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ANTENNA LOBE SUPPRESSION

Volume III - Radiating Mechanisms in a Reflector
Antenna System

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ABSTRACT

The corrugated horn represents a good feed in a reflector antenna system. It is used in this report as a feed for an offset parabolic antenna. The various radiation mechanisms are discussed and means are suggested for further reduction of undesired radiation.

RADIATING MECHANISMS IN A REFLECTOR ANTENNA SYSTEM

I. INTRODUCTION

The various radiating mechanisms of a reflector antenna system have been described in a previous paper [1] as (a, aperture radiation, (b) direct radiation, and (c) diffracted radiation. The desired main lobe is that which results from aperture radiation. It was shown during World War II that the side lobes of the reflector Antenna system could be reduced to approximately 30 db below the main beam maximum by control of the aperture radiation. These side lobes, the direct radiation, and the diffracted radiation all represent radiation that contributes only to interference. Further reduction of the side lobes associated with the main beam (i.e., the aperture radiation) can be obtained only by a substantial increase in antenna size to obtain a required gain. However, considerable reduction can be obtained in direct and diffracted radiation by a relatively small increase in the reflector size, provided the feed pattern has a large slope in the direction of the edge of the reflector and that it has low back lobes. * Such a feed pattern has been obtained in the form of the horn with corrugated walls in the E-plane.

The purpose of this report is to first demonstrate the manner in which the entire pattern of a reflector antenna can be obtained from the characteristics of the feed, and, second, to illustrate the manner in which undesired radiation and consequently radio-frequency interference would be reduced.

II. THE OFFSET PARABOLA

In order to simplify the experimental studies, a small reflector surface is treated. Use of conventional center-fed reflector systems would, in this case, introduce significant aperture blocking. Consequently an offset feed system is used. The antenna and its dimensions are shown in Fig. 1. The feed antenna is the small corrugated horn described in a previous report [2]. Its pattern at 13.2 Gc is shown in Fig. 2. It has

* This particular boundary determined by the phase center of the feed and the edges of the reflector is known as the shadow boundary. From optics it is known that the antenna pattern is approximately 6 db below the feed pattern at this angle.

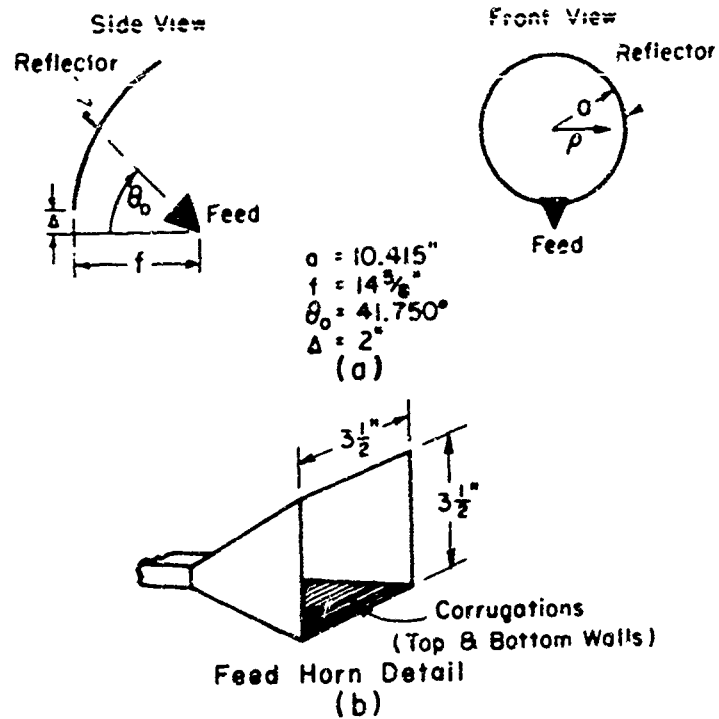


Fig. 1. Horn reflector assembly.

nearly identical E- and H-plane patterns. The reflector dimensions are chosen so that the feed pattern is down 18 db at the reflector edge. These points are shown on the pattern of Fig. 2. The slope of the pattern in the vicinity of these points is large and the back lobes are low, thus the conditions stated in the introduction are satisfied. The larger corrugated horn treated in the previous report has a much sharper slope at the 18 db points and far lower back lobes. It would thus be a much better feed to be used with a larger reflector.

III. THE COMPOSITE PATTERN OF THE OFFSET PARABOLA

The aperture radiation pattern of this configuration can be obtained from the feed antenna pattern. First the aperture is obtained by means of ray optics and the feed pattern. The amplitude of the feed pattern between the -18 db points can be described as a function $f(r, \phi')$, where $r = \rho/a$ and is the normalized coordinate in the $\theta = 90^\circ$ plane, as illustrated in Fig. 3. Because of spatial attenuation, the amplitude of the source field at an arbitrary point on the reflector a distance l from the feed is given by

$$(1a) \quad f_l(r, \phi') = F(l) f(r, \phi'),$$

where $F(l)$ is the spatial attenuation factor [3]. For this configuration $F(l) = \frac{l_0}{l}$, where l_0 is the distance to the center of the reflector, as shown

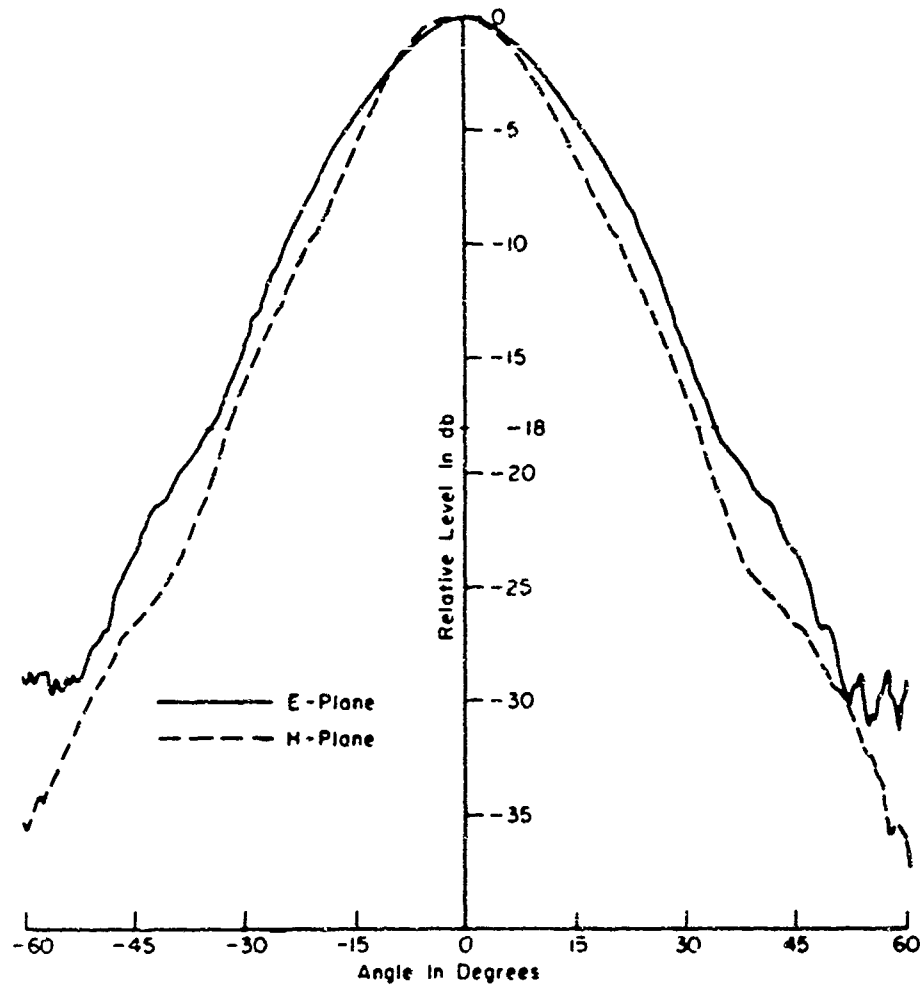


Fig. 2. Feed horn radiation patterns
Frequency: 13.2 Gc.

in Fig. 4. Substituting in Eq. (1a) yields

$$(1b) \quad f_l(r, \phi') = \frac{l_0}{l} f(r, \phi')$$

The aperture radiation pattern is obtained from the diffraction integral [4]

$$(2) \quad u_p = \frac{j}{\lambda R} e^{-jkR} \left(\int f_l(r, \phi') e^{jkr \cos(\phi - \phi')} r dr d\phi' \right),$$

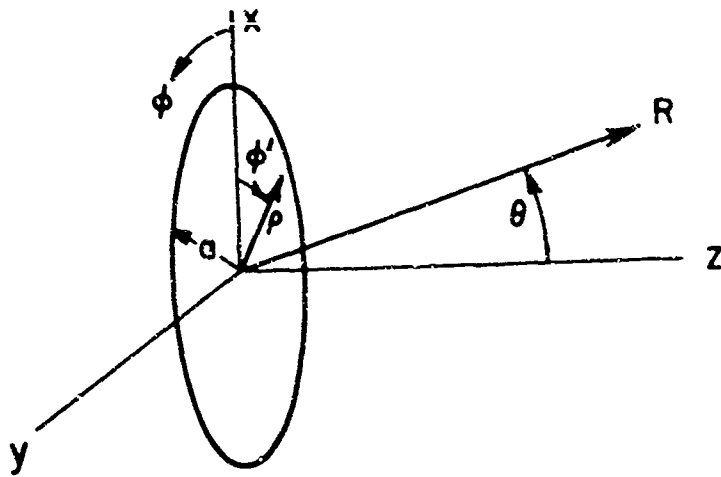


Fig. 3. Coordinate system for the circular aperture.

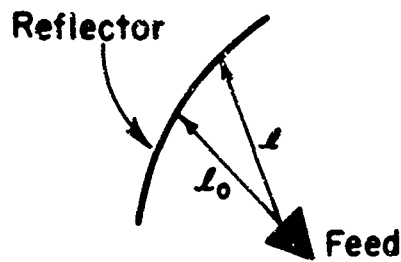


Fig. 4. Geometry for spatial attenuation.

where

- a is the radius of the aperture,
- $k = 2\pi/\lambda$,
- $u = ka \sin \theta$, and
- R is the distance to the far field.

The diffraction integral can be evaluated for any aperture distribution with the aid of a modern digital computer. The validity of this method is well known and consequently is not carried further.

The direct radiation is given by

$$(3) \quad E = \frac{I_0}{R} f(r, \phi')$$

where

I_0 is the distance from the source to the center of the reflector and

R is the distance from the source to the point of observation.

The relation between the levels of the aperture radiation and the direct feed radiation can be obtained by comparing Eqs. (2) and (3). This would, of course, require that the integral be evaluated. The relative level of the two patterns may also be obtained by determining the directivity of the main beam caused by aperture radiation and the directivity of the feed antenna. This is easily done by means of the approximate formula for the directivity of a pencil beam antenna,

$$(4) \quad D = \frac{41,253}{\theta_{\frac{1}{2}} \phi_{\frac{1}{2}}}$$

where

$\theta_{\frac{1}{2}}, \phi_{\frac{1}{2}}$ are the principal-plane half-power beamwidths in degrees.

Denoting the principal-plane half-power beamwidths of the feed by $\theta_{F\frac{1}{2}}, \phi_{F\frac{1}{2}}$ and of the parabola by $\theta_{p\frac{1}{2}}, \phi_{p\frac{1}{2}}$, the directivity of the parabola relative to the feed is

$$(5) \quad \frac{D_p}{D_F} = \frac{\theta_{F\frac{1}{2}} \phi_{F\frac{1}{2}}}{\theta_{p\frac{1}{2}} \phi_{p\frac{1}{2}}}$$

From the measured patterns

$$\theta_{F\frac{1}{2}} = 22.5^\circ$$

$$\theta_{p\frac{1}{2}} = 4.8^\circ$$

$$\phi_{F\frac{1}{2}} = 20.4^\circ$$

$$\phi_{p\frac{1}{2}} = 4.5^\circ$$

Substitution of these values in Eq. (5) yields

$$(6) \quad \frac{D_p}{D_F} = 21.3, \text{ or } +13.3 \text{ db.}$$

The diffraction of fields at the edges of the reflector is illustrated in Fig. 5(a). It is assumed that the reflector can be replaced by infinite perfectly conducting half-planes, as shown in Fig. 5(b). Sommerfeld[5] obtained the diffracted field in the form

$$(7) \quad v_B(r, \phi) = e^{-j\pi/4} \left[\frac{2}{\pi a} \right]^{\frac{1}{2}} e^{jkr \cos \phi} \cos \frac{\phi}{2} \int_{+\sqrt{akr}}^{\infty} e^{-j\tau^2} d\tau,$$

where

$\phi = \psi \pm \psi_0$ (the (-) sign yields the incident fields; the (+) sign yields the reflected fields),

$$a = 1 + \cos \phi,$$

$$k = \frac{2\pi}{\lambda}, \text{ and } \psi, \psi_0 \text{ are the angles shown in Fig. 5(b).}$$

The total diffracted field is the sum

$$u = v_B(r, \psi + \psi_0) + v_B(r, \psi - \psi_0).$$

In asymptotic form the diffracted field expression for a thin edge is

$$(8) \quad v_B(r, \phi) \cong \frac{\left[2\pi kr \right]^{-\frac{1}{2}} e^{-j\left(kr + \frac{\pi}{4} \right)}}{2 \cos \frac{\phi}{2}}.$$

If $\phi \approx 180^\circ$, this yields a maximum component of diffracted radiation. It would be desirable to force this maximum in the direction of the main beam where its contribution would be negligible.

Let $u_1(\theta)$ and $u_2(\theta)$ denote the diffracted fields from edges (1) and (2) respectively. Then

$$(9) \quad \text{and} \quad \left. \begin{aligned} u_1(\theta) &= v_B(r_1, \psi_1 - \psi_{01}) + v_B(r_1, \psi_1 + \psi_{01}) \\ u_2(\theta) &= v_B(r_2, \psi_2 - \psi_{02}) + v_B(r_2, \psi_2 + \psi_{02}) \end{aligned} \right\} .$$

The phase difference from edge (1) to edge (2) is obtained from Fig. 5(c) as

$$(10) \quad kd = 2\pi x_0 \cos(\psi_2 - \psi_1) ,$$

where the distance x_0 from edge (1) to edge (2) is measured in wavelengths.

The total diffracted field is

$$(11) \quad u_T(\theta) = u_1(\theta) + [u_2(\theta)] e^{-j2\pi x_0 \cos(\psi_2 - \psi_1)} .$$

The computed diffracted field pattern is shown in Fig. 6 and it should be noted that the appropriate phase factors have been included.

The total pattern of the reflector antenna may be obtained approximately by simply placing the component parts on a single pattern. No effort is made to sum the phasor fields since it is the average value that is of interest. The results are compared with the experimental pattern in Fig. 7. It is seen that reasonable agreement is obtained for the component parts of the pattern with the exception of the region $160^\circ < \theta < 180^\circ$, in which the experimental pattern is much lower than the computed pattern. This deviation appears because the main source or throat of the horn is shielded from the edge by the wall of the horn, as shown in Fig. 8. The pattern of the horn in this region results from diffraction at the horn edges and multiple reflections from the wall of the horn. The diffracted fields from these various sources are not in phase and consequently the total diffracted fields are lower than the predicted values. This type of diffraction represents a new phenomenon and requires further study.

It should also be noted that the actual pattern is 7 db below the antenna feed pattern at an angle of 105° . Diffraction theory would predict this level to be 6 db below the feed pattern. This is another reasonably

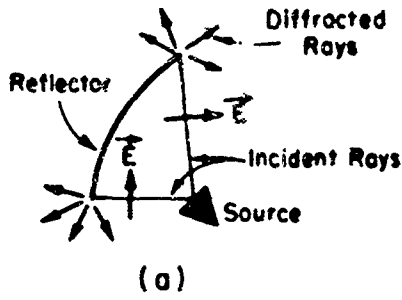


Fig. 5(a). Edge diffraction.

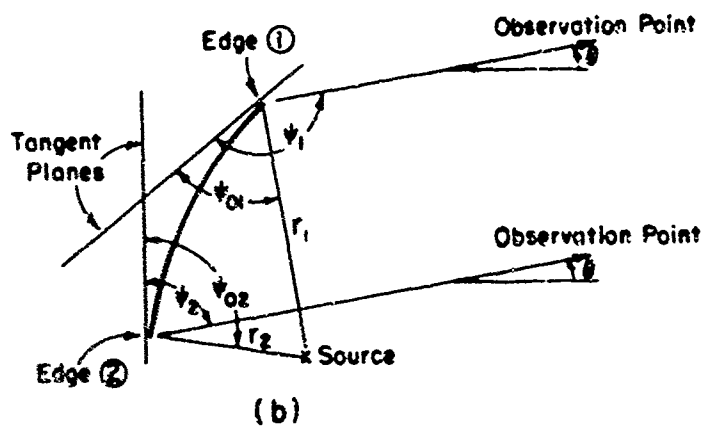


Fig. 5(b). Geometry of edge diffraction.

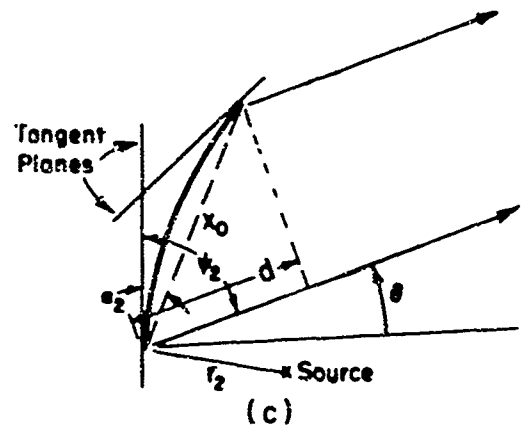


Fig. 5(c). Geometry of edge diffraction.

accurate, simple method of predicting the level of this point on the pattern. Figure 7 shows that angles ψ_{01} and ψ_{02} can be selected so that maximum edge diffraction is in the direction of the main beam, i.e., $\phi \approx 90^\circ$ for $\theta = 0^\circ$. Thus this highest level diffracted energy does not contribute to any new side lobes.

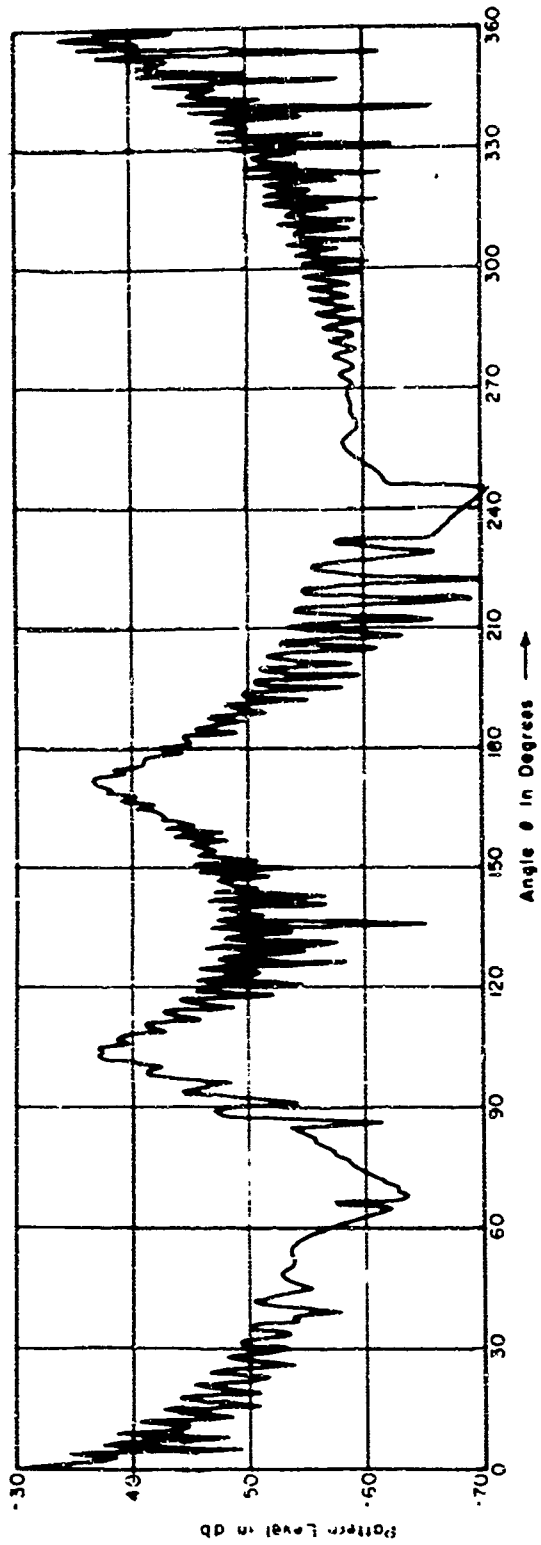


Fig. 6. Diffraction pattern for the offset feed antenna.

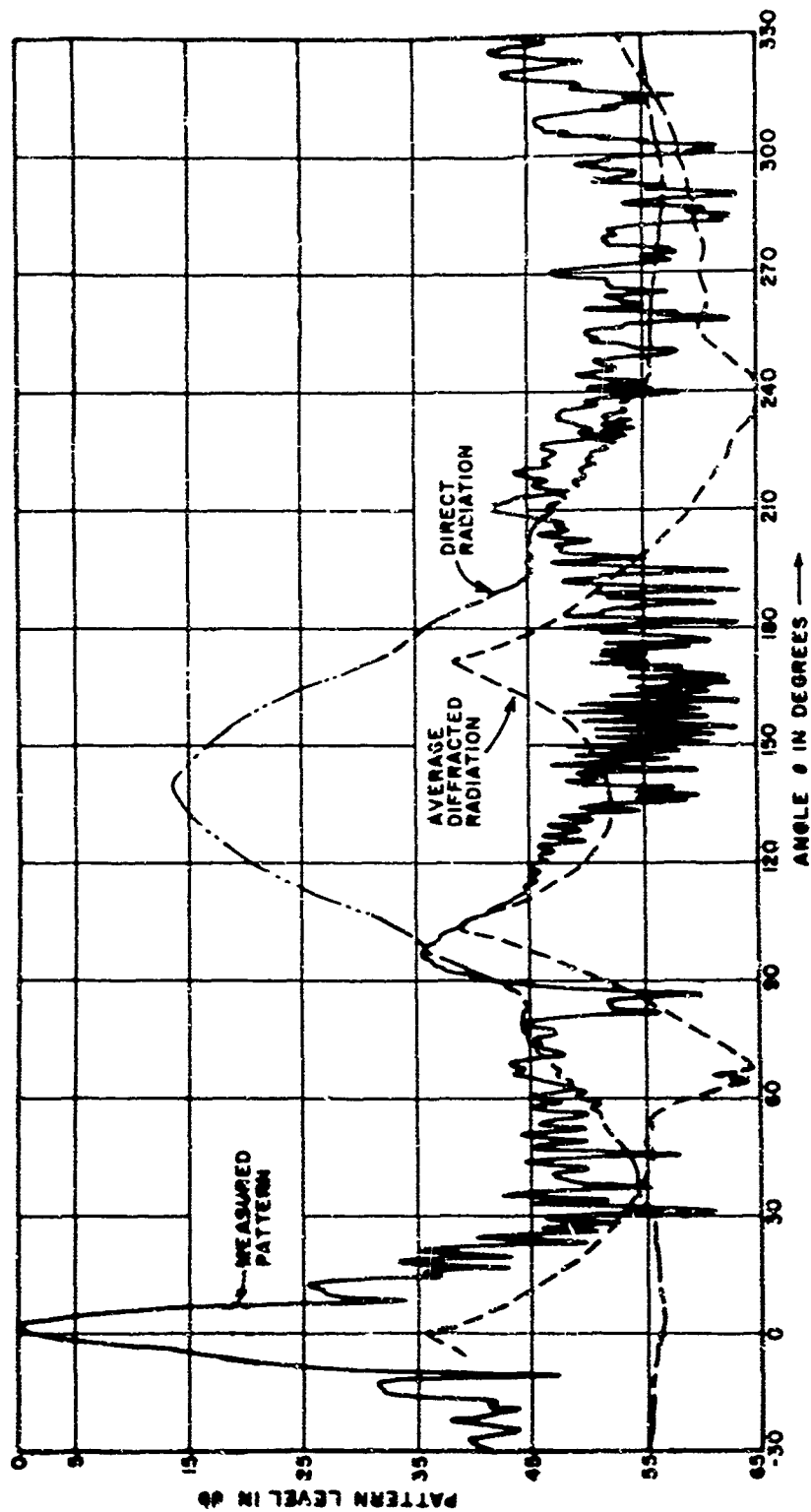


Fig. 7. Experimental pattern compared with component parts.
 Note that the direct radiation for $105^\circ \leq \theta \leq 173^\circ$ is shown only for clarity. This part of the direct radiation is intercepted by the reflector.

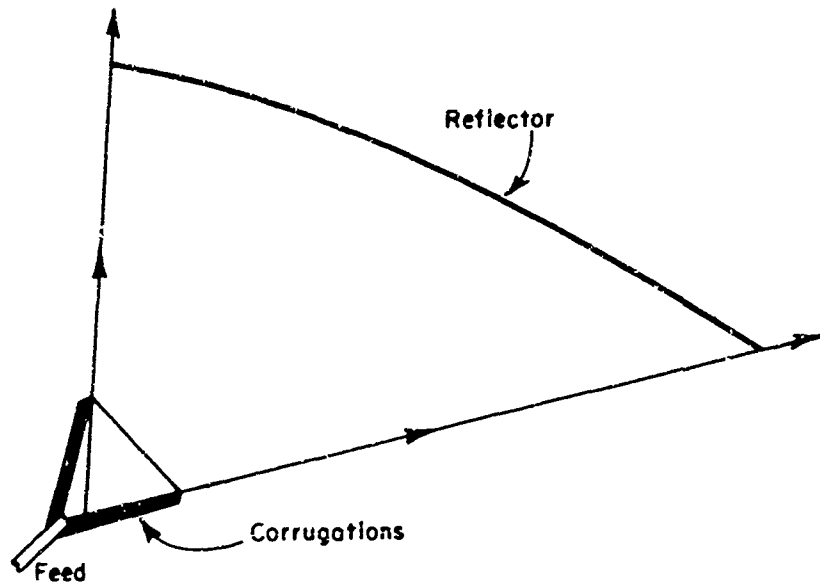


Fig. 8. Direct feed radiation.

IV. FURTHER REDUCTION OF UNDESIRED RADIATION

The major component of undesired radiation is the lobe appearing at $\theta = 95^\circ$. This lobe can be eliminated by extending the reflector by 9" so that it subtends an additional angle of 15° . This could also be done by surrounding the reflector by a "tunnel" extending 6" from the edge of the reflector, as shown in Fig. 9. Both of these approaches require a significant increase in the size of the antenna structure.

A redesign of the feed structure could possibly accomplish the same goal without increasing the reflector size. The flare angle of the feed antenna should be reduced to eliminate the direct illumination of the edge of the reflector from the throat region of the feed antenna. It is expected that this would yield a radiation pattern in the vicinity of $\theta = 95^\circ$ which is similar to that obtained at about 165° .

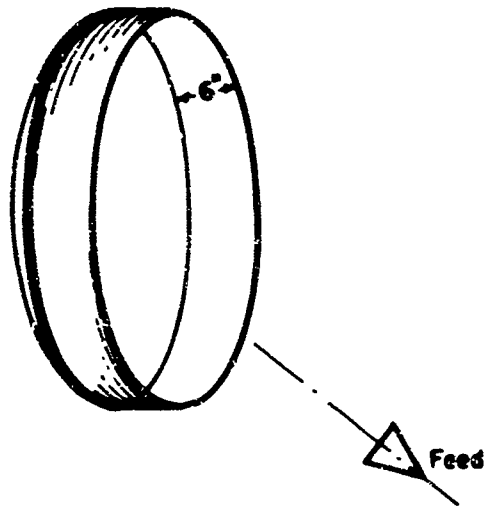


Fig. 9. "Tunnel" dish.

V. CONCLUSIONS

Techniques have been given for determining the total radiation pattern of a reflector antenna from the properties of the feed antenna. The feed antenna discussed in this report has the desirable properties of relatively low back lobes and a relatively large slope in the vicinity of the shadow boundary. The average level of the back lobes is approximately 50 db. This is not an optimum, however, since the goal of this effort is to determine analytically the magnitude of the undesired radiation. Lower back lobes should be obtainable by further consideration of these techniques.

Several guidelines for the expected levels of undesired radiation have been given. First, the level of the direct radiation is related by the gain of the reflector and of the feed antenna. Second, the diffracted radiation on the shadow boundary is 6 db below the level of the feed antenna at this angle. Third, the maximum diffracted radiation can be successfully directed in the direction of the main beam by an appropriate choice of reflector geometry.

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