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DUAL FREQUENCY MICROWAVE APERTURE-TYPE ANTENNA PROVIDING  
SIMILAR RADIATION PATTERN ON BOTH FREQUENCIES

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3 Sheets-Sheet 1

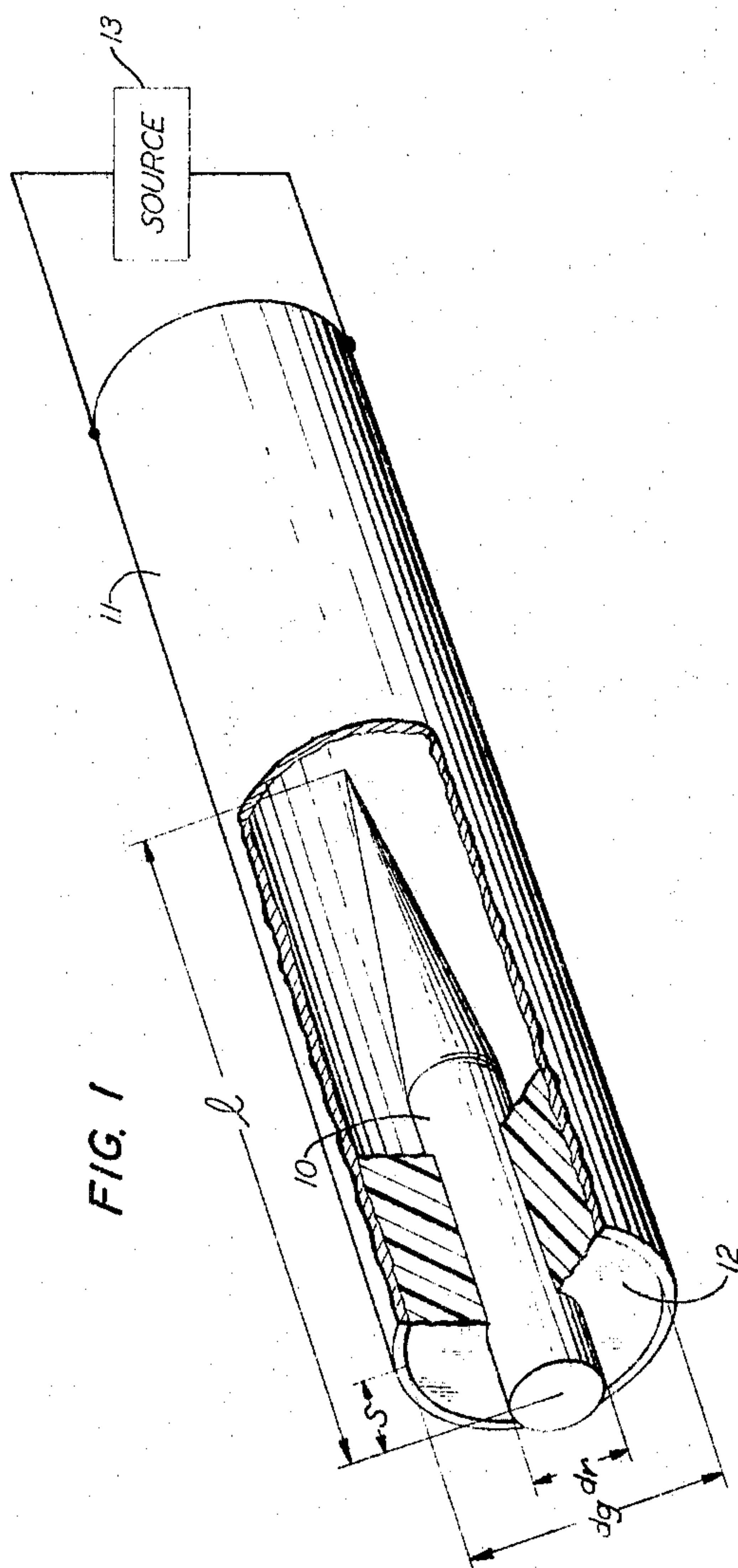


FIG. 2C

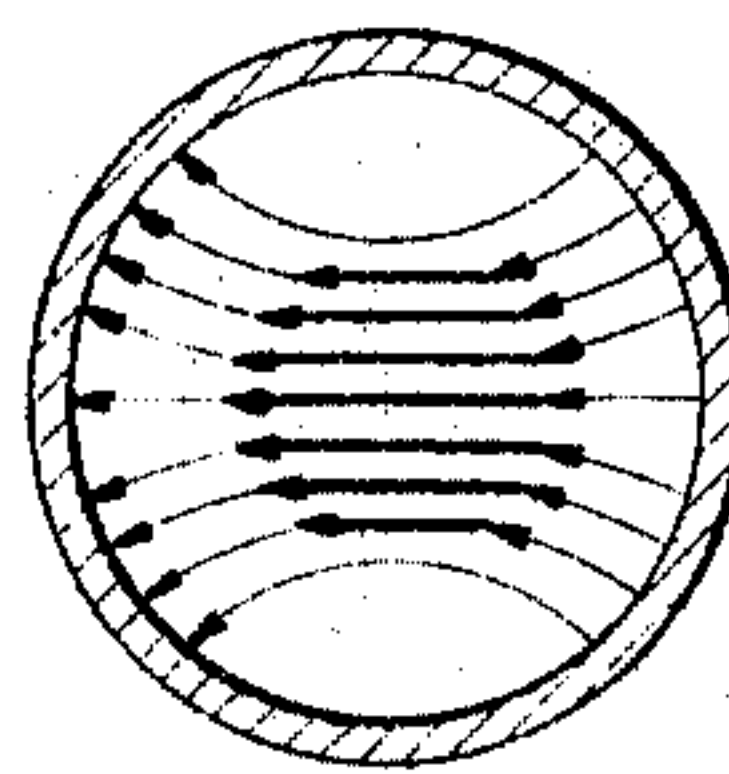


FIG. 2B

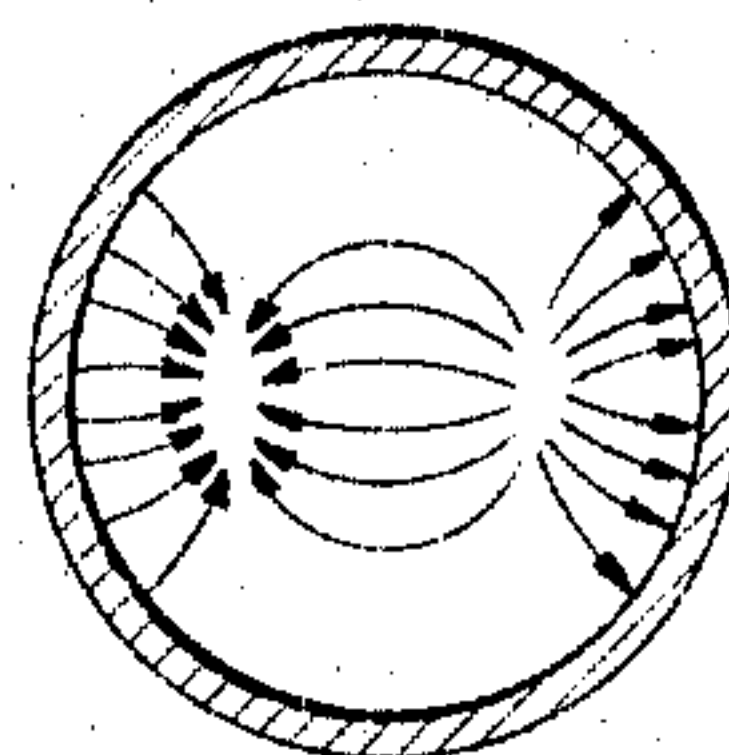
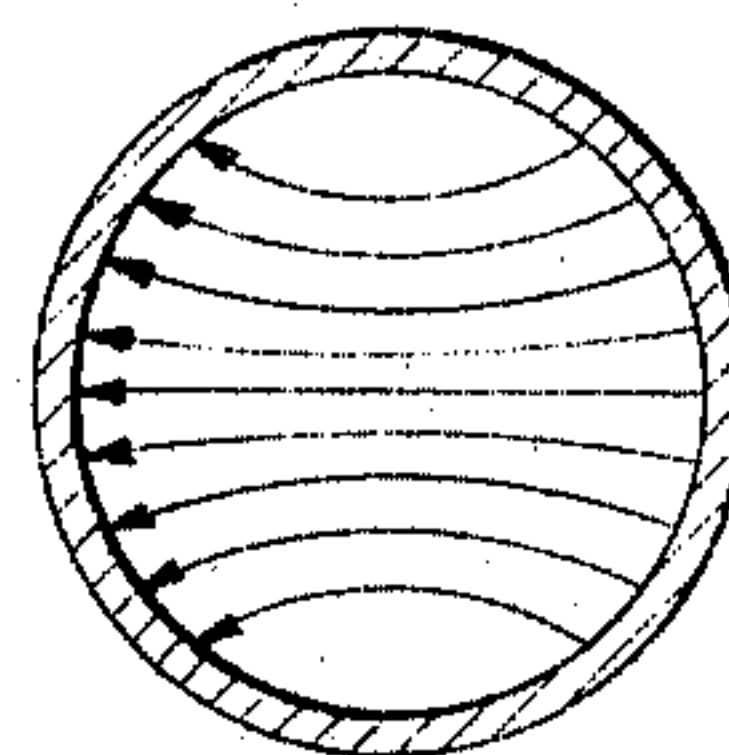


FIG. 2A



COMBINED TE<sub>11</sub> AND TM<sub>11</sub> MODES  
SHOWING CONCENTRATION OF ELECTRIC  
FIELD TOWARDS CENTER OF WAVEGUIDE

TM<sub>11</sub>

TE<sub>11</sub>

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FIG. 3

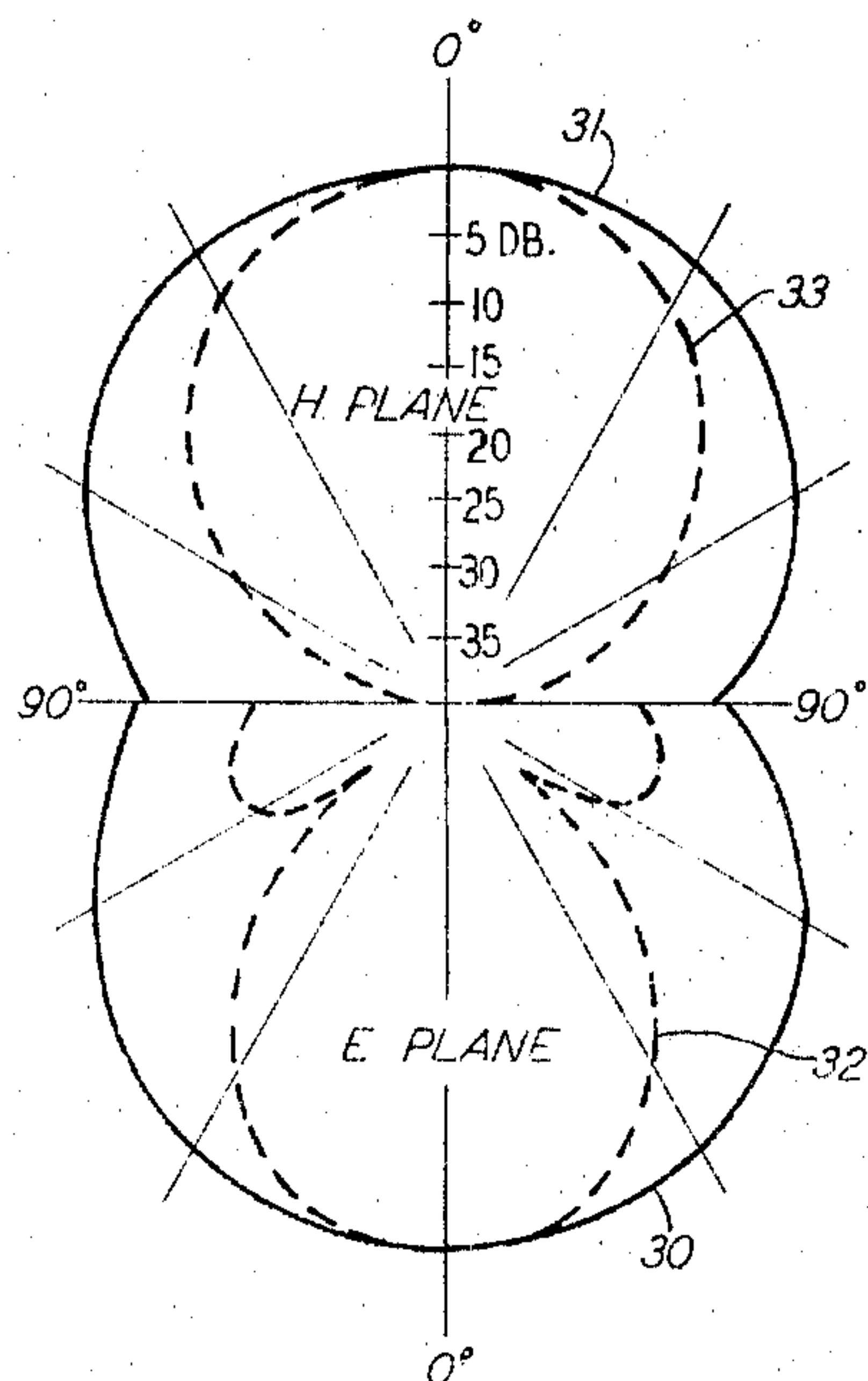


FIG. 4

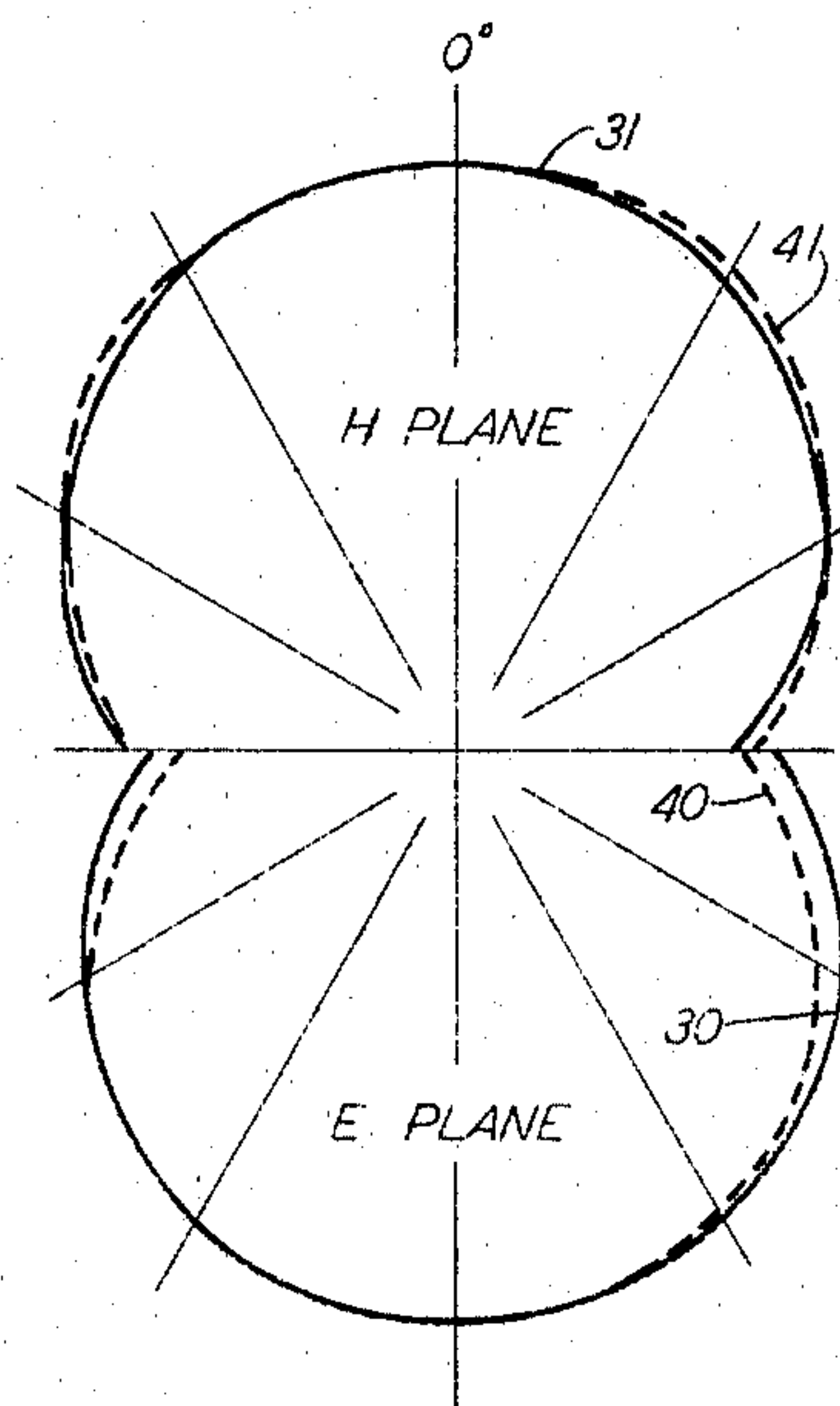


FIG. 5

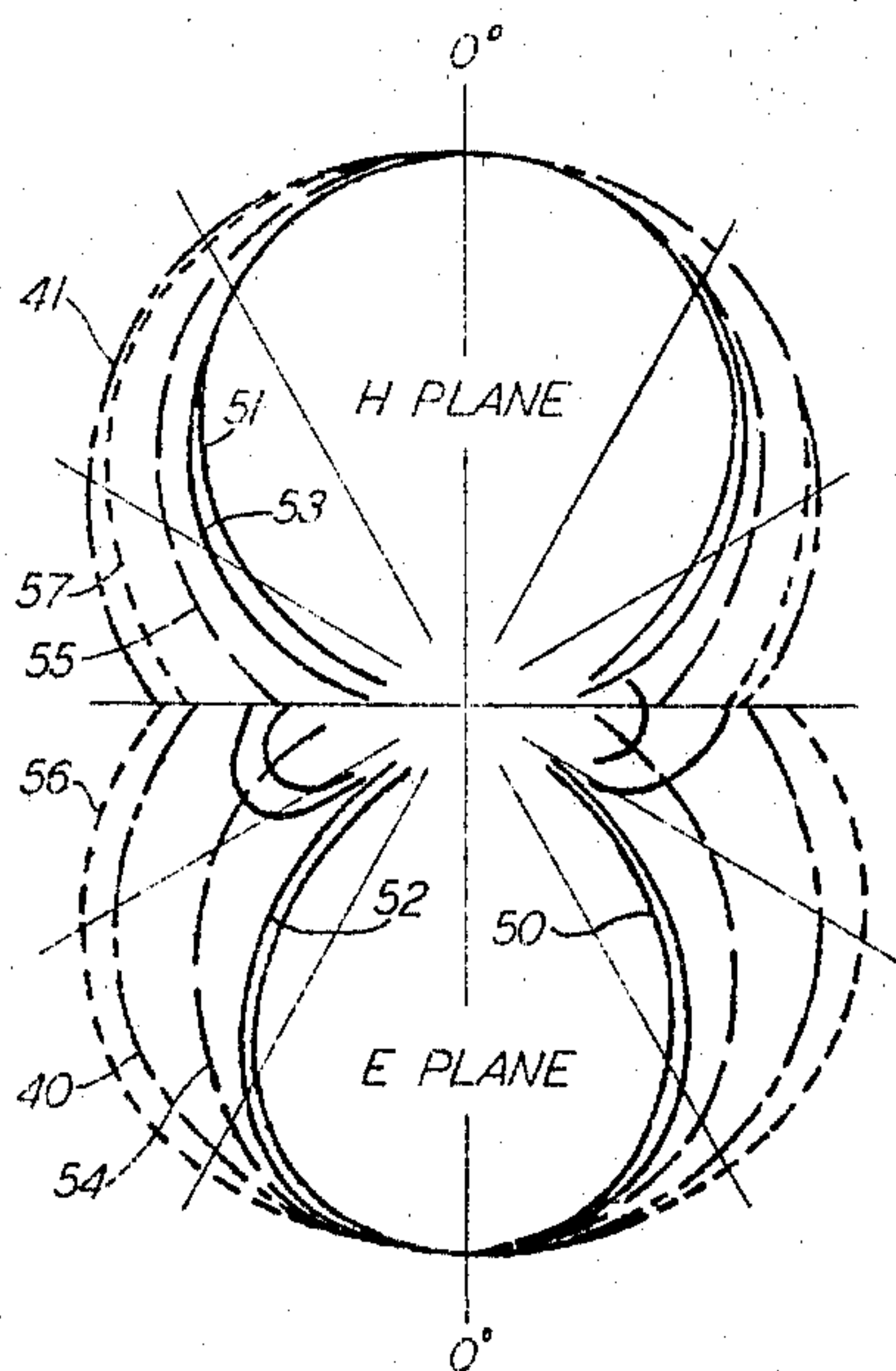
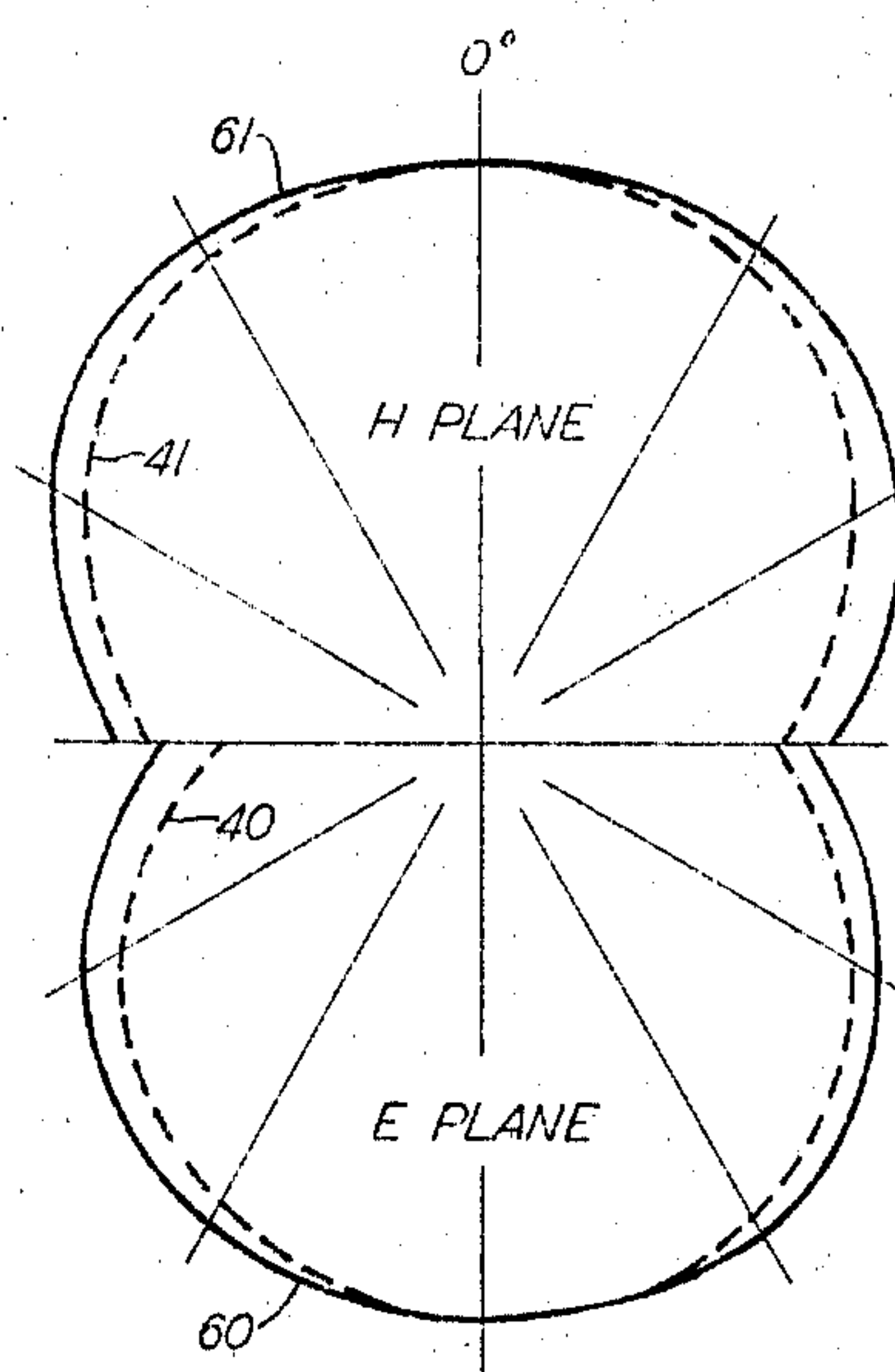


FIG. 6





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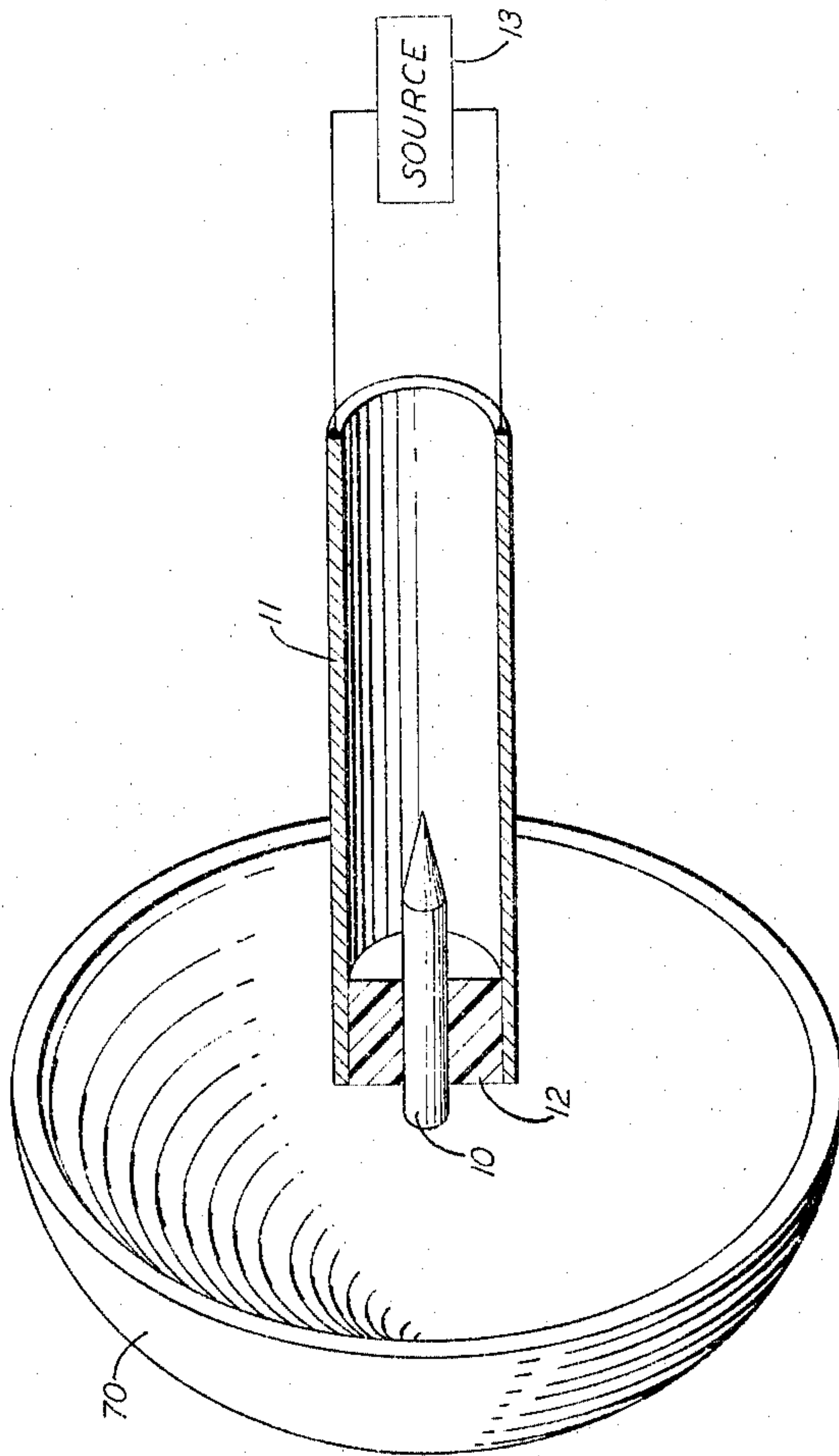
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FIG. 7





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## DUAL FREQUENCY MICROWAVE APERTURE-TYPE ANTENNA PROVIDING SIMILAR RADIATION PATTERN ON BOTH FREQUENCIES

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This invention relates to microwave antennas and more particularly to dual frequency microwave antennas of the small aperture type.

Frequently in the field of microwave communication it is desirable to utilize a single antenna structure for radiating and directing two signals occupying separate and distinct frequency bands. For example, in cross-country microwave systems which utilize many repeater stages at spaced intervals along the transmission path, one frequency may be utilized for signals transmitted in one direction and another for receiving signals transmitted in the reverse direction. In addition, it is also desirable to transmit the signals at both frequencies with orthogonal polarized fields. By so doing, it is possible to achieve a two-fold increase in information transmission by utilizing the well known null property of cross-polarized plane wave fields. In such systems it is understandable that if a single antenna can be utilized for both frequencies and for both planes of polarization, substantial economic savings can be enjoyed.

It is therefore a general object of the present invention to provide a dual frequency microwave antenna.

A fundamental problem encountered by one attempting to utilize a single small-aperture antenna for radiating directly or for illuminating a large reflector at two separated frequencies is the difference in the radiation pattern of the antenna at the two frequencies. In general, the beamwidth of the radiation pattern of an aperture-type antenna is inversely related to frequency. Thus, for a small-aperture antenna such as an open-ended waveguide, the radiation pattern becomes narrower as the frequency of the radiated energy becomes higher. This difference in radiation pattern at the two frequencies is undesirable.

It is, therefore, a further object of the present invention to provide a dual frequency microwave antenna having substantially the same radiation pattern over two separated frequency ranges.

It is yet another object of the present invention to provide a primary feed for a large aperture-type antenna capable of illuminating the large aperture to the same extent over two separated frequency ranges.

The above objects are accomplished in accordance with the present invention by decreasing the effective area of a radiating aperture at the higher of two frequencies while retaining the effective aperture size at the lower frequency. In general, this can be accomplished by concentrating the wave energy at the higher frequency in the center region of the aperture. In a preferred embodiment this is done by loading the aperture with a coaxially located rod of dielectric material. The position and dimensions of the dielectric rod determine the shape of the high frequency radiation pattern.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a pictorial view, partially broken away, of one embodiment of the present invention;

FIG. 2A is a cross-sectional view of a circular waveguide showing the electric field lines in the  $TE_{11}$  wave mode;

FIG. 2B is a cross-sectional view of a circular wave-

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guide showing the electric field lines in the  $TM_{11}$  wave mode;

FIG. 2C is a cross-sectional view of a circular waveguide showing the combined  $TE_{11}$  and  $TM_{11}$  electric field lines;

FIG. 3 is a graphical representation of the radiation pattern of an unloaded circular waveguide aperture at two frequencies;

FIG. 4 is a graphical representation of the radiation pattern of the embodiment of FIG. 1 at the same two frequencies;

FIG. 5 shows, in graph, the effect of a change in the diameter of rod 10 of FIG. 1 on the radiation pattern;

FIG. 6 shows, in graph, the effect of the position of rod 10 of FIG. 1 on the radiation pattern; and

FIG. 7 is a pictorial view, partially broken away, of the embodiment of FIG. 1 utilized as a primary feed in a parabolic reflector-type antenna.

Referring more particularly to the drawings, FIG. 1 is a partially broken away pictorial view of a preferred embodiment of the present invention. A cylindrical dielectric rod 10 having a diameter  $d_r$  and length  $l$  is coaxially located within a hollow, conductively bounded section of cylindrical waveguide 11 having an inside diameter  $d_g$ . In general, the dielectric constant of rod 10 is significantly greater than that of the medium filling guide 11. For example, if the medium filling guide 11 is air which has a dielectric constant near unity, rod 10 is preferably formed of a material having a dielectric constant of two or greater. Rod 10 is held in position by an annular member 12 of polyfoam, or other low-loss dielectric material having a dielectric constant substantially equal to that of the medium filling the remainder of guide 11—in the exemplary case, unity. Rod 10 is tapered at the end thereof extending within guide 11. The other end of rod 10 is blunt and extends a distance  $s$  out of the end of guide 11. As will be discussed in greater detail hereinbelow the distance  $s$  is generally quite small with respect to the overall length  $l$ .

When used as a transmitting antenna or as a primary feed for a reflector-type antenna, electromagnetic wave energy from a source or transmitting device 13, shown in simplified block diagram form, is fed into the end of guide 11 most distant from rod 10 in the  $TE_{11}$  wave mode. This energy can be applied through a coaxial line-to-waveguide transducer, through a waveguide transformer section or through another length of circular waveguide, depending upon the nature of the transmission means connecting guide 11 to the source. On the other hand, if the device is being used as a receiving antenna, it is obvious that the received energy can be extracted from the end of guide 11 for delivery to the input of the receiver by the same transmission means.

At this point it may be helpful, in understanding the operation of the invention, to consider the radiation characteristics of an unloaded, open-ended, circular waveguide (i.e., a guide with no dielectric rod). When such a guide acts as a radiator for wave energy propagating therethrough in the dominant  $TE_{11}$  wave mode, the radiation patterns are as shown in FIG. 3. When the frequency of the radiated energy is slightly above the cutoff frequency of the guide for the  $TE_{11}$  wave mode, the resulting radiation pattern is that shown by curves 30 and 31 in the electric and magnetic planes, respectively. As the frequency of the radiated wave energy is increased, the radiation pattern becomes narrower, as indicated by broken line curves 32 and 33 of FIG. 3.

With the above facts in mind, the question arises, how to obtain a radiation pattern at the higher frequency which has substantially the same shape and beamwidth as the radiation pattern at the lower frequency. Obviously, this can be accomplished by physically scaling down the



size of the waveguide aperture when utilized at the higher frequency so that its diameter is proportionately smaller for this shorter wavelength. In most cases, however, it is impractical to physically change the aperture dimension, especially in view of the fact that such structure is generally mounted at the top of a high tower or other comparatively inaccessible point.

In accordance with the present invention, an equivalent reduction in aperture size is accomplished without physically varying the size of the waveguide aperture by mode conversion effects. In FIG. 2A there is shown a cross-sectional view of a circular waveguide such as guide 11 of FIG. 1. The arrows represent the electric field configuration in the guide for wave energy propagating in the  $TE_{11}$  wave mode. If a smaller guide were utilized, it is clear that the field configuration would have exactly the same shape, merely reduced in scale. If, however, a portion of the total wave energy is caused to propagate in the  $TM_{11}$  wave mode, the effective aperture size can be substantially decreased. FIG. 2B is a cross-sectional view of the same circular waveguide supporting wave energy in the  $TM_{11}$  wave mode. Again, the arrows represent the electric field configuration for such wave mode. If the two field patterns are combined, the resulting field configuration is somewhat as shown in FIG. 2C.

As indicated in FIG. 2C, the electric fields for the two modes will cancel to a certain extent in the regions near the guide wall but will be enhanced in the region near the center of the guide. The degree of cancellation and enhancement, of course, depends upon the relative magnitudes of the fields in each of the two modes. The result, however, is that the wave energy is, to a large extent, confined to the center of the guide, just as if the size of the aperture itself had been decreased. By adjusting the relative phase and magnitude of the wave energy in the  $TM_{11}$  wave mode, the radiation pattern of the guide can be made much broader.

Returning to the embodiment of FIG. 1, one method of inducing a partial conversion of the energy in the  $TE_{11}$  wave mode to the  $TM_{11}$  wave mode is by utilizing dielectric rod 10. As will be discussed in greater detail hereinafter, the dimensions and position of rod 10 within guide 11 determine the phase and magnitude of the  $TM_{11}$  wave energy, and consequently the shape of the radiation pattern of the embodiment. Since, for a given diameter circular waveguide, the cutoff frequency of  $TM_{11}$  wave energy is more than twice that of  $TE_{11}$  wave energy, it is a simple matter to proportion the guide diameter so that the energy in the  $TM_{11}$  wave mode is propagated only at the higher and not at the lower of the two frequencies of operation. In this manner, the low frequency radiation pattern of the device is not affected by rod 10, whereas the high frequency radiation pattern is broadened.

Although the above description is in terms of the electric fields inside a circular waveguide, it is equally applicable to the magnetic fields. That is, the magnetic fields in the  $TE_{11}$  and  $TM_{11}$  wave modes also cancel in the regions near the guide wall and add in the center region of the guide in much the same manner. This results in a broadening of the radiation pattern in the magnetic or H plane at the high frequency which can be made to correspond to the normally broad pattern at the low frequency.

Several experimental models of the embodiment of FIG. 1 were constructed and operated. These devices were designed for low frequency operation at 6.175 kilomegacycles per second, and for high frequency operation at 11.2 kilomegacycles per second. In these structures, the inside diameter  $d_g$  of guide 11 was 1.75 inches. The radiation pattern for this open-ended circular waveguide at the low frequency when radiating energy propagated in the  $TE_{11}$  wave mode is shown in the graph of FIG. 3. The solid curve 30 represents the radiation pattern measured in the electric field or E plane, whereas curve 31 represents the radiation pattern in the magnetic field

or H plane. Curves 30 and 31 represent the "unloaded" condition, that is, without a dielectric rod. In the graph of FIG. 3 as well as those of FIGS. 4, 5 and 6, the curves are shown on a normalized scale, with the maximum radiation intensity equated to zero decibels.

At the high frequency, the radiation pattern for the unloaded guide is shown by curves 32 and 33. Curve 32 represents the E-plane pattern and curve 33 represents the pattern in the H plane. As mentioned above, it is readily seen that the high frequency radiation patterns are considerably narrower than those at the lower frequency.

In order to broaden the high frequency radiation patterns while leaving the low frequency radiation pattern substantially unaffected, dielectric rod 10 was disposed within guide 11 in the manner described in connection with FIG. 1. A dielectric rod having a diameter  $d_r$  of 0.5 inch, a length  $l$  of 3 inches, and a taper of 1.3 inches was utilized. This rod was fabricated with Teflon having a dielectric constant of approximately 2.0 over the frequency range of operation. Annular spacing member 12 was fabricated of polyfoam having a dielectric constant substantially equal to 1.0. It was found that this rod, when inserted into guide 11 to a point where  $s$  equalled 0.25 inch, resulted in a radiation pattern at the high frequency substantially identical to that of the unloaded guide at the low frequency. It was further found that the presence of rod 10 in guide 11 did not significantly alter the low frequency radiation pattern.

FIG. 4 is a graphical representation of the results of the above-mentioned findings. Curves 30 and 31 again represent the low frequency radiation pattern of the device in the E and H planes, respectively. As mentioned above these curves were substantially identical regardless of whether rod 10 was in place or not in place. Curves 40 and 41 represent the high frequency pattern in the E and H planes, respectively. Curves 40 and 41, when compared with curves 32 and 33 of FIG. 3 illustrate the beam broadening effect of dielectric rod 10. It is readily seen from the similarity of curves 30 and 40 and curves 31 and 41 that by providing guide 11 with a dielectric rod load the radiation patterns can be made substantially identical for two widely separated frequencies.

It is evident that in the embodiment of FIG. 1 there are several variable parameters. First the diameter of rod 10 can be varied in order to vary the radiation pattern of the device. In general the radiation pattern at the low frequency remains substantially unchanged in the presence of a dielectric rod of any diameter. On the other hand the high frequency radiation pattern in general produces a broadening in beamwidth for increasing rod diameter. FIG. 5 shows the measured radiation patterns for the high frequency for various rod diameters. In each case the distance  $s$  was maintained at 0.25 inch. Curves 50 and 51 represent the radiation pattern for the unloaded guide. Curves 52 and 53 are the patterns utilizing a rod having a diameter of 0.25 inch. Curves 54 and 55 and curves 40 and 41 represent the radiation patterns for rods having diameters of 0.375 and 0.50 inch respectively. Curves 56 and 57 represent the pattern resulting from a 0.75 inch diameter rod.

With regard to curves 40, 41, 56 and 57, it is seen that the E-plane pattern for the 0.50 inch rod is slightly narrower than that for the 0.75 inch rod, whereas in the H plane, the 0.75 inch rod produced the narrower pattern.

As mentioned above in making the measurements reproduced in FIG. 5 the distance  $s$  which rod 10 protrudes from the end of guide 11 was maintained at 0.25 inch. This distance  $s$  is also a parameter which can be varied to change the radiation pattern of the device at its high frequency. FIG. 6 is a graphical representation of the radiation pattern of the embodiment of FIG. 1 utilizing a rod of 0.5 inch diameter. Curve 40 again represents the E-plane pattern produced with  $s$  equal to 0.25 inch.



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Curve 41 represents the H-plane pattern for the same value of  $s$ . Curves 60 and 61 represent the patterns for  $s$  equal to zero in the E and H planes respectively. It is seen therefore that some degree of adjustment is provided by moving rod 10 in or out of guide 11. As rod 10 is moved more and more into guide 11 so that  $s$  becomes less and less the radiation pattern of the device broadens.

In addition to varying the diameter of rod 10 and the position thereof, one can also vary the length  $l$  of the rod and the length of the taper. In general, the length of the taper with respect to the total length  $l$  of the rod has no significant effect on the radiation patterns of the device. On the other hand, the length  $l$  of the rod does have an effect on the high frequency radiation patterns. It was found that a 7 inch rod yielded a high-frequency beam-width several percent narrower than that produced with a 3 inch rod.

The dielectric loaded small-aperture antenna of FIG. 1 can also be utilized as a primary feed for large-aperture antennas of the reflecting or refracting type. In FIG. 7 there is shown in a partially broken away pictorial view, a reflecting paraboloid 70 of the type well known in the art. Paraboloid 70 is fed by means of guide 11 containing dielectric rod 10. Again, corresponding numerals have been carried over from FIG. 1 to designate corresponding structural elements.

The operation of the embodiment of FIG. 7 is substantially identical to other paraboloid or "dish" reflectors well known in the art except that the means employed for feeding the antenna allows the reflector to be illuminated to the same degree at two separated frequency bands. That is, in accordance with the principles explained in connection with the embodiment of FIG. 1, substantially the same radiation pattern is produced by the feed at both the low and high frequency bands. This results in increased high-frequency gain for the large-aperture antenna.

It is understood that the above-described arrangements are merely illustrative of the application of the principles of the present invention. It is obvious that by appropriate design techniques other arrangements including those utilizing other than circular waveguides or rods and other beam focusing means may be devised by those skilled in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. An aperture-type antenna comprising, in combination, a hollow conductively bounded waveguide of circular cross section having an input end and an output end, means for applying electromagnetic wave energy of at least two separate frequencies to said input end of said guide in the  $TE_{11}$  wave mode, means for radiating wave energy from said output end of said guide at both said frequencies with substantially the same radiation pattern, said latter means comprising a dielectric rod coaxially aligned with said guide and extending from a point within said guide to beyond the output end of said guide, said rod having a dielectric constant and a diameter such that said guide, over the interval coextensive with said rod,

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is supportive of wave energy at the lower of said frequencies exclusively in the  $TE_{11}$  mode of wave propagation and, simultaneously, is supportive of wave energy at the higher of said frequencies in both the  $TE_{11}$  and the  $TM_{11}$  modes of wave propagation.

2. The antenna according to claim 1 wherein said rod diameter is less than one-half said guide diameter.

3. The antenna according to claim 1 including additional means for focusing said radiated wave energy.

4. A dual frequency microwave antenna comprising, in combination, a hollow conductively bounded cylindrical waveguiding section, means for applying electromagnetic wave energy of first and second frequency ranges to one end of said section in the  $TE_{11}$  wave mode, means for converting the wave energy at the higher of said frequency ranges to the  $TM_{11}$  wave mode while leaving the wave energy at the lower of said frequency ranges exclusively in the  $TE_{11}$  wave mode, and means for radiating said energy from the other end of said section.

5. The antenna according to claim 4 wherein said mode conversion means comprises a dielectric rod coaxially disposed within said section at said other end thereof.

6. The antenna according to claim 4 including additional means for focusing said radiated wave energy.

7. A dual frequency aperture-type antenna comprising, in combination, a hollow conductively bounded waveguiding section of circular cross section capable of supporting propagating electromagnetic wave energy over at least two separated frequency bands, means for concentrating the wave energy of the higher of said two frequency bands towards the center of said waveguiding section comprising a dielectric rod coaxially disposed within said section at one end thereof, said rod having a dielectric constant substantially greater than the medium filling the remainder of said section and having a diameter substantially less than the diameter of said section, said dielectric constant and the diameter of said rod being further selected such that at the lower of said frequency bands said waveguide is supportive exclusively of  $TE_{11}$  mode wave energy over the portion of said section coextensive with said rod, and, simultaneously, at the higher of said frequency bands is supportive of both the  $TE_{11}$  and the  $TM_{11}$  modes of wave propagation.

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