Design Analysis

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Revision: -

Subject: Radiation Hazard Analysis of the Foxtrot 7.3M Antenna

1. Introduction

This analysis has been prepared to determine the radiation hazard levels for the Foxtrot 7.3M antenna. This analysis is not intended to certify that a safety hazard does or does not exist. It is the responsibility of the organization operating the antenna to evaluate the results of this analysis, along with other sources of data, and determine if a safety hazard exists.

2. Applicable Safety Standards

The applicable safety standard for electromagnetic field exposure specified in the Antenna System Requirements Specification is summarized in Table 1.

TABLE 1 - ELECTROMAGNETIC FIELD EXPOSURE STANDARDS

Standard Title	Issuing Organization	Power Density Limit	
		General public exposure	Occupational exposure
Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz), issued 1998	International Commission on Non-Ionizing Radiation Protection (ICNIRP)	1.0 mW/cm^2	5.0 mW/cm^2

The power density values given are those that apply to the transmit frequency band of the Foxtrot antenna, 2.000-2.125 GHz.

3. Antenna Description

The antenna being considered in this analysis utilizes a 7.3-meter diameter axi-symmetric prime-focus design. Some of the antenna dimensions are shown in Figure 1.

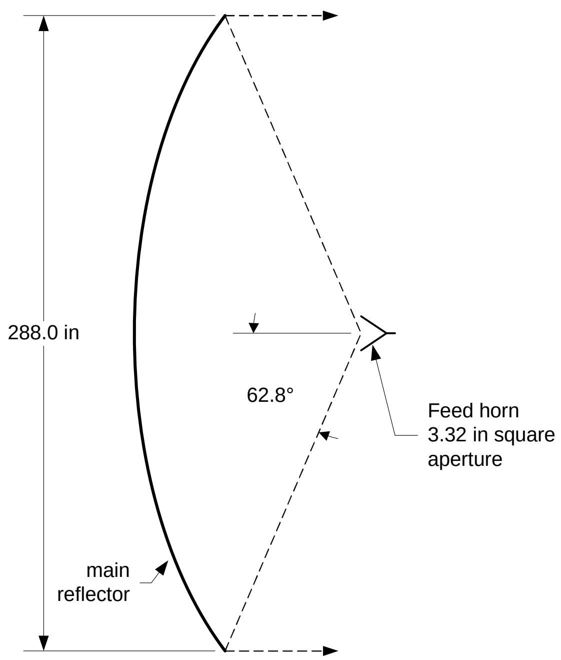

FIGURE 1 - ANTENNA GEOMETRY

The antenna is capable of transmitting over the 2.000 to 2.125 GHz frequency band. This analysis will be performed at the mid-band frequency of 2.06 GHz.

The antenna is equipped with a high power solid-state amplifier (SSPA) that is capable of producing a saturated output power level of 50 watts.

The power delivered to the antenna is determined by subtracting the transmission line and diplexer losses from the SSPA output power. The loss between the SSPA output and the antenna feed horn is approximately 3.0 dB. This results in 25.0 watts maximum being radiated by the antenna feed.

4. Analysis

4.1 General

The power flux densities in the spatial areas surrounding the antenna can be estimated from the geometry of the antenna system and by the use of computer programs capable of computing the near- and far-field radiation patterns of the antenna. The spatial areas around the antenna will be divided into specific regions and an appropriate analysis method will be used for each region. The following regions will be considered:

- Region between the feed horn aperture and the main reflector
- Region directly in front of the reflector aperture (parallel beam region)
- Nearfield region
- Far-field region

These regions are illustrated in Figure 2. For a large antenna of aperture diameter D, most of the energy in the far-field region, beginning at a distance $R=2D^2/\lambda$, occurs within a conical volume having a half-angle of λ/D radians. Close to the antenna, the energy is mostly confined to a cylindrical volume of diameter D. This energy is substantially parallel over the first part of the Nearfield region, diverging into a cone of half-angle λ/D at a transition range $R_0=D^2/2\lambda$. The transition from one region to the next is gradual, and the dimensions shown indicate the traditional boundaries. Within the region between the feed and main reflector, the energy radiated by the feed is enclosed in a conical shaped volume extending from the feed aperture to the main reflector.

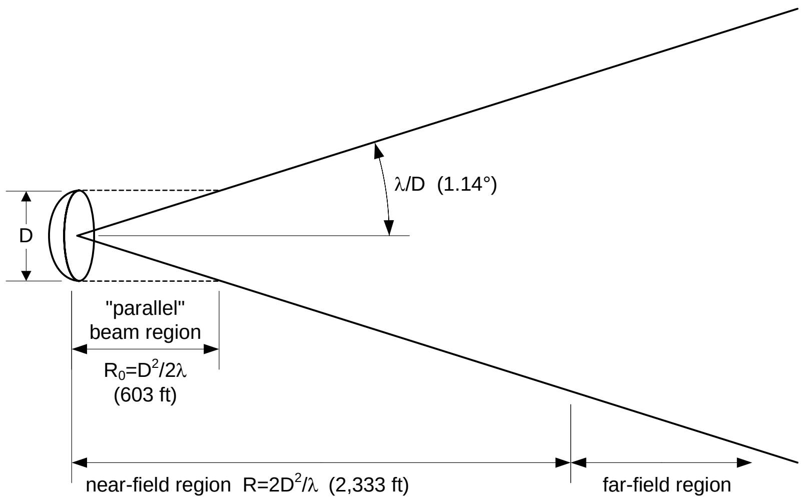

FIGURE 2 - FIELD REGIONS

4.2 Main Reflector – Feed Region

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 main reflector. The energy reflects from the surface of the main reflector and is directed back along the antenna boresite direction. The feed horn is designed such that the energy level at the edge of the main reflector is less than the level at the center of the main reflector. 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:

$$W = \frac{P}{A}$$

where A = cross sectional area of the conical region in square centimeters

P = radiated power in milliwatts.

At the feed aperture (3.32 inches square) we have a power density of:

$$A_f = (W_f)^2 = (8.43\,\text{cm})^2 = 71.1\,\text{cm}^2$$

$$P = 25.0\,\text{W} = 2.5\times10^4\ \text{mW}$$

$$W_f = 351.6\,\text{mW/cm}^2$$

Assuming that total reflection occurs at the main reflector, the power density over the reflector aperture is:

$$A_m = \pi\left(\frac{D}{2}\right)^2 = \pi(365.76\,\text{cm})^2 = 420{,}283.4\,\text{cm}^2$$

$$P = 25.0\,\text{W} = 2.5\times10^4\,\text{mW}$$

$$W_m = 0.06\,\text{mW/cm}^2$$

Throughout most of the region between the feed 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 feed 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:

Feed Aperture	W_f =	1,406.2 mW/cm^2
Main Reflector Surface	W_m =	0.24 mW/cm^2

4.3 On-Axis Power Density

The radiated power in the region directly in front of the antenna reflector is primarily confined to a cylindrical volume having the same diameter as the reflector and extending out to a distance of approximately $R_0=D^2/2\lambda$. In this region, the power density varies as both a function of distance along the antenna axis and of distance away from the antenna axis. Figure 3 shows the on-axis power density vs. distance for a circular aperture with a 10 dB edge taper, computed using the expression derived by Mumford [3]. Also shown in Figure 3 are approximate formulas by Mumford that can be used to estimate the maximum power density.

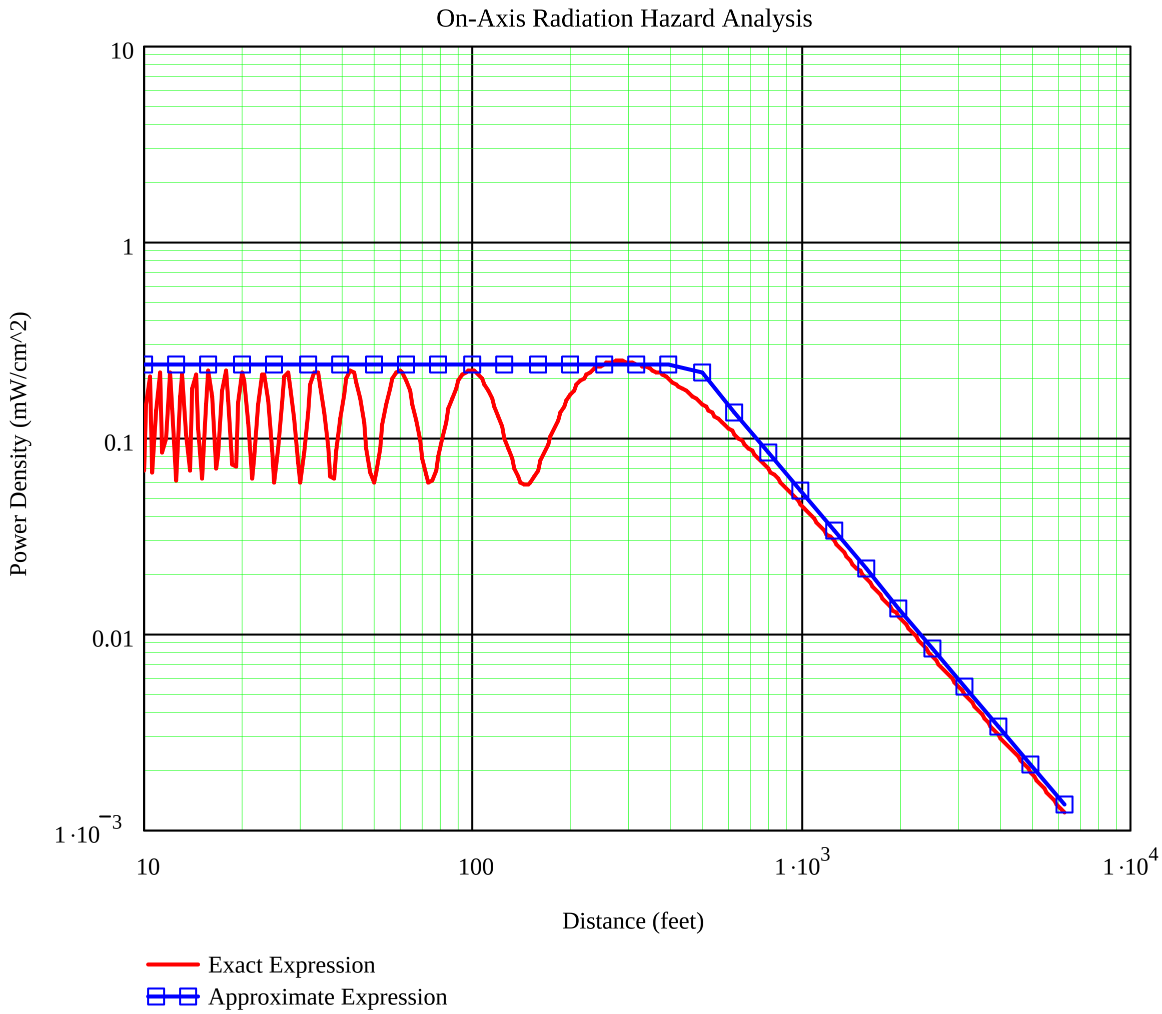

FIGURE 3 - ON-AXIS POWER DENSITY VS. DISTANCE FOR A CIRCULAR APERTURE WITH A 6 DB PARABOLIC ON PEDESTAL APERTURE TAPER

The simple expression for the maximum on-axis power density in the near-field region is:

$$W_{nf} = \frac{4P}{A_m} \text{ mW/cm}^2$$

where P is the transmit power and A_m is the reflector aperture area. For the Foxtrot antenna, this is:

$$A_m = \pi(R_m)^2 = \pi(365.8\text{ cm})^2 = 420{,}283.4\text{ cm}^2$$

$$P = 25.0\text{ W} = 2.5\times10^4\text{ mW}$$

$$W_{nf} = 0.24\text{ mW/cm}^2$$

The simple expression for the maximum on-axis power density in the far-field region is:

$$W_{ff} = \frac{A_m P}{\lambda^2 r^2} \text{ mW/cm}^2$$

where λ is the wavelength and r is the distance from the aperture.

4.4 Off-Axis Power Density

In order to determine the variation of power density off of the antenna axis, more sophisticated antenna analysis methods must be used. One such tool is the GRASP9 computer code, which permits the near- and far-field patterns of reflector antennas, such as the Foxtrot antenna, to be analyzed. Previous analyses of similar antennas shows that the power density is relatively constant over the angular region corresponding to the cylindrical projection of the main reflector aperture, and that the power drops off rapidly outside the main reflector boundaries. The magnitude of the power density corresponds to the on-axis power density levels predicted by the approximate expression in the previous sections. Because the on-axis power density for the Foxtrot antenna is well below the 1.0 mW/cm^2 power density limit of the general public exposure standard, it is not necessary to compute the off-axis power density levels.

5. Summary of Results

The results of the analyses are summarized in Table 2.

TABLE 2 - SUMMARY OF RESULTS

Region	**Power Density** mW/cm^2	**Comparison to Safety Standard** General public exposure 1 mW/cm^2	Occupational exposure 5 mW/cm^2
Feed Aperture	1,406.2	Exceeded	Exceeded
Main Reflector Surface	0.24	Acceptable	Acceptable
Aperture Plane	0.24	Acceptable	Acceptable
Near-field at a Radius of 1,000 feet	0.05	Acceptable	Acceptable
Far-field (beam peak)	See Figure 3	Acceptable	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 main reflector. Personnel hazards in this area may be avoided by disabling the transmitter whenever anyone attempts to access the area between the feed and main reflector.

6. References

1. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz), International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998.
2. Mumford, W.W., “Some Technical Aspects of Microwave Radiation Hazards”, Proc. IRE, vol. 49, pp. 427-447, February 1961.