Radiation Hazard Analysis
Fixed Customer Premises Earth Station Terminals

Introduction

This analysis calculates the non-ionizing radiation levels for two types of experimental SpaceX fixed customer premises earth station terminal (collectively, the "CP terminals"). 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 CP terminals are compliant and 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 will typically deploy its CP terminals Occupational/Controlled Environments, but some will be deployed in General Population/Uncontrolled Environments. Accordingly, this analysis discusses only the Maximum Permissible Exposure ("MPE") limit for the more restrictive uncontrolled types of exposure, which for the Ku-band frequencies used by these CP terminals is a power density equal to 1 mW/cm^2 averaged over a thirty-minute period.[1]

As described in the definitional section below, this report analyzes the maximum power density levels in the vicinity of each type of CP terminal antenna in four regions: (1) the far field, (2) the near field, (3) near the main reflector surface, and (4) between the main reflector and the feed.[2] These radiation regions were analyzed using the definitions and formulas in Bulletin 65 for aperture antennas. Note that one of the SpaceX CP terminals is a flat phased array, such that the region between the main reflector and the feed is not applicable in this case. The results of these analyses are summarized in Table 1 (for the phased array) and Table 2 (for the parabolic antenna), which identify the potential exposure under worst-case operating conditions.

CP Terminal Descriptions

Both types of terminals SpaceX intends to deploy transmit bursts of information at designated times that are assigned to the terminal by the network. The duty cycle of the uplink transmissions

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1 *See* 47 C.F.R. § 1.1310(e).

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.

is controlled by the network and independently monitored by the software controlling the CP terminal; this ensures that the transmit duty cycle of a terminal cannot exceed 11% under any circumstances.

The first type of CP terminal is a flat phased array capable of steering its beams to track NGSO satellites passing within its field of view. In addition, as the terminal steers the transmitting beam, it also adjusts the power to maintain a constant level at the receiving antenna of its target satellite, compensating for variations in antenna gain and path loss associated with the steering angle. At the phased array's equivalent of an "antenna flange," the highest transmit power (4.06 W) occurs at maximum slant, while the lowest transmit power (0.76 W) occurs at boresight. There is no difference in transmit power between these CP terminals at the center or edge of the spot or between clear sky or heavy rain conditions.

The second type of CP terminal is a traditional parabolic antenna. Here too, the terminal adjusts the power to maintain a constant level at the receiving antenna of its target satellite. The highest transmit power (0.65 W) occurs at slant, while the lowest (0.21 W) occurs at boresight.

Explanation of the Analysis

The "Calculated Values" in Tables 1 and 2 are the exposure rates calculated using the formulae from Bulletin 65 for a system with continuous (100% transmit duty cycle) transmission. SpaceX phased array terminals, however, transmit only short bursts of data periodically as instructed by the network and are neither designed for nor capable of continuous transmission. Therefore, in order to compute the effective radiated energy of such terminals, the terminal's maximum possible transmitter duty cycle has been used to adjust the values calculated using the Bulletin 65 methodology. Accordingly, the calculated figures in Table 1 reflect the total potential for human exposure based on the length of time that the CP terminal transmits energy during a rolling thirty-minute period.

In Table 2, power density at feed mouth is calculated based on the "fail safe" features of the SpaceX parabolic terminal. When the receive signal is lost due to signal blockage, the transmitter is shut down until the received down link is restored. The transmitter is shutdown in less than 50 milliseconds of the loss of the downlink. Since the areas of high field strength near the reflector and the feed are very sensitive to blockage of the down link, this "fail safe" feature minimizes the potential for human exposure. If the blockage due to human exposure occurs in these areas, the down link will be interrupted causing the transmitter to turn off almost immediately and it will remain off until the blockage is removed. After the blockage is removed, the terminal will have to reacquire the receive downlink and wait to be invited back into the network before the transmitter will be enabled. The complete downlink recovery time is at least 10 seconds, hence the transmitter cannot transmit more than 0.5% of any rolling 30 minute period with significant blockage near the feed mouth.

Results of Analysis

This analysis demonstrates that the SpaceX CP terminals are not a radiation hazard because they do not exceed the MPE limit of 1 mW/cm^2 averaged over a thirty-minute period.

Conclusion

This radiation hazard analysis demonstrates that SpaceX CP terminals 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).

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: RADIATION FROM SPACEX PHASED ARRAY CP TERMINAL

Input Parameters

Antenna Diameter	$D = 0.48$ m
Frequency	$f = 14.5$ GHz
Power into antenna w/ beam at boresight	$P_{min} = 0.76$ W
Power into antenna w/ beam at slant	$P_{max} = 4.06$ W
Aperture efficiency [%]	$\eta = 56.7\%$
Cosine loss w/ beam at slant	$loss = 0.551$
Maximum Transmit Duty Cycle	$DTx = 11\ \%$

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0207\ m$
Area of Reflector	$A = \frac{\pi D^2}{4} = 0.181\ m^2$
Antenna Gain w/ beam at boresight	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 3012.0$ $10\log(G_{max}) = 34.79\ dB$
Antenna Gain w/ beam at slant	$G_{min} = \frac{\eta 4\pi A}{\lambda^2} loss = 1658.6$ $10\log(G_{min}) = 32.20\ dB$
Length of Near Field	$R_{nf} = \frac{D^2}{4\lambda} = 2.78\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D^2}{\lambda} = 6.68\ m$

Power Density Calculations with Beam at Boresight

Power Density in Far Field	$S_{ff} = DTx\frac{P_{min}G_{max}}{4\pi R_{ff}^2} = 0.04\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{min}}{A} = 0.10\ \frac{mW}{cm^2}$
Power Density at Antenna Surface	$S_{ref} = DTx\frac{4P_{min}}{A} = 0.18\ \frac{mW}{cm^2}$

Power Density Calculations with Beam at Slant

Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{min}}{4\pi R_{ff}^2} = 0.13\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{max}}{A} = 0.56\ \frac{mW}{cm^2}$
Power Density at Antenna Surface	$S_{ref} = DTx\frac{4P_{max}}{A} = 0.99\ \frac{mW}{cm^2}$

TABLE 2: RADIATION FROM SPACEX PARABOLIC CP TERMINAL

Input Parameters

Antenna Diameter	D = 1.016 m
Frequency	f = 14.5 GHz
Diameter of Feed Mouth	D_{feed} = 5.77 cm
Max Power into Antenna	P_{max} = 0.65 W
Aperture efficiency [%]	η = 62.1%
Maximum Transmit Duty Cycle	DTx = 11 %
Maximum Fail-Safe Duty Cycle	DFS = 0.5 %

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0207\ m$
Area of Reflector	$A = \frac{\pi D^2}{4} = 0.81\ m^2$
Area of Feed Mouth	$A_{feed} = \frac{\pi D_{feed}^2}{4} = 0.0026\ m^2$
Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 14779.9$ $10\log(G_{max}) = 41.7\ dB$
Length of Near Field	$R_{nf} = \frac{D^2}{4\lambda} = 12.47\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D^2}{\lambda} = 29.94\ m$

Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{max}}{4\pi R_{ff}^2} = 0.01\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{max}}{A} = 0.02\ \frac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = DTx\frac{4P_{max}}{A} = 0.04\ \frac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = DFS\frac{4P_{max}}{A_{feed}} = 0.49\ \frac{mW}{cm^2}$
Power Density Between Main Reflector and Feed	Between 0.04 and 0.49 $\frac{mW}{cm^2}$