- Satellite will operate in the lower portion of the 8025 – 8400 MHz band

X-Band Radar (9200-10400 MHz)

Umbra demonstrates that the Satellite will meet the limits specified by the ITU for protection of the Fixed Satellite Service in the 9900 - 10400 MHz band. See Section 3.

7.1 Interference Between EESS Systems Operating in the band 8025-8400MHz

Interference between the Satellite and those of other systems is unlikely because EESS systems operating in the 8025-8400 MHz band normally transmit only in short periods of time while visible from the dedicated receiving earth stations (typically less than 10 minutes for a single pass). Further, the Satellite will use the lower 250 MHz of the 375 MHz band.

The Satellite is designed to be a non-broadcast. For interference to happen, satellites belonging to different systems would have to travel through the antenna beam of the receiving earth station and transmit at the same time and at same frequency. In such a very unlikely event, interference can be still be avoided by coordinating the satellite transmissions so that they do not occur simultaneously. This frequency coordination is managed by the commercial operator that controls the earth stations.

In addition, orbital parameters can also be adjusted such that phasing of the contacts can be offset over time. The satellite is equipped with a propulsion system which will allow additional maneuverability and phasing throughout their life.

7.2 Interference with the Fixed Service and the FSS in the band 8025-8400 MHz

Umbra demonstrates that the Satellite will meet the limits specified by the ITU for protection of geostationary FSS satellites in the 8025-8400 MHz band. See Section 6.4 above.

7.3 Protection of the Deep Space Research in the Band 8400-8450 MHz

Umbra will use the lower 250 MHz of the 8025-8400 MHz band, leaving a guard band of 125 MHz to protect the 8400-8450 MHz band. Further, a directive antenna will be employed as shown in Figure 3. Further, the Satellite will operate a non-broadcast mode and will not be intentionally commanded to transmit unless the main beam is oriented towards a licensed earth station.

7.4 Protection of the Radio Astronomy Service in the Frequency Band 10.6-10.7 GHz

The ITU Recommendation RS.2066-0 provides an operational procedure to avoid main-beam to main-beam coupling between Earth exploration-satellite service (EESS) (active) SAR systems when transmitting near 9 600 MHz and radio astronomy service (RAS) stations performing observations in the band 10.6-10.7 GHz in order to avoid damage to the sensitive RAS low noise amplifier.

In accordance with this recommendation Umbra will:

- Establish geographic exclusion zones around RAS sites as required.
- Operate using a 9600 MHz center frequency when bandwidth requirements do not exceed 600 MHz.
- Attempt to coordinate with RAS operators prior to illumination.

8.0 Answers to Previous Questions from FCC OET

Comments from FCC POC are in **BOLD:**

The following should be submitted:

ODAR:	Submitted separately
Point of Communication:	Umbra-2001 (name of satellite)
NTIA Space Record Data form:	**S**ubmitted separately
Transmitter Antenna (Space station):	S-Band & X-Band
Location:	Non-geostationary (500 to 600-km altitude)
Polarization:	RHCP (S-Band Communication) RHCP (X-Band communications), HH or VV (Radar, single simultaneous polarization)
Orientation:	Commanded pointing
Gain (dBi):	5.6 (S-Band Comm) at a beam width of 102°, 50.9 (X-Band SAR) at a beam width of 0.5°, 12 (X-Band Comms) at a beam width of 40°
Receiver Antenna (Earth station):	See Section 4.0.

Orbital characteristics:

Inclination angle (in degree): 97.4 (@583-km)
Apogee (in km): Circular @ 583-km
Perigee (in km): Circular @ 583-km
Period (in hour): 1.61

Number of satellites in the system:	1 (initial application)
Number of transmitting satellites:	1
Number of receiving satellites:	1

Point of contact if interference occurs:

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