ASSET MANAGEMENT SOLUTIONS

Electric Field Strength Measurements as a Function of Distance on Boresight from a Reflector Antenna

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Abbreviations List

AMS	Asset Management Solutions Division
dBi	Gain of the reflector antenna in deciBel with respect to an isotropic radiator
GHz	Giga-Hertz
ICNIRP	International Commission on Non-Ionizing Protection
MHz	Mega-Hertz
NRPB	National Radiological Protection Board
PFD	Power Flux Density
RAM	Radio-frequency Absorbing Material
RF	Radio Frequency
RFTD	Radio Frequency Technology Division

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1. Introduction

The Communications and Sensor Solutions (CSS) Division at ERA have developed various types of microwave antennas that are used in the Communications Industries. One type of antenna is a twist reflector antenna that operates in the Ka band at a centre frequency of 28.5 GHz. The antenna has been accurately modelled to determine its antenna gain and the boresight power flux density (PFD). The gain of several of these antennas has also been measured on ERA's antenna range and varies between 25.6 to 26.4 dBi. The antenna tested had a gain of 26.2 dBi at 28.5GHz.

Although these theoretical and measured values are accurate, the requirement of clients was to have the radiated electric field strength measured by an independent body and to determine whether there are any exposure risks arising from the radiated near fields.

The task of measuring the near fields was given to the Electromagnetics group of the Asset Management Solutions Division (AMS) at ERA Technology Ltd.

This short report deals with the measurement programme, the results obtained and comparison with the existing exposure standards to ascertain whether the exposure of the radiated near electric fields is of concern to maintenance engineers.

1.1 Physical Description and operation of the Reflector Antenna

The reflector tested has an elliptical radiating aperture with a major axis of 130 mm and minor axis of 75 mm. The reflector is centre fed by a conventional Ka band open waveguide with the input polarisation parallel with the major axis. The radiated input power density is reflected onto the parabolic reflecting surface of the antenna by a series of finely spaced parallel conductors on the inside of the plastic cover some 30mm from the input waveguide aperture. The parabolic reflector surface is composed of parallel slots inclined at approximately 45° with respect to the major axis. The overall effect is to radiate the electromagnetic power with the polarisation that is now parallel with the minor axis, which is perpendicular with the input polarisation. The boresight gain of the antenna is approximately 26.2 dBi. All measurements were conducted with an input power of approximately 10mW although the actual power the antennas are used in practice is 100mW.

2. Radiated electric field strength measurements

2.1 Equipment Used

The following is a list of all calibrated equipment used in the measurements

(1) Test antenna, ERA Reflector MRI Ant0021-1000-MRI, Issue 01, s/n 713/01.

(2) Narda isotropic electric field probe, model 8721D (300MHz – 50GHz), s/n 03008.

(3) Narda meter unit 8718, connected via 1.5m high resistance lead to the probe (2).

(4) Sweep oscillator, HP8350B with RF Plug-in HP83572B (26.5GHz to 40GHz).

(5) HP432 power meter connected to a thermistor power head mount, model R486A (26.5GHz to 40GHz).

(6) Connecting 0.3m waveguide

2.2 Experimental Set up

All measurements were conducted inside an anechoic chamber. The equipment was set up on a wooden bench and the reflector antenna was pointed down the chamber over the “walk-on” pyramidal RAM blocks. The isotropic electric field probe was mounted on a wooden stand that could be moved away from the reflector antenna with the isotropic electric field probe’s sensor pointing towards the reflector on boresight for all measurements.

2.3 Power Calibration

The sweep oscillator was set at 28.5GHz and the output RF power from the RF plug-in was set at 10dBm. The power meter was set on 100% calibration factor and on a scale of 10dBm full scale. A warm up time of 2 hours was given for these instruments to stabilise. One end of the 0.3m Ka waveguide was connected to the output open waveguide from the RF plug-in and the other end was the reference point to which the reflector antenna was to be connected.

The thermistor power head was connected to the reference point with the RF source switched off. The power meter was zeroed and then the RF power was switched on. Several measurements were made of the reference power level. The mean power level measured was 10.06mW, which was divided by the correction factor of 93.84% extrapolated at 28.5GHz to give the actual reference power level of 10.72mW.

2.4 Isotropic Electric field Probe Calibration

The Narda isotropic electric field probe was calibrated, a correction factor of 1.06 at 28.5GHz was fed into the Narda meter unit so that the actual electric field strength could be registered without having to account for it later in the analysis. The physical size of the probe in which the sensor was located was 40mm diameter and approximately 60mm long. This meant that probe sensor was some 30mm back from the front edge of the probe, so that 0mm measurement would actually correspond to a separation of 30mm from the face of the reflector.

2.5 Measurement Procedure

The reflector antenna was bolted to the reference point at the end of the 0.3m waveguide connecting the RF plug-in output waveguide. The probe was brought close to the reflector antenna’s face and aligned centrally. Before each measurement the probe was zeroed. The RF power was switched on and the probe registered the effective electric field strength, irrespective of polarisation. The probe was then moved back in small increments, initially at 10mm, and the electric field strength was measured at each separation distance. It was important to move the probe off boresight alignment in both vertical and horizontal directions in order to determine if there were any changes in the measured electric field strength. Once the maximum electric field strength was measured it was also important to rotate the probe along its handle through ± 90° to account for any isotropicity variation. The maximum electric field strengths were noted at each separation distance.

It was noted that measurements beyond 2.5m became increasingly difficult due to low field electric strengths and also problems in zeroing the isotropic electric field probe.

3. Results and Analysis

Before reviewing the measurement results one needs to determine some initial parameters. These are calculated in the following section.

3.1 Preliminary calculations

The near to far field boundary is generally given as

$$d_{n/f} = 2D^2/\lambda \qquad (1)$$

Where D is the greatest dimension in metres of a surface or an aperture type antenna, and λ is the wavelength in metres. For the reflector antenna tested, D = 0.13, and λ = 0.0105m, which gives the near to far field boundary at 3.22m. In actual fact one can equate the maximum near field power flux density ($4P/A_{eff}$) to the far field power flux density ($PG/4\pi d^2$) and transpose for the distance d(m) where the two field boundaries overlap. Hence,

$$d = [A_{eff}G/16\pi]^{1/2} \qquad (2)$$

Where A_{eff} is the effective radiating area of the antenna, P is the power input to the antenna and G is the gain of the antenna. Substituting the gain of 414.2 (26.172dBi) and an approximate physical area of 0.0083m^2 (assuming 100% uniform illumination of the antenna surface) into equation 2 gives d = 0.262m. The maximum near field power flux density is 5.17 W/m^2 and the power flux density at 1m (using far field equation) is 0.35 W/m^2. These calculated values will be used as guide only in the analysis.

3.2 Analysis of results

Table 1 lists the measured electric field strength as well as the calculated power flux density (assuming far field conditions). These results are plotted in figures 1 and 2, respectively. In figure 2 the dotted line with triangle symbols shows the maximum near field power density of 5.17 W/m^2 and the dotted line with circular symbols shows the far field power flux density, which varies as the inverse distance squared. The far field power flux density plot is derived using the input power of 10.72mW and a gain of 26.172dBi.

The probe had an uncertainty in its isotropicity of ± 1dB and also uncertainty in its sensitivity of +1.25/-3.0 dB over the frequency range 0.3GHz to 40GHz. If the uncertainties are added for the worst case, that is +2.25/-4.0 dB, then the variation in the measured electric field strengths would be within +30%/-37% of those given in table 1. These uncertainties in the measured values have been included in the electric field strength plot in figure 1. The +30% values are plotted as "+" points and the "-37% values have been plotted as "×" points in both figures 1 and 2 (and later in figures 3 and 4). It should be noted that the maximum near field power flux density of 5.17W/m^2 has not been exceeded, as expected. There is a good agreement between the measurements and theory as shown in figure 2.

Table 1 Results of Electric Field Strength Measurements

Distance, d(m)	Measured E-field (V/m)	Calculated far-field PFD (W/m^2)
0	33.5	2.98
0.01	32.12	2.74
0.02	34.54	3.17
0.03	30.1	2.40
0.045	31.6	2.65
0.058	36.97	3.63
0.07	27.21	1.97
0/11	28.7	2.19
0.15	24.32	1.57
0.191	31.13	2.57
0.224	29.19	2.26
0.306	26.75	1.90
0.407	22.38	1.33
0.509	20.92	1.16
0.613	18	0.86
0.718	16.54	0.73
0.834	13.38	0.48
0.935	12.76	0.43
1.045	12.01	0.38
1.325	9.62	0.25
1.5	7.92	0.17
2	6.32	0.11
2.5	5.53	0.08
3	-	-

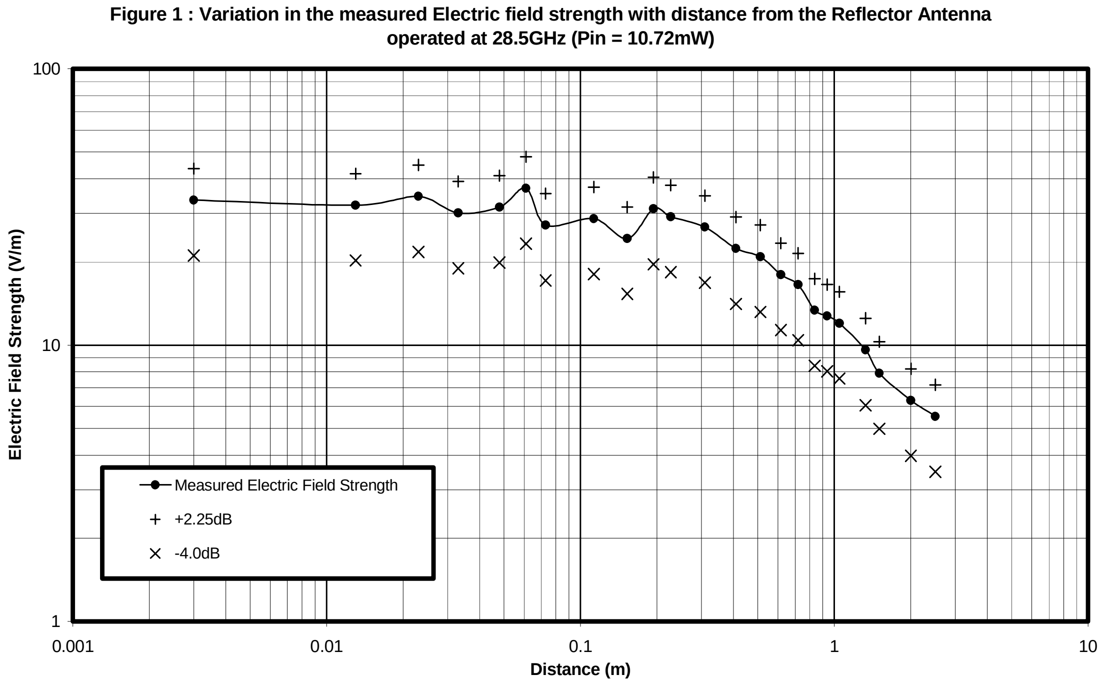

Figure 1 Variation in the measured Electric field strength with distance from the Reflector antenna operated at 28.5GHz (Pin = 10.72mW)

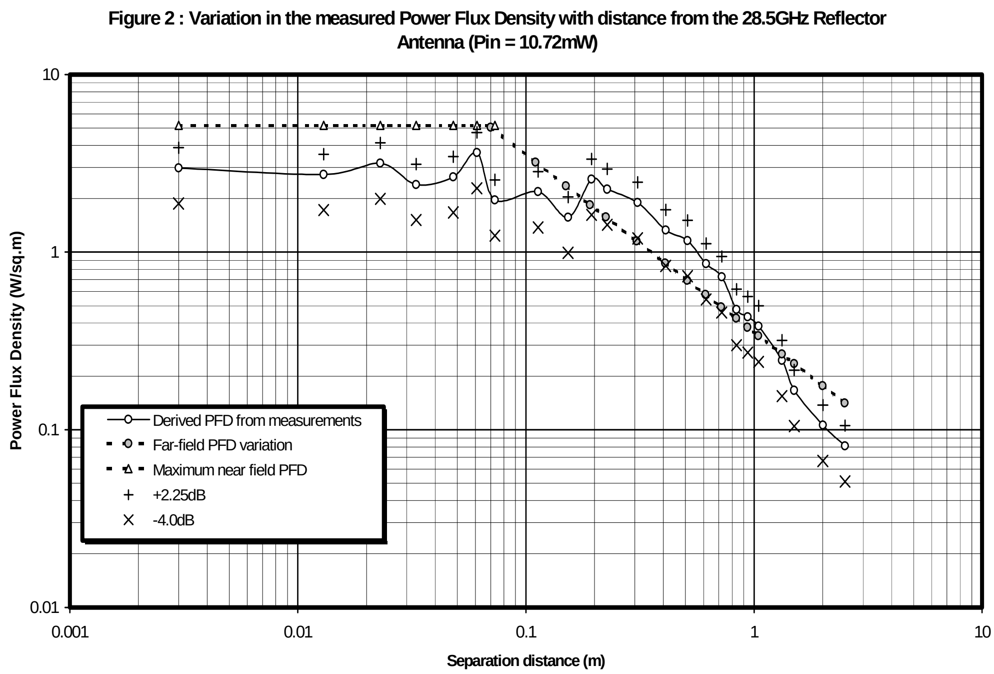

Figure 2 Variation in the measured Power Flux Density with distance from the Reflector antenna operated at 28.5GHz (Pin = 10.72mW)

4. Comparison of Measured Electric Field Strength with the Exposure Standards

The maximum measured near electric field strength is 36.97V/m and the theoretical maximum near electric field strength is $\sqrt{(5.17 W/m^2 \times 376.73\Omega)}$ = 44.13 V/m with the input power of 10.72mW. Table 2 shows the National Radiological Protection Board (NRPB) and also the International Commission on Non-Ionizing Protection (ICNIRP) investigation and reference levels at 28.5GHz, respectively.

The reflector antenna used an input power of 20dBm (100mW) which would be a gain of 9.698dB on 10.72mW used in the tests. This would mean that the measured electric field strength values would need to be multiplied by 3.054 in order to correct for this input power level. Figures 3 and 4 are adjusted to show the electric field strength and power flux density variations with distance, respectively, assuming the antenna response is linear at 28.5 GHz. Table 2 shows the extrapolated results at 100mW from measurements at 10.72mW.

Table 2 Comparison between the extrapolated electric field strength at 100mW input power level and the exposure standard levels

NRPB Investigation Level of E-Field (V/m)	ICNIRP Reference Level for Occupational exposure (V/m)	ICNIRP Reference Level for the General Public exposure (V/m)	Maximum measured near electric field strength for 100mW input power level (V/m)	Maximum far field electric field strength at 1 m for 100mW input power level (V/m)
194	137	61	112.9 *(+30% gives 146.8 V/m)*	47.6

The maximum measured electric field strength is 112.9V/m which with the +30% uncertainty is 146.8V/m. Although this value is lower than the NRPB investigation level of 194V/m it is greater than the ICNIRP reference level of 137 V/m for occupational exposure. For this ICNIRP reference level to apply it is recommended that the safe distance from the reflector antenna to be a minimum of 0.26m. For exposure to the general public, ICNIRP prescribed a reference level of 61 V/m. Electric field strength levels lower than 61 V/m occur at distances greater than 0.8m from the reflector antenna. However, precautions would be in place to ensure that the general public cannot be closer than 3m from the antenna and there is no chance boresight exposure. The above safe distance of 0.8m for the general public exposure is for the worst case boresight exposure, which would be highly unlikely.

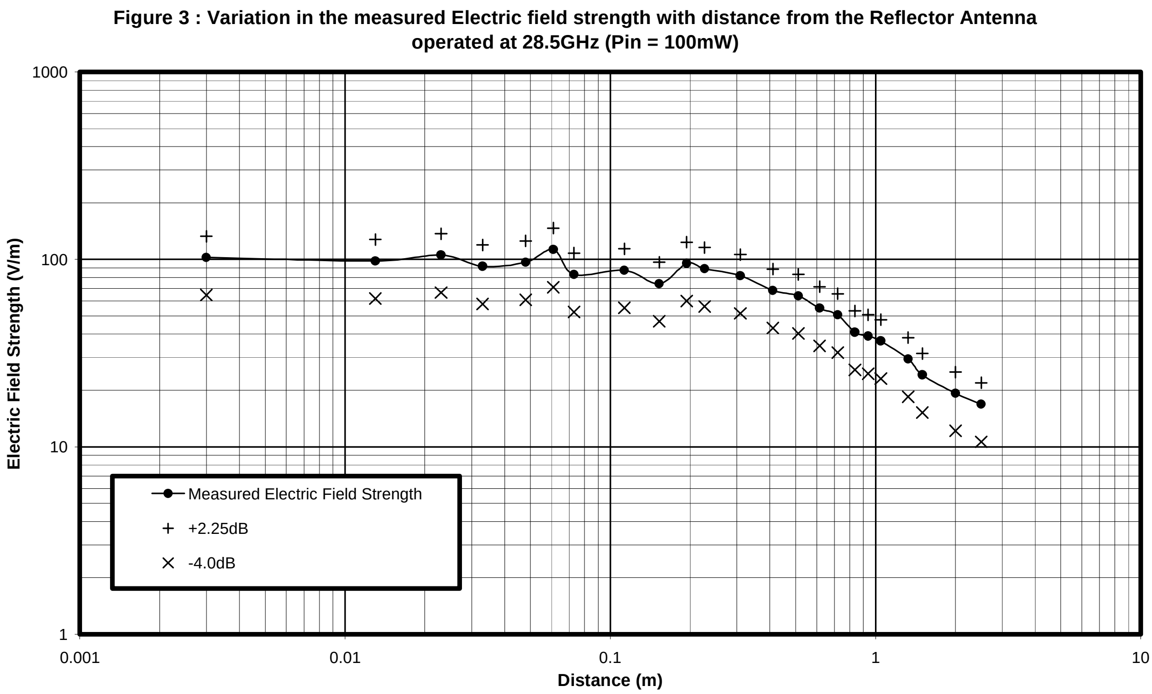

Figure 3 Variation in the measured Electric field strength with distance from the reflector antenna operated at 28.5GHz (Pin = 100mW)

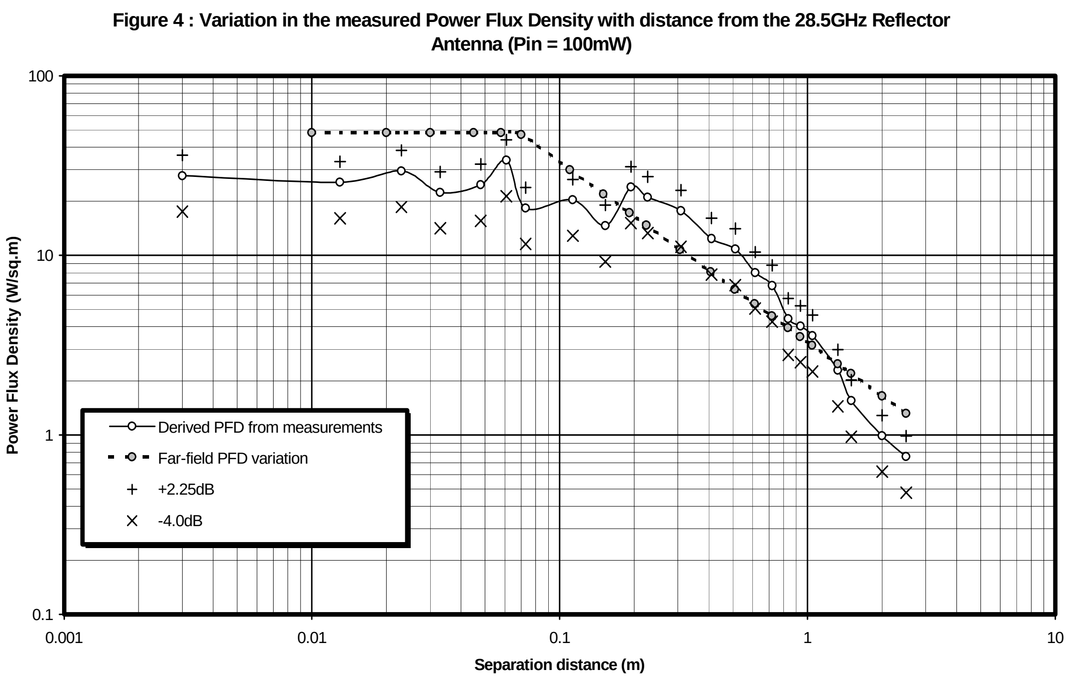

Figure 4 Variation in the measured Power Flux Density with distance from the Reflector antenna operated at 28.5GHz (Pin = 100mW)

5. Discussion

Near field measurements are difficult to perform because the fields vary quite dramatically from point to point in the reactive near fields of the antenna. The best that can be achieved is to measure the effective electric field strength ($E_{eff} = \sqrt{[E_x^2 + E_y^2 + E_z^2]}$) directly in front of the antenna on boresight. The effective electric field strength was measured using the Narda isotropic electric field probe. The main draw back to the probe was its large physical size, which meant that the electric field strength at a point was integrated over the probe's sensor volume. However by moving the probe off boresight by about 20mm showed the variations in the electric field strengths to be within 5 V/m. The significant uncertainties were the probe's sensitivity and isotropicity which were accounted for by taking the worst case of adding these uncertainties.

6. Conclusions

All measurements were made on the reflector antenna with an input power of 10.72mW at 28.5GHz, the measured maximum near electric field strength of 36.97V/m is well below the more stringent exposure for the general public given in the ICNIRP exposure standard.

However, in practice an input power of 100mW is applied to the reflector antenna. This would present problems for exposure to antenna and maintenance engineers who might be very close to the reflector antenna whilst it is operating. Primarily, exposure to the near electric field exceeds the ICNIRP reference level of 137 V/m and a safe distance of 0.26m is recommended, which is the boundary from near to far field.

7. Recommendations

If localised near field exposure in the very near field cannot be avoided then exposure time must be limited to ($360s \times [137V/m]^2 / [146.8V/m]^2$) = 314 seconds or 5 minutes and 14 seconds, after which the engineer needs to be out of the exposure for a minimum period of 6 minutes before returning to the near field of the reflector antenna. This recommendation only applies to localised exposure of the body and limbs but not the head, particularly, the eyes as these are one of the most sensitive parts of the body. Therefore as a safety measure it is recommended that approach to the antennas are made from the side where only the hands and arms are in the radiated near fields and not on boresight.

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