# United States Patent

[11] 3,633,209


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[33] **Netherlands**
[31] **6812786**


## [54] OFFSET PARABOLOID-PLANE REFLECTOR ANTENNA

**5 Claims, 9 Drawing Figs.**


[52] **U.S. Cl.** ..... **343/781,** 343/837, 343/840
[51] **Int. Cl.** ..... **H01q 19/14**
[50] **Field of Search** ..... 343/781, 786, 837, 840, 912, 914, 840



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**ABSTRACT:** A microwave antenna assembly which includes a second reflector in the form of an asymmetrical portion of a paraboloid and a main reflector in the form of a generally flat planar surface which forms an acute angle with the second reflector. A radiating or receiving device is located at the focal point of the paraboloid spaced from but in proximity to the end of the main reflector remote from the second reflector.

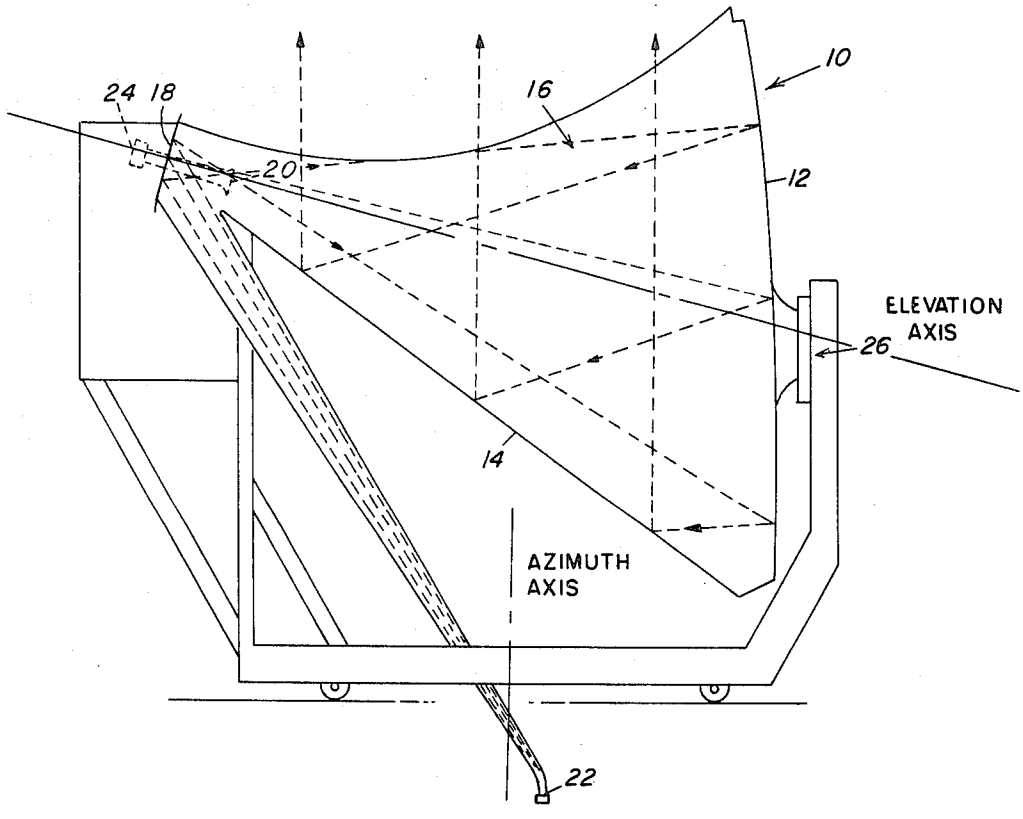



FIG. 1

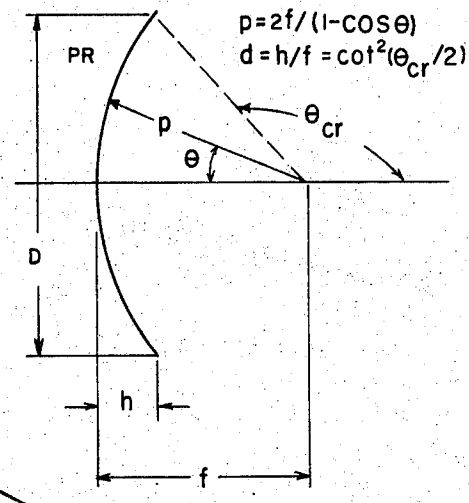






FIG. 2

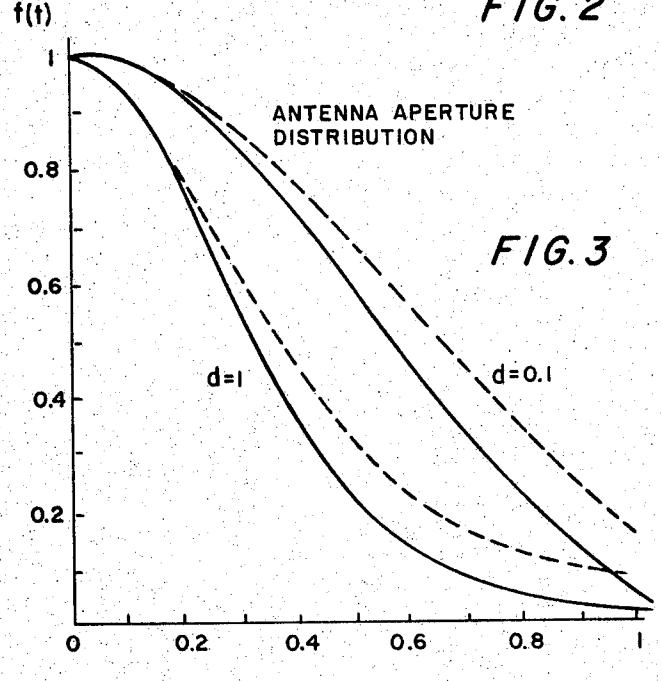



FIG. 3

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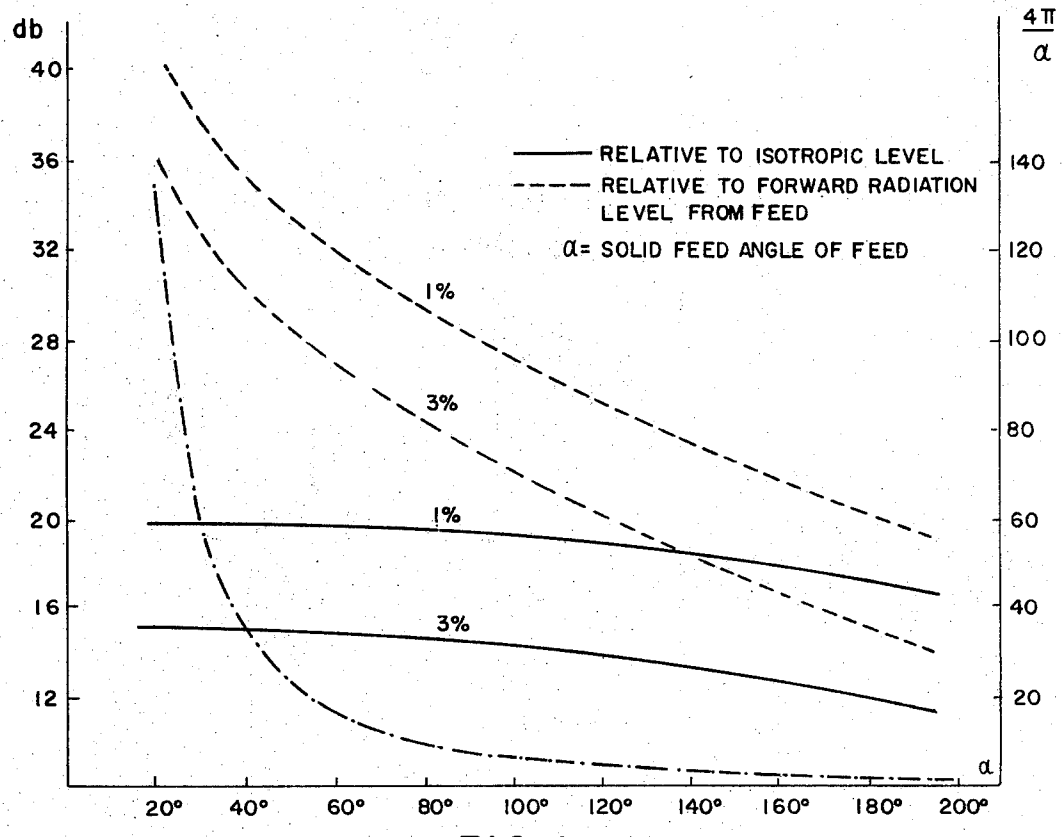

db
40
36
32
28
24
20
16
12
4π/α
140
120
100
80
60
40
20
RELATIVE TO ISOTROPIC LEVEL
RELATIVE TO FORWARD RADIATION LEVEL FROM FEED
α= SOLID FEED ANGLE OF FEED
1%
3%
1%
3%
α
20°
40°
60°
80°
100°
120°
140°
160°
180°
200°

FIG. 4

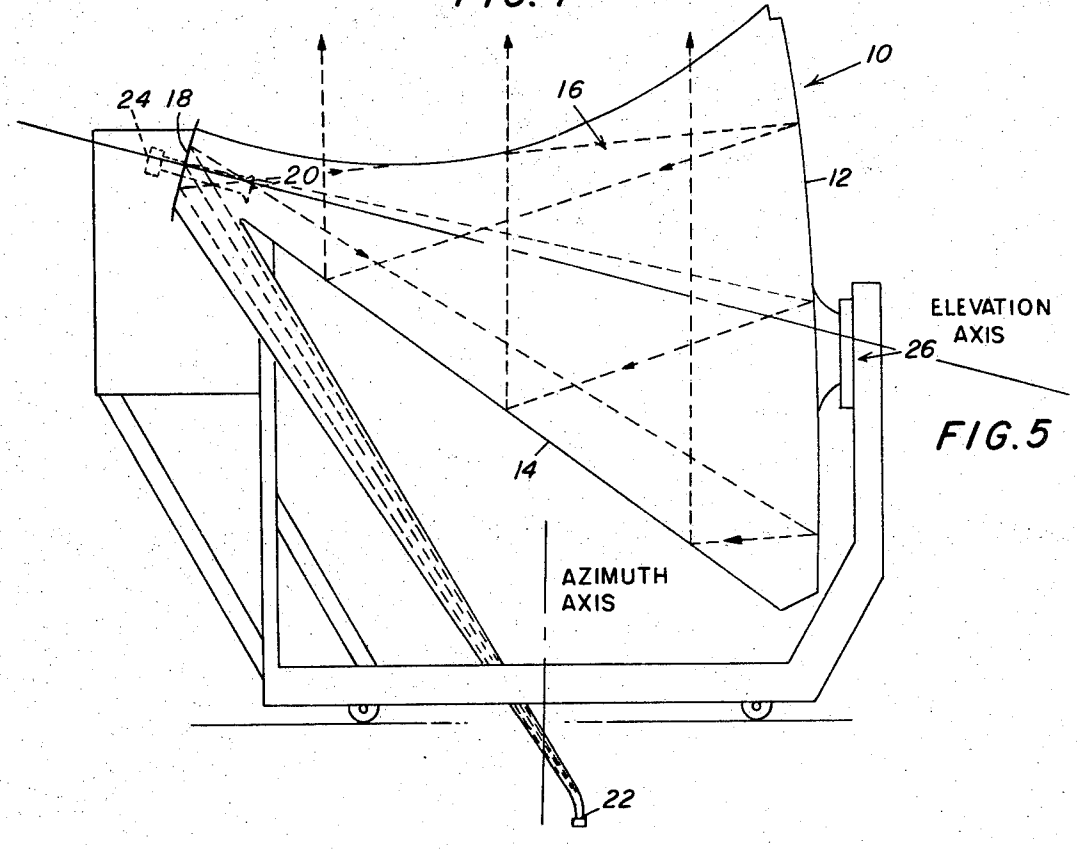

10
16
24
18
20
12
ELEVATION AXIS
26
14
AZIMUTH AXIS
22

FIG. 5

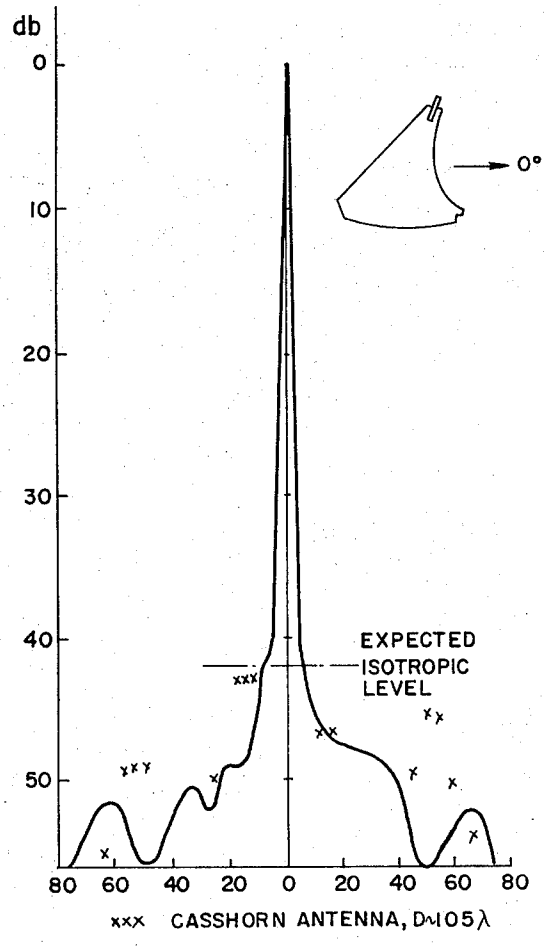

db
0
10
20
30
40
50
0°
EXPECTED
ISOTROPIC
LEVEL
80 60 40 20 0 20 40 60 80
xxx CASSHORN ANTENNA, D≈105λ

FIG. 6

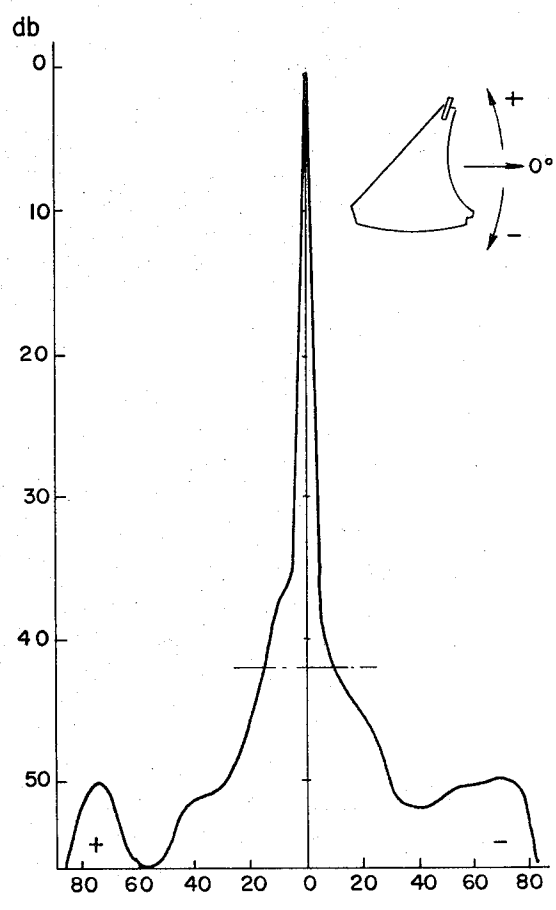

db
0
10
20
30
40
50
+
0°
−
80 60 40 20 0 20 40 60 80

FIG. 7

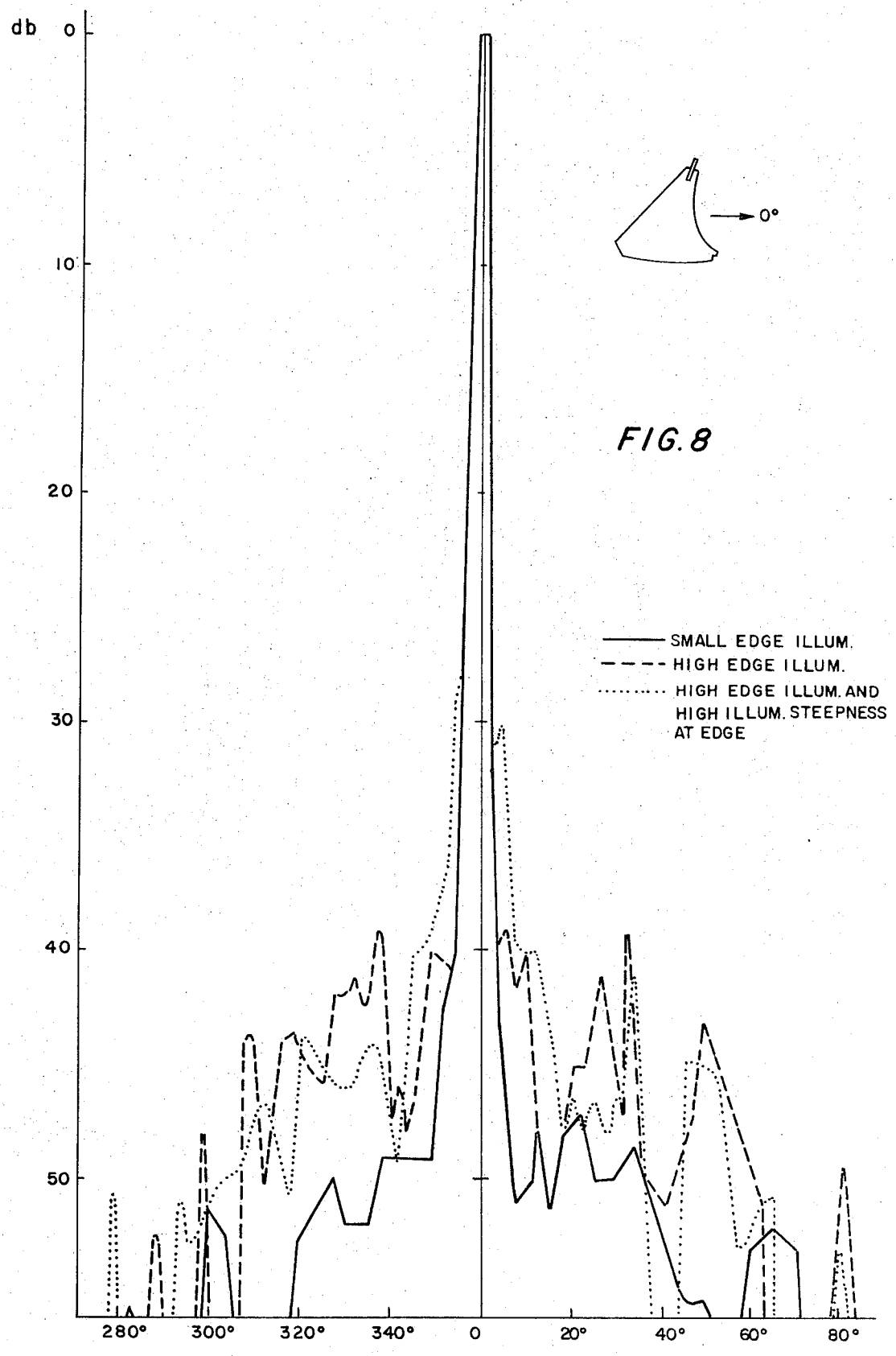

db
0
10
20
30
40
50
280°
300°
320°
340°
0
20°
40°
60°
80°
0°
SMALL EDGE ILLUM.
HIGH EDGE ILLUM.
HIGH EDGE ILLUM. AND HIGH ILLUM. STEEPNESS AT EDGE

FIG. 8

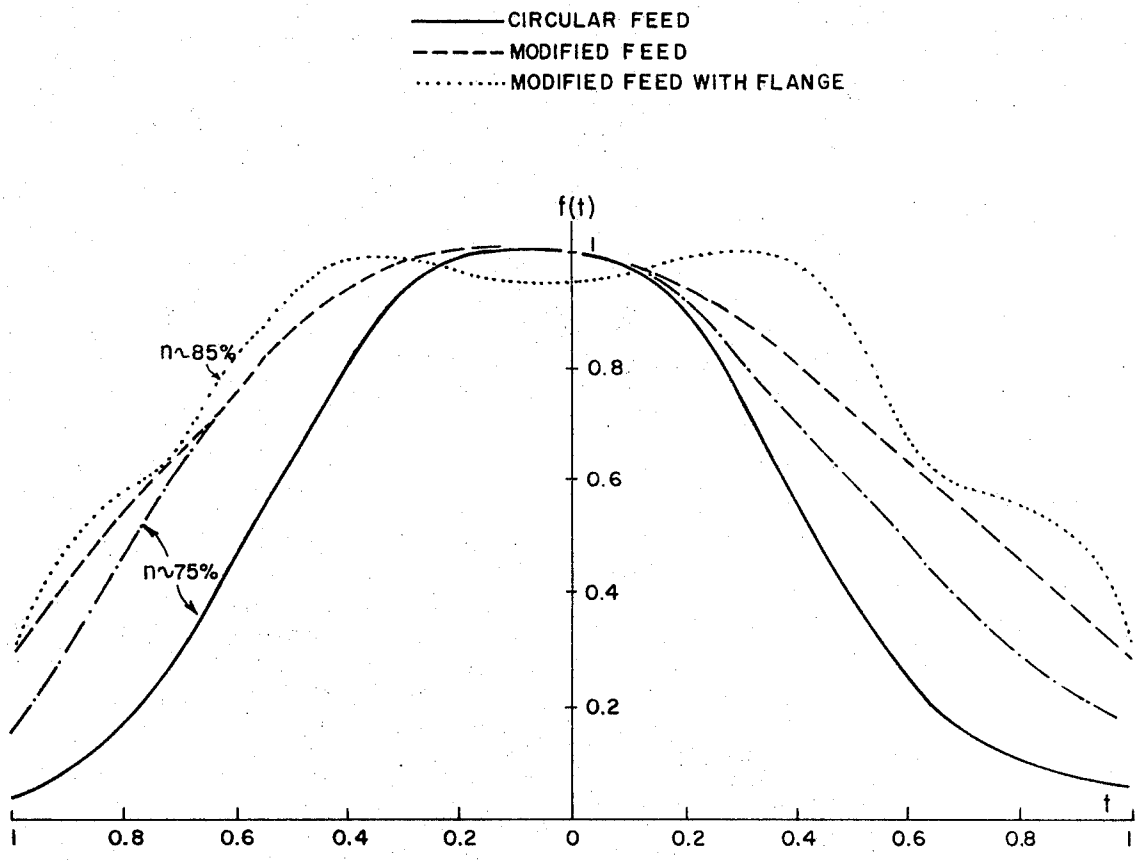

CIRCULAR FEED
MODIFIED FEED
MODIFIED FEED WITH FLANGE
f(t)
1
0.8
0.6
0.4
0.2
η~85%
η~75%
t
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1

FIG. 9

# OFFSET PARABOLOID-PLANE REFLECTOR ANTENNA

Field of the Invention

The present invention relates to paraboloid-plane reflector antennas.

Background of the Invention

The paraboloid-plane reflector antenna has generated considerable interest in the field of microwave antennas because of the minimum value of scattered radiation provided thereby. Although different models of this antenna have been constructed, in general, the paraboloid-plane reflector antenna comprises a paraboloidal reflector fed by a primary radiator which extends through an opening in the main reflector. The main reflector is formed by a flat plane or surface and both reflectors being joined together by a side construction. Both circular and rectangular forms of these constructions have been used. Exemplary forms of the paraboloid-plane reflector antenna are shown in Netherlands Pat. 6612715 and British Pat. 1,099,429.

## SUMMARY OF THE INVENTION

In accordance with the present invention, an extremely low-noise paraboloid-plane reflector antenna assembly is provided which operates with maximum gain and minimum scattered radiation.

In accordance with a presently preferred embodiment of the invention, the antenna assembly comprises a second reflector in the form of an asymmetrical portion of a paraboloid, a main or primary reflector in the form of a generally flat planar surface arranged at an angle with respect to the first reflector and a radiating or receiving device located at the focal point of the second reflector in proximity to the end of the main reflector remote from the second reflector. For optimum performance, a shallow reflector is used, the "depth" $d$ of this reflector preferably lying in the range between the values 0.05 and 0.1. The edge ratio of the reflector, denoted $n$, is determined by the formula

$$n=K(1-d)(1+d)^{-1}\{(p+1)K^{-2}-J_{p-2}(K)/J_{p+1}(K)\}\,p_2+_(1+d)^{-1}\{d(p-1a)-(p+1)\}$$

with $p$ preferably being approximately equal to unity and $K$ preferably being approximately equal to 3.5.

In one form of the invention, the antenna assembly may include a subreflector having a focal point coinciding with the focal point of the second reflector and a horn located behind the second reflector for feeding the subreflector.

Other features and advantages of the invention will be set forth in or apparent from the detailed description of preferred embodiments thereof found hereinabove.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram used in explanation of certain of the theoretical considerations on which the present invention is based;

FIG. 2 shows a series of curves representing the edge ratio $n$ of a paraboloid reflector plotted as a function of the depth $d$ of the reflector for various values of $p$;

FIG. 3 illustrates antenna aperture distribution curves plotted for various values of reflector depth $d$;

FIG. 4 is a plot of the average level of radiation away from a reflector as a function of the percentage of the radiation loss;

FIG. 5 is a schematic representation of a presently preferred embodiment of the offset paraboloid-plane reflector antenna of the invention; and

FIGS. 6 through 9 are curves used in explanation of the operation of the offset paraboloid-plane reflector antenna of the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

As an introduction, it is noted that a number of general conclusions have been searched from previous testing of paraboloid-plane reflector antenna assemblies of the prior art. For example, the relative angle between the reflectors, for the range of practical interest, has a minimum effect on the gain of the reflector although this angle influences the spillover radiation. Further, the form of the side construction used influences the level of side radiation from the antenna, especially in the plane perpendicular to the main axis of the paraboloid. It has been determined that the level of this side radiation is principally determined by the amount of energy radiated from the feed away from the paraboloidal surface. An object of the present invention is to determine the optimum position of the feed in the antenna, or stated in other terms, to find the depth and configuration of the paraboloid reflector which combines a maximization of the gain with a minimization of the scattered radiation. It will be seen that results provided in accordance with the present invention hold also if the paraboloid is used, alone, as an antenna. In an optimum embodiment, the relative angle between both reflectors has also been chosen for the attainment of a minimum area for the reflecting surfaces.

It is noted that most of the energy radiated away from the reflector surface exists near the reflector rim (with the assumption that the illumination field strength has a monotonic decay, to negligible levels, away from the reflector edge). A practical demonstration concerning the influence of this edge illumination on the scattered radiation is provided hereinbelow. This important part of the energy together with the contribution from the edge currents of the paraboloid, in absence of a side construction, causes the well-known spillover lobe in the radiation pattern of the paraboloid. The amplitude of the scattered field from the parabola (contribution from edge currents), in the penumbra, is in zero approximation one-half of the direct-radiated field in this direction. The first higher order term in the expansion representing this field is proportional to $G^{-1/2}$ and multiplied by a term proportional to the steepness of illumination at the reflector edge, where $G=\pi D/\lambda$, where $D$ is the reflector diameter and $\lambda$ is the wavelength. Increasing this steepness at the edge will increase the gain. The zero-order term in the expansion of the radiated field will not change if the amplitude of edge illumination is kept fixed. Consequently, the relative level of the spillover lobe decreases. This decrease will be limited by the growth of the first-order term in the expansion due to the increase of the steepness. A condition for attaining a minimum level for the spillover lobe will be realized if the amplitude of the zero-order term in the expansion is equalized by the amplitude of the first order term. This yields the edge relation:

$$e=G^{1/2} \qquad (1)$$

where

$$e=\{f'(t)\}_{t\,1}/\{f(t)\}_{1\,1} \qquad (2)$$

The quantity $e$, which will be referred hereinafter to as the edge ratio, is a measure of the steepness of illumination at the edge divided by the illumination at this edge. The quantity $f(t)$ represents the field distribution in the reflector aperture whereas the quantity $t$ is the normalized radius vector in this aperture to the radius of the rim.

It will be proved hereinbelow that testing the edge relation for different values of the reflector depth, when simple primary feed configurations are used, will determine the choice of the reflector depth for an optimum configuration. In spite of the choice of the feeder opening, the radiation efficiency (in contrast to spillover radiation) is concomitant with the edge ratio $e$ which in turn is concomitant with $d^{-1}$, where, referring to FIG. 1, $d$ is the depth of a parabolic reflector as determined by the formula:

$$d=h/f\cot^2(\tfrac{1}{2}\theta_{cr}) \qquad (3)$$

It is noted that relationships set forth also hold when the parabola is used alone. When the parabola is employed as part of a paraboloid-plane reflector antenna, the effect of its edge currents disappears and the attainment of high values for the edge ratio $e$ remains as a requirement for minimizing the scattered radiation from the antenna.

Referring to FIG. 1, a feeder (not shown) having a circular opening of a diameter $w$, is located at the focal point $f$ of a paraboloid reflector PR having a diameter $D$. The field in the opening of the feeder (not shown) is presumed to be linearly polarized and to have a rotational symmetric intensity dis-

tribution. Further, this field is assumed to be represented by the formula

$$f(r)=(1-r^2)^p \qquad (4)$$

where $r$ is the normalized radius vector of any point in the feed opening to the radius of this opening and $p$ is an arbitrary number (0, 1, 2 . . . etc.). An increase of $p$ corresponds to a broader beam width from the feed and a smaller level of radiation away from the reflector surface. It is noted that a value of $p=1$ approximates the condition of matching the field distribution in the opening of the feed to the field distribution in the middle circle of an Airy pattern. This Airy pattern is assumed to produce a uniform aperture distribution for the antenna with sharp cut off away from its edge. The assumed distribution in the feed opening, as given by equation (4), yields a radiation pattern in the form

$$F(\theta)=2^{p+1}p'\cdot\{J_{p+1}\{(\pi\omega/\lambda)\sin\theta\}\}/\{(\pi\omega/\lambda)\sin\theta\}^{p+1} \qquad (5)$$

Taking into consideration the path length variations to the reflector surface from the focal point and changing the variable $\theta$ to the normalized radius $t$ in the aperture of the parabola, where $t=q^{-1}\tan(\frac{1}{2}\theta)$, the normalized aperture distribution of the reflector will be given by

$$f(t)=2^{p+1}(p+1)!\ (1+dt^2)^{-1}\{J_{p+1}\{(2\pi\omega/\lambda)qt(1+dt^2)^{-1}\}\}\{(2\pi\omega/\lambda)qt(1+dt^2)^{-1}\}^{-p-1} \qquad (6)$$

It is well known that the choice of the feed type is affected by the opening angle of the reflector, the edge illumination and the steepness of this illumination at the reflector edge. Disregarding the steepness at the edge for the moment, it is possible to establish a relation between the opening angle of the reflector and the size of the feed opening when the edge illumination is determined and for a given field distribution in the feed opening.

The edge illumination is determined from the argument of Bessel coefficient in (6) when $t=1$. If this argument is given by $K$, it follows that

$$\pi\omega/\lambda=K/\sin\theta_{cr} \qquad (7)$$

Using equation (7), the following resultant equation can be derived:

$$f(t)=2^{p+1}(p+1)!\ (1+dt^2)^{-1}\{J_{p+1}\{K(1+d)t(1+dt^2)^{-1}\}\}\{K(1+d)t(\text{ahz}dt^2)^{-1}\}^{-p-1} \qquad (8)$$

The first derivative of the illumination function will then be given by the formula

$$f'(t)=2^{p+1}(p+1)!\{K(1+d)\}^{p-1}(1+dt^2)^{p-1}\{K(1+d)(1+dt^2)^{-1}(1-dt^2)t^{-p-1}J_{p+1}\{K(1+d)t(1+dt^2)^{-1}\}+t^{-p-2}\{dt^2(p-1)-(p+1)\}J_{p+1}\{K(1+d)t(1+dt^2)^{-1}\} \qquad (9)$$

Using equations (8) and (9), the edge ratio may be expressed as follows:

$$e=K(1-d)(1+d)^{-1}\{(p+1)K^{-2}-J_{p+2}(K)/J_{p+1}(K)\}+(1+d)^{-1}\{d(p-1-(p+1)\} \qquad (10)$$

It is noted that the quantity $K$ is a relatively large number in this form and that values of $p$ of more than unity are of a negligible practical importance. Further, $\{J_{p-2}/J_{p-1}\}$is $>>(p+1)/K$for a wide range of practical values. This means that the second term in equation (10) is smaller than the first for values of $d$ different from unity. It can also be said that the first term represents the influence of the reflector depth on the edge ratio $e$ and the second term represents the effect of the choice of the feed on this ratio. It can be seen in the first term that $(1-d)$ increases from zero to unity when $d$ approaches zero, i.e., as the reflector becomes more shallow. This means that large values of $e$ are attainable using shallow reflectors. A plot is shown in FIG. 2 for the edge ratio $e$ for conveniently chosen values for $K$ and for different values of $p$. The following conclusions can be drawn from equation (10):

(1) The edge ratio $e$ is not dependent on the edge illumination for focal plane reflectors (where $d=1$) and using the assumed simple feed. This indicates also that high edge illumination is always accompanied by high steepness at the reflector edge because the edge ratio $e$ is always unity for $d=1$.



(2) The second term of the equation is also independent of the illumination when $d=1$. The value of this term, however, increases for small values of $d$. This means that when $d$ is small an improved edge ratio is obtained. Values of $d>1$ are of little practical importance in that in this situation the size of this feed will become too small to realize the required illumination function. In FIG. 3 the aperture distribution of a focal plane reflector and a shallow reflector are shown. It is clear from FIG. 3 that when the same feed configuration is used, the aperture efficiency increases by nearly 100 percent when $d$ is reduced from 1 to 0.1 (corresponding to a reduction in the feed angle from 180° to 67°).

Considering now the steepness of illumination at the reflector edge $\{f'(1)\}$, this steepness is given by the formula:

$$n=f'(1)=2^{p+1}(p+1)!\ K^{-p}(1+d)^2\{(1-d)J_{p+1}(K)+K^{-1}\{d(p-1)-(p+1aq)\}J_{p+1}(K)\} \qquad (11)$$

For a focal plane reflector, with $p=0$ and $K=2.5\{f(1)\approx 0.3\}$, $n$ will be 0.2; that is, $n$ will be of a value which is relatively very small. For the same edge illumination and using a shallow reflector ($d=0.1$) the steepness $n$ increases to 0.8 which is also small in accordance with the edge relation given by equation (1). When the edge illumination is reduced to 0.04, $n$ will increase by a factor of approximately 15 (See FIG. 2), i.e., $n\approx 3$, when $d$ is reduced from 1 to 0.1. This condition of small edge illumination is fortunately easy to realize for shallow reflectors because the required large diameter of the feed opening enables a well-defined deep minimum to be obtained at the reflector edge.

From the previous discussion the following conclusions may be drawn: (1) It is impossible to attain high gain when conventional feeds (an open end of a waveguide) are used in combination with deep reflectors ($d\approx 1$). Special techniques must be employed under these circumstances to control the feed pattern for attaining the required gain and spillover. (2) Shallow paraboloids, employing simple feeds, can give satisfactory results for gain and spillover radiation. (3) Combining the use of a shallow reflector and with a properly designed feed can lead to an excellent performance for microwave reflector antennas. (4) The large size of the required feed for a shallow reflector is accompanied by relative small level of the radiation field away from the feed angle of the reflector. In FIG. 4, the required average level of radiation from the feed away from the feed solid angle, for various percentages of power loss due to this radiation, is shown. Fortunately, this level (relative to the isotropic source level) is nearly constant in the range where high steepness for the illumination at the edge is attainable by shallowing the reflector ($d< 0.2$). This indicates that in this range the more shallow the reflector is, the larger the size of the feed and the smaller the spillover radiation.

It is clear from the discussion hereinabove that the choice of a shallow reflector simplifies the design problems of the feed and reduces the radiation from this feed away from the reflector feed angle. When a symmetric paraboloid is used for the construction of a paraboloid-plane reflector antenna, the outermost position of the feed on the paraboloid axis is at the center of the plane reflector. If the lower edge of the plane reflector is kept near the rim of the paraboloid, to keep the side construction as short as possible, and the angle between the plane reflector and the aperture of the paraboloid is 45°, the depth of the parabola in this situation will be 0.171 ($\alpha=90°$ as can be seen in FIG. 2 and FIG. 4).

It can be seen in FIG. 2 that a more shallow paraboloid can be used to attain higher values for $e$. However, a feed for a more shallow paraboloid ($d<0.171$), located at the focal point of the reflector, would be located behind the plane reflector. This situation increases blockage because of the intersection of the illuminating cone of the feed with the plane reflector. In accordance with one aspect of the present invention, to avoid this blockage, the feed is placed in proximity to but spaced from the upper plane surface and an offset reflector is used. The outermost position of the feed is located at the upper end of the plane reflector.

Referring to FIG. 5, a presently preferred embodiment of the invention is shown. A microwave antenna assembly generally denoted 10 includes an offset parabolic reflector 12 formed by an unsymmetrical portion of a paraboloid. Reflector 12 is joined to a main or primary reflector 14 formed by a substantially flat planar surface by a side construction generally indicated at 16. Side construction 16 is formed by a first part-cylindrical surface whose axis of generation is generally perpendicular to the plane of the edges of the reflector 12 and a second part-cylindrical surface whose axis of generation is perpendicular to the plane of reflector 14. The line along which these surfaces are joined is a function of the shape of the offset parabola. The antenna assembly further includes an ellipsoidal subreflector 18 having a focal point 20 coincident with the focal point of reflector 12. Subreflector 18 is fed by an horn 22 located behind planar reflector 14 as shown. It will be understood that the feed system shown may be replaced by a simplified system wherein a radiating or receiving device is located at the focal point 20 of parabolic reflector 12 and thus a radiating horn 24 is indicated in phantom in FIG. 5. The entire antenna assembly 10 is mounted on a support structure generally denoted 26 which permits rotation thereof, support structure 26 including wheels 28 which also permit displacement of the assembly 10. The precise construction of the antenna assembly is generally conventional and further description thereof is deemed unnecessary.

The offset paraboloid-plane antenna shown in FIG. 5 provides a number of advantages. First, placing the feed near the reflecting plane as indicated at 24, makes it easy to interchange the feed or adjust the position thereof. This arrangement also ensures a short connection to the receiving equipment. Secondly, the small depth of the parabola 12 makes the parabola 12 easy to scan for wide angles off the main beam axis by deviating the position of the feed 24. Further, the alignment of the antenna and adjustment of the proper feed position are also simplified. Third, the offset parabola arrangement provides a substantial reduction in the amount of scattered radiation from the paraboloidal surface 12. In addition, the total surface area of the reflecting surfaces of antenna 10 is smaller than that of a symmetric paraboloid-plane reflector antenna of the prior art. Further, the scattered radiation from antenna 10 is less dependent on the form of the side construction 16 than in conventional paraboloid-plane reflector antennas. Still further, blockage of the feed 24 or feed 18, 12 and its supporting construction 26 is totally avoided. In FIG. 6, the radiation pattern of antenna 10 is compared with the pattern of a Casshorn antenna with an opening aperture five times greater than that of the present invention.

It is noted that an antenna in accordance with the present invention has been constructed having a diameter of 20 cm. and has been tested at $\lambda$=4.3 mm. The radiation patterns in the horizontal and vertical planes are shown in FIGS. 6 and 7. These patterns have been measured with a feed for which a



deep minimum exists near the edge of the paraboloid. An aperture efficiency of approximately 75 percent is expected (See FIG. 9). High values of edge illumination have been provided by introducing feed modifications such as illustrated in FIG. 5. The resulting illumination functions due to these modifications are shown in FIG. 9. The corresponding radiation patterns from the antenna are shown in FIG. 8 and it is noted that these modifications produce a little influence on the vertical plane radiation patterns. The increase in the level of the scattered radiation with increase of edge illumination demonstrates the importance of the part of radiation from the feed to the reflector rim. It is also pointed out that for the same edge illumination, greater steepness at the reflector edge results in an improved level of scattered radiation from the antenna (which can be seen by inspection of FIG. 8 and FIG. 9). This high steepness at the edge means small spillover energy from the feed away from the reflector surface.

Although the present invention has been described relative to presently preferred embodiments thereof, it will be understood by those skilled in the art that variations and modifications can be effected within the scope and spirit of the invention.

I claim:

1. A microwave antenna assembly comprising a main reflector in the form of a flat planar surface, a second reflector in the form of an asymmetrical portion of a paraboloid, means for supporting said main reflector relative to said second reflector so that said main reflector and said second reflector are joined together in a continuous surface at a generally acute angle therebetween and a radiating or receiving means located at the focal point of said second reflector situated near the edge of said main reflector opposite the end joined to the second reflector.

2. A microwave antenna as claimed in claim 1 wherein said second reflector is relatively shallow.

3. A microwave antenna assembly as claimed in claim 2 wherein the depth of $d$ of said second reflector lies in range $0.05 < d < 0.1$, wherein the depth of $d$ is the ratio of $h$, the perpendicular distance between a plane determined by the edge of said second reflector and the nadir point of the second reflector, and F, the focal length of said second reflector.

4. A microwave antenna assembly as claimed in claim 3 wherein the edge ratio determined by the formula $K(1-d)(1+d)^{-1}[(p+1)K^{-2}-J_{p+2}(K)/J_{p+1}(K)]+(1+d)^{-1}[d(p-1)-(p+1)]$wherein $K$ is the argument of the Bessel coefficient and is approximately equal to 3.5 and $p$ is an arbitrary number which takes a value near unity.

4. A microwave antenna assembly as claimed in claim 1 wherein said radiating or receiving means comprises an ellipsoidal subreflector having a focal point coinciding with the focal point of said second reflector and a horn located behind said main reflector for feeding said subreflector.

* * * * *