

Measurement of the field inside a microwave horn

R.J.Cook[†], D.F.Gibbs[‡], W. Liang[†] and J.F.Nye[‡].

[†] National Physical Laboratory, Teddington

[‡] Department of Physics, University of Bristol.

Abstract.

An optically modulated scatterer, small compared with the wavelength, has been used at 10 GHz to measure the field inside, and close to pyramidal horns. A model has been developed, from first principles, using diffraction theory and edge waves to predict the ripples in directivity, as a function of frequency, observed in accurate measurements of boresight gain.

Introduction.

In conventional planar near-field scanning the probes used are comparable, or even larger than, the wavelength at which the measurements are made and in order to minimise the multiple interactions between the probe and the antenna under test measurements are made a few wavelengths in front of the antenna under test. Using an optically modulated scatterer, small compared with the wavelength at 10 GHz, measurements have been made, in a monostatic manner, of the amplitude and phase of the electric field E_y close to and deep inside the mouth of a pyramidal horn. A probe of only 5 mm in length was used to minimise the perturbation of the measured field.

Measurement of field close to and within the horn.

All of the measurements were made using a small dipole scatterer with a semiconductor element connected between the dipole arms. An amplitude modulated laser was connected to the semiconductor element by means of an optical fibre, causing the scattering cross-section of the dipole to change at the modulation frequency.

The horn to be measured (Scientific Atlanta) was driven by a locked microwave source and set up as shown in figure 1. The scattered modulated signal entered the horn under test and was detected in the homodyne and phase sensitive detectors. The probe gives a measure of E^2 . Measurements of the field were made along the axis of the horn (z) and at selected planes (x - y) in front of the horn. Measured and theoretical values of electric field amplitude and phase E_y in the plane $z = 2$ mm in front of the horn aperture are shown in figures 2 and 3. Measurements are also shown in figure 4 for E_y along the axis (z) of the long Flann horn from - 614.4 mm to + 204.8 mm, deep inside the horn to well outside the aperture. In order to establish the magnitude of the interaction between the probe and horn structure measurements were made inside the horn with probes of different lengths. The results obtained deep inside the long horn, figure 4, using a 5 mm probe gave a very

good measure of the field because of the low interaction between this probe and the horn structure.

Theoretical model of pyramidal horn

The primary wave emerging from the horn is nearly spherical, with its centre at the apex of the horn. The objective is to model the field of a pyramidal horn by using diffraction theory and the concept of edge waves. Usually the interest lies in the far-field which is calculated using the Geometrical Theory of diffraction (GTD)⁽¹⁾ by combining the field of geometrical optics with that due to the edge waves. In this case the intention has been to calculate the field in the immediate vicinity of the horn, and particularly the field in the aperture plane itself, both inside and outside the physical aperture. The far field is then inferred by Fourier transformation. This method of proceeding has been facilitated by the availability of accurate measurements of amplitude and phase almost in the aperture plane and inside the horn, made possible by the use of the modulated scatterer⁽²⁾. A model was set up for calculating the near-field which could be compared point by point with the measurements. The relative contributions of the various edge waves and their reflections were then assessed and the significant ones retained. The model included the small effect of interaction between the probe and the horn, so that the effect of this on the measurements could be seen. Then to model the true near-field the interaction was switched off. In this way a model was evolved which reproduced the measured data.

In this work it has been assumed that when a wave is incident on an edge it creates an edge wave that is the same as if the incident wave were locally plane and incident on a half-plane. Thus it may be calculated from the classic Sommerfeld solution for a plane wave incident on a half plane. Beyond this, the approach used has been different from conventional GTD. The edge wave has been found numerically by taking the Sommerfeld solution and subtracting the geometrical field for the half plane. Importantly, the edge wave thus calculated is valid as close as one wants to the edge itself. In the present problem subsequent reflection of the edge wave is adequately treated by geometrical optics and subsequent diffraction by other edges is negligible.

The model shows that the effect in the aperture of the first few reflections is comparatively small; in fact the greatest contribution arises from the higher order reflections. Roughly speaking, these highest-order reflections represent a wave reflected from the throat of the horn; the changes of curvature of this emerging wavefront caused by the interference of the reflections with the main wave are responsible for the changes of directivity occurring with change of microwave frequency of the radiated power.

If the near-field can be calculated in sufficient detail, then the far-field and hence the directivity can be calculated. The far-field pattern may be computed, in theory, by forming an appropriate Fourier integral over any transverse plane beyond the aperture. However,

there are great advantages in choosing for the integration plane the plane of the aperture itself. The advantage of using the modulated scatterer is that field measurements can be made in the aperture plane, with a small correction for interaction.

The total power radiated W by the horn is given by,

$$W = \int \int_{\text{aperture}} S_z \, dx dy$$

where S_z (real) is the z component of the time-averaged Poynting vector and the integral is over the aperture of the horn. The magnitude of the far-field on axis at distance r_0 is given in terms of the aperture field E_y by

where

$$\left| E_y^\infty \right|^2 = \frac{k^2}{4\pi^2 r_0^2} P$$

where

$$P = \left| \int \int_{\text{aperture plane}} E_y \, dx dy \right|^2$$

the integration being over the infinite aperture plane. The directivity D of the horn can be expressed as

$$D = \frac{k^2 P}{2\pi W}$$

While the integral W has to be taken in the plane $z = 0$, to avoid the problem of backwards radiation, the integral for P could, in principle, be taken over any plane orthogonal to the z axis outside the horn. However, there is an advantage in choosing the plane $z = 0$ because edge wave diffraction theory shows that the field E_y in this plane outside the aperture consists entirely of edge waves, radiated from the four edges of the aperture. Now, to a first approximation, these are transverse cylindrical waves centred on the respective edges. Therefore, in the aperture plane itself, to this approximation, they

contain no component E_y , which would be longitudinal. It follows that the edge wave contribution to the P integral will be an order of magnitude smaller than would otherwise be the case. To express the same thing in another way, the edge waves at large kr decay in general, as $(kr)^{-0.5}$. However, the longitudinal component, which in the plane $z = 0$ is E_y , decays as $(kr)^{-1.5}$. Thus, the P integral converges much more rapidly. The P integral can be evaluated analytically and there is therefore no truncation error.

The model has been used to calculate the field in the aperture plane and from this the directivity as a function of frequency for the Scientific Atlanta horn. The calculated and measured results, supplied by David Gentle⁽³⁾, are shown in figure 5.

References

- 1) V A Borovikov and B Ye Kimber, Geometrical theory of diffraction, London, Institution of Electrical Engineers, England, 1994.
- 2) J F Nye and G Hygate, "Measuring a microwave field close to a conductor", Measurement Science & Technology vol 2, pp 838-845, 1991.
- 3) D G Gentle and P A C McNair, "A gain intercomparison between the NPL planar near-field scanner and extrapolation range", BEMC, Malvern, UK, 6-9 November 1995.

Legends for figures

- Figure 1 Long horn used for measurements and the axes used.
- Figure 2 Contours of amplitude of E_y in the plane $z = 2$ mm, (a) measured, (b) theoretical. The rectangular outline shows the horn aperture.
- Figure 3 Contours of phase of E_y in the plane $z = 2$ mm, (a) measured, (b) theoretical. Full lines are at intervals of 2π ; contour spacing $\pi/4$.
- Figure 4 Amplitude as a function of z measured for the long horn. The upper curves show measured values, while the lower curve is calculated and displaced downwards by 0.3 units for clarity.
- Figure 5 Directivity on axis (upper curve) calculated as a function of frequency for the Scientific Atlanta horn, and compared with measurements of gain measured by D Gentle. The lower curve is the mean curvature of the wavefront in the aperture.

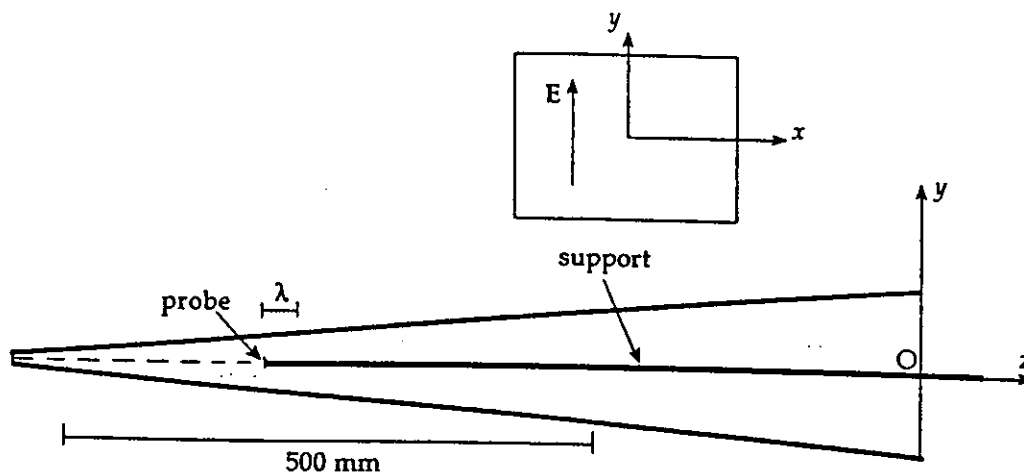
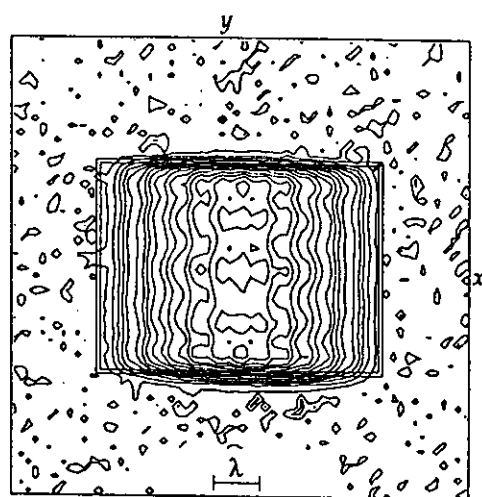
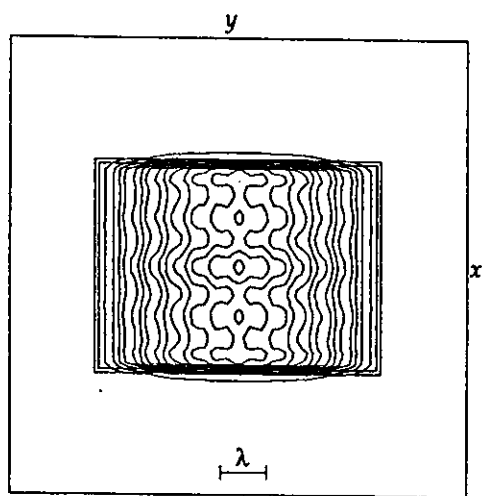


Figure 1

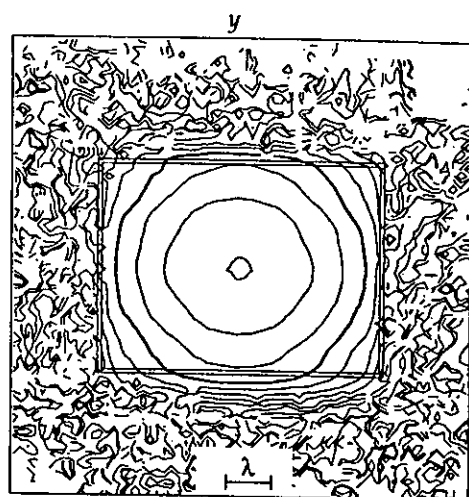


(a) measured

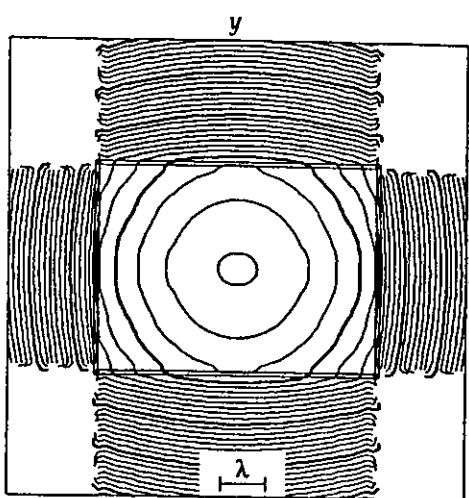


(b) theoretical

Figure 2



(a) measured



(b) theoretical

Figure 3

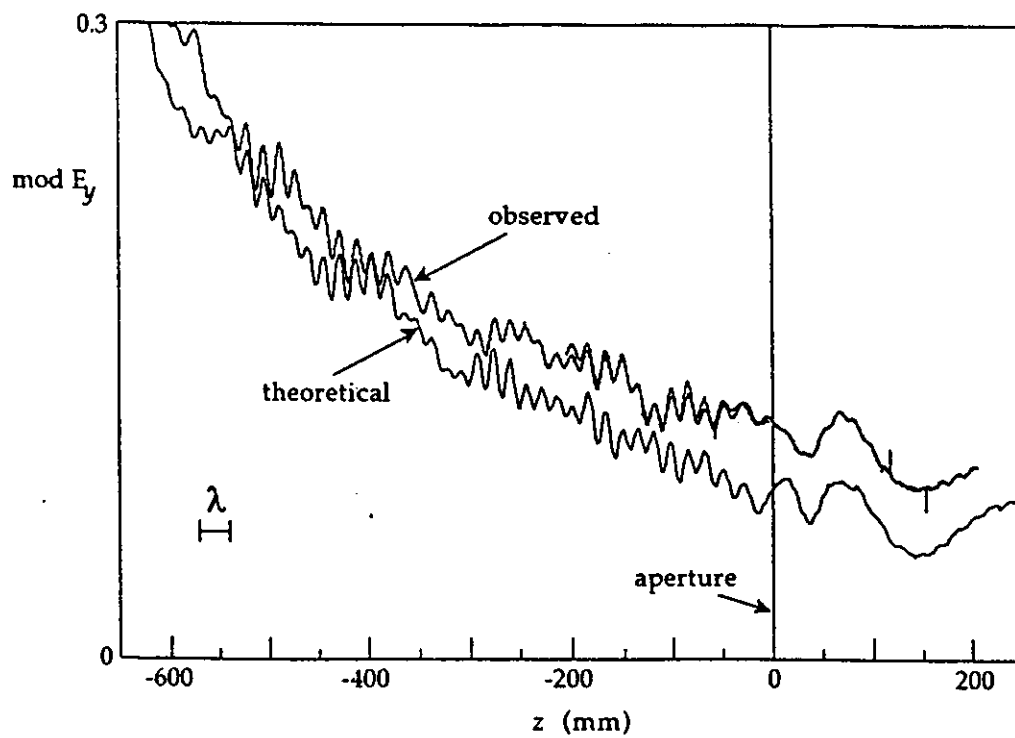


Figure 4

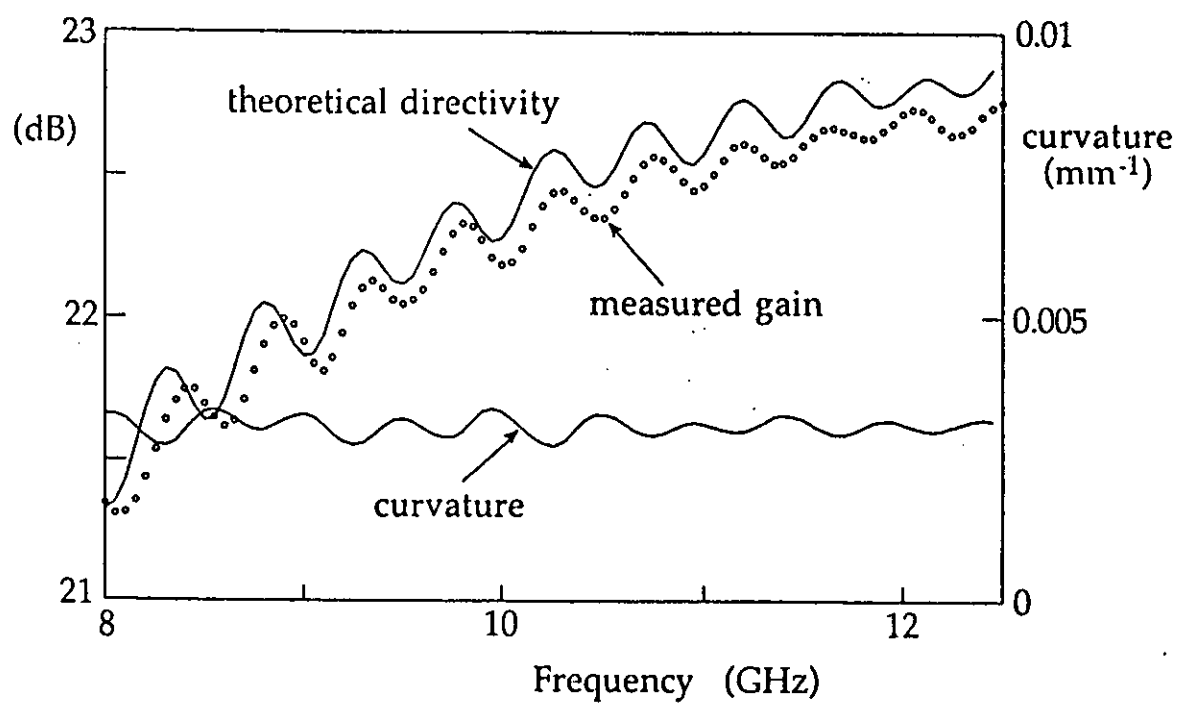


Figure 5