Radiation Hazard Analysis
Viasat, Inc.
Viasat Duluth S-band Exp STA

This analysis predicts the radiation levels around a proposed satellite terminal, comprised of one (array) type antenna which will be tested in both mobile, vehicle mounted, and fixed environments. 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 an 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.

Satellite Terminal Technical Parameter Table

Antenna Actual Diameter	7.3 meters
Antenna Surface Area	41.9 sq. meters
Antenna Isotropic Gain	40.5 dBi
Number of Identical Adjacent Antennas	1
Nominal Antenna Efficiency (ε)	45.50%
Nominal Frequency	2.052 GHz
Nominal Wavelength (λ)	0.1462 meters
Maximum Transmit Power / Carrier	17.7 Watts
Number of Carriers	1
Total Transmit Power	17.7 Watts
W/G Loss from Transmitter to Feed	0.0 dB
Total Feed Input Power	17.70 Watts
Near Field Limit	$R_{nf} = D^2/4\lambda$ =91.13 meters
Far Field Limit	$R_{ff} = 0.6\ D^2/\lambda$ = 218.70 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.

1.0 At the Antenna Surface

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

$PD_{refl} = 4P/A =$ **0.169** mW/cm^2 (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 shall receive training specifying this area as a high exposure area. Procedures will be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

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 Rnf above.

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

$PD_{nf} = (16\varepsilon P)/(\pi D^2) =$ **0.061** mW/cm² (2)
from 0 to 91.13 meters

Evaluation

Uncontrolled Environment:	**Meets Controlled Limits**
Controlled Environment:	**Meets Controlled 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:

$PD_t =$ $(PD_{nf})(R_{nf})/R$ = dependent on R (3)
where: PD_{nf} = near field power density
R_{nf} = near field distance
R = distance to point of interest
For: $91.13 < R < 218.7$ 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}:	5.6
Controlled Environment Safe Operating Distance,(meters), R_{safec}:	1.1

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:

$PD_{ff} = PG/(4\pi R^2)$ = dependent on R (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: $R > R_{ff} = 218.7$ meters
PD_{ff} = **0.026** mW/cm² at R_{ff}

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 one (1) degree off axis At the far-field limit, we can calculate the power density as:

$G_{off} = 32 - 25\log(1) = 32 - 0$ dBi = 1585 numeric

$PD_{1\text{ deg off-axis}} = PD_{ff} \text{x } 1585/G =$
0.0037
mW/cm² (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:

$PD_{nf(off\text{-}axis)} = PD_{nf}/100 =$ **0.05209** mW/cm² at D off axis (6)

See Section 8 for the calculation of the distance vs. elevation angle required to achieve this rule for a given object height.

7.0 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 D = 7.3 meters
h = 2.0 meters

Then:

α	S
10	21.34 meters
15	14.58meters
20	11.32 meters
25	9.45 meters
35	7.51 meters

The operational area proposed for the experimental testing of this terminal will not involve antenna elevation angles less than 35 degrees, so the minimum separation distance between the in motion terminal and the general public is 0.41 meters (1.35 feet). When in motion the operation of the vehicle will preclude harmful interference in an uncontrolled environment by maintain the appropriate safe distance. When not in motion and testing the area will be operated in an area not accessible to the general public and all operating personnel will be aware of the minimum safe distances.

Summary

The satellite terminal will be protected from uncontrolled access while in operation. There will also be proper emission warning signs placed and all operating personnel will be aware of the human exposure levels at and around the terminal. The applicant agrees to abide by the conditions specified in Condition 5208 provided below:

> *Condition 5208 - The licensee shall take all necessary measures to ensure that the antenna does not create potential exposure of humans to radiofrequency radiation in excess of the FCC exposure limits defined in 47 CFR 1.1307(b) and 1.1310 wherever such exposures might occur. Measures must be taken to ensure compliance with limits for both occupational/controlled exposure and for general population/uncontrolled exposure, as defined in these rule sections. Compliance can be accomplished in most cases by appropriate restrictions such as fencing. Requirements for restrictions can be determined by predictions based on*

> *calculations, modeling or by field measurements. The FCC's OET Bulletin 65 (available on-line at www.fcc.gov/oet/rfsafety) provides information on predicting exposure levels and on methods for ensuring compliance, including the use of warning and alerting signs and protective equipment for worker.*

The following table summarizes all of the above calculations:

Table Summary of All RadHaz Parameters				**Viasat Duluth S-band Exp STA**
Parameter	Abbr.		Units	Formula
Dish #		Test Antenna		
Antenna Diameter	Df	7.3	meters	
Antenna Centerline	h	4.4	meters	
Antenna Surface Area	Sa	41.9	meters^2	$(\pi * Df^2)/ 4$
Antenna Ground Elevation	GE	280.0	meters	
Frequency of Operation	f	2.052	GHz	
Wavelength	λ	0.1462	meters	c / f
HPA Output Power	P_{HPA}	17.7	watts	
HPA to Antenna Loss	L_{tx}	0.0	dB	(! dB Radome Loss) P = 2.4 watts
Transmit Power at Flange	P	12.5	dBW	$10 * Log(P_{HPA}) - L_{tx}$
		17.70	watts	
Antenna Gain	G_{es}	40.5	dBi	
		11196.2	n/a	
PI	π	3.1415927	n/a	
Antenna Aperture Efficiency	η	45.50%	n/a	$G_{es} / (PI * Df /\lambda)^2$
1. Reflector Surface Region Calculations				
Reflector Surface Power Density	PDas	1.69	W/m^2	$(16 * P)/(\pi * D^2)$
		0.169	mW/cm^2	**Meets Controlled Limits**
				Meets Controlled Limits
2. On-Axis Near Field Calculations				
Extent of Near Field	Rn	91.13	meters	$D^2 / (4 *\lambda)$
		298.89	feet	
Near Field Power Density	PDnf	0.61	W/m^2	$(16 * \eta * P)/ (\pi *D^2)$
		0.061	mW/cm^2	**Meets Controlled Limits**
				Meets Controlled Limits
3. On-Axis Transition Region Calculations				
Extent of Transition Region (min)	Rtr	91.13	meters	$D^2 / (4 *\lambda)$
Extent of Transition Region (min)		298.89	feet	
Extent of Transition Region (max)	Rtr	218.70	meters	$(0.6 * D^2) /\lambda$
Extent of Transition Region (max)		717.34	feet	
Worst Case Transition Region Power Density	PDtr	0.61	W/m^2	$(16 *\eta * P)/ (\pi * D^2)$
		0.061	mW/cm^2	**Meets Controlled Limits**
				Meets Controlled Limits
Uncontrolled Environment Safe Operating Dist	Rsu	5.6	m	=(PDnf)*(Rnf)/Rsu
Controlled Environment Safe Operating Distan	Rsc	1.1	m	=(PDnf)*(Rnf)/Rsc
4. On-Axis Far Field Calculations				
Distance to the Far Field Region	Rf	218.7	meters	$(0.6 * D^2) /\lambda$
		717.34	feet	
On-Axis Power Density in the Far Field	PDff	0.26	W/m^2	$(G_{es} * P) / (4 * \pi * Rf^2)$
		0.026	mW/cm^2	**Meets Controlled Limits**
				Meets Controlled Limits
5. Off-Axis Levels at the Far Field Limit and Beyond				
Reflector Surface Power Density	PDs	0.037	W/m^2	$(G_{es} * P) / (4 * \pi * Rf^2)*(Goa/Ges)$
Goa/Ges at example angle θ 1 degree		0.142		Goa = 32 - 25*log(θ)
		0.0037	mW/cm^2	**Meets Controlled Limits**
6. Off-axis Power Density in the Near Field and Transitional Regions Calculations				
Power density 1/100 of Wn for one diameter removed	PDs	0.0061	W/m^2	$((16 * \eta * P)/ (\pi *D^2))/100$
		0.00061	mW/cm^2	**Meets Controlled Limits**
7. Off-Axis Safe Distances from Earth Station				$S = (D/ \sin \alpha) + (2h - D - 2)/(2 \tan \alpha)$
α = minimum elevation angle of antenna		35	deg	
h = maximum height of object to be cleared, meters		2.0	m	
GD = Ground Elevation Delta antenna-obstacl		1.0	m	
elevation angle	10	21.34	m	
	15	14.58	m	
	20	11.32	m	
	25	9.45	m	
	35	**7.51**	m	
Note: Maximum FCC power density limits for 30 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.				