RF RADIATION HAZARD ANALYSIS
FOR PROPOSED 3.7- METER KU-BAND
TRANSMIT/RECEIVE SATELLITE EARTH STATION

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September 12, 2011

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 FCC-adopted MPE limits 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	=	3.7 meters (12.1 feet)
d	=	sub-reflector diameter	=	0.478 meters (18.8 inches)
f	=	frequency	=	14,500 MHz
λ	=	wavelength	=	0.0207 meters
π	=	Pi	=	3.1416
A	=	physical aperture area ($\pi D^2/4$)	=	10.75 square meters
a	=	surface area of sub-reflector ($\pi d^2/4$)	=	0.179 square meters
G	=	antenna transmit gain	=	53.4 dBi
			=	218,776
P	=	maximum power into antenna feed	=	126.2 Watts
η	=	antenna efficiency	=	0.69 dBi
EIRP	=	maximum EIRP from antenna	=	74.4 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 ($0.2\ D^2$) / λ. For the proposed Ku-band satellite

[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.***

earth station, this distance will be 132 meters (434 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 entire length of the near-field region R_n, where R_n is determined as follows:

$$R_n = D^2/(4\lambda) = 165 \text{ m } (543 \text{ ft})$$

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:

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

$$= 4\ [(0.69)\ (126.2 \text{ W})]\ /\ (10.75 \text{ m}^2\ )$$

$$= 32.54 \text{ W/m}^2 = 3.25 \textbf{ mW/cm}^{\mathbf{2}}$$

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 14 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 3.7 meters (12.1 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:

$$(\ 3.25 \text{ mW/cm}^2\ )\ /\ 100 = 0.0325 \textbf{ mW/cm}^{\mathbf{2}}$$

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 (165 meters or 543 feet) to the to the beginning of the far-field, which is determined as follows:

$$R_f = (0.6\ D^2\ )\ /\ \lambda = 397 \text{ m } (1{,}303 \text{ ft})$$

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

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

$$= (3.25\ \text{mW/cm}^2) \times (165\ \text{m} / R_t)$$

$$< 3.25\ \textbf{mW/cm}^{\mathbf{2}}$$

where R_t is point of interest in meters, with 165 meters (543 feet) < R_t < 397 meters (1,303 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 3.7 meters (12.1 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 0.0325 **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:

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

$$= [(126.2\ \text{W})(218{,}776)] / [4 \pi (397\ \text{m})^2]$$

$$= 1.39\ \textbf{mW/cm}^{\mathbf{2}}$$

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:

$$\text{PD} = (1.39\ \text{mW/cm}^2) / 1{,}000$$

$$= 0.00139\ \textbf{mW/cm}^{\mathbf{2}}$$

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 $\leq$ (126.2 W) / (10.75 m^2) - 6 dB

= 0.293 **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) (126.2 W) / (10.75 m^2)

= 46.9 W/m^2

= 4.69 **mW/cm^2**

where "A" is the surface area of the reflector (10.75 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 feed flange surface, and is determined as follows:

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

= (4) (126.2 W) / (0.179 m^2)

= 2,818.5 W/m^2

= 281.8 **mW/cm^2**

where "a" is the surface area of the feed output flange (0.179 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 = (126.2 W) / (10.75 m^2) - 6 dB

= 0.293 **mW/cm^2**

III. SUMMARY OF CALCULATION RESULTS

Region	**Maximum Radiation Level (mW/cm^2)**	**Hazard Assessment**
Between main reflector & sub-reflector	281.8	***Potential hazard***.
Reflector surface	4.69	***Potential hazard***.
Between antenna and ground	0.293	Complies with guidelines.
Beside and behind antenna	0.293	Complies with guidelines.
Near field, R_n < 165 m	3.25 (on-axis)	***Potential hazard***.
	< 0.0325 (off-axis)	Complies with guidelines.
Transition region, R_t (165 m < R_t < 397 m)	< 3.25 (on-axis)	***Potential hazard***.
	< 0.0325 (off-axis)	Complies with guidelines.
Far field, R_f > 397 m	1.39 (on-axis)	***Potential hazard***.
	< 0.00139 (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 FCC-adopted MPE limit 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 281.8 mW/cm^2).

The preceding analyses also show that power density levels in excess of the FCC-adopted MPE limit of 1.0 mW/cm^2 for general population/uncontrolled exposure could occur in the following region:

- On the main reflector surface (maximum power density of 4.69 mW/cm^2).
- Near field (maximum power density of 3.25 mW/cm^2).
- Transition region (maximum on-axis power density of less than 3.25 mW/cm^2).
- Far field (maximum power density of 1.39 mW/cm^2).

The proposed Ku-band satellite earth station consists of a 3.7-meter antenna approximately 14 meters (or higher) from the ground (the antenna is mounted on the roof of a tall building). This will minimize the possibility of personnel in the general vicinity of the antenna being accidentally exposed to harmful levels of RF radiation. In addition, 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. Due to the antenna elevation angle range (to cover the full domestic arc), the rising edges of the cylindrical near-field, transition regions, and far field of the antenna will be such that these regions will not be accessible to the general population located on the ground. 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 Feed Type: Gregorian)

Antenna diameter:	D = 3.7	meters
	D = 12.1	feet
	D = 146	inches
Sub-reflector diameter:	d = 18.8	inches
	d = 0.478	meters
Frequency (maximum):	f = 14,500	MHz
Wavelength:	λ = 0.0207	meters
Antenna transmit gain:	G = 53.4	dBi
	G = 218,776	numeric
Antenna physical aperture area:	A = 10.75	sq. meters
Sub-reflector physical area:	a = 0.179	sq. meters
Antenna efficiency:	η = 0.69	numeric
HPA maximum power output:	P_{max} = 200.0	Watts
	P_{max} = 23.0	dBW

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

Transmit system losses:	L_t =	**-2.0**	dB
	L_t =	0.63	numeric
Maximum RF power into antenna feed:	P =	126.2	Watts
	P =	21.0	dBW
Maximum EIRP from antenna:	EIRP =	74.4	dBW
	EIRP =	27,607,685	Watts

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COMPUTATIONAL RESULTS
(Antenna Feed Type: Gregorian)

Distance to beginning of the far field:	**R_f =**	**397**	**meters**
	R_f =	1,303	feet
Maximum on-axis power density in the far field:	S =	13.94	Watts/sq. meter
	S =	**1.39**	**mW/sq. cm**
Off-axis power density in the far field:	S <	0.0139	Watts/sq. meter
	S <	**0.00139**	**mW/sq. cm**
Extent of the near field:	**Rn =**	**165**	**meters**
	Rn =	543	feet
Maximum on-axis power density in the near field:	S =	32.54	Watts/sq. meter
	S =	**3.25**	**mW/sq. cm**
Distance to maximum on-axis power density in the near field:	**0.2(D^2)/λ =**	**132**	**meters**
	0.2(D^2)/λ =	434	feet
Off-axis power density in the near field:	S <	0.325	Watts/sq. meter
	S <	**0.0325**	**mW/sq. cm**

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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 < 32.5	Watts/sq. meter
	S < 3.25	**mW/sq. cm**
Off-axis power density in the transition region between the near field and the far field:	S < 0.325	Watts/sq. meter
	S < 0.0325	**mW/sq. cm**
Between main reflector and sub-reflector:	S = 2,818.5	Watts/sq. meter
	S = 281.8	**mW/sq. cm**
On reflector surface:	S = 46.9	Watts/sq. meter
	S = 4.69	**mW/sq. cm**
Between antenna and ground:	S < 2.93	Watts/sq. meter
	S < 0.293	**mW/sq. cm**
Beside and behind antenna:	S < 2.93	Watts/sq. meter
	S < 0.293	**mW/sq. cm**

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August 28, 2011

POWER DENSITY CALCULATIONS FOR TRANSMITTED SIGNALS FROM KU-BAND SATELLITE EARTH STATION

I. SIGNAL TYPES AND BANDWIDTHS

At any given time during the operation of the Ku-band satellite earth station, one or more of the following signal type will be uplinked to a selected satellite within the domestic arc.

Signal Type	Occupied Signal Bandwidth	
Digital QPSK (medium-rate MCPC)	5.00	MHz

II. SIGNAL COMBINATIONS AND PER-CARRIER POWER LEVELS

Current operational plans for the Ku-band satellite earth station include the following uplinked signal:

- One or more medium-rate MCPC signals, with per-carrier RF power density levels (into the antenna) that will not exceed -14.0 dBW/4 kHz.

III. INPUT POWER LEVELS AND POWER DENSITIES (TO ANTENNA)

For any of the possible transmitted signal types, the RF power density into the antenna is given by:

Power Density (dBW/4 kHz) = P (dBW) + 36.0 dB-Hz - 10 log B + PF,

where P = per-carrier input power (to the antenna)

36.0 dB-Hz is a factor to convert power density from a 1 Hz bandwidth to a 4 kHz bandwidth

B is the bandwidth occupied by the signal

PF = signal peaking factor (dependent on the signal type)

The per-carrier input power (to the antenna) is determined by reducing the per-carrier output power from the HPA by the transmitting system losses, or

$$P\ (\text{dBW}) = P_t\ (\text{dBW}) + L_t\ (\text{dB})$$

where P_t = per-carrier output power (from the HPA)

and L_t = transmitting system losses (a fractional numeric, with a negative dB value)

For routine licensing of Ku-band narrowband digital transmissions from antennas less than 5 meters in diameter, it is understood that the per-carrier power density into the antenna should be no greater than -14.0 dBW/4 kHz. No specific additional constraints/limitations related to transmitted power levels (or power densities) of narrowband digital signals at Ku-band are known to exist.

As shown below, all signals to be transmitted from the Ku-band satellite earth station will be operated in strict compliance with all known applicable limitations on input power levels and input power densities for Ku-band signals. Maximum power levels are established for the signal type listed in Section I, and input power densities are calculated for it. Maximum EIRP and EIRP density levels, both on-axis and toward the horizon, are also calculated for the specified signal type.

A. MEDIUM-RATE MCPC SIGNAL

1 Input Power Level (to antenna)

For the Ku-band satellite earth station, the maximum operating power level (at the output of the HPA) for a medium-rate compressed MCPC signal will never exceed **51** Watts, or **17.1** dBW. Using a minimum value of **2.0** dB for the aggregate transmitting system losses, the corresponding maximum power level into the antenna will therefore be:

P (dBW) = P_t (dBW) + L_t (dB)

= **17.1** **dBW** - **2** **dB**
= **15.1**

A per-carrier operating input power level of 15.1 dBW will be substantially above what will be required for good performance margins to a network of 1.2-meter to 3.7-meter receiving antennas. Such a high power level will normally only be used during occasional periods of uplink degradation due to rainfall.

2 Input Power Density (to antenna)

Assuming a maximum antenna input power level of **15.1** dBW, the worst-case input power density for the medium-rate compressed MCPC signal can be determined. This signal is in the MCPC format, with an information rate of **4.91** Mbps. Use of 3/4 FEC encoding results in a transmitted data rate of approximately **6.55** Mbps. The modulation technique is QPSK and the transmitted symbol rate is approximately **3.27** Msps. The occupied signal bandwidth is approximately **4.42** Mhz, but (for conservatism) an even lower bandwidth equal to the symbol rate of **3.27** MHz, or **65.15** dB-Hz, will be used to calculate the input power density to the antenna. For this bandwidth, a peaking factor of 0.0 dB can be safely assumed, and the calculation is as follows:

Input Power Density (dBW/4 kHz) = P (dBW) + 36.0 dB-Hz - 10 log B + PF
= **15.1** dBW + 36.0 dB-Hz - **65.15** dB-Hz + 0.0 dB
= **-14.07** dBW/4 kHz

Under no circumstances will the input power density (to the antenna) of the specified MCPC signal be permitted to exceed -14.0 dBW/4 kHz.

IV. TRANSMITTED EIRPs AND EIRP DENSITIES (FROM ANTENNA)

For the Ku-band satellite earth station, the maximum (on-axis) value of per-carrier EIRP is calculated as follows:

EIRP (dBW) = P_t (dBW) + L_t (dB) + G_t (dBi) ,

where P_t = maximum value of per-carrier power (from the HPA)

L_t = minimum value of transmitting system losses = - 2.0 dB

G_t = maximum value of transmit antenna gain = 53.4 dBi

For a given transmitted signal, the maximum (on-axis) RF power density (at the output of the antenna) is given by:

EIRP Density (dBW/4 kHz) = EIRP (dBW) + 36.0 dB-Hz - 10 log B + PF,

where EIRP = maximum (on-axis) value of per-carrier output EIRP

36.0 dB-Hz is a factor to convert power density from a 1 Hz bandwidth to a 4 kHz bandwidth
B is the bandwidth occupied by the signal

PF = signal peaking factor (dependent on the signal type)

Equivalently, maximum (on-axis) EIRP density values can be determined by simply increasing the maximum values of per-carrier input power density (determined previously for each signal type) by the on-axis antenna gain.

At any off-axis angle, the EIRP and EIRP density values will be reduced by an amount equal to the antenna gain reduction. For any given transmitted signal type from the Ku-band satellite earth station being considered, the maximum EIRP density toward the horizon will occur when the elevation angle is at its minimum value of 15.5 degrees. At an off-axis angle of 15.5 degrees, the antenna gain will be no greater than the allowable sidelobe envelope. At this angle, the off-axis gain will therefore be no greater than:

29 - 25log (15.5 deg) = **-0.8** dBi

The gain <u>reduction</u> at an off-axis angle of 15.5 degrees will be equal to the difference in on-axis and off-axis gain values, and will be at least:

53.4 dBi - -0.8 dBi = **54.2** dB

A. MEDIUM-RATE MCPC COMPRESSED DIGITAL VIDEO SIGNALS

1 Maximum EIRP (on-axis)

Assuming that per-carrier input power level (to the antenna) is increased up to its maximum allowable value of
15.1 dBW, the maximum EIRP for the specified low-rate MCPC compressed digital video signal can be determined as follows:

$$\text{EIRP (dBW)} = P_t\text{ (dBW)} + L_t\text{ (dB)} + G_t\text{ (dBi)} ,$$

= 17.1 dBW - 2 dB + 53.4 dBi

= **68.5** dBW

2 Maximum EIRP Density (on-axis)

EIRP Density (dBW/4 kHz) = EIRP (dBW) + 36.0 dB-Hz - 10 log B + PF

= 68.5 dBW + 36.0 dB-Hz - 65.15 dB-Hz + 0.0 dB

= **39.3** dBW/4 kHz

3. Maximum EIRP Density (toward horizon)

EIRP Density (at 15.5 degrees) = EIRP Density (on-axis) - 54.2 dB

= 39.3 dBW/4 kHz - 54.2 dB

= **-14.8** dBW/4 kHz

V. SUMMARY OF RESULTS

Signal Type	Minimum Signal Bandwidth* (MHz)	Maximum Input Power to Antenna (dBW)	Maximum Input Power Density to Antenna (dBW/4kHz)	Maximum On-Axis EIRP (dBW)	Maximum On-Axis EIRP Density (dBW/4kHz)	Maximum EIRP Density Toward Horizon (dBW/4kHz)
Digital MCPC	3.27	15.1	-14.07	68.5	39.3	-14.8

Symbol rate bandwidth (very conservative assumption).

VI. CONCLUSIONS

The analyses presented herein, and summarized in the preceding table, show that the maximum power levels and maximum power density values (for all of the possible signal types) are all within the values that are considered applicable for routine licensing of Ku-band transmit/receive earth stations.