

ATTACHMENT 3

RaySat StealthRay Antenna

Radiation Hazard Analysis

This analysis predicts the radiation levels around a proposed earth station complex, comprised of a phased array antenna. This report is developed in accordance with the prediction methods contained in OET Bulletin No. 65, Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields, Edition 97-01, pp 26-30. The maximum level of non-ionizing radiation to which employees may be exposed is limited to a power density level of 5 milliwatts per square centimeter (5 mW/cm^2) averaged over any 6 minute period in a controlled environment and the maximum level of non-ionizing radiation to which the general public is exposed is limited to a power density level of 1 milliwatt per square centimeter (1 mW/cm^2) averaged over any 30 minute period in a uncontrolled environment. Note that the worse-case radiation hazards exist along the beam axis. Under normal circumstances, it is highly unlikely that the antenna axis will be aligned with any occupied area since that would represent a blockage to the desired signals, thus rendering the link unusable.

Earth Station Technical Parameter Table

Antenna Actual Diameter	.59x0.8 meters
Antenna Surface Area	.472 sq. meters
Antenna Isotropic Gain	26.75dBi
Number of Identical Adjacent Antennas	1
Nominal Antenna Efficiency (ϵ)	10%
Nominal Frequency	14250 MHz
Nominal Wavelength (λ)	0.0211 meters
Maximum Transmit Power / Carrier	3 Watts
Number of Carriers	1
Total Transmit Power	3 Watts
W/G & Radome Loss	1.75 dB
Total Feed Input Power	2.005 Watts
Near Field Limit	$R_{\text{nf}} = D^2/4\lambda = 4.13 \text{ meters}$
Far Field Limit	$R_{\text{ff}} = 0.6 D^2/\lambda = 9.92 \text{ meters}$
Transition Region	R_{nf} to R_{ff}

In the following sections, the power density in the above regions, as well as other critically important areas will be calculated and evaluated. The calculations are done in the order discussed in OET Bulletin 65. In addition to the input parameters above, input cells are provided below for the user to evaluate the power density at specific distances or angles.

1.0 At the Antenna Surface

The power density at the reflector surface can be calculated from the expression:

$$PD_{\text{refl}} = 4P/A = 2.933 \text{ mW/cm}^2 \quad (1)$$

Where: P = total power at feed, milliwatts

A = Total area of reflector, sq. cm

In the normal range of transmit powers for satellite antennas, the power densities at or around the reflector surface is expected to exceed safe levels. This area will not be accessible to the general public. Operators and technicians should receive training specifying this area as a high exposure area. Procedures must be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

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2.0 On-Axis Near Field Region

The geometrical limits of the radiated power in the near field approximate a cylindrical volume with a diameter equal to that of the antenna. In the near field, the power density is neither uniform nor does its value vary uniformly with distance from the antenna. For the purpose of considering radiation hazard it is assumed that the on-axis flux density is at its maximum value throughout the length of this region. The length of this region, i.e., the distance from the antenna to the end of the near field, is computed as R_{nf} above.

The maximum power density in the near field is given by:

$$PD_{nf} = (16\epsilon P)/(\pi D^2) = 0.179 \text{ mW/cm}^2 \text{ (2)}$$

from 0 to 4.13 meters

Evaluation

Uncontrolled Environment:	Complies to FCC Limits
Controlled Environment:	Complies to FCC Limits

3.0 On-Axis Transition Region

The transition region is located between the near and far field regions. As stated in Bulletin 65, the power density begins to vary inversely with distance in the transition region. The maximum power density in the transition region will not exceed that calculated for the near field region, and the transition region begins at that value. The maximum value for a given distance within the transition region may be computed for the point of interest according to:

$$PD_t = (PD_{nf})(R_{nf})/R = \text{dependent on } R \text{ (3)}$$

where: PD_{nf} = near field power density
 R_{nf} = near field distance
 R = distance to point of interest

For: $4.13 < R < 9.92$ meters

We use Eq (3) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation

Uncontrolled Environment Safe Operating Distance,(meters), R_{safeu} :	1
Controlled Environment Safe Operating Distance,(meters), R_{safec} :	0

4.0 On-Axis Far-Field Region

The on- axis power density in the far field region (PD_{ff}) varies inversely with the square of the distance as follows:

$$PD_{ff} = PG/(4\pi R^2) = \text{dependent on } R \text{ (4)}$$

where: P = total power at feed
 G = Numeric Antenna gain in the direction of interest relative to isotropic radiator
 R = distance to the point of interest

For: $R > R_{ff} = 9.92$ meters
 $PD_{ff} = 0.077 \text{ mW/cm}^2$ at R_{ff}

We use Eq (4) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation

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Uncontrolled Environment Safe Operating Distance,(meters), R_{safeu} : See Section 3
Controlled Environment Safe Operating Distance,(meters), R_{safec} : See Section 3

5.0 Off-Axis Levels at the Far Field Limit and Beyond

In the far field region, the power is distributed in a pattern of maxima and minima (sidelobes) as a function of the off-axis angle between the antenna center line and the point of interest. Off-axis power density in the far field can be estimated using the antenna radiation patterns prescribed for the antenna in use. Usually this will correspond to the antenna gain pattern envelope defined by the FCC or the ITU, which takes the form of:

$$G_{off} = 32 - 25\log(\theta)$$

for θ from 1 to 48 degrees; -10 dBi from 48 to 180 degrees
(Applicable for commonly used satellite transmit antennas)

Considering that satellite antenna beams are aimed skyward, power density in the far field will usually not be a problem except at low look angles. In these cases, the off axis gain reduction may be used to further reduce the power density levels.

For example: At 1 degrees off axis At the far-field limit, we can calculate the power density as:

$$G_{off} = 32 - 25\log(1.25) = 32 - 0 \text{ dBi} = 1585 \text{ numeric}$$

$$PD_{1 \text{ deg off-axis}} = PD_{ff} \times 1585/G = 0.2569 \text{ mW/cm}^2 \text{ (5)}$$

6.0 Off-Axis power density in the Near Field and Transitional Regions

According to Bulletin 65, off-axis calculations in the near field may be performed as follows: assuming that the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point is at least a factor of 100 (20 dB) less than the value calculated for the equivalent on-axis power density in the main beam. Therefore, for regions at least D meters away from the center line of the dish, whether behind, below, or in front under of the antenna's main beam, the power density exposure is at least 20 dB below the main beam level as follows:

$$PD_{nf(off-axis)} = PD_{nf} / 100 = 0.002 \text{ mW/cm}^2 \text{ at D off axis (6)}$$

See page 5 for the calculation of the distance vs elevation angle required to achieve this rule for a given object height.

7.0 Region Between the Antenna and Ground

Assuming uniform illumination of the reflector surface, the power density between the antenna and the ground can be calculated as follows:

$$PD_{nf(gr)} = (4 \cdot P) / (\pi \cdot D^2) = 0.872 \text{ mW/cm}^2 \text{ (7)}$$

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8.0 Evaluation of Safe Occupancy Area in Front of Antenna

The distance (S) from a vertical axis passing through the dish center to a safe off axis location in front of the antenna can be determined based on the dish diameter rule (Item 6.0). Assuming a flat terrain in front of the antenna, the relationship is:

$$S = (D / \sin \alpha) + (2h - D - 2) / (2 \tan \alpha) \quad (7)$$

Where: α = minimum elevation angle of antenna

D = dish diameter in meters

h = maximum height of object to be cleared, meters

For distances equal or greater than determined by equation (7), the radiation hazard will be below safe levels for all but the most powerful stations (> 4 kilowatts RF at the feed).

For	D =	.59 meters
	h =	2 meters

Then:

α	S
20	4.7 meters
25	3.8 meters
30	3.2 meters

The earth station will not be accessible to anyone not directly involved with the operation of the earth station.

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Summary of All RadHaz Parameters		RaySat		
Parameter	Abbr.	Value	Units	Formula
Dish #		RaySat		
Antenna Diameter (effective aperture)	Df	0.59	meters	largest dimension
Antenna Centerline	h	2.0	meters	
Antenna Surface Area	Sa	0.472	meters ²	$(\pi * D^2) / 4$
Antenna Ground Elevation	GE	0.0	meters	
Frequency of Operation	f	14.25	GHz	
Wavelength	λ	0.0211	meters	c / f
HPA Output Power	P _{HPA}	2.4	watts	
HPA to Antenna Loss (includes radome)	L _{bx}	0.50	dB	
Transmit Power at Flange	P	3.27	dBW	$10 * \text{Log}(P_{\text{HPA}}) - L_{\text{bx}}$
		2.01	watts	
Antenna Gain	G _{es}	26.8	dBi	
		473.2	n/a	
PI	π	3.1415927	n/a	
Antenna Aperture Efficiency	eff	6%	n/a	$G_{\text{es}} / (\pi * Df / \lambda)^2$
1. Reflector Surface Region Calculations				
Reflector Surface Power Density	Was	29.33	W/m ²	$(16 * P) / (\pi * D^2)$
		2.933	mW/cm ²	
2. On-Axis Near Field Calculations				
Extent of Near Field	Rn	4.13	meters	$D^2 / (4 * \lambda)$
		13.56	feet	
Near Field Power Density	Wn	1.79	W/m ²	$(16 * \text{eff} * P) / (\pi * D^2)$
		9.92085		
		4.1336875	0.179	mW/cm ²
3. On-Axis Transition Region Calculations				
Extent of Transition Region (min)	Rtr	4.13	meters	$D^2 / (4 * \lambda)$
Extent of Transition Region (min)		13.56	feet	
Extent of Transition Region (max)	Rtr	9.92	meters	$(0.6 * D^2) / \lambda$
Extent of Transition Region (max)		32.54	feet	
Worst Case Transition Region Power Density	Wtr	1.79	W/m ²	$(16 * \text{eff} * P) / (\pi * D^2)$
		0.179	mW/cm ²	
4. On-Axis Far Field Calculations				
Distance to the Far Field Region	Rf	9.9	meters	$(0.6 * D^2) / \lambda$
		32.54	feet	
On-Axis Power Density in the Far Field	Wf	0.77	W/m ²	$(G_{\text{es}} * P) / (4 * \pi * Rf^2)$
		0.077	mW/cm ²	
5. Off-Axis Levels at the Far Field Limit and Beyond				
Reflector Surface Power Density	Ws	2.569	W/m ²	$(G_{\text{es}} * P) / (4 * \pi * Rf^2) * (Goa / G_{\text{es}})$
Goa/Ges at example angle θ 1 degree		3.350		$Goa = 32 - 25 * \log(\theta)$
		0.2569	mW/cm ²	
6. Off-axis Power Density in the Near Field and Transitional Regions Calculations				
Power density 1/100 of Wn for one diameter removed	Ws	0.0179	W/m ²	$((16 * \text{eff} * P) / (\pi * D^2)) / 100$
		0.00179	mW/cm ²	
7. Region Between Antenna and Ground Calculations				
Reflector Surface Power Density	Ws	8.72	W/m ²	$(4 * P) / (\pi * D^2)$
		0.872	mW/cm ²	
8. Safe Distances from Earth Station				$S = (D / \sin \alpha) + (2h - D - 2) / (2 \tan \alpha)$
α = minimum elevation angle of antenna		10	deg	
h = maximum height of object to be cleared, meters		3	m	antenna is on car roof
elevation angle	20	0.9	m	
	25	0.8	m	
	30	0.7	m	
	35	0.6	m	
	40	0.6	m	
Note: Maximum FCC power density limits for 6 GHz is 1 mW/cm ² for general population/uncontrolled exposure as per FCC OE&T Bulletin No. 65, Edition 97-01 August 1997, Appendix A page 67.				