RF RADIATION HAZARD ANALYSIS FOR PROPOSED 13.1 METER KU-BAND TRANSMIT/RECEIVE SATELLITE EARTH STATION

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I. INTRODUCTION

Because of the highly directional nature of parabolic antenna systems, the possibility of significant human exposure to RF radiation is unlikely if precautions are taken to prevent incidental human access to those few areas where the existing power densities are in excess of those recommended for human exposure.[1]

The predicted RF power density levels that can be generated by the proposed Ku-band satellite earth station are calculated below. The calculations show that there will be a region in the vicinity of the antenna that can experience substantial power density levels (the area between the feed and the reflector of the antenna). However, operational procedures will be rigidly enforced to ensure that personnel are never exposed to radiation levels above the ANSI recommended value of **5.00 mW/cm^2** for occupational/controlled exposure, and **1.00 mW/cm^2** for general population/uncontrolled exposure, even during periods of peak power output.

Specific parameters used in the following RF radiation analyses for the proposed Ku-band satellite earth station are as follows:

D	=	antenna diameter	=	13.1 meters (42.97891667 feet)
d	=	diameter of subreflector	=	1.333502667 meters (52.5 inches)
f	=	frequency	=	14500 MHz
λ	=	wavelength	=	0.020689655 meters
π	=	Pi	=	3.1416
A	=	physical aperture area ($\pi D^2/4$)	=	134.7821788 square meters
a	=	physical area of subreflector ($\pi d^2/4$)	=	1.396618076 square meters
G	=	antenna transmit gain	=	64.05 dBi
			=	2540972.706
P	=	maximum power into antenna feed	=	350.8310635 Watts
η	=	antenna efficiency	=	0.642190931 dBi
EIRP	=	maximum EIRP from antenna	=	89.5009804 dBW

II. POWER DENSITY CALCULATIONS

A. NEAR-FIELD REGION

Within the near-field region of a parabolic reflector antenna, the maximum value of RF power

[1] ***"Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," OST Bulletin No. 65, August 1997, Federal Communications Commission, Office of Science and Technology, Washington, DC 20554.***

density occurs on-axis, at a distance of (0.2 D^2) / λ. For the proposed Ku-band satellite earth station, this distance will be 1658.896667 meters (5442.563481 feet) from the antenna. For conservatism in this analysis, however, it will be assumed that the maximum value of power density will exist throughout the <u>entire length of the near-field</u> region R_n, where R_n is determined as follows:

$$R_n = D^2/(4\lambda) = 2073.620833 \text{ m } (6803.204351 \text{ ft})$$

The maximum value of on-axis power density that will be possible within the near-field region of the proposed Ku-band satellite earth station antenna can be calculated as follows:

$$PD \text{ (near-field)} = (16\ \eta\ P)/(\pi\ D^2) = (4\ \eta\ P)\ /\ A$$

$$= 4\ [(0.642190931)\ (350.8310635 \text{ W})]\ /\ (134.7821788 \text{ m}^2)$$

$$= 6.686359557 \text{ W/m}^2 = 0.668635956 \ \mathbf{mW/cm^2}$$

Conservative estimates of <u>off-axis</u> power density calculations in the near-field region can be made assuming a point of interest at least one antenna diameter from the center of the main beam. The resulting off-axis power density at any given distance from the antenna will be at least a factor of 100 (20 dB) less than the on-axis power density value at the same distance from the antenna. Therefore, for the proposed Ku-band satellite earth station, it may be assumed that the off-axis power density will be at least 20 dB below the maximum level at a radial distance of 13.1 meters (42.97891667 feet) from the center line axis of the antenna. At distances within the near field the maximum <u>off-axis</u> power density will, therefore, be no greater than:

$$(0.668635956 \text{ mW/cm}^2)\ /\ 100 = 0.00668636 \ \mathbf{mW/cm^2}$$

B. TRANSITION REGION

The power density in the transition region between the near field and the far field of a parabolic reflector antenna decreases inversely with distance from the antenna. For purposes of evaluating RF radiation levels, it is assumed that the transition region will extend from the end of the near field (2073.620833 meters or 6803.204351 feet) to the to the beginning of the far-field, which is determined as follows:

$$R_f = (0.6\ D^2)\ /\ \lambda = 4976.69 \text{ m } (16327.69044 \text{ ft})$$

The maximum power density levels in the transition region are again on-axis, and can be conservatively estimated (upper-bounded) in the following manner:

$$PD \text{ (transition)} = PD \text{ (near-field)} \times (R_n / R_t)$$

$$= (0.668635956 \text{ mW/cm}^2) \times (2073.620833 \text{ m} / R_t)$$

$$< 0.668635956 \ \mathbf{mW/cm^2}$$

where R_t is point of interest in meters, with 2073.620833 meters (6803.204351 feet) < R_t < 4976.69 meters (16327.69044 feet).

Conservative estimates of off-axis calculations in the transition region can be made in the same fashion as for the near-field region, by again assuming a point of interest at least one antenna diameter from the center of the main beam. The resulting off-axis power density at any given distance from the antenna will be at least a factor of 100 (20 dB) less than the on-axis power density value at the same distance from the antenna. Therefore, for the proposed Ku-band satellite earth station, it may be assumed that the off-axis power density will be at least 20 dB below the maximum level at a radial distance of 13.1 meters (42.97891667 feet) from the center line axis of the antenna. Within the transition region, the maximum off-axis power density will be less than the maximum value of 0.00668636 **mW/cm²** that was determined above for the near-field region.

C. FAR-FIELD REGION

In the far-field region of a parabolic reflector antenna, 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. For the proposed Ku-band satellite earth station, the maximum possible value of on-axis power density in the far-field region can be determined as follows:

$$\text{PD (far-field)} = [(P)(G)] / (4 \pi R_f^2)$$

$$= [(350.8310635 \text{ W})(2540972.706)] / [4 \pi (4976.69 \text{ m})^2]$$

$$= 0.286422412 \ \mathbf{mW/cm^2}$$

Off-axis power densities in the far-field region are reduced by at least 30 dB at angles of one degree or more from beam center). Therefore, for the proposed Ku-band satellite earth station, the far-field off-axis power density will be less than:

$$\text{PD} = (0.286422412 \text{ mW/cm}^2) / 1{,}000$$

$$= 0.000286422 \ \mathbf{mW/cm^2}$$

D. IMMEDIATE VICINITY OF THE ANTENNA

1. BESIDE AND BEHIND ANTENNA

For areas beside and behind the antenna structure, the radiation level will be less than the tapered illumination level of the reflector. For the proposed Ku-band satellite earth station, this level will be as follows:

PD $\leq$ the transmit power, P, divided by the area of the antenna reflector, A, less 6 dB taper.

$$PD \leq (350.8310635\ W) / (134.7821788\ m^2) - 6\ dB$$

$$= 0.0650737113\ \mathbf{mW/cm^2}$$

This value will be applicable at the edge of the main reflector, so the power density levels beside and behind the reflector will be even smaller.

2. REFLECTOR SURFACE

For the proposed Ku-band satellite earth station, the maximum power density on the reflector surface can be determined as follows:

$$PD = (4)\ (P) / (A)$$

$$= (4)\ (350.8310635\ W) / (134.7821788\ m^2)$$

$$= 10.4117938\ W/m^2$$

$$= 1.04117938\ \mathbf{mW/cm^2}$$

where "A" is the surface area of the reflector (134.7821788 m^2) and the factor of 4 again results from the 6 dB tapered illumination level.

3. BETWEEN MAIN REFLECTOR AND SUB-REFLECTOR

For the proposed Ku-band satellite earth station, the maximum power density in this region is determined as follows:

$$PD = (4)\ (P)\ /\ (a)$$

$$= (4)\ (350.8310635\ W)\ /\ (1.396618076\ m^2)$$

$$= 1004.801727\ W/m^2$$

$$= 100.4801727\ \mathbf{mW/cm^2}$$

where "a" is the surface area of the sub-reflector (1.396618076 m^2) and the factor of 4 results from the 6 dB tapered illumination level.

4. BETWEEN ANTENNA AND GROUND

For this area, the radiation level will be less than the tapered illumination level of the main reflector, and can be calculated in a fashion identical to that used for areas beside and behind the main reflector. As shown previously, this level will be bounded by:

$$PD = (350.8310635\ W)\ /\ (134.7821788\ m^2) - 6\ dB$$

$$= 0.065073711\ \mathbf{mW/cm^2}$$

III. SUMMARY OF CALCULATION RESULTS

Region	Maximum Radiation Level (mW/cm^2)	Hazard Assessment
Between main reflector and sub-reflector	100.4801727	***Potential hazard***.
Reflector surface	1.04117938	Complies with guidelines
Between antenna and ground	0.065073711	Complies with guidelines
Beside and behind antenna	0.0650737113	Complies with guidelines
Near field, R_n < 2073.620833 m	0.668635956 (on-axis)	Complies with guidelines
	< 0.00668636 (off-axis)	Complies with guidelines.
Transition region, R_t (2073.620833 m < R_t < 4976.69 m)	< 0.668635956 (on-axis)	Complies with guidelines
	< 0.00668636 (off-axis)	Complies with guidelines.
Far field, R_f > 4976.69 m	0.286422412 (on-axis)	Complies with guidelines
	< 0.000286422 (off-axis)	Complies with guidelines.

IV. CONCLUSIONS

The above analyses show that, if the proposed Ku-band satellite earth station were to operate at its **highest possible value of peak power**, power density levels in excess of the ANSI recommended value of 5.0 mW/cm^2 for occupational/controlled exposure could occur in the following region:

- Between the feed and reflector surface (maximum power density of 100.4801727 mW/cm^2).

The preceding analyses also show that there are no areas where power density levels in excess of the ANSI recommended value of 1.0 mW/cm^2 for general population/uncontrolled exposure could occur.

The proposed Ku-band satellite earth station consists of 13.1-meter antenna. The bottom edge of the antenna reflector will be at least 6 feet from the ground, and in most cases will be higher. This will minimize the possibility of personnel in the general vicinity of the antenna being accidentally exposed to harmful levels of RF radiation. However, the following measures will also be exercised to further guarantee that neither the general public nor technical/operations personnel will ever be subjected to harmful levels of RF radiation, should they temporarily be in the immediate vicinity of the antenna:

- **The antenna will be marked with standard radiation hazard warnings, advising personnel to stay away from the area in front of the reflector when the transmitter is operating.**

- **The HPA will be turned off whenever maintenance or repair personnel are required to work on or in front of the antenna.**

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EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS

Antenna diameter:	D =	13.1	meters
	D =	43.0	feet
	D =	516	inches
Sub-reflector diameter:	d =	52.5	inches
	d =	1.33	meters
Frequency (maximum):	f =	14,500	MHz
Wavelength:	λ =	0.0207	meters
Antenna transmit gain:	G =	64.1	dBi
	G =	2,540,973	numeric
Antenna physical aperture area:	A =	134.78	sq. meters
Sub-reflector physical area:	a =	1.40	sq. meters
Antenna efficiency:	η =	0.64	numeric
HPA maximum power output:	P_{max} =	700	Watts
	P_{max} =	28.5	dBW

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EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS, cont'd

Transmit system losses:	L_t =	**-3.0**	dB
	L_t =	0.50	numeric
Maximum RF power into antenna feed:	P =	351	Watts
	P =	25.5	dBW
Maximum EIRP from antenna:	EIRP =	89.5	dBW
	EIRP =	891,452,157	Watts

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COMPUTATIONAL RESULTS

Distance to beginning of the far field:	**R_f = 4,977**	**meters**
	R_f = 16,328	feet
Maximum on-axis power density in the far field:	S = 2.86	Watts/sq. meter
	S = 0.29	**mW/sq. cm**
Off-axis power density in the far field:	S < 0.0029	Watts/sq. meter
	S < 0.00029	**mW/sq. cm**
Extent of the near field:	**Rn = 2074**	**meters**
	Rn = 6,803	feet
Maximum on-axis power density in the near field:	S = 6.7	Watts/sq. meter
	S = 0.67	**mW/sq. cm**
Distance to maximum on-axis power density in the near field:	**0.2(D*2)/L = 1659**	**meters**
	0.2(D*2)/L = 5,443	feet
Off-axis power density in the near field:	S < 0.067	Watts/sq. meter
	S < 0.0067	**mW/sq. cm**

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COMPUTATIONAL RESULTS, cont'd

Maximum on-axis power density in the transition region between the near field and the far field:	S < 6.7	Watts/sq. meter
	S < 0.67	**mW/sq. cm**
Off-axis power density in the transition region between the near field and the far field:	S < 0.067	Watts/sq. meter
	S < 0.0067	**mW/sq. cm**
Between main reflector and sub-reflector:	S = 1,004.8	Watts/sq. meter
	S = 100.5	**mW/sq. cm**
On reflector surface:	S = 10.4	Watts/sq. meter
	S = 1.04	**mW/sq. cm**
Between antenna and ground:	S < 0.65	Watts/sq. meter
	S < 0.065	**mW/sq. cm**
Beside and behind antenna:	S < 0.65	Watts/sq. meter
	S < 0.065	**mW/sq. cm**