Radiation Hazard Analysis
Gateway Earth Station

Introduction

This analysis calculates the non-ionizing radiation levels for a SpaceX Services, Inc. ("SpaceX Services") gateway site. 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 gateway sites are 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 fixed earth station transmitters (gateway antennas) in Occupational/Controlled Exposures environments. The Maximum Permissible Exposure ("MPE") limits for all frequencies used by these gateway antennas 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 as well as the summated power density expected from all gateway antennas at a given gateway site.

Gateway Antenna Description

The gateway antenna has a 2.0-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 per frequency band is 70W at Ka-band, 20W at V-Band, 40W at E-band, and 100W at W-band. Note the antenna is capable of transmitting simultaneously in all four bands. Although unlikely in practice, for simplifying this analysis we have conservatively assumed that the gateway antenna can transmit at 100% duty cycle.

[1] *See* 47 C.F.R. § 1.1310(e).

Gateway Site Description

The gateway site is an area that contains 40 gateway antennas. These gateway antennas function completely independent of each other and can transmit simultaneously. Further, the pointing angles of each gateway antenna are completely independent. Given the overall objective of the gateway site is to connect to as many independent NGSO satellites as possible at any given instant in time, the pointing angles (azimuth and elevation) are well distributed, and no two gateway antennas would ever point in the same direction. However, for simplifying this analysis, we have conservatively assumed the gateway antennas will all be oriented to have their main-beam overlap at a common, nearby conjunction location. The standard layout of a gateway site including the site boundaries–typically a 2.5 meter high fence–are shown in Figure 1.

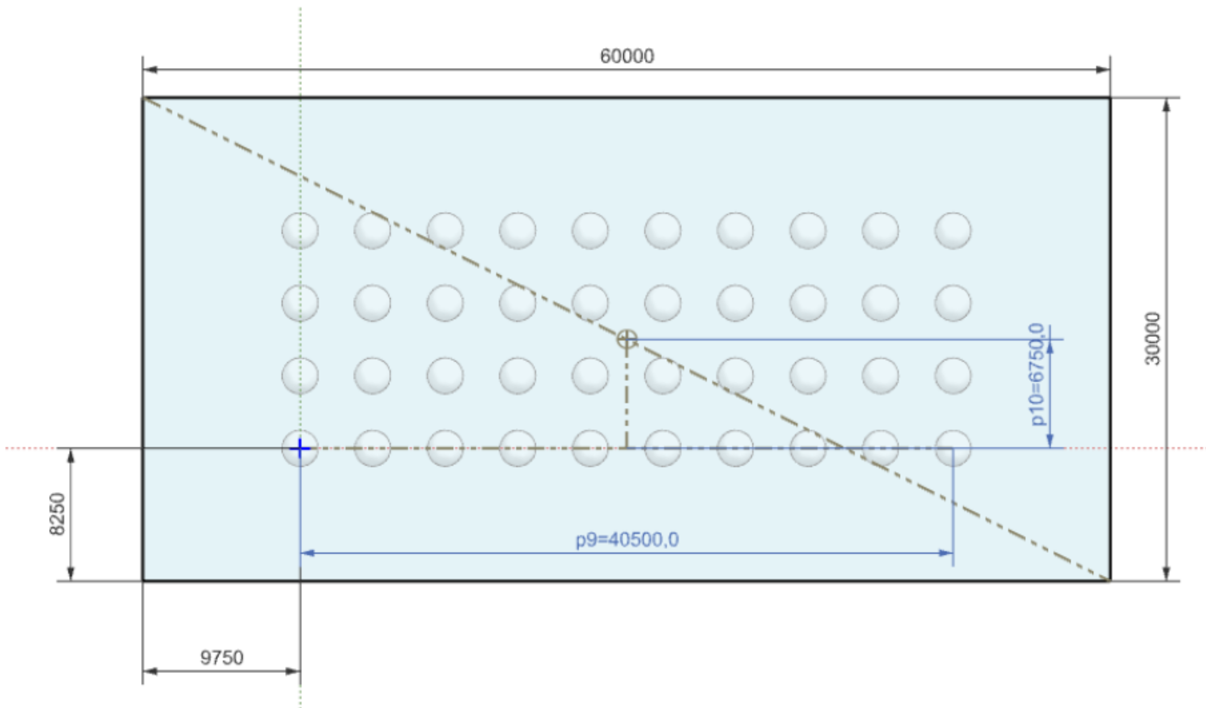

Figure 1: Standard layout of a gateway site

Explanation of the Analysis

The "Calculated Values" in Table 1 through Table 4 are individual exposure rates for Ka-band, V-band, E-band, and W-band, calculated using formulae from Bulletin 65 for a gateway with continuous (100% duty cycle) transmission. Two important calculated values to note are: 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 expected power density in the near field, off axis, for a spacing several antenna diameters away. These are based upon a reference cited in Bulletin 65, published by the US EPA.[2] The "Calculated Values" for Table 5 are exposure rates when transmitting simultaneously in all four bands, calculated using the formulae from Bulletin 65 for a system with continuous (100% duty cycle) transmission. However, it is not accurate to use these equations alone to determine the total summated power density at a location where a person could be, as the distance from observer to each gateway antenna under consideration is different. Rather than calculating a single value for *off axis power density at least one or more antenna diameters away*, and multiplying by the number of antennas, a more compressive theoretical calculation is presented. A review of Hankin (1986, pp. 49-50) indicates that exponential reductions in near field power density occur with an increase in lateral distance from the main beam ("off-axis") as well as longitudinal distance from the antenna reflector. Complementing this modeling method, Bulletin 65 indicates that antenna radiation patterns can be useful for practical estimation of RF fields in the off-axis vicinity of aperture antennas, and that these are generally sufficient for estimating RF field levels in the surrounding environment. To maximize the accuracy of the analysis, power flux density was first simulated in the near field of a *single* gateway. Then, it was verified that the output of that simulation aligned with figure 14 presented in Hankin (1986, pp. 50), where near field power density falls rapidly with further separation from the main beam. These simulations were done using industry standard simulation tools.

A simulation of power density around the gateway site was completed for all four frequency bands, targeting a height of 2m above ground level. A 2m height was chosen as it is conservatively above the P99 stature height of the U.S. population,[3] who are the tallest percentage of the population most likely to be around the site. Main-beam elevation of the gateway antennas was fixed at their minimum elevation angle, 15 degrees above the horizon. The combined near field power flux density of all frequency bands was then overlaid on the area around the gateway site. This simulates the power density field in all areas that could be accessed by the general population. The area inside of the gateway site boundary was not considered, as it is restricted access only.

To account for multiple gateway antennas, the total power density of 40 gateway antennas (the maximum number installed per site) was summated at all points in a reasonable vicinity to the gateway site (≥80 meters away in every direction) extending from the gateway site's boundary. Figure 2 shows the analyzed near field space and gateway antenna locations. All gateway antennas were pointed at a common location: 50 m distance from site center (+y direction in figure 2), at 15 degree elevation above the horizon. This very conservative configuration would never occur at a gateway site, given that operationally each gateway antenna points to distinct satellites in different regions of the sky. However, it greatly simplifies the analysis.

---

[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

[3] "Basic human body measurements for technological design—Part 2: Statistical summaries of body measurements from national populations," CP 401, Ch. de Blandonnet 8, CH-1214 Vernier, Geneva. ISO/TR 7250-2:2024, 2024, pp.39

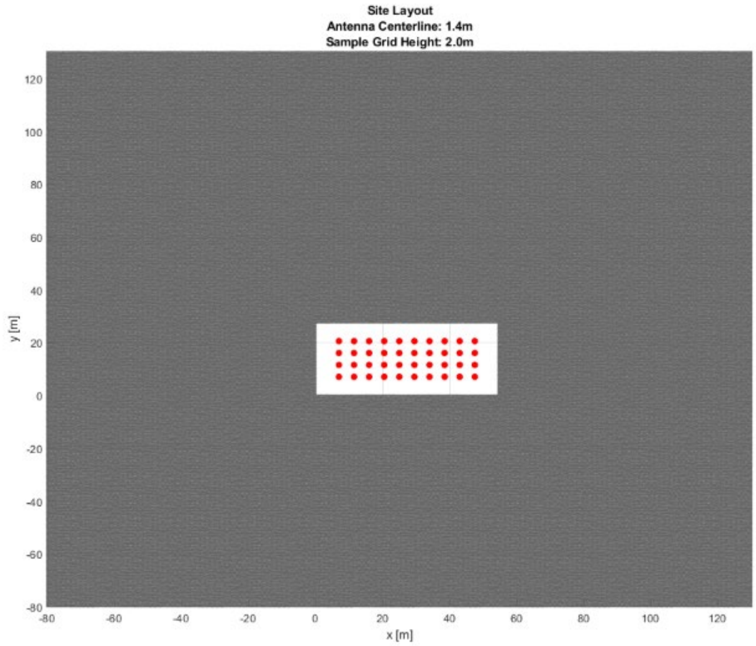

Figure 2: Analyzed gateway site near field space, red dots indicate gateway locations, white space indicates the interior fenced area of the site (not analyzed) and the grey area is all analyzed space around the site

Results of Analysis

Figure 3 shows a plot of relative power density in the near field for one gateway antenna. The reference level 0dB is associated with antenna aperture power density. This is plotted on axes of distance from the gateway antenna aperture, and the theta angle ("off-axis" angle), relative to the direction that the gateway antenna is pointed. The results align well with results presented in Hankin (1986)[4] for a circular aperture antenna, where power density decreases rapidly with increasing separation distance from the main beam.

This same method was iterated over multiple times, to calculate the total power density from all gateway antennas at a site, at a uniform 2m height above ground level, outside the restricted access area surrounding the gateway site.

[4] 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

\

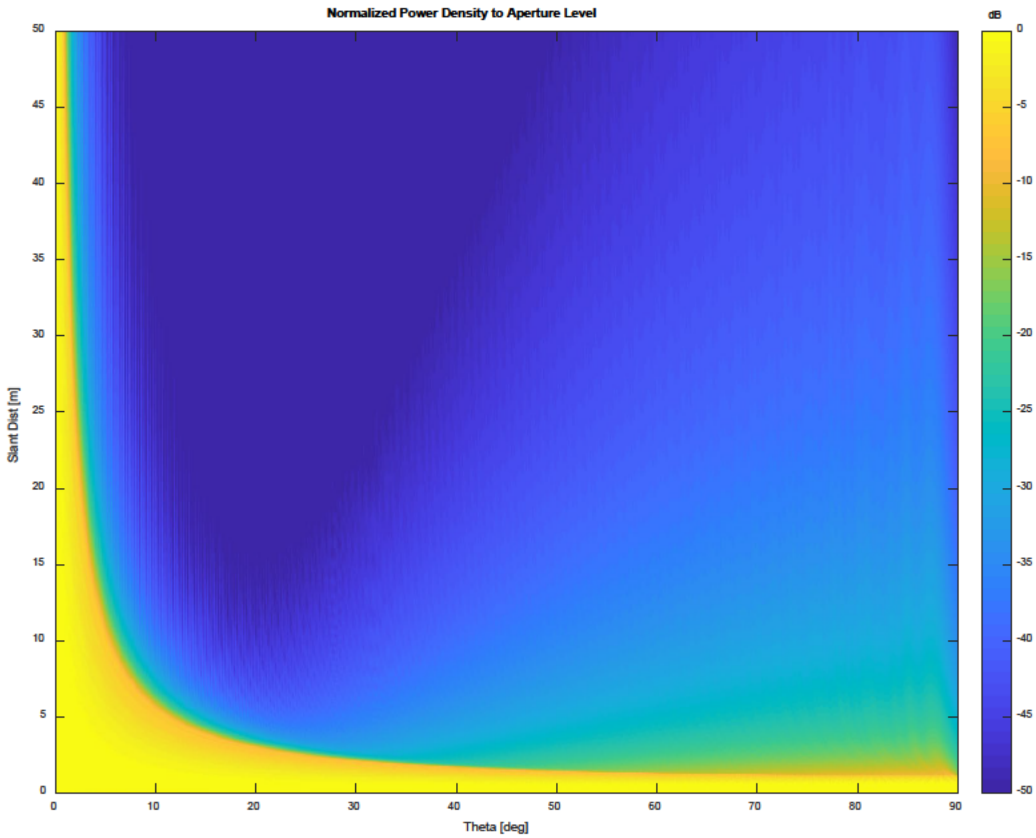

Figure 3: The total field strength from a gateway antenna at 100% duty cycle with all frequencies transmitting simultaneously.

Figure 4 plots power density at all points in the analyzed space at that 2m height. No point in the analyzed space exceeded the MPE limits for the general population, as power density was elevated to less than 0.1 mW/cm^2 outside the restricted access area, and only in limited regions. RF levels may potentially exceed general population MPE limits, in the main beam, at distances less than or equal to 1,528 meters for all bands in the aggregate. However, this occurs sufficiently above the standing height of persons outside of the restricted access area (i.e. higher than 2 meters) which ensures a boundary distance of several antenna diameters from any given gateway antenna to the general public. Further, antenna minimum elevation angle will be 15 degrees and no nearby buildings or elevated terrain will intersect with any portion of the main beam. Accordingly, there is no risk of radiation exposure beyond MPE limits for general population in generally accessible areas. Around the feed mouth (a point between the feed and the sub-reflector), at the main reflector surface, and in the on-axis near field, the MPE levels are exceeded. Standard operating procedure requires occupational workers to turn off power to the transmitters remotely whenever work needs to be performed in any of these regions. This mitigates the risk of exposure to high power densities. In addition, signage will mark the area for Radiation Hazards and access by qualified personnel only, ensuring awareness and enhancing safety.

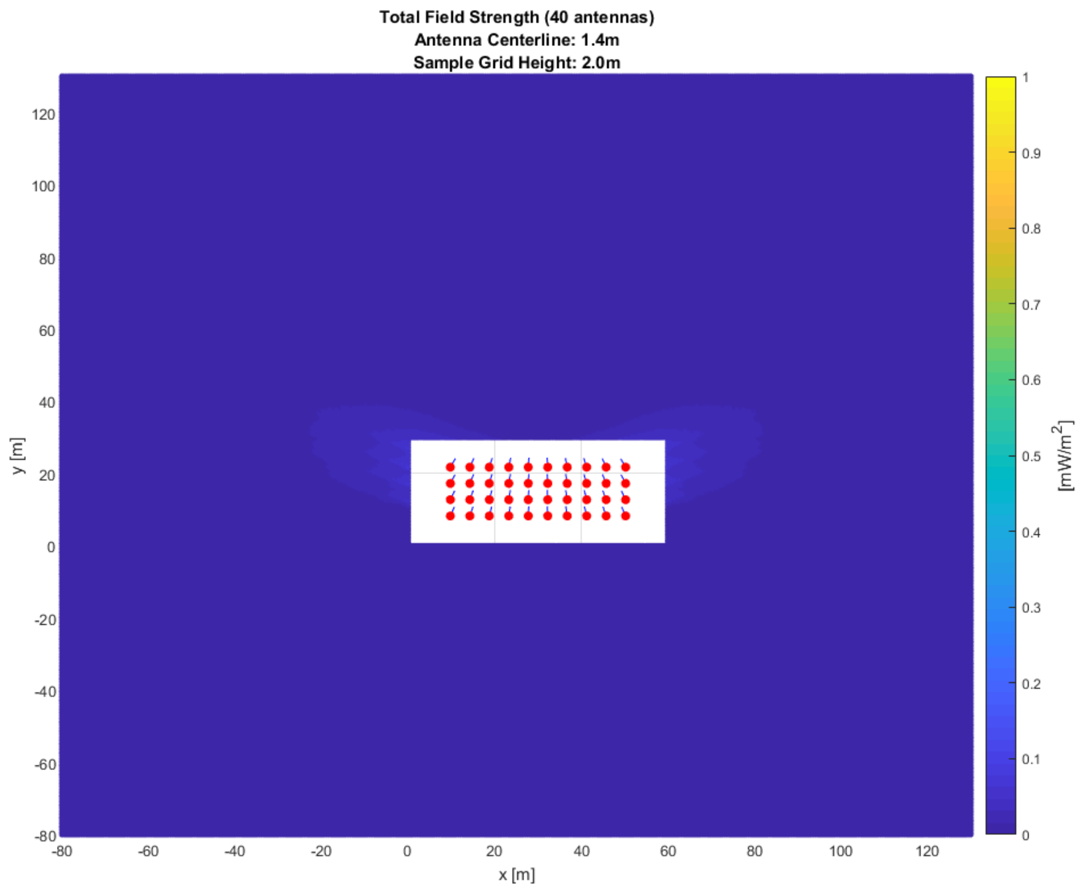

Figure 4: The total field strength at 2-meter height, from all gateway antennas at 100% duty cycle, with all frequencies transmitting simultaneously.

Conclusion

This analysis demonstrates that the SpaceX Services gateway site is not a radiation hazard because accessible areas around it do not exceed MPE limits for general population, and in fact are below those limits by an order of magnitude. Even in the extremely conservative case of 40 gateway antennas all pointing to the same spatial location outside the site fence where near field power density is summated and the general population could stand, MPE limits for general population are not exceeded. To prevent occupational exposure from exceeding occupational limits, SpaceX will meet FCC's requirements for Category III mitigating actions.[5] Gateway antennas will be installed inside of a restricted access area with positive access controls (a fenced area with locked gate), outside of which Radiation Hazard signage (yellow "CAUTION" signs) will be posted. No access by the general public will be allowed, as only occupational personnel can unlock and enter sites. All occupational personnel are trained on the locations of radiation hazards, how to reduce the radiation hazard of a gateway antenna via "lockout/tagout" controls, and how to wear a

[5] *See* 47 CFR 1.1307(b)(4)

dosimeter to track their time-averaged dose. Consequently, there is no risk of radiation exposure beyond acceptable occupational limits.

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 = 1.999 m
Frequency	f = 29.0 GHz
Diameter of Feed Mouth	D_{feed} = 1.1 cm
Max Power into Antenna	P_{max} = 70 W
Aperture efficiency [%]	η = 69 %
Maximum Transmit Duty Cycle	DTx = 100 %

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0103\ m$
Area of Reflector	$A = \frac{\pi D^2}{4} = 3.14\ m^2$
Area of Feed Mouth	$A_{feed} = \frac{\pi D_{feed}^2}{4} = 0.0001\ m^2$
Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 254{,}289$ $10\log(G_{max}) = 54.1\ dB$
Length of Near Field	$R_{nf} = \frac{D^2}{4\lambda} = 97\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D^2}{\lambda} = 232\ m$
Main-beam separation distance required to meet the General Population/ Uncontrolled Exposure limit (GP_{lim} = 1mW/cm^2)	$R_{1,Ka} = \sqrt{DTx\frac{P_{max}G_{max}}{4\pi GP_{lim}}} = 376\ m$

Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{max}}{4\pi R_{ff}^2} = 2.6\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4P_{max}}{\eta A} = 12.9\ \frac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = DTx\frac{4P_{max}}{A} = 8.92\ \frac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = DTx\frac{4P_{max}}{A_{feed}} = 2{,}946{,}339\ \frac{mW}{cm^2}$

Power Density in Near Field, Off Axis	$S_{nf,oa} = S_{nf} - 20dB = 0.129 \frac{mW}{cm^2}$
Power Density in Near Field, Off Axis, Several Diameters Away[6]	$S_{nf,oa} = S_{nf} - 30dB = 0.013 \frac{mW}{cm^2}$

Table 2: V band

Input Parameters

Antenna Diameter	D = 1.999 m
Frequency	f = 49 GHz
Diameter of Feed Mouth	D_{feed} = 1.1 cm
Max Power into Antenna	P_{max} = 20 W
Aperture efficiency [%]	η = 67 %
Maximum Transmit Duty Cycle	DTx = 100 %

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0061\ m$
Area of Reflector	$A = \frac{\pi D^2}{4} = 3.14\ m^2$
Area of Feed Mouth	$A_{feed} = \frac{\pi D_{feed}^2}{4} = 0.0001\ m^2$
Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 704{,}936$ $10\log(G_{max}) = 58.5\ dB$
Length of Near Field	$R_{nf} = \frac{D^2}{4\lambda} = 163\ m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D^2}{\lambda} = 392\ m$
Main-beam separation distance required to meet the General Population/ Uncontrolled Exposure limit (GP_{lim} = 1 mW/cm^2)	$R_{1,E} = \sqrt{DTx\frac{P_{max}G_{max}}{4\pi GP_{lim}}} = 335\ m$

[6] 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

Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{max}}{4\pi R_{ff}^2} = 0.73\ \frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4P_{max}}{\eta A} = 3.8\ \frac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = DTx\frac{4P_{max}}{A} = 2.55\ \frac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = DTx\frac{4P_{max}}{A_{feed}} = 841{,}811\ \frac{mW}{cm^2}$
Power Density in Near Field, Off Axis	$S_{nf,oa} = S_{nf} - 20dB = 0.038\ \frac{mW}{cm^2}$
Power Density in Near Field, Off Axis, Several Diameters Away[7]	$S_{nf,oa} = S_{nf} - 30dB = 0.004\ \frac{mW}{cm^2}$

Table 3: E band

Input Parameters

Antenna Diameter	D = 1.999 m
Frequency	f = 83.5 GHz
Diameter of Feed Mouth	D_{feed} = 1.1 cm
Max Power into Antenna	P_{max} = 40 W
Aperture efficiency [%]	η = 79 %
Maximum Transmit Duty Cycle	DTx = 100 %

Calculated Values

Wavelength	$\lambda = \frac{c}{f} = 0.0036\ m$
Area of Reflector	$A = \frac{\pi D^2}{4} = 3.14\ m^2$
Area of Feed Mouth	$A_{feed} = \frac{\pi D_{feed}^2}{4} = 0.0001\ m^2$
Antenna Gain	$G_{max} = \frac{\eta 4\pi A}{\lambda^2} = 2{,}413{,}697$ $10\log(G_{max}) = 63.8\ dB$

[7] 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

Length of Near Field	$R_{nf} = \frac{D^2}{4\lambda} = 278\, m$
Beginning of Far Field	$R_{ff} = 0.6\frac{D^2}{\lambda} = 668\, m$
Main-beam separation distance required to meet the General Population/ Uncontrolled Exposure limit (GP_{lim} = 1 mW/cm^2)	$R_{1,E} = \sqrt{DTx\frac{P_{max}G_{max}}{4\pi GP_{lim}}} = 876\, m$

Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\frac{P_{max}G_{max}}{4\pi R_{ff}^2} = 1.73\,\frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\frac{4P_{max}}{\eta A} = 6.45\,\frac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = DTx\frac{4P_{max}}{A} = 5.10\,\frac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = DTx\frac{4P_{max}}{A_{feed}} = 1{,}683{,}622\,\frac{mW}{cm^2}$
Power Density in Near Field, Off Axis	$S_{nf,oa} = S_{nf} - 20dB = 0.0645\,\frac{mW}{cm^2}$
Power Density in Near Field, Off Axis, Several Diameters Away[8]	$S_{nf,oa} = S_{nf} - 30dB = 0.0065\,\frac{mW}{cm^2}$

Table 4: W band

Input Parameters

Antenna Diameter	D = 1.999 m
Frequency	f = 103.13 GHz
Diameter of Feed Mouth	D_{feed} = 1.1 cm
Max Power into Antenna	P_{max} = 100 W
Aperture efficiency [%]	η = 79.5 %
Maximum Transmit Duty Cycle	DTx = 100 %

[8] 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

Calculated Values

Wavelength	$\lambda = \dfrac{c}{f} = 0.0029\ m$
Area of Reflector	$A = \dfrac{\pi D^2}{4} = 3.14\ m^2$
Area of Feed Mouth	$A_{feed} = \dfrac{\pi D_{feed}^2}{4} = 0.0001\ m^2$
Antenna Gain	$G_{max} = \dfrac{\eta 4\pi A}{\lambda^2} = 3{,}704{,}911$ $10\log(G_{max}) = 65.7\ dB$
Length of Near Field	$R_{nf} = \dfrac{D^2}{4\lambda} = 344\ m$
Beginning of Far Field	$R_{ff} = 0.6\dfrac{D^2}{\lambda} = 825\ m$
Main-beam separation distance required to meet the General Population/ Uncontrolled Exposure limit (GP_{lim} = 1 mW/cm^2)	$R_{1,E} = \sqrt{DTx\dfrac{P_{max}G_{max}}{4\pi GP_{lim}}} = 986\ m$

Power Density Calculations

Power Density in Far Field	$S_{ff} = DTx\dfrac{P_{max}G_{max}}{4\pi R_{ff}^2} = 4.34\ \dfrac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = DTx\dfrac{4P_{max}}{\eta A} = 16.0\ \dfrac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = DTx\dfrac{4P_{max}}{A} = 12.8\ \dfrac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = DTx\dfrac{4P_{max}}{A_{feed}} = 4{,}209{,}056\ \dfrac{mW}{cm^2}$
Power Density in Near Field, Off Axis	$S_{nf,oa} = S_{nf} - 20dB = 0.16\ \dfrac{mW}{cm^2}$
Power Density in Near Field, Off Axis, Several Diameters Away[9]	$S_{nf,oa} = S_{nf} - 30dB = 0.016\ \dfrac{mW}{cm^2}$

[9] 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

Table 5: Ka band + V band + E band + W band

Calculated Values

Length of Near Field (min R_{nf} between Ka-band and E-band)	$R_{nf\,(Ka-Band)} = 96.6\,m$
Beginning of Far Field (max R_{ff} across bands)	$R_{ff} = 904\,m$
Main-beam separation distance required to meet the General Population/ Uncontrolled Exposure limit (GP_{lim} = 1 mW/cm^2)	$R_1 = \sqrt{R_{1,Ka}^2 + R_{1,V}^2 + R_{1,E}^2 + R_{1,W}^2} = 1{,}993\,m$

Power Density Calculations

Power Density in Far Field	$S_{ff} = S_{ff\,(Ka-Band)} + S_{ff\,(V-Band)} + S_{ff\,(E-Band)} + S_{ff\,(W-Band)} = 9.4\,\frac{mW}{cm^2}$
Power Density in Near Field	$S_{nf} = S_{nf\,(Ka-Band)} + S_{nf\,(V-Band)} + S_{nf\,(E-Band)} + S_{nf\,(W-Band)} = 39.2\,\frac{mW}{cm^2}$
Power Density at Antenna Surface (Main Reflector)	$S_{ref} = S_{ref\,(Ka-Band)} + S_{ref\,(V-Band)} + S_{ref\,(E-Band)} + S_{ref\,(W-Band)} = 29.3\,\frac{mW}{cm^2}$
Power Density at Feed Mouth	$S_{feed} = S_{feed\,(Ka-Band)} + S_{feed\,(V-Band)} + S_{feed\,(E-Band)} + S_{feed\,(W-Band)} = 9{,}680{,}829\,\frac{mW}{cm^2}$
Power Density in Near Field, Off Axis	$S_{nf,oa} = S_{nf} - 20dB = 0.39\,\frac{mW}{cm^2}$
Power Density in Near Field, Off Axis, Several Diameters Away[10]	$S_{nf,oa2} = S_{nf} - 30dB = 0.039\,\frac{mW}{cm^2}$

[10] 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