# Design Analysis

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**Revision:** -

**Subject:** Radiation Hazard Analysis of the ViaSat Ka-Band 9.1M Antenna used for testing antenna radiation patterns

## 1. Introduction

In compliance with FCC Rules 1.1307, this analysis has been prepared to determine the radiation hazard levels for the ViaSat Ka-Band 9.1M antenna, that will be used for testing antenna radiation patterns. This report is developed in accordance with OET Bulletin No. 65, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields", Edition 97-01, pp. 26 – 30 (August 1997).

## 2. Applicable Safety Standards

Per the document above, 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 evironment**. 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 unuseable.

# 3. Antenna Description

The antenna being considered in this analysis utilizes a high efficiency 9.14-meter diameter axi-symmetric dual-reflector Cassegrain design. Some of the antenna dimensions are shown in Figure 1.

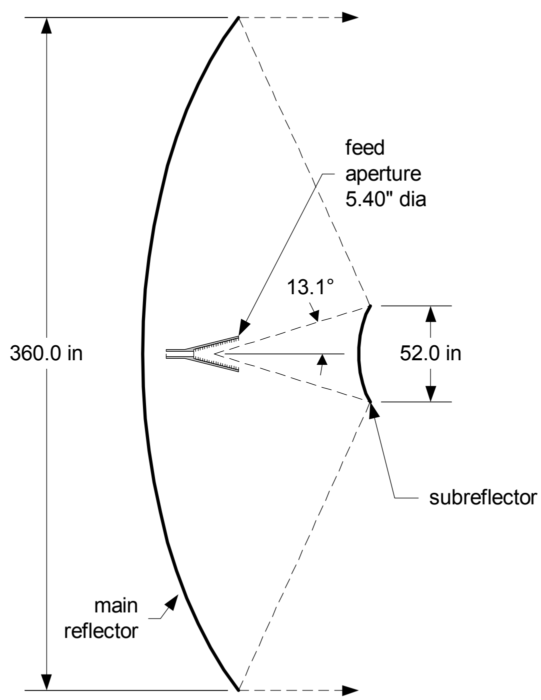


**FIGURE 1 - ANTENNA GEOMETRY**

The antenna is capable of transmitting over the 28.35 to 29.60 GHz frequency band. This analysis will be performed at the mid-band frequency of 28.975 GHz.

The antenna is equipped with a high power amplifier (HPA) assembly that will produce a maximum output power level of 3.5W.

Transmission line losses from the HPA assembly are included with the antenna gain.

A summary of the primary technical parameters of this earth station antenna is given in table 1.

| Parameter | Value |
|---|---|
| Antenna Aperture Diameter | 9.14 m |
| Antenna Surface Area | 65.61 $m^2$ |
| Antenna Isotropic Gain | 64.97 dBi |
| Number of Identical Adjacent Antennas | 0 |
| Nominal Antenna Efficiency ($\eta$) | 41% |
| Nominal Frequency | 28975 MHz |
| Nominal Wavelength ($\lambda$) | 0.0104 m |
| Maximum Transmit Power/Carrier | 3.5W |
| Number of Carriers | 1 |
| Total Transmit Power | 3.5W |
| Waveguide Loss from Transmitter to Feed* | 0 dB |
| Total Feed Input Power | 3.5W |
| Near Field Limit | $R_{nf} = D^2/4\lambda = 2017$ m |
| Far Field Limit | $R_{ff} = 0.6\ D^2/\lambda = 4841$ m |
| Transition Region | $R_{nf}$ to $R_{ff}$ |

Table 1: Earth Station Technical Parameters

* Included in antenna gain

# 4. Analysis

## *4.1 At the Antenna Surface*

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

$S_{surface} = 4P/A = 0.021\ mW/cm^2$

Where:

P = total power at feed assembly input = 3500 mW

A = total area of reflector = 65.6 $m^2$ = 656,118.5 $cm^2$

## *4.2 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 hazards 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 $R_{nf}$ above.

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

$S_{nf} = 16\ \eta\ P/(\pi D^2) = 0.087\ mW/cm^2$

This applies for the region from 0 to 2017m from the antenna.

Evaluation:

| | |
|---|---|
| Uncontrolled Environment: | Complies to FCC limits |
| Controlled Environment: | Complies to FCC limits |

## *4.3 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 in secton 4.2 above, and the transition region begins at that value. Thus, the maximum value of the power density in the transition region is:

$S_t\ (max) = S_{nf} = 0.087\ mW/cm^2$

This applies for the region from 2017 m to 4841 m from the antenna.

Evaluation:

| | |
|---|---|
| Uncontrolled Environment Safe Operating Distance: | 0 m |
| Controlled Environment Safe Operating Distance: | 0 m |

## *4.4 On-axis Far-Field Region*

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

$S_{ff} = PG/(4\pi R^2)$

Where:

P = power fed to the antenna

G = power gain of the antenna (numeric) in the direction of interest relative to an isotropic radiator

R = distance to the point of interest

Thus, for $R \geq R_{ff}$ = 4841 m,

$S_{ff}$ = 0.037 mW/cm$^2$ at $R_{ff}$, and beyond.

Evaluation:

| | |
|---|---|
| Uncontrolled Environment Safe Operating Distance: | 0 m |
| Controlled Environment Safe Operating Distance: | 0 m |

## *4.5 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 $\Theta$ from 1˚ to 48˚ degrees; -10 dBi from 48˚ to 180˚, from the peak of the main beam. (Applicable worst case 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 $R_{ff}$, we can calculate the power density as:

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

$S_{1\ deg\ off\text{-}axis} = S_{ff} \times 1585/G = 1.9 \times 10^{-5}$ mW/cm$^2$

## *4.6 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:

$S_{nf(off\text{-}axis)} = S_{nf}$ /100 = 0.00087 mW/cm$^2$ at D = 9.14 m off axis

## *4.7 Region between the Feed Horn and Subreflector*

The energy radiated from the feed horn is confined to a conically shaped region that extends from the feed aperture to the surface of the subreflector. The energy reflects from the surface of the subreflector and is directed back towards the main reflector surface. The feed horn is designed such that the energy level at the edge of the subreflector is less than the level at the center of the subreflector. As a first approximation, the energy distribution can be assumed to be uniform over the conical region's cross-section and the power density can be expressed as:

$S_{feed} = P_{feed}/(\pi R_{feed}^2)$

Where:

$S_{feed}$ = power density at feed horn aperture

$P_{feed}$ = power at feed horn = P less feed insertion loss;

Estimated feed insertion loss from HPA output to feed horn = -2.14 dB = 0.61 numeric; thus $P_{feed}$ = 3500 mW x 0.61 = 2100 mW

$R_{feed}$ = radius of feed horn aperture = 6.86 cm

Thus:

$S_{feed} = 2100/(\pi \times 6.86^2) = 14.2$ mW/cm$^2$

At the subreflector we can use this same equation to calculate its power density to be:

$S_{sub} = P_{feed}/(\pi R_{sub}^2)$

Where:

$S_{sub}$ = power density at subreflector

$P_{feed}$ = power at feed horn = P less feed insertion loss;

Estimated feed insertion loss from HPA output to feed horn = -2.14 dB = 0.61 numeric; thus $P_{feed}$ = 3500 mW x 0.61 = 2100 mW

$R_{sub}$ = radius of subreflector = 66 cm

Thus:

$S_{sub} = 2100/(\pi \times 66^2) = 0.15$ mW/cm$^2$

Throughout most of the region between the subreflector and the main reflector, the actual power density that exists at a particular point is the combination of direct radiation and reflected radiation. For example, over most of the reflector aperture a person would be exposed to direct energy from the subreflector scattered field and to energy reflected from the main reflector. As a result, the electric field in some regions could be twice as strong, resulting in a power density four times as strong (power is proportional to voltage squared). As a conservative estimate, the power densities computed above are multiplied by four, resulting in the following power density values (note that this factor has already been used in the antenna surface power density calculation of section 4.1 above (per the OET formula):

| | | |
|---|---|---|
| Feed Aperture | $S_{feed}$ = | 56.8 mW/cm$^2$ |
| Subreflector Surface | $S_{sub}$ = | 0.6 mW/cm$^2$ |

Evaluation:

| | |
|---|---|
| Uncontrolled Environment: | Exceeds to FCC limits |
| Controlled Environment: | Exceeds to FCC limits |

Transmissions from the feed horn are directed toward the subreflector surface, and are confined within the conical shape defined by the feed horn and subreflector, as discussed above. The energy in the volume between the feed horn and subreflector, except right at the subreflector, 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 will receive training specifying this area as a high exposure area. Procedures will be established that will assure that all transmitters are rerouted or turned off before access by maintenance personnel to this area is possible.

# 5. Summary of Results

The results of the analyses are summarized in Table 1.

**TABLE 1 - SUMMARY OF RESULTS**

| Region | Power Density $mW/cm^2$ | Comparison to Safety Standard FCC OET Bulletin 65 (uncontrolled areas) $1\ mW/cm^2$ |
|---|---|---|
| At the Antenna Surface | 0.021 | Acceptable |
| On-axis Near Field Region | 0.087 | Acceptable |
| On-axis Transition Region | 0.087 | Acceptable |
| On-axis Far Field Region | 0.037 | Acceptable |
| Off-axis Levels at the Far-field Limit and Beyond | $1.9 \times 10^{-5}$ | Acceptable |
| Off-axis Power Density in the Near Field and Transitional Regions | 0.00087 | Acceptable |
| Feed Aperture | 56.8 | Exceeded |
| Subreflector Surface | 0.6 | Acceptable |

These results indicate that the only region where the referenced safety standards are exceeded is the following:

- The conical shaped region between the feed and subreflector. Personnel hazards in this area will be avoided by disabling the transmitter whenever anyone attempts to access the area between the feed and subreflector.

# 6. References

1. Federal Communications Commission, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, OET Bulletin 65, Revision 97-01, Appendix A, August 1997.