# RF Radiation Analysis
# For
# Experimental Testing of
# GD M17-M17A
# Ka Band Antenna System

20130607m02v01_M17-M17A_Rad_HazCalcs.doc
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Prepared by
Intellicom Technologies, Inc.

iNTELLICOM
Satellite & Wireless
Engineering and Management
www.ITCcom.net

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# 1.0 INTRODUCTION

This report is in response to the original 1985 FCC adoption of the 1982 American National Standards Institute (ANSI) guidelines and the further 1993 adoption of the 1992 ANSI and 1991 Institute of Electrical and Electronics Engineers (IEEE) guidelines[1] for evaluating exposure to RF transmitters licensed and authorized by the FCC. In 1996, the FCC adapted a modified version of its original proposal[2], which also fulfills the requirements of the Telecommunications Act of 1996 RF exposure guidelines[3].

The Maximum Permissible Exposure (MPE) radiation limit specifies two separate tiers as shown in ***Table 1***:

- **(A) Occupational/Controlled Exposure**: The time-averaged exposure period is 6 minutes.
- **(B) General Population/Uncontrolled Exposure**: The time-averaged exposure period is 30 minutes.

## Table 1 - Maximum Permissible Exposure Limits

| | ***(A) Controlled Exposure (6-Minute Average)*** | | | ***(B) Uncontrolled Exposure (30-Minute Average)*** | | |
|---|---|---|---|---|---|---|
| ***Frequency Range (MHz)*** | ***Electric Field Strength (E) (V/m)*** | ***Magnetic Field Strength (H) (A/m)*** | ***Power Density (S) ($mW/cm^2$)*** | ***Electric Field Strength (E) (V/m)*** | ***Magnetic Field Strength (H) (A/m)*** | ***Power Density (S) ($mW/cm^2$)*** |
| 0.3-3.0 | 614 | 1.63 | (100)* | | | |
| 3.0-30 | 1842/f | 4.89/f | $(900/f^2)$* | | | |
| 0.3-1.34 | | | | 614 | 1.63 | (100)* |
| 1.34-30 | | | | 824/f | 2.19/f | $(180/f^2)$* |
| 30-300 | 61.4 | 0.163 | 1.0 | 27.5 | 0.073 | 0.2 |
| 300-1500 | -- | -- | f/300 | -- | -- | f/1500 |
| **1,500-100,000** | -- | -- | **5** | -- | -- | **1.0** |

F = frequency in MHz
* = Plane Wave equivalent Power Density
-- = Not specified.

[1] ANSI/IEEE C95.1-1992 (IEEE Standard for Safety Levels with Respect to Human Exposure to RF Electromagnetic Fields, 3 kHz to 300 GHz)
[2] Refer to ET Docket 93-62 References 55 and 56, and FCC Office of Engineering (OET) Bulletin 65 Reference 57 Edition 97-01 for detailed information.
[3] See Section 704(b) of the Telecommunications Act of 1996, Pub. L No 104-104, Stat 56.

The satellite earth station being analyzed in this report is a dual optics parabolic antenna that communicates via geosynchronous satellites. The antenna will be mounted on the ground, on a wheeled cart or table, or to the top of an unmanned helicopter. Precision tracking methods using an Inertial Navigation Unit and GPS tracking maintain antenna pointing accuracy to within a few 10ths of a degree of boresight. The antenna is protected from the elements by a radome.

The antenna control systems include the **automatic shutdown of RF transmissions** when the following conditions exist:

1. When the antenna **boresight error** is greater than 0.5 of a degree. This error is in Azimuth or Elevation, or a combination of both. This is a settable parameter.
2. When the **elevation angle** goes below a preprogrammed value (usually 5$^{o}$ to 20$^{o}$) or mask.

The purpose of this analysis is to determine the Power Flux Density (S) for the earth station and to compare these levels to the specified MPE's of ***Table 1***. Several formulas and parameters to be used for determining the Power Flux Densities are provided in ***Table 2***.

## Table 2 - Formulas and Parameters Used in this Document

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| Parameter | Symbol | Formula | Value | Units |
|---|---|---|---|---|
| Frequency | F | Input | 30,000 | MHz |
| Wavelength | $\lambda$ | C/F | 0.0100 | m |
| | | | | |
| **Antenna Diameter (inches)** | | | | |
| Major (Azimuth) | $D_1$ | | 17 | inches |
| Minor (Elevation) | $D_2$ | | 17.0 | inches |
| **Antenna Diameter (m)** | | | | |
| Major (Azimuth) | $D_1$ | | 0.43 | m |
| Minor (Elevation) | $D_2$ | | 0.43 | m |
| **Antenna Radius** | | | | |
| Major (Azimuth) | $R_1$ | | 0.22 | m |
| Minor (Elevation) | $R_2$ | | 0.22 | m |
| | | | | |
| **Antenna Reflector** | | | | |
| Antenna Surface Area (plane) | $A_{surface}$ | area of an ellipse, $\pi$*$R_1$*$R_2$ | 0.15 | $m^2$ |
| Equivalent Diameter (as if circular) | De | 2*sqrt($A_{surface}$/$\pi$) | 0.43 | m |
| | | | | |
| **Subreflector** | | | | |
| Sub-reflector Diameter | $D_{sr}$ | Input | 5 | cm |
| Area of Subreflector | $A_{sr}$ | $\pi$*$R_1$*$R_2$ | 0.0079 | $m^2$ |
| | | | | |
| **Power Amplifier** | | | | |
| Transmit Power - saturated | Psat | | 41.8 | dBm |
| Line Losses between SSPA output and feed input | L | Measured | 0.75 | dB |
| Net Power Into Feed | P | Measured | 41.0 | dBm |
| Net Power Into Feed | P | | 13 | Watts |

## *1.1 Assumptions used for this Analysis*

The antenna will be mounted on the ground, on a wheeled cart or table, or to the top of an unmanned helicopter.

Since the antenna may be mounted at or below the height of a person, as a conservative safety measure we must assume that a person could be in the path of the main beam of the antenna while transmitting.

Personnel near the antenna are well within the high power of the main beam and lower adjacent sidelobes of the antenna. It is this area that poses the greatest hazard. It is further exacerbated by the protective dome that surrounds the antenna, since it conceals the antenna's direction. Those who may be in close proximity to the vehicle could be in a direct path of the main beam, and be to harmful RF radiation.

# 2.0 ANALYSIS

## 2.1 Far Field Distance Calculation

In the Far Field or Fraunhofer region of the antenna, the power density decreases inversely with the ***square*** of the distance from the main reflector. The distance to the beginning of the far field is[4,5]:

| 2.1 Far Field Distance Calculation | | | | |
|---|---|---|---|---|
| Distance to the **Far Field Region** | $R_{ff}$ | $0.6*D^2 / \lambda$ | | |
| | $R_{ff}$ | $0.6*(D_1D_2) / \lambda$ | 11.2 | m |
| | $R_{ff}$ | | 37 | ft |

The maximum main beam power density at the beginning of the far field is[6]:

| | | | | |
|---|---|---|---|---|
| On-Axis Power Density (PD) in the Far Field | $S_{ff}$ | $P\ G / (4\ \pi\ R_{ff}^2)$ | 93 | $W/m^2$ |
| | | | 9 | $mW/cm^2$ |

## 2.2 Safe Far Field Distance Calculation

It is important to know the minimum distance from the center of the antenna to where the Uncontrolled Exposure ***Power Density (S)*** in ***(mW/cm²)*** is considered safe. Per FCC OET Bulletin 65, a safe limit for uncontrolled exposure is **1.0 mW/cm²**. For a 0° elevation angle, the minimum distance at which this level is achieved is:

| 2.2 Safe Far Field Distance Calculation | | | | |
|---|---|---|---|---|
| Uncontrolled Exposure ***Power Density (S)*** in ***(mW/cm²)*** is considered safe | Sffsd | | 1 | $mW/cm^2$ |
| | Sffsd | | 10 | $W/m^2$ |
| Safe Distance away from Antenna Center | $R_{ffsd}$ | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | 34 | m |
| | | | 112 | ft |

## 2.3 Near Field Distance Calculation

In the radiating Near Field region, the average power density remains fairly constant at different distances from the antenna, although there are localized energy fluctuations. This area is called the Fresnel Region, or the focusing region of the antenna.

The distance to the end of the Near Field is[7]:

| 2.3 Near Field Distance Calculation | | | | |
|---|---|---|---|---|
| Extent of the **Near Field** | $R_{nf}$ | $= D^2 / (4\ \lambda)$ | | |
| | | $= (D_1D_2) / (4\ \lambda)$ | 5 | m |
| | | | 15 | ft |

[4] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (16).
[5] $D_1$ = Width; $D_2$ = Height
[6] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (18).
[7] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (12).

The maximum power density in the Near Field is[8]:

| | | | | |
|---|---|---|---|---|
| On-Axis Near Field Power Density | $S_{nf}$ | $= 16\ \eta\ P / (\pi\ D^2)$ | 217 | $W/m^2$ |
| | | $1000\ mW/W / (10000\ cm^2/m^2)$ | 21.7 | $mW/cm^2$ |

## 2.4 Transition Region Calculation

The area between the Near and Far Field regions is called the Transition region. Power density in this region decreases inversely with the distance from the antenna. This region extends from $R_{nf}$ to $R_{ff}$. The power density at a distance $R_t$ in this region can be determined from the following equation[9]:

| 2.4 Transition Region Calculation | | | | |
|---|---|---|---|---|
| Transition Region Power Density | $S_t$ | $= S_{nf}\ R_{nf} / R_t$, Rt=**Rnf** | 217 | $W/m^2$ |
| | | $1000\ mW/W / (10000\ cm^2/m^2)$ | 21.7 | $mW/cm^2$ |
| | | | | |
| | | $= S_{nf}\ R_{nf} / R_t$, Rt=**Rff** | 90 | $W/m^2$ |
| | | $1000\ mW/W / (10000\ cm^2/m^2)$ | 9.0 | $mW/cm^2$ |

## 2.5 Region between Main Reflector and Sub-reflector

The energy between the sub-reflector and the main reflector of a Cassegrain antenna can be calculated by determining the Power Density at the sub-reflector surface. This can be determined from the following equation

| 2.5 Region between Main Reflector and Subreflector | | | | |
|---|---|---|---|---|
| Power Density at Subreflector | $S_{sr}$ | = 4P / Asr | 6412 | $W/m^2$ |
| | | $1000\ mW/W / (10000\ cm^2/m^2)$ | 641 | $mW/cm^2$ |

## 2.6 Main Reflector Region

Power Density in the main reflector can be determined from the following equation[10]:

| 2.6 Main Reflector Region | | | | |
|---|---|---|---|---|
| Power Density at Main **Reflector Surface** | $S_{mr}$ | $= 4\ P / A_{surface}$ | 344 | $W/m^2$ |
| | | $1000\ mW/W / (10000\ cm^2/m^2)$ | 34.4 | $mW/cm^2$ |

## 2.7 Region between Main Reflector and Ground

Assuming uniform illumination of the main reflector surface, the Power Density between the antenna and the ground can be determined from the following equation:

| 2.7 Region between Main Reflector and Ground | | | | |
|---|---|---|---|---|
| Power Density between Reflector and Gnd | $S_g$ | $= 4P / A_{surface}$ | 344 | $W/m^2$ |
| | | $1000\ mW/W / (10000\ cm^2/m^2)$ | 34.4 | $mW/cm^2$ |

[8] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (13).
[9] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (17).
[10] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (11).

## 2.8 Safe Distances from Antenna

Following are calculations for determining the minimum safe distance a person must be away from the transmitting antenna. Per FCC OET Bulletin 65, a safe limit for uncontrolled exposure is **1.0 mW/cm²**. At the distances to be calculated, the power density will be less than or equal to 1.0 mW/cm².

- Personnel must be over **112 ft away** from the main beam. Since a radome covers the antenna, one would not be certain where the antenna is pointing.

| | | | | |
|---|---|---|---|---|
| 20130607m01v01_M17-17C_Rad_HazCalcs.xls | | | | |
| **Main Beam** | | | | |
| **Main Beam, 0°<\|elevation\|<2.2°, 0°<\|azimuth\|<2.2°** | | | | |
| Antenna Gain (dBi) @30 GHz | $G_{es}$ | Measured | 40.7 | dBi |
| Antenna Gain (main lobe factor) | G | $10^{Ges/10}$ | 11614 | n/a |
| Theoretical Gain | Gt | $4\pi A / \lambda^2$ | 18402 | n/a |
| Antenna Efficiency | η | G / Gt | 63% | % |
| *Antenna Gain with Line Losses @ 14.5 GHz* | $G_{es\ total}$ | $G_{es}$ - L | *39.9* | *dBi* |
| Safe Distance (1 mW/cm²) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **112** | ft |

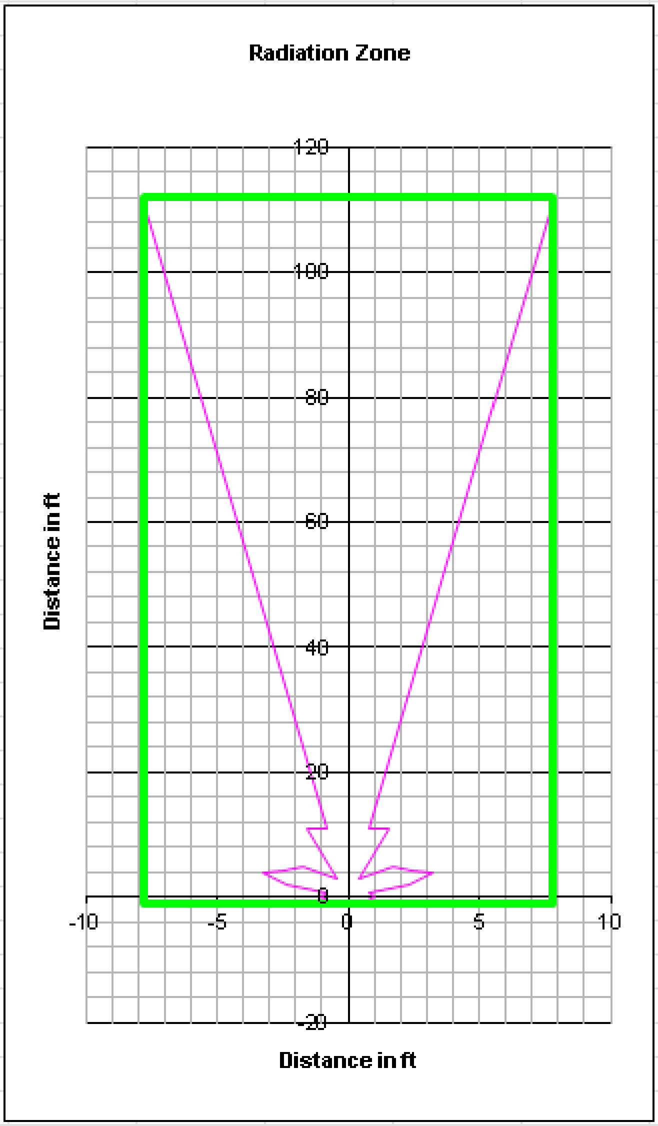
| | | | | |
|---|---|---|---|---|
| **Elevation Pattern (Azimuth=0)** | | | | |
| **2.2°<\|θ\|<8° SideLobe (Elevation Pattern)** | | | | |
| Sidelobe Discrimination/Loss (from main beam) | $L_{SL}$ | Measured | 20.8 | dB |
| Antenna Gain @ sidelobes | $G_{es\ sidelobe}$ | Ges – $L_{SL}$ | 19.9 | dBi |
| Antenna Gain (main lobe factor) | G | $10^{Ges/10}$ | 97 | n/a |
| Safe Distance (1 mW/cm²) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **11** | ft |
| **8°<\|θ\|<20°, (Elevation Pattern)** | | | | |
| Sidelobe Discrimination/Loss (from main beam) | $L_{SL}$ | Measured | 34.7 | dB |
| Antenna Gain | $G_{es\ sidelobe}$ | Ges – $L_{SL}$ | 5.9 | dBi |
| Antenna Gain | G | $10^{Ges/10}$ | 4 | n/a |
| Safe Distance (1 mW/cm²) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **3** | ft |
| **20°<\|θ\|<50°, (Elevation Pattern)** | | | | |
| Sidelobe Discrimination/Loss (from main beam) | $L_{SL}$ | Measured | 41.8 | dB |
| Antenna Gain | $G_{es\ sidelobe}$ | Ges – $L_{SL}$ | -1.2 | dBi |
| Antenna Gain | G | $10^{Ges/10}$ | 1 | n/a |
| Safe Distance (1 mW/cm²) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **1** | ft |
| **50°<\|θ\|<90° (Elevation Pattern)** | | | | |
| Antenna Gain | $G_{es\ sidelobe}$ | Ges – $L_{SL}$ | -8.0 | dBi |
| Antenna Gain | G | $10^{Ges/10}$ | 0.2 | n/a |
| Safe Distance (1 mW/cm²) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **1** | ft |

| **Azimuth Pattern (Elevation=0)** | | | | |
|---|---|---|---|---|
| **2.2°<\|θ\|<8° SideLobe (Azimuth Pattern)** | | | | |
| Sidelobe Discrimination/Loss (from main beam) | $L_{SL}$ | Measured | *20.8* | dB |
| Antenna Gain @ sidelobes | $G_{es\ sidelobe}$ | $Ges – L_{SL}$ | 19.9 | dBi |
| Antenna Gain (main lobe factor) | G | $10^{Ges/10}$ | 97 | n/a |
| Safe Distance (1 mW/cm$^2$) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **11** | ft |
| **8°<\|θ\|<20°, (Azimuth Pattern)** | | | | |
| Sidelobe Discrimination/Loss (from main beam) | $L_{SL}$ | Measured | *34.7* | dB |
| Antenna Gain | $G_{es\ sidelobe}$ | $Ges – L_{SL}$ | 5.9 | dBi |
| Antenna Gain | G | $10^{Ges/10}$ | 4 | n/a |
| Safe Distance (1 mW/cm$^2$) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **3** | ft |
| **20°<\|θ\|<50°, (Elevation Pattern)** | | | | |
| Sidelobe Discrimination/Loss (from main beam) | $L_{SL}$ | Measured | *41.8* | dB |
| Antenna Gain | $G_{es\ sidelobe}$ | $Ges – L_{SL}$ | -1.2 | dBi |
| Antenna Gain | G | $10^{Ges/10}$ | 1 | n/a |
| Safe Distance (1 mW/cm$^2$) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **1** | ft |
| **50°<\|θ\|<180° (Azimuth Pattern)** | | | | |
| Antenna Gain | $G_{es\ sidelobe}$ | $Ges – L_{SL}$ | *-8.0* | dBi |
| Antenna Gain | G | $10^{Ges/10}$ | 0.2 | n/a |
| Safe Distance (1 mW/cm$^2$) | | $\sqrt{(P\ G / (4\ \pi\ S_{ffsd}))}$ | **1** | ft |

The following figures show the area that personnel must stay out of to be at or below **1.0 mW/cm²**.

## Figure 1 - Radiation Keep out Zone

- Red shows keep out zone
- Green Shows a simplified keep out zone

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# 3.0 SUMMARY AND CONCLUSIONS

## *3.1 Conclusions*

Table 3 provides the summary of the previous calculations and the expected radiation levels.

Based upon the above analysis, it is concluded that harmful levels of radiation levels exist in all regions identified in ***Table 3***. This hazardous exposure applies to those who may be around the antenna while it is transmitting.

### Table 3 - Summary of Expected Radiation Levels

| Region | distance (ft) | | Power Density(mW/cm2) | | |
|---|---|---|---|---|---|
| Far Field - Main Beam | 37 | $S_{ff}$ | 9 | mW/cm$^2$ | Potential Hazzard |
| Far Field - Side Lobe | 37 | $S_{nf}$ | 0.1 | mW/cm$^2$ | Satisfies MPE for Controlled Environment |
| Transition Region | transition | $S_t$ | 22 | mW/cm$^2$ | Potential Hazzard |
| Near Field | 15 | $S_{nf}$ | 22 | mW/cm$^2$ | Potential Hazzard |
| Main Reflector | at surface | $S_{mr}$ | 34 | mW/cm$^2$ | Potential Hazzard |
| Sub Reflector | at surface | $S_{sr}$ | 641 | mW/cm$^2$ | Potential Hazzard |
| Between Main Reflector and Subreflector | | $S_{mr}$ | 34 | mW/cm$^2$ | Potential Hazzard |
| Between Main Reflector and Ground | | $S_g$ | 34 | mW/cm$^2$ | Potential Hazzard |

Table – 4 provides a simplified summary of the radiation hazard area. It is recommended that the operator perform radiation flux density measurements around the antenna during typical operation to verify the area of hazard to personnel and ensure that personnel are restricted from entering the hazard area.

### Table 4 - Radiation Hazard Area

| Radiation Hazard Area |
|---|
| 1. Keep a distance of **112 ft** or more during operation.<br>2. This area shall be roped off around the antenna, and radiation hazard signs shall be posted during the operation of this antenna.<br>3. Operator shall perform measurements to verify hazard area. |

## 3.2 Manufacturer Responsibility

1. The manufacturer shall advise the owner/operator to have or seek sufficient knowledge on the safe operation of radio transmitters.
2. The manufacturer shall be responsible for installing permanent RF hazard warning labels on the antenna housing, similar to the one in ***Figure 5***.
3. Radiation hazard warnings signs shall be of sufficient size and in clear view of personnel nearby.
4. Labels shall include a **diagram** (similar to **Figures 6, 7**) showing the regions around the earth station where the levels could exceed 1.0 $mW/cm^2$.
5. The manufacturer shall include warnings in the Operation, Installation, and Maintenance Manuals furnished with each antenna system regarding the potential hazard from RF radiation.
6. The manufacturer shall impose elevation restrictions that turns off the RF transmission when the antenna elevation movements fall below the above specified limits (Table-4).
7. The manufacturer shall pre-program the antenna system with elevation restrictions (Table-4) before delivery.
8. The manufacturer shall provide safety warnings to the operator regarding reducing or removing elevation restrictions.
9. The manufacturer shall maintain this document particularly if parameters of the transmission system change which could impact safety.
10. If a system is delivered that includes a modem and an antenna system, the manufacturer shall ensure that the system is muted within 3 seconds if it is not locked to a receive signal.
11. The manufacturer shall include warnings that an operational system shall include a modem that mutes its transmitter within 3 seconds if it is not locked to a receive signal.
12. The manufacturer shall provide updated labels and documentation to all customers if the safety information is revised.
13. The manufacturer shall recommend that the operator perform a **radiation safety test** of the areas in which personnel will be located during transmission. If radiation exceeds recommended levels, all transmission shall cease until radiation levels have been corrected.


**Figure 2 - Radiation Hazard Warning Label Sample**

## *3.2 Operator Responsibility*

1. The operator shall have sufficient knowledge or seek training on the safe operation of radio transmitters.
2. The operator shall adhere to the warnings provided by the manufacturer's labels, manuals, updates, or other documentation.
3. The operator shall keep the labels on the antenna platform in good shape and within clear view of anyone within close proximity.
4. The operator shall ensure that individuals will be prevented from straying within the hazard region (Table-4) by means of signs, fencing or caution tape, verbal warnings, and placement of the earth station or other appropriate means so as to minimize access to the hazardous region.
5. The operator shall perform a visual inspection of the area around the antenna within the hazard area to ensure that all personnel are below the antenna base and removed from the hazard area (Table-4) during transmission.
6. The operator shall ensure that the antenna system is configured with elevation restrictions (Table-4) that turn off the RF transmission when the antenna elevation falls below the above specified limits (Table-4).
7. The operator shall ensure that the system mutes its transmitter within 3 seconds if it is not locked to a receive signal.
8. The operator shall perform a **radiation safety test** of the areas in which personnel will be located during transmission. If radiation exceeds recommended levels, all transmission shall cease until radiation levels have been corrected.