# EXHIBIT A

# RADIATION HAZARD STUDIES

# GENERAL DYNAMICS 1.2M ANTENNA

GENERAL DYNAMICS
SATCOM Technologies

# RADIATION HAZARD ANALYSIS FOR PRODELIN SERIES 1134 1.2m Ku-Band Antenna

**PERFORMED FOR WSYR-TV**

**November 8, 2011**

**Prepared By: COLIN M ROBINSON**

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# RADIATION HAZARD ANALYSIS FOR PRODELIN SERIES 1134 Ku-BAND 1.2m ANTENNA

## (PERFORMED FOR WSYR-TV)


**SUMMARY:**

This Rad-Haz analysis has been undertaken for WSYR-TV for a Prodelin 1134 Series Ku-band 1.2 m diameter antenna. The analysis follows the guidelines published in the FCC OET Bulletin 65 titled, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields", dated August 1997. (Refer to Appendix 1 & 2 attached hereto.) The referenced document identifies two exposure levels for non-ionizing microwave radiation to which (a) employees and operators and (b) the general public may be exposed. The former condition (a), is defined as a controlled environment wherein the maximum exposure power density is limited to 5 mW / $cm^2$ averaged over any 6-minute period. The second condition (b), applies to the general public and is defined as an uncontrolled environment, wherein the exposure is limited to 1 mW / $cm^2$ averaged over any 30-minute period.

For this analysis we have assumed the condition (b) (1 mW / $cm^2$), time-averaged for a 30 minute exposure and a transmitter input power of 25 watts.


**KEY PARAMETERS:**

The following information lists the key parameters and assumptions used in this analysis.

| | |
|---|---|
| Antenna Diameter (D) | 1.2m (120 cm) |
| Mid-band Tx Frequency (F) | 14.25 GHz |
| Nominal Antenna Efficiency (η) | 64.8% |
| Nominal input power to antenna (P) | 25 watts |
| Mid band antenna gain (dB) | 43.2 dBi |

**DERIVED PARAMETERS**:

This section presents the values derived from the antenna parameters, frequency etc. following the FCC guidelines.

**Regions:**

(a) Mid-band wavelength λ (cm) = 30 / Freq (GHz) = (30 / 14.25) = 2.11 cm

(b) Near Field Limit ($R_{nf}$) = ($D^2$ / 4λ ) = ($120^2$) / (4 x 2.11) = 1706.2 cm (17.1 m)

(c) Approx. Far Field Limit ($R_{ff}$) = (0.6 $D^2$ / λ = (0.6 x $120^2$) / (2.11) = 4094.0 cm (40.9 m)

The “Transition Region” is defined as region between $R_{nf}$ and $R_{ff}$. In this case it extends over a distance of 17.1 m to 40.9 m in front of the antenna.

## POWER DENSITY CALCULATIONS (ON AXIS):

### Power Density at Antenna Surface (PD ref):

$$
\begin{aligned}
PD_{ref} &= 4P/ \text{ reflector area} \\
&= 4P / \{\pi D^2 / 4\} \\
&= 4 \times 25{,}000 / \{\pi \times 120^2 / 4\} \\
&= 8.84 \text{ mW / cm}^2
\end{aligned}
$$

### Maximum Power Density in the Nearfield Region (PDnf):

$$
\begin{aligned}
PD_{nf} &= 16\eta P/\pi D^2 \\
&= 16 \times 0.648 \times 25000 / \pi \times 120^2 \\
&= 5.73 \text{ mW / cm}^2
\end{aligned}
$$

### Power Density at beginning of Farfield Region ($PD_{ff}$)

$$
\begin{aligned}
PD_{ff} \text{ (approx)} &= (P \times G_{abs}) / (4 \times \pi \times R_{ff}^2) \\
&= (25000 \times 10^{43.2/10}) / (4 \times \pi \times 4094^2) \\
&= 2.48 \text{ mW / cm}^2
\end{aligned}
$$

To establish the distance at which a 1 mW/ $cm^2$ power density is achieved when using a 25 watt transmitter, we would set the limit at 1 mW / $cm^2$ and utilize the equation above to compute the corresponding R value. Thus the 1 mW / $cm^2$ limit is achieved at a distance of approx. 64.5 meters (211.5’) in front of the antenna – measured along the radiation axis. At a typical elevation look angle of 40 deg above the horizon, the 1mW / $cm^2$ for this case occurs at a height of 136’ above the local ground level.

## OFF-AXIS POWER DENSITY CONSIDERATIONS (Near Field & Transition Region)

Off-axis power densities are typically 20 dB, or more, below the corresponding on-axis levels for locations displaced by one antenna diameter from the center of the main beam. As the maximum power density levels (on-axis) are approx. 5.73 mW / $cm^2$ in the near-field, the off-axis exposure levels 1.2m of the central radiation axis will be reduced by a further factor 100 or 20 dB. This equates to a power density exposure of 0.06 mW / $cm^2$. Per the FCC OET-65 Bulletin, it can be assumed that these off axis power density predictions apply through the near-field and transition field regions. In the case of the 1.2m antenna for the WSYR-TV application, the 0.06 mW/$cm^2$ condition would extend out to a distance of 4094 cm (134’). At this distance the edge of the off-axis cylinder would be approximately 86 feet above ground level assuming a 40 degree elevation look angle to the satellite of interest.

## OFF-AXIS POWER DENSITY CONSIDERATIONS (Far Field Region)

The radiation pattern for the Prodelin 1134 antenna in far field region will be such that the antenna gain (dBi) from 1 to 48 degrees will below 32 – (25 $\log_{10}(\theta)$), where θ is the angle in degrees from the axis of the main lobe. The off-axis gain for an angle of 40 degrees off beam peak will be – 8.05 dBi. Since the on-axis power density on at the beginning of the far field (4094 cm from the antenna) is 2.48 $mW/cm^2$, the power density at 40 degrees (essentially ground level at this distance is 0.39 mW / $cm^2$. This falls below the 1.0 mW / $cm^2$ limit recommended by the FCC.

## POWER DENSITY – FEED CONSIDERATIONS:

A condition not directly addressed by OET-65, covers the region immediately in front of, and close to the antenna feed. Here the radiated field is confined to a cylindrical beam with a diameter matching that of the feed horn aperture. The power density in this region is determined from the input power to the feed divided by the feed aperture area. The feed for the Prodelin model 1134 Ku-band antenna has a nominal aperture diameter of 14.6 cm. With this diameter, and an input power of 25 watts, power density levels of approx. 149 mW / $cm^2$ can be anticipated. Clearly this is a region of concern if work is performed on the antenna when the transmitter is supplying an input power of 25 watts to the feed. Warning decals are strongly recommended, alerting personnel to potential radiation hazards in the immediate antenna vicinity.

## CONCLUSIONS:

The operational conditions for this application have been investigated following the FCC OET-65 guidelines. Safe operations require that precautions be limit the public exposure to a maximum of 1 mW / $cm^2$ when the antenna is supplied with an input power of 25 watts. This can be accomplished by the operator, (WSYR-TV) ensuring that no un-trained personnel are allowed access to the front of the antenna of the feed region the transmitter is activated. Further the operator, (WSYR-TV) shall ensure that the transmitter is only turned on when the antenna is set to an elevated look angle following satellite acquisition. We recommend that prominent warning signs be displayed indicating the potential hazards from microwave radiation when the antenna is operating at its maximum power level. It is the responsibility of WSYR-TV and its operators to ensure that no person is accidentally permitted to enter the region in front of the antenna where power densities exceed the allowable 1 mW limit established by the FCC for the general population and in an uncontrolled exposure environment.

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## APPENDIX 1: FCC LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE [MPE]

***(From supplement C to FCC OET-65)***

### (A) Limits for Occupational/Controlled Exposure

| Frequency Range (MHz) | Electric Field Strength (E) (V/m) | Magnetic Field Strength (H) (A/m) | Power Density (S) ($mW/cm^2$) | Averaging Time $\lvert E\rvert^2$, $\lvert H\rvert^2$ or S (minutes) |
|---|---|---|---|---|
| 0.3-3.0 | 614 | 1.63 | (100)* | 6 |
| 3.0-30 | 1842/f | 4.89/f | $(900/f^2)$* | 6 |
| 30-300 | 61.4 | 0.163 | 1.0 | 6 |
| 300-1500 | -- | -- | f/300 | 6 |
| 1500-100,000 | -- | -- | 5 | 6 |

### (B) Limits for General Population/Uncontrolled Exposure

| Frequency Range (MHz) | Electric Field Strength (E) (V/m) | Magnetic Field Strength (H) (A/m) | Power Density (S) ($mW/cm^2$) | Averaging Time $\lvert E\rvert^2$, $\lvert H\rvert^2$ or S (minutes) |
|---|---|---|---|---|
| 0.3-1.34 | 614 | 1.63 | (100)* | 30 |
| 1.34-30 | 824/f | 2.19/f | $(180/f^2)$* | 30 |
| 30-300 | 27.5 | 0.073 | 0.2 | 30 |
| 300-1500 | -- | -- | f/1500 | 30 |
| 1500-100,000 | -- | -- | 1.0 | 30 |

f = frequency in MHz *Plane-wave equivalent power density

**NOTE 1: See Section 1 for discussion of exposure categories.**

**NOTE 2: The averaging time for General Population/Uncontrolled exposure to fixed transmitters is not applicable for mobile and portable transmitters. See 47 CFR §§2.1091 and 2.1093 on source-based time-averaging requirements for mobile and portable transmitters.**

## APPENDIX 2: EXTRACT FROM FCC OET 65, EVALUATING COMPLIANCE WITH FCC GUIDELINES FOR HUMAN EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC FIELDS.

**Aperture Antennas**

Aperture antennas include those used for such applications as satellite-earth stations, point-to-point microwave radio and various types of radar applications. Generally, these types of antennas have parabolic surfaces and many have circular cross sections. They are characterized by their high gain which results in the transmission of power in a well-defined collimated beam with little angular divergence. Systems using aperture antennas operate at microwave frequencies, i.e., generally above 900 MHz.

Those systems involved in telecommunications applications operate with power levels that depend on the distance between transmit and receive antennas, the number of channels required (bandwidth) and antenna gains of transmit and receive antennas. The antennas used typically have circular cross sections, where antenna diameter is an important characteristic that determines the antenna gain. With regard to some operations, such as satellite-earth station transmitting antennas, the combination of high transmitter power and large antenna diameter (high gain) produces regions of significant power density that may extend over relatively large distances in the main beam. Many "dish" type antennas used for satellite-earth station transmissions utilize the Cassegrain design in which power is fed to the antenna from a waveguide located at the center of the parabolic reflector. Radiation from this source is then incident on a small hyperbolic sub-reflector located between the power feed and the focal point of the antenna and is then reflected back to the main reflector resulting in the transmission of a collimated beam. An example of this is illustrated in Figure 3.

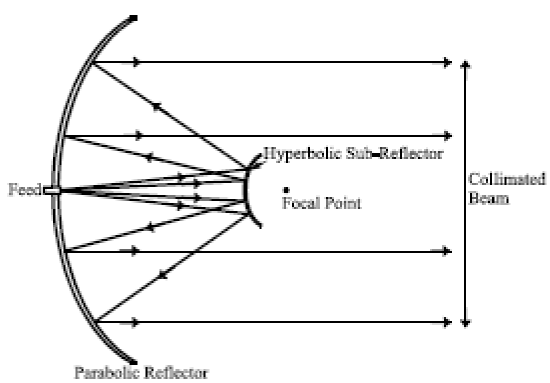


**FIGURE 3. Cassegrain Antenna**

Because of the highly directional nature of these and other aperture antennas, the likelihood of significant human exposure to RF radiation is considerably reduced. The power densities existing at locations where people may be typically exposed are substantially less than on-axis power densities. Factors that must be taken into account in assessing the potential for exposure are main-beam orientation, antenna height above ground, location relative to where people live or work and the operational procedures followed at the facility.

Satellite-earth uplink stations have been analyzed and their emissions measured to determine methods to estimate potential environmental exposure levels. An empirical model has been developed, based on antenna theory and measurements, to evaluate potential environmental exposure from these systems [Reference 15]. In general, for parabolic aperture antennas with circular cross sections, the following information and equations from this model can be used in evaluating a specific system for potential environmental exposure. More detailed methods of analysis are also acceptable. For example, see References [18] and [21].

**Antenna Surface.** The maximum power density directly in front of an antenna (e.g., at the antenna surface) can be approximated by the following equation:

$$S_{surface} = \frac{4P}{A} \qquad (11)$$

where: $S_{surface}$ = maximum power density at the antenna surface
P = power fed to the antenna
A = physical area of the aperture antenna

**Near-Field Region.** In the near-field, or Fresnel region, of the main beam, the power density can reach a maximum before it begins to decrease with distance. The extent of the near-field can be described by the following equation (**D** and **λ** in same units):

$$R_{nf} = \frac{D^2}{4\lambda} \qquad (12)$$

where: $R_{nf}$ = extent of near-field
D = maximum dimension of antenna (diameter if circular)
λ = wavelength

The magnitude of the on-axis (main beam) power density varies according to location in the near-field. However, the maximum value of the near-field, on-axis, power density can be expressed by the following equation:

$$S_{nf} = \frac{16\eta P}{\pi D^2} \qquad (13)$$

where: $S_{nf}$ = maximum near-field power density
$\eta$ = aperture efficiency, typically 0.5-0.75
P = power fed to the antenna
D = antenna diameter

Aperture efficiency can be estimated, or a reasonable approximation for circular apertures can be obtained from the ratio of the effective aperture area to the physical area as follows:

$$\eta = \frac{\left(\frac{G\lambda^2}{4\pi}\right)}{\left(\frac{\pi D^2}{4}\right)} \qquad (14)$$

where: $\eta$ = aperture efficiency for circular apertures
G = power gain in the direction of interest relative to an isotropic radiator
$\lambda$ = wavelength
D = antenna diameter

If the antenna gain is not known, it can be calculated from the following equation using the actual or estimated value for aperture efficiency:

$$G = \frac{4\pi\eta A}{\lambda^2} \qquad (15)$$

where: $\eta$ = aperture efficiency
G = power gain in the direction of interest relative to an isotropic radiator
$\lambda$ = wavelength
A = physical area of the antenna

**Transition Region.** Power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field (Fraunhofer region) of the antenna decreases inversely with the *square* of the distance. For purposes of evaluating RF exposure, the distance to the beginning of the far-field region (farthest extent of the transition region) can be approximated by the following equation:

$$R_{ff} = \frac{0.6\ D^2}{\lambda} \qquad (16)$$

where: $R_{ff}$ = distance to beginning of far-field
D = antenna diameter
$\lambda$ = wavelength

The transition region will then be the region extending from $\mathbf{R_{nf}}$, calculated from Equation (12), to $\mathbf{R_{ff}}$. If the location of interest falls within this transition region, the on-axis

$$S_t = \frac{S_{nf}\ R_{nf}}{R} \qquad (17)$$

power density can be determined from the following equation:

where: $S_t$ = power density in the transition region
$S_{nf}$ = maximum power density for near-field calculated above
$R_{nf}$ = extent of near-field calculated above
R = distance to point of interest

**Far-Field Region.** The power density in the far-field or Fraunhofer region of the antenna pattern decreases inversely as the square of the distance. The power density in the far-field region of the radiation pattern can be estimated by the general equation discussed earlier:

$$S_{ff} = \frac{PG}{4\pi R^2} \qquad (18)$$

where: $S_{ff}$ = power density (on axis)
P = power fed to the antenna
G = power gain of the antenna in the direction of interest relative to an isotropic radiator
R = distance to the point of interest

In the far-field region, power is distributed in a series of maxima and minima as a function of the off-axis angle (defined by the antenna axis, the center of the antenna and the specific point of interest). For constant phase, or uniform illumination over the aperture, the main beam will be the location of the greatest of these maxima. The on-axis power densities calculated from the above formulas represent the maximum exposure levels that the system can produce. Off-axis power densities will be considerably less.

For off-axis calculations in the near-field and in the transition region it can be assumed that, if the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point would be at least a factor of 100 (20 dB) less than the value calculated for the equivalent distance in the main beam (see Reference [15] ).

For practical estimation of RF fields in the off-axis vicinity of aperture antennas, use of the antenna radiation pattern envelope can be useful. For example, for the case of an earth station in the fixed-satellite service, the Commission's Rules specify maximum allowable gain for antenna sidelobes not within the plane of the geostationary satellite orbit, such as at ground level.[19] In such cases, the rules require that the gain of the antenna shall lie below the envelope defined by:

$$32 - \{25\log_{10}(\theta)\}\ \text{dBi} \quad \textit{for} \quad 1^\circ \leq \theta \leq 48^\circ$$
$$\textit{and:} \quad -10\ \text{dBi} \quad \textit{for} \quad 48^\circ < \theta \leq 180^\circ$$

Where: $\theta$ = the angle in degrees from the axis of the main lobe
**dBi** = dB relative to an isotropic radiator

Use of the gain obtained from these relationships in simple far-field calculations, such as Equation 18, will generally be sufficient for estimating RF field levels in the surrounding environment, since the apparent aperture of the antenna is typically very small compared to its frontal area.

**END OF DOCUMENT**

# TOUGHSAT 1.2M ANTENNA

**GENERAL DYNAMICS**
SATCOM Technologies

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For this analysis we have assumed the condition (b) (1 mW / $cm^2$), time-averaged for a 30 minute exposure and a transmitter input power of 25 watts.

**KEY PARAMETERS:**

The following information lists the key parameters and assumptions used in this analysis.

| | |
|---|---|
| Antenna Diameter (D) | 1.2m (120 cm) |
| Mid-band Tx Frequency (F) | 14.25 GHz |
| Nominal Antenna Efficiency (η) | 64.8% |
| Nominal input power to antenna (P) | 25 watts |
| Mid band antenna gain (dB) | 43.2 dBi |

**DERIVED PARAMETERS**:

This section presents the values derived from the antenna parameters, frequency etc. following the FCC guidelines.

**Regions:**

(a) Mid-band wavelength λ (cm) = 30 / Freq (GHz) = (30 / 14.25) = 2.11 cm

(b) Near Field Limit ($R_{nf}$) = ($D^2$ / 4λ ) = ($120^2$) / (4 x 2.11) = 1706.2 cm (17.1 m)

(c) Approx. Far Field Limit ($R_{ff}$) = (0.6 $D^2$ / λ = (0.6 x $120^2$) / (2.11) = 4094.0 cm (40.9 m)

The “Transition Region” is defined as region between $R_{nf}$ and $R_{ff}$. In this case it extends over a distance of 17.1 m to 40.9 m in front of the antenna.

**POWER DENSITY CALCULATIONS (ON AXIS):**

**Power Density at Antenna Surface (PD ref):**

$PD_{ref}$ = 4P/ reflector area
= $4P / \{\pi D^2 / 4\}$
= $4 \times 25{,}000 / \{\pi \times 120^2 / 4\}$
= 8.84 mW / $cm^2$

**Maximum Power Density in the Nearfield Region (PDnf):**

$PD_{nf}$ = $16\eta P / \pi D^2$
= $16 \times 0.648 \times 25000 / \pi \times 120^2$
= 5.73 mW / $cm^2$

**Power Density at beginning of Farfield Region ($PD_{ff}$)**

$PD_{ff}$ (approx) = $(P \times G_{abs}) / (4 \times \pi \times R_{ff}^2)$
= $(25000 \times 10^{43.2/10}) / (4 \times \pi \times 4094^2)$
= 2.48 mW / $cm^2$

To establish the distance at which a 1 mW/ $cm^2$ power density is achieved when using a 25 watt transmitter, we would set the limit at 1 mW / $cm^2$ and utilize the equation above to compute the corresponding R value. Thus the 1 mW / $cm^2$ limit is achieved at a distance of approx. 64.5 meters (211.5’) in front of the antenna – measured along the radiation axis. At a typical elevation look angle of 40 deg above the horizon, the 1mW / $cm^2$ for this case occurs at a height of 136’ above the local ground level.

**OFF-AXIS POWER DENSITY CONSIDERATIONS (Near Field & Transition Region)**

Off-axis power densities are typically 20 dB, or more, below the corresponding on-axis levels for locations displaced by one antenna diameter from the center of the main beam. As the maximum power density levels (on-axis) are approx. 5.73 mW / $cm^2$ in the near-field, the off-axis exposure levels 1.2m of the central radiation axis will be reduced by a further factor 100 or 20 dB. This equates to a power density exposure of 0.06 mW / $cm^2$. Per the FCC OET-65 Bulletin, it can be assumed that these off axis power density predictions apply through the near-field and transition field regions. In the case of the 1.2m antenna for the WSYR-TV application, the 0.06 mW/$cm^2$ condition would extend out to a distance of 4094 cm (134’). At this distance the edge of the off-axis cylinder would be approximately 86 feet above ground level assuming a 40 degree elevation look angle to the satellite of interest.

## OFF-AXIS POWER DENSITY CONSIDERATIONS (Far Field Region)

The radiation pattern for the Prodelin 1134 antenna in far field region will be such that the antenna gain (dBi) from 1 to 48 degrees will below 32 – (25 $\log_{10}$ (θ)), where θ is the angle in degrees from the axis of the main lobe. The off-axis gain for an angle of 40 degrees off beam peak will be – 8.05 dBi. Since the on-axis power density on at the beginning of the far field (4094 cm from the antenna) is 2.48 $mW/cm^2$, the power density at 40 degrees (essentially ground level at this distance is 0.39 mW / $cm^2$. This falls below the 1.0 mW / $cm^2$ limit recommended by the FCC.

## POWER DENSITY – FEED CONSIDERATIONS:

A condition not directly addressed by OET-65, covers the region immediately in front of, and close to the antenna feed. Here the radiated field is confined to a cylindrical beam with a diameter matching that of the feed horn aperture. The power density in this region is determined from the input power to the feed divided by the feed aperture area. The feed for the Prodelin model 1134 Ku-band antenna has a nominal aperture diameter of 14.6 cm. With this diameter, and an input power of 25 watts, power density levels of approx. 149 mW / $cm^2$ can be anticipated. Clearly this is a region of concern if work is performed on the antenna when the transmitter is supplying an input power of 25 watts to the feed. Warning decals are strongly recommended, alerting personnel to potential radiation hazards in the immediate antenna vicinity.

## CONCLUSIONS:

The operational conditions for this application have been investigated following the FCC OET-65 guidelines. Safe operations require that precautions be limit the public exposure to a maximum of 1 mW / $cm^2$ when the antenna is supplied with an input power of 25 watts. This can be accomplished by the operator, (WSYR-TV) ensuring that no un-trained personnel are allowed access to the front of the antenna of the feed region the transmitter is activated. Further the operator, (WSYR-TV) shall ensure that the transmitter is only turned on when the antenna is set to an elevated look angle following satellite acquisition. We recommend that prominent warning signs be displayed indicating the potential hazards from microwave radiation when the antenna is operating at its maximum power level. It is the responsibility of WSYR-TV and its operators to ensure that no person is accidentally permitted to enter the region in front of the antenna where power densities exceed the allowable 1 mW limit established by the FCC for the general population and in an uncontrolled exposure environment.

Colin M. Robinson.

## APPENDIX 1: FCC LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE [MPE]
### *(From supplement C to FCC OET-65)*

**(A) Limits for Occupational/Controlled Exposure**

| Frequency Range (MHz) | Electric Field Strength (E) (V/m) | Magnetic Field Strength (H) (A/m) | Power Density (S) ($mW/cm^2$) | Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes) |
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| 3.0-30 | 1842/f | 4.89/f | $(900/f^2)$* | 6 |
| 30-300 | 61.4 | 0.163 | 1.0 | 6 |
| 300-1500 | -- | -- | f/300 | 6 |
| 1500-100,000 | -- | -- | 5 | 6 |

**(B) Limits for General Population/Uncontrolled Exposure**

| Frequency Range (MHz) | Electric Field Strength (E) (V/m) | Magnetic Field Strength (H) (A/m) | Power Density (S) ($mW/cm^2$) | Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes) |
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| 1.34-30 | 824/f | 2.19/f | $(180/f^2)$* | 30 |
| 30-300 | 27.5 | 0.073 | 0.2 | 30 |
| 300-1500 | -- | -- | f/1500 | 30 |
| 1500-100,000 | -- | -- | 1.0 | 30 |

f = frequency in MHz *Plane-wave equivalent power density

**NOTE 1: See Section 1 for discussion of exposure categories.**

**NOTE 2: The averaging time for General Population/Uncontrolled exposure to fixed transmitters is not applicable for mobile and portable transmitters. See 47 CFR §§2.1091 and 2.1093 on source-based time-averaging requirements for mobile and portable transmitters.**

## APPENDIX 2: EXTRACT FROM FCC OET 65, EVALUATING COMPLIANCE WITH FCC GUIDELINES FOR HUMAN EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC FIELDS.

### Aperture Antennas

Aperture antennas include those used for such applications as satellite-earth stations, point-to-point microwave radio and various types of radar applications. Generally, these types of antennas have parabolic surfaces and many have circular cross sections. They are characterized by their high gain which results in the transmission of power in a well-defined collimated beam with little angular divergence. Systems using aperture antennas operate at microwave frequencies, i.e., generally above 900 MHz.

Those systems involved in telecommunications applications operate with power levels that depend on the distance between transmit and receive antennas, the number of channels required (bandwidth) and antenna gains of transmit and receive antennas. The antennas used typically have circular cross sections, where antenna diameter is an important characteristic that determines the antenna gain. With regard to some operations, such as satellite-earth station transmitting antennas, the combination of high transmitter power and large antenna diameter (high gain) produces regions of significant power density that may extend over relatively large distances in the main beam. Many "dish" type antennas used for satellite-earth station transmissions utilize the Cassegrain design in which power is fed to the antenna from a waveguide located at the center of the parabolic reflector. Radiation from this source is then incident on a small hyperbolic sub-reflector located between the power feed and the focal point of the antenna and is then reflected back to the main reflector resulting in the transmission of a collimated beam. An example of this is illustrated in Figure 3.

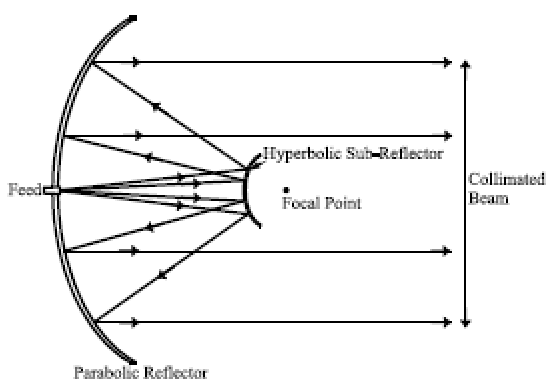


**FIGURE 3. Cassegrain Antenna**

Because of the highly directional nature of these and other aperture antennas, the likelihood of significant human exposure to RF radiation is considerably reduced. The power densities existing at locations where people may be typically exposed are substantially less than on-axis power densities. Factors that must be taken into account in assessing the potential for exposure are main-beam orientation, antenna height above ground, location relative to where people live or work and the operational procedures followed at the facility.

Satellite-earth uplink stations have been analyzed and their emissions measured to determine methods to estimate potential environmental exposure levels. An empirical model has been developed, based on antenna theory and measurements, to evaluate potential environmental exposure from these systems [Reference 15]. In general, for parabolic aperture antennas with circular cross sections, the following information and equations from this model can be used in evaluating a specific system for potential environmental exposure. More detailed methods of analysis are also acceptable. For example, see References [18] and [21].

**Antenna Surface.** The maximum power density directly in front of an antenna (e.g., at the antenna surface) can be approximated by the following equation:

$$S_{surface} = \frac{4P}{A} \qquad (11)$$

where: $S_{surface}$ = maximum power density at the antenna surface
$P$ = power fed to the antenna
$A$ = physical area of the aperture antenna

**Near-Field Region.** In the near-field, or Fresnel region, of the main beam, the power density can reach a maximum before it begins to decrease with distance. The extent of the near-field can be described by the following equation (**D** and **λ** in same units):

$$R_{nf} = \frac{D^2}{4\lambda} \qquad (12)$$

where: $R_{nf}$ = extent of near-field
$D$ = maximum dimension of antenna (diameter if circular)
$\lambda$ = wavelength

The magnitude of the on-axis (main beam) power density varies according to location in the near-field. However, the maximum value of the near-field, on-axis, power density can be expressed by the following equation:

$$S_{nf} = \frac{16\eta P}{\pi D^2} \qquad (13)$$

where: $S_{nf}$ = maximum near-field power density
$\eta$ = aperture efficiency, typically 0.5-0.75
P = power fed to the antenna
D = antenna diameter

Aperture efficiency can be estimated, or a reasonable approximation for circular apertures can be obtained from the ratio of the effective aperture area to the physical area as follows:

$$\eta = \frac{\left(\frac{G\lambda^2}{4\pi}\right)}{\left(\frac{\pi D^2}{4}\right)} \qquad (14)$$

where: $\eta$ = aperture efficiency for circular apertures
G = power gain in the direction of interest relative to an isotropic radiator
$\lambda$ = wavelength
D = antenna diameter

If the antenna gain is not known, it can be calculated from the following equation using the actual or estimated value for aperture efficiency:

$$G = \frac{4\pi\eta A}{\lambda^2} \qquad (15)$$

where: $\eta$ = aperture efficiency
G = power gain in the direction of interest relative to an isotropic radiator
$\lambda$ = wavelength
A = physical area of the antenna

**Transition Region.** Power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field (Fraunhofer region) of the antenna decreases inversely with the *square* of the distance. For purposes of evaluating RF exposure, the distance to the beginning of the far-field region (farthest extent of the transition region) can be approximated by the following equation:

$$R_{ff} = \frac{0.6\ D^2}{\lambda} \qquad (16)$$

where: $R_{ff}$ = distance to beginning of far-field
D = antenna diameter
$\lambda$ = wavelength

The transition region will then be the region extending from $\mathbf{R_{nf}}$, calculated from Equation (12), to $\mathbf{R_{ff}}$. If the location of interest falls within this transition region, the on-axis

$$S_t = \frac{S_{nf}\ R_{nf}}{R} \qquad (17)$$

power density can be determined from the following equation:

where: $S_t$ = power density in the transition region
$S_{nf}$ = maximum power density for near-field calculated above
$R_{nf}$ = extent of near-field calculated above
R = distance to point of interest

**Far-Field Region.** The power density in the far-field or Fraunhofer region of the antenna pattern decreases inversely as the square of the distance. The power density in the far-field region of the radiation pattern can be estimated by the general equation discussed earlier:

$$S_{ff} = \frac{PG}{4\pi R^2} \qquad (18)$$

where: $S_{ff}$ = power density (on axis)
P = power fed to the antenna
G = power gain of the antenna in the direction of interest relative to an isotropic radiator
R = distance to the point of interest

In the far-field region, power is distributed in a series of maxima and minima as a function of the off-axis angle (defined by the antenna axis, the center of the antenna and the specific point of interest). For constant phase, or uniform illumination over the aperture, the main beam will be the location of the greatest of these maxima. The on-axis power densities calculated from the above formulas represent the maximum exposure levels that the system can produce. Off-axis power densities will be considerably less.

For off-axis calculations in the near-field and in the transition region it can be assumed that, if the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point would be at least a factor of 100 (20 dB) less than the value calculated for the equivalent distance in the main beam (see Reference [15] ).

For practical estimation of RF fields in the off-axis vicinity of aperture antennas, use of the antenna radiation pattern envelope can be useful. For example, for the case of an earth station in the fixed-satellite service, the Commission's Rules specify maximum allowable gain for antenna sidelobes not within the plane of the geostationary satellite orbit, such as at ground level.[19] In such cases, the rules require that the gain of the antenna shall lie below the envelope defined by:

$$\mathbf{32 - \{25\log_{10}(\theta)\}\ dBi} \quad \textit{for} \quad \mathbf{1^\circ \leq \theta \leq 48^\circ}$$
$$\textit{and:} \quad \mathbf{-10\ dBi} \quad \textit{for} \quad \mathbf{48^\circ < \theta \leq 180^\circ}$$

Where: $\theta$ = the angle in degrees from the axis of the main lobe
**dBi** = dB relative to an isotropic radiator

Use of the gain obtained from these relationships in simple far-field calculations, such as Equation 18, will generally be sufficient for estimating RF field levels in the surrounding environment, since the apparent aperture of the antenna is typically very small compared to its frontal area.

**END OF DOCUMENT**

# AVL 1.2M ANTENNA

**RADIATION HAZARD STUDY**
For
**AvL Technologies** 1.2m Antenna

This analysis predicts the radiation levels around a proposed earth station complex, comprised of one or more aperture (reflector) type antennas. This report is developed in accordance with the prediction methods contained in OET Bulletin No. 65, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields," Edition 97-01, pp 26-30. The maximum level of non-ionizing radiation to which employees may be exposed is limited to a power density level of 5 milliwatts per square centimeter (5 $mW/cm^2$) averaged over any 6 minute period in a **controlled environment** and the maximum level of non-ionizing radiation to which the general public is exposed is limited to a power density level of 1 milliwatt per square centimeter (1 $mW/cm^2$) averaged over any 30 minute period in a **uncontrolled environment**. Note that the worse-case radiation hazards exist along the beam axis. Under normal circumstances, it is highly unlikely that the antenna axis will be aligned with any occupied area since that would represent a blockage to the desired signals, thus rendering the link unusable.

# Earth Station Technical Parameter Table

| | | |
|---|---|---|
| Antenna Actual Diameter | | 1.2 meters |
| Antenna Surface Area | | 1.13 sq. meters |
| Antenna Isotropic Gain | | 43.1 dBi |
| Number of Identical Adjacent Antennas* | | 0 |
| Nominal Antenna Efficiency (ε) | | 65% |
| Nominal Frequency | | 14125 MHz |
| Nominal Wavelength (λ) | | 0.0212 meters |
| Maximum Transmit Power / Carrier | | 6 Watts |
| Number of Carriers | | 1 |
| Total Transmit Power | | 6 Watts |
| W/G Loss from Transmitter to Feed | | 0.1 dB |
| Total Feed Input Power | | 5.9 Watts |
| Near Field Limit | $R_{nf} = D^2/4\lambda =$ | 17.0 Meters |
| Far Field Limit | $R_{ff} = 0.6\ D^2/\lambda =$ | 40.7 Meters |
| Transition Region | $R_{nf}$ to $R_{ff}$ | |

*The Radiation Levels will be increased directly by the number of antennas indicated, on the assumption that all antennas may illuminate the same area.

In the following sections, the power density in the above regions, as well as other critically important areas will be calculated and evaluated. The calculations are done in the order discussed in OET Bulletin 65. In addition to the input parameters above, input cells are provided below for the user to evaluate the power density at specific distances or angles.

### 1.0 At the Antenna Surface

The power density at the reflector surface can be calculated from the expression:

$PD_{refl}$ = 4P/A = 2.07 mW/cm² (1)

Where: P = total power at feed, milliwatts

A = Total area of reflector, sq. cm

In the normal range of transmit powers for satellite antennas, the power densities at or around the reflector surface is expected to exceed safe levels. This area will not be accessible to the general public. Operators and technicians should receive training specifying this area as a high exposure area. Procedures must be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

### 2.0 On-Axis Near Field Region

The geometrical limits of the radiated power in the near field approximate a cylindrical volume with a diameter equal to that of the antenna. In the near field, the power density is neither uniform nor does its value vary uniformly with distance from the antenna. For the purpose of considering radiation hazard it is assumed that the on-axis flux density is at its maximum value throughout the length of this region. The length of this region, i.e., the distance from the antenna to the end of the near field, is computed as Rnf above.

The maximum power density in the near field is given by:

$PD_{nf} = (16\ \varepsilon\ P)/(\pi\ D^2)$ = 1.35 mW/cm² (2)

From 0 to 17.0 meters

Evaluation

| | |
|---|---|
| Uncontrolled Environment: | See Section 3 |
| Controlled Environment: | 17 meters |

### 3.0 On-Axis Transition Region

The transition region is located between the near and far field regions. As stated in Bulletin 65, the power density begins to vary inversely with distance in the transition region. The maximum power density in the transition region will not exceed that calculated for the near field region, and the transition region begins at that value. The maximum value for a given distance within the transition region may be computed for the point of interest according to:

$PD_t$ = $(PD_{nf})(R_{nf})/R$ = dependent on R (3)

where: $PD_{nf}$ = near field power density

$R_{nf}$ = near field distance

R = distance to point of interest

For: $17.0 < R < 40.7$ meters

We use Eq (3) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation:

Uncontrolled Environment Safe Operating Distance,(meters), $R_{safeu}$: 22.8 meters
Controlled Environment Safe Operating Distance,(meters), $R_{safec}$: See Section 2

## 4.0 On-Axis Far-Field Region

The on- axis power density in the far field region ($PD_{ff}$) varies inversely with the square of the distance as follows:

$$PD_{ff} = PG/(4 \pi R^2) = \text{dependent on } R \qquad (4)$$

where: P = total power at feed
G = Numeric Antenna gain in the direction of interest relative to isotropic radiator
R = distance to the point of interest

For: $R > R_{ff} = 40.7$ meters

$PD_{ff} = 0.58$ mW/cm² at $R_{ff}$

We use Eq (4) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation:

Uncontrolled Environment Safe Operating Distance,(meters), $R_{safeu}$ : See Section 3
Controlled Environment Safe Operating Distance,(meters), $R_{safec}$ : See Section 2

## 5.0 Off-Axis Levels at the FarField Limit and Beyond

In the far field region, 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. Off-axis power density in the far field can be estimated using the antenna radiation patterns prescribed for the antenna in use. Usually this will correspond to the antenna gain pattern envelope defined by the FCC or the ITU, which takes the form of:

$G_{off} = 32 - 25\log(\Theta)$
for Θ from 1 to 48 degrees; -10 dBi from 48 to 180 degrees
(Applicable for commonly used satellite transmit antennas)

Considering that satellite antenna beams are aimed skyward, power density in the far field will usually not be a problem except at low look angles. In these cases, the off axis gain reduction may be used to further reduce the power density levels.

For example: At one (1) degree off axis At the far-field limit, we can calculate the power density as:

$G_{off} = 32 - 25\log(1) = 32 - 0$ dBi = 1585 numeric

$$PD_{1\ deg\ off\text{-}axis} = PD_{ff} \times 1585/G = 0.04\ mW/cm^2 \qquad (5)$$

**6.0 Off-Axis power density in the Near Field and Transitional Regions**

According to Bulletin 65, off-axis calculations in the near field may be performed as follows: assuming that the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point is at least a factor of 100 (20 dB) less than the value calculated for the equivalent on-axis power density in the main beam. Therefore, for regions at least D meters away from the center line of the dish, whether behind, below, or in front under of the antenna's main beam, the power density exposure is at least 20 dB below the main beam level as follows:

$PD_{nf(off\text{-}axis)} = PD_{nf}/100 =$ 0.013 $mW/cm^2$ at D off axis (6)

See page 5 for the calculation of the distance vs elevation angle required to achieve this rule for a given object height.

**7.0 Region Between the Feed Horn and Reflector**

Transmissions from the feed horn are directed toward the reflector surface, and are confined within a conical shape defined by the feed horn. The energy between the feed horn and reflector is conceded to be in excess of any limits for maximum permissible exposure. This area will not be accessible to the general public. Operators and technicians should receive training specifying this area as a high exposure area. Procedures must be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

Note 1:
Mitigation of the radiation level may take several forms. First, check the distance from the antenna to the nearest potentially occupied area that the antenna could be pointed toward, and compare to the distances appearing in Sections 2, 3 & 4. If those distances lie within the potentially hazardous regions, then the most common solution would be to take steps to insure that the antenna(s) are not capable of being pointed at those areas while RF is being transmitted. This may be accomplished by setting the tracking system to not allow the antenna be pointed below certain elevation angles. Other techniques, such as shielding may also be used effectively.

Evaluation of Safe Occupancy Area in Front of Antenna

The distance (S) from a vertical axis passing through the dish center to a safe off axis location in front of the antenna can be determined based on the dish diameter rule (Item 6.0). Assuming a flat terrain in front of the antenna, the relationship is:

$$S = (D/ \sin \alpha ) + (2h - D - 2)/(2 \tan \alpha) \qquad (7)$$

Where: $\alpha$ = minimum elevation angle of antenna
D = dish diameter in meters
h = maximum height of object to be cleared, meters

For distances equal or greater than determined by equation (7), the radiation hazard will be below safe levels for all but the most powerful stations (> 4 kilowatts RF at the feed).

| | | | |
|---|---|---|---|
| For | D = | 1.2 | meters |
| | h = | 3 | meters |

Then:

| **α** | **S** | |
|---|---|---|
| 5 | 29.8 | meters |
| 10 | 14.9 | meters |
| 15 | 9.9 | meters |
| 20 | 7.4 | meters |
| 25 | 5.8 | meters |
| 30 | 4.8 | meters |
| 45 | 3.1 | meters |

Suitable fencing or other barrier should be provided to prevent casual occupancy of the area in front of the antenna within the limits prescribed above at the lowest elevation angle required.

# AVL 1.8M ANTENNA



**RADIATION HAZARD STUDY**
For
**AvL Technologies** 1.8m Antenna

This analysis predicts the radiation levels around a proposed earth station complex, comprised of one or more aperture (reflector) type antennas. This report is developed in accordance with the prediction methods contained in OET Bulletin No. 65, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields," Edition 97-01, pp 26-30. The maximum level of non-ionizing radiation to which employees may be exposed is limited to a power density level of 5 milliwatts per square centimeter (5 $mW/cm^2$) averaged over any 6 minute period in a **controlled environment** and the maximum level of non-ionizing radiation to which the general public is exposed is limited to a power density level of 1 milliwatt per square centimeter (1 $mW/cm^2$) averaged over any 30 minute period in a **uncontrolled environment**. Note that the worse-case radiation hazards exist along the beam axis. Under normal circumstances, it is highly unlikely that the antenna axis will be aligned with any occupied area since that would represent a blockage to the desired signals, thus rendering the link unusable.

# Earth Station Technical Parameter Table

| | | |
|---|---|---|
| Antenna Actual Diameter | | 1.8 meters |
| Antenna Surface Area | | 2.54 sq. meters |
| Antenna Isotropic Gain | | 46.6 dBi |
| Number of Identical Adjacent Antennas* | | 0 |
| Nominal Antenna Efficiency (ε) | | 65% |
| Nominal Frequency | | 14125 MHz |
| Nominal Wavelength (λ) | | 0.0212 meters |
| Maximum Transmit Power / Carrier | | 6 Watts |
| Number of Carriers | | 1 |
| Total Transmit Power | | 6 Watts |
| W/G Loss from Transmitter to Feed | | 0.1 dB |
| Total Feed Input Power | | 5.9 Watts |
| Near Field Limit | $R_{nf} = D^2/4\lambda =$ | 38.1 Meters |
| Far Field Limit | $R_{ff} = 0.6\ D^2/\lambda =$ | 91.5 Meters |
| Transition Region | $R_{nf}$ to $R_{ff}$ | |

*The Radiation Levels will be increased directly by the number of antennas indicated, on the assumption that all antennas may illuminate the same area.

In the following sections, the power density in the above regions, as well as other critically important areas will be calculated and evaluated. The calculations are done in the order discussed in OET Bulletin 65. In addition to the input parameters above, input cells are provided below for the user to evaluate the power density at specific distances or angles.

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## 1.0 At the Antenna Surface

The power density at the reflector surface can be calculated from the expression:

$PD_{refl}$ = 4P/A = 0.92 mW/cm² (1)

Where: P = total power at feed, milliwatts
A = Total area of reflector, sq. cm

In the normal range of transmit powers for satellite antennas, the power densities at or around the reflector surface is expected to exceed safe levels. This area will not be accessible to the general public. Operators and technicians should receive training specifying this area as a high exposure area. Procedures must be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

## 2.0 On-Axis Near Field Region

The geometrical limits of the radiated power in the near field approximate a cylindrical volume with a diameter equal to that of the antenna. In the near field, the power density is neither uniform nor does its value vary uniformly with distance from the antenna. For the purpose of considering radiation hazard it is assumed that the on-axis flux density is at its maximum value throughout the length of this region. The length of this region, i.e., the distance from the antenna to the end of the near field, is computed as Rnf above.

The maximum power density in the near field is given by:

$PD_{nf} = (16\ \varepsilon\ P)/(\pi\ D^2)$ = 0.60 mW/cm² (2)

From 0 to 38.1 meters

Evaluation

| | |
|---|---|
| Uncontrolled Environment: | 22.8 meters |
| Controlled Environment: | 4.6 meters |

## 3.0 On-Axis Transition Region

The transition region is located between the near and far field regions. As stated in Bulletin 65, the power density begins to vary inversely with distance in the transition region. The maximum power density in the transition region will not exceed that calculated for the near field region, and the transition region begins at that value. The maximum value for a given distance within the transition region may be computed for the point of interest according to:

$PD_t = (PD_{nf})(R_{nf})/R$ = dependent on R (3)

where: $PD_{nf}$ = near field power density
$R_{nf}$ = near field distance
R = distance to point of interest

For: $17.0 < R < 40.7$ meters

We use Eq (3) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation:

Uncontrolled Environment Safe Operating Distance,(meters), $R_{safeu}$: See Section 2
Controlled Environment Safe Operating Distance,(meters), $R_{safec}$: See Section 2

## 4.0 On-Axis Far-Field Region

The on- axis power density in the far field region ($PD_{ff}$) varies inversely with the square of the distance as follows:

$$PD_{ff} = PG/(4 \pi R^2) = \text{dependent on } R \quad (4)$$

where: P = total power at feed
G = Numeric Antenna gain in the direction of interest relative to isotropic radiator
R = distance to the point of interest

For: $R > R_{ff} = 40.7$ meters

$PD_{ff} = 0.26$ mW/cm² at $R_{ff}$

We use Eq (4) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation:

Uncontrolled Environment Safe Operating Distance,(meters), $R_{safeu}$ : See Section 2
Controlled Environment Safe Operating Distance,(meters), $R_{safec}$ : See Section 2

## 5.0 Off-Axis Levels at the FarField Limit and Beyond

In the far field region, 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. Off-axis power density in the far field can be estimated using the antenna radiation patterns prescribed for the antenna in use. Usually this will correspond to the antenna gain pattern envelope defined by the FCC or the ITU, which takes the form of:

$G_{off} = 32 - 25\log(\Theta)$
for $\Theta$ from 1 to 48 degrees; -10 dBi from 48 to 180 degrees
(Applicable for commonly used satellite transmit antennas)

Considering that satellite antenna beams are aimed skyward, power density in the far field will usually not be a problem except at low look angles. In these cases, the off axis gain reduction may be used to further reduce the power density levels.

For example: At one (1) degree off axis At the far-field limit, we can calculate the power density as:

$G_{off}$ = 32 - 25log(1) = 32 - 0 dBi = 1585 numeric

$$PD_{1\ deg\ off\text{-}axis} = PD_{ff} \times 1585/G = 0.01\ mW/cm^2 \qquad (5)$$

## 6.0 Off-Axis power density in the Near Field and Transitional Regions

According to Bulletin 65, off-axis calculations in the near field may be performed as follows: assuming that the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point is at least a factor of 100 (20 dB) less than the value calculated for the equivalent on-axis power density in the main beam. Therefore, for regions at least D meters away from the center line of the dish, whether behind, below, or in front under of the antenna's main beam, the power density exposure is at least 20 dB below the main beam level as follows:

$PD_{nf(off\text{-}axis)} = PD_{nf}/100 =$ 0.006 mW/cm² at D off axis (6)

See page 5 for the calculation of the distance vs elevation angle required to achieve this rule for a given object height.

## 7.0 Region Between the Feed Horn and Reflector

Transmissions from the feed horn are directed toward the reflector surface, and are confined within a conical shape defined by the feed horn. The energy between the feed horn and reflector is conceded to be in excess of any limits for maximum permissible exposure. This area will not be accessible to the general public. Operators and technicians should receive training specifying this area as a high exposure area. Procedures must be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

Note 1:
Mitigation of the radiation level may take several forms. First, check the distance from the antenna to the nearest potentially occupied area that the antenna could be pointed toward, and compare to the distances appearing in Sections 2, 3 & 4. If those distances lie within the potentially hazardous regions, then the most common solution would be to take steps to insure that the antenna(s) are not capable of being pointed at those areas while RF is being transmitted. This may be accomplished by setting the tracking system to not allow the antenna be pointed below certain elevation angles. Other techniques, such as shielding may also be used effectively.

Evaluation of Safe Occupancy Area in Front of Antenna

The distance (S) from a vertical axis passing through the dish center to a safe off axis location in front of the antenna can be determined based on the dish diameter rule (Item 6.0). Assuming a flat terrain in front of the antenna, the relationship is:

$$S = (D/ \sin \alpha) + (2h - D - 2)/(2 \tan \alpha) \qquad (7)$$

Where: $\alpha$ = minimum elevation angle of antenna
D = dish diameter in meters
h = maximum height of object to be cleared, meters

For distances equal or greater than determined by equation (7), the radiation hazard will be below safe levels for all but the most powerful stations (> 4 kilowatts RF at the feed).

| | | | |
|---|---|---|---|
| For | D = | 1.2 | meters |
| | h = | 3 | meters |
| Then: | | | |
| | **α** | **S** | |
| | 5 | 33.2 | meters |
| | 10 | 16.6 | meters |
| | 15 | 11.1 | meters |
| | 20 | 8.3 | meters |
| | 25 | 6.6 | meters |
| | 30 | 5.5 | meters |
| | 45 | 3.6 | meters |

Suitable fencing or other barrier should be provided to prevent casual occupancy of the area in front of the antenna within the limits prescribed above at the lowest elevation angle required.

# RAYSAT 1.2M ANTENNA

**Radiation Hazard Analysis**

**SR2000 and SR3000**

This analysis predicts the radiation levels around a proposed earth station complex, comprised of a single panel type antenna. This report is developed in accordance with the prediction methods contained in OET Bulletin No. 65, Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields, Edition 97-01, pp 26-30. The maximum level of non-ionizing radiation to which employees may be exposed is limited to a power density level of 5 milliwatts per square centimeter (5 $mW/cm^2$) averaged over any 6 minute period in a controlled environment and the maximum level of non-ionizing radiation to which the general public is exposed is limited to a power density level of 1 milliwatt per square centimeter (1 $mW/cm^2$) averaged over any 30 minute period in a uncontrolled environment. Note that the worse-case radiation hazards exist along the beam axis. Under normal circumstances, it is highly unlikely that the antenna axis will be aligned with any occupied area since that would represent a blockage to the desired signals, thus rendering the link unusable.

**Earth Station Technical Parameter Table**

| | |
|---|---|
| Antenna Aperture Size | 0.59 m x 0.08m |
| Antenna Effective Diameter | 0.245 meters |
| Antenna Surface Area | 0.047 sq. meters |
| Antenna Isotropic Gain | 27.5 dBi |
| Number of Identical Adjacent Antennas | 1 |
| Nominal Antenna Efficiency (ε) | 42% |
| Nominal Frequency | 14.25 GHz |
| Nominal Wavelength (λ) | 0.0211 meters |
| Maximum Transmit Power / Carrier | 40.0 Watts |
| Number of Carriers | 1 |
| Total Transmit Power | 40.0 Watts |
| W/G Loss from Transmitter to Feed | 1.5 dB |
| Total Feed Input Power | 28.32 Watts |
| Radome Losses | 0.5 dB |
| Effective RF Power at radome | 25.24 Watts |
| Near Field Limit | $R_{nf} = D^2/4\lambda$ = 0.714 meters |
| Far Field Limit | $R_{ff} = 0.6\ D^2/\lambda$ = 1.71 meters |
| Transition Region | $R_{nf}$ to $R_{ff}$ = 0.714 meters to 1.71 meters |

In the following sections, the power density in the above regions, as well as other critically important areas will be calculated and evaluated. The calculations are done in the order discussed in OET Bulletin 65.

## 1.0 At the Antenna Surface

The power density at the reflector surface can be calculated from the expression:

$PD_{as} = 4P/A =$ **240.29** $mW/cm^2$ (1)

Where: P = total power at feed, milliwatts
A = Total area of reflector, sq. cm

In the normal range of transmit powers for satellite antennas, the power densities at or around the reflector surface is expected to exceed safe levels. This area will not be accessible to the general public.

This antenna will incorporate a radome which has 0.5 dB of loss. The worst case power density at the surface of the radome is shown below:

$PD_{radome}=4P_{rad}/A$ = **214.16** mW/cm² (2)
Where: Prad = total power at feed less radome losses, milliwatts
A = Total area of reflector, sq. cm (this would represent worst case)

Operators and technicians should receive training specifying this area as a high exposure area. Procedures must be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

## 2.0 On-Axis Near Field Region

The geometrical limits of the radiated power in the near field approximate a cylindrical volume with a diameter equal to that of the antenna. In the near field, the power density is neither uniform nor does its value vary uniformly with distance from the antenna. For the purpose of considering radiation hazard it is assumed that the on-axis flux density is at its maximum value throughout the length of this region. The length of this region, i.e., the distance from the antenna to the end of the near field, is computed as Rnf above.

The maximum power density in the near field is given by:

$PD_{nf} = (16\varepsilon P)/(\pi D^2)$ = **90.10** mW/cm² (3)
from 0 to 0.713 meters

Evaluation
Uncontrolled Environment: **Does Not Meet Controlled Limits**
Controlled Environment: **Does Not Meet Uncontrolled Limits**

## 3.0 On-Axis Transition Region

The transition region is located between the near and far field regions. As stated in Bulletin 65, the power density begins to vary inversely with distance in the transition region. The maximum power density in the transition region will not exceed that calculated for the near field region, and the transition region begins at that value. The maximum value for a given distance within the transition region may be computed for the point of interest according to:

$PD_{tr} = (PD_{nf})(R_{nf})/R$ = dependent on R (4)
where: $PD_{nf}$ = near field power density
$R_{nf}$ = near field distance
R = distance to point of interest
$PD_{tr}$ = **90.10** mW/cm²
For: $0.713 < R < 1.71$ meters

We use Eq (4) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation

Uncontrolled Environment Safe Operating Distance, (meters), $R_{safeu}$: 64.2
Controlled Environment Safe Operating Distance, (meters), $R_{safec}$: 12.8

## 4.0 On-Axis Far-Field Region

The on- axis power density in the far field region ($PD_{ff}$) varies inversely with the square of the distance as follows:

$PD_{ff} = PG/(4\pi R^2)$ = dependent on R (5)
where: P = total power at feed
G = Numeric Antenna gain in the direction of interest relative to isotropic radiator
R = distance to the point of interest
For: $R > R_{ff} =$ 1.71 meters
$PD_{ff} =$ **38.60** mW/cm² at $R_{ff}$

We use Eq (5) to determine the safe on-axis distances required for the two occupancy conditions:

Evaluation

Uncontrolled Environment Safe Operating Distance,(meters), $R_{safeu}$ : See Section 3
Controlled Environment Safe Operating Distance,(meters), $R_{safec}$ : See Section 3

### 5.0 Off-Axis Levels at the Far Field Limit and Beyond

In the far field region, 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. Off-axis power density in the far field can be estimated using the antenna radiation patterns prescribed for the antenna in use. Usually this will correspond to the antenna gain pattern envelope defined by the FCC or the ITU, which takes the form of:

$G_{off} = 32 - 25\log(\Theta)$
for Θ from 1 to 48 degrees; -10 dBi from 48 to 180 degrees
(Applicable for commonly used satellite transmit antennas)

Considering that satellite antenna beams are aimed skyward, power density in the far field will usually not be a problem except at low look angles. In these cases, the off axis gain reduction may be used to further reduce the power density levels.

*For example:* At two (2) degrees off axis At the far-field limit, we can calculate the power density as:

$G_{off} = 32 - 25\log(2) = 32 – 7.52$ dBi = 280.2 numeric

$PD_{2\ deg\ off\text{-}axis} = PD_{ff} \times 280.2/G =$ **19.23** mW/cm$^2$ **(6)**

### 6.0 Off-Axis power density in the Near Field and Transitional Regions

According to Bulletin 65, off-axis calculations in the near field may be performed as follows: assuming that the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point is at least a factor of 100 (20 dB) less than the value calculated for the equivalent on-axis power density in the main beam. Therefore, for regions at least D meters away from the center line of the dish, whether behind, below, or in front under of the antenna's main beam, the power density exposure is at least 20 dB below the main beam level as follows:

$PD_{nf(off\text{-}axis)} = PD_{nf} /100 =$ **0.901** $mW/cm^2$ at D off axis (7)

See Section 7 for the calculation of the distance vs. elevation angle required to achieve this rule for a given object height.

### 7.0 Evaluation of Safe Occupancy Area in Front of Antenna

The distance (S) from a vertical axis passing through the dish center to a safe off axis location in front of the antenna can be determined based on the dish diameter rule (Item 6.0). Assuming a flat terrain in front of the antenna, the relationship is:

$S = (D/ \sin \alpha) + (2h - D - 2)/(2 \tan \alpha)$ (8)

Where: $\alpha$ = minimum elevation angle of antenna
D = dish diameter in meters
h = maximum height of object to be cleared, meters

For distances equal or greater than determined by equation (8), the radiation hazard will be below safe levels for all but the most powerful stations (> 4 kilowatts RF at the feed).

| | | |
|---|---|---|
| For | $\alpha$ = | 20 degrees, minimum elevation angle of antenna |
| | h = | 2.0 meters, delta between antenna and object >1 m |
| Then: | | |
| | $\alpha$ | S |
| | 10 | 0.7 meters |
| | 15 | 0.5 meters |
| | 20 | 0.4 meters |
| | 25 | 0.3 meters |
| | 30 | 0.3 meters |

## 8.0 Summary of Results

The earth station site will be protected from uncontrolled access by virtue of the fact that it will be mounted on the roof of a vehicle. There will also be proper emission warning signs placed and all operating personnel will be aware of the human exposure levels at and around the earth station. The applicant agrees to abide by the conditions specified in Condition 18 provided below:

> *(18) - The Raysat Antenna Systems LLC shall take all reasonable and customary measures to ensure that the MET does not create potential for harmful non-ionizing radiation to persons who may be in the vicinty of the MET when it is in operation. At a minimum, permanent warning label(s) shall be affixed to the MET warning of the radiation hazard and including a diagram showing the regions around the MET where the radiation levels could exceed 1.0mW/cm2. The operator of the MET shall be responsible for assuring that individuals do not stray into the region around the MET where there is a potential for exceeding the maximum permissible exposure limits required by Section 1.1310 of the Commission's rules 47 C.F.R § 1.1310. This shall be accomplished by means of signs, caution tape, verbal warnings, placement of the MET so as to minimize access to the hazardous region and/or any other appropriate means*

The table below summarizes all of the above calculations.

| Parameter | Abbr. | | Units | Formula |
|---|---|---|---|---|
| Antenna Effective Diameter | Df | 0.245 | meters | |
| Antenna Centerline | h | 2 | meters | |
| Antenna Surface Area | Sa | 0.047 | $meter^2$ | $(\pi * Df^2)/4$ |
| Antenna Ground Elevation | GE | 2 | meters | |
| Frequency of Operation | f | 14.25 | GHz | |
| Wavelength | λ | 0.0211 | meters | |
| HPA Output Power | $P_{HPA}$ | 40 | watts | |
| HPA to Antenna Loss | $L_{Tx}$ | 1.5 | dB | |
| Radome Loss | $L_{Rad}$ | 0.5 | dB | |
| Transmit Power at Flange | P | 28.32 | watts | $P/10Log^{-1}(L_{Tx}/10)$ |
| Effective Power after Radome | | 25.24 | watts | $P/10Log^{-1}$(Radome Loss/10) |
| Antenna Gain | $G_{es}$ | 27.5 | dBi | does not include radome loss |
| Antenna Aperature Efficiency | η | 42% | n/a | |
| **1. Reflector Surface Region Calculations** | | | | |
| Antenna Surface Power Density | Pdas | 2402.9 | $W/m^2$ | $(16 * P)/(\pi * D^2)$ |
| | | 240.29 | $mW/cm^2$ | |
| Power at Radome Surface | Pdrad | 2141.6 | $W/m^2$ | $(16 * P)/(\pi * D^2)$ |
| (outside radome) | | 214.16 | $mW/cm^2$ | **Does not meet controlled limits**<br>**Does not meet uncontrolled limits** |
| **2. On Axis Near Field Calculations** | | | | |
| Extent of Near Field | Rn | 0.713 | meters | $D^2 / (4 * \lambda)$ |
| | | 2.338 | feet | |
| Near Field Power Density | PDnf | 901.0 | $w/m^2$ | $(16 * \eta * P)/(\pi * D^2)$ |
| | | 90.10 | $mW/cm^2$ | **Does not meet controlled limits**<br>**Does not meet uncontrolled limits** |
| **3. On Axis Transition Region Calculations** | | | | |
| Extent of Transition Region (min) | $R_{Tr}$ | 0.713 | meters | $D^2 / (4 * \lambda)$ |
| Extent of Transition Region (min) | | 2.338 | feet | |
| Extent of Transition Region (max) | $R_{Tr}$ | 1.711 | meters | $0.6 * D^2 / \lambda$ |
| Extent of Transition Region (max) | | 5.612 | feet | |
| Worst Case Transition Region Power Density | $PD_{tr}$ | 901.0 | $w/m^2$ | |
| | | 90.10 | $mW/cm^2$ | **Does not meet controlled limits**<br>**Does not meet uncontrolled limits** |
| Uncontrolled enviorment safe operating distance | Rsu | 64.2 | meters | $(PD_{nf})/R_{nf})/Rsu$ |
| Controlled enviorment safe operating distance | Rsc | 12.8 | meters | $(PD_{nf})/R_{nf})/Rsc$ |
| **4. On Axis Far Field Calculations** | | | | |
| Distance to Far Field Region | Rf | 1.71 | meters | $0.6 * D^2 / \lambda$ |
| | | 5.61 | feet | |
| On Axis Power Density in the Far Field | $PD_{ff}$ | 386.0 | $W/m^2$ | $(G_{es} * P) / (4 * \pi * Rf^2)$ |
| | | 38.60 | $mW/cm^2$ | **Does not meet controlled limits**<br>**Does not meet uncontrolled limits** |
| **5. Off-axis Power Density in the Far Field Limit and Beyond** | | | | |
| Antenna Surface Power Density | PDs | 192.3 | $W/m^2$ | $(G_{es} * P) / (4 * \pi * Rf^2) * (Goa/Ges)$ |
| Goa/Ges at a sample angle of θ=2 degrees | | 0.498 | | Goa = 32 - 25*log(θ) |
| | | 19.23 | $mW/cm^2$ | |
| **6. Off Axis Power Density in the Near Field and Transitional Region Calculations** | | | | |
| Power Density of Wn/100 for 1 diameter | PDs | 9.01 | $W/m^2$ | $[(16 * \eta * P)/(\pi * D^2)] / 100$ |
| removed | | 0.901 | $mW/cm^2$ | **Meets controlled limits**<br>**Meets Uncontrolled limits** |
| **7.0 Off-axis Safe Distances from Earth Station** | | | | |
| minimum elevation angle of antenna | α | 10 | degree | |
| hieght of object to be cleared | h | 2 | meter | |
| Groun elevation delta antenna-obstacle elevation ang | **GD** | **S** | | |
| | 10 | 0.7 | meter | S=(D/sinα) + (2h - D- 2) / (2tanα) |
| | 15 | 0.5 | meter | |
| | 20 | 0.4 | meter | |
| | 25 | 0.3 | meter | |
| | 30 | 0.3 | meter | |

Note: Maximum FCC power density limits for 6GHz is 1mW/cm2 for general population exposure as per FCC OS&T