Radiation Hazard Analysis
Gateway Earth Station

Introduction

This analysis calculates the non-ionizing radiation levels for a SpaceX Services, Inc. ("SpaceX Services") gateway earth station. 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 gateways are generally compliant and will not result in exposure levels exceeding the applicable radiation hazard limits, and any radiation hazard that may exist will be mitigated by limited access and various protocols to ensure safe exposure levels.

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 its gateways in Occupational/Controlled Exposures Environments. The Maximum Permissible Exposure ("MPE") limits for the Ka-band frequencies used by these gateways are a power density equal to 5 mW/cm^2 averaged over a six-minute period (for Occupational/Controlled Exposure) and 1 mW/cm^2 averaged over a thirty-minute period (for General Population/Uncontrolled Exposure).[1]

As described in the definitional section below, this report analyzes the maximum power density levels in the vicinity of a gateway antenna in five regions: (1) the far field, (2) the near field, on-axis, (3) the near field, off-axis, (4) near the main reflector surface, and (5) between the main reflector and the feed mouth. These radiation regions were analyzed using the definitions and formulas in Bulletin 65 for aperture antennas. The results of this analysis are summarized in Tables 1-3, which identifies the potential exposure under worst-case operating conditions.

Gateway Description

The gateway antenna is a 1.5-meter parabolic dish capable of steering its beams to track NGSO satellites passing within its field of view. At the antenna flange, the maximum transmit power is 50W for Ka-band. Although unlikely in practice, for purposes of this analysis we have conservatively assumed that the gateway can transmit at 100% duty cycle.

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[1] *See* 47 C.F.R. § 1.1310(e).

Explanation of the Analysis

The "Calculated Values" in Table 1 are the exposure rates for Ka-band calculated using the formulae from Bulletin 65 for a system with continuous (100% transmit duty cycle) transmission.

The "Calculated Values" include the power density in the near field, off axis, for spacings at least one antenna diameter removed from the center of the main beam as well as the expected power density in the near field, off axis, for a spacing several antenna diameters away based upon a reference cited in Bulletin 65.[2] A calculated value that includes a very conservative assumption of 40 total transmitting antennas all adding in power in the near field, off axis, is also included to calculate the absolute worst case radiation hazard from a multi-antenna site; this worst case radiation hazard will never happen given the distribution of pointing angles of antennas and variable distance to each antenna but is included as a very conservative bounding case.

Results of Analysis

This analysis demonstrates that the SpaceX Services gateway is not a radiation hazard because it does not exceed the MPE limits in generally accessible areas. These gateways will be located in an area clearly marked with Radiation Hazard signage with no access by the general public. The near field region creates no concern for the general public as it lies behind signage where only authorized personnel may enter. RF levels may potentially exceed general population MPE limits in the main beam out to a distance of up to 188.3 meters. However, outside of SpaceX's controlled facility, which maintains a boundary several antenna diameters from any given antenna, the antenna main beam is not accessible to the general public because the antenna minimum elevation angle will be 25 degrees, and no nearby buildings or elevated terrain will intersect with this portion of the antenna main beam. Accordingly, there is no risk of radiation exposure beyond the acceptable limits in generally accessible areas. Around the feed mouth (this measurement is taken at a point between the feed and the sub-reflector), at the main reflector surface, and in the near field on-axis the relevant radiation levels are exceeded. Power to the transmitters will be turned off remotely whenever work needs to be performed in any of these regions. Signage will mark the area for Radiation Hazard and access by qualified personnel only, ensuring awareness and enhancing safety. Even in the extremely conservative case of 40 antennas all adding in power at a given point in the near field, off-axis, the radiation hazard does not exceed the MPE limit. Consequently, there is no risk of radiation exposure beyond the acceptable limits.

[2] Hankin, N., "The Radiofrequency Radiation Environment: Environmental Exposure Levels and RF Radiation Emitting Sources," U.S. Environmental Protection Agency, Washington, D.C. 20460. Report No. EPA 520/1-85-014, July 1986, pp. 26-27

Conclusion

This radiation hazard analysis demonstrates that SpaceX Services gateways will not result in unacceptable radiation exposure levels.

Definitions

1) Far Field Region

The far field region extends outward from the antenna surface, beginning at a distance $\frac{0.6D^2}{\lambda}$ meters where the D is the diameter of the antenna.

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 (main reflector illumination is uniform).

5) Region between the Main Reflector and the Feed

The power radiated from the feed toward the reflector is conical in shape with the vertex at the feed. The maximum power is at the feed mouth and can be estimated as four times the transmit power divided by the area of the feed mouth.

Table 1: Ka band

Input Parameters

Antenna Diameter	D = 1.47 m
Frequency	f = 30.0 GHz
Diameter of Feed Mouth	D_{feed} = 1.07 cm
Max Power into Antenna	P_{max} = 50 W
Aperture efficiency [%]	η = 41.8 %
Maximum Transmit Duty Cycle	DTx = 100 %

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.01\ m$
Area of Reflector	$A = \frac{\pi D^2}{4} = 1.70\ m^2$
Area of Feed Mouth	$A_{feed} = \frac{\pi D_{feed}^2}{4} = 0.0001\ m^2$
Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 89{,}147.8$ $10\log(G_{max}) = 49.5\ dB$
Length of Near Field	$R_{nf} = \frac{D^2}{4\lambda} = 54.01\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D^2}{\lambda} = 129.65\ m$
Main-beam separation distance required to meet the General Population/ Uncontrolled Exposure limit (GP_{lim} = 1mW/cm^2)	$R_1 = \sqrt{DTx\frac{P_{max}G_{max}}{4\pi GP_{lim}}} = 188.3\ m$

Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{max}}{4\pi R_{ff}^2} = 2.11\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4P_{max}}{\eta A} = 28.19\ \frac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = DTx\frac{4P_{max}}{A} = 11.78\ \frac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = DTx\frac{4P_{max}}{A_{feed}} = 223{,}755.7\ \frac{mW}{cm^2}$
Power Density in Near Field, Off Axis	$S_{nf,oa} = S_{nf} - 20dB = 0.28\ \frac{mW}{cm^2}$

Power Density in Near Field, Off Axis, Several Diameters Away[3]	$S_{nf,oa} = S_{nf} - 30dB = 0.028\ \frac{mW}{cm^2}$

[3] Hankin, N., "The Radiofrequency Radiation Environment: Environmental Exposure Levels and RF Radiation Emitting Sources," U.S. Environmental Protection Agency, Washington, D.C. 20460. Report No. EPA 520/1-85-014, July 1986, pp. 26-27