Radiation Hazard Analysis
Phased Array Fixed Earth Station

Introduction

This analysis calculates the non-ionizing radiation levels for two new versions of a SpaceX Services, Inc. ("SpaceX Services") user terminal earth station ("UT") for use at fixed locations: one designed for high-performance use cases and one designed for more portable use cases. The calculations performed in this analysis comply with the methods described in FCC Office of Engineering and Technology Bulletin, Number 65 (Edition 97-01) ("Bulletin 65"). This analysis demonstrates that SpaceX Services UTs will not result in exposure levels exceeding the applicable radiation hazard limits.

Bulletin 65 and Section 1.1310 of the Commission's rules specify two separate tiers of exposure limits: one for Occupational/Controlled Exposures and one for General Population/Uncontrolled Exposures. Limits for Occupational/Controlled Exposures apply in situations where persons are exposed as a consequence of their employment and are fully aware of and can control their exposure. These limits also apply in situations where a person is transient through a location where such limits would otherwise apply provided the person is made aware of the potential for exposure. The limits for General Population/Uncontrolled Exposure apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or cannot exercise control over their exposure.

SpaceX Services will deploy two types of each new UT version, one for General Population /Uncontrolled Environments and one for Occupational/Controlled Environments, especially for enterprise customers. These two types differ only in the software that determines their maximum duty cycle. As a result, this analysis discusses the Maximum Permissible Exposure ("MPE") limit for both the General Population/Uncontrolled exposures and the Occupational/Controlled exposures, which for the Ku-band frequencies used by these UTs is a power density equal to 1 mW/cm^2 averaged over a thirty-minute period and 5 mW/cm^2 averaged over a six-minute period, respectively.[1]

Because this application requests authority to deploy two different versions of the UT hardware, SpaceX Services presents four radiation hazard analyses below, one for each of the two versions of the UT hardware for uncontrolled settings and one for each of the two versions of the UT hardware in controlled/occupational settings.

As described in the definitional section below, this report analyzes the maximum power density levels in the vicinity of a UT antenna in three regions: (1) the far field, (2) the near field, and (3) near the main reflector surface. These radiation regions were analyzed using the definitions and formulas in Bulletin 65 for aperture antennas. Note that the SpaceX Services UTs are flat phased array antennas, such that the other region normally included in analyses for parabolic dishes (*i.e.*,

[1] See 47 C.F.R. § 1.1310(e).

between the main reflector and the feed) is not applicable in this case.[2] The results of this analysis are summarized in Tables 1 and 2 for the first version of the UT and Tables 3 and 4 for the second version of the UT, which identifies the potential exposure under worst-case operating conditions.

The Commission's website indicates that Bulletin 65 is currently under review to reflect updated guidance to applicants.[3] However, in the interest of timely review of this application and in an abundance of caution, the results of an analysis reflecting the Updated IEEE Standard are summarized in Tables 1 and 3 (for the General Population/Uncontrolled version) and Tables 2 and 4 (for the Occupational/Controlled version), similarly identifying the potential exposure under worst-case operating conditions. However, SpaceX notes that this standard is excessively conservative for SpaceX's phased array antennas and therefore results in more limited broadband service for American consumers.

UT Description

The UTs are flat phased array antennas capable of steering beams to track NGSO satellites passing within their field of view. At the phased array's equivalent of an "antenna flange," the highest transmit power is 3.69W and 1.37W for UT Versions 1 and 2, respectively.

The UTs transmit bursts of information at designated times that are assigned to the UT by the network. The duty cycle of the uplink transmissions is controlled by the network and independently monitored by the software controlling the UT; this ensures that the transmit duty cycle of a UT cannot exceed a specified level under any circumstances.

Explanation of the Analysis

The "Calculated Values" in Tables 1-4 are calculated using the formulae from Bulletin 65 for a system with continuous (100% transmit duty cycle) transmission. But SpaceX Services UTs transmit only short bursts of data periodically as instructed by the network and are neither designed for nor capable of continuous transmission. Therefore, to compute the effective radiated power density of a SpaceX Services UT, the UT's maximum possible transmitter duty cycle has been adjusted using the Bulletin 65 methodology. Accordingly, the calculated figures reflect the total potential for human exposure based on the length of time that the UTs transmit energy during the relevant period for consideration.

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2 Bulletin 65 also calls for consideration of the transition region between near field and far field. However, the power density in the transition region will be less than the maximum power density in the near field and more than the minimum power density in the far field for the purpose of evaluating potential exposure. Accordingly, if the analysis demonstrates compliance for both the near field and far field, it necessarily demonstrates compliance for the transition region.

3 See Federal Communications Commission, "OET – Bulletins On-line," https://www fcc.gov/general/oet-bulletins-line (visited February 27, 2023).

Results of Analysis

This analysis demonstrates that the SpaceX Services UTs are not a radiation hazard because the UTs do not exceed (1) the MPE limit of 1 mW/cm^2 averaged over a thirty-minute period when used in general population/uncontrolled environments, and (2) the MPE limit of 5 mW/cm^2 averaged over a six-minute period when used in occupational/controlled environments.

Conclusion

This radiation hazard analysis demonstrates that SpaceX Services UTs will not result in exposure levels exceeding the applicable MPE limits.

Definitions

1) Far Field Region

   The far field region extends outward from the antenna surface, beginning at a distance of $\frac{0.6D^2}{\lambda}$ meters where the D is the diameter of the antenna. The maximum power density is calculated using the equation recommended in Bulletin 65.

2) Near Field Region

   The near field region is a volume co-incident with the direction of the main beam extending outward from the antenna surface the length of the near field $\frac{D^2}{4\lambda}$ meters.

3) Transition Region

   The transition region is located between the near field region and the far field region. This region has a power density that decreases with increasing distance. Therefore, the power density in the transition region will be less than the maximum power density in the near field and more than the maximum power density in the far field for the purpose of evaluating potential exposure.

4) Region Near the Antenna Surface

   The power density near the antenna surface can be estimated as equal to four times the power divided by the area of the main reflector surface (phased array illumination is uniform).

TABLE 1: RADIATION FROM SPACEX PHASED ARRAY UT VERSION 1 (GENERAL POPULATION / UNCONTROLLED)[4]

Input Parameters

Antenna Dimensions, D_1, D_2	0.57, 0.36 m
Frequency, f	14.25 GHz
Max Power into antenna, P_{max}	3.69 W
Max EIRP, $EIRP_{max}$	16218 W
Max EIRP, 10 log($EIRP_{max}$)	42.1 dBW
Aperture efficiency, η	74.3%
Maximum Transmit Duty Cycle, DTx[5]	10.2%

Calculated Values

Wavelength, $\lambda = \frac{c}{f}$	0.0211 m
Area of Reflector, $A = D_1 D_2$	0.2052 m^2
Max Antenna Gain, $G_{max} = \frac{\eta 4\pi A}{\lambda^2}$	4322.8
Max Antenna Gain, 10 log(G_{max})	36.4 dBi
Length of Near Field, $R_{nf} = \frac{D_1^2}{4\lambda}$	3.86 m
Beginning of Far Field, $R_{ff} = 0.6\frac{D_1^2}{\lambda}$	9.26 m

Maximum Power Density Calculations

Power Density in Far Field, $S_{ff} = DTx\frac{EIRP_{max}}{4\pi R_{ff}^2}$	0.15 mW/cm^2
Power Density in Near Field, $S_{nf} = DTx\frac{4P_{max}}{\eta A}$	0.99 mW/cm^2
Power Density Off-axis Near Field (20dB below peak), $S_{nf,off-axis} = \frac{S_{nf}}{100}$	0.01 mW/cm^2
Power Density at Antenna Surface, $S_{ref} = DTx\frac{4P_{max}}{A}$	0.73 mW/cm^2

4 Calculated Values and Power Density Calculations may vary due to rounding.
5 As averaged over 30 minutes per FCC OET Bulletin 65 Supplement C.

TABLE 2: RADIATION FROM SPACEX PHASED ARRAY UT VERSION 1 (OCCUPATIONAL / CONTROLLED) [6]

Input Parameters

Antenna Dimensions, D_1, D_2	0.57, 0.36 m
Frequency, f	14.25 GHz
Max Power into antenna, P_{max}	3.69 W
Max EIRP, $EIRP_{max}$	16218 W
Max EIRP, 10 log($EIRP_{max}$)	42.1 dBW
Aperture efficiency, η	74.3%
Maximum Transmit Duty Cycle, DTx[7]	51.5%

Calculated Values

Wavelength, $\lambda = \frac{c}{f}$	0.0211 m
Area of Reflector, $A = D_1 D_2$	0.2052 m^2
Max Antenna Gain, $G_{max} = \frac{\eta 4\pi A}{\lambda^2}$	4322.8
Max Antenna Gain, 10 log(G_{max})	36.4 dBi
Length of Near Field, $R_{nf} = \frac{D_1^2}{4\lambda}$	3.86 m
Beginning of Far Field, $R_{ff} = 0.6\frac{D_1^2}{\lambda}$	9.26 m

Maximum Power Density Calculations

Power Density in Far Field, $S_{ff} = DTx\frac{EIRP_{max}}{4\pi R_{ff}^2}$	0.78 mW/cm^2
Power Density in Near Field, $S_{nf} = DTx\frac{4P_{max}}{\eta A}$	4.99 mW/cm^2
Power Density Off-axis Near Field (20dB below peak), $S_{nf,off-axis} = \frac{S_{nf}}{100}$	0.05 mW/cm^2
Power Density at Antenna Surface, $S_{ref} = DTx\frac{4P_{max}}{A}$	3.70 mW/cm^2

6 Calculated Values and Power Density Calculations may vary due to rounding.
7 As averaged over 6 minutes per FCC OET Bulletin 65 Supplement C.

TABLE 3: RADIATION FROM SPACEX PHASED ARRAY UT VERSION 2 (GENERAL POPULATION / UNCONTROLLED)[8]

Input Parameters

Antenna Dimensions, D_1, D_2	0.29, 0.25 m
Frequency, f	14.25 GHz
Max Power into antenna, P_{max}	1.37 W
Max EIRP, $EIRP_{max}$	2089.0 W
Max EIRP, 10 log($EIRP_{max}$)	33.2 dBW
Aperture efficiency, η	74.3%
Maximum Transmit Duty Cycle, DTx[9]	9.7%

Calculated Values

Wavelength, $\lambda = \frac{c}{f}$	0.0211 m
Area of Reflector, $A = D_1 D_2$	0.0725 m^2
Max Antenna Gain, $G_{max} = \frac{\eta 4\pi A}{\lambda^2}$	1527.3
Max Antenna Gain, 10 log(G_{max})	31.8 dBi
Length of Near Field, $R_{nf} = \frac{D_1^2}{4\lambda}$	1.00 m
Beginning of Far Field, $R_{ff} = 0.6\frac{D_1^2}{\lambda}$	2.40 m

Maximum Power Density Calculations

Power Density in Far Field, $S_{ff} = DTx\frac{EIRP_{max}}{4\pi R_{ff}^2}$	0.28 mW/cm^2
Power Density in Near Field, $S_{nf} = DTx\frac{4P_{max}}{\eta A}$	0.99 mW/cm^2
Power Density Off-axis Near Field (20dB below peak), $S_{nf,off-axis} = \frac{S_{nf}}{100}$	0.01 mW/cm^2
Power Density at Antenna Surface, $S_{ref} = DTx\frac{4P_{max}}{A}$	0.74 mW/cm^2

8 Calculated Values and Power Density Calculations may vary due to rounding.

9 As averaged over 30 minutes per FCC OET Bulletin 65 Supplement C.

TABLE 4: RADIATION FROM SPACEX PHASED ARRAY UT VERSION 2 (OCCUPATIONAL / CONTROLLED)[10]

Input Parameters

Antenna Dimensions, D_1, D_2	0.29, 0.25 m
Frequency, f	14.25 GHz
Max Power into antenna, P_{max}	1.37 W
Max EIRP, $EIRP_{max}$	2089.0 W
Max EIRP, 10 log($EIRP_{max}$)	33.2 dBW
Aperture efficiency, η	74.3%
Maximum Transmit Duty Cycle, DTx[11]	48.9%

Calculated Values

Wavelength, $\lambda = \frac{c}{f}$	0.0211 m
Area of Reflector, $A = D_1 D_2$	0.0725 m^2
Max Antenna Gain, $G_{max} = \frac{\eta 4\pi A}{\lambda^2}$	1527.3
Max Antenna Gain, 10 log(G_{max})	31.8 dBi
Length of Near Field, $R_{nf} = \frac{D_1^2}{4\lambda}$	1.00 m
Beginning of Far Field, $R_{ff} = 0.6\frac{D_1^2}{\lambda}$	2.40 m

Maximum Power Density Calculations

Power Density in Far Field, $S_{ff} = DTx\frac{EIRP_{max}}{4\pi R_{ff}^2}$	1.42 mW/cm^2
Power Density in Near Field, $S_{nf} = DTx\frac{4P_{max}}{\eta A}$	4.99 mW/cm^2
Power Density Off-axis Near Field (20dB below peak), $S_{nf,off-axis} = \frac{S_{nf}}{100}$	0.05 mW/cm^2
Power Density at Antenna Surface, $S_{ref} = DTx\frac{4P_{max}}{A}$	3.71 mW/cm^2

10 Calculated Values and Power Density Calculations may vary due to rounding.

11 As averaged over 6 minutes per FCC OET Bulletin 65 Supplement C.