Radiation Hazard Analysis
Earth Station in Motion Terminal

Introduction

This analysis calculates the non-ionizing radiation levels for a SpaceX Services, Inc. ("SpaceX Services") Earth Station In Motion terminal ("ESIM terminal"). 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 ESIM 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. Accordingly, this analysis discusses Maximum Permissible Exposure ("MPE") limit for Occupational/Controlled exposures, which for the Ku-band frequencies used by these ESIM terminals is a power density equal to 5 mW/cm^2 averaged over a six-minute period. Similarly, the MPE limit for General Population/Uncontrolled exposure, which is a power density equal to 1 mW/cm^2 averaged over a thirty-minute period.[1]

SpaceX Services will deploy its ESIM terminals in both Occupational/Controlled and General Population/Uncontrolled Exposures. Examples of locations where an ESIM terminal may be deployed with Occupational/Controlled Exposures include the masts of ships or the tops of semi-trucks that are not generally accessible to the public. Terminals with Occupational/Controlled Exposures will have a label attached to the surface of the terminal warning about the radiation hazard and will include a diagram showing the regions around the terminal where the radiation levels could exceed the MPE limit[2]. Examples of where an ESIM terminal may be deployed with General Population/Uncontrolled Exposure are on passenger cars or pleasure boats where the general public may have uncontrolled access to the ESIM terminal. In these cases, the terminals will be limited to the General Population/Uncontrolled MPE levels by reducing the transmit duty cycle of the terminal relative to terminals deployed with Occupational/Controlled Exposures.

As described in the definitional section below, this report analyzes the maximum power density levels in the vicinity of a ESIM terminal 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 ESIM

---

[1] *See* 47 C.F.R. § 1.1310(e).

[2] *See* 47 C.F.R § 25.218(d).

terminal is a flat phased array, such that the other region normally included in analyses for parabolic dishes (*i.e.*, between the main reflector and the feed) is not applicable in this case.[3] The results of this analysis are summarized in Table 1, which identifies the potential exposure under worst-case operating conditions.

ESIM Terminal Description

The ESIM terminal is a flat phased array capable of steering its beams to track NGSO satellites passing within its field of view. 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 ESIM terminals at the center or edge of the spot or between clear sky or heavy rain conditions.

The ESIM terminal transmits bursts of information at designated times that are assigned to the terminal by the network. The duty cycle of the uplink transmissions is controlled by the network and independently monitored by the software controlling the ESIM terminal. Terminals installed with Occupational/Controlled Exposures will be limited to a transmit duty cycle of 33% under all circumstances and terminals deployed with General Population/Uncontrolled Exposures will be limited to a transmit duty cycle of 11% to ensure that the MPE limits are met for those environments.

Explanation of the Analysis

The "Calculated Values" in Table 1 are the exposure rates calculated using the formulae from Bulletin 65 for a system with continuous (100% transmit duty cycle) transmission. SpaceX Services 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 a SpaceX Services ESIM terminal, 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 reflect the total potential for human exposure based on the length of time that the ESIM terminal transmits energy during a rolling six-minute or thirty-minute period, as appropriate for Occupational/Controlled Exposures and General Population/Uncontrolled Exposures.

Definitions

1) Far Field Region

The far field region extends outward from the antenna surface, beginning at a distance of

3 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.

$\frac{0.6D^2}{\lambda}$ 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).

Results of Analysis

This analysis demonstrates that the SpaceX Services ESIM terminal is not a radiation hazard because terminals deployed with Occupational/Controlled Exposures will not exceed the MPE limit of 5 mW/cm^2 averaged over a six-minute period at the surface of the antenna by limiting their duty cycle to 33%. The power density of terminals deployed with Occupational/Controlled Exposures will fall below the General Population/Uncontrolled limits in the transition region between the near and far fields at between 2.78 m and 6.68 m for the surface of the antenna.

Similarly, this analysis demonstrates that the SpaceX Services ESIM terminal is not a radiation hazard because terminals deployed in terminals deployed with General Population/Uncontrolled Exposures will not exceed the MPE limit of 1 mW/cm^2 averaged over a thrity-minute period at the surface of the antenna by limiting their duty cycle to 11%.

Conclusion

This radiation hazard analysis demonstrates that SpaceX Services ESIM terminals deployed with Occupational/Controlled Exposures and with General Population/Uncontrolled Exposures will not result in exposure levels exceeding the applicable MPE limits.

TABLE 1: RADIATION FROM SPACEX SERVICES ESIM TERMINAL

Input Parameters

	Occupational/Controlled	General Population/Uncontrolled
Antenna Diameter	D = 0.48 m	D = 0.48 m
Frequency	f = 14.5 GHz	f = 14.5 GHz
Power into antenna w/ beam at boresight	P_{min} = 0.76 W	P_{min} = 0.76 W
Power into antenna w/ beam at slant	P_{max} = 4.06 W	P_{max} = 4.06 W
Aperture efficiency [%]	η = 56.7%	η = 56.7%
Cosine loss w/ beam at slant	$loss$ = 0.551	$loss$ = 0.551
Maximum Transmit Duty Cycle	DTx = 33 %	DTx = 11 %

Calculated Values

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

Power Density Calculations with Beam at Boresight

	Occupational/Controlled	General Population/Uncontrolled
Power Density in Far Field	$S_{ff} = DTx\frac{P_{min}G_{max}}{4\pi R_{ff}^2} = 0.13\ \frac{mW}{cm^2}$	$S_{ff} = DTx\frac{P_{min}G_{max}}{4\pi R_{ff}^2} = 0.04\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{min}}{A} = 0.31\ \frac{mW}{cm^2}$	$S_{nf} = DTx\frac{4\eta P_{min}}{A} = 0.10\ \frac{mW}{cm^2}$
Power Density at Antenna Surface	$S_{ref} = DTx\frac{4P_{min}}{A} = 0.55\ \frac{mW}{cm^2}$	$S_{ref} = DTx\frac{4P_{min}}{A} = 0.18\ \frac{mW}{cm^2}$

Power Density Calculations with Beam at Slant

	Occupational/Controlled	General Population/Uncontrolled
Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{min}}{4\pi R_{ff}^2} = 0.40\ \frac{mW}{cm^2}$	$S_{ff} = DTx\frac{P_{max}G_{min}}{4\pi R_{ff}^2} = 0.13\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{max}}{A} = 1.68\ \frac{mW}{cm^2}$	$S_{nf} = DTx\frac{4\eta P_{max}}{A} = 0.56\ \frac{mW}{cm^2}$
Power Density at Antenna Surface	$S_{ref} = DTx\frac{4P_{max}}{A} = 2.96\ \frac{mW}{cm^2}$	$S_{ref} = DTx\frac{4P_{max}}{A} = 0.99\ \frac{mW}{cm^2}$