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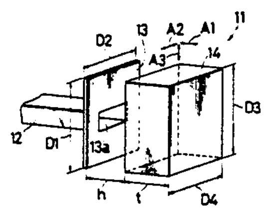
(54) **Dielectric or magnetic medium loaded antenna.**

(57) A loaded antenna (11) comprises a wave source (12) of an arbitrary polarized wave, a reflector (13) disposed near the wave source (12), with the surface opposite to the wave source (12) limited in area, and a dielectric (14) disposed on the opposite side of the reflector across the wave source (12), at least with the surface opposite to the reflector (13) formed parallel to the reflector (13).

By properly selecting the mutual interval among the dielectric (14), wave source (12) and reflector (13), the dimension and the dielectric constant of the dielectric (14), the vibration component in the running direction of the wave within the dielectric (14), the vibration component in the direction vertical to the running direction, and the vibration component between the reflector and dielectric are superposed, so that the electromagnetic field distribution in the vicinity of the dielectric (14) is made uniform. Thereby, high gain and high efficiency are realized, and the structure may be notably reduced in size.

Fig. 4



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Dielectric or Magnetic Medium Loaded Antenna

The present invention relates to dielectric or magnetic medium loaded antenna having reflectors that are outstandingly enhanced in the gain and radiation efficiency, being preferably used in transmission and reception of radio waves in a frequency band of, for example, over microwaves.

Fig. 1 is a sectional view showing a construction of a typical conventional short backfire antenna (SBF antenna). Referring to Fig. 1, the SBF antenna 1 is described below. The SBF antenna 1 comprises, for example, a radio wave source 2 such as dipole antenna, and a pair of reflectors 3, 4 made of parallel metal plates being disposed mutually at opposite sides thereof. The reflector 4 has an edge tubular part 4a with a rising height of a1 (for example, 0.25λ) toward the reflector 3 side. The contour of the reflectors 3, 4 may be, for example, a square or a circle, and the outer dimension D1 is selected at 0.4λ with respect to the wavelength λ of the radio wave being used, or when the contour is circular, the outer dimension d1 is selected at 2.0λ. The interval h1 of the reflectors 3, 4 is selected at λ/2 with respect to the wavelength λ. This SBF antenna 1 realizes radiation by making use of the reflection of the radio wave between the reflectors 3, 4 and the diffraction of radio wave at end parts of the reflectors 3, 4.

In such SBF antenna 1, it is known that a gain of about 15 dB can be obtained at the aperture efficiency of only about 100%, but it is also known well that it is difficult to achieve higher aperture efficiency and higher gain in thus composed SBF antenna 1.

Fig. 2 is a perspective view showing a constitution of a second conventional example of dielectric rod antenna (hereinafter called rod antenna) 5. Referring to Fig. 2, the rod antenna 5 is described below. The rod antenna 5 excites a dielectric rod 7 fixed at one end of a waveguide 6 along the longitudinal direction by means of the waveguide 6, and realizes radiation by making use of the generated surface waves. In such rod antenna 5, the diameter D2 of the dielectric rod 7 is less than the wavelength λ, and the rod length D3 must be 5λ to more than 10λ. Therefore, in such rod antenna, structurally, it is difficult to reduce the size, and the gain is known to be about 16 to 17 dB at most.

Fig. 3 is a plan view showing a basic construction of a third conventional Yagi antenna 8. Referring to Fig. 3, the Yagi antenna 8 is described below. The Yagi antenna 8 comprises a feeder element 8a, a waveguide 8b, and a reflector 8c. The Yagi antenna 8 uses a resonance element made of conductor rod, and it had a problem of narrow band of usable frequency.

Therefore, concerning antennae for transmitting and receiving radio waves in the frequency band of over millimeter waves and microwaves, in particular, development of antennae capable of reducing the size and outstandingly enhancing the gain and radiation efficiency has been desired.

It is hance a primary object of this invention, in order to solve the aforesaid problems, to present a dielectric or magnetic medium loaded antenna possessing reflectors capable of enhancing the gain and radiation efficiency overwhelmingly, while solving the above problems and reducing by far the size of the constitution.

In accomplishing the above object, a dielectric or magnetic medium loaded antenna according to the invention comprises a wave source of an arbitrary polarized wave, a reflector disposed near the wave source, with the surface opposite to the wave source limited in area, and a dielectric disposed on the opposite side of the reflector across the wave source, at least with the surface opposite to the reflector formed parallel to the reflector.

In a preferred embodiment, the specific inductive capacity of the dielectric is selected approximately within 10.

In another preferred embodiment, the projection area of the dielectric to the reflector is selected to be not larger than the area of the reflector.

According to this invention, a dielectric antenna is composed by comprising a wave source of an arbitrary polarized wave pattern, a reflector disposed near the wave source, with the surface opposite to the wave source being limited in area, and a dielectric disposed on the opposite side of the reflector across the wave source, at least with the surface opposite to the reflector formed parallel to the reflector. In thus composed dielectric or magnetic medium loaded antenna, the radio wave from the wave source is reflected in multiplex between the reflector and the dielectric, or within the dielectric.

In this invention, by properly selecting the mutual interval among the dielectric, wave source and reflector, the dimension and the dielectric constant of the dielectric, the vibration component in the running direction of the wave within the dielectric, the vibration component in the direction vertical to the running direction, and the vibration component between the reflector and dielectric are superposed, so that the electromagnetic field distribution (in particular the phase) in the vicinity of the dielectric is made uniform. As a result, high gain and high efficiency of the antenna are realized, and the structure may be notably reduced in size as compared with the conventional antenna of similar efficiency or similar gain.

Thus, according to this invention, the dielectric or magnetic medium loaded antenna is composed by comprising wave source, reflector and dielectric, and properly selecting the outer dimensions of the reflector and dielectric. In such dielectric antenna, the radio wave from the wave source is reflected in multiplex between the reflector and dielectric, or within the dielectric. Therefore, the vibration component in the running direction of the wave in the dielectric, the vibration component in the direction vertical to the running direction, and the vibration component between the reflector and dielectric are superposed, and the electromagnetic field distribution (especially the phase) in the vicinity of the dielectric is made uniform. As a result, high gain and high efficiency of the antenna are realized, and hence the structure may be notably reduced in size as compared with the conventional antenna having similar efficiency or similar gain.

It is other object of this invention to present a dielectric or magnetic medium loaded antenna with beam deflection, high efficiency and high gain capable of realizing deflection of directivity in a desired direction without excessively lowering the gain, while solving the above-discussed problems, reducing the size outstandingly, and notably enhancing the gain and radiation efficiency.

In accomplishing the above object, a dielectric or magnetic medium loaded antenna according to the invention comprises a reflector having a limited area, a wave source with an arbitrary polarized wave being disposed on the reflector, and at least either a dielectric equivalent piece or a magnetic equivalent piece disposed in the vicinity of the wave source side surface of the reflector, with the limited area on the side of the wave source, and having the center of the surface faced on the reflector positioned at a position different from the central axis of the wave source, high efficiency and high gain being realized in a small size.

In a preferred embodiment, projection area of at least either the dielectric equivalent piece or magnetic equivalent piece to the reflector is selected to be not larger than the area of the reflector.

In another preferred embodiment, both of a length in the axial direction of the dielectric equivalent piece or the magnetic equivalent piece and a maximum length of a sectional external form in a virtual plane of an arbitrary position parallel to the reflector are selected to be the operating wavelength multiplied by 2.5 or less.

In still another preferred embodiment, the dielectric equivalent piece and the magnetic equivalent piece are selected from materials such as high-molecular compound of Teflon resin, polyethylene resin or polypropylene resin; plural laminated or compounded materials differing in the dielectric constant; an artificial dielectric material; a dielectric equivalent materials in which the dielectric constant is assumed to be equivalent; a magnetic equivalent material in which the magnetic permeability is assumed to be equivalent; or other magnetic materials.

In yet another preferred embodiment, the wave source is a patch antenna.

In still another preferred embodiment, the axial line of the dielectric equivalent piece or the magnetic equivalent piece is inclined to a direction intersecting the normal direction of the reflector.

According to this invention, a dielectric or magnetic medium loaded antenna is composed by comprising a reflector with a limited area, a wave source of an arbitrary polarized wave pattern disposed on the reflector, and a dielectric medium disposed in the vicinity of the wave source side surface of the reflector, with the source side surface limited in area. In such dielectric antenna, the radio wave form the wave source is reflected in multiplex inside the dielectric in various directions.

In this invention, by properly selecting the relative displacement of the dielectric medium and the wave source, and the dimensions of dielectric medium or electric constants, superposition of vibration component in the running direction of the radio wave in the dielectric medium and the vibration component in the direction vertical to the running direction is realized, so that the electromagnetic field distribution (in particular the phase) in the dielectric medium is made uniform. As a result, high gain and high efficiency of the antenna are realized, and therefore the size of the construction may be notably reduced as compared with the conventional antenna with similar efficiency or similar gain.

Besides, since the wave source and the dielectric medium are displaced relatively, the direction of radiation of the electromagnetic wave emitted from the dielectric medium may be controlled in the direction crossing with the direction vertical to the reflector. Moreover, the beam deflection may be also formed so that the axial line of the dielectric medium may run along the direction crossing with the normal direction of the dielectric medium side surface of the reflector. Furthermore, by realizing the displacement of the dielectric and inclination of the axial line of the dielectric at the same time, the degree of the beam deflection which is one of the objects of this invention may be further enhanced.

In this way, according to the present invention, superposition of the vibration component in the running direction of the radio wave in the dielectric and the vibration component in the direction vertical to the running direction may be realized easily, and the electromagnetic field distribution (in particular the phase) in the dielectric is made uniform. As a result, high gain and high efficiency of this antenna are realized, and therefore when compared with the conventional antenna having similar efficiency or similar gain, the structure may be notably reduced in size. Besides, by disposing the wave source at a position different from the central position of at least one (dielectric medium) of dielectric equivalent piece and magnetic equivalent piece, the radiation direction of the electromagnetic wave emitted from the dielectric medium can be set in the direction crossing with the direction vertical to the reflector.

These and other obejcts, features and advantages of the invention will become more apparent upon a reading of the following detailed specification and drawings, in which:

Fig. 1 is a sectional view of a short backfire (SBF) antenna 1 as a first prior art;

Fig. 2 is a perspective view of a rod antenna 5 as a second prior art;

Fig. 3 is a plan view of a Yagi antenna 8 as a third prior art;

Fig. 4 is a perspective view of basic construction of an antenna 11 in one of the embodiments of this invention;

Fig. 5 is a plan view of the antenna 11;

Fig. 6 is a gain characteristic graph, using the function t/λ_0 of thickness of a dielectric 14 as a parameter in the same antenna 11;

Fig. 7 is a graph showing the gain and aperture efficiency with respect to the operating frequency f;

Fig. 8 is a graph showing the voltage standing wave ratio (VSWR) with respect to the operating frequency f;

Fig. 9A and Fig. 9B are graphs showing the directivity of the antenna 11;

Fig. 9C is a perspective view of an electromagnetic horn antenna in a reference example;

Fig. 9D is a perspective view showing the principle of the construction of the antenna 11;

Fig. 10 is a perspective view of a dielectric or magnetic medium loaded antenna of other embodiment of this invention using a dipole antenna 17 as the wave source;

Fig. 11 is a perspective view of a dielectric or magnetic medium loaded antenna of a further different embodiment of this invention using a patch antenna 18 as the wave source;

Fig. 12 is a front view of a dielectric or magnetic medium loaded antenna of another different embodiment of this invention using a stripline antenna 19 as the wave source;

Fig. 13 and Fig. 14 are front views showing the reflector 13 or dielectric 14 in an embodiment of this invention;

Fig. 15 and Fig. 16 are plan views showing array antennas 21, 21a in a still different embodiment of this invention;

Fig. 17 is an exploded perspective view of an antenna 11a in a different embodiment of this invention;

Fig. 18 is an exploded perspective view of an antenna 11b in a further different embodiment of this invention;

Fig. 19 is a front view of a reflector 13 of the antenna 11b;

Fig. 20 is an exploded perspective view of an antenna 11c in another different embodiment of this invention;

Fig. 21 is a plan view of an antenna 11d;

Fig. 22 is a front view of an antenna 111 is one of the embodiments of this invention;

Fig. 23 is a side view of the antenna 111;

Fig. 24 to Fig. 28 are diagrams to show the changes in directivity;

Fig. 29 is a perspective view showing the basic construction of an antenna 111a in a different embodiment of this invention;

Fig. 30 is a diagram to show the directivity of the antenna 111a;

Fig. 31 is a graph showing the changes in the gain of the antenna 111a;

Fig. 32 is a diagram to show the directivity of the antenna 111a; and

Fig. 33 is a graph showing the changes in the gain of the antenna 111a.

Referring now to the drawings, embodiments of the invention are described below.

Fig. 4 is a perspective view showing a basic constitution of a dielectric or magnetic medium loaded antenna (hereinafter abbreviated as antenna) 11 in one of the embodiments of this invention, and Fig. 5 is a plan view of the same antenna 11. The antenna 11 of this embodiment is explained below by referring to Fig. 4 and Fig. 5. The antenna 11 of this embodiment comprises a waveguide 12 of which section at right angle to the axis is, for example, a square, and a reflector 13 of rectangular plate made of metal material is fixed at one end thereof in the longitudinal direction, at right angle to the axial line of the waveguide 12. This reflector 13 has an aperture 13a communicating with the waveguide 12. At an interval of h from this reflector 13, a dielectric 14 of rectangular parallelopiped is disposed. This dielectric 14 is made of, for example, Teflon resin, polyethylene resin or epoxy resin.

The contour of said reflector 13 is, for example, a rectangular form, possessing side lengths D1, D2. The dielectric 14, possesses a thickness t along the axial line direction of the waveguide 12, a length D3 in the vertical direction along two directions orthogonally crossing with the axial line direction of the waveguide 12, and a length D4 in the lateral direction.

Relating to the antenna possessing the reflector 13, using the waveguide 12 as the wave source, as stated above, by disposing the dielectric 14 as described hereabove, the electromagnetic wave emitted from the aperture 13a is reflected between the reflector 13 and the dielectric 14 along the two directions along the axial line direction of the waveguide 12 as indicated by arrow A1 in Fig. 4. In the dielectric 14, moreover, it is reflected in multiplex in the arrow A1 direction and in the direction along the directions mutually crossing orthogonally (indicated by arrows A2, A3 in Fig. 4) to compose a plane orthogonally crossing with the direction of arrow A1. Consequently, the surface wave and diffraction wave are excited in the directions of said arrows A1 to A3 between the reflector 13 and dielectric 14, and inside the dielectric 14, so that standing waves are generated.

Besides, between the reflector 13 and dielectric 14, the electromagnetic wave is reflected along the direction of arrow A1 as mentioned above, and by such electromagnetic wave, the gain is increased by the diffraction at the end parts 15, 16 of the reflector 13 and dielectric 14. That is, the electromagnetic field distribution (especially the phase) in the vicinity of the dielectric 14 may be made uniform. Making uniform here means the action of superposing the electromagnetic wave reflected or diffracted by said end parts 15, 16, and the electromagnetic wave reflected in multiplex between the dielectric 14 and the reflector 13. The area of the reflector 13 is finite, and thereby by repeating reflection or diffraction at the end parts 15, 16, the phases of the emitted electromagnetic waves are aligned. As a result, the gain is enhanced.

Fig. 6 is a graph showing the characteristics of the same antenna 11. The axis of abscissas denotes a numerical value of the thickness t normalized by the operating wavelength λ_0, and the axis of ordinates represents the gain. The dielectric 14 of this embodiment is, for example, made of Teflon, which is selected at the specific inductive capacity of 2.0 and the interval of $h = \lambda_0/2$. This example is explained below. In Fig. 6, curve $\ell 1$ shows the characteristic of

$D1 = D2 = D3 = D4 = 1.5\lambda_0$ .... (1)

in Fig. 1, curve $\ell 2$ shows the characteristic of

$D1 = D2 = D3 = D4 = 2.0\lambda_0$ .... (2)

and curve $\ell 3$ shows the characteristic of

$D1 = D2 = D3 = D4 = 4.0\lambda_0$ .... (3)

Referring also to Fig. 6, hereinafter, the characteristic of antenna 11 is described in details. In the case of equiation (1), as clear in Fig. 6, the gain becomes maximum at

$t/\lambda_0 \fallingdotseq 1.5$ .... (4)

and in the case of equation (2), the gain reaches the maximum at

$t/\lambda_0 \fallingdotseq 2$ .... (5)

which may be understood easily. In the case of equation (3), the gain is unstable as shown in Fig. 6, and in the range of

$t/\lambda_0 > 0.5$ .... (6)

the maximal values of vibrations are nearly equal, which may be understood to be approximate to the phenomenon when the dielectric 14 is sufficiently (or infinitely) broad.

That is, in the antenna 11 possessing the construction as shown in Fig. 4 and Fig. 5, when the area of the surfaces 13s, 14s mutually opposing to the reflector 13 and dielectric 14 is more than $16\lambda_0^2$ approximately, it may be understood that the effect of reflection and diffraction by the end parts 15, 16 does not appear. Moreover, as the side lengths D1 to D4 of the reflector 13 and dielectric 14 vary from $4\lambda_0$ to $1.5\lambda_0$, the gain of the antenna 11 tends to be improved. It has been confirmed by the present inventor that such trend is not changed if the interval h between the reflector 13 and the dielectric 14 varies.

Fig. 7 is a graph shows the experimental result about the gain and aperture efficiency with respect to the operating frequency f [GHz] of the same antenna 11. In Fig. 7, the x-mark indicates the aperture efficiency, and the ●-mark denotes the gain. Meanwhile, the dielectric used in this experiment is, same as explained in Fig. 6, made of Teflon, of which specific inductive capacity is selected at 2.0 and interval at $h = \lambda_0/8$. The present inventor confirmed that the gain and aperture efficiency become the most preferable numerical values, as mentioned below, when the interval h is $\lambda_0/8$. This experiment was conducted, using the antenna 11 in the structure shown in Fig. 4, in the conditions of

$D/\lambda_0 = 1.5$ .... (7)

$t/\lambda_0 = 1.874$ .... (8)

$h/\lambda_0 = 1/8$ .... (9)

assuming the side lengths D1, D2, D3, D4 to be reference symbol D commonly. At this time, as clear from Fig. 7, the frequency band width BW is

$BW/f_0 > 0.3$ .... (10)

and within the range of the frequency band width BW, the efficiency was over 100%, and the maximum efficiency of 225% was obtained.

Fig. 8 is a graph showing the relation between the frequency and voltage standing wave ratio (VSWR). The experimental data disclosed in Fig. 8 was obtained in the same conditions as in equations (7) to (9) above. The voltage standing wave ratio (VSWR) of TE_{10} mode in the waveguide 12 is indicated by the ●-mark in Fig. 8. Within the frequency band shown in Fig. 8,

$VSWR < 1.5$ .... (11)

is obtained.

Fig. 9A and Fig. 9B are graphs respectively showing the radiation characteristics of plane E (electric field plane) and plane H (magnetic field plane) at the operating frequency f_0 in the conditions shown in equations (7) to (9) above. The antenna 11 of this embodiment has been confirmed to possess the radiation characteristic shown in Fig. 9A.

The present inventor experimented to compare the function of this antenna 11 with the typical conventional electromagnetic horn antenna. The structural principles of the electromagnetic horn antenna 23 and the antenna 11 used in this experiment are shown in Fig. 9C and Fig. 9D. The electromagnetic horn antenna 23 is composed by coaxially connecting an electromagnetic horn 25 in truncated pyramid form to the front end of a waveguide 24. Examples of dimensions of the parts of such electromagnetic horn antenna 23 and antenna 11, and changes in the gain are explained below. Outer dimensions of the aperture are, relating to the symbols used in Fig. 9C and Fig. 9D, A = 50.7 mm, B = 66.7 mm, and D = 38.1 mm, and therefore the aperture area is 2824.0 mm^2 in the electromagnetic horn antenna 23, and 1452.3 mm^2 in the antenna 11. The depths were designed at L = 119.5 mm, H = 50.7 mm. The gains of such electromagnetic horn antenna 23 and antenna 11 were respectively 13.2 dB and 14.5 dB at the operating frequency of 8 GHz.

Thus, in the antenna 11 of this invention, as compared with the electromagnetic horn antenna 23, the aperture area is about half and the depth is about 0.43 times, while the gain in the operating frequency band can be enhanced in a range or 1.3 dB. As a result, the antenna 11 having a capacity similar to that of the electromagnetic horn antenna 23 has been confirmed to be notably reduced in size.

The explanation of this embodiment related to the aperture antenna as shown in Fig. 4, but the same embodiment may be easily executed by using, as the wave source, a dipole antenna 17 as shown in Fig. 10, a patch antenna 18 as shown in Fig. 11, or a stripline antenna 19 as shown in Fig. 12. Moreover, the present invention is not limited to these wave sources alone, but it may be embodied in any arbitrary wave source including slit antenna.

In the dielectric antenna using dipole antenna 17, patch antenna 18 and stripline antenna 19 as the wave source shown in Fig. 10 to Fig. 12, an intervening member 30 being made of, for example, styrene resin is disposed as spacer between the reflector 13 and the dielectric 14. Regarding such intervening member 30, a hollow capavity is formed between the wave source and the dielectric 14. Such constitution using the intervening member 30 may be similarly realized in the antenna 11 shown in Fig. 4 and Fig. 5.

In the above embodiment, the reflector 13 was explained as a rectangular plate and the dielectric 14 as a rectangular parallelopiped, but such reflector 13 or dielectric 14 may be of rectangular or square shape as shown in the drawings in the view from the longitudinal direction of the waveguide 12 (Fig. 13, Fig. 14), or may be of a circular shape. The polarized wave pattern of the electromagnetic wave emitted from the wave source may be linear polarized wave, circular polarized wave or ellipsolidal polarized wave, and the shape of the dielectric 14 may be polygonal plate, polygonal rod, disc or circular rod, and embodiments will be possible in any shape thereof.

As a further different embodiment of this invention, using the antenna 11 shown in Fig. 4 as the basic element, a plurality thereof may be arranged to be used as an array antenna. Such example is shown in Fig. 15 and Fig. 16. Fig. 15 is a configuration of the wave sources 20 in the square matrix form at pitch L. Fig. 16 is a zigzag arrangement of wave sources 20 at mutual distance of L. In these constitutions, too, the above effects of this embodiment may be realized, and antennae of higher gain and higher efficiency may be composed.

The mutually opposing surfaces 13a and 14s of the reflector 13 and dielectric 14 of this invention are not limited to flat surfaces, generally, and curved surfaces of the second order or higher or continued surface of small flat planes may be applied. That is, the "parallelism" between the reflector 13 and dielectric 14 in this invention means that the corresponding parts should be parallel to each other when the mutually opposing surfaces 13s, 14s of the two are divided into small areas in the corresponding units, and it is not intended to limit to the state in which the surfaces 13s, 14s should be flat surfaces on the whole and be parallel to each other.

Fig. 17 is an exploded perspective view showing the composition of antenna 11a in a different embodiment of this invention. This antenna 11a is similar to that of the foregoing embodiment, and the corresponding parts are identified with same reference numbers. What is of note in this embodiment is that the reflector 13 connected to the waveguide 12 as a wave source, for example, is composed so that the surface 13s opposing to the dielectric 14 may be approximately conical, and also that the surface 14s of the dielectric 14 opposite to the reflector 13, and the surface 14r of the dielectric 14 at the opposite side of the surface 14s are formed so as to be shaped corresponding to the surface 13s of the reflector 13.

The approximately conical surface formed by said surfaces 13s 14s, 14r may be selected so that the apex angle $\theta 1$ when cut off at the virtual plane including their axia line may be an acute triangle as shown in Fig. 17. Even in such constitution, it is possible to realize the same effects as those mentioned in the foregoing embodiment may be realized.

Fig. 18 is an exploded perspective view showing a constitution of antenna 11b of another embodiment of this invention, and Fig. 19 is a front view of the reflector 13 of the antenna 11b. Referring then to Fig. 18 and Fig. 19, the antenna 11b is described below. This antenna 11b is also similar to the antennae disclosed in the foregoing embodiments, and corresponding parts are identified with same reference numbers. What is of note in this embodiment is that the reflector 13 connected to the waveguide 12 as a wave source is formed in a shape so that a pair of flat metal plates may mutually form an angle $\theta 2$. This angle $\theta 2$ may be selected as

$\theta 2 > 90$ degrees. .... (12)

That is, the dielectric 14 is formed so that its section at right angle to the axis thereof may be approximately V-shaped. The aperture 13a of the reflector 13 is formed so that the length L1 long the longitudinal direction of the junction part 13b of the reflector 13 and the length L2 in the direction orthogonally crossing therewith are in the relation of

$L1 < L2$ .... (13)

Even in such antenna 11b, the same effects as mentioned in the foregoing embodiments may be realized.

Fig. 20 is an exploded perspective view showing a constitution of antenna 11c in another different embodiment of this invention. This invention is fundamentally similar to the antenna 11b explained by reference to Fig. 18 and Fig. 19, except that a patch array antenna 22 is used as the wave source, intead of the waveguide 12, being disposed parallel at both sides of the junction part 13b of the reflector 13. In this constitution, too, the same effects as in the foregoing embodiment may be obtained.

Fig. 21 is a plan view of antenna 11d in a still different embodiment of this invention. This embodiment is also similar to the antenna 11b of the foregoing embodiment, in principle, and its feature is that a single row of patch array antenna 22 is disposed on the junction 13b of the reflector 13 in its longitudinal direction. In this constitution, similarly, the same effects as in the foregoing embodiment may be obtained.

Incidentally, in the antenna 11a explained by reference to equation (14), the reflector 13 and dielectric 14 were formed to possess approximately conical surfaces, but it may be also possible to compose so as to form polygonal conical surfaces, instead of conical surface.

Fig. 22 is a front view showing a basic composition of a dielectric antenna (hereinafter called antenna) 111 in a different embodiment of this invention, and Fig. 23 is a side view of the antenna 111. The antenna 111 of this embodiment is described below while referring to Fig. 22 and Fig. 23. The antenna 111 of this embodiment contains a patch antenna 112, and the patch antenna 112 is mounted in a square-shaped reflector 113 having a side length of D11. The reflector 113 is composed of a copper plate 113a, and a resin layer 113b, such as Teflon resin, to cover this copper plate 113a, and the patch antenna 112 is fixed on the resin layer 113b.

At an interval of h1 from this reflector 113, a dielectric 114 of a rectangular parallelopiped is disposed. This dielectric 114 may be made of, for example, Teflon resin, polyethylene resin or epoxy resin. The dielectric 114 may not be made of a single resin alone, but may be composed by laminating plural materials differing in the dielectric constant, or a dielectric equivalent material such as an artificial dielectric may be used, too. Or not limiting to the dielectric equivalent materials in which the dielectric constant is assumed, a magnetic equivalent material in which the magnetic permeability is assumed may be used. As such magnetic equivalent material, ferrite or other magnetic materials may be used.

The dielectric 114 possesses a thickness t1 along the normal direction of the reflector 113, and a vertical direction length D13 and a lateral direction length D12 along the two directions orthogonal to the axial line direction of the patch antenna 112.

In such constitution possessing the reflector 113 using patch antenna 112 as wave source, by disposing said dielectric 114, the electromagnetic wave generated from the patch antenna 112 is reflected between the reflector 113 and dielectric 114 along the two directions along the normal direction of the patch antenna 112 as indicated by arrow A11 in Fig. 22. Within the dielectric 114, moreover, it is reflected in multiplex in the arrow A11 direction, and in the direction along the directions (indicated by arrows A12, A13 in Fig. 22) orthogonally crossing with each other to form a plane which orthogonally crosses with the arrow A11 direction. As a result, the surface wave and diffraction wave are excited in the directions of said arrows A11 to A13 between the reflector 113 and dielectric 114 and within the dielectric 114, so that standing waves are produced.

It is an essential aim of this invention to, relating to the antenna 111 having a basic constitution as shown in Fig. 22 and Fig. 23, set a displacement δ_E (δ_H) between the central position of the patch antenna 112 and the axial line $\ell 11$ of the dielectric 114, and emit the electromagnetic waves in the direction (indicated by arrow B12 in Fig. 23) intersecting at angle $\theta 1$ with the normal direction (indicated by arrow B11 in Fig. 23) of the reflector 113.

Subscripts E , H of said displacement δ_E (δ_H) denote the displacements along the direction of electric field (indicated by arrow E in Fig. 22) of the electromagnetic wave in which said displacement δ_E (δ_H) is emitted as shown in fig. 22, and the displacement $\delta_H$indicates a displacement along the direction vertical to said electric field direction E.

Meanwhile, between the reflector 113 and the dielectric 114, as mentioned above, the electromagnetic wave is reflected along the direction of arrow A11, and by such electromagnetic wave, the gain is increased by the diffraction at the end parts 115, 116 of the dielectric 114. That is, the elecromagnetic field distribution (in particular the phase) in the vicinity of the dielectric 114 may be made uniform. Making uniform, here, means the action of superposing the electromagnetic wave reflected or diffracted by the end parts 115, 116 with the electromagnetic wave reflected in multiplex between the dielectric 114 and the reflector 113. The area of the dielectric 114 is finite, and there by repeating the reflection or diffraction at the end parts 115, 116, the phases of the irradiated electromagnetic waves are aligned. As a result, the gain is raised.

Fig. 24 is a diagram showing the directivity when the displacement δ_E of the antenna 111 shown in Fig. 22 and Fig. 23 is changed to $0.25\lambda_o$, $0.5\lambda_o$ in the condition shown in Table 1. As clear from Fig. 24, this antenna 111 shows the maximum deflection angle of about 25 degrees at $\delta_E = 0.5\lambda_o$, and as compared with the case of $\delta_E = 0$, although the level is lowered, the output is notably amplified when comparing with the output level with the patch antenna 112 only as indicated by curve ℓp in Fig. 24.

Table 1 Type of wave source : Square patch antenna
Dielectric : Teflon
Area of reflector (D1) : $6.5(\lambda_o) \times 6.5(\lambda_o)$
Area of dielectric (D2) : $1.5(\lambda_o) \times 1.5(\lambda_o)$
Thickness of dielectric (t1) : $2(\lambda_o)$
Reflector-dielectric interval (h1) : $0.125(\lambda_o)$
Frequency (f) : 8.85(GHz)
Recorder (full scale) : 102(mV. ∝W)

Fig. 25 is a diagram to show the changes in the directivity when the antenna 111 of this embodiment is set at δ_E = 0, 0.25, $0.5\lambda_o$ in the condition shown in Table 2. In this experiment, the interval h1 between the reflector 113 and the dielectric 114 is nearly 1 mm, and the thickness t1 of the dielectric is increased about 5 to 10 mm as compared with the above cases.

Table 2 Type of wave source : Square patch antenna
Dielectric :Teflon
Area of reflector (D1) : $6.5(\lambda_o) \times 6.5(\lambda_o)$
Area of dielectric (D2) : $1.5(\lambda_o) \times 1.5(\lambda_o)$
Thickness of dielectric (t1) : $2.1(\lambda_o)$
Reflector-dielectric interval(h1) : $0.03(\lambda_o)$
Frequency (f) : 8.85(GHz)
Recorder (full scale) : 102(mV. ∝W)

In this case, as shown in Fig. 25, as compared with the interval of about 3.2 mm in Fig. 24, it may be understood that the gain is not lowered so much if the directivity changes. Incidentally, curve ℓp in Fig. 25 represents the directivity in the state of disposing only the patch antenna 112 on the reflector 113, except the dielectric 114, in the constitution shown in Fig. 22 and Fig. 23. According to the data obtained from this experiment, the maximum value of the relative electric power has been confirmed to be about 10 times as high as compared with curve ℓp above.

Fig. 26 is a diagram showing the directivity changes when the displacement δ_H of the dielectric 114 in Fig. 22 is changed to 0, 0.25, $0.5\lambda_o$ in the condition shown in Table 3. As graphically shown, the variation of directivity on plane H has been confirmed to be nearly same as that of directivity on plane E.

Table 3 Type of wave source : Square patch antenna
Dielectric :Teflon
Area of reflector (D1) : $6.5(\lambda_o) \times 6.5(\lambda_o)$
Area of dielectric (D2) : $1.5(\lambda_o) \times 1.5(\lambda_o)$
Thickness of dielectric (t1) : $1.9(\lambda_o)$
Reflector-dielectric interval(h1) : $0.125(\lambda_o)$
Frequency (f) : 8.85 (9.04) (GHz)
Recorder (full scale) : 120(mV. ∝W)

Fig. 27 is a diagram showing the directivity when the operating frequency is set at 8.0 GHz in the condition shown in Table 4. In this experiment, the displacement of dielectric 114 is set at $\delta_H = 0.5\lambda_o$. According to the experiment by the present inventor, if the operating frequency was changed to 9.0 or 9.5 GHz in the same condition as in Table 4, the deflection of the directivity was confirmed to be nearly the same if the displacement δ_H of the dielectric 114 was unchanged.

Table 4 Type of wave source : Square patch antenna
Dielectric : Teflon
Area of reflector (D1) : $6.5(\lambda_0) \times 6.5(\lambda_0)$
Area of dielectric (D2) : $1.5(\lambda_0) \times 1.5(\lambda_0)$
Thickness of dielectric (t1) : $2.22(\lambda_0)$
Reflector-dielectric interval(h1) : $0.03(\lambda_0)$
Frequency (f) : 8.85 8.0(GHz)
Recorder (full scale) : 57.0(mV. $\propto$W)

Fig. 28 shows the changes in the directivity when the operating frequency band is set at 8.0, 8.5, 9.0, 9.5 GHz in the condition nearly same as shown in Table 5. In these diagrams, the recorder (full scale) was set at 44, 58, 53, 33 mV, respectively. The displacement was commonly set at $\delta_E = 0.5\lambda_0$.

Table 5 Type of wave source : Square patch antenna
Dielectric : Teflon
Area of reflector (D1) : $6.5(\lambda_0) \times 6.5(\lambda_0)$
Area of dielectric (D2) : $1.5(\lambda_0) \times 1.5(\lambda_0)$
Thickness of dielectric (t1) : 74.5(mm)-(λ_0)
Reflector-dielectric interval(h1) : $0.03(\lambda_0)$
Frequency (f) : 8.0(GHz)
Recorder (full scale) : 44(mV. $\propto$W)

In this experiment, on plane E, different from the case of directivity of plane H explained by reference to Fig. 27, it has been confirmed that the displacement increases as the operating frequency goes up.

In the above experiments, in the antenna 111 of this embodiment shown in Fig. 22 and Fig. 23, the phenomenon of deflection of the directivity of emitted electromagnetic wave by angle θ (see Fig. 23) was realized by setting the displacement δ_E, δ_H, and it was found that such deflection of radiation electromagnetic wave is realized also in a consitution, as shown in Fig. 28, where the axial line ℓ11 of the dielectric 114 disposed on the reflector 113 in Fig. 23 is inclined by angle α with respect to the normal B11 of the reflector 113 (omitted in Fig. 29). Hereinafter the experimental data confirming this phenomenon is explained. In the experiment described below, a spacer 117 made of dielectric substance is disposed between the dielectric 114 and the reflector 113. The directivity was measured by varying the deflection δ between the graphic center of the surface of the reflector 113 side of the dielectric 114 and the graphic center of the patch antenna 112.

Fig. 30 shows the changes in the directivity of plane E when the displacement is changed as δ_E = 0 λ_0/8, -2λ_0/8, -4λ_0/8, -6λ_0/8, -8λ_0/8, in the condition as shown in Table 6, with the displacement direction of said displacement δ as the direction of electric field E1, and the inclination angle of dielectric 114 as α = 20°. In this experiment, the minus sign of the displacement $\delta_E$denotes the displacement in the opposite direction of the arrow E1.

As shown in Fig. 30, when the dielectric 114 is inglined by angle α as indicated in Fig. 29, it has been confirmed that the gain is increased when the directivity of the obtained beam is deviated off the normal direction B11 of the reflector 113. It is also known that the deviation angle exceeds the maximum of 30°.

Table 6 Type of wave source : Square patch antenna
Dielectric : Polyethylene
Area of reflector (D1) : $6.5(\lambda_0) \times 6.5(\lambda_0)$
Area of dielectric (F2) : $1.5(\lambda_0) \times 1.5(\lambda_0)$
Thickness of dielectric (t1) : $1.89(\lambda_0)$
Reflector-dielectric interval(h1) : $0.125(\lambda_0)$
Frequency (f) : 9.0(GHz)
Recorder (full scale) : 103(mV. $\propto$W)

Fig. 31 is a graph showing the change in the gain of the antenna 112 in the same condition as in the condition to explain Fig. 30 (including the condition of Table 6). As shown in Fig. 31, this antenna 111 has been confirmed to have the maximum gain in the vicinity of the operating frequency of 9.0 GHz.

Fig. 32 is a diagram to show the changes in the directivity of plane H when the condition is set as follows as for the displacement δ_H (= δ) of the dielectric 114 at the inclination angle of α = 20° of the dielectric 114. Changes in the directivity of plane H were measured at the displacement of δ_H = 0λ_0/8, -2λ_0/8, -4δ_0/8, -6λ_0/8, -8λ_0/8. Thus, as for plane H, it has been found that the emitted beam is deviated according to the displacement H of the dielectric 114.

Fig. 33 is a graph showing the changes in the gain of plane H of the antenna 111 in the measuring condition in Fig. 32. Thus, on plane H, too, it has been confirmed that similar characteristics as observed on plane E explained by referring to Fig. 30 and Fig. 31 are obtained.

Summing them up all, in the antenna 111 composed as shown in Fig. 29, if changing in magnitude continuously in individual directions as the displacement δ_H or displacement δ_E, it has been confirmed that the directivity of the emitted beam changes also continuously. As the displacement of the directivity increases, it has been recognized that a by far great output may be obtained as compared with the conventional case of using only patch antenna 112 without using dielectric 114, although the gain of the emitted beam is lowered.

In the foregoing embodiments, meanwhile, the antenna 111 was explained as a single element, not an array, but this is for the sake of convenience of explaining the principle of this invention, and this antenna 111 may be naturally used in the array antenna arranged in a matrix, zigzag form or linear form. In this case, this antenna 111 used as one element may be restricted in the gain to a certain extent, and a desired gain as the entire array antenna may be realized. Thus, an array antenna of a notably small size and high gain may be realized.

This invention is intended to make sue of the edge effect based on the reflection and diffraction of the electromagnetic waves by the end parts 115, 116 of the square dielectric 114, and is not designed to make use of the well-known so-called lens effect of the dielectric mounted on the antenna. That is, this is to make sue of the so-called guide effect based on the multiplex reflection of the electromagnetic wave in the dielectric 114.

Besides, considering that the dielectric 114 is square-shaped, this invention is intended to realize the above-mentioned effects on the basis of said guide effect along the normal direction (arrow B1 in Fig. 23) of the reflector 113 and the guide effect along the direction vertical to the normal direction.

This invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

Claims

1. A dielectric or magnetic medium loaded antenna (11) comprising:

a wave source (12) of an arbitrary polarized wave,

a reflector (13) disposed near the wave source (12), with the surface opposite to the wave source (12) limited in area, and

a dielectric (14) disposed on the opposite side of the reflector across the wave source (12), at least with the surface opposite to the reflector (13) formed parallel to the reflector (13).

2. A dielectric or magnetic medium loaded antenna (11) as claimed in claim 1, wherein the specific inductive capacity of the dielectric (14) is selected approximately within 10.

3. A dielectric or magnetic medium loaded antenna (11) as claimed in claim 1, wherein the projection area of the dielectric (14) to the reflector (13) is selected to be not larger than the area of the reflector (13).

4. A dielectric or magnetic medium loaded antenna (111) comprising:

a reflector (113) having a limited area,

a wave source (112) with an arbitrary polarized wave being disposed on the reflector (113), and

at least either a dielectric equivalent piece (114) or a magnetic equivalent piece (114) disposed in the vicinity of the wave source (112) side surface of the reflector (113), with the limited area on the side of the wave source, and having the center of the surface faced on the reflector (113) positioned at a position different from the central axis of the wave source (112),

high efficiency and high gain being realized in a small size.

5. A dielectric or magnetic medium loaded antenna (111) as claimed in claim 4, wherein projection area of at least either the dielectric equivalent piece (114) or magnetic equivalent piece (114) to the reflector (113) is selected to be not larger than the area of the reflector (113).

6. A dielectric or magnetic medium loaded antenna (111) as claimed in claim 4, wherein both of a length in the axial direction of the dielectric equivalent piece (114) or the magnetic equivalent piece (114) and a maximum length of a sectional external form in a virtual plane of an arbitrary position parallel to the reflector (113) are selected to be the operating wavelength multiplied by 2.5 or less.

7. A dielectric or magnetic medium loaded antenna (111) as claimed in claim 4, wherein the dielectric equivalent piece (114) and the magnetic equivalent piece (114) are selected from materials such as high-molecular compound of Teflon resin, polyethylene resin or polypropylene resin; plural laminated or compounqrded materials differing in the dielectric constant; an artificial dielectric material; a dielectric equivalent materials in which the dielectric constant is assumed to be equivalent; a magnetic equivalent material in which the magnetic permeability is assumed to be equivalent; or other magnetic materials.

8. A dielectric or magnetic medium loaded antenna (111) as claimed in claim 4, wherein the wave source (112) is a patch antenna.

9. A dielectric or magnetic medium loaded antenna (111) as claimed in claim 4, wherein the axial line of the dielectric equivalent piece (114) or the magnetic equivalent piece (114) is inclined to a direction intersecting the normal direction of the reflector (113).

Fig. 1

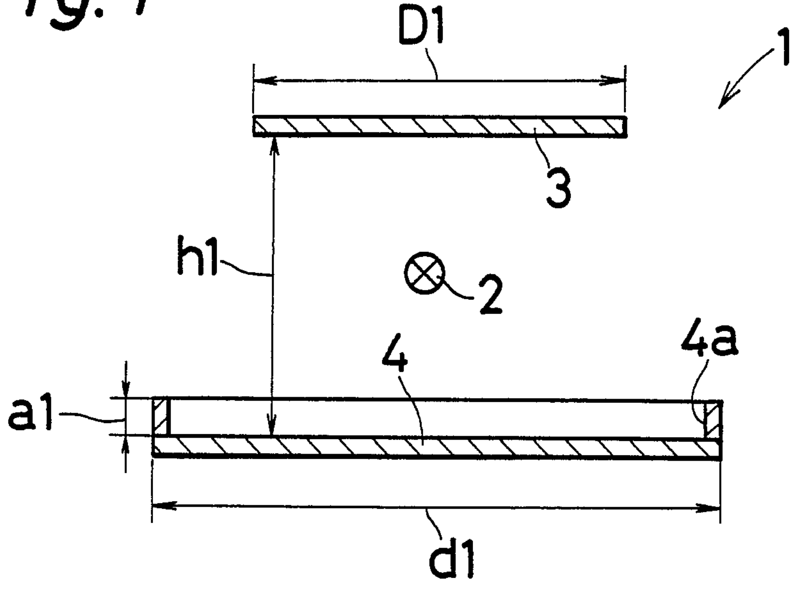

Fig. 2

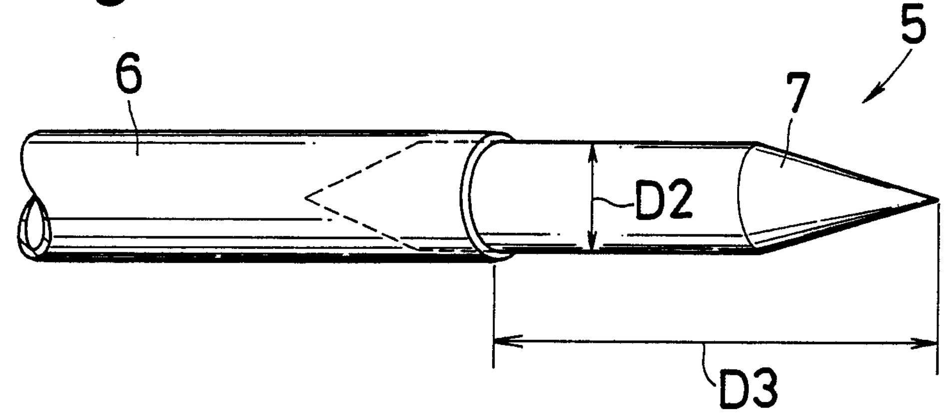

Fig. 3

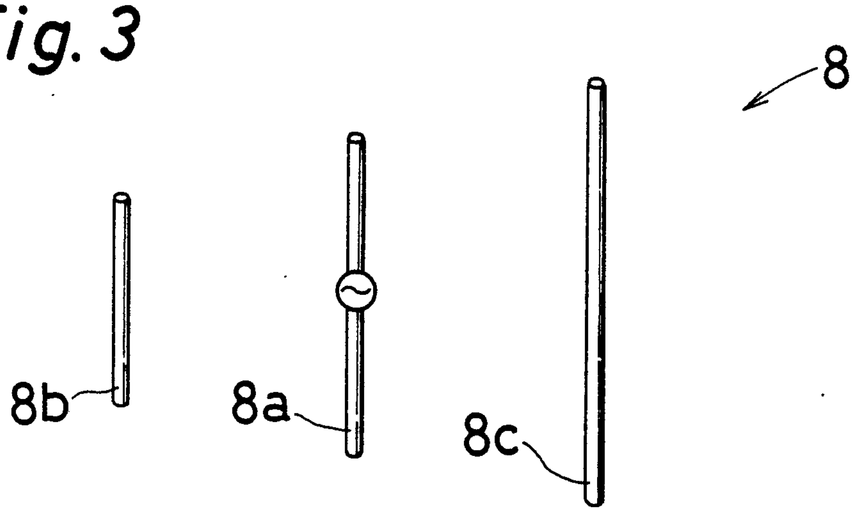

Fig. 4

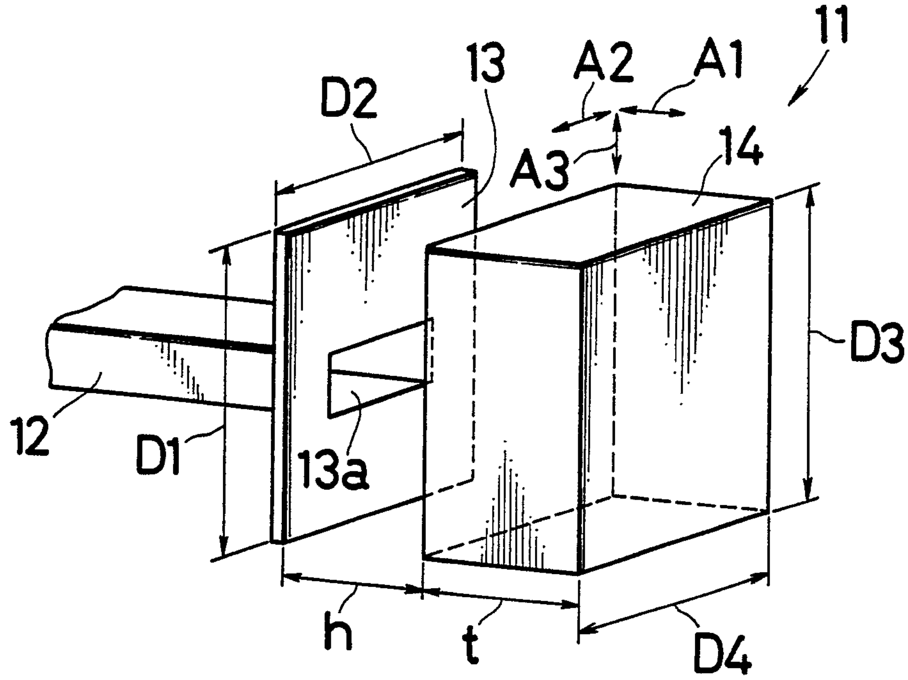
11
13
A2
A1
D2
A3
14
D3
12
D1
13a
h
t
D4

Fig. 5

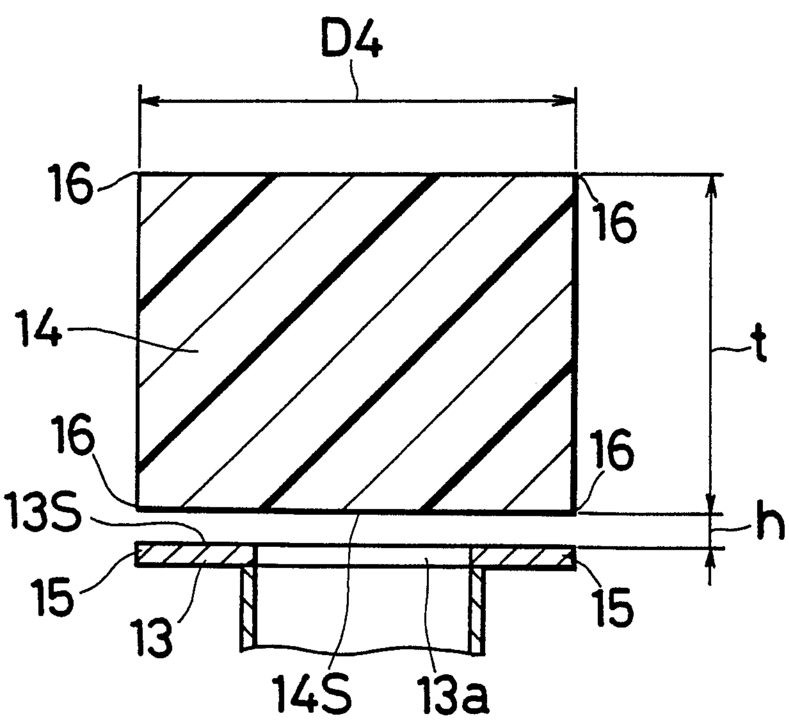
D4
16
16
14
t
16
16
13S
h
15
15
13
14S
13a

Fig. 6

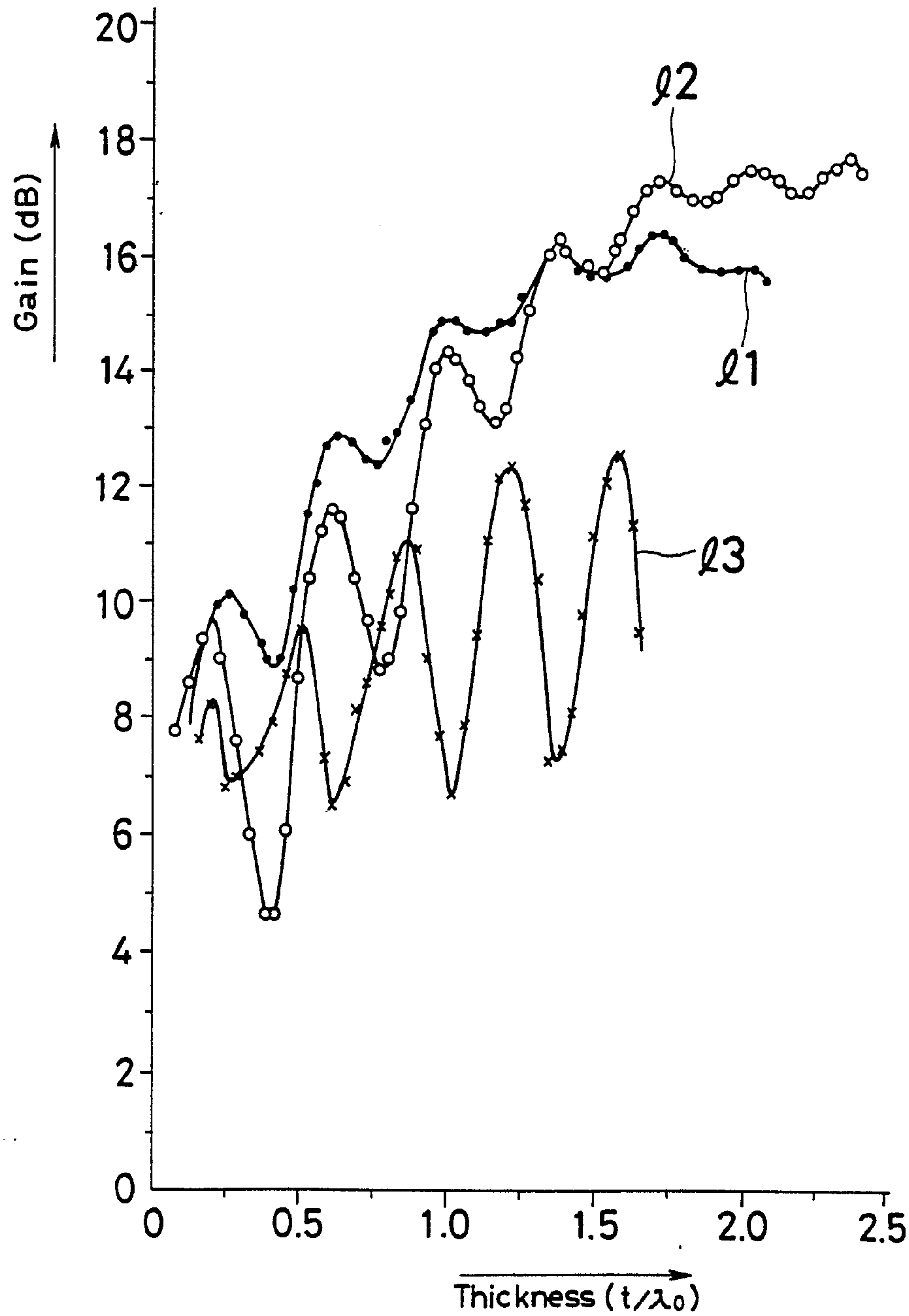
Gain (dB)
20
18
16
14
12
10
8
6
4
2
0
0
0.5
1.0
1.5
2.0
2.5
Thickness (t/λ0)
ℓ1
ℓ2
ℓ3

Fig. 7

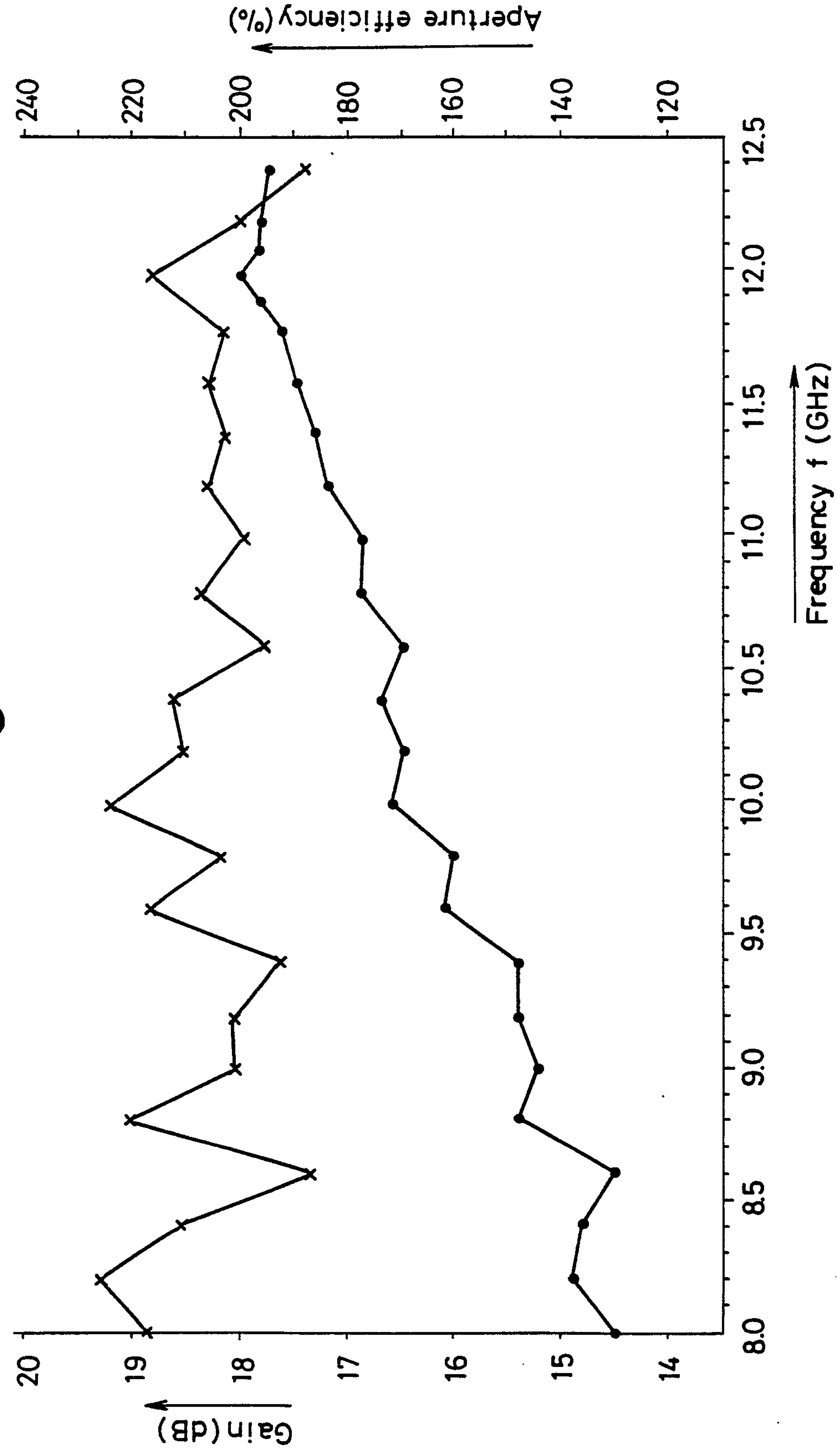
Aperture efficiency (%)
240
220
200
180
160
140
120
Gain (dB)
20
19
18
17
16
15
14
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
Frequency f (GHz)

Fig. 8

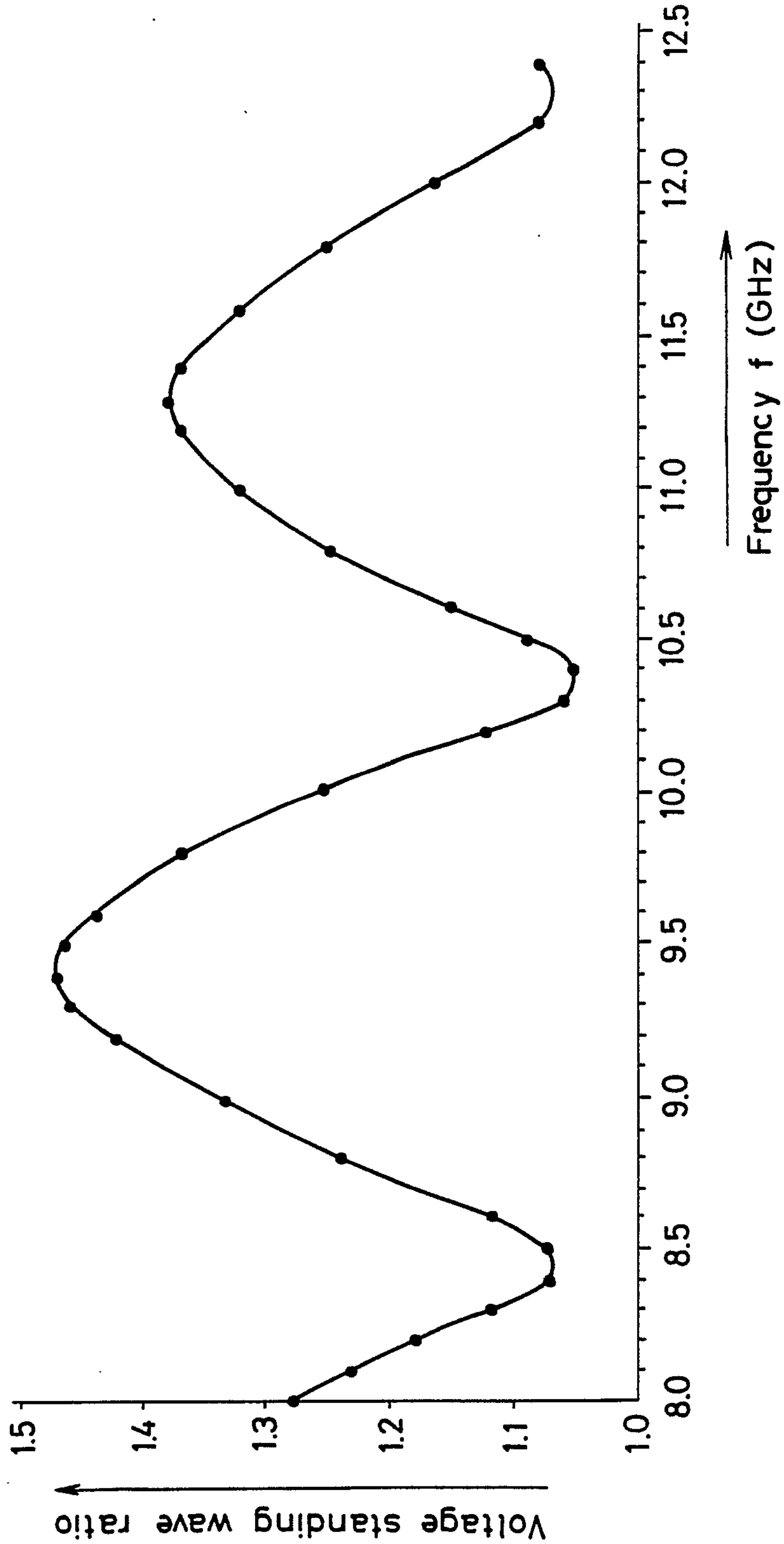
Voltage standing wave ratio
1.0
1.1
1.2
1.3
1.4
1.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
Frequency f (GHz)

Fig. 9A

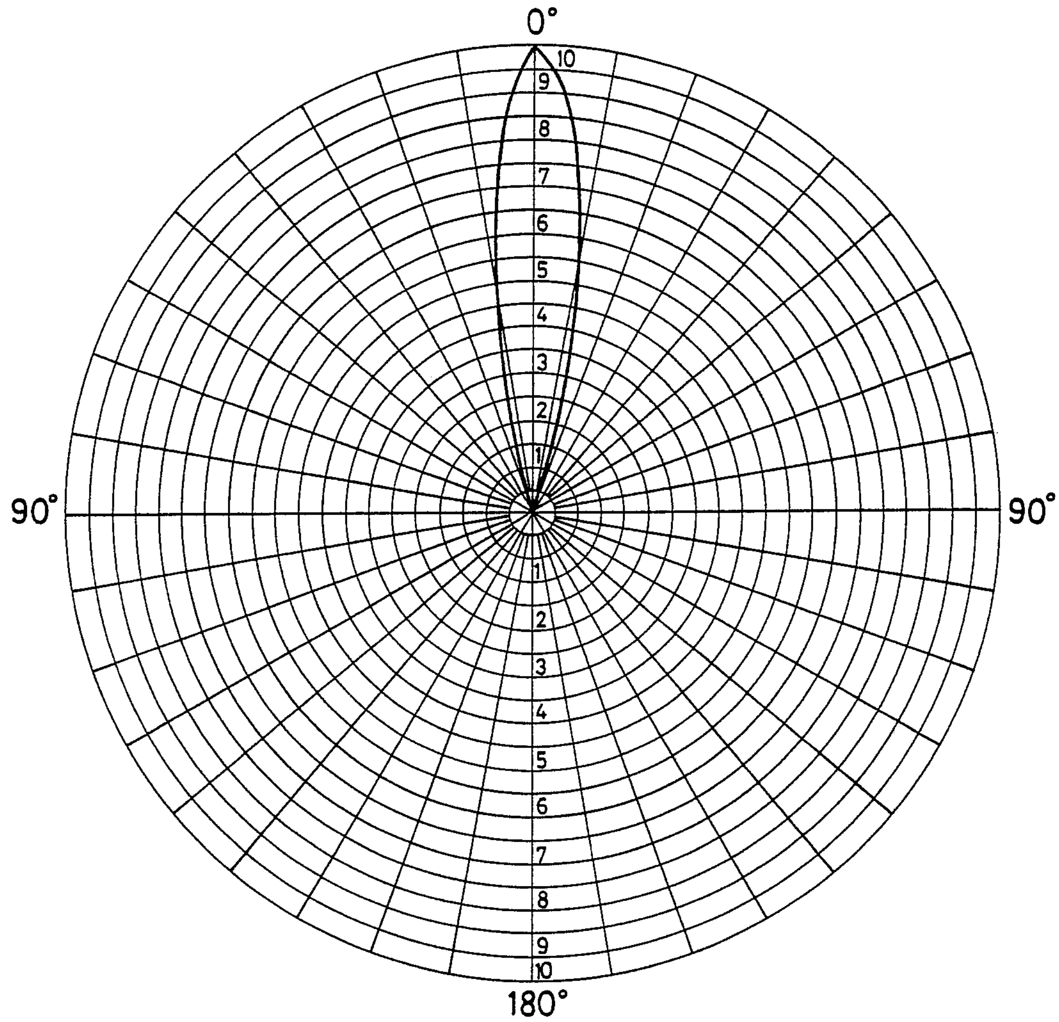

Fig. 9B

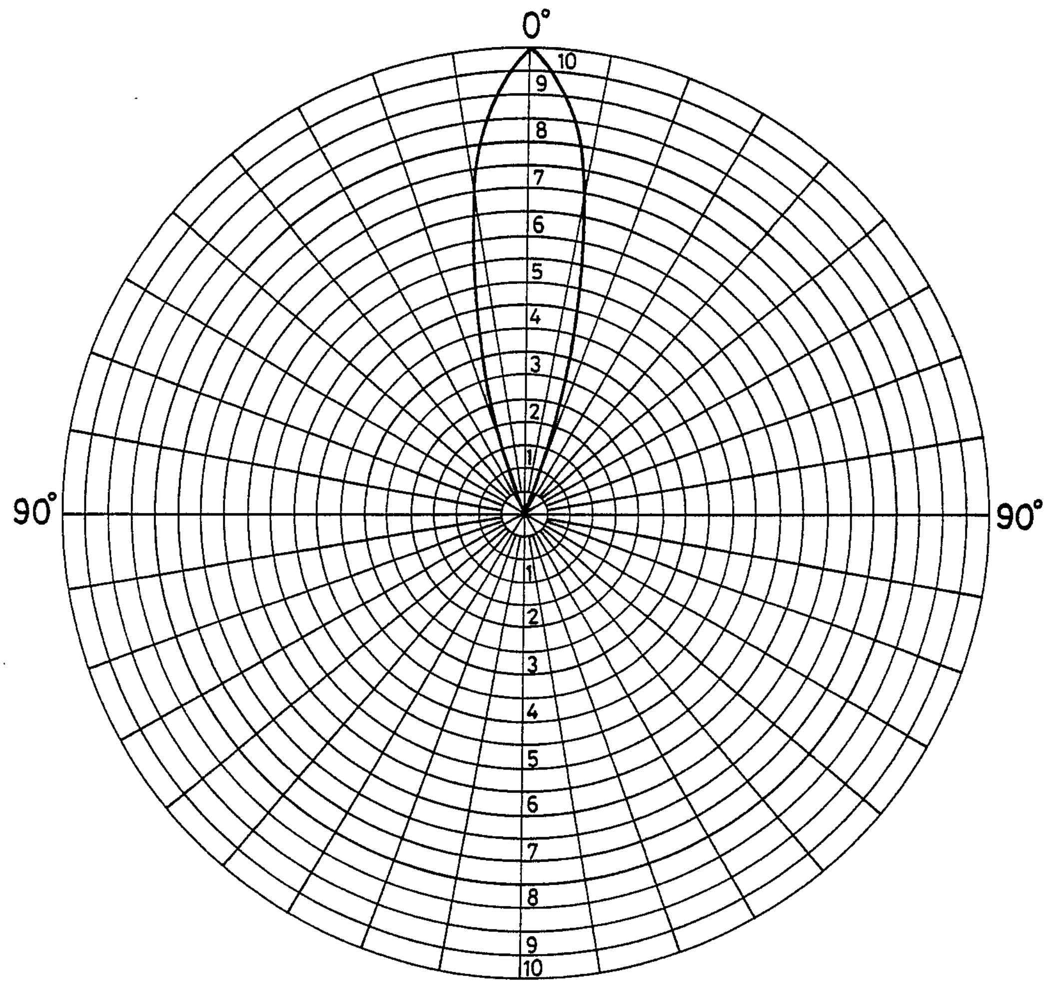

Fig. 9C

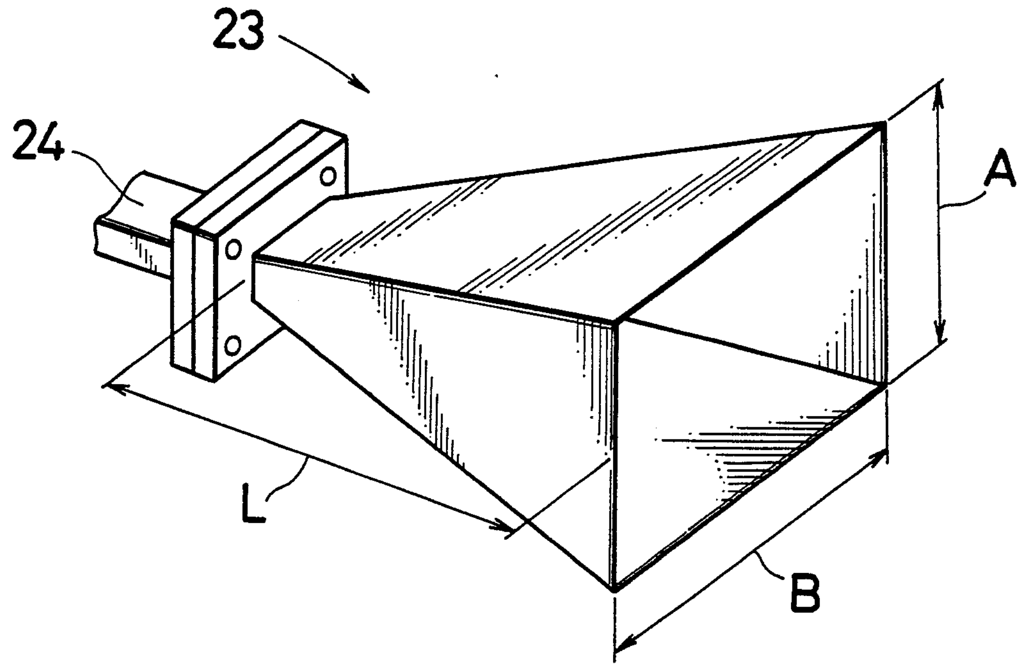

Fig. 9D

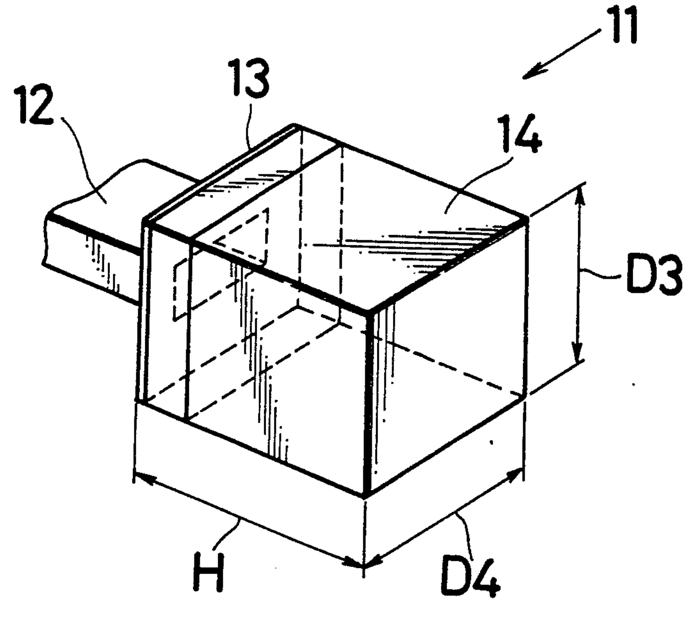

Fig. 10

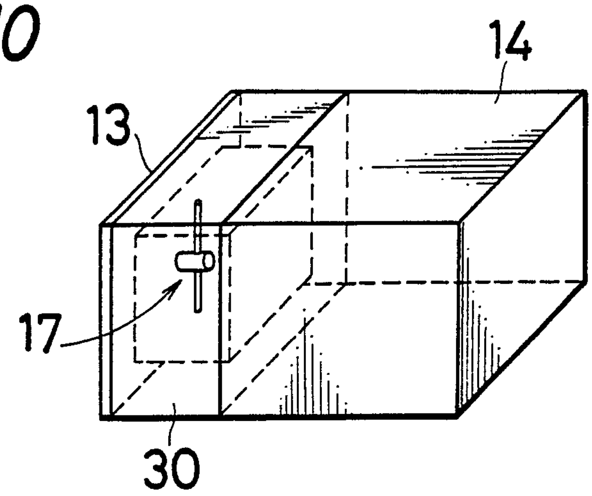

Fig. 11

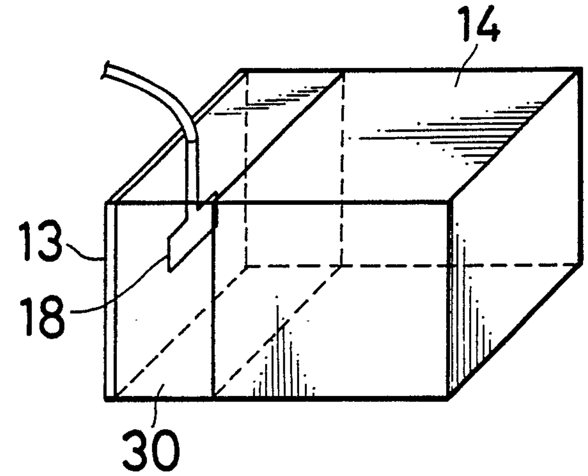

Fig. 12

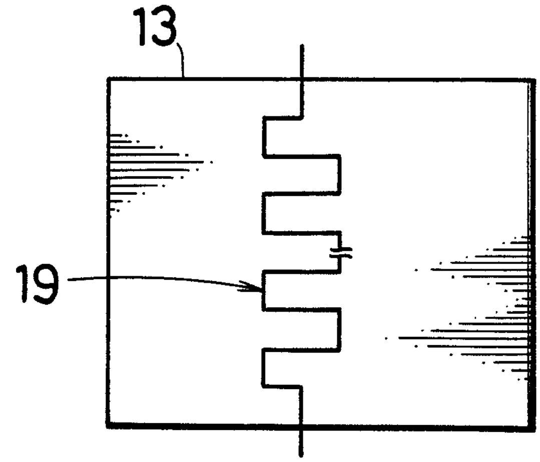

Fig. 13

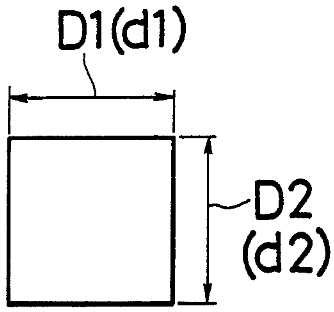

Fig. 14

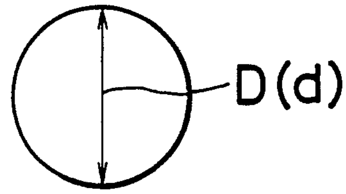

Fig. 15

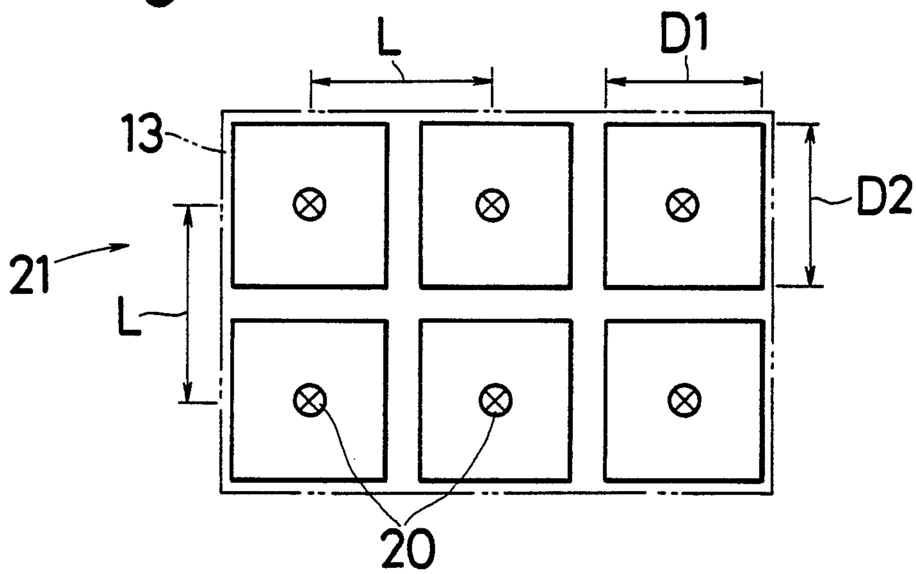

Fig. 16

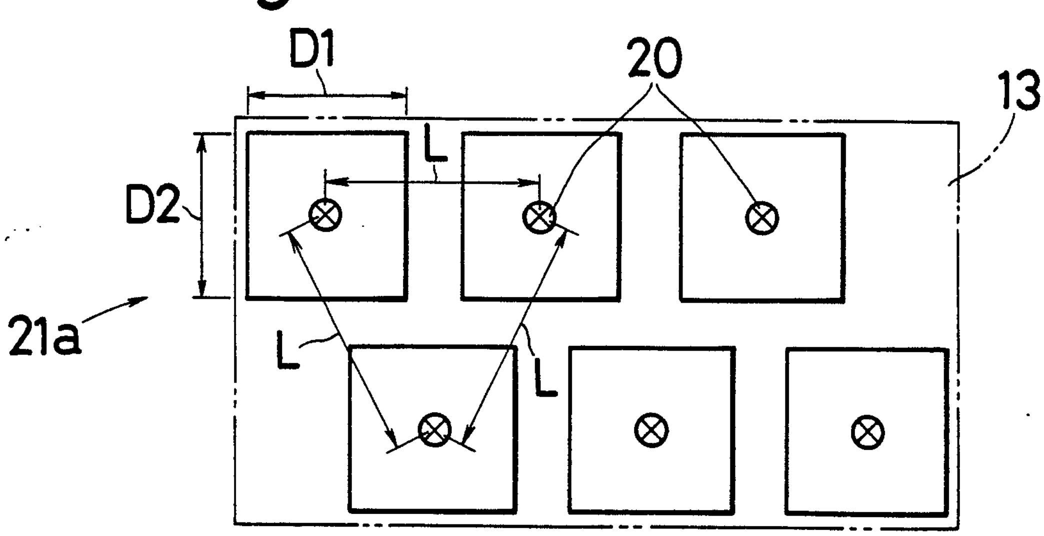

Fig. 17

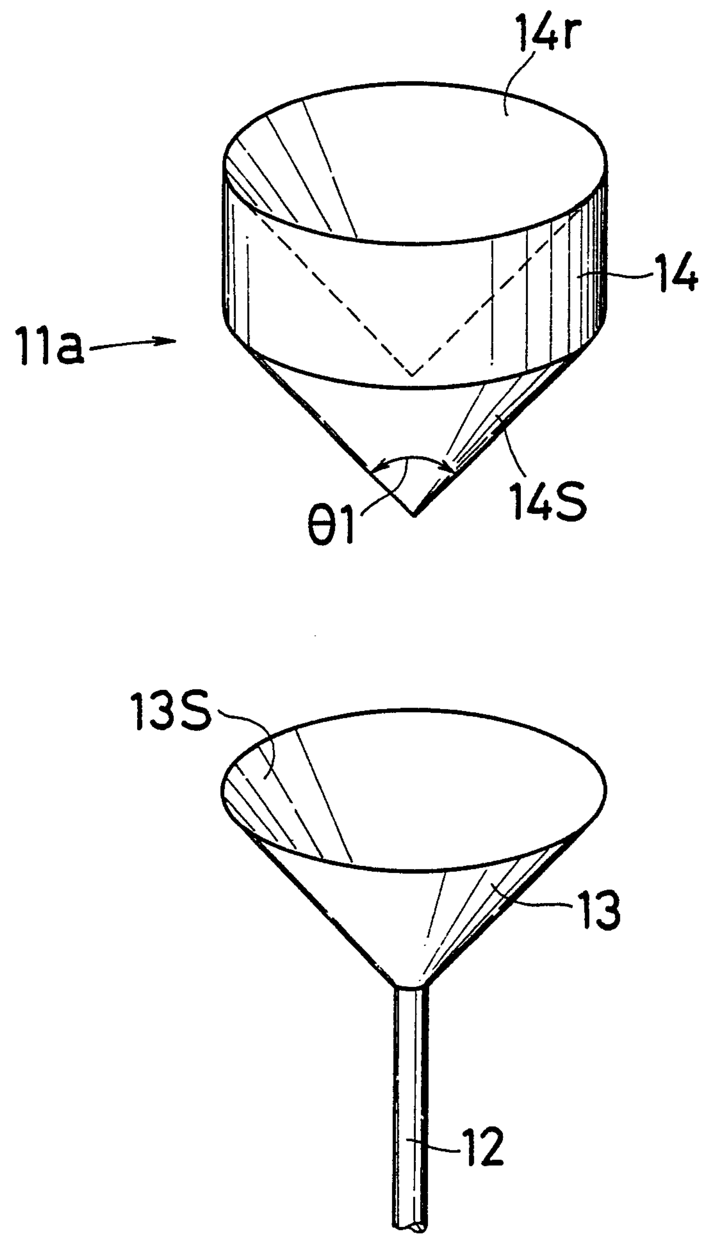

Fig. 18

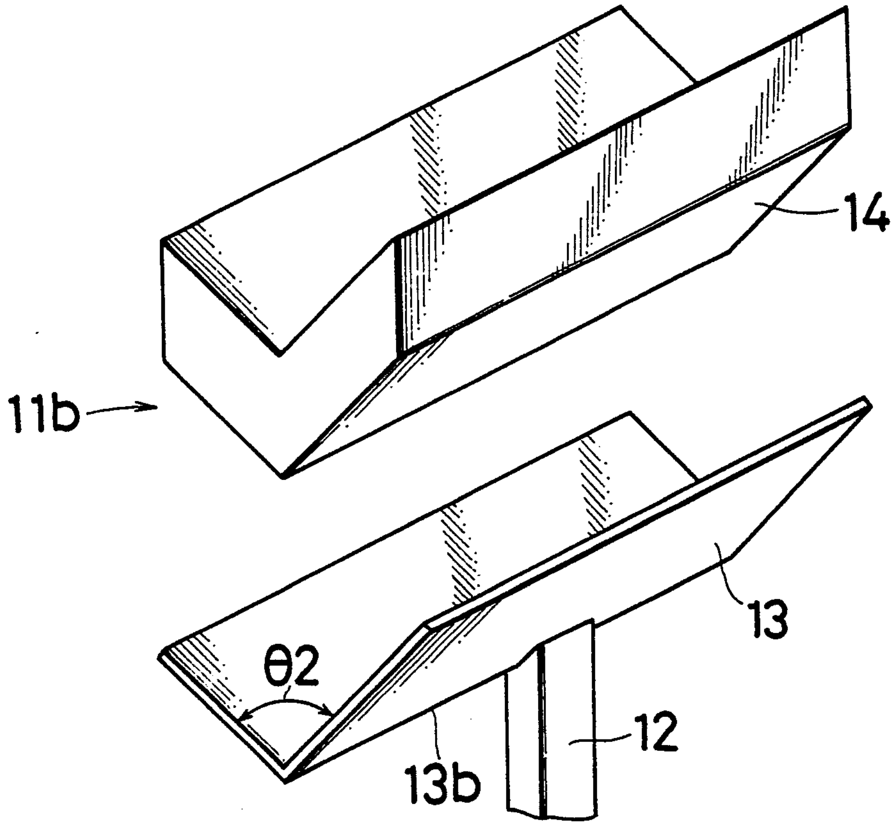

Fig. 19

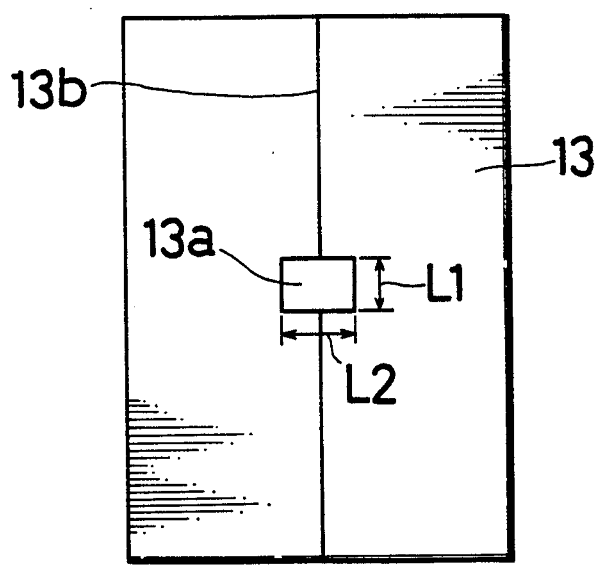

Fig. 20

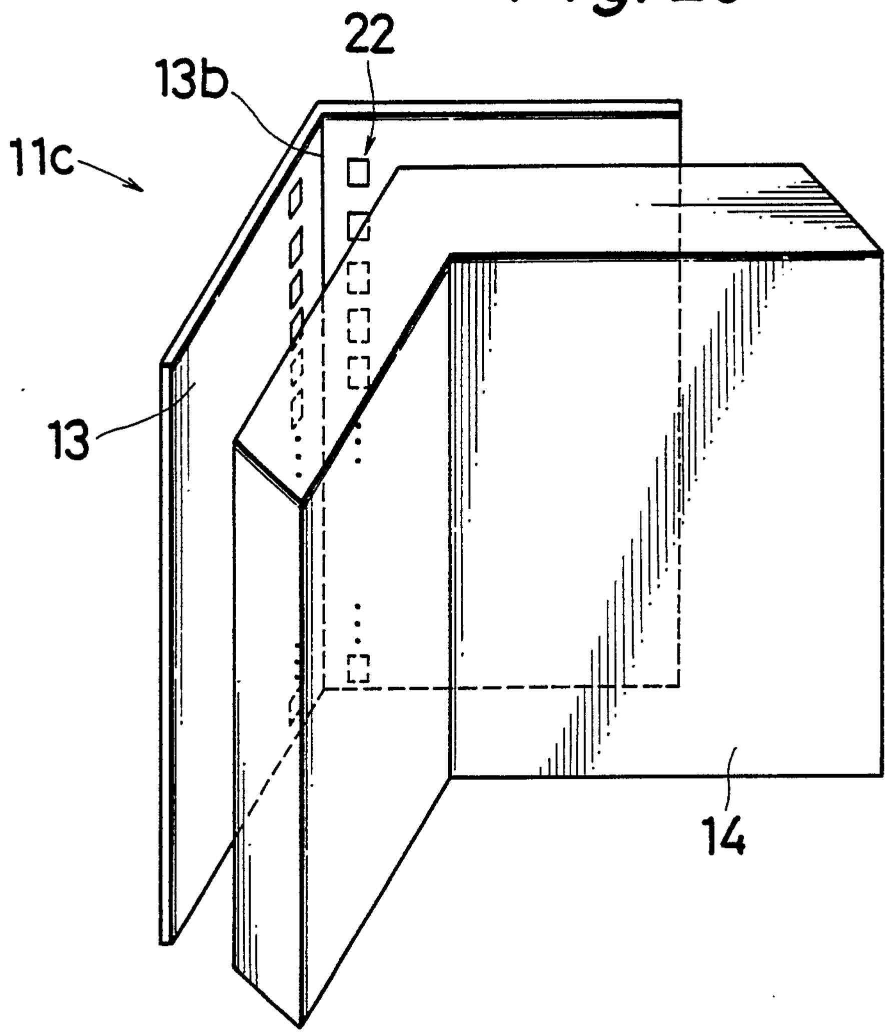

Fig. 21

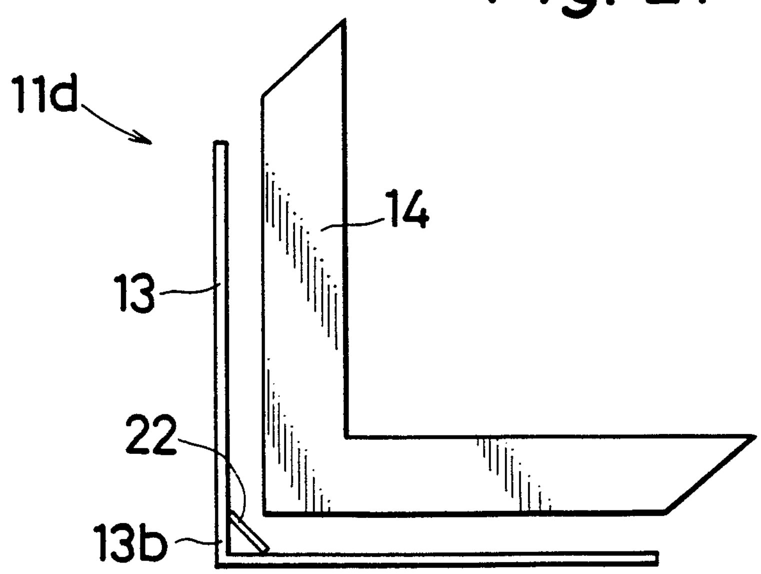

Fig. 22

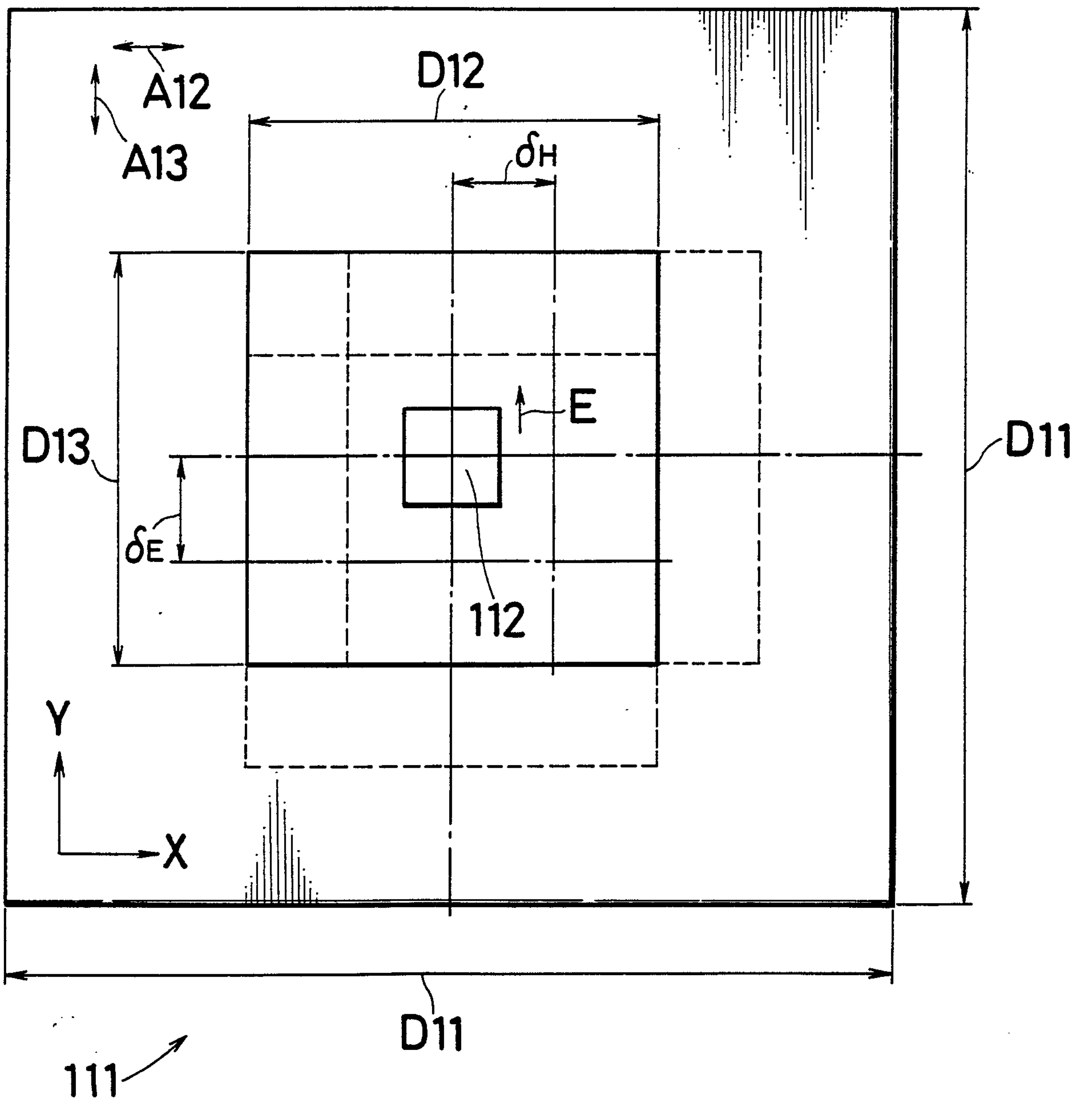

Fig. 23

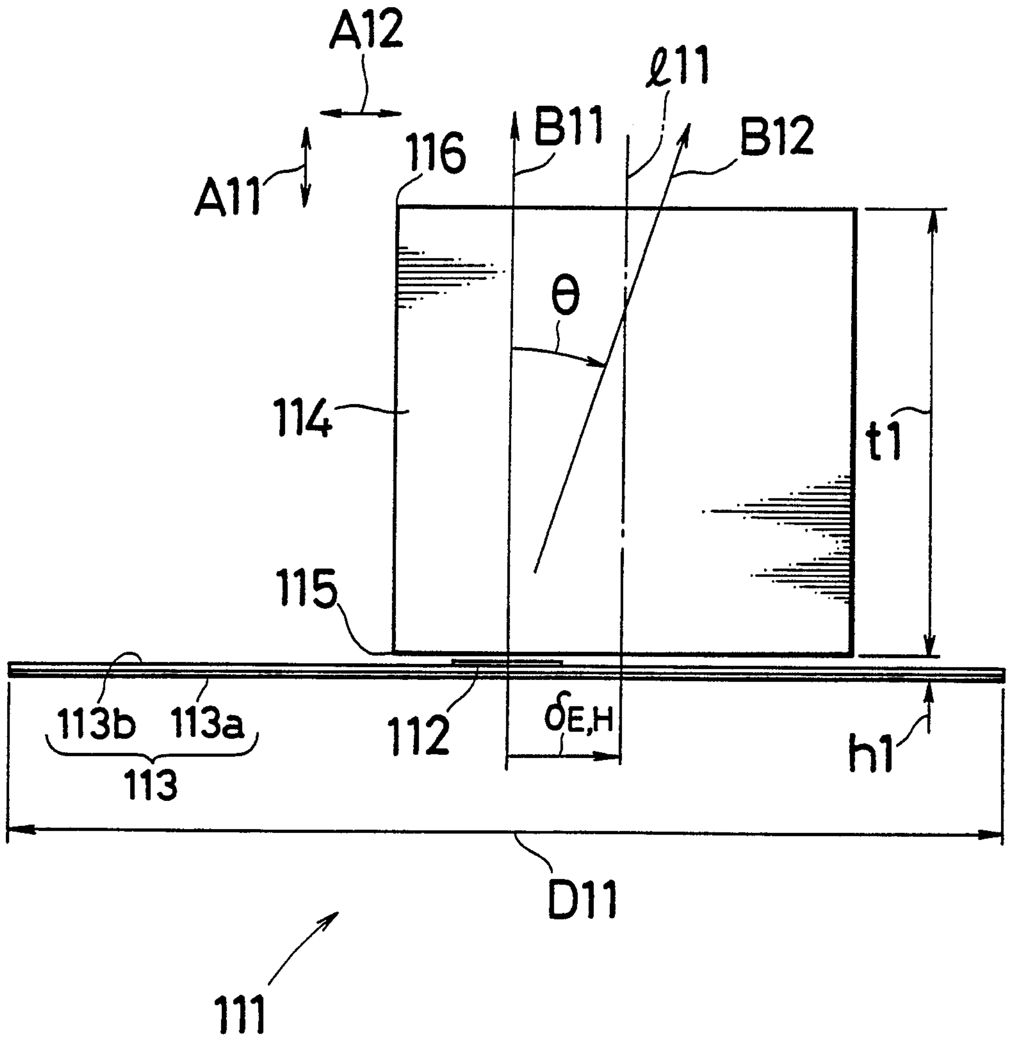
A12
ℓ11
B11
B12
A11
116
θ
114
t1
115
113b
113a
113
112
$\delta_{E,H}$
h1
D11
111

Fig. 24

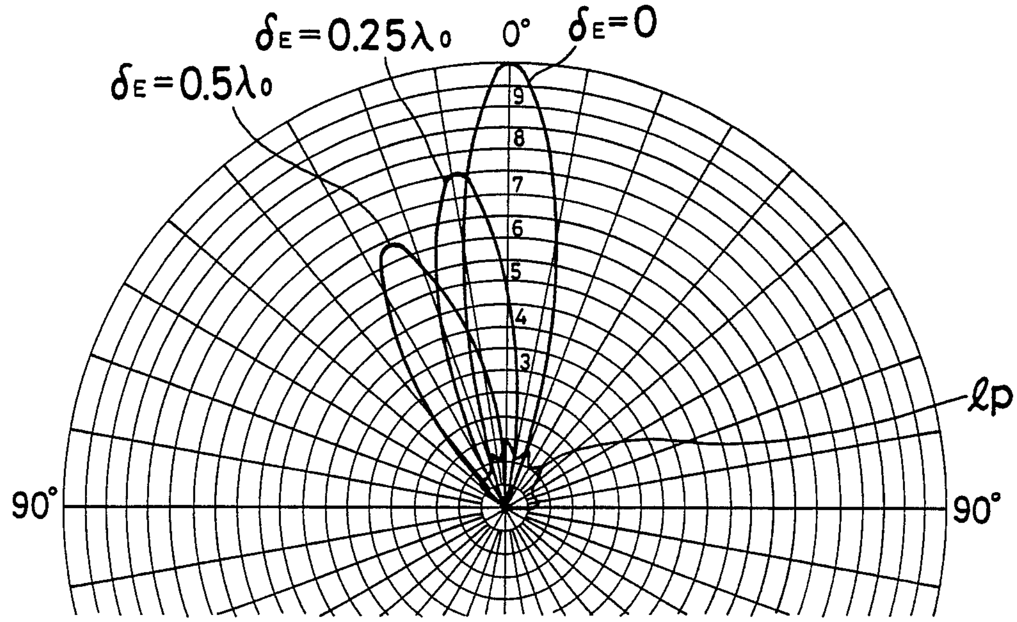
$\delta_E = 0.25\lambda_0$
0°
$\delta_E = 0$
$\delta_E = 0.5\lambda_0$
9
8
7
6
5
4
3
ℓp
90°
90°

Fig. 25

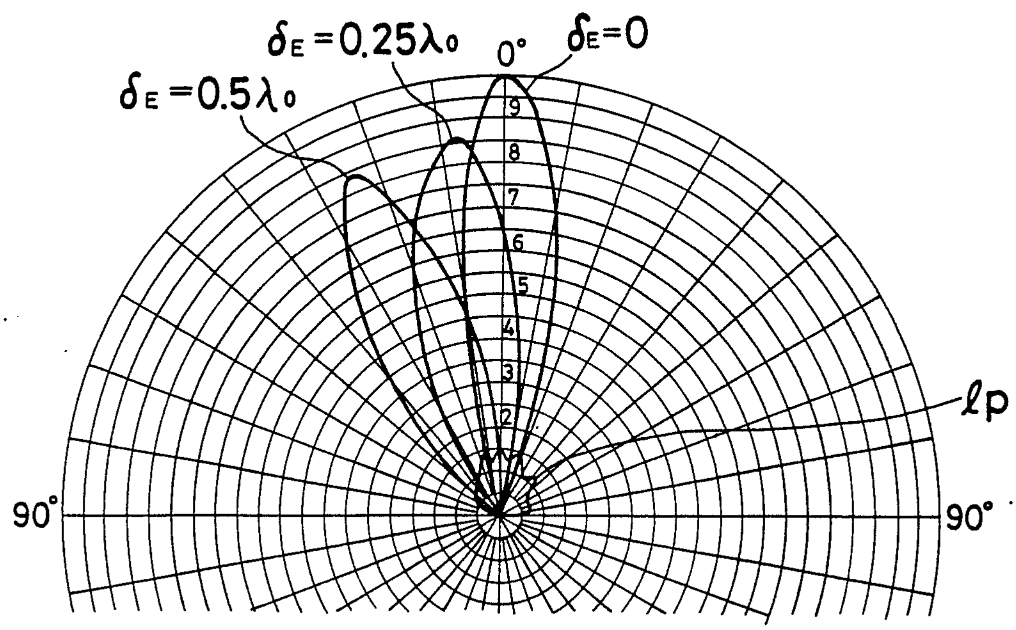
$\delta_E = 0.25\lambda_0$
0°
$\delta_E = 0$
$\delta_E = 0.5\lambda_0$
9
8
7
6
5
4
3
2
ℓp
90°
90°

Fig. 26

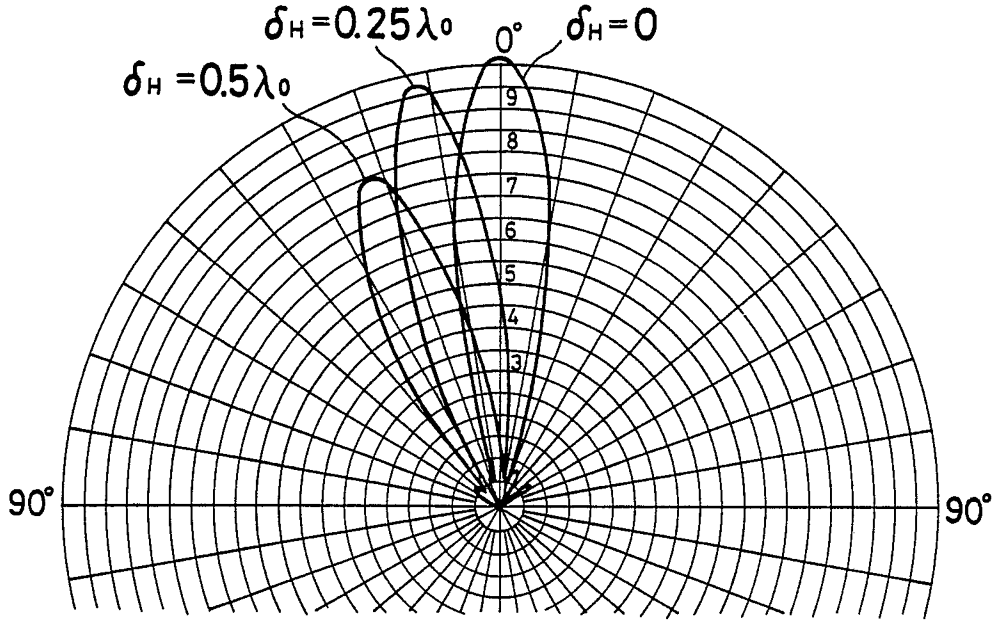
$\delta_H = 0.25\lambda_0$
0°
$\delta_H = 0$
$\delta_H = 0.5\lambda_0$
9
8
7
6
5
4
3
90°
90°

Fig. 27

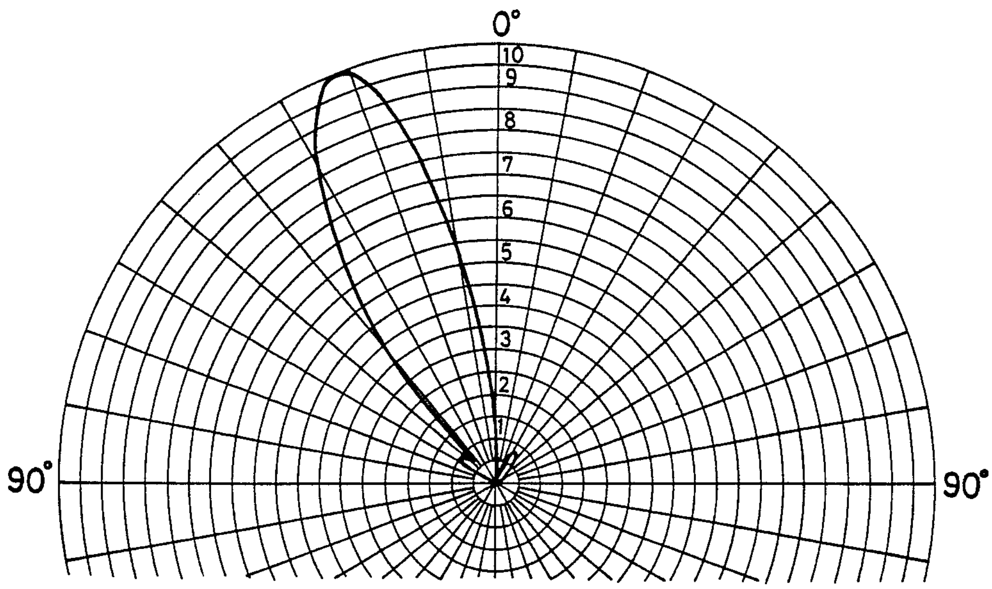
0°
10
9
8
7
6
5
4
3
2
1
90°
90°

Fig. 28

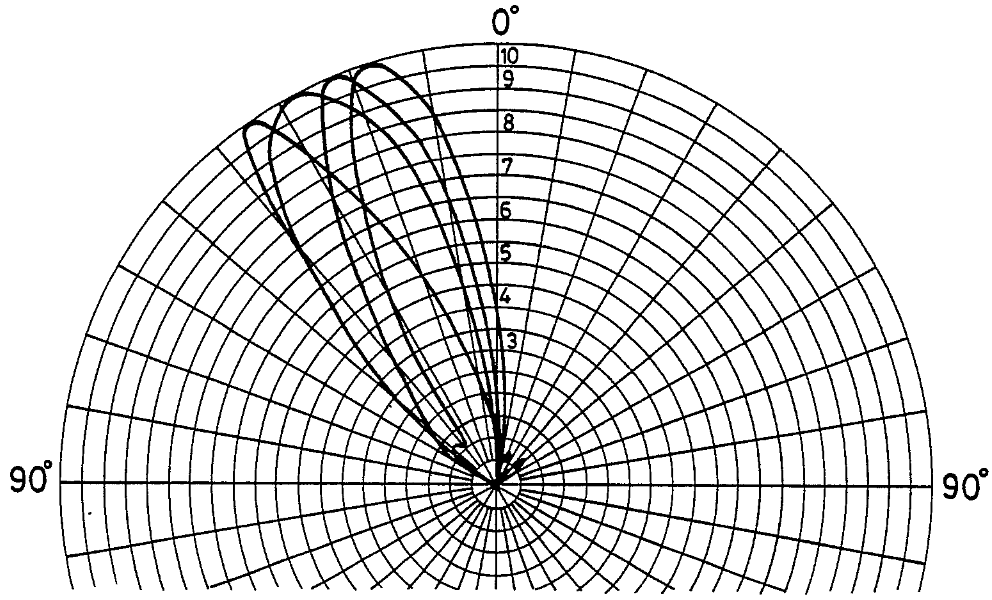
0°
10
9
8
7
6
5
4
3
90°
90°

Fig. 30

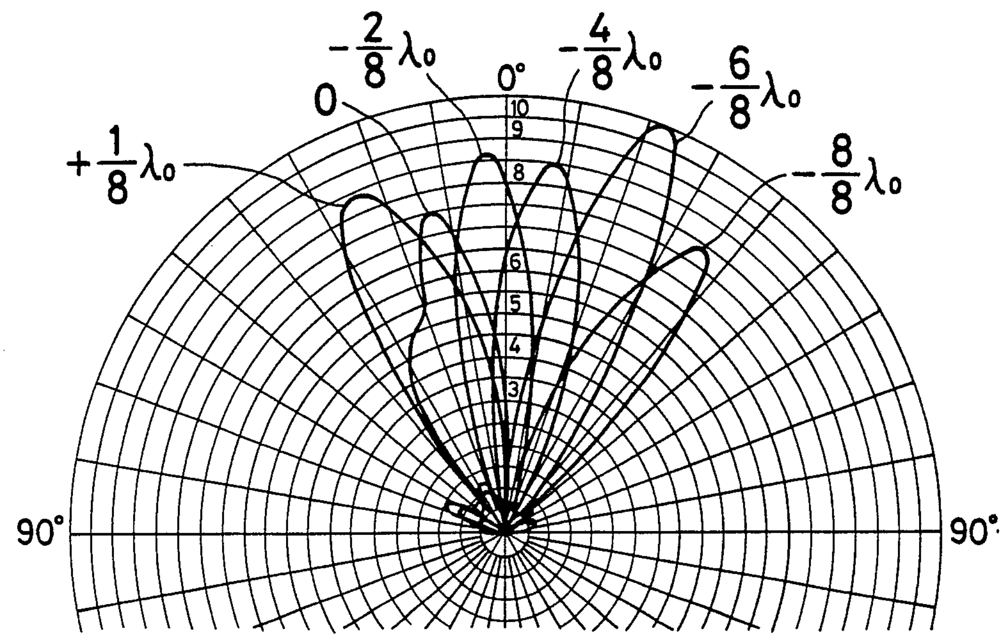
$-\frac{2}{8}\lambda_0$
$-\frac{4}{8}\lambda_0$
$-\frac{6}{8}\lambda_0$
0
$+\frac{1}{8}\lambda_0$
$-\frac{8}{8}\lambda_0$
0°
10
9
8
6
5
4
3
90°
90°

Fig. 29

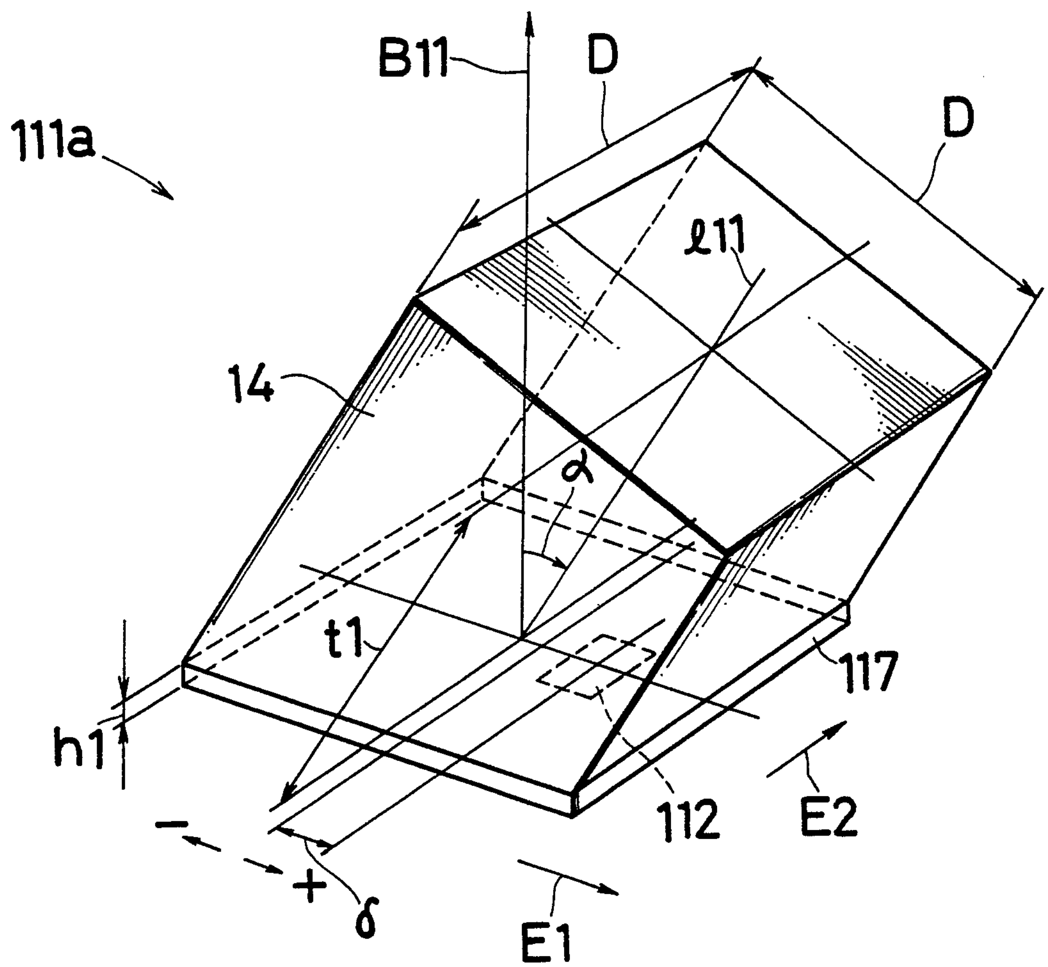

Fig. 31

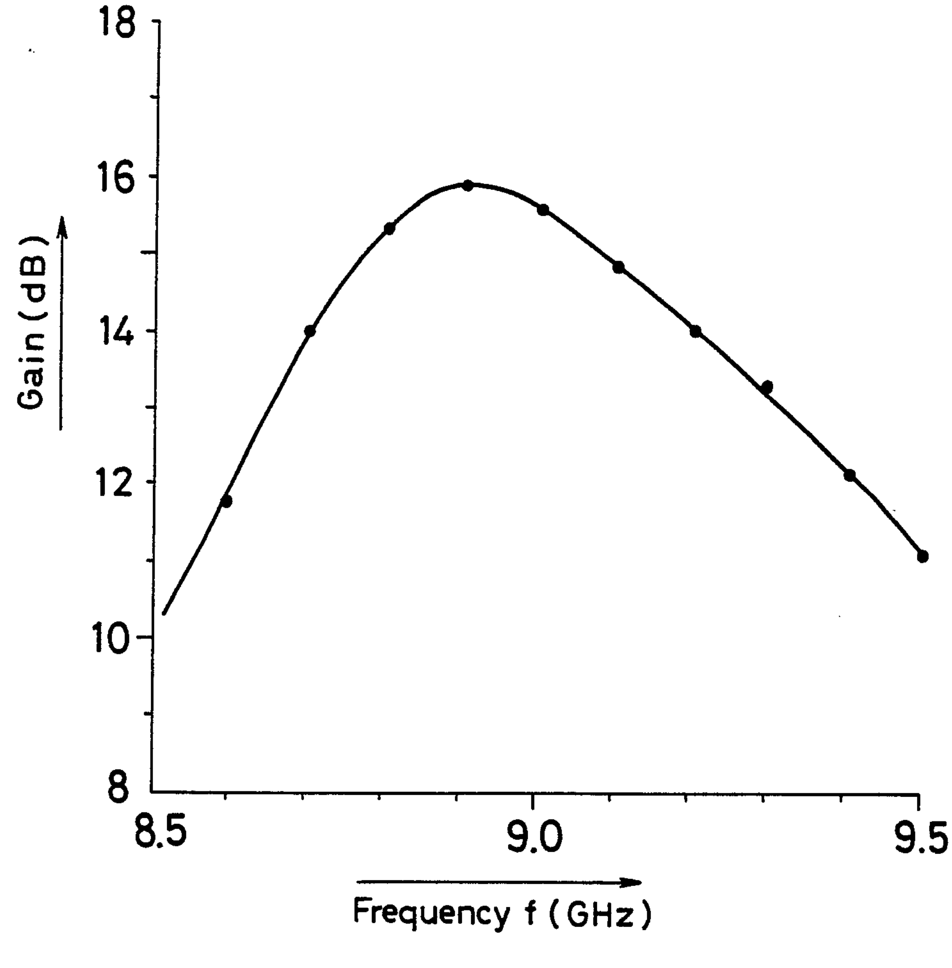

Fig. 32

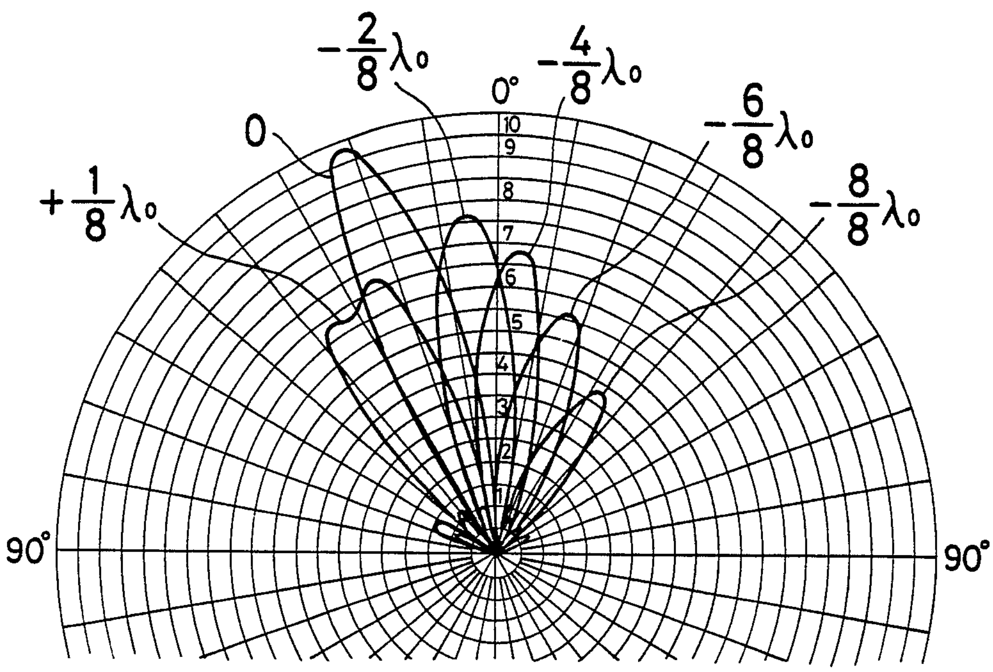
$-\frac{2}{8}\lambda_0$
$-\frac{4}{8}\lambda_0$
0°
0
$-\frac{6}{8}\lambda_0$
$+\frac{1}{8}\lambda_0$
$-\frac{8}{8}\lambda_0$
10
9
8
7
6
5
4
3
2
1
90°
90°

Fig. 33