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(71) Applicant: ANDREW CORPORATION
10500 West 153rd Street
Orland Park Illinois 60462(US)

(72) Inventor: Knop, Charles M.
Route 6 Box 279
Lockport Illinois 60441(US)

(72) Inventor: Ostertag, Edward L.
1918-38 Heatherway Lane
New Lenox Illinois 60451(US)

(74) Representative: MacDougall, Donald Carmichael et al,
Messrs. Cruikshank & Fairweather 19 Royal Exchange Square
Glasgow G1 3AE, Scotland(GB)

(54) **Planar-parabolic reflector antenna with recessed feed horn.**

(57) An axisymmetrical planar-parabolic reflector antenna has a paraboloidal reflector dish (10) and a planar reflector (13) into which the feed horn (11) illuminating the dish (10) is recessed so as to reduce (and preferably minimise) aperture blocking caused by the feed horn (11). In its upper frequency band, the feed horn (11) has a vanishing electric field at the edge of its aperture which suppresses edge currents at the mouth of the feed horn (11) and along the planar reflector surface (13), thereby preventing the flow of ground-plane currents in the planar reflector (13) which would degrade the antenna's performance. In its lower frequency band, the feed horn's choke surrounding the mouth of the feed horn (11) effectively accomplishes the edge current suppression. At a given frequency band, the feed horn (11) produces virtually equal E and H-plane radiation patterns.

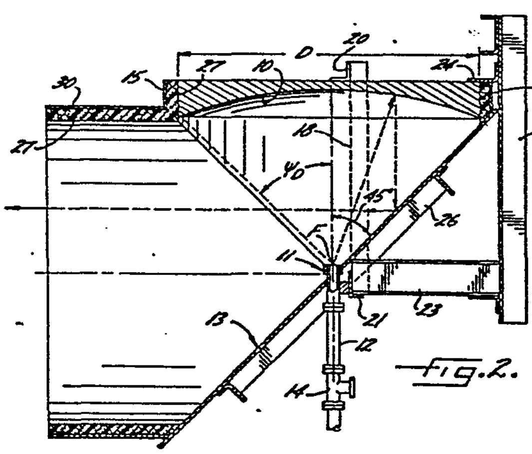

FIG. 2.

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PLANAR-PARABOLIC REFLECTOR ANTENNA WITH RECESSED FEED HORN

The present invention relates generally to microwave antennas and, more particularly, to planar-parabolic dual-reflector antennas.

Since offset-reflector antennas reduce aperture-blocking effects, they have tended to be favoured over non-offset or axisymmetrical reflector antennas where performance outweighs cost in importance. Offset-reflector antennas are those which have the feed horn longitudinal axis non-coincident with the axis of the paraboloidal antenna dish; whereas axisymmetrical antennas are those which have the longitudinal axis of the feed horn positioned coincident with the paraboloidal axis. By moving the feed horn away from the axis of the paraboloidal dish, the offset-reflector antenna is able to illuminate its main dish without the feed horn blocking the dish aperture. In many applications, this reduction of the aperture-blocking effect in offset-reflector antennas is a very significant advantage. Aperture blocking by a feed horn leads to 1) a decrease in the effective aperture area of the dish which results in a loss of system gain, and 2) the scattering of radiation off the feed horn itself and off the connecting waveguide which results in a general degradation of side lobe suppression. Because the air-waves are becoming increasingly crowded and, as a result, spurious radiation specifications for antennas have tightened, these aperture-blocking effects are becoming increasingly important. As a result of the offset-reflector antenna's ability to reduce the aperture-blocking effect, the offset-reflector antenna has been favoured in most applications calling for tight performance specifications.

Unfortunately, the offset-reflector configuration has several major disadvantages. One of these disadvantages is that it generates a cross-polarized component in the antenna's radiation field. This cross-polarization can be a significant problem when the antenna is required to conform to strict cross-polarization radiation specifications which may increase the mechanical rigidity requirements (and hence cost) of the tower on which the antenna is mounted. In addition, the geometry of an offset-reflector configuration can be a major construction problem since it is more expensive to manufacture than an axisymmetrical antenna design.

Typically in antenna designs, the reflector is chosen as large as practical and the feed horn is thereafter designed for efficient illumination of the reflector surface. Normally the design is for maximum gain or for the maximum reduction of side lobe levels. Because the reflector is large in both axisymmetrical and offset-reflector antenna designs, there inherently is a problem with wind-loading. Expensive mountings often must be provided for the antenna in order to provide the structural integrity required to minimise the bowing of the antenna mast which occurs as a result of the sail-like capturing of the wind by the antenna reflector. If bowing is sufficiently severe, beam tilting and increased cross-polarized radiation can become a significant problem.

It is a primary object of the present invention to provide an improved axisymmetrical planar-parabolic reflector antenna with superior radiation pattern envelopes (i.e., RPEs). In this connection, it is a related object of this invention to provide an axisymmetrical planar-parabolic reflector antenna with both a reduced wind-loading factor and superior RPEs.

It is another object of this invention to provide an axisymmetrical planar-parabolic reflector antenna achieving the above objectives and operating over a dual frequency band.

It is a further object of this invention to provide an axisymmetrical antenna which is of a simple design, and is inexpensive to manufacture.

In accordance with the invention an axisymmetrical antenna in the form of a planar-parabolic reflector antenna is provided having a paraboloidal dish reflector and a planar reflector wherein the feed horn illuminating the paraboloidal dish is recessed into the planar reflector so as to reduce aperture blocking caused by the feed horn; preferably, the feed horn is fully recessed into the planar reflector so as to minimise the aperture-blocking effect. In its upper frequency band, the feed horn has a vanishing electric field at the edge of its aperture which suppresses edge currents at the mouth of the feed horn and along the planar reflector surface, thereby preventing the flow of ground-plane currents in the planar reflector which would degrade the antenna's performance. In its lower frequency band, the feed horn's choke surrounding the mouth of the feed horn effectively accomplishes the edge current suppression.

In a first embodiment the reflector is configured as a 45° circular-paraboloidal dish with a focal length-to-diameter ratio of approximately 0.6, so that the recessed feed horn fully illuminates the paraboloidal dish without interference from the planar reflector. The feed horn preferably utilised in connection with the invention has a small aperture which further reduces the aperture-blocking effect.

In a second embodiment, a noncircular-paraboloidal reflector creates unequal horizontal and vertical plane radiation patterns to provide narrower horizontal plane radiation patterns for terrestrial applications of the antenna. Preferably, the noncircular-paraboloidal reflector has focal length-to-diameter ratios of approximately 0.833 and 0.333 in the vertical and horizontal planes, respectively.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a frontal view of an axisymmetrical planar-parabolic reflector antenna according to the invention;

Fig. 2 is a cross-sectional view of the antenna in Fig. 1 taken along the line 2-2;

Fig. 3 is an enlarged cross-sectional view of a feed horn preferably used in connection with the invention;

Fig. 4 is a graph of the E-plane and H-plane radiation power patterns for the feed horn in Fig. 3 measured with respect to the longitudinal axis of the feed horn and at a frequency of 3.95 GHz;

Fig. 5 is a graph of the E-plane and H-plane radiation phase patterns for the feed horn in Fig. 3 measured with respect to the longitudinal axis of the feed horn and at a frequency of 3.95 GHz;

Fig. 6 is a graph of the E-plane and H-plane radiation power patterns for the feed horn in Fig. 3 measured with respect to the longitudinal axis of the feed horn and at a frequency of 6.175 GHz;

Fig. 7 is a graph of the E-plane and H-plane radiation phase patterns for the feed horn in Fig. 3 measured with respect to the longitudinal axis of the feed horn and at a frequency of 6.175 GHz;

Fig. 8 is a graph of the near-in H-plane radiation pattern for an axisymmetrical planar-parabolic reflector antenna according to the invention predicted at 3.95 GHz compared to H-plane radiation pattern envelopes for an offset-reflector antenna and a prior art axisymmetrical antenna measured at 3.95 GHz with all the antennas having an approximately equal gain;

Fig. 9 is a graph of the near-in E-plane radiation pattern for an axisymmetrical planar-parabolic reflector antenna according to the invention predicted at 3.95 GHz compared to E-plane radiation pattern envelopes for an offset-reflector antenna and a prior art axisymmetrical antenna measured at 3.95 GHz with all the antennas having an approximately equal gain;

Fig. 10 is a graph of the full 360° E-plane radiation pattern for an axisymmetrical planar-parabolic reflector antenna according to the invention predicted at 3.95 GHz compared to E-plane radiation pattern envelopes for an offset-reflector antenna and a prior art axisymmetrical antenna measured at 3.95 GHz with all the antennas having an approximately equal gain;

Fig. 11 is a graph of the full 360° H-plane radiation pattern for an axisymmetrical planar-parabolic reflector antenna according to the invention predicted at 3.95 GHz compared to H-plane radiation pattern envelopes for an offset-reflector antenna and a prior art axisymmetrical antenna measured at 3.95 GHz with all the antennas having an approximately equal gain;

Fig. 12 is a frontal view of an alternative embodiment of an axisymmetrical planar-parabolic reflector antenna according to the invention;

Fig. 13 is a cross-sectional view of the antenna in Fig. 12 taken along the line 13-13; and

Fig. 14 is a perspective view of a paraboloidal reflector for the alternative embodiment of an axisymmetrical antenna in Figs. 12 and 13.

While the invention will be described in connection with certain preferred embodiments, it will be understood that it is not intended to limit the invention to those particular embodiments. On the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included within the scope of the invention as defined by the appended claims.

Turning now to the drawings and referring first to

Figs. 1 and 2, there is illustrated a dual-reflector axisymmetrical planar-parabolic reflector antenna (hereinafter planar-parabolic reflector antenna) comprising a paraboloidal main reflector dish 10, a primary feed horn 11 connected to and supported by a circular waveguide 12 extending along the axis of the circular dish 10, and a planar reflector 13 positioned along, and at a 45° angle with respect to, the axis of the main dish. The axis of the main dish 10 is vertically positioned and coincident with the longitudinal axis of the waveguide 12 and the feed horn 11. (The term "feed" as used herein, although having an apparent implication of use in a transmitting mode, will be understood to encompass use in a receiving mode as well, as is conventional in the art.)

In the transmitting mode, the feed horn 11 receives microwave signals via the circular waveguide 12 and a combiner 14 and launches those signals as spherical waves upwardly onto the paraboloidal main reflector dish 10; the main dish 10 reflects the signals in a generally planar wave downwardly onto the planar reflector 13, which in turn reflects the signals laterally in a planar horizontal wave. In the receiving mode, the planar reflector 13 is illuminated by an incoming planar horizontal wave and reflects its energy to the main dish 10; the main dish 10 reflects this incoming energy into a spherical wave and directs it into the feed horn 11 for transmission to the receiving equipment via the circular waveguide 12 and the combiner 14.

The paraboloidal main dish 10 has a diameter D and, as is required in dual-reflector antennas of this type, the focal point F of the paraboloidal surface of the main reflector is located at the phase centre of the feed horn 11 (usually at the mouth of the feed horn). To achieve this configuration, the planar reflector 13 has a central opening which allows the feed horn 11 to illuminate the main dish 10 without interference from the surface of the planar reflector.

The planar reflector 13 is positioned to intercept substantially all of the radiation launched from the feed horn 11 after it is reflected from the main dish 10 (in the transmitting mode). Since the aperture of the main dish 10 is circular, the planar reflector 13 has an elliptical shape because of its angled position with respect to the axis of the main dish. The planar reflector's position of 45^{o} with respect to the axis of the main reflector dish 10 causes the vertically travelling radiation from the main dish 10 to be redirected to a horizontal path. In the receiving mode, the planar reflector 13 redirects incoming horizontal radiation to a vertical path which illuminates the main dish 10.

To support the main dish 10, the planar reflector 13 and the feed horn 11 in their desired positions, a cylindrical housing 15 is provided. In the illustrated embodiment, the antenna's cylindrical housing 15 has an opening 16 to allow radiation to enter the cylindrical housing and illuminate the planar reflector 13. Because of the 45^{o} angle of the planar reflector with respect to the axis of the paraboloidal main dish 10, radiation which best illuminates the main dish 10 travels along a horizontal beam path whose direction of propagation is orthogonal to the axis of the main dish. Around the opening 16 in the cylindrical housing 15 is fitted an absorber-lined cylindrical shield 30 which serves to reduce incoming radiation which is off-axis from the main horizontal beam path. The shield 30 is preferably constructed of a continuous metal or fibreglass projection in an annular shape whose inner and outer walls are substantially parallel to the direction of propagation of the main horizontal radiation beam path. Conventional microwave absorbing material 27 having a pyramidal, flat or convoluted surface, or even "hair" absorber, can be used on the inside surface of the shield.

In order to support the antenna, a frame consisting of a pair of vertical beams 18 and 19 and a pair of horizontal beams 20 and 21 surround the cylindrical housing 15. A vertical mast beam 22 is coupled to the horizontal beam 21 by way of a perpendicular beam 23. To provide support for the antenna in the area of the paraboloidal dish 10, an L-bracket 24 joins the back of the dish 10 to the vertical mast beam 22. To support and hold flat the planar reflector 13, a pair of diagonal beams 25 and 26 are provided at the ends of the reflector. In order to provide additional protection from off-axis radiation, absorber material 27 is located around the periphery of the dish 10 as well as on the inner wall of the shield 30.

Referring next to Fig. 3, the feed horn 11 preferably comprises two straight circular waveguide sections 40 and 41 interconnected by a conical circular waveguide section 42. This particular feed horn 11 produces substantially equal E-plane and H-plane patterns in two different frequency bands. This is accomplished by selecting the diameter of the horn mouth to be approximately equal to one wavelength in the lower frequency band and then selecting the slope β of the conical wall to cancel the radial electric field at the edge of the horn's aperture (having an inner diameter D_1) in the upper frequency band. The one-wavelength diameter of the lower frequency band produces substantially equal patterns in the E and H-planes for the lower frequency signals, while the cancellation of the electric field of the higher frequency signals at the inside wall of the horn aperture produces substantially equal patterns in the E and H-planes for the higher frequency signals. The horn is both small and inexpensive to fabricate, and yet it simultaneously produces equal main beam patterns in both the E and H-planes in each of two frequency bands. The small size of the horn minimises horn blockage caused by the presence of the horn at the centre of the planar reflector 13.

Section 40 of the illustrative feed horn 11 (Fig. 3) is a conventional smooth-wall TE_{11} mode horn at the low frequency (e.g., 3.95 GHz) with an inside diameter D1 approximately equal to one wavelength at the centre frequency (e.g., 3.95 GHz) of the lower frequency band. The second cylindrical section 41 of the feed horn has a smaller inside diameter D2, and the two cylindrical sections 40 and 41 are joined by the uniformly tapered conical section 42 to generate (at the junction of sections 40 and 42) and propagate the TM_{11} mode in the upper frequency band (e.g., 6 GHz). More specifically, the conical section 42 generates (at the junction of sections 40 and 42) a TM_{11} mode from the TE_{11} mode propagating from bottom to top in the smaller cylindrical section 41 and in the section 42. At the end of the conical section 42 the freshly generated TM_{11} mode leads the TE_{11} mode by about 90^o in phase. The slope β of the conical section 42 determines the amplitude of the TM_{11} mode signal, while the length L of the larger cylindrical section 40 determines the phase relationship between the two modes at the aperture of the feed horn.

Proper selection of the length L of the cylindrical section 40 of the feed horn 11 insures that the TM_{11} and TE_{11} modes are in phase at the feed horn aperture, in the upper frequency band. Also, good impedance matching is obtained, with the feed horn design of Fig. 3 having a VSWR of less than 1.1. The inside diameter of the waveguide 12 coupled to the small end of the feed horn is the same as that of the smaller cylindrical section 41. A pair of coupling flanges 43 and 44 on the waveguide and feed horn, respectively, are used to fasten the two together by means of a plurality of screws 45.

To suppress back radiation at the low band from the external surface of the horn 11, the open end of the horn is surrounded by a quarter-wave choke 46 comprising a short conductive cylinder 47, concentric with the horn 11, and a shorting ring 48. The inner surface of the cylinder 47 is spaced away from the outer surface of the horn 11 along a length of the horn about equal to a quarter wavelength (at the lower end of the low band) from the end of the horn, and then the cylinder 47 is shorted to the horn 11 by the ring 48 to form a quarter-wave coaxial choke which suppresses current flow on the outer surface of the horn.

At the high frequency band (for which the free space wavelength is λ_H), back radiation is suppressed, and equal main beams are obtained in the E and H-planes, by cancelling the electric field at the aperture boundary. To achieve this, the ratio of the mode powers $W_{TM_{11}}$ and $W_{TE_{11}}$ must be:

$$\frac{W_{TM_{11}}}{W_{TE_{11}}} = 0.4191 \frac{\lambda_{gTM_{11}} \lambda_{gTE_{11}}}{\lambda_H^2} \qquad (1)$$

where the guide wavelength of the TM_{11} mode is

$$\lambda_{gTM_{11}} = \lambda_H / \sqrt{1-(3.83/C)^2} \qquad (2)$$

The guide wavelength of the TE_{11} mode is

$$\lambda_{gTE_{11}} = \lambda_H / \sqrt{1-(1.84/C)^2} \qquad (3)$$

and

$$C = \pi D1/\lambda_H \qquad (4)$$

The relationship between the above mode power ratio, the diameter D1 at the large end of the conical section 42, and the half flare angle β (in degrees) of the conical section 42 is known to be given by the following equation:

$$\frac{W_{TM_{11}}}{W_{TE_{11}}} = 2.11 \times 10^{-4} \left(\frac{D1 \cdot \beta}{\lambda_H}\right)^2 \frac{\lambda_{gTM_{11}} \lambda_{gTE_{11}}}{\lambda_H^2} \qquad (5)$$

Equating equations (1) and (5) yields:

$$2.11 \times 10^{-4} \left(\frac{D1 \cdot \beta}{\lambda_H}\right)^2 = 0.4191 \qquad (6)$$

To produce approximately equal E and H patterns in the low frequency band, the diameter D1 is made about equal to one wavelength, λ_L, at the midband frequency of the low band, i.e.:

$$D1 = \lambda_L \tag{7}$$

Thus, equation (6) becomes:

$$2.11 \times 10^{-4} \left(\frac{\lambda_L \beta}{\lambda_H}\right)^2 = 0.4191 \tag{8}$$

Equation (5) can then be solved for β:

$$\beta = 44.57^{\circ} \frac{\lambda_H}{\lambda_L} \quad \text{, in degrees} \tag{9}$$

This value of β results, at the high band, in cancellation of the electric field at the aperture boundary, which in turn results in approximately equal E and H-patterns of the main beam radiated from the horn in the high frequency band.

To ensure that the TM_{11} mode is generated at the junction between the cylindrical section 40 and the conical section 42, the diameter D1 must be such that the value of C, which is defined by equation (4) as $\frac{\pi D1}{\lambda_H}$, is above the Eigen value of 3.83 for the TM_{11} mode in the high frequency band. To ensure that <u>only</u> the TM_{11} mode is generated, the diameter D1 must be such that the value of C is below the Eigen value of 5.33 for the TE_{12} mode in the high frequency band. Thus, the value of C must be within the range of from about 3.83 to about 5.33. The symmetry of the cylindrical sections 40 and 41 and of the conical section 42 insures that the other higher order modes (TM_{01} and TE_{21}) which can also propagate (for $C > 3.83$) will not be excited. Since D1 is selected to be equal to one wavelength λ_L for the low frequency band, equation (4) gives:

$$C = \frac{\pi \lambda_L}{\lambda_H} \tag{10}$$

and, therefore, the ratio λ_L/λ_H must be within the range of from about $3.83/\pi$ to about $5.33/\pi$, which is 1.22 to 1.61.

Thus, the two frequency bands must be selected to satisfy the above criteria. One suitable pair of frequency bands is 4GHz and 6GHz, because λ_L and D1 are 2.953 inches, λ_H is 1.969 inches, and λ_L/λ_H is 1.5. This value of the ratio λ_L/λ_H is, of course, within the prescribed range of 1.22 to 1.61.

In one working example of the feed horn, a feed horn of the type shown in Fig. 3 had an inner diameter of 2.125 inches in its smaller cylindrical section 40 and 2.810 inches in its larger cylindrical section 41. The conical section 42 connecting the two cylindrical sections had a half flare angle β (via equation (9)) of 30° with respect to the axis of the feed horn. The axial length of the conical section was 0.593 inches. The lengths of the two cylindrical sections 41 and 40 were 1.0 inches and 4.531 inches, respectively.

The working example described above produced the E-plane and H-plane power patterns shown in Figs. 4 and 6 at 3.95 GHz and 6.175 GHz, respectively. The power patterns in Figs. 4 and 6 represent amplitude in decibels along an arc length of a circle whose centre is coincident with the position of the centre of the aperture of the antenna and whose radius is 11 inches or more. This same feed horn produced the E-plane and H-plane phase patterns shown in Figs. 5 and 7 at 3.95 GHz and 6.175 GHz, respectively.

From Figs. 4 and 6 it can be seen that, at a given band, the patterns are virtually identical in the E and H-planes, and the amplitude is sufficiently low at 45° off axis (which is the location of the edge of the main reflector) to ensure adequate total energy capture by the reflector. As to the phase patterns shown in Figs. 5 and 7, it will be noted that these curves are relatively flat, in both the E and H-planes, out to 45° off axis.

In accordance with one important aspect of the invention, the feed horn 11 is recessed into the planar reflector 13 such that the aperture-blocking effect of the feed horn is minimised, and currents in the planar reflector, as a result of the planar reflector functioning as a ground plane for the feed horn, are avoided because of the insignificant amount of edge current at the feed horn aperture. By utilising a feed horn such as illustrated in Fig. 3, the antenna produces substantially equal E and H-plane patterns and very low horizontal plane radiation (i.e. 90^o radiation is transmitted directly from the feed horn without reflection). Other feed horns may also be used in connection with the invention. For example, a corrugated feed horn (flared or in pipe form) may also provide low edge currents at the feed horn aperture and equal E and H-plane radiation patterns. But, because of its small aperture, the feed horn in Fig. 3 provides the smallest amount of aperture blocking and, therefore, is preferred.

By configuring the main reflector dish as a 45^o dish (the subtended angle ψ_D is 45^o), the recessed feed horn 11 can illuminate the entire surface of the main reflector without interference from the angled planar reflector 13. Since the ratio between the focal length and the main dish diameter are related by

$$F/D = 1/4 \tan\ (\psi_D/2) \qquad (11)$$

the ratio must be approximately 0.6039 in the antenna according to the invention, i.e., $\psi_D = 45^o$.

In its fully recessed position, the feed horn 11, or a flared corrugated feed horn, is positioned such that the phase centre of the feed horn's open end is located 1) coincident with the focal point F of the paraboloidal dish, and 2) at a distance from the surface of the planar reflector 13, as measured along the axis of the paraboloidal dish 10, approximately equal to the radius r of the feed horn at its open end. The radius r of the feed horn's open end is defined as the distance of the outermost surface of the feed horn from the centre of the feed horn's open end. This second approximate relationship exists since, as indicated in Fig. 3, the main dish axis, the surface plane of the feed horn aperture and the surface plane of the planar reflector 13 describe a right-angle triangle with acute angles of 45^{o}.

By reducing the aperture-blocking effect by recessing the feed horn into the planar reflector 13, and controlling the amount of surface current generated in the planar reflector by the feed horn 11, there results a planar-parabolic reflector antenna with RPEs equivalent or, in some instances, superior to the RPEs of an offset-reflector configuration. The reflector generated cross-polarised interference common in off-axis antenna configurations is eliminated by the axisymmetrical configuration of an antenna according to the invention. By utilising a feed horn which provides equal E and H-plane radiation patterns, cross-polarized interference is further reduced.

The antenna of this invention displays greatly improved RPEs, and a relatively low wind-loading factor, in comparison to prior axisymmetrical antenna designs. The mounting structure for this antenna can be much less costly than the equivalent mounting for other types of antenna designs.

Figs. 8-11 illustrate the radiation patterns for a planar-parabolic reflector antenna according to the invention at a 3.95 GHz frequency. To measure the performance of the antenna, a 7.098 scaled version of the antenna was constructed. Specifically, to simulate the performance of a full-size antenna with a 10-foot diameter paraboloidal dish, and to predict the patterns at 3.95 GHz (shown by Figs. 8-11), a 17-inch diameter dish antenna was constructed and measured using a scaled frequency (i.e., 7.058 times 3.95 GHz or 27.88 GHz). Accordingly, a 7.098 scaled version of the feed horn 11 which produced the patterns in Figs. 4-7 was used in combination with the 17-inch diameter dish antenna.

From the measured near-in E and H-plane radiation patterns for the 7.098 scaled version of the planar-parabolic reflector antenna according to the invention, the patterns A in Figs. 8 and 9 were obtained. They indicate a superior performance by the antenna in comparison to a radiation pattern envelope (RPE) B at 3.95 GHz for a shielded axisymmetrical single-reflector paraboloidal dish antenna. Measured E and H-plane RPEs C in Figs. 8 and 9, respectively, are for an offset-reflector antenna at 3.95 GHz. As a comparison of the patterns and envelopes indicates, the planar-parabolic reflector antenna according to the invention (patterns A) performs substantially as well as an offset configuration (RPEs C).

The full 360° E and H-plane radiation patterns A at 3.95 GHz for an antenna according to the invention are shown in Figs. 10 and 11, respectively. These patterns were also measured using the 7.098 scaled antenna. For comparison, Figs. 10 and 11 also include the full 360° E and H-plane radiation pattern envelopes B and C for the shielded single-reflector paraboloidal dish antenna and the offset-reflector antenna, respectively, measured at 3.95 GHz.

As the patterns in Figs. 8-11 indicate, the patterns of the planar-parabolic reflector antenna according to the invention are superior to the axisymmetrical single-reflector antenna RPEs B and virtually equivalent in overall performance to the offset-reflector antenna RPEs C. Predictions of the performance of the antenna according to the invention at a 6 GHz frequency band indicate the antenna should have radiation patterns similar or superior to the 3.95 GHz patterns.

Referring to Figs. 12-14, an alternative embodiment of the invention utilises a noncircular-paraboloidal reflector 50 in place of the circular-paraboloidal reflector 10 in Figs. 1 and 2. In terrestrial applications, the width of an antenna's horizontal plane radiation pattern is of greater importance than the width of the antenna's vertical plane radiation pattern. This is so since interference between adjacent terrestrial antennas is of greatest concern along the earth's surface (i.e., horizontal plane), thus making the width of the vertical plane of lesser concern. The predicted radiation patterns for the planar-parabolic reflector antenna of Figs. 12 and 13, utilising a noncircular-paraboloidal reflector 50 (Fig. 14) and the feed horn in Fig. 3, are superior to the predicted radiation patterns for the planar-parabolic reflector antenna of Figs. 1 and 2 which utilises a 10-foot circular-paraboloidal reflector.

Referring to Fig. 14, by choosing, for example, a circular-paraboloidal reflector having a 5-foot focal length and a 15-foot diameter (shown by the dashed lines), and cutting the paraboloid to form a 6-foot strip, the non-circular-paraboloidal reflector 50 results. It has a focal length-to-diameter ratio of 5/15 or 1/3 (i.e., 0.333) in the horizontal plane and a ratio of 5/6 (i.e., 0.833) in the vertical plane (this is in contrast to the single focal length-to-diameter ratio of 0.6036 of the reflector 10 in Figs. 1 and 2).

These different focal length-to-diameter ratios in the horizontal and vertical planes of the reflector 50 produce horizontal and vertical plane radiation patterns which are narrower and broader, respectively, than the horizontal and vertical plane radiation patterns associated with the circular-paraboloidal reflector 10; yet the reflector 50 has approximately the same gain as the reflector 10. Specifically, the ratio between the 10-foot diameter of the circular paraboloid and the 15-foot horizontal dimension of the noncircular paraboloid is inversely proportional to the ratio between the 3 decibel (db) beam width of the horizontal plane of the circular paraboloid and the 3db beam width of the horizontal plane radiation pattern of the noncircular paraboloid; correspondingly, the ratio between the 10-foot diameter of the circular paraboloid and the 6-foot vertical dimension of the noncircular paraboloid is inversely proportional to the ratio between the 3db of the beam width radiation pattern vertical plane of the circular paraboloid and the 3db of the beam width vertical plane of the non-circular paraboloid. In order to replace the circular paraboloidal reflector 10 in the planar-parabolic reflector antenna according to the invention with a noncircular-paraboloidal reflector 50 having the same gain, the surface areas of the two reflectors should be approximately equal. Accordingly, by selecting a horizontal dimension of 15 feet and a vertical dimension of 6 feet for the noncircular-paraboloidal reflector 50, the antenna maintains about the same gain as that of a 10-foot diameter circular-paraboloidal reflector.

Although the mountings and support structures are the same for both the noncircular-paraboloidal antenna and the circular-paraboloidal antenna, they must be re-sized to conform to the shape of the noncircular-paraboloidal reflector. In particular, the X-axis dimensions of the mounting and support structures in Fig. 12 must be longer than the analogous dimensions in Fig. 1 to accommodate the lengthening of the paraboloidal reflector along the X-axis from 10 feet to 15 feet and the associated increase in the subtended angle ψ_D; the Y-axis dimensions of the mounting and support structures in Fig. 13 must be shorter than the analogous dimensions in Fig. 2 to accommodate the shortening of the paraboloidal reflector along the Y-axis from 10 feet to 6 feet.

Since the mounting and support structure for both embodiments of the planar-parabolic reflector antenna according to the invention are virtually the same, the numerical identifiers used in connection with Figs. 1 and 2 are repeated in Figs. 12 and 13. Also, since the mounting and support structure is completely described in connection with the description of the embodiment of the invention in Figs. 1 and 2, the description will not be repeated here in connection with the alternative embodiment of the invention in Figs. 12 and 13. But it should be noted that the opening 16 in the cylindrical housing 15 in Fig. 12 is changed in shape from the opening 16 in Fig. 1. It will be appreciated that this change in shape of the opening 16 results from the change in shape of the paraboloidal reflector from a circular paraboloidal to a noncircular paraboloid. The feed horn 11 of Fig. 3 utilised in connection with the noncircular-paraboloidal reflector 50 is of the same dimensions as that utilised in connection with a 10-foot circular-paraboloidal reflector.

The generally oval shape of the noncircular-paraboloidal reflector 50 in Fig. 14 is illustrative only. It will be appreciated that the noncircular-paraboloidal reflector 50 may have non-circular shapes other than that of Fig. 14. For example, the paraboloidal reflector may have an elliptical shape with its major axis being about 15 feet in length and its minor axis being about 6 feet in length. Although the planar-parabolic reflector antenna according to the invention in Figs. 12 and 13 utilises the feed horn 11 in Fig. 3, other feed horns may also be used. A flared corrugated feed horn is one example. Because of the non-circular shape of the paraboloidal reflector 50, feed horns having non-circular apertures may be desirable (e.g., an elliptical or rectangular aperture) to improve gain.

From the foregoing, it can be seen that a planar-parabolic reflector antenna with its feed horn recessed into the planar reflector minimises the degradation of the performance of an axisymmetrical antenna caused by the feed horn's aperture-blocking effect. By utilising a feed horn with substantially reduced edge currents, the recessed feed horn does not generate significant ground currents in the planar reflector. By utilising a feed horn as shown in

Fig. 3, the aperture opening for the feed horn in planar reflector 13 is small, thereby allowing a further reduction of aperture blocking. Also, because of the antenna's geometry, the feed horn's contribution to the horizontal plane radiation of the antenna is the radiation 90^{o} off the feed horn's axis. Therefore its contribution is quite low. Accordingly, an inexpensive axisymmetrical antenna is realised which has superior radiation patterns and a low wind-loading factor.

CLAIMS

1. A planar-parabolic reflector microwave antenna of an axisymmetrical type comprising:

a paraboloidal reflector dish (10) having a focal point F;

a feed horn (11) located with the centre of its aperture proximal to the focal point F of said dish (10) and for receiving and transmitting radiation along a beam path;

a planar reflector (13) positioned along the axis of said dish (10) and at an angle thereto so as to redirect radiation to and from said dish (10), characterised in that

said planar reflector (13) is positioned along the axis of said dish (10) such that said feed horn (11) is recessed into said planar reflector (13) so as to reduce the aperture-blocking effect caused by said feed horn (11); and

said feed horn (11) has a vanishing electric field at the feed horn aperture in a selected frequency band such that the radiation pattern envelope of the antenna in said selected frequency band is substantially unaffected by the ground plane created by the planar reflector (13).

2. An antenna as claimed in claim 1, characterised in that the phase centre of said feed horn aperture is approximately located at a distance above the surface of the planar reflector (13), as measured along the axis of said dish (10), equal in magnitude to the radius (r) of the aperture.

3. An axisymmetrical microwave antenna comprising:

a dish (10) having a focal point F;

a planar reflector (13) positioned along the axis of said dish and at an angle thereto so as to redirect microwave radiation to and from said dish (10);

a feed horn (11) for receiving and transmitting radiation to and from said dish (10) along a beam path, and being located with the centre of its aperture proximal to the focal point F of said dish (10), characterised in that

the aperture of said feed horn (11) has its centre located above said planar reflector (13) as measured along the axis of said dish (10) at a distance approximately equal to the radius (r) of the aperture, whereby said feed horn (11) is recessed into said planar reflector (13) so as to minimize the aperture-blocking effect of the feed horn (11).

4. An antenna as claimed in claim 3, characterised in that said feed horn (11) has a vanishing electric field at its aperture edge such that edge currents at the feed horn aperture are insufficient to cause ground-plane currents in said planar reflector (13) which degrade the antenna's radiation pattern envelope.

5. An antenna as claimed in any one of claims 1-4, characterised in that said dish (10) has a circular paraboloidal-shaped surface with a focal length-to-diameter ratio of approximately 0.6.

6. An antenna as claimed in any one of claims 1-4, characterised in that said dish (10) has a noncircular paraboloidal-shaped surface with a focal length-to-diameter ratio which is greater in value in the vertical plane than in the horizontal plane.

7. An antenna as claimed in any preceding claim, characterised in that said feed horn (11) operates over at least two frequency bands and comprises,

a conical waveguide section (42) whose aperture at the large end has an inside diameter (D_1) approximately equal to one wavelength at the midband frequency of the lower frequency band so as to produce substantially equal patterns in the E and H-planes in said lower frequency band,

the slope (β) of the inside walls of said conical waveguide section (42) being such as to cancel the electric field at the edge of the horn aperture in the higher frequency band, thereby producing substantially equal patterns in the E and H-planes in said higher-frequency band.

8. An antenna as claimed in claim 7, characterised in that the small end of said conical waveguide section (42) has a diameter (D_2) small enough to prevent propagation of the TM_{11} mode of microwave signals therethrough.

9. An antenna as claimed in claim 7 or claim 8, characterised in that a straight waveguide section (40) of uniform inside diameter (D_1) is connected to the large end of said conical waveguide section (42), the length (L) of said straight waveguide section (40) being selected to produce in-phase TE_{11} and TM_{11} modes of microwave signals in said upper frequency band at the open end of said straight waveguide section (40).

10. An antenna as claimed in any one of claims 7-9, characterised in that the diameter (D_1) at the large end of said conical waveguide section (42) is large enough to allow propagation of the TM_{11} mode of microwave signals in said upper frequency band, and small enough to prevent propagation of the TE_{12} mode of such signals.

11. An antenna as claimed in claim 7, characterised in that the inside diameter (D_1) at the large end of said conical waveguide section (42) yields a value of $C = \frac{\pi D1}{\lambda_H}$ within the range of from about 3.83 to about 5.33 at said higher frequency band, so that the only excited higher order mode that can propagate in said higher frequency band through the large end of said conical waveguide section (42) is the TM_{11} mode.

12. An antenna as claimed in any one of claims 7-11, characterised in that the ratio of the wavelength at the midband frequency of said lower frequency band to the wavelength at the midband frequency of said higher frequency band is within the range of from about 1.22 to about 1.61.

13. An antenna as claimed in any one of claims 7-12, characterised in that said conical waveguide section (42) has a uniform slope β (in degrees) defined by the equation

$$\beta = 44.56 \frac{\lambda_H}{\lambda_L}$$

where λ_H is the wavelength at the midband frequency of said higher frequency band, and λ_L is the wavelength at the mid-band frequency of said lower frequency band.

14. An antenna as claimed in any one of claims 1-6, characterised in that said feed horn (11) is a corrugated feed horn.

15. An antenna as claimed in any preceding claim, characterised in that said dish (10) is approximately a 45^{o} paraboloidal dish having a focal length-to-dish diameter ratio of approximately 0.6 so as to allow said feed horn (11) to be recessed into said planar reflector (13) while maintaining full illumination of said paraboloidal dish (10).

16. An antenna as claimed in claim 6, characterised in that said dish reflector has focal length-to-diameter ratios of approximately 0.833 and 0.333 in the vertical plane and horizontal plane, respectively.

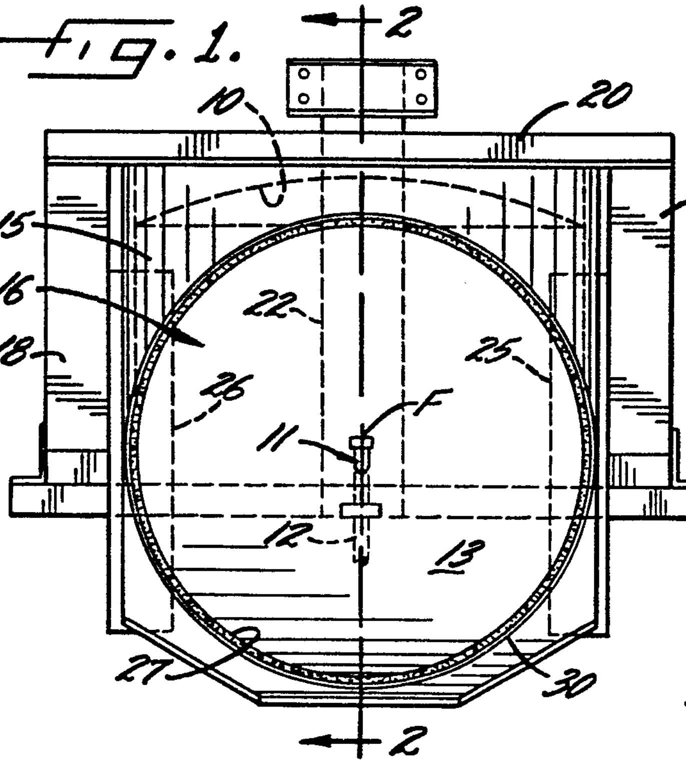


Fig. 1.

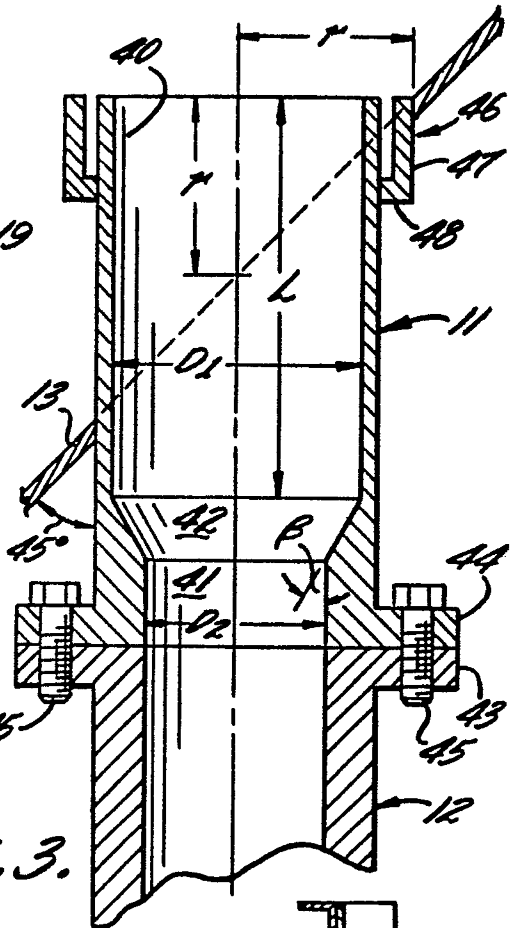


Fig. 3.

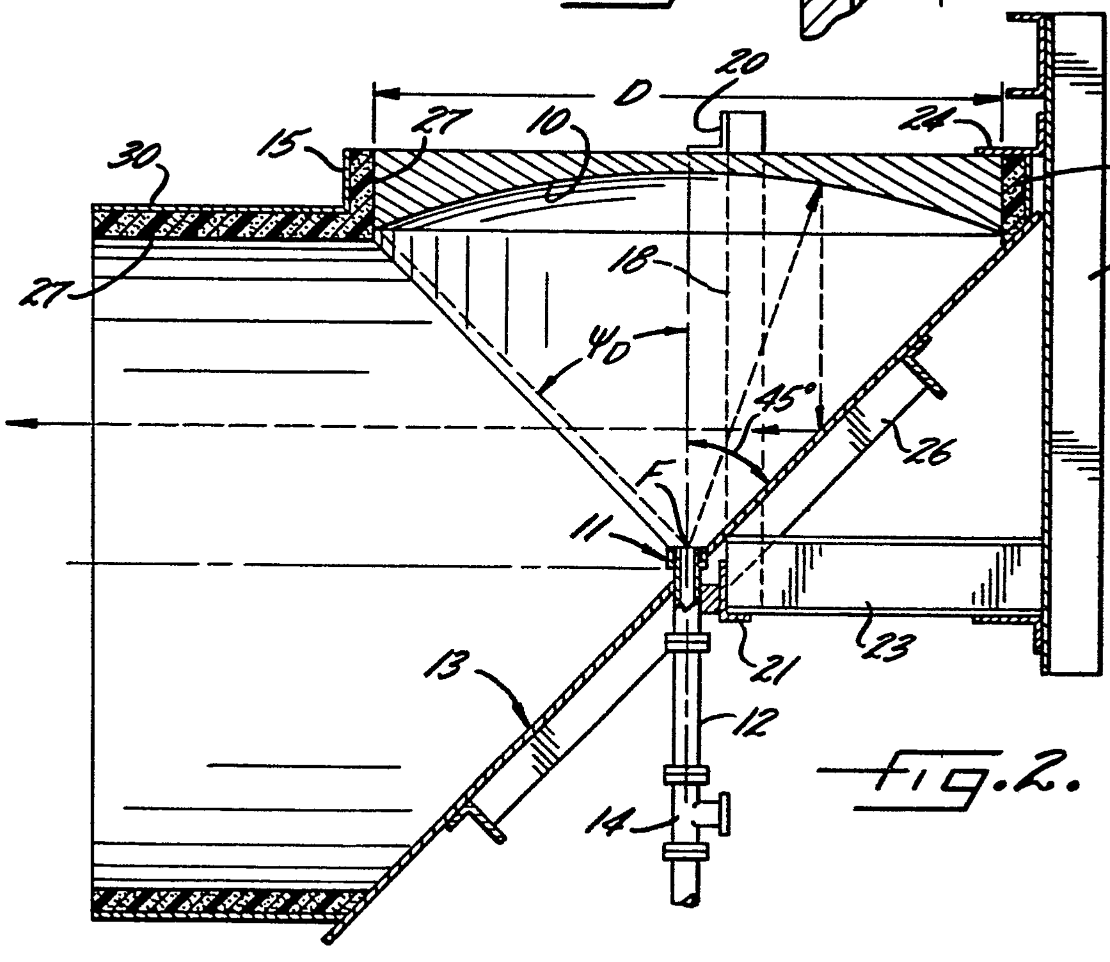
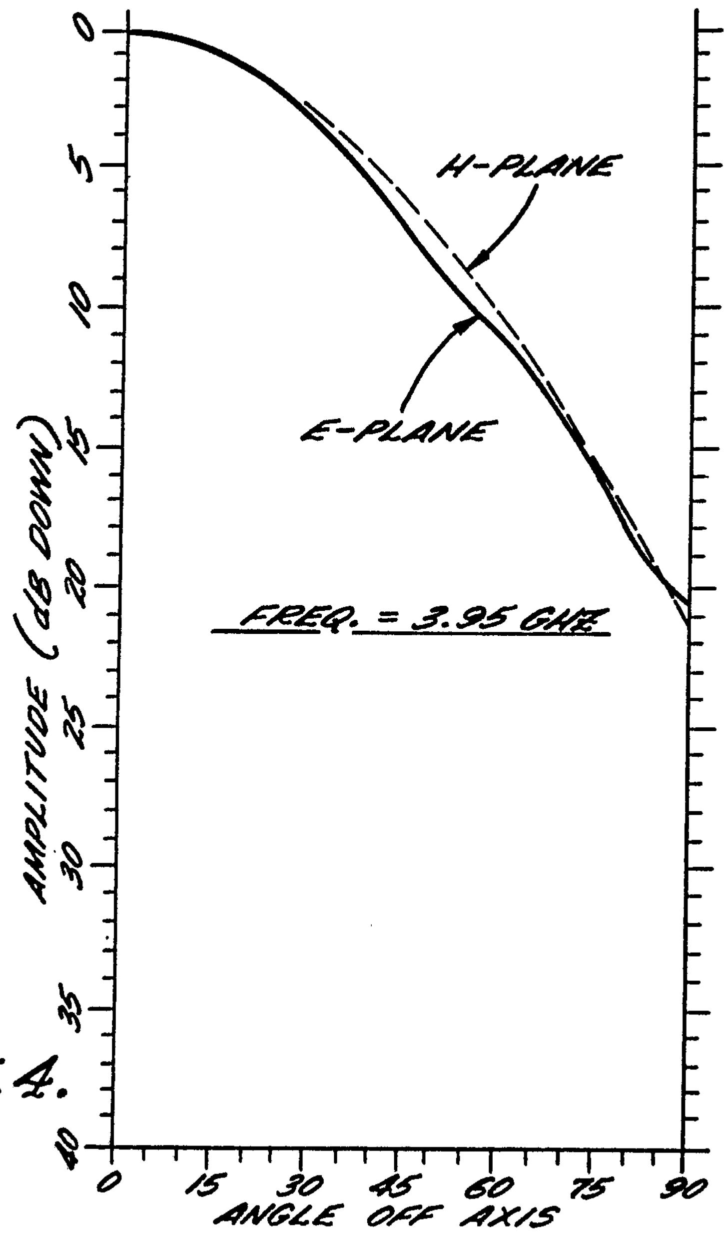


Fig. 2.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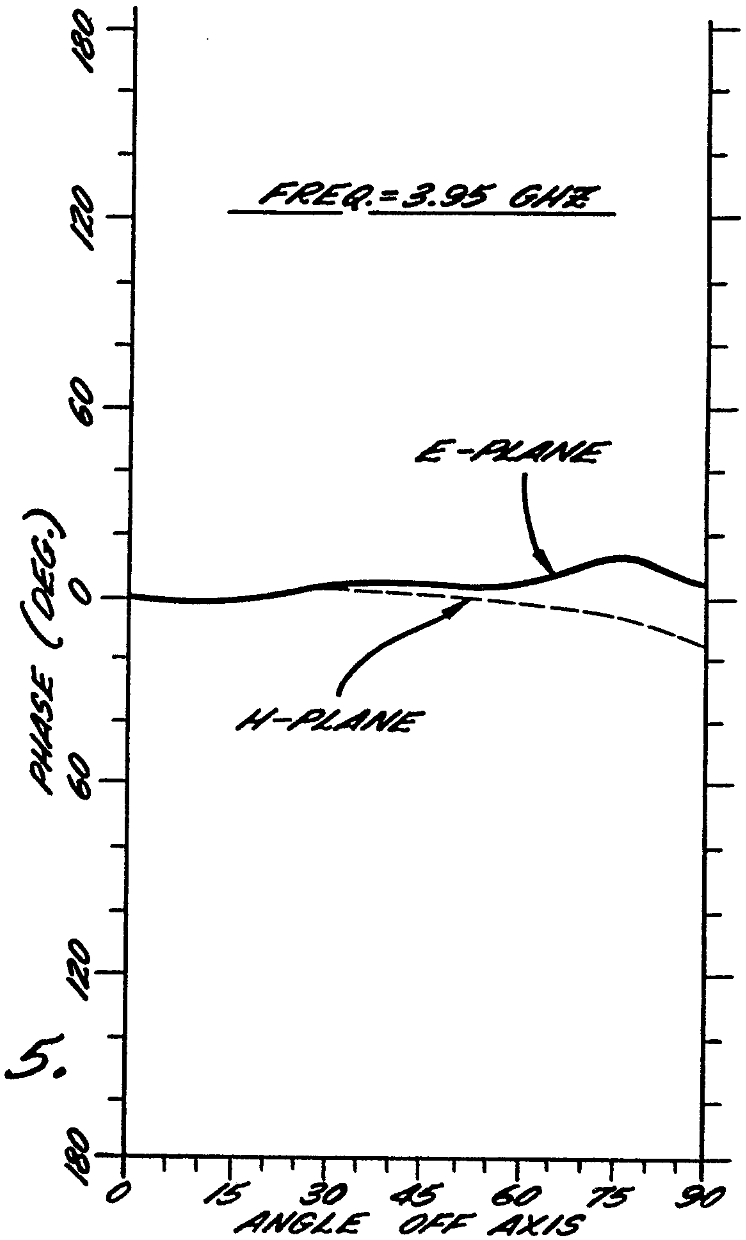
0
5
10
15
20
25
30
35
40
H-PLANE
E-PLANE
FREQ. = 3.95 GHZ
0
15
30
45
60
75
90
ANGLE OFF AXIS

FIG. 4.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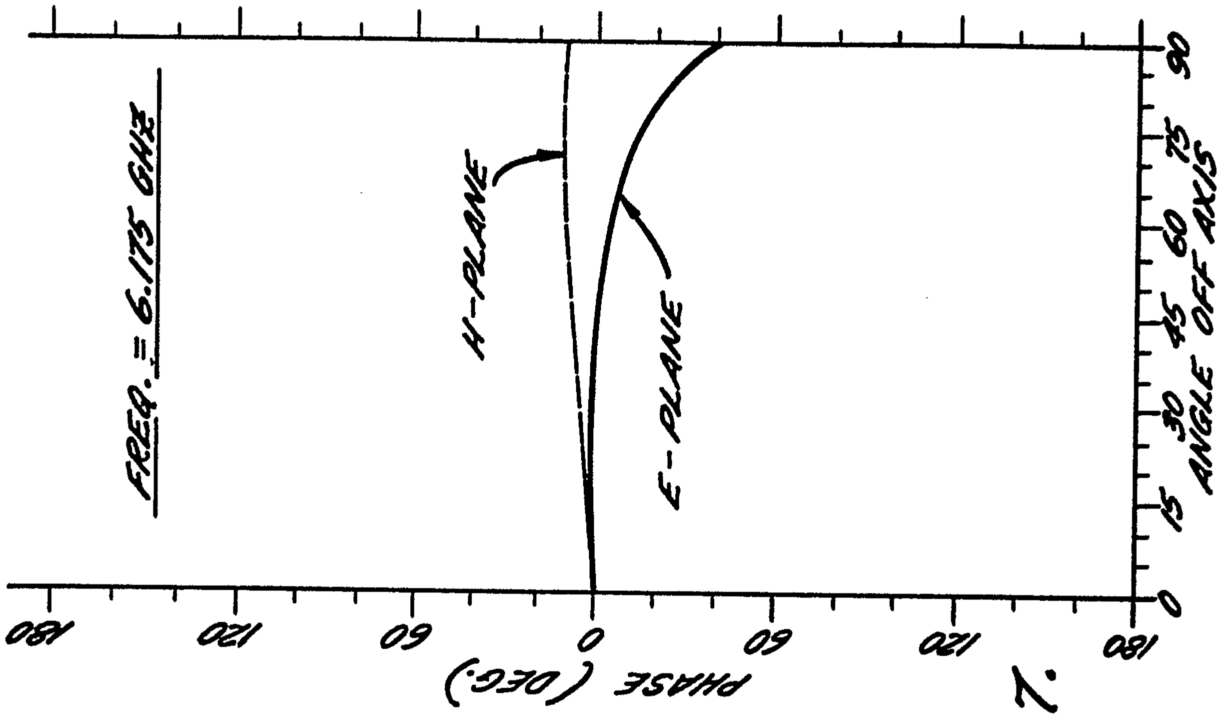
120
60
0
60
120
180
FREQ.=3.95 GHZ
E-PLANE
H-PLANE
0
15
30
45
60
75
90
ANGLE OFF AXIS

FIG. 5.


FREQ. = 6.175 GHZ
H-PLANE
E-PLANE
PHASE (DEG.)
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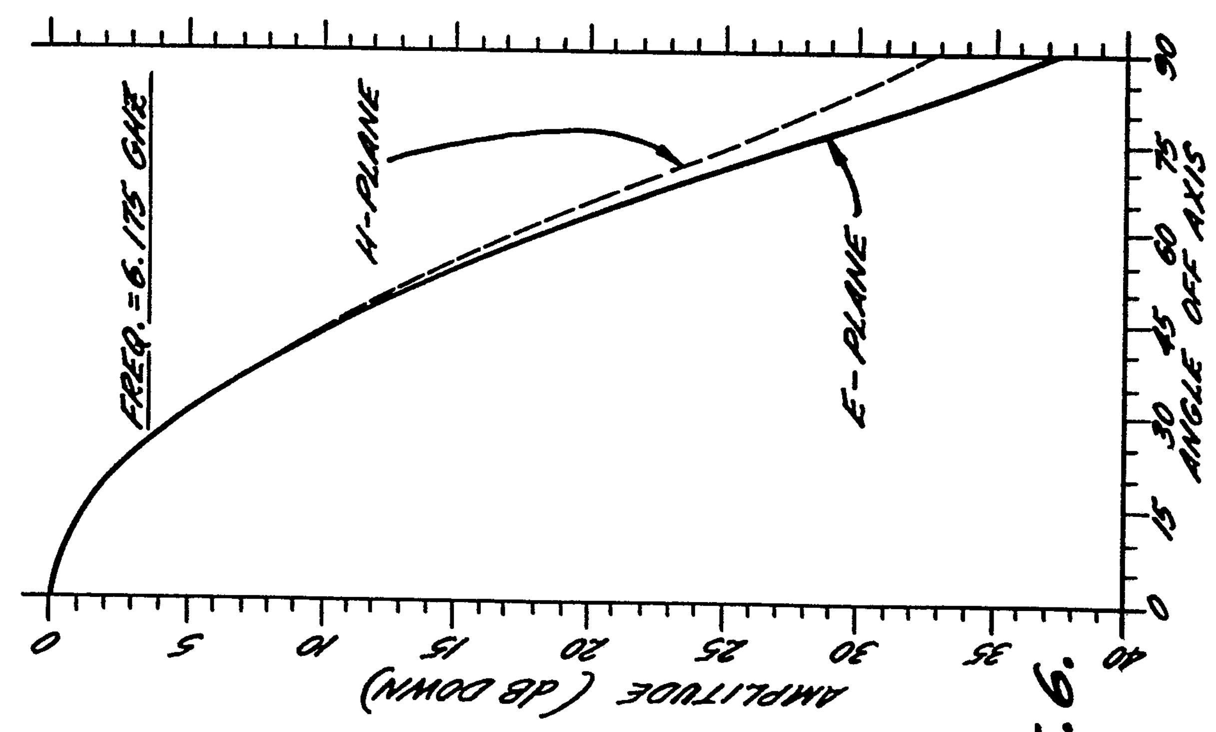
0
60
120
180
ANGLE OFF AXIS
0
15
30
45
60
75
90

FIG. 7.


FREQ. = 6.175 GHZ
H-PLANE
E-PLANE
AMPLITUDE (dB DOWN)
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10
15
20
25
30
35
40
ANGLE OFF AXIS
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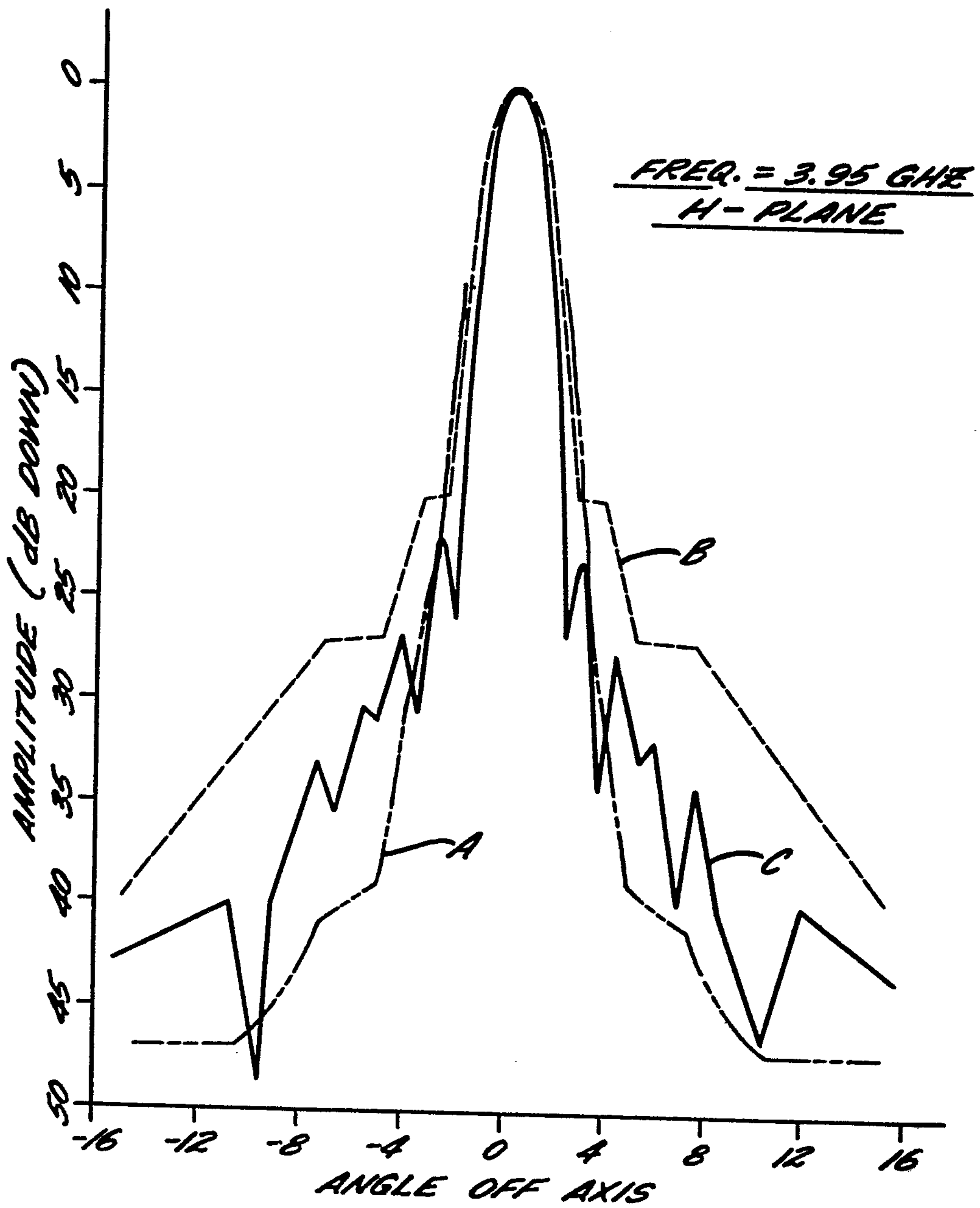
15
30
45
60
75
90

FIG. 6.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H-PLANE
AMPLITUDE (dB DOWN)
0
5
10
15
20
25
30
35
40
45
50
-16
-12
-8
-4
0
4
8
12
16
ANGLE OFF AXIS
A
B
C

Fig. 8.

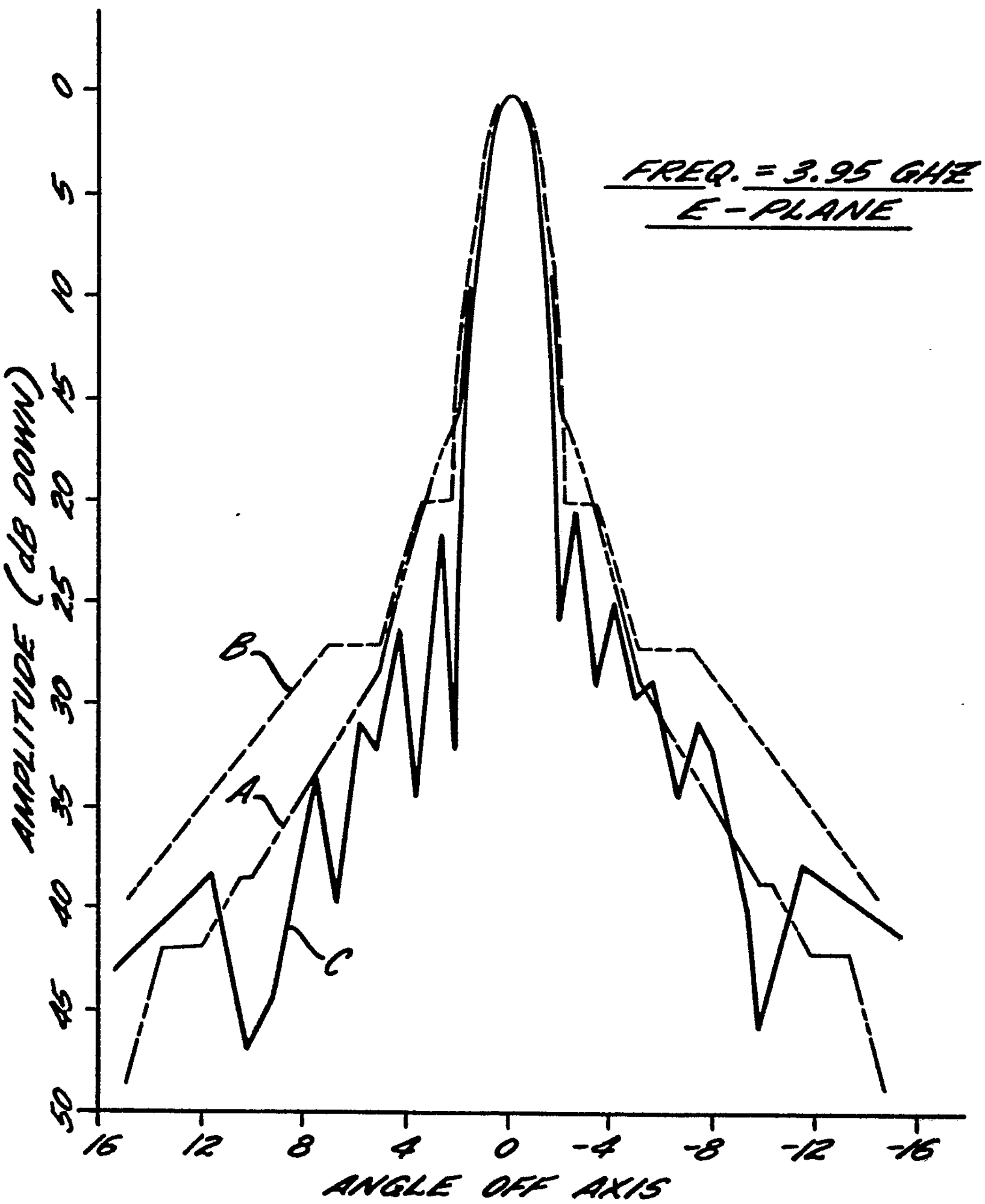
FREQ. = 3.95 GHZ
E-PLANE
AMPLITUDE (dB DOWN)
0
5
10
15
20
25
30
35
40
45
50
B
A
C
16
12
8
4
0
-4
-8
-12
-16
ANGLE OFF AXIS

Fig. 9.

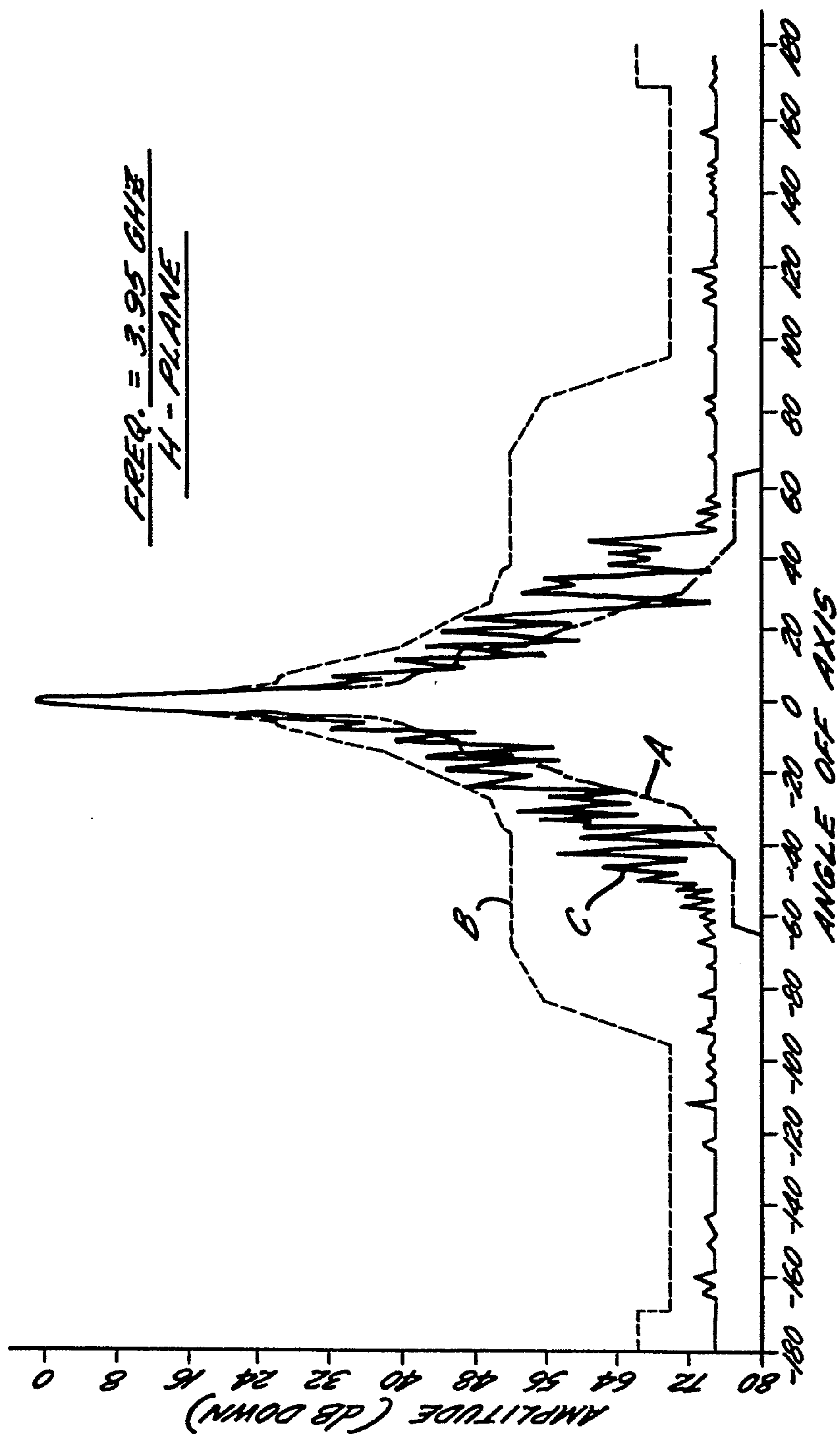
FREQ. = 3.95 GHZ
H - PLANE
A
B
C
AMPLITUDE (dB DOWN)
0 8 16 24 32 40 48 56 64 72 80
ANGLE OFF AXIS
-180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180

FIG. 10.

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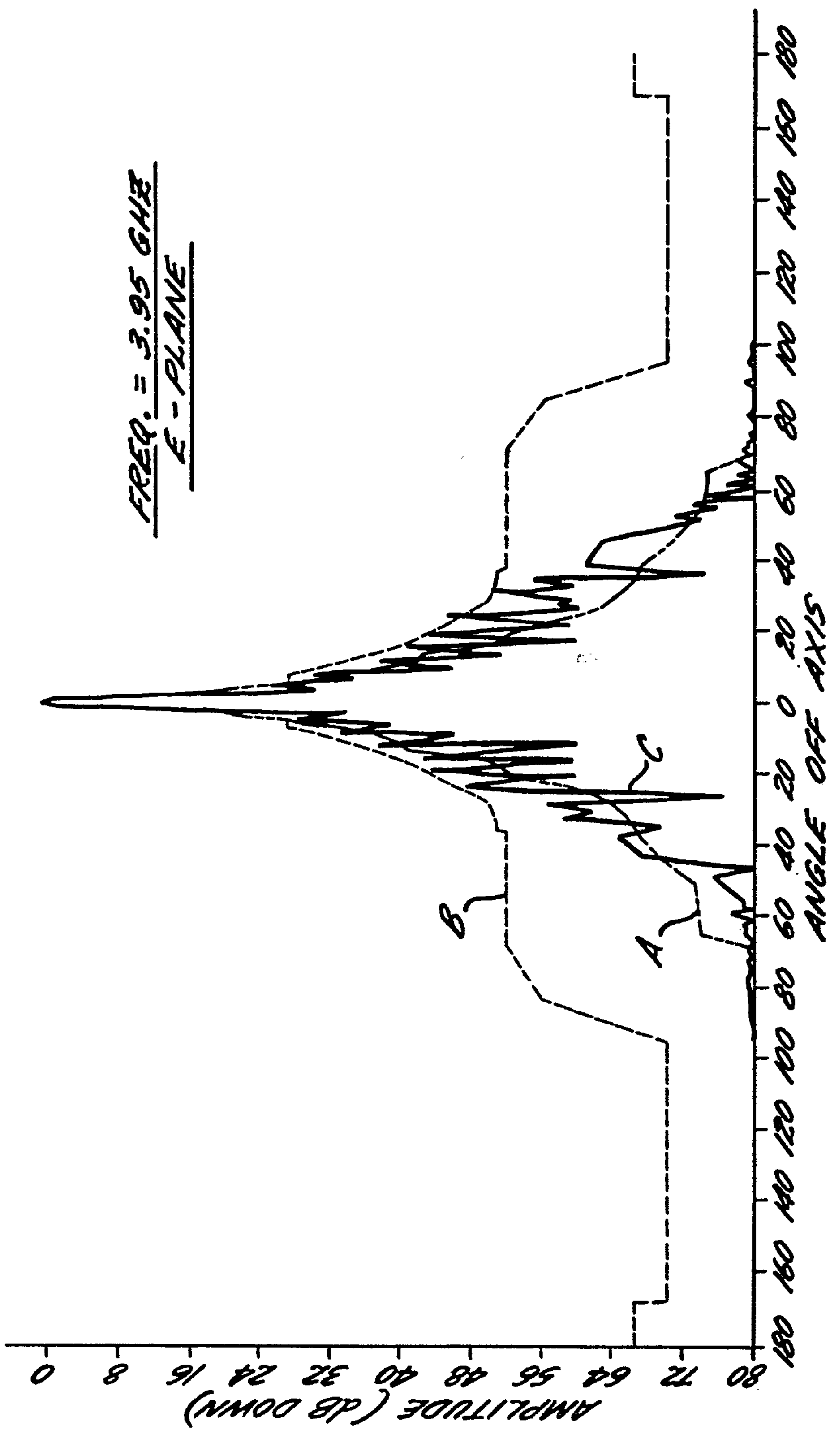

FIG. 11.

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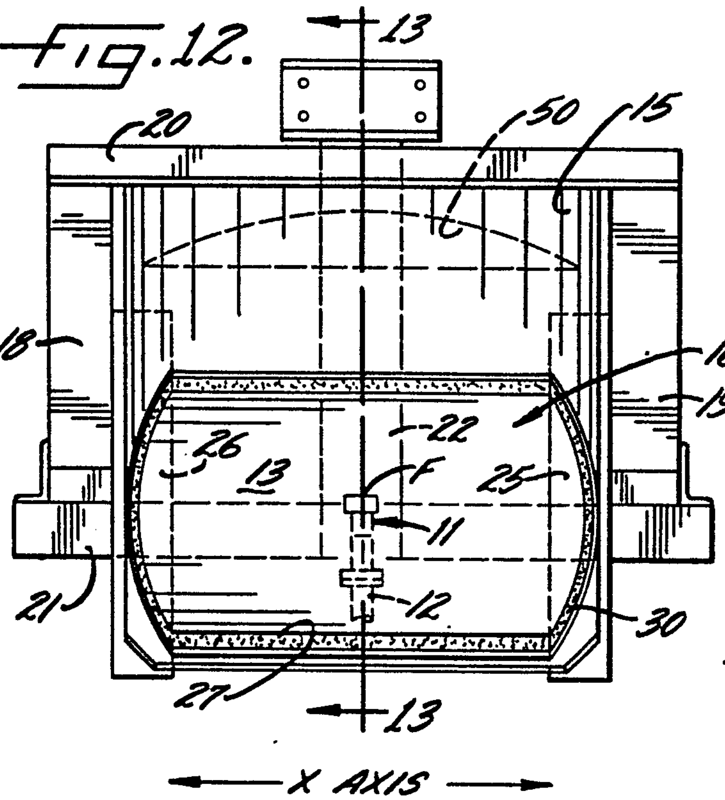

Fig. 12.

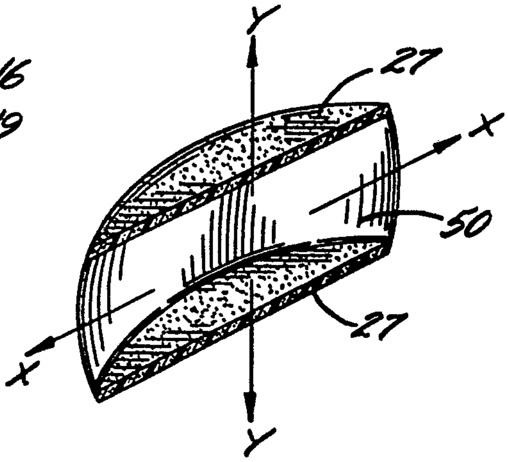

Fig. 14.

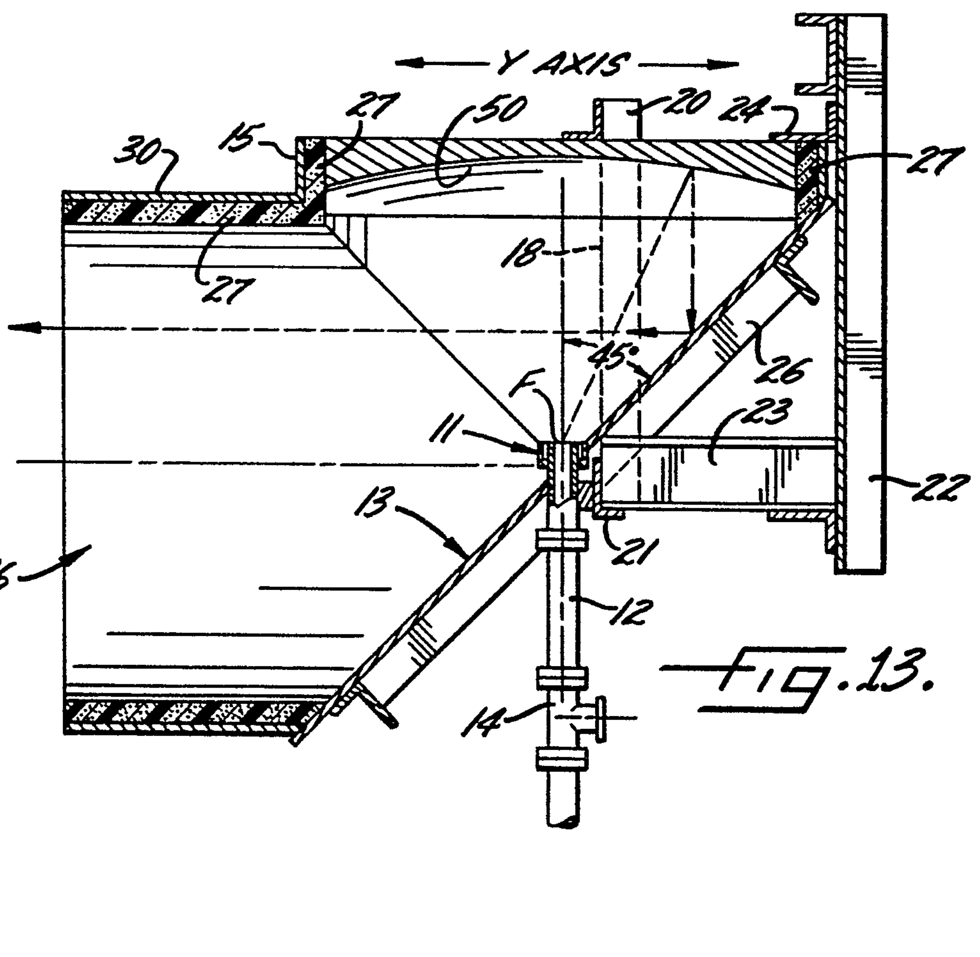

Fig. 13.

European Patent Office

EUROPEAN SEARCH REPORT

0155761

Application number

EP 85 30 0961

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
Y	US-A-3 763 493 (SADAKUNI SHIMADA et al.) * Figure 8; column 6, lines 22-42 *	1	H 01 Q 19/18

Y	FR-A-2 531 276 (AGENCE SPATIALE EUROPEENNE) * Figure 1, abstract *	1	

A	GB-A-2 056 181 (SIEMENS) * Figure 1, abstract *	7,14	

A	IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-28, no. 3, March 1980, New York, USA;M.A. STUCHLY et al. "Diathermy Applicators with Circular Aperture and Corrugated Flange", pages 267-271 * Page 268; figure 1; column 1, line 4 *	7	TECHNICAL FIELDS SEARCHED (Int. Cl.4) H 01 Q 19/18 H 01 Q 19/10 H 01 Q 19/19

A	GB-A-1 099 429 (MINISTER OF TECHNOLOLGY) * Figure 1; page 2, lines 4-20 *		

A	GB-A-1 603 657 (MARCONI) * Figure 1 *		
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	10-05-1985	BREUSING J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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Application number

EP 85 30 0961

Page 2

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
A	US-A-3 633 209 (M.S. AFIFI) * Figure 5 * -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	10-05-1985	BREUSING J

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