RF RADIATION HAZARD ANALYSIS FOR PROPOSED 4.6 METER KU-BAND TRANSMIT/RECEIVE SATELLITE EARTH STATION IN ALPHARETTA, GEORGIA

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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 regions in the vicinity of the antenna that can experience substantial power density levels, such as the area between the feed and the reflector and the area directly in front and along the axis 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	= 4.6 meters (15.1 feet)
d	=	sub-reflector diameter	= 0.61 meters (24.0 inches)
f	=	frequency	= 14,500 MHz
λ	=	wavelength	= 0.0207 meters
π	=	Pi	= 3.1416
A	=	physical aperture area ($\pi D^2/4$)	= 16.62 square meters
a	=	surface area of sub-reflector ($\pi d^2/4$)	= 0.29 square meters
G	=	antenna transmit gain	= 55.0 dBi
			= 316,228
P	=	maximum power into antenna feed	= 150 Watts
η	=	antenna efficiency	= 0.65
EIRP	=	maximum EIRP from antenna	= 76.8 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 density occurs on-axis, at a distance of $(0.2\ D^2)\ /\ \lambda$. For the proposed Ku-band satellite uplink earth station, this distance will be 205 meters (671 feet) from the antenna. For conservatism in this analysis, however, it will be assumed that the maximum value of

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.*

power density will exist throughout the <u>entire length of the near-field</u> region R_n, where R_n is determined as follows:

$$R_n = D^2/(4\lambda) = 256 \text{ m } (839 \text{ ft})$$

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:

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

$$= 4\, [(0.65)(150 \text{ W})] / (16.62 \text{ m}^2)$$

$$= 23.5 \text{ W/m}^2 = \mathbf{2.35\ mW/cm^2}$$

The on-axis power density (energy) in the near-field region of a parabolic reflector antenna can be assumed to be contained within a cylinder having a diameter equal to the antenna's diameter and extending upward into space at an angle equal to the antenna's elevation angle. For the proposed Ku-band satellite earth station, the elevated geometry of the reflector (the bottom edge will be approximately 2 meters or higher from the ground) and the rising edges of the cylindrical near-field and transition regions of the antenna will be such that these regions will generally not be accessible by the public or by earth station personnel.

Conservative estimates of off-axis 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 4.6 meters (15.1 feet) from the center line axis of the antenna. At distances within the near field the maximum off-axis power density will, therefore, be no greater than:

$$(2.35 \text{ mW/cm}^2) / 100 = \mathbf{0.0235\ mW/cm^2}$$

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 (256 meters or 839 feet) to the to the beginning of the far-field, which is determined as follows:

$$R_f = 0.6\, D^2/\lambda = 614 \text{ m } (2{,}013 \text{ ft})$$

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

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

$$= (2.35\ \text{mW/cm}^2) \times (256\ \text{m} / R_t)$$

$$< \mathbf{2.35\ mW/cm^2}$$

where R_t is point of interest in meters, with 256 meters (839 feet) < R_t < 614 meters (2,013 feet).

The on-axis power density (energy) in the transition region of the antenna can again be assumed to be contained within a cylinder having a diameter equal to the antenna's diameter and extending upward into space at an angle equal to the antenna's elevation angle. For the proposed Ku-band satellite earth station, this geometry will make the transition region well out of reach by either the general public or by earth station technical/operations personnel.

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 4.6 meters (15.1 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 **0.0235 mW/cm^2** 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:

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

$$= [(150)\,(316{,}228)] / [4\pi\ (614\ \text{m})^2]$$

$$= \mathbf{1.00\ mW/cm^2}$$

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:

$$\text{PD} = (1.00\ \text{mW/cm}^2) / (1{,}000)$$

$$= \mathbf{0.00100\ mW/cm^2}$$

D. IMMEDIATE VICINITY OF THE ANTENNA

1. BESIDE AND BEHIND ANTENNA

For areas beside and behind the antenna structure, where station personnel and working environments exist, 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.

$$PD \leq (150\text{ W}) / (16.62\text{ m}^2) - 6\text{ dB}$$

$$= \mathbf{0.226\ mW/cm^2}$$

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:

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

$$= (4)\,(150\text{ W}) / (16.62\text{ m}^2)$$

$$= 36.2\text{ W/m}^2$$

$$= \mathbf{3.62\ mW/cm^2}$$

where "A" is the surface area of the reflector (16.62 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 will be on the sub-reflector surface, and is determined as follows:

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

$$= (4)\,(150\text{ W}) / (0.29\text{ m}^2)$$

$= 2,060.6\ W/m^2$

$= \mathbf{206.1\ mW/cm^2}$

where "a" is the surface area of the sub-reflector (0.29 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:

$PD = (150) / (16.62)\ W/m^2 - 6\ dB$

$= \mathbf{0.226\ mW/cm^2}$

III. SUMMARY OF CALCULATION RESULTS

Region	Maximum Radiation Level (mW/cm^2)	Hazard Assessment
Between main reflector & sub-reflector	**206.1**	***Potential hazard*.**
Reflector surface	**3.62**	***Potential hazard*.**
Between antenna & ground	0.226	Complies with guidelines.
Beside and behind antenna	0.226	Complies with guidelines.
Near field, R_n < 256 m	**2.35 (on-axis)**	***Potential hazard*.**
	< 0.0235 (off-axis)	Complies with guidelines.
Transition region, R_t (256 m < R_t < 614 m)	**< 2.35 (on-axis)**	***Potential hazard*.**
	< 0.0235 (off-axis)	Complies with guidelines.
Far field, R_f > 614 m	1.00 (on-axis)	Complies with guidelines.
	< 0.00100 (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 main reflector and sub-reflector (maximum power density of 206.1 mW/cm^2).

As noted previously, the bottom edge of the antenna reflector will be approximately 2 meters (or higher) from the ground. 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 any 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 HPAs will be turned off whenever maintenance or repair personnel are required to work on or in front of the antenna.

The preceding analyses also show that power density levels in excess of the ANSI recommended value of 1.0 mW/cm^2 for general population/uncontrolled exposure could occur in the following regions:

- On the main reflector surface (maximum power density of 3.62 mW/cm^2).

- Near field (maximum on-axis power density of 2.35 mW/cm^2).

- Transition region (maximum on-axis power density of less than 2.35 mW/cm^2).

Potentially high RF power density levels along the antenna pointing axis will not pose a hazard to either the general public or the earth station personnel. In order to cover the full domestic arc, the antenna elevation angle will range between a minimum of 28.5 degrees and a maximum of 49.5 degrees. Thus, the rising edges of the cylindrical near-field and transition regions of the antenna will be such that these regions will not be accessible to the general population located on the ground.

RADIATION HAZARD ANALYSIS
for
PROPOSED 4.6-METER KU-BAND TRANSMIT/RECEIVE SATELLITE EARTH STATION

EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS
(Antenna Feed Type: Gregorian)

Antenna diameter:	D = **4.6**	meters
	D = 15.1	feet
	D = 181	inches
Sub-reflector diameter:	d = **24**	inches
	d = 0.61	meters
Frequency (maximum):	f = **14,500**	MHz
Wavelength:	λ = 0.0207	meters
Antenna transmit gain:	G = **55.0**	dBi
	G = 316,228	numeric
Antenna physical aperture area:	A = 16.62	sq. meters
Sub-reflector physical area:	a = 0.29	sq. meters
Antenna efficiency:	η = 0.65	numeric
HPA maximum power output:	P_{max} = **300**	Watts
	P_{max} = 24.8	dBW

RADIATION HAZARD ANALYSIS
for
PROPOSED 4.6-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
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EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS, cont'd

(Antenna Feed Type: Gregorian)

Transmit system losses:	L_t = **-3.0**	dB
	L_t = 0.50	numeric
Maximum RF power into antenna feed:	P = 150	Watts
Maximum EIRP from antenna:	EIRP = 76.8	dBW
	EIRP = 47,546,796	Watts

RADIATION HAZARD ANALYSIS
for
PROPOSED 4.6-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
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COMPUTATIONAL RESULTS
(Antenna Feed Type: Gregorian)

Distance to beginning of the far field:	**R_f = 614**	**meters**
	R_f = 2,013	feet
Maximum on-axis power density in the far field:	S = 10.05	Watts/sq. meter
	S = 1.00	**mW/sq. cm**
Off-axis power density in the far field:	S < 0.0100	Watts/sq. meter
	S < 0.00100	**mW/sq. cm**
Extent of the near field:	**Rn = 256**	**meters**
	Rn = 839	feet
Maximum on-axis power density in the near field:	S = 23.5	Watts/sq. meter
	S = 2.35	**mW/sq. cm**
Distance to maximum on-axis power density in the near field:	**0.2(D*2)/L = 205**	**meters**
	0.2(D*2)/L = 671	feet
Off-axis power density in the near field:	S < 0.235	Watts/sq. meter
	S < 0.0235	**mW/sq. cm**

RADIATION HAZARD ANALYSIS
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PROPOSED 4.6-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
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COMPUTATIONAL RESULTS, cont'd
(Antenna Feed Type: Gregorian)

Maximum on-axis power density in the transition region between the near field and the far field:	S < 23.5	Watts/sq. meter
	S < 2.35	**mW/sq. cm**
Off-axis power density in the transition region between the near field and the far field:	S < 0.235	Watts/sq. meter
	S < 0.0235	**mW/sq. cm**
Between main reflector and sub-reflector:	S = 2,060.6	Watts/sq. meter
	S = 206.1	**mW/sq. cm**
On reflector surface:	S = 36.2	Watts/sq. meter
	S = 3.62	**mW/sq. cm**
Between antenna and ground:	S < 2.26	Watts/sq. meter
	S < 0.226	**mW/sq. cm**
Beside and behind antenna:	S < 2.26	Watts/sq. meter
	S < 0.226	**mW/sq. cm**

RF RADIATION HAZARD ANALYSIS
FOR PROPOSED 2.4 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 regions in the vicinity of the antenna that can experience substantial power density levels, such as the area between the feed and the reflector and the area directly in front and along the axis 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	=	2.4 meters (7.9 feet)
d	=	sub-reflector diameter	=	0.76 meters (30.0 inches)
f	=	frequency	=	14,500 MHz
λ	=	wavelength	=	0.0207 meters
π	=	Pi	=	3.1416
A	=	physical aperture area ($\pi D^2/4$)	=	4.52 square meters
a	=	surface area of sub-reflector ($\pi d^2/4$)	=	0.46 square meters
G	=	antenna transmit gain	=	48.8 dBi
			=	75,858
P	=	maximum power into antenna feed	=	150 Watts
η	=	antenna efficiency	=	0.57
EIRP	=	maximum EIRP from antenna	=	70.6 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 density occurs on-axis, at a distance of $(0.2 D^2) / \lambda$. For the proposed Ku-band satellite uplink earth station, this distance will be 56 meters (183 feet) from the antenna. For conservatism in this analysis, however, it will be assumed that the maximum value of

[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.***

power density will exist throughout the <u>entire length of the near-field</u> region R_n, where R_n is determined as follows:

$$R_n = D^2/(4\lambda) = 70 \text{ m (228 ft)}$$

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:

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

$$= 4\ [(0.57)(150 \text{ W})] / (4.52 \text{ m}^2)$$

$$= 75.9 \text{ W/m}^2 = \mathbf{7.59\ mW/cm^2}$$

The on-axis power density (energy) in the near-field region of a parabolic reflector antenna can be assumed to be contained within a cylinder having a diameter equal to the antenna's diameter and extending upward into space at an angle equal to the antenna's elevation angle. For the proposed Ku-band satellite earth station, the elevated geometry of the reflector (the bottom edge will be approximately 1.2 meters or higher from the ground) and the rising edges of the cylindrical near-field and transition regions of the antenna will be such that these regions will generally not be accessible by the public or by earth station personnel.

Conservative estimates of off-axis 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 2.4 meters (7.9 feet) from the center line axis of the antenna. At distances within the near field the maximum off-axis power density will, therefore, be no greater than:

$$(7.59 \text{ mW/cm}^2) / 100 = \mathbf{0.0759\ mW/cm^2}$$

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 (70 meters or 228 feet) to the to the beginning of the far-field, which is determined as follows:

$$R_f = 0.6\ D^2 / \lambda = 167 \text{ m (548 ft)}$$

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

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

$$= (\ 7.59\ mW/cm^2\ ) \times (70\ m\ /\ R_t\ )$$

$$< \ \mathbf{7.59\ mW/cm^2}$$

where R_t is point of interest in meters, with 70 meters (228 feet) < R_t < 167 meters (548 feet).

The on-axis power density (energy) in the transition region of the antenna can again be assumed to be contained within a cylinder having a diameter equal to the antenna's diameter and extending upward into space at an angle equal to the antenna's elevation angle. For the proposed Ku-band satellite earth station, this geometry will make the transition region well out of reach by either the general public or by earth station technical/operations personnel.

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 2.4 meters (7.9 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 **0.0759 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:

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

$$= [(150)\ (75{,}858)]\ /\ [4\ \pi\ (167\ m)^2\ ]$$

$$= \mathbf{3.25\ mW/cm^2}$$

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:

$$PD = (3.25\ mW/cm^2\ )\ /\ (1{,}000)$$

$$= \mathbf{0.00325\ mW/cm^2}$$

D. IMMEDIATE VICINITY OF THE ANTENNA

1. BESIDE AND BEHIND ANTENNA

For areas beside and behind the antenna structure, where station personnel and working environments exist, 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 $\leq$ (150 W) / (4.52 m^2) - 6 dB

= **0.831 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) (150 W) / (4.52 m^2)

= 132.9 W/m^2

= **13.29 mW/cm^2**

where "A" is the surface area of the reflector (4.52 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 will be on the sub-reflector surface, and is determined as follows:

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

= (4) (150 W) / (0.46 m^2)

= 1318.8 W/m^2

$$= \mathbf{131.9\ mW/cm^2}$$

where "a" is the surface area of the sub-reflector (0.46 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:

$$PD = (150) / (4.52)\ W/m^2 - 6\ dB$$

$$= \mathbf{0.831\ mW/cm^2}$$

III. SUMMARY OF CALCULATION RESULTS

Region	Maximum Radiation Level (mW/cm^2)	Hazard Assessment
Between main reflector & sub-reflector	**131.9**	***Potential hazard***.
Reflector surface	**13.29**	***Potential hazard***.
Between antenna & ground	0.831	Complies with guidelines.
Beside and behind antenna	0.831	Complies with guidelines.
Near field, R_n < 70 m	**7.59 (on-axis)**	***Potential hazard***.
	< 0.0759 (off-axis)	Complies with guidelines.
Transition region, R_t (70 m < R_t < 167 m)	**< 7.59 (on-axis)**	***Potential hazard***.
	< 0.0759 (off-axis)	Complies with guidelines.
Far field, R_f > 167 m	**3.25 (on-axis)**	***Potential hazard***.
	< 0.00325 (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 regions in the immediate vicinity of the antenna:

- Between the main reflector and sub-reflector (maximum power density of 131.9 mW/cm^2).
- On the main reflector surface (maximum power density of 13.29 mW/cm^2).

As noted previously, the bottom edge of the antenna reflector will be approximately 1.2 meters (or higher) from the ground. 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 any 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 HPAs will be turned off whenever maintenance or repair personnel are required to work on or in front of the antenna.

The preceding analyses also show that power density levels in excess of the ANSI recommended value of 1.0 mW/cm^2 for general population/uncontrolled exposure could occur in the following regions extending out from the immediate vicinity of the antenna:

- Near field (maximum on-axis power density of 7.59 mW/cm^2).

- Transition region (maximum on-axis power density of less than 7.59 mW/cm^2).

- Far field (maximum on-axis power density of less than 3.25 mW/cm^2).

However, for the proposed Ku-band satellite earth station, these RF power density levels along the antenna pointing axis will not pose a hazard to either the general public or to earth station personnel. In order to cover the full domestic arc, the antenna elevation angle will range between a minimum of 28.5 degrees and a maximum of 49.5 degrees. Thus, the rising edges of the cylindrical near-field region, transition region, and the far field region of the antenna will not be accessible to the general population located on the ground.

RADIATION HAZARD ANALYSIS
for
PROPOSED 2.4-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION

EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS
(Antenna Feed Type: Gregorian)

Antenna diameter:	D = **2.4**	meters
	D = 7.9	feet
	D = 94	inches
Sub-reflector diameter:	d = **30**	inches
	d = 0.76	meters
Frequency (maximum):	f = **14,500**	MHz
Wavelength:	λ = 0.0207	meters
Antenna transmit gain:	G = **48.8**	dBi
	G = 75,858	numeric
Antenna physical aperture area:	A = 4.52	sq. meters
Sub-reflector physical area:	a = 0.46	sq. meters
Antenna efficiency:	η = 0.57	numeric
HPA maximum power output:	P_{max} = **300**	Watts
	P_{max} = 24.8	dBW

RADIATION HAZARD ANALYSIS
for
PROPOSED 2.4-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Lawrenceville, Georgia

EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS, cont'd
(Antenna Feed Type: Gregorian)

Transmit system losses:	L_t =	**-3.0**	dB
	L_t =	0.50	numeric
Maximum RF power into antenna feed:	P =	150	Watts
Maximum EIRP from antenna:	EIRP =	70.6	dBW
	EIRP =	11,405,682	Watts

RADIATION HAZARD ANALYSIS
for
PROPOSED 2.4-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Lawrenceville, Georgia

COMPUTATIONAL RESULTS
(Antenna Feed Type: Gregorian)

Distance to beginning of the far field:	**R_f =**	**167**	**meters**
	R_f =	548	feet
Maximum on-axis power density in the far field:	S =	32.53	Watts/sq. meter
	S =	**3.25**	**mW/sq. cm**
Off-axis power density in the far field:	S <	0.0325	Watts/sq. meter
	S <	**0.00325**	**mW/sq. cm**
Extent of the near field:	**Rn =**	**70**	**meters**
	Rn =	228	feet
Maximum on-axis power density in the near field:	S =	75.9	Watts/sq. meter
	S =	**7.59**	**mW/sq. cm**
Distance to maximum on-axis power density in the near field:	**0.2(D*2)/L =**	**56**	**meters**
	0.2(D*2)/L =	183	feet
Off-axis power density in the near field:	S <	0.759	Watts/sq. meter
	S <	**0.0759**	**mW/sq. cm**

RADIATION HAZARD ANALYSIS
for
PROPOSED 2.4-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Lawrenceville, Georgia

COMPUTATIONAL RESULTS, cont'd
(Antenna Feed Type: Gregorian)

Maximum on-axis power density in the transition region between the near field and the far field:	S < 75.9	Watts/sq. meter
	S < 7.59	**mW/sq. cm**
Off-axis power density in the transition region between the near field and the far field:	S < 0.759	Watts/sq. meter
	S < 0.0759	**mW/sq. cm**
Between main reflector and sub-reflector:	S = 1,318.8	Watts/sq. meter
	S = 131.9	**mW/sq. cm**
On reflector surface:	S = 132.9	Watts/sq. meter
	S = 13.29	**mW/sq. cm**
Between antenna and ground:	S < 8.31	Watts/sq. meter
	S < 0.831	**mW/sq. cm**
Beside and behind antenna:	S < 8.31	Watts/sq. meter
	S < 0.831	**mW/sq. cm**

RF RADIATION HAZARD ANALYSIS FOR PROPOSED 9.3 METER KU-BAND TRANSMIT/RECEIVE SATELLITE EARTH STATION IN ALPHARETTA, GEORGIA

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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 regions in the vicinity of the antenna that can experience substantial power density levels, such as the area between the feed and the reflector and the area directly in front and along the axis 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	=	9.3 meters (30.5 feet)
d	=	sub-reflector diameter	=	0.76 meters (30.0 inches)
f	=	frequency	=	14,500 MHz
λ	=	wavelength	=	0.0207 meters
π	=	Pi	=	3.1416
A	=	physical aperture area ($\pi D^2/4$)	=	67.93 square meters
a	=	surface area of sub-reflector ($\pi d^2/4$)	=	0.46 square meters
G	=	antenna transmit gain	=	61.0 dBi
			=	1,258,925
P	=	maximum power into antenna feed	=	200 Watts
η	=	antenna efficiency	=	0.63
EIRP	=	maximum EIRP from antenna	=	84.0 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 density occurs on-axis, at a distance of $(0.2 D^2) / \lambda$. For the proposed Ku-band satellite uplink earth station, this distance will be 836 meters (2,743 feet) from the antenna. For conservatism in this analysis, however, it will be assumed that the maximum value of

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[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.***

power density will exist throughout the <u>entire length of the near-field</u> region R_n, where R_n is determined as follows:

$$R_n = D^2/(4\lambda) = 1{,}045 \text{ m } (3{,}429 \text{ ft})$$

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:

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

$$= 4\ [(\ 0.63\ )\ (200\ W\ )]\ /\ (\ 67.93\ m^2\ )$$

$$= 7.5\ W/m^2 = \mathbf{0.75\ mW/cm^2}$$

The on-axis power density (energy) in the near-field region of a parabolic reflector antenna can be assumed to be contained within a cylinder having a diameter equal to the antenna's diameter and extending upward into space at an angle equal to the antenna's elevation angle. For the proposed Ku-band satellite earth station, the elevated geometry of the reflector (the bottom edge will be approximately 1.5 meters or higher from the ground) and the rising edges of the cylindrical near-field and transition regions of the antenna will be such that these regions will generally not be accessible by the public or by earth station personnel.

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 9.3 meters (30.5 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:

$$(0.75\ \ mW/cm^2\ )\ /\ 100 = \mathbf{0.0075\ mW/cm^2}$$

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 (1,045 meters or 3,429 feet) to the to the beginning of the far-field, which is determined as follows:

$$R_f = 0.6\ D^2\ /\lambda = 2{,}508 \text{ m } (8{,}229 \text{ ft})$$

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

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

$$= (0.75\ mW/cm^2) \times (1{,}045\ m / R_t)$$

$$< \mathbf{0.75\ mW/cm^2}$$

where R_t is point of interest in meters, with 1,045 meters (3,429 feet) < R_t < 2,508 meters (8,229 feet).

The on-axis power density (energy) in the transition region of the antenna can again be assumed to be contained within a cylinder having a diameter equal to the antenna's diameter and extending upward into space at an angle equal to the antenna's elevation angle. For the proposed Ku-band satellite earth station, this geometry will make the transition region well out of reach by either the general public or by earth station technical/operations personnel.

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 9.3 meters (30.5 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 **0.0075 mW/cm^2** 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:

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

$$= [(200)\ (1{,}258{,}925)] / [4 \pi\ (2{,}508\ m)^2]$$

$$= \mathbf{0.32\ mW/cm^2}$$

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:

$$PD = (0.32\ mW/cm^2) / (1{,}000)$$

$= \mathbf{0.00032\ mW/cm^2}$

D. IMMEDIATE VICINITY OF THE ANTENNA

1. BESIDE AND BEHIND ANTENNA

For areas beside and behind the antenna structure, where station personnel and working environments exist, 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.

$PD \leq (200\ W) / (67.93\ m^2) - 6\ dB$

$= \mathbf{0.074\ mW/cm^2}$

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:

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

$= (4)(200\ W) / (67.93\ m^2)$

$= 11.8\ W/m^2$

$= \mathbf{1.18\ mW/cm^2}$

where "A" is the surface area of the reflector ($67.93\ m^2$) 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 will be on the sub-reflector surface, and is determined as follows:

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

$= (4)\ (200\ W) / (0.46\ m^2)$

$= 1{,}758.4\ W/m^2$

= **175.8 mW/cm^2**

where "a" is the surface area of the sub-reflector (0.46 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:

$PD = (200) / (67.93)\ W/m^2 - 6\ dB$

= **0.074 mW/cm^2**

III. SUMMARY OF CALCULATION RESULTS

Region	Maximum Radiation Level (mW/cm^2)	Hazard Assessment
Between main reflector & sub-reflector	**175.8**	***Potential hazard***.
Reflector surface	**1.18**	***Potential hazard***.
Between antenna & ground	0.074	Complies with guidelines.
Beside and behind antenna	0.074	Complies with guidelines.
Near field, $R_n < 1{,}045$ m	0.75 (on-axis)	Complies with guidelines.
	< 0.0075 (off-axis)	Complies with guidelines.
Transition region, R_t ($1{,}045 \text{ m} < R_t < 2{,}508$ m)	< 0.75 (on-axis)	Complies with guidelines.
	< 0.0075 (off-axis)	Complies with guidelines.
Far field, $R_f > 2{,}508$ m	0.32 (on-axis)	Complies with guidelines.
	< 0.00032 (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 regions:

- Between the main reflector and sub-reflector (maximum power density of 175.8 mW/cm^2).
- On the main reflector surface (maximum power density of 1.18 mW/cm^2).

As noted previously, the bottom edge of the antenna reflector will be approximately 1.5 meters (or higher) from the ground. 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 any 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 HPAs will be turned off whenever maintenance or repair personnel are required to work on or in front of the antenna.

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.

RADIATION HAZARD ANALYSIS
for
PROPOSED 9.3-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Alpharetta, GA

EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS
(Antenna Feed Type: Gasagrain)

Antenna diameter:	D = 9.3	meters
	D = 30.5	feet
	D = 366	inches
Sub-reflector diameter:	d = 30	inches
	d = 0.76	meters
Frequency (maximum):	f = 14,500	MHz
Wavelength:	λ = 0.0207	meters
Antenna transmit gain:	G = 61.0	dBi
	G = 1,258,925	numeric
Antenna physical aperture area:	A = 67.93	sq. meters
Sub-reflector physical area:	a = 0.46	sq. meters
Antenna efficiency:	η = 0.63	numeric
HPA maximum power output:	P_{max} = 400	Watts
	P_{max} = 26.0	dBW

RADIATION HAZARD ANALYSIS
for
PROPOSED 9.3-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Alpharetta, GA

EQUIPMENT SPECIFICATIONS and PERFORMANCE PARAMETERS, cont'd
(Antenna Feed Type: Gasagrain)

Transmit system losses:	L_t =	**-3.0**	dB
	L_t =	0.50	numeric
Maximum RF power into antenna feed:	P =	200	Watts
Maximum EIRP from antenna:	EIRP =	84.0	dBW
	EIRP =	252,382,938	Watts

RADIATION HAZARD ANALYSIS
for
PROPOSED 9.3-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Alpharetta, GA

COMPUTATIONAL RESULTS
(Antenna Feed Type: Gasagrain)

Distance to beginning of the far field:	**R_f = 2,508**	**meters**
	R_f = 8,229	feet
Maximum on-axis power density in the far field:	S = 3.19	Watts/sq. meter
	S = 0.32	**mW/sq. cm**
Off-axis power density in the far field:	S < 0.0032	Watts/sq. meter
	S < 0.00032	**mW/sq. cm**
Extent of the near field:	**Rn = 1045**	**meters**
	Rn = 3,429	feet
Maximum on-axis power density in the near field:	S = 7.5	Watts/sq. meter
	S = 0.75	**mW/sq. cm**
Distance to maximum on-axis power density in the near field:	**0.2(D*2)/L = 836**	**meters**
	0.2(D*2)/L = 2,743	feet
Off-axis power density in the near field:	S < 0.075	Watts/sq. meter
	S < 0.0075	**mW/sq. cm**

RADIATION HAZARD ANALYSIS
for
PROPOSED 9.3-METER KU-BAND TRANSMIT/RECEIVE
SATELLITE EARTH STATION
in
Alpharetta, GA

COMPUTATIONAL RESULTS, cont'd
(Antenna Feed Type: Gasagrain)

Maximum on-axis power density in the transition region between the near field and the far field:	S < 7.5	Watts/sq. meter
	S < 0.75	**mW/sq. cm**
Off-axis power density in the transition region between the near field and the far field:	S < 0.075	Watts/sq. meter
	S < 0.0075	**mW/sq. cm**
Between main reflector and sub-reflector:	S = 1,758.4	Watts/sq. meter
	S = 175.8	**mW/sq. cm**
On reflector surface:	S = 11.8	Watts/sq. meter
	S = 1.18	**mW/sq. cm**
Between antenna and ground:	S < 0.74	Watts/sq. meter
	S < 0.074	**mW/sq. cm**
Beside and behind antenna:	S < 0.74	Watts/sq. meter
	S < 0.074	**mW/sq. cm**