Radiation Hazard Analysis
High Performance Phased Array Earth Station In Motion

Introduction

This analysis calculates the non-ionizing radiation levels for a SpaceX Services, Inc. ("SpaceX Services") high-performance phased array earth station for use on moving platforms ("HP ESIM"). 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 HP ESIMs 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 Services will ensure installation of HP ESIM terminals on vehicles, vessels, and aircraft by qualified installers who have an understanding of the antenna's radiation environment and the measures best suited to maximize protection of the general public and persons operating the vehicle and equipment. Many HP ESIMs will be deployed in Occupational/Controlled Environments. When deployed as ESAAs, they will be installed on the top of commercial aircraft, well away from the public—whether on the airport tarmac (where the public is not allowed) or in flight. In addition, many installations will be made on vehicles and vessels in areas that are inaccessible to the public as well. However, some HP ESIMs will likely be deployed in General Population/Uncontrolled Environments as well. Accordingly, SpaceX will deploy two versions of these terminals that differ only in the software that determines their maximum duty cycle, and will ensure that the higher duty cycle is only deployed in areas that are not accessible to the general public. As a result, this analysis discusses the Maximum Permissible Exposure ("MPE") limit for both the Occupational/Controlled exposures and for General Population/Uncontrolled exposures, which for the Ku-band frequencies used by these HP ESIMs is a power density equal to 5 mW/cm^2 averaged over a six-minute period and 1 mW/cm^2 averaged over a thirty-minute period, respectively.[1]

As described in the definitional section below, this report analyzes the maximum power density levels in the vicinity of an HP ESIM 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 HP ESIM is a flat phased array, such that the other region normally included in analyses for parabolic dishes

1 *See* 47 C.F.R. § 1.1310(e).

(*i.e.*, between the main reflector and the feed) is not applicable in this case.[2] The results of this analysis are summarized in Table 1 (for the General Population/Uncontrolled version) and Table 2 (for the Occupational/Controlled version), each of which identifies the potential exposure under worst-case operating conditions.

HP ESIM Description

The HP ESIM 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 to the extent possible, 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 is 4.0 W. There is no difference in transmit power between HP ESIMs at the center or edge of the spot or between clear sky or heavy rain conditions.

The HP ESIM 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 HP ESIM; this ensures that the transmit duty cycle of a terminal cannot exceed a specified level under any circumstances.

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 Services HP ESIMs, 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 HP ESIM, 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 HP ESIM transmits energy during the relevant period for consideration.

Results of Analysis

This analysis demonstrates that the SpaceX Services HP ESIM is not a radiation hazard because the terminal does not exceed the MPE limit of 1 mW/cm^2 averaged over a thirty-minute period.

Conclusion

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

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.

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 HP PHASED ARRAY EARTH STATION IN MOTION (GENERAL POPULATION/UNCONTROLLED)

Input Parameters

Antenna Dimensions	D_1 = 0.52 m, D_2 = 0.48 m
Frequency	f = 14.5 GHz
Max Power into antenna	P_{max} = 4.0 W
Max EIRP	$EIRP_{max}$ = 6606.9 W $10\log(EIRP_{max}) = 38.2\ dBW$
Aperture efficiency [%]	η = 74.2%
Maximum Transmit Duty Cycle	DTx = 15.5%

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0207\ m$
Area of Reflector	$A = 0.2496\ m^2$
Max Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 5437$ $10\log(G_{max}) = 37.35\ dBi$
Length of Near Field	$R_{nf} = \frac{D_1^2}{4\lambda} = 3.27\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D_1^2}{\lambda} = 7.84\ m$

Maximum Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{EIRP_{max}}{4\pi R_{ff}^2} = 0.13\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{max}}{A} = 0.74\ \frac{mW}{cm^2}$
Power Density at Antenna Surface	$S_{ref} = DTx\frac{4P_{max}}{A} = 0.99\ \frac{mW}{cm^2}$

Table 2: Radiation from SpaceX HP Phased Array Earth Station in Motion (Occupational/Controlled)

Input Parameters

Antenna Dimensions	$D_1 = 0.52$ m, $D_2 = 0.48$ m
Frequency	$f = 14.5$ GHz
Max Power into antenna	$P_{max} = 4.0$ W
Max EIRP	$EIRP_{max} = 6606.9$ W $10\log(EIRP_{max}) = 38.2\ dBW$
Aperture efficiency [%]	$\eta = 74.2\%$
Maximum Transmit Duty Cycle	$DTx = 33\%$

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0207\ m$
Area of Reflector	$A = 0.2496\ m^2$
Max Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 5437$ $10\log(G_{max}) = 37.35\ dBi$
Length of Near Field	$R_{nf} = \frac{D_1^2}{4\lambda} = 3.27\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D_1^2}{\lambda} = 7.84\ m$

Maximum Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{EIRP_{max}}{4\pi R_{ff}^2} = 0.28\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4\eta P_{max}}{A} = 1.57\ \frac{mW}{cm^2}$
Power Density Off-axis Near Field (20dB below peak)	$S_{nf,off\ axis} = \frac{S_{nf}}{100} = 0.0157\ \frac{mW}{cm^2}$
Power Density at Antenna Surface	$S_{ref} = DTx\frac{4P_{max}}{A} = 2.12\ \frac{mW}{cm^2}$