

(12) PATENT
(19) AUSTRALIAN PATENT OFFICE

(11) Application No. AU 199723720 B2
(10) Patent No. 716231

(54) Title
Lens antenna having an improved dielectric lens for reducing disturbances caused by internally reflected waves

(51)⁶ International Patent Classification(s)
H01Q 015/08 H01Q 013/16
H01Q 013/02 H01Q 019/06

(21) Application No: **199723720** (22) Application Date: **1997.05.30**

(30) Priority Data

(31) Number	(32) Date	(33) Country
8-158837	1996.05.30	JP

(43) Publication Date : **1997.12.04**

(43) Publication Journal Date : **1997.12.04**

(44) Accepted Journal Date : **2000.02.24**

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(56) Related Art
US 4447811
US 3329958

Lens Antenna Having an Improved Dielectric Lens for Reducing
Disturbances Caused by Internally Reflected Waves

ABSTRACT

A lens antenna (40) is disclosed which comprises a conical horn
5 (14') and a lens attached to an aperture of the horn. The lens has a
first planar surface (42a) at a first side which faces free space and a
hyperboloid of revolution (18') at a second side opposite the first side
and is made of a dielectric material with relative permittivity ranging
from 2 to 4. The lens is provided with a cylindrical portion (44) which
10 has a second planar surface (44a) parallel to the first planar surface
and displaced from the first planar surface (42a) by a predetermined
distance. The cylindrical portion (44) being concentric with the lens.

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DLGD1Q27027F

AUSTRALIA
PATENTS ACT 1990

COMPLETE SPECIFICATION

FOR A STANDARD PATENT

ORIGINAL

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Invention Title: Lens Antenna Having an Improved Dielectric Lens for
Reducing Disturbances Caused by Internally Reflected
Waves

The following statement is a full description of this invention, including the
best method of performing it known to me/us:-

TITLE OF THE INVENTION

Lens antenna having an improved dielectric lens for reducing disturbances caused by internally reflected waves

BACKGROUND OF THE INVENTION

5 **1. Field of the Invention**

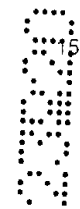
The present invention relates generally to improvements in a lens antenna which comprises a dielectric lens attached to an aperture of a horn, and more specifically to a lens antenna which includes an improved dielectric lens for effectively lowering disturbances caused by electromagnetic waves internally reflected in the lens.

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2. Description of the Related Art

As is known in the art, a lens antenna is comprised of a dielectric lens secured at an aperture (mouth) of a horn. The dielectric lens functions as a wave collimating element. A lens antenna is typically used in line-of-sight terrestrial microwave communications systems.

Before turning to the present invention it is deemed preferable to describe a known lens antenna with reference to Fig. 1.



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Fig. 1 is a side view, partly sectional, of a known lens antenna, generally denoted by numeral 10, which comprises a plano-convex dielectric lens 12 and a conical horn 14 serving as a flared-out waveguide. The plano-convex lens 12 is made of a dielectric material such as polyethylene, polystyrene, etc. with a relative permittivity ranging about from 2 to 4. The lens 12 has a plane surface 16 facing a free space and a hyperboloid of revolution (denoted by numeral 18) at the inner side. The horn 14 has a circular aperture to which the lens 12 is secured at its periphery. The horn 14 has an inner wall covered with an electrically conductive layer, and has a flange 20 to which a corresponding flange 22 of a waveguide member 24 is attached. Reference numeral 26 denotes a wave guide.

As is well known in the art, the lens 12 transforms the spherical wave front of the wave radiated from a source 28 (i.e., primary antenna) into a plane wave front. To be more explicit, the field (viz., electromagnetic field) over the plane surface (viz., plane wave front) can be made everywhere in phase by shaping the

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lens so that all paths from the wave source 28 to the lens plane are of equal electrical length (Fermat's principle).

As shown in Fig. 1, part of a given incident wave 30 is reflected at two points of the lens 12: at the convex surface 18 (the reflected component is indicated by a broken line arrow 29) and at the plane surface 16. The reflection from the convex surface 18 does not return to the source 28 except from points at or near an axis 32 and thus are of no consequence. However, the energy reflected from the lens plane 16 returns back exactly along the radiation line 30 and may adversely affect the energy to be radiated from the wave source 28.

It is therefore highly desirable to reduce the above mentioned undesirable influence caused by the reflections from the plane lens surface.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a lens antenna which has an improved dielectric lens for reducing disturbances caused by internally reflected waves.

The present invention resides in a lens antenna comprising:

a conical horn and a plano-convex lens attached to an aperture of said horn and collimating waves from said conical horn, said lens being a circular lens with a diameter r , said lens having a first planar surface parallel to a first side which faces free space and a second side opposite the first side,

wherein said lens is provided with a cylindrical portion which has a second planar surface substantially parallel to the said first planar surface and displaced from the said first planar surface by a predetermined distance, said cylindrical portion being concentric with said lens.



shaped and thus hereinafter may be referred to as a disk or cylindrical portion 44. This disk portion 44 is formed on the lens 42 in a manner to be concentric therewith. It is to be noted that the disk portion 44 is part of the lens 42 and thus shaped when fabricating the lens 42. For the convenience of description, the plane surface of the disk portion 44 is denoted by numeral 44a, while the plane surface of the lens 42 except for the plane surface 44a is denoted by 42a. As in the prior art of Fig. 1, the lens 42 has a hyperboloid of revolution 18' at the inner side (see Fig. 3). The remaining portions of the lens antenna 40 are exactly the same as the counterparts of Fig. 1 and accordingly, the descriptions thereof will be omitted.

Designating the diameters of the lens 42 and the disk portion 44 as D1 and D2, respectively, it is preferable that the diameter D2 is set to about one third of D1 (viz., $(D1)/3$). This relationship of dimensions of D1 and D2 is determined as follows. It is known that the electromagnetic field near the edge of the lens 42 is less than that at and near the center thereof. That is, the amount of waves reflected from near the edge of the lens 42 differs from that at and near the center thereof. In order to effectively reduce the undesirable phenomenon caused by the reflected waves, it is highly desirable to equalize the amounts of waves reflected from the surfaces 42a and 44a. In view of this, it is preferable that the diameter D2 is determined so as to equal about one third of D1 (viz., $(D1)/3$).

In Fig. 3, two waves 50 and 52, which originate from the wave source 28, are shown. The waves 50 and 52 are respectively directed such as to pass through the surfaces 42a and 44a. As mentioned above, the energy of each of the waves passing through the lens plane (such as 42a and 44a) is partly reflected from the plane boundary. In Fig. 3, notations 50r and 52r represent respectively the reflected waves of the waves 50 and 52. It is understood that the reflected wave 52r is retarded by the electrical path length of $2 \times h$ compared to the reflected wave 50r. According to the study conducted by the inventors, it was found that the height "h" was preferably about $0.17 \lambda_0$ (λ_0 is a wave length of a center frequency of a designed frequency range). This means that the reflected wave 52r is retarded by $2 \times 0.17 \lambda_0 = 0.34 \lambda_0$ expressed in free space (air or



vacuum) compared to the reflected wave 50r.

Further, the inventors conducted a computer simulation under the following conditions. That is to say, the lens 42 was made of polycarbonate with relative permittivity (ϵ_r) of 2.85, while the diameters D1 and D2 were 200mm and 60mm, respectively. It is assumed that the available frequency band ranged from 37.00GHz to 39.50GHz and accordingly, the center frequency was 38.25GHz ($\lambda_0=7.84\text{mm}$) Therefore, the height "h" of the disk portion 44 was calculated using the following equation:

$$h = 0.17 \lambda_0 / \epsilon_r^{1/2} = (0.17 \times 7.84) / 2.85^{1/2} \approx 0.8\text{mm}$$

As mentioned above, the wave reflected from the plane surface 44a (such as 52r) is delayed $0.34 \lambda_0$ (expressed in free space (air or vacuum)) as compared to the wave reflected at the plane surface 42a (such as 50r).

One particular example showing the advantage of the first embodiment over the prior art will be discussed. First, the case where the above mentioned disk portion 44 is not provided is given (as in the prior art shown in Fig. 1).

Defining the parameters associated with the lens plane 16 as follows:

E_{1i} : wave incident on the lens plane 16;

E_{1t} : wave passing through the plane 16;

E_{1r} : wave reflected from the plane 16; and

R_1 : reflection coefficient (vector) at the plane 16.

Further, assuming:

$$|R_1| = |E_{1r} / E_{1i}| = 0.3 \quad \dots (1)$$

Since the reflection loss RL is given by $10 \log |R|^2$, then

$$\begin{aligned} \text{RL} &= 10 \log |R|^2 \\ &= 20 \log |R| \\ &= 20 \log 0.3 \\ &= -10.5 \text{ (dB)} \quad \dots (2) \end{aligned}$$

On the other hand, in connection with the first embodiment, the parameters associated with the plane 44a of the disk portion 44 are defined as follows:

E_{2i} : the wave incident on the lens plane 44a;

E_{2t} : wave passing through the plane 44a;

E_{2r} : the wave reflected from the plane 44a; and

R_2 : reflection coefficient (vector) at the plane 44a.

Further, the parameters associated with the plane 42a of the lens 42 are defined as follows;

- 5 E_{3i} : wave incident on the lens plane 42a;
- E_{3t} : wave passing through the plane 42a;
- E_{3r} : wave reflected from the plane 42a; and
- R_3 : reflection coefficient (vector) at the plane 44a
- $R_t = R_2 + R_3$

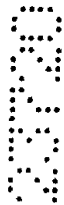
10 Since $E_{2i}=E_{3i}$ and $|E_{2r}|=|E_{3r}|$, then

$$\begin{aligned}
 R_t &= R_2 + R_3 \\
 &= \{ |E_{2r}|^2 / (|E_{2i}|^2 + |E_{3i}|^2) \}^2 \times (E_{2r} / E_{2i}) \\
 &\quad + \{ |E_{3r}|^2 / (|E_{2i}|^2 + |E_{3i}|^2) \}^2 \times (E_{3r} / E_{3i}) \\
 &= (1/\sqrt{2} \cdot E_{2i}) \times (E_{2r} + E_{3r}) \qquad \dots (3)
 \end{aligned}$$

15 Therefore, the phase difference (denoted by θ) between E_{2r} and E_{3r} is given by

$$\theta = 0.17 \times 2 \times 2\pi = 0.68\pi$$

In the above, it is assumed that the wave amounts reflected at the planes 40a and 42a are equal each other.



20 Fig. 4 is a vector diagram showing the relationship of E_{2r} and E_{3r} whose phase difference is θ .

 Assuming $|E_{2r}/E_{2i}|=0.3$, then we obtain

$$\begin{aligned}
 R_t &= 1/\sqrt{2} \times 0.3 \{ (1 + \cos \theta)^2 + \sin^2 \theta \} \\
 &= 1/\sqrt{2} \times 0.3 \times 0.964 \\
 &= 0.204 \qquad \dots (4)
 \end{aligned}$$



25 As a result, the reflection loss (denoted by RL') in the above case is as follows.

$$\begin{aligned}
 RL' &= 10 \log |R_t| \\
 &= -13.8\text{dB} \qquad \dots (5)
 \end{aligned}$$



It is understood, from the above computation, that the reflection loss can be reduced by 3.3dB as compared to the prior art.

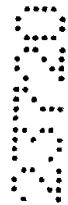
30 The inventors conducted a computer simulation to determine a wave radiation pattern when a vertically polarized wave is applied from the waveguide

26. Fig. 5 is a graph showing the result of the computer simulation, which clearly indicates that a good radiation pattern can be obtained even if the disk portion 44 is formed.

Further, the inventors investigated reflection losses occurring in the first
5 embodiment (the result is shown in Fig. 6) and in the prior art (the result is show in Fig. 7), both over the frequencies ranging from 35GHz to 40GHz. This frequency range includes the frequency band (37.0GHz to 39.5GHz) over which the lens antenna embodying the present invention is preferably utilized. In this investigation, a reference level (0dB) was determined when the waves radiated
10 from the waveguide 26 were totally reflected at the plane surfaces of the lens 12 (Fig. 1) and 42 (Fig. 3). As shown in Fig. 6, the worst reflection loss in the first embodiment was about -16.4dB. In contrast to this, the worst reflection loss in the prior art was about -11.0dB as plotted in Fig. 7. That is, this examination indicates that the first embodiment was able to reduce the reflection loss by about
15 5.4dB compared to the prior art.

Fig. 8 is a diagram showing a second embodiment of the present invention. As shown, a lens antenna 40' includes a dielectric lens 42' which has a cylindrical recess 44' with the depth h. Other than this, the second embodiment of Fig. 8 is identical to the first embodiment with respect to structure. With the second
20 embodiment, each wave reflected from the inner surface of the recess 44' becomes shorter by 0.34-wavelength ($2h=0.34$) than that reflected from the inner surface other than the recess 44'. It is understood that the operations as discussed above with respect to the first embodiment is applicable to those of the second embodiment.

25 It will be understood that the above disclosure is representative of only two possible embodiments of the present invention and that the concept on which the invention is based is not specifically limited thereto.



The claims defining the invention are as follows:

1. A lens antenna comprising:
a conical horn; and
5 a plano-convex lens attached to an aperture of said horn and collimating waves from said conical horn, said lens being a circular lens with a diameter r , said lens having a first planar surface parallel to a first side which faces free space and a second side opposite the first side,
wherein said lens is provided with a cylindrical portion which has a second
10 planar surface substantially parallel to the said first planar surface and displaced from the said first planar surface by a predetermined distance, said cylindrical portion being concentric with said lens.
2. The antenna as claimed in claim 1, wherein said cylindrical portion
15 protrudes from the first planar surface.
3. The antenna as claimed in claim 1, wherein said cylindrical portion is
recessed from the first planar surface.
- 20 4. The antenna as claimed in any one of claims 1-3, wherein the cylindrical portion has a diameter of about $r/3$.
- 25 5. The antenna as claimed in any one of claims 1-4, wherein the predetermined distance is about $0.17 \lambda_0$, where λ_0 is a wavelength of a center frequency of a frequency range used with said antenna.
- 30 6. The antenna as claimed in any one of claims 1-5, wherein said lens has a hyperboloid of revolution at said second side of a dielectric material with relative permittivity ranging from about 2 to about 4.
7. The antenna as claimed in claim 6 wherein said hyperboloid of revolution is made of a dielectric material with relative permittivity ranging from about 2 to about 4.



8. A lens antenna substantially as described herein with reference to Figs. 2 to 6; or to Fig. 8 of the accompanying drawings.

DATED this twenty-ninth Day of November, 1999

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FIG. 1
(PRIOR ART)

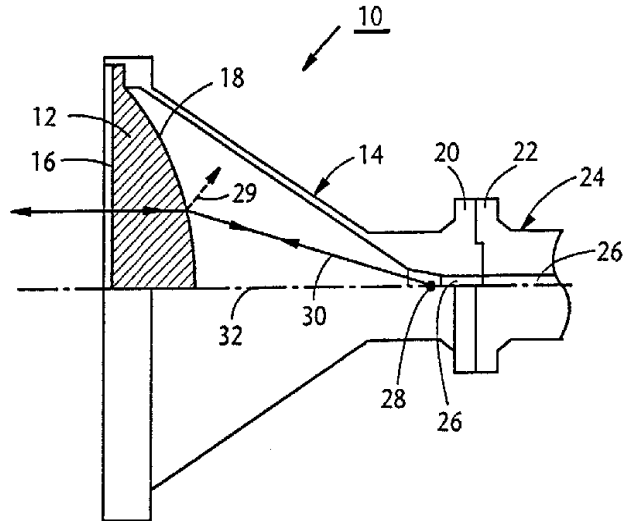
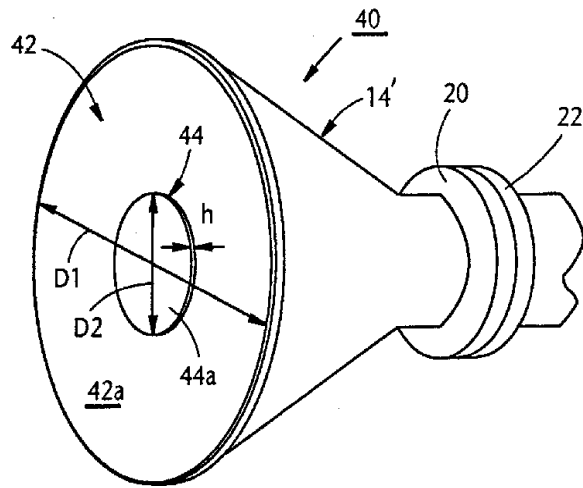


FIG. 2



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FIG. 3

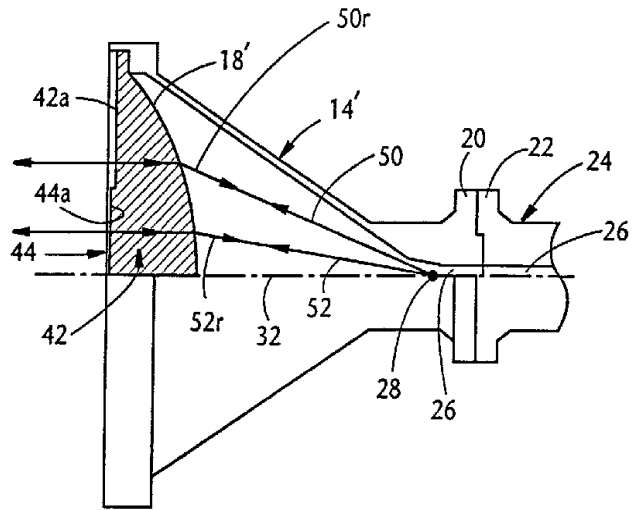
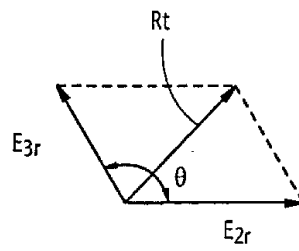


FIG. 4

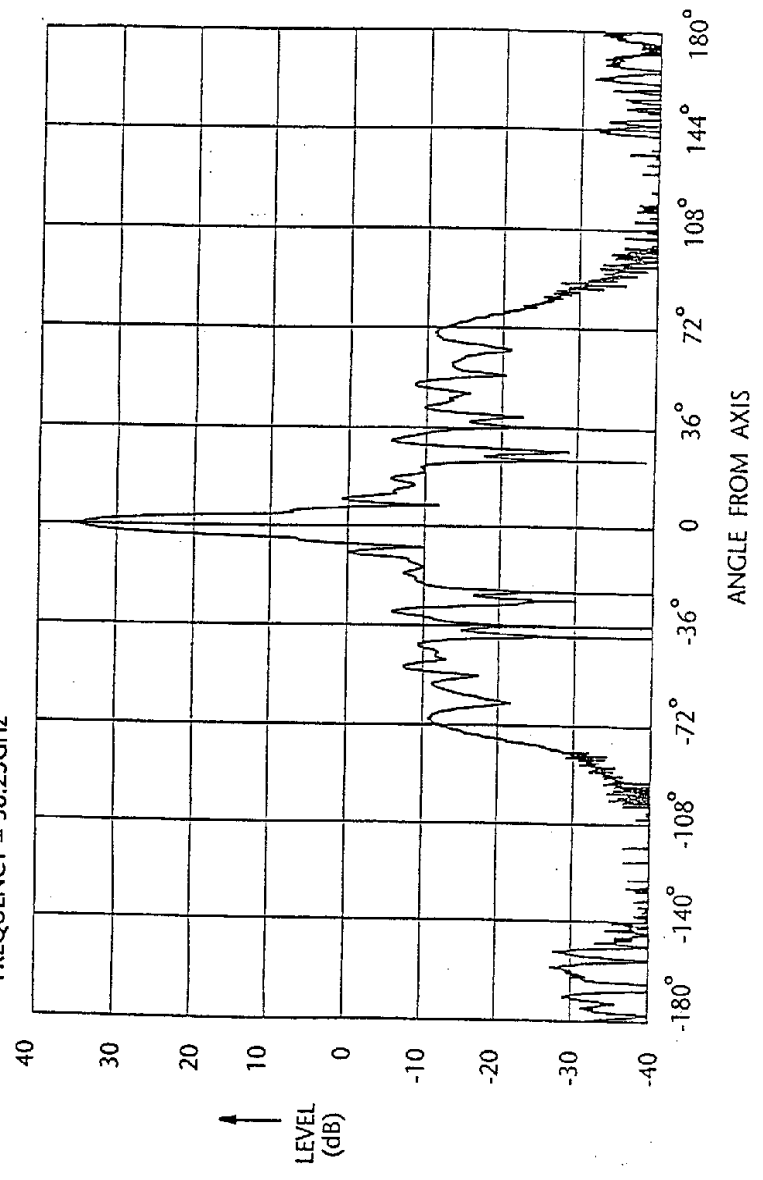


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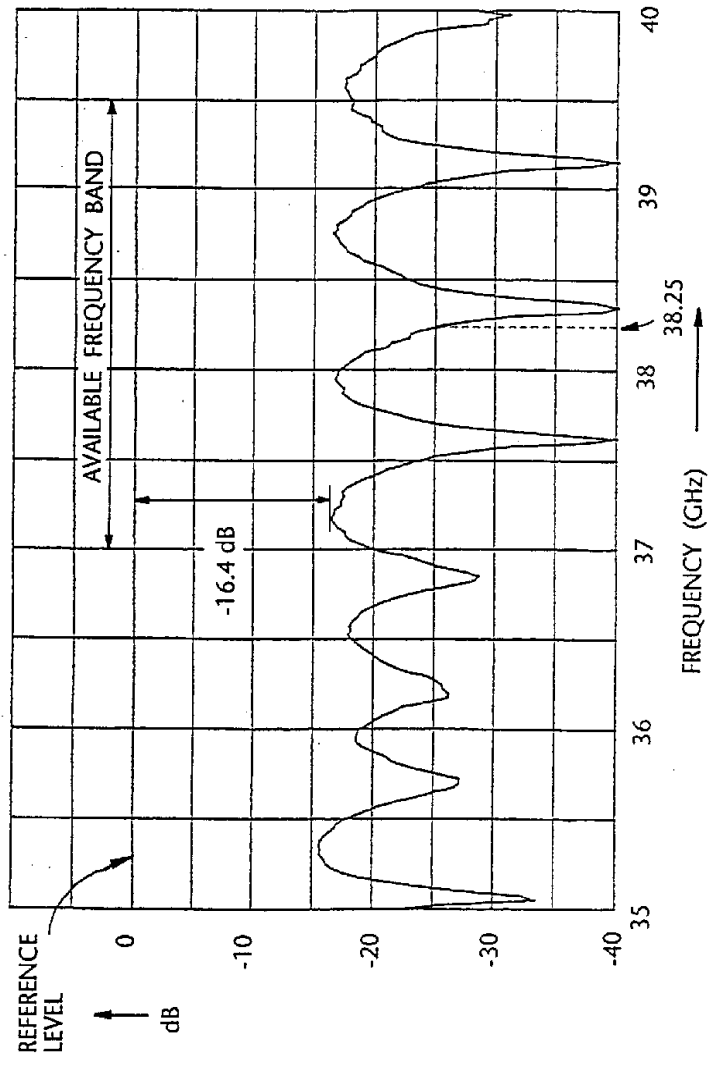
FIG. 5

FREQUENCY = 38.25GHZ



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FIG. 6



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FIG. 7 (PRIOR ART)

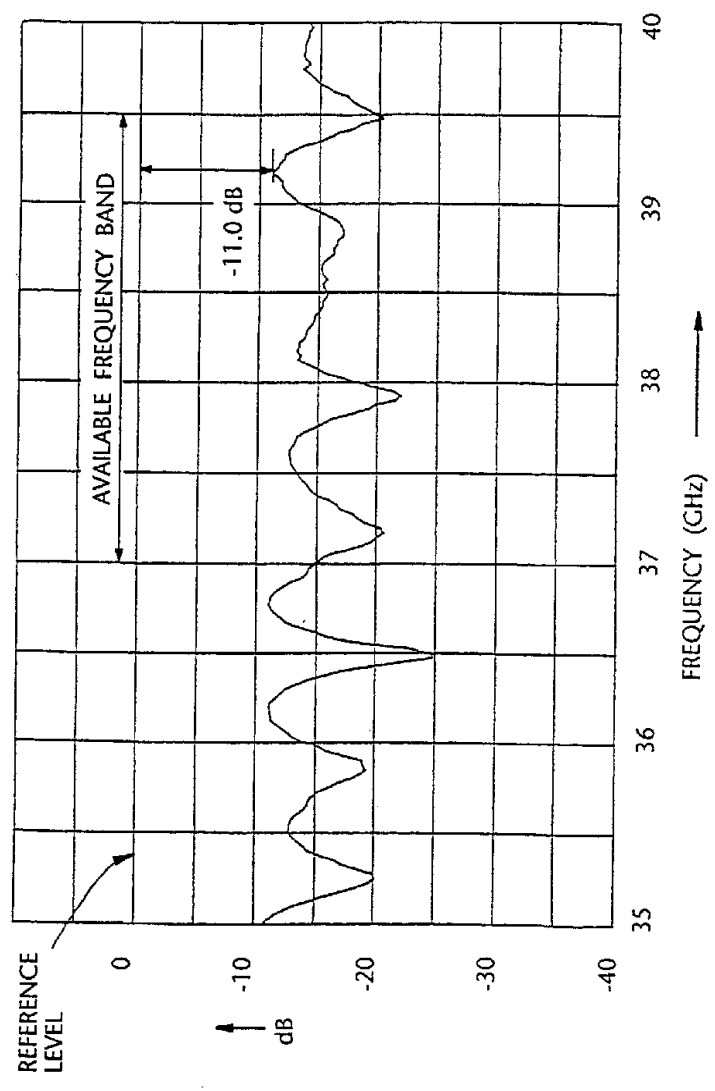
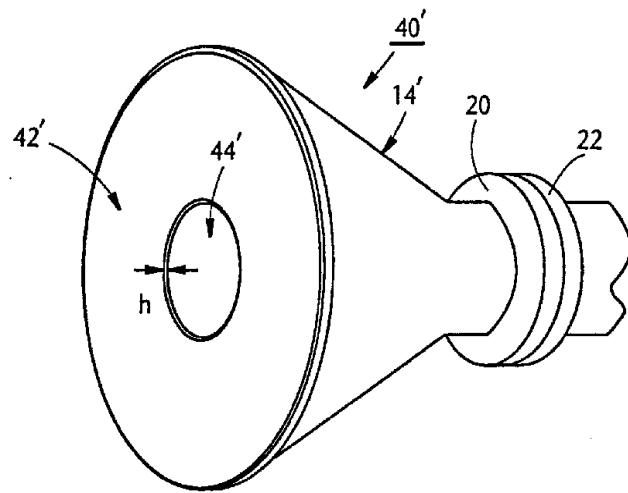


FIG. 8



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