# RF RADIATION HAZARD ANALYSIS FOR PROPOSED 7.3 METER KU-BAND TRANSMIT/RECEIVE SATELLITE EARTH STATION IN LAS VEGAS, NEVADA

Prepared by:
Paul Fleming, Senior Staff Engineer
Omnitracs, LLC
10260 Sorrento Valley Road
San Diego, CA 92121

## 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 sub-reflector, the sub-reflector and main reflector, and the area directly in front of 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 5.00mW/cm$^2$ for occupational/controlled exposure, and 1.00mW/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 antenna (Cassegrain type) are as follows:

| | | |
|---|---|---|
| $D$ | = antenna (main reflector) diameter | = 7.3279 meters |
| $A$ | = main reflector area ($\pi D^2/4$) | = 42.17 meters$^2$ |
| $d_s$ | = sub-reflector diameter | = 1.05664 meters |
| $a_s$ | = sub-reflector area ($\pi d_s^2/4$) | = 0.88 meters$^2$ |
| $d_f$ | = feed window diameter | = 0.21 meters |
| $a_f$ | = feed window area ($\pi d_f^2/4$) | = 0.035 meters$^2$ |
| $G$ | = antenna gain (14.5 GHz) | = 58.3 dBi |
| $G^*$ | = $10^{G/10}$ | = 676,083 |
| $\eta$ | = antenna efficiency ($G^*\lambda^2/(\pi^2 D^2)$) | = 0.5495 |
| $f$ | = maximum frequency | = 14,500 MHz |
| $\lambda$ | = wavelength | = 0.0207 meters |
| $\pi$ | = pi | = 3.14159 |
| P1dB | = amplifier power at max gain | = 40 Watts (16 dBW, 46 dBm) |
| losses | = (1 dB waveguide) | = 1.00 dB |
| P | = maximum power at antenna flange | = 31.62 Watts (15 dBW, 45.0 dBm) |
| EIRP | = maximum EIRP from antenna | = 73.3 dBW |

1. *"Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," OET Bulletin No. 65, Edition 97-01, August 1997, Federal Communications Commission, Office of Engineering and Technology, Washington, DC 20554.*

## 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 518.8 meters 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:

$$R_n = D^2 / (4\lambda) = 648.5 \text{ meters}$$

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:

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

$$= 4\ [(0.5495)\ (31.62\ \text{W})] / (42.17\ \text{m}^2)$$

$$= 1.65\ \text{W/m}^2$$

$$= \mathbf{0.165\ mW/cm^2}$$

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 7.3 meters 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:

$$(0.165\ \text{mW/cm}^2) / 100$$

$$= 0.00165\ \text{mW/cm}^2$$

B. TRANSITION REGION

The power density in the transition region between the near and 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 (648.5 m) to the beginning of the far-field, which is determined as follows:

$$R_f = 0.6D^2/\lambda = 1556.5 \text{ meters}$$

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

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

$$= (0.165 \text{ mW/cm}^2) \times (648.5 \text{ m} / R_t)$$

$$< \mathbf{0.165\ mW/cm^2}$$

where $R_t$ is point of interest in meters, with 648.5 meters < $R_t$ <1556.5 meters.
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 on 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 7.3 meter 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 0.00165 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:

$$PD\text{ (far-field)} = [(P)(10^{G/10})] / (4\pi R_f^2)$$

$$= [(31.62\text{ W})(676{,}083)] / [4\pi(1556.5\text{ m})^2]$$

$$= \mathbf{0.070\ mW/cm^2}$$

Off-axis power densities in the far-field region are reduced by at least 29 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:

$$PD = (0.070\text{ mW/cm}^2) / 10^{(29/10)}$$

$$= \mathbf{0.000088\ mW/cm^2}$$

## D. IMMEDIATE VICINITY OF THE ANTENNA

### 1. BETWEEN FEED WINDOW AND SUB-REFLECTOR

For the proposed Ku-band satellite earth station, the maximum power density in this region will be on the feed window surface, and is determined as follows:

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

$$= (4)(31.62\text{ W}) / (0.035\text{ m}^2)$$

$$= \mathbf{361.4\ mW/cm^2}$$

where "$a_f$" is the surface area of the feed window (0.035 $m^2$) and the factor of 4 results from the 6 dB tapered illumination level.

### 2. BETWEEN SUB-REFLECTOR AND MAIN 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:

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

$$= (4)(31.62\text{ W}) / (0.88\text{ m}^2)$$

$$= \mathbf{14.4\ mW/cm^2}$$

where "$a_s$" is the surface area of the sub-reflector (0.88 $m^2$) and the factor of 4 results from the 6 dB tapered illumination level.

3. REFLECTOR SURFACE

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

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

$$= (4)\ (31.62W)\ /\ (42.17\ m^2)$$

$$\mathbf{= 0.300\ mW/cm^2}$$

where "A" is the surface area of the reflector (42.17 $m^2$) and the factor of 4 again results from the 6 dB tapered illumination level.

4. 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 ≤ the transmit power, P, divided by the area of the antenna reflector, A, less 6 dB taper.

$$PD \le [31.62\ W\ /\ (42.17\ m^2)] - 6\ dB = (31.62\ W\ /\ 42.17\ m^2)\ (0.25)$$

$$\mathbf{= 0.019\ mW/cm^2}$$

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.

5. 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:

$$PD = [31.62\ W\ /\ (42.17\ m^2)] - 6\ dB = (31.62\ W\ /\ 42.17\ m^2)\ (0.25)$$

$$\mathbf{= 0.019\ mW/cm^2}$$

## III. SUMMARY OF CALCULATION RESULTS

| Region | Maximum Radiation Level (mW/cm$^2$) | Hazard Assessment |
|---|---|---|
| Near field, $R_n$ < 648.5 m | 0.165 (on-axis) | Complies with guidelines |
| | < 0.00165 (off-axis) | Complies with guidelines |
| Transition region, $R_t$ | < 0.165 (on-axis) | Complies with guidelines |
| 648.5 m < $R_t$ < 1556.5 m | < 0.00165 (off-axis) | Complies with guidelines |
| Far field, $R_f$ > 1556.5 m | 0.070 (on-axis) | Complies with guidelines |
| | < 0.000088 (off-axis) | Complies with guidelines |
| Between feed window & sub-reflector | **361.4** | **Potential hazard** |
| Between sub-reflector & main reflector | **14.4** | **Potential hazard** |
| Reflector surface | 0.300 | Complies with guidelines |
| Beside & behind antenna | 0.019 | Complies with guidelines |
| Between antenna & ground | 0.019 | Complies with guidelines |

## IV. CONCLUSIONS / HAZARD MITIGATION

The above analyses show that, if the proposed Ku-band satellite earth station was operated 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 between the feed window and sub-reflector, and between the sub-reflector and main reflector.

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 is enclosed by fencing, with access controlled by a badge reader, and only accessible by trained earth station personnel. Based upon an evaluation of the operating angle of the antenna and the site configuration, it will not be possible for the general public to approach closer than 4 meters from the bottom edge of the dish.
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> Additionally, the entire fenced-in, earth station/antenna facility is further enclosed in a highly controlled and access-restricted communications complex. By security protocol, there is no loitering in the vicinity of the earth station and there are no RF levels above 1.0 mW/cm$^2$.
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> The antenna will be marked with standard RF 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 personnel are required to work on or in front of the antenna.

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 satellite arc, the antenna elevation angle will range between a minimum of 29.4 degrees and a maximum of 48.0 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.