Reutech Radar Systems, a Division of Reutech Limited.

RADIATION EXPOSURE

IN FRONT OF THE

MSR ANTENNA

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1 SCOPE

This document describes the calculation of the radiation exposure in front of a 1.2 m diameter parabolic reflector antenna when fed with an MSR300 radar transmitter.

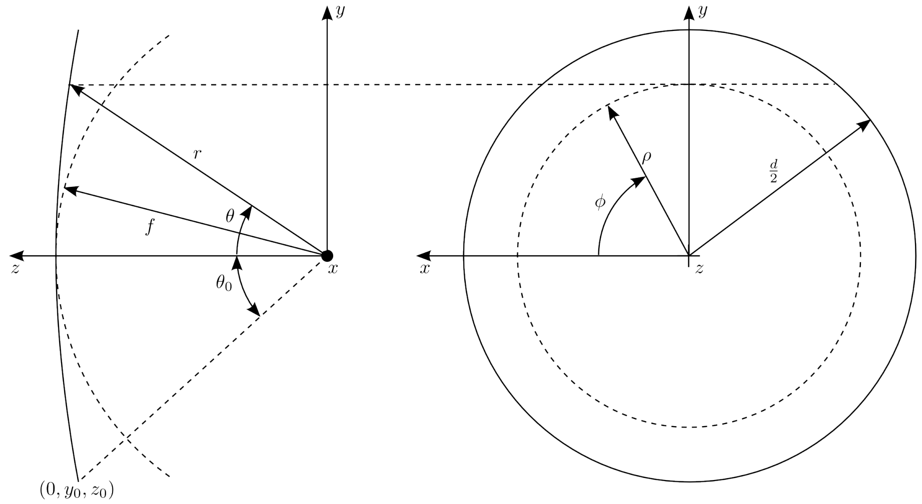


Figure 1: Definition of the variables used to describe the parabolic reflector.

2 INTRODUCTION

The radiation exposure of personnel working in the vicinity of radio and radar transmitters needs to be quantified in order to ensure the safety of persons in the vicinity of the transmitter [4, 3].

The MSR300 radar system [1] radiates less than 56 milliwatts of power from a feedhorn that is reflected by an offset parabolic reflector to form a directed beam ef electromagnetic energy. The radiation exposure in front of the antenna can be accurately estimated by mathematical calculations.

This document describes the calculation of fields in front of a parabolic reflector antenna. In the interests of simplicity, the calculations are done for a centre-fed parabolic parabolic reflector of the same area as the MSR offset parabolic refltor antenna. While the field pattern of a centre-fed parabolic reflector differs slightly from that of an offset reflector, the maximum field strengths are similar, so that conclusions regarding radiation exposure drawn from the centre-fed reflector also apply to the offset fed reflector to a high degree of accuracy.

3 MATHEMATICAL DESCRIPTION OF THE PARABOLOID

The parabolic antenna with diameter d and focal distance f is decribed with the quantities defined in Figure 1 as follows [2].

The defining property of the parabola is that the sum of distances from the focus to the parabola and from the parabola to a fixed line is a constant. From Figure 1,

$$r + r\cos\theta = 2f \tag{1}$$

from which the definition of the paraboloid in spherical coordinates follows as

$$r = \frac{2f}{1+\cos\theta}, \tag{2}$$

independent of the angle ϕ. In cartesian coordinates,

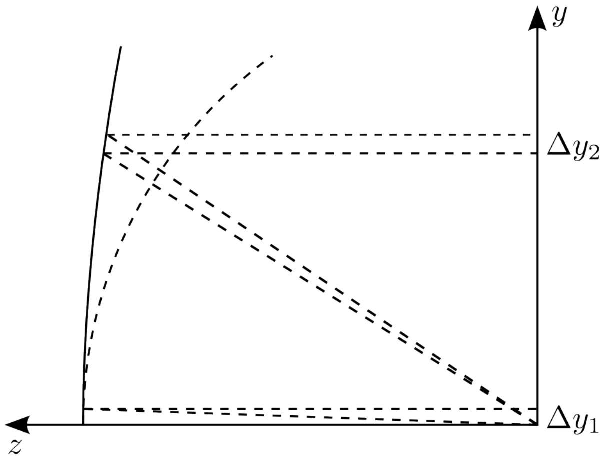


Figure 2: Power distribution due to path length differences between the focus and different points on the reflector.

$$\sqrt{\rho^2 + z^2} + z = \sqrt{x^2 + y^2 + z^2} + z = 2f, \tag{3}$$

from which follows

$$\rho^2 + z^2 = (2f - z)^2 = 4f^2 - 4fz + z^2 \tag{4}$$

and from which we find

$$\rho^2 = 4f(f - z). \tag{5}$$

The angle θ_0 to the edge of the reflector, where $\rho = d/2$, is found from

$$\theta_0 = \arctan \frac{\frac{d}{2}}{z_0} = \arctan \frac{\frac{d}{2}}{f - \frac{1}{4f}\left(\frac{d}{2}\right)^2} = \arctan \frac{\frac{d}{2}}{f - \frac{d^2}{16f}} = \arctan \frac{8\frac{f}{d}}{16\left(\frac{f}{d}\right)^2 - 1}. \tag{6}$$

The MSR antenna has a diameter of 1.2 m and an f/d ratio of 0.8, so that $\theta_0 = 0.6058 = 34.7°$.

4 APERTURE POWER DISTRIBUTION

The power density distribution on a radial line, such the y-axis, is now determined. Due to symmetry, the power density is the same on all radial lines.

The power distribution is determined by the radiation pattern G_f of the feedhorn combined with a space attenuator factor G_p due to the difference in path length from the feed to the centre of the reflector and from the feed to other points on the reflector[2], as illustrated in Figure 2. The figure shows two sets of rays with the same angular spacing reflected to the y-axis. Since $\Delta y_2 > \Delta y_1$, rays near the edge of the reflector are spread further apart when reflected to the y-axis than those near the centre, with a resultant lowering in the power density on the y-axis. (By virtue of the definition of the paraboloid, the total path length from the feed to points on the x-y plane (called the focal plane of the paraboloid) is of course the same for all reflected rays.)

According to the $1/r^2$ law and Equation 1, G_p is given by

$$G_p = \left(\frac{f}{r}\right)^2 = \left(\frac{1 + \cos\theta}{2}\right)^2 = \cos^4\left(\frac{\theta}{2}\right) \tag{7}$$

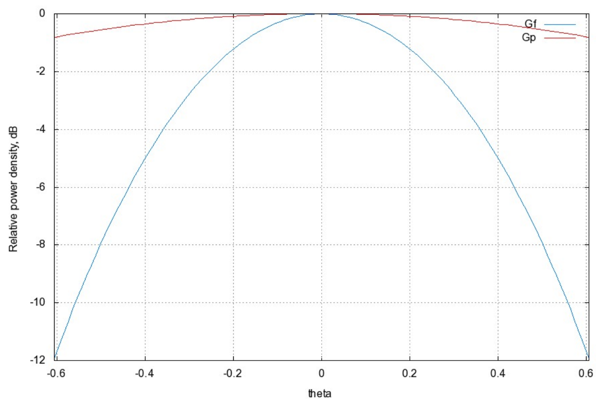


Figure 3: The gain functions of the feedhorn and reflector illumination due to path length differences.

The feed horn is designed to illuminate the reflector with an amplitude taper that drops off to -12 dB at the edge of the reflector with respect to the illumination at the centre. The feed horn gain function is approximated well by the relative gain function [2]

$$G_f = \cos^{14}\theta. \tag{8}$$

The two gain functions are shown in Figure 3.

The relative power density distribution accross the reflector is given by the product of the two gain functions,

$$G_t = G_p G_f. \tag{9}$$

5 ESTIMATE 1: POWER DENSITY IN FRONT OF THE MSR300 ANTENNA

Since the rays reflected from the paraboloid are parallel to each other, the power distribution on the y-axis is the same as the power distribution on the reflector at corresponding y-values.

We can now find the total power reflected by the reflector onto a plane through the focus perpendicular to the z-axis by performing an integration over contiguous rings with width $\Delta\rho$ on the z-plane, namely

$$P = \int_0^{d/2} 2\pi\rho p_d d\rho, \tag{10}$$

where p_d is the power density in each ring on the reflector, given by

$$p_d = p_0 G_f G_p \tag{11}$$

where p_0 is the maximum power density of the distribution, situated on the z-axis.

With the change of variables defined by

$$\rho = r\sin\theta \tag{12}$$

and with

$$d\rho = \left[\frac{2f\sin^2\theta}{(1+\cos\theta)^2} + \frac{2f\cos\theta}{1+\cos\theta}\right] d\theta = \frac{2f}{1+\cos\theta} d\theta, \tag{13}$$

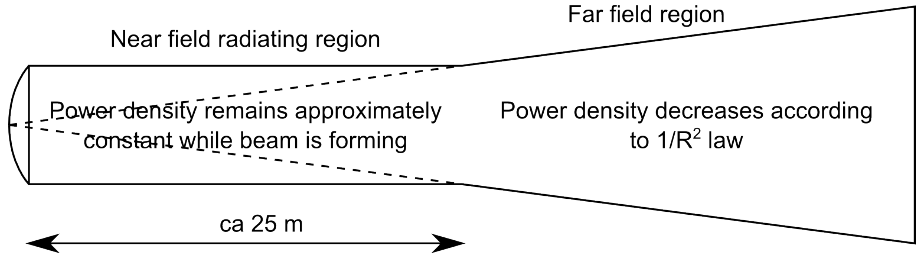


Figure 4: Field regions in front of a directive antenna.

the integral becomes

$$P = \int_0^{\theta_0} 2\pi r \sin\theta p_0 G_p G_f \frac{2f}{1+\cos\theta} d\theta \quad (14)$$

$$= \int_0^{\theta_0} 2\pi \frac{2f}{1+\cos\theta} \sin\theta p_0 \cos^{14}\theta \left(\frac{1+\cos\theta}{2}\right)^2 \frac{2f}{1+\cos\theta} d\theta \quad (15)$$

$$= 2\pi p_0 f^2 \int_0^{\theta_0} \cos^{14}\theta \sin\theta d\theta \quad (16)$$

which for $f = 0.96$ m, the focal distance of the MSR antenna, is evaluated as

$$P = 0.3656 p_0. \quad (17)$$

Since the total power radiated by the MSR is 0.056 W, the maximum power density in the plane of the focus is determined as

$$p_0 = \frac{P}{0.3656} = \frac{0.056}{0.3656} = 0.153 \text{ W/m}^2 = 0.0153 \text{ mW/cm}^2. \quad (18)$$

The maximum power density is 18 dB below the allowable infinite duration exposure limit of 10 W/m^2 (or 1 mW/cm^2) for the general public.

6 NATURE OF THE BEAM PRODUCED BY A HIGHLY DIRECTIVE ANTENNA

The space around a directive antenna is usually subdivided into three regions: (a) the reactive near field, (b) the radiating near field (Fresnel) and (c) far field (Fraunhofer) regions. The reactive nearfield region exists in the close vicinity of the antenna. There is not a unique boundary between the near field and far field regions, and depending on the application, the far-field region is usually defined to start at a distance of between $d^2/2\lambda$ to $2d^2/\lambda$ from a circular antenna, where d is the diameter of the antenna and λ is the wavelength of the electromagnetic wave. The first value is known as the Rayleigh criterion and usually used for radiation safety purposes [3].

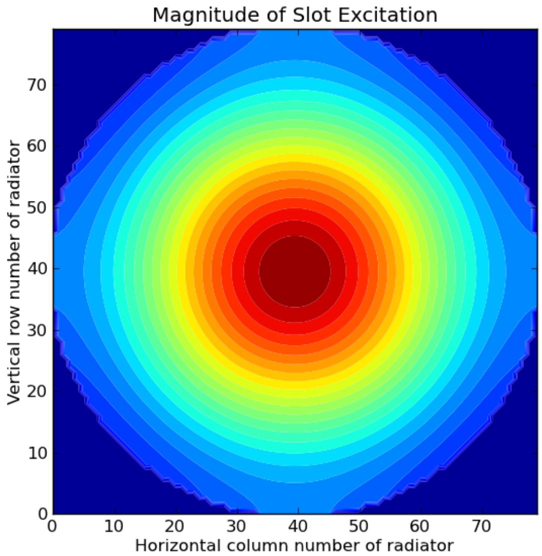
For the MSR 300 which transmits at a wavelength of 30 mm with a 1.2 m diameter antenna, the radiating near field extends to about 25 m in front of the antenna and the far field region to infinity, as illustrated in Figure 4. In the radiating near field, power density decreases slowly with distance, while in the far field power density decreases with the square of the distance. The power density as calculated in the previous section remains relatively constant between the aperture of the parabolic reflector up to a distance of 20 m or more.

7 ESTIMATE 2: POWER DENSITY IN FRONT OF THE MSR300 ANTENNA

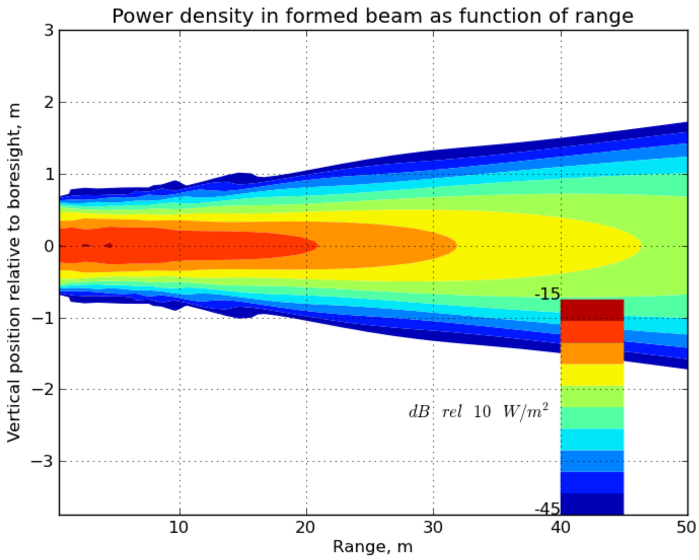
A second independent estimate of the power density in front of the MSR antenna will now be made to validate the estimate in Section 5.

The power density in front of a circular array of radiators with a diameter equal to that of a reflector antenna and with a similar amplitude taper produces fields quite similar to those in front of the reflector antenna. Figure 5 shows the aperture illumination and power density in front of a circular array with a spacing of half wavelength between radiators in the horizontal and vertical directions. The antenna transmits a total power of 56 mW. The calculation is made by summing the contributions of each of the radiators in the circular aperture with the correct amplitude, phase and direction in the space in front of the antenna.

The calculation shows that the maximum power density in the near-field region reaches a maximum of -18 dB on the boresight of the antenna, and remains within 3 dB of this value out to a distance of more than 20 m. It confirms the calculation of the Section 5 to an accuracy of better than 1 dB. The power density in front of the MSR 300 antenna is at least 18 dB below the ICNIRP public exposure limit.



(a) Aperture illumination shows near to circular symmetry.



(b) Power density in a vertical plane on the boresight of the antenna.

Figure 5: Aperture illumination and power density in front of a square array. The power density is shown in dB relative to the public exposure limit for RF radiation.

8 CONCLUSION

The power density in front of the MSR 300 antenna was estimated by means of two independent calculations and is shown to be at least 18 dB below the ICNIRP safety standard for public exposure of infinite duration to RF radiation at all ranges.

The MSR 300 radar system therefore poses no RF radiation exposure hazard.

References

[1] RRS Document, 5840-SL-0000V4.0SD :" SYSTEM SPECIFICATION FOR THE SLOPE STABILITY RADAR".

[2] Balanis, C.A., *Antenna Theory*, 3rd. Ed. Wiley, 2005

[3] Kitchen, R., *RF and Microwave Radiation Safety Handbook,* 2nd Ed., Newness, Oxford, 2001.

[4] ICNIRP, Guidelines for Limiting Exposure to time-varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz), available online at http://www.icnirp.de/documents/emfgdl.pdf