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(54) **Omni-directional antenna.**

(57) An azimuthally omni-directional antenna for radio waves comprises a dielectric lens (3) having an elliptic surface in vertical plane (1) and a reflector arrangement (2) which cooperate to focus rays (4) onto an array of elements at the surfacial plane (5). Local oscillator power can be injected and mixed.

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OMNI-DIRECTIONAL ANTENNA

This invention relates to an azimuthally omni-directional antenna suitable particularly but not exclusively for millimetre wave applications.

In this specification the term omni-directional means significant angles up to and including 360° in azimuth.

The prior art employs a lens antenna which is shaped as shown in Fig. 1c with an elliproidal rotationally-symmetric face 10. This focusses parallel received rays 11 onto a basal planar array at the focal surface 12 without the focal surface interfering with the ray paths.

However this arrangement has the disadvantage that only rays received predominantly parallel to the lens axis are well focussed in the basal plane. It therefore cannot be used to provide 360° coverage in the azimuthal plane except by employing multiple such units with associated high cost, size, weight.

In its simplest form an omni-directional lens has perfect circular symmetry in azimuth (Fig. 1a) and Fig. 1b shows the extent to which parallel rays are focussed by such an arrangement viewed in vertical section. For a dielectric constant (ϵ) of greater than 4, the radial distance (ℓ) at which rays cross the undiffracted ray which passes through the centre of the lens, is given by

$$\ell = \frac{R}{\sqrt{\varepsilon - (d/_R)^2} - \sqrt{1 - (d/_R)^2}}$$

where R is the radius of the circle and d is the displacement of the given ray from the undiffracted ray. The crossovers always occur on the side of the lens away from source of the rays and for $\varepsilon < 4$ some or all of the rays will crossover outside of the lens. The extent to which a beam is focussed (ie how closely the crossovers are bunched) increases with increasing ε, with perfect focussing occuring at the centre of the lens for infinite ε.

In elevation the surface may be shaped as desired but an ellipse is convenient since this provides a well focussed beam over a range of elevation angles. A ray diagram is shown in Fig. 1b.

A lens as shown in Fig. 1 is not immediately useful because the focal surface is buried inside the lens and cannot be accessed without interfering with the ray paths. In addition, the focal surface is curved which means that the lens cannot be used directly with a planar array of signal detection elements.

The object of the present invention is to provide an antenna producing multiple independent beams covering up to 360° in azimuth from one lens with lower cost, size and weight.

According to the present invention there is provided an antenna providing up to 360° in azimuth for electromagnetic radiation comprising a dielectric lens and a cooperating reflector arrangement arranged to feed a surface array.

According to another aspect of the present invention there is provided an omni-directional antenna for electromagnetic rays comprising a rotationally-symmetric dielectric lens, a cooperating rotationally-symmetric reflecting surface, and a surface array of elements arranged at the surfacial focus of the combined

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lens and reflecting surface.

Such an antenna can provide uniform 360° coverage in azimuth and a specified performance in elevation. The angles of arrival of received signals can be determined from voltages on elements of the array. Additional reflecting surfaces can be provided to allow direct injection of local oscillator power to the array so that simple elements with integrated mixers may be employed.

An important aspect is the arrangement of refracting and reflecting surfaces to produce an omni-directional antenna which can use a planar array of elements to provide directional information.

Another important aspect lies in the method of using additional reflectors and feed for the injection of local oscillator power.

Such an arrangement is particularly suitable for mm wave systems.

In order that the invention can be clearly understood, reference will now be made to the remainder of the accompanying drawings, in which:

Fig. 2 shows an antenna design in vertical cross-section according to an embodiment of the invention;

Fig. 3 show focussing diagrams comprising the performance of the antenna of Figs. 1(a) and 1(b);

Fig. 4 shows a modification of the antenna of Fig. 2, and

Figs. 5 and 6 are alternative embodiments of the invention.

Reference will now be made to Fig. 2 which shows an antenna of dielectric material e.g. optically smooth to e.g. one tenth of a wavelength ceramic or even plastics material. The antenna comprises the combination of a lens 1 and reflector 2 in a unitary dielectric body 3. The lens 1 is elliptic in vertical cross-section and the reflector 2 conical and the rays 4 are focussed onto a horizontal image plane 5 at which is arranged a surface in this case planar, array of dipole elements. The axis of the elevation ellipse is tilted so that rays are directed downwards sufficiently to enter inside the relector cone 2 as shown. The angle of the cone 2 is chosen so that reflection results in the rays 4 being focussed onto the horizontal image plane 5. Both the reflecting and refracting surfaces may be shaped in elevation in order to optimise focussing in that plane. In addition, the condition that ε should be greater than 4 to obtain a suitable focus is relaxed.

A further advantage of this arrangement is that reflection from the concave surface gives rise to improved focussing over the basic circular lens of Fig. 1. This can be seen from simple calculations for a limiting two-dimensional case (no downward movement of rays).

The position (ℓ) of crossovers from the centre of the lens is evaluated. Plots of $^{\ell}/_{R}$ as a function of $^{d}/_{R}$ are shown in Fig. 3 for two values of ε and various values of $^{R'}/_{R}$ where R' is the radius of the reflecting circle. A horizontal straight line corresponds to perfect focussing and it can be seen that the plots with reflection (Fig. 3B corresponding to the Fig. 2 embodiment) approach that condition more closely than those without reflection (Fig. 1 and Fig. 3A).

In order to allow wide elevation coverage the lens could be made in sections with separate array planes for different parts of the elevation range; for example an upper and lower half could deal separately with positive and negative elevations.

Fig. 4 shows a modification to the basic lens of Fig. 2. The modified antenna has a cusp-shaped reflector 10 which does not interfere with the rays 4, and which focusses local oscillator power from a TM01 mode horn 11.

Otherwise the antenna is as described in Fig. 2. This allows local oscillator (LO) power to be fed to the elements. This permits the use of arrays which employ this form of LO injection. A single horn 11 supporting the TM01 mode is used to illuminate the central conical (cusp-like) reflector 10 as shown. The TM01 mode gives rise to a circularly symmetric pattern with a null on boresight. The reflector 10 is shaped to direct the LO energy onto the annulus of elements in the array plane.

Fig. 5 shows a vertical cross-section through a further embodiment in which an antenna has an elliptical lens 30 shown receiving parallel rays 31, 32, the axis of the elipse being x-x. A hyperbolic reflector 33 shown in vertical cross-section has an axis at 34 (in reality a conical imaginary surface) which crosses with the virtual focal line 35 at F_1 (in reality an imaginary cylindrical surface).

The function of the hyperbolic section reflector is to drive F_2 further away from the reflector than would one having a plane section (for which $f_2 = f_1$) so that f_2 is greater than f_1.

The virtual focal line 35 is not at right angles to the hyperbolic axis 34. So as elevation is scanned, defocussing occurs so the arrangement is preferred for a chosen elevation or small range of elevations.

Fig. 6 shows another embodiment of an antenna according to the invention. The lens 40 which is elliptic refracts the rays 41 onto hyperbolic reflector 42. The hyperbole axis 43 crosses the focal line 44 of the ellipse 40 at 45, and local oscillator injection horn 46 is located adjacent the element array at the focal surface 47. The advantage of this arrangement are that the elements would be close together, the elements are at the bottom of the lens system so the signal connections can be provided easily, and the local oscillator feed can be provided by rear-fed techniques.

The discussion above regards the antenna as a quasi-optical system: that is to say the rays of electromagnetic energy are regarded as if they were light rays in a true optical system. The lens diameter needs to be about ten wavelengths or more for this analogy to hold true.

The antenna would normally be optically opaque. The "optical" accuracy of the surfaces would need to be about one tenth of a wavelength.

The elements in the array referred to would preferably be arranged so that different elements receive rays from different directions and hence provide directional information relative to the antenna. Thus for twenty beams there would be twenty elements.

The element signals i.e. the received electromagnetic waves and the injected local oscillator would be mixed to provide an intermediate frequency.

CLAIMS:-

1. An antenna providing up to 360° in azimuth for electromagnetic radio rays comprising a dielectric lens and a cooperating reflector arrangement arranged to feed a surface array.

2. An antenna as claimed in claim 1 comprising means for injecting local oscillator power into the array.

3. An antenna as claimed in claim 2, said means comprising a cusp-like reflector arranged to reflect local oscillator power from a source on to an annulus of said array of elements.

4. An antenna as claimed in claim 1, wherein the lens comprises an elevation ellipse and a conical reflector, the axis of the ellipse being tilted so that with the reflector beneath the lens, received rays are directed downwards to enter inside the conical reflector.

5. An antenna as claimed in claim 1 wherein the lens is made in sections with separate array planes for different parts of the elevational range.

6. An antenna as claimed in claim 1, wherein the reflector has a hyperbolic vertical section located before the virtual focal line of the lens.

7. An omni-directional antenna for millimetre wavelength electromagnetic rays comprising a rotationally-symmetric dielectric lens, a cooperating rotationally-symmetric reflecting surface, and a surface array of elements arranged at the surfacial focus of the combined lens and reflecting surface.

8. An antenna substantially as hereinbefore described with reference to and as illustrated in Figs. 2, 3B, 4, 5, or 6 of the accompanying drawings.

Fig.1(a)

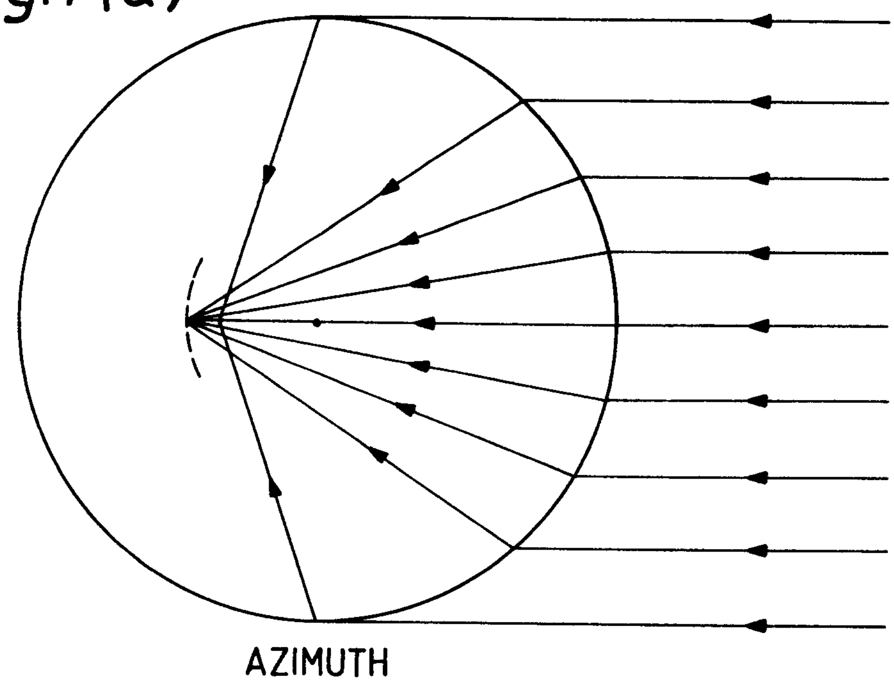


Fig.1(b)

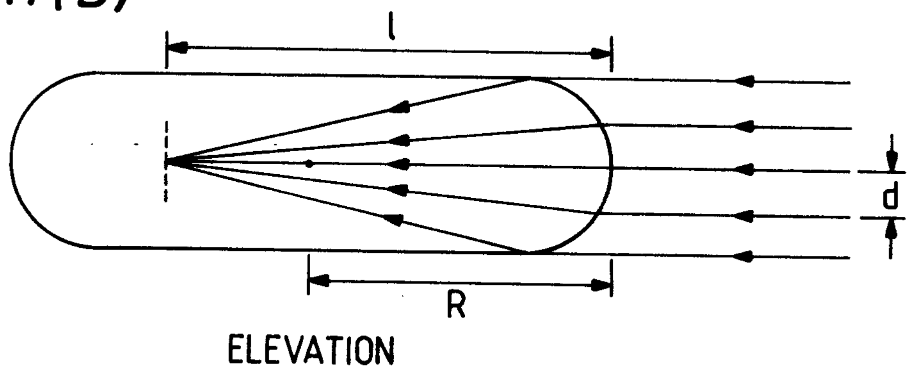


Fig.1(c)

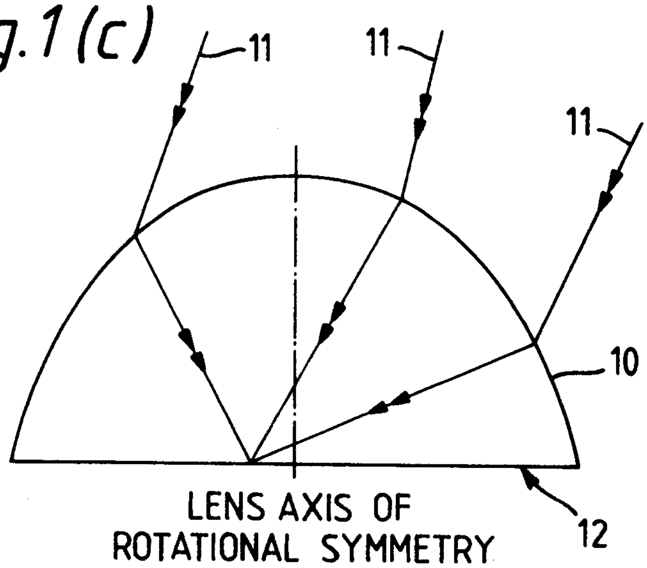


Fig. 2.

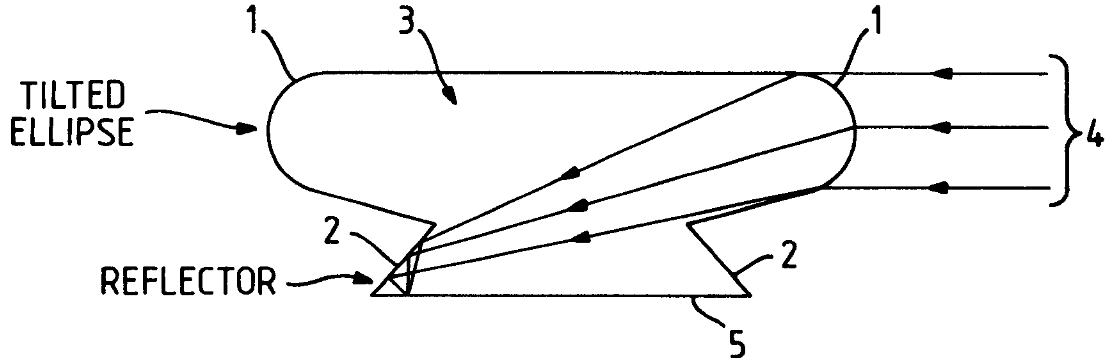


Fig. 4.

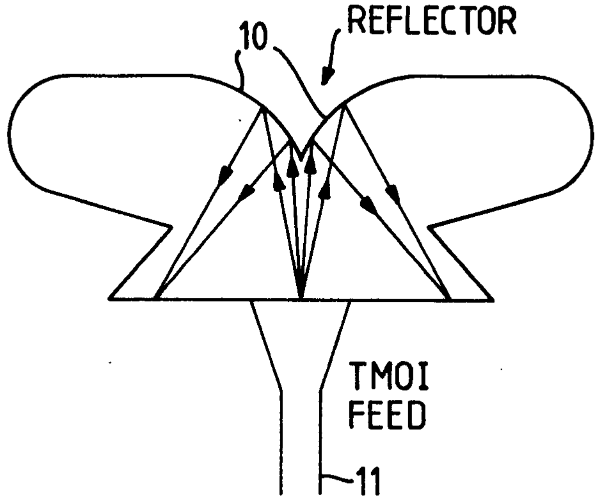


Fig. 5.

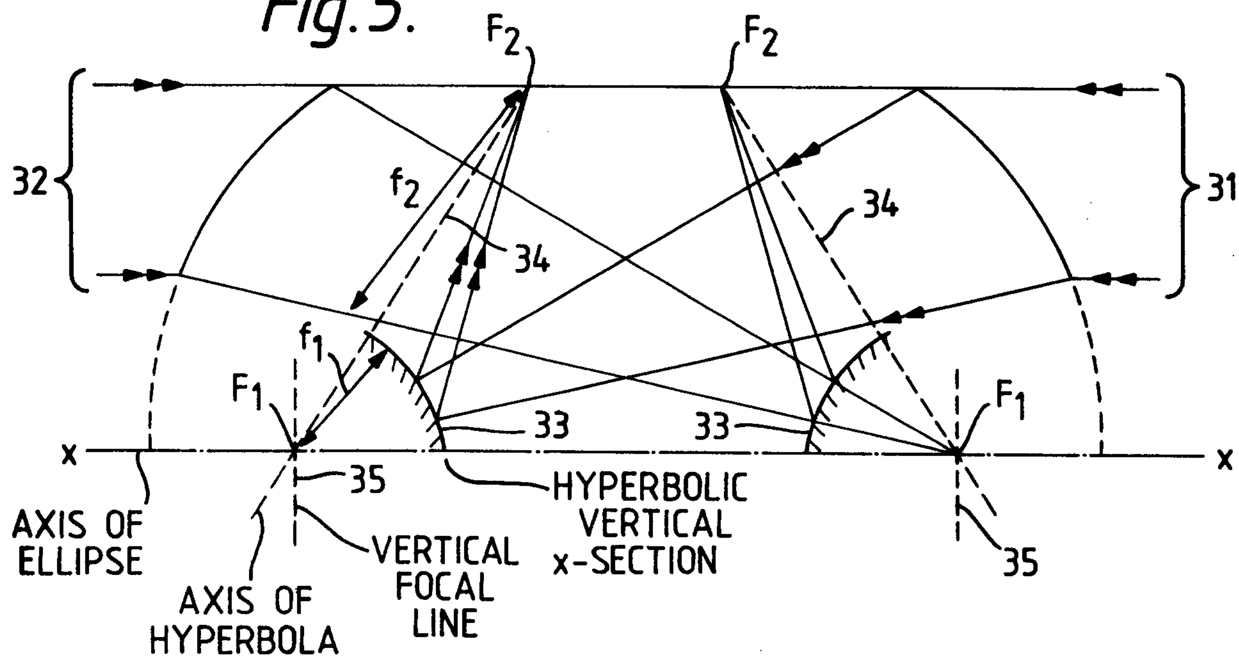
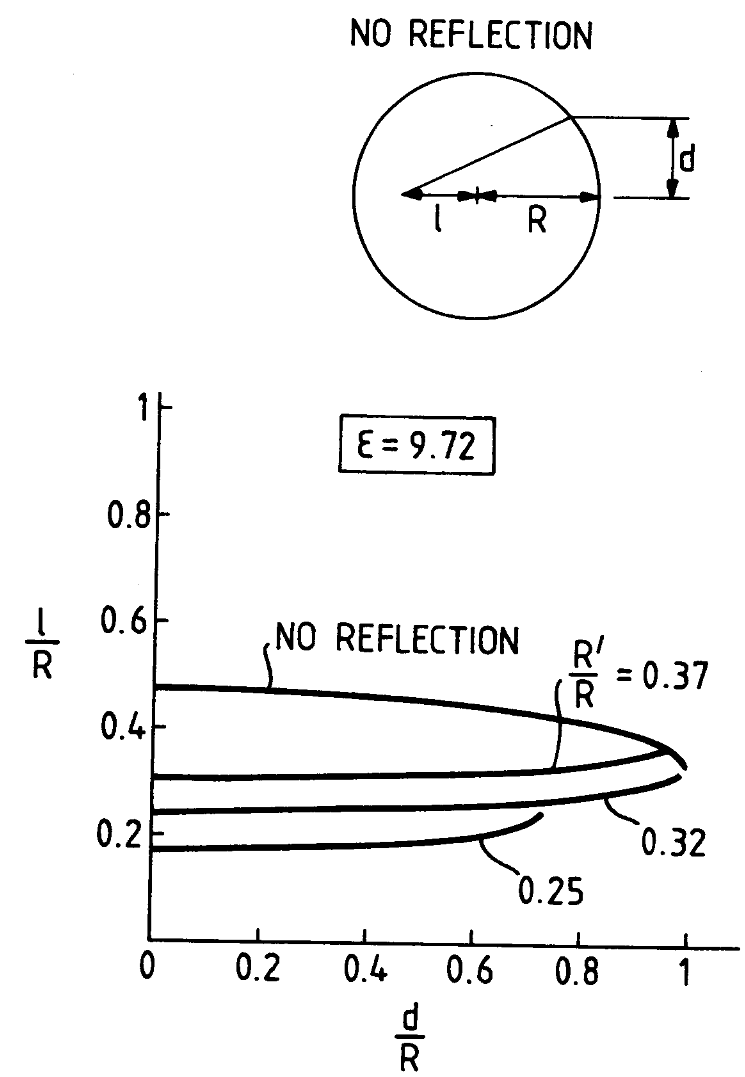


Fig.3 (a)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d
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NO REFLECTION
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0.25
l/R
d/R
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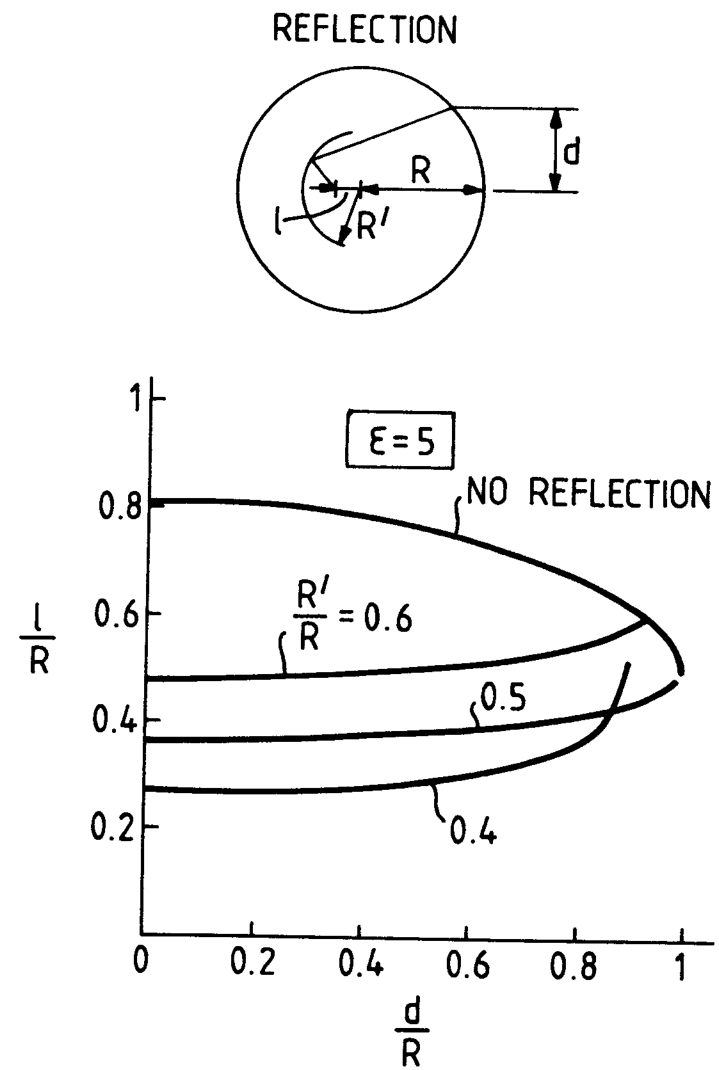
0.2
0.4
0.6
0.8
1

Fig.3(b)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R'
d
ε = 5
NO REFLECTION
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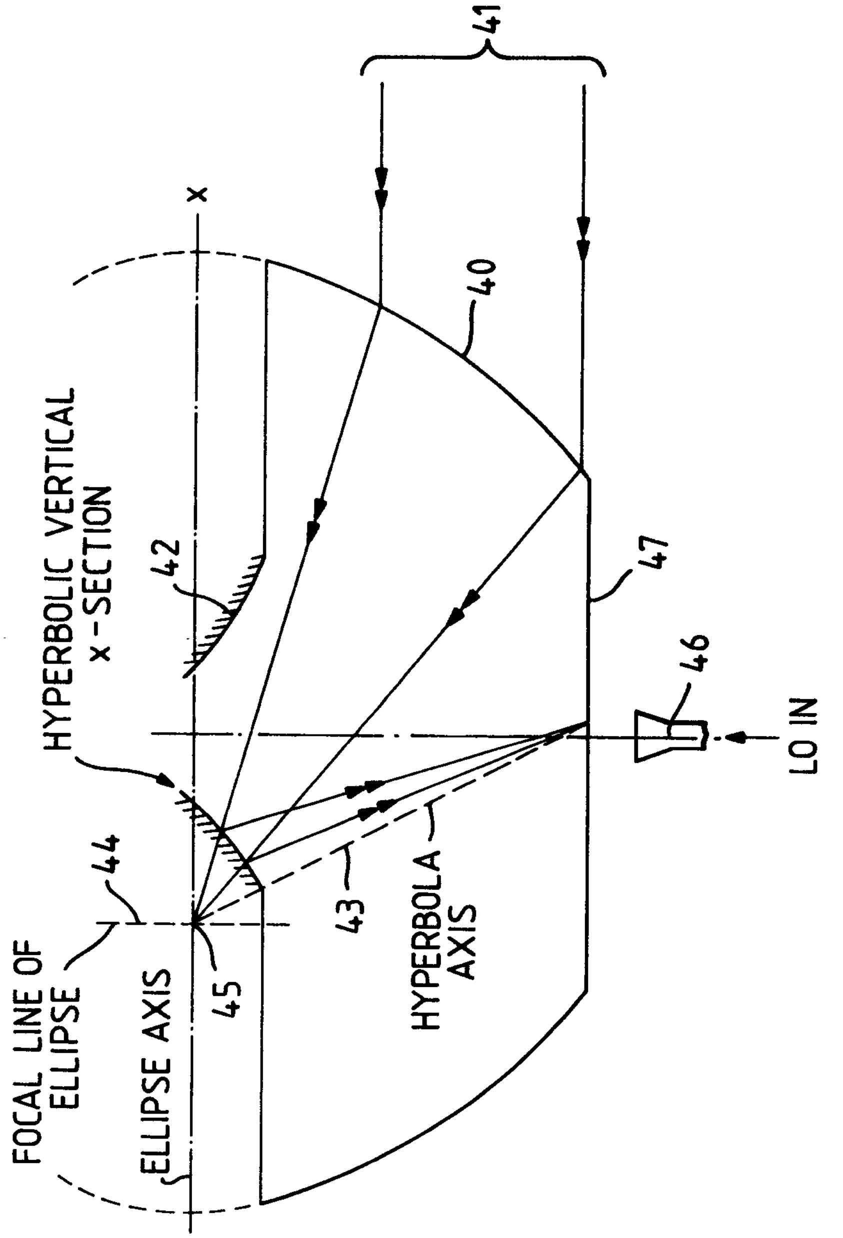
d/R
0
0.2
0.4
0.6
0.8
1

Fig.6.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40
47
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42
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FOCAL LINE OF
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HYPERBOLA
AXIS
x
x