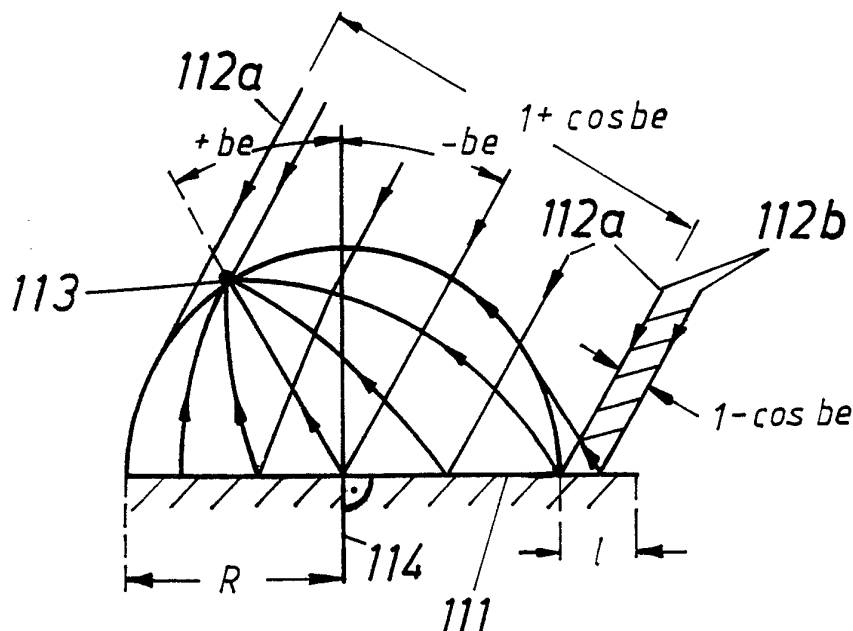




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: DIELECTRIC MATERIAL FOR ANTENNAS**(57) Abstract**

This invention relates to the fabrication of dielectric material suitable for dielectric antennas such as Luneburg-type lens antennas and to an according antenna system. It is an object of the present invention to produce dielectric material with a low weight and the possibility of adjusting a dielectric constant quite easily. According to the invention dielectric pieces, which collectively form the dielectric material, have a hollow shape. By the variation of the thickness, the effective dielectric constant can be varied. The antenna system according to the invention includes a virtual lens antenna with extended reflecting means. The material produced according to this invention can preferably be used for the production of Luneburg-type lenses.

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Dielectric material for antennas

The present invention relates to a production method of dielectric material suitable for dielectric antennas such as Luneburg-type lens antennas and to an according antenna.

Dielectric antennas are well known, e.g. from US 4 531 129. In this patent the use of Luneburg antennas and appropriate feeds are described for the use of a satellite broadcasting receiver system to receive microwave signals. Such antennas can also be used as part of a transmitter system.

Several combinations of dielectrical antennas with different kinds of feeders are described in the European patent application 91400179.9.

Several methods for the fabrication of Luneburg-type lenses have been described in the European patent applications 90403051.7 and 91401444.4.

Virtual dielectric antennas, e.g. Luneburg-type antennas are known from the article "Virtual Source Luneburg Lenses"; G. D. M. Peeler et al., IRE TRANSACTIONS - ANTENNAS AND PROPAGATION, July 1954. In this article there are also virtual source lenses described, in which reflecting means, realized as one or more reflectors, are arranged.

Dielectric lenses can be produced by dielectric material e.g. with voids, which are created in solid plastic material by hemispherical indentations in plastic sheets which are vertically stacked and fixed together. Such a method is known from the article "Artificial dielectrics utilizing cylindrical and spherical voids"; Proceedings of the IRE, Vol. 44, pp 171 - 174, 1956.

It is an object of the present invention to provide a new method for the fabrication of dielectric antennas with reduced production costs.

This can be realised by the method according to claim 1.

Dielectric antennas can be e.g. Luneburg-type lens antennas, homogenous-type lens antennas, Eaton-Lippmann lens antennas, or thelike. The said antennas may be shaped e.g. spherical, hemispherical, quarter sphere, cylindrical or the like.

The present invention is based on the following principle.

A dielectric material composed of individual pieces will appear essentially homogeneous (continuous) to signals whose frequency is such that their wavelength is greater than the dimension of the pieces. This means, that at microwave frequencies of about 10 GHz, normally used for direct broadcasting from a satellite (wavelength is in the range of about 2.5 cm), pieces of several millimeters in dimension may be used to fabricate the dielectric material.

By changing their packing density by adjustment of the piece shape the dielectric constant of the resulting material can be changed. The relative dielectric constant ϵ_r is related to the density of the material by

$$\epsilon_r = 0,4 * \epsilon_{ro}^{(d/d_o)} + 0,6 * (1 + (\epsilon_{ro} - 1) * d/d_o), \quad (1)$$

where

d_o is the density of the material used to fabricate the pieces,

d is the density of the resulting material,

ϵ_{ro} is the dielectric constant of the pieces.

According to the present invention pieces of dielectric material are packed in a given shape, whereby a dielectric body

with the desired resulting dielectric constant can be produced, which forms a dielectric antenna or is part of the antenna to be produced.

Because of their symmetry spherical pieces appear the same to signals approaching from any direction. For multisatellite applications therefore, spheres are the preferred shape and have an associated packing density of approximately 0,6. Assuming the spheres are made from polystyrene for example (do is approximately $1,05 \text{ g/cm}^3$) the resulting material would have a density of $0,63 \text{ g/cm}^3$.

Lighter densities could be achieved by using hollow spheres or indentations on their surface.

Since the pieces could be formed accurately using plastic molding techniques the dielectric constant value could be accurately achieved in this way.

If the size of the dielectric pieces is very small with respect to the wavelength (that means less than about 1/10 of the wavelength), their symmetry becomes less important and the spheres could be replaced by other shapes, e.g. like tubes, of either solid or hollow form. This is advantageous because raw plastic material for injection molding is usually supplied in small approximately round shaped pieces typically 3 millimeters long and 3 millimeters in diameter. These raw forms can be used immediately to achieve medium density material.

Assuming that there is a virtual lens antenna, e.g. a hemispherical, a quartersphere Luneburg-type antenna, or thelike, with a reflecting plate located at the flat sides, the loss of an incoming wave increases with an increasing angle of incidence.

The use of preferred kinds of virtual dielectric lens antennas with used reflecting means, e.g. a reflecting metal plate, which are extended outside the boundaries of the lens, has the advantage that the loss in gain with an angle of incidence not perpendicular to one of the reflecting means can be decreased.

To receive the according wave a feeder horn or an endfire or a backfire helical antenna or thelike can be used. Using an antenna outside the boundaries of the lens the system is more flexible for receiving waves from several directions, because the feeds have a greater physical separation and do not cause aperture blockage.

Using an antenna which is integrated in the lens the antenna system is more compact.

Further characteristics, advantages and details of the present invention will be explained with the aid of the following embodiment and accompanying drawings, where

- Fig. 1 shows some dielectric pieces, which collectively form a dielectric body;
- Fig. 2 shows another kind of a dielectric piece;
- Fig. 3 shows a radome cover containing dielectric pieces;
- Fig. 4 shows a hemispherical Luneburg lens which is state of the art;
- Fig. 5 shows a hemispherical Luneburg-type antenna according to a first preferred embodiment of a lens antenna to be produced;
- Fig. 6 shows a quartersphere Luneburg-type antenna according to a further preferred embodiment of a lens antenna to be produced;
- Fig. 7 shows a top view of different kind of dielectric lenses and in principle according runs of an incident wave.

Fig. 1 shows some dielectric pieces 10, which collectively form a dielectric block, which itself has the shape of a dielectric antenna to be produced, from which such an antenna may be separated (cut), or which is a part of the said antenna. The pieces 10 may be fixed to each other, e.g. by glueing, or may just lay near or on each other.

In this embodiment the pieces 10 are shaped as hollow spheres with a diameter d less than the wavelength of a radiation to be received or to be transmitted.

As it is given by equation (1), the resulting dielectric constant E_r depends on the dielectric constant of the dielectric material 11, which forms the pieces 10, and the relationship of densities d and d_0 . In this embodiment d_0 is given by the thickness t of the dielectric material 11 compared to the diameter h of the hollow interior 12.

For the production of a Luneburg-type antenna a variation of the resulting dielectric constant in dependence on the diameter of the Luneburg lens is required. This variation can be achieved e.g. by using different kinds of pieces 10, which collectively form the lens or by producing different kinds of blocks, e.g. shaped as a shell or the like, which collectively form the lens. Each of these blocks can be produced by pieces 10 identical inside of each block or with a variation in thickness t , diameter d or by using pieces 10 with a non-spherical shape.

Fig. 2 shows another type of dielectric pieces 10'. In this embodiment the shape of piece 10' shows some indentations. By the number or the size of these indentations the resulting dielectric constant E_r can be varied.

Referring to fig. 3, it may be mentioned, that normally a microwave lens antenna must be protected by a radome cover, which may also serve as a matching layer to reduce the amount

of reflected signal at the lens surface. Normally this radome cover is made of plastic and may be used as a vessel 13 to contain the unbound plastic pieces 10, 10' respectively. The vessel 13 shown in fig. 3 is used for the fabrication of a hemispherical lens.

It is evident, that large volume lenses can be produced in this way without long cooling cycles since no heat forming process is needed to produce a large volume shape other than to form the radome cover 13.

Instead of using spherical or hemispherical shaped vessels, which can be used later as radome cover, other kinds of vessels are possible. Other preferred types have the shape of a quarter sphere or a pyramid. Some of these pyramids may collectively form the dielectric antenna to be produced.

For a variation of the dielectric constant inside of each block, a tool with a similiar function as a ice-cream shape-maker (scoop) may be used.

As an extension, multiple shell lenses could be made by employing several thin solid shells to sepearate bands of different density pieces. The said shells can be removed after positioning the pieces.

It may be also mentioned, that the medium density plastic material is necessary for Luneburg and homogeneous lens applications where dielectric constants in the range 1 - 2,5 are typically required. For values close to approximately 2 to 2,5 solid plastic material can be used. In principle values in the range of approximately 1,8 to 2 can be achieved using low density polypropelene and finally values in the range of approximately 1 to 1,15 can be achieved using foamed plastic material.

The intension of this invention is to provide a method for obtaining accurate large volumes of dielectric material with a dielectric constant in the range of about 1,15 to 1,8, which does not require large cooling cycles.

In a variation of the embodiments described the pieces 10, 10' respectively could be made from a mixture of a first material with a high dielectric constant, such as ceramic material, ferroelectric ceramics, or thelike, and a second material with a low dielectric constant, such as foamed plastic material, e.g. polyethelene. Thereby a lighter weight dielectric material can be produced. Additionally the resulting dielectric constant may be varied more accurately.

It is another variation of the said embodiments to connect or to form the dielectric pieces 10, 10' respectively in such a way that lines or sheets of pieces are formed. These lines or sheets may contain pieces with the same dielectric constant or with various dielectric constants.

As an extension, sheets containing hollow spherical indentations may be used collectively to form material containing spherical voids similar to the material shown in fig. 1.

These lines or sheets may be arranged in such a way that the shape of the antenna or the block to be produced is formed and that a variation of the dielectric constant is achieved as desired.

For the fabrication of a hemi-spherical Luneburg antenna, first a small round sheet with the effective dielectric constant ϵ_{r1} of about 2,0 may be taken and laid on a core located in the center of the lens. On this first sheet a second one with a dielectric constant ϵ_{r2} (smaller than ϵ_{r1}) is laid, where the size is a little bit larger than the one of the first sheet. This method is continued to a last sheet (n)

with an effective dielectric constant ϵ_{eff} of about 1,0 and a quite big size.

If lines of pieces are used, the effective dielectric constant inside of each line may be constant or may vary. With an appropriate variation each line may start in the center point of a (hemi-)spherical Luneburg lens and end at its surface. Such lines can also be used for the fabrication of other parts, as pyramids, which collectively form the lens to be produced.

By using lines or sheets it is easy to handle the dielectric pieces and many hollow spheres can be realized at the same time.

Versions of the embodiments concerning the fabrication method may include at least one of the following variations:

- the variation of the dielectric constant E with radius may have such a slope that the value n of the refraction index ($E = n^2$) at the center of a sphere is
$$n = 1,7 \dots 1,35.$$

Thereby a parallel incoming wave is focussed outside of the surface of a spherical-type lens;

- the distance between the parts 10 can be smaller than the wavelength of a wave to be received.

Fig. 4 shows the principle of a virtual dielectric lens to be produced. A hemispherical Luneburg lens 110 with a radius R has a reflecting plate 111. A first part 112a of a beam 112 to be received is refracted by the lens 110 and reflected by the plate 111 in such a way that it is focused in the focal point 113. The location of this focal point is determined by the angle of incidence be relative to the perpendicular line 114 of the plate 111 and by the profile of the refraction index of the lens 110.

As this lens 110 is a Luneburg lens with a radius R, the refraction index n is given by

$$n^2 = 2 - (r/R)^2, \quad (2)$$

where r is the actual point.

Near the focal point 113, which can also be inside or outside of the boundaries of the lens 110, a non-shown antenna is located, which can be realized e.g. as feeder horn or helical antenna.

As can be seen from fig. 4, a second part 112b of the beam 112 to be received passes outside of the lens 110. The portion of the first part 112a of the beam decreases with increasing angle θ_e and the portion of the second part 112b increases with increasing angle θ_e . This shows that there is a loss of effective antenna area with angle θ_e hence a loss in antenna gain.

Fig. 5 shows a first development of the antenna system of fig. 4. Means with the same function as those in fig. 4 are marked with the same reference numbers and they will be explained only as far as it is necessary for the understanding.

The main difference of this embodiment compared to the arrangement of fig. 4 is that the reflecting plate 111 is extended outside of the boundaries of the lens 110 by the length l. Thereby the second part 112b of the beam can also be reflected by the plate 111 and refracted by the lens 110 in such a way that it is essentially also focussed in the focal point 113.

The extension length l of the plate 111 which is necessary depends on the range of the scan angle θ_e required according to

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$$l = R * ((1/\cos \theta) - 1).$$

An embodiment has been realized as a hemi-spherical Luneburg-type lens with a radius R of 15 cm and an extension length l of 15 cm. Measurements with a wave of 12 GHz showed that the gain using this extension could be increased by about 2 dB at an angle of incidence θ of about 62.5 degrees.

Fig. 6 shows a three-dimensional sketch of another embodiment of an antenna to be produced. The main difference compared to the antenna system of fig. 5 is that a quartersphere lens is used which can be shaped as a orange slice.

The beam 112 to be received is transmitted from a satellite 115 and focussed by the quarter sphere lens 116 in the focal point 113 where a feeder horn 117 is provided. This lens 116 has two reflector plates 111 and 111a respectively. These reflectors 111, 111a can have the same size as the according adjacent flat side of the quarter sphere lens 116, but they may also be extended in horizontal direction and/or in vertical direction. Thereby losses can be reduced and the antenna gain can be maintained with scan angle, similar to the construction of fig. 5.

It is preferred to extend the reflectors more in the upper half than in the lower half of the antenna. This is due to the elevation angle of satellites to be received being not equal to 0 degrees, but typically about 30 degrees.

Fig. 7 shows a top view of a spherical lens 120, the hemi-spherical lens 110 and the quartersphere lens 116 and in principle according runs of the incident ray 112.

Having the full sphere lens 120, which can be a Luneburg-type lens, homogenous type lens or the like, without any of the reflectors 111 and 111a the wave 112 is focussed at a focal

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point 113a which is on the opposite side compared to the direction of incidence of wave 112.

Using half of the lens 120 which means the hemispherical lens 110 including the reflector 111 the wave 112 is focussed at focal point 113b.

Using a quarter of lens 120 which means the quarter sphere lens 116 including the reflectors 111 and 111a the wave 112 is focussed at focal point 113c.

It may be mentioned that the focal points 113 may be outside of the boundaries of the lenses 120, 110, 116 when using a homogeneous type lens with a relative dielectric constant ϵ_r where

ϵ_r is about or less than 2

or when using a Luneburg-type lens but with a modified variation of the refraction index n with radius r as given by equation (2).

Versions of the antennas to be produced may include at least one of the following variations:

- instead of a hemi-spherical or a quartersphere lens just a lens with a conical or pyramide-like shape may be used. In this case it is preferred that the shape of the according reflecting means is varied in such a manner that it covers at least one of those sides of the lens which are not penetrated by the wave to be received. One or more of these reflecting means can be extended;
- a homogeneous-type lens may be used, which means that the refraction index may be essentially constant throughout the lens;
- the antenna system according to the invention may also be used as transmitter antenna;

- the antennas presented by this patent application may also be produced according to other fabrication methods, e.g. as presented by the European patent applications 90403051.7 and 91401444.4.

By the present invention a fabrication method for dielectric lens antennas and according antenna systems are presented, where the said lens is realized as a virtual source lens by using reflecting means. These reflecting means are preferably extended outside the boundaries of the lens, whereby the gain of the antenna system can be increased.

The maximum operating frequency for the antenna of a preferred embodiment is 12,75 Ghz and a void diameter of 8 mm and separation of 1 cm were chosen. The plastic material employed was polysterene with a dielectric constant of 2,44. This resulted in an effective dielectric constant of 1,52.

The quarter sphere lens is well suited to multi satellite reception because it provides the necessary scan range with minimum volume.

Claims

1. Method for the production of dielectric material suitable for dielectric antennas, resulting dielectric constant of said dielectric material may be constant or variable, characterized by composing dielectric pieces (10) having dimensions and/or distances to each other less than the wavelength of a radiation to be received or to be transmitted.
2. Method according to claim 1, characterized by varying the resulting dielectric constant by a variation of the size of the dielectric pieces.
3. Method according to claim 1 or 2, characterized in that said dielectric pieces are made from materials with different dielectric constants.
4. Method according to claim 3, characterized in that a first material is used, which is ceramic-like, and a second material is used, which is plastic-like.
5. Method according to one of the claims 1 to 4, characterized in that the dielectric pieces are hollow.
6. Method according to one of the claims 1 to 5, characterized in that at least some of the dielectric pieces used have a shape showing indentations.
7. Method according to one of the claims 1 to 6, characterized in that said dielectric pieces are in a vessel at least during the production process.

8. Dielectric lens antenna system including a virtual source dielectric lens (110) with according reflecting means (11), characterised in that the reflecting means (111) are extended outside the boundaries of the lens (110).
9. Antenna system according to claim 8, characterised in that the virtual source dielectric lens (110) is a Luneburg-type or homogeneous-type lens.
10. Antenna system according to one of the claims 8 or 9, characterised in that the shape of the virtual source dielectric lens (10) is hemispherical-like, quartersphere-like, pyramide-like, or conical-like.
11. Antenna system according to one of the claims 7 to 10, characterised in that it may be used for receiving and/or transmitting.

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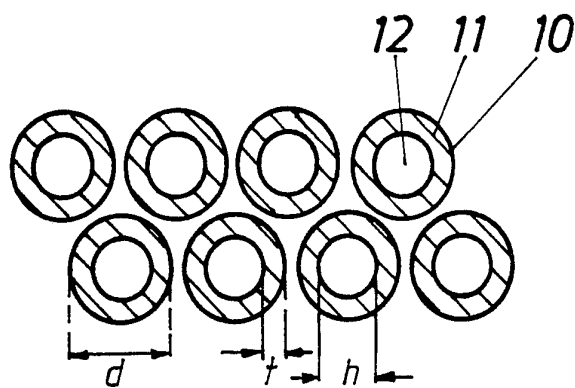


FIG. 1

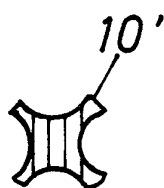


FIG. 2

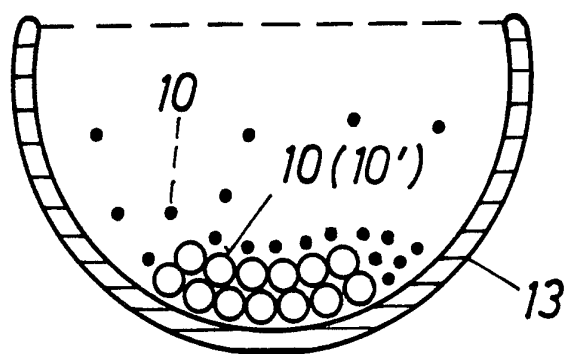
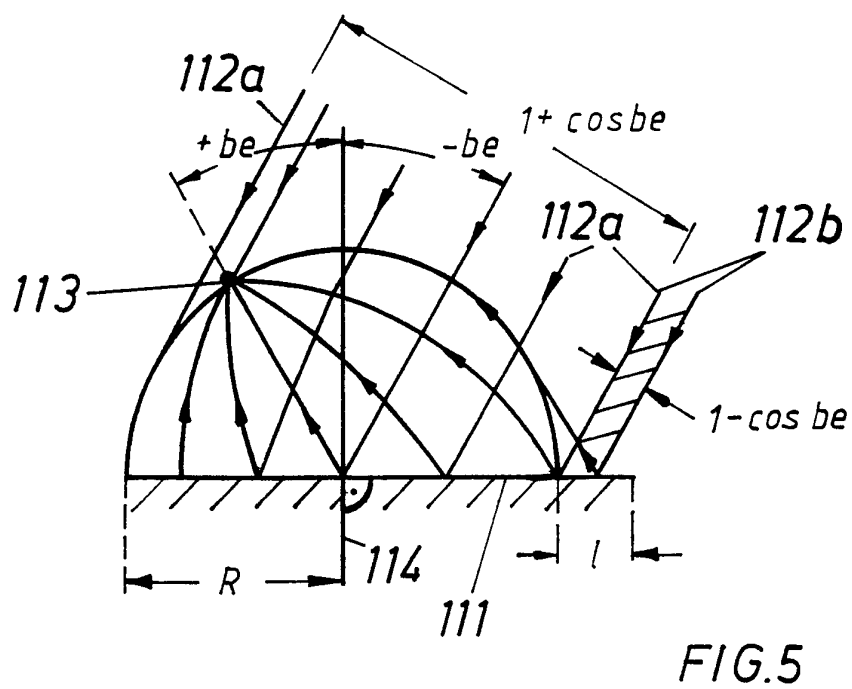
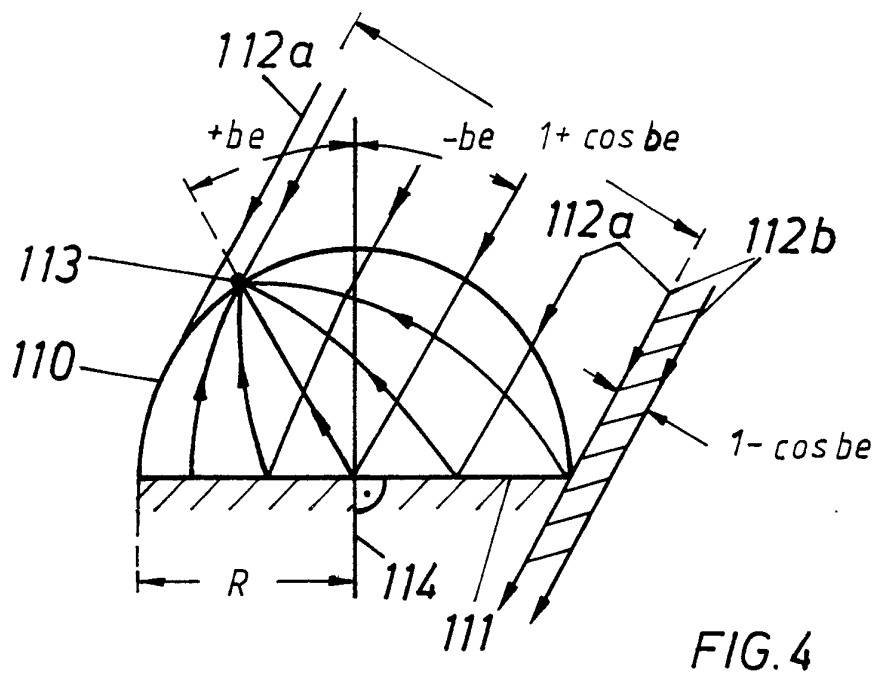


FIG. 3



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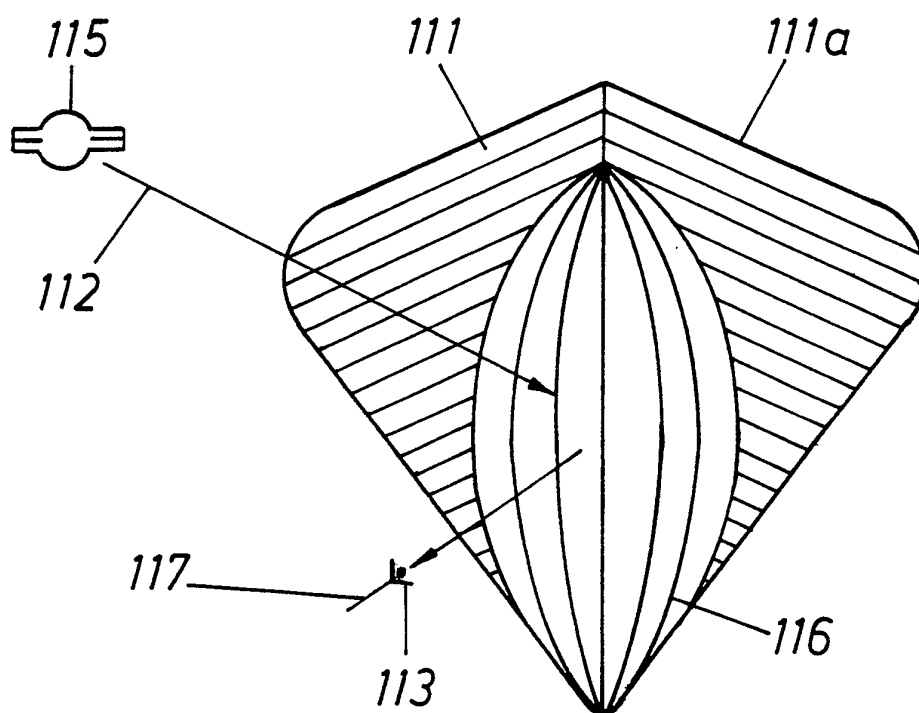


FIG. 6

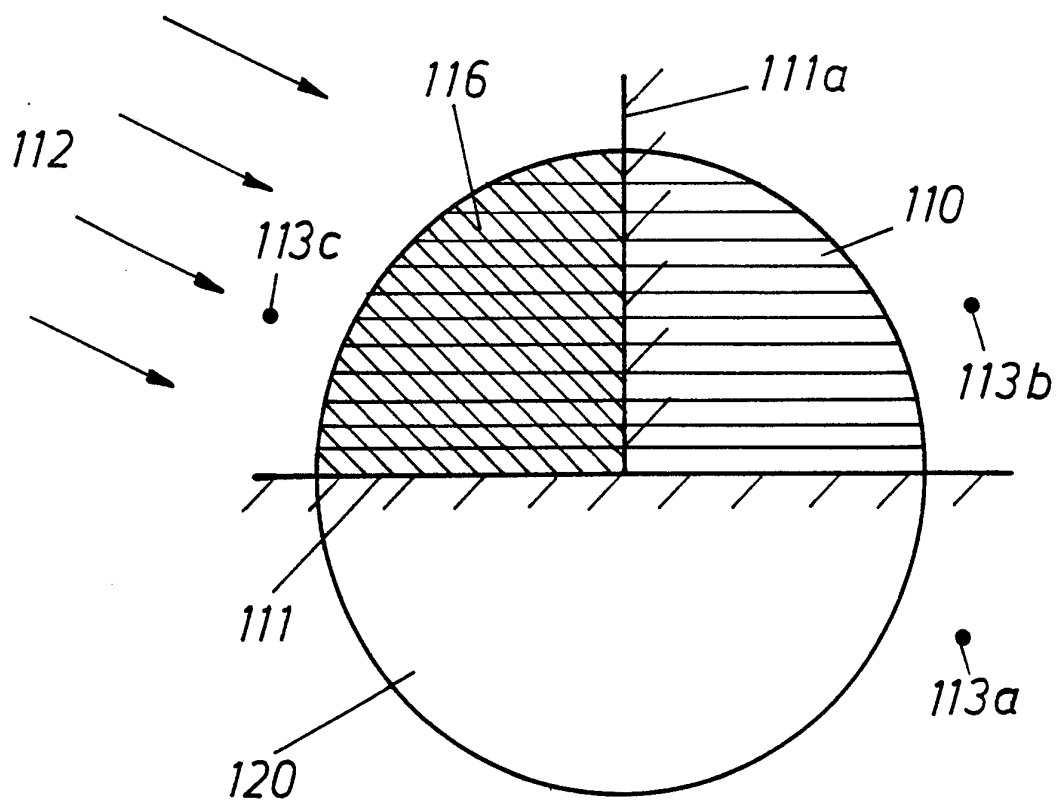


FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/EP 92/02384

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC ⁵ : H 01 Q 19/06, H 01 Q 15/08		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
IPC ⁵	H 01 Q	
Documentation Searched other than Minimum Documentation to the extent that such documents are included in the fields searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 4 288 337 (OTA) 08 September 1981 (08.09.81), see fig. 1-3, 10-13; column 1, line 11 - column 2, line 53; column 3, line 34 - column 4, line 34.	1, 3, 5
A	--	2, 4, 9, 11
X	US, A, 3 866 234 (GATES) 11 February 1975 (11.02.75), see fig. 3, 5; column 3, lines 23-41.	1, 5, 7
X	US, A, 3 914 769 (ANDREWS) 21 October 1975 (21.10.75), see fig. 2; claims.	1
A	DE, A1, 3 134 122	1-4, 8,
¹⁴ Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "Z" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search 30 December 1992		Date of Mailing of this International Search Report 15 JAN 1993
International Searching Authority EUROPEAN PATENT OFFICE		Signature of Authorized Officer HEINICH e.h.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages	Relevant to Claim No.
	(LICENTIA) 17 March 1983 (17.03.83), see totality; especially page 5, lines 25,26. --	9,11
A	US, A, 4 482 513 (AULETTI) 13 November 1984 (13.11.84), see fig.; column 4, line 17 - column 5, line 12. --	1-4,7, 9-11
A	US, A, 3 307 196 (HORST) 28 February 1967 (28.02.67), see fig. 1,7; claims. --	1,8-11
A	GB, A, 1 125 828 (LIGNES) 05 September 1968 (05.09.68), see fig. 3; claims. --	1-4
X	US, A, 2 835 891 (PEELER) 20 May 1958 (20.05.58), see fig. 2,6-10; column 2, lines 17-36, especially 30. --	8-11
A	SOVIET INVENTIONS ILLUSTRATED, E1 section, week 8703 DERWENT PUBLICATIONS LTD., London, see SU-A-1233 229, (04 March 1987), & SU-A1-1233 229 (VYLEG- (ZHANIN) -----	8-11

ANHANG

zum internationalen Recherchen-
bericht über die internationale
Patentanmeldung Nr.

ANNEX

to the International Search
Report to the International Patent
Application No.

ANNEXE

au rapport de recherche inter-
national relatif à la demande de brevet
international n°

PCT/EP 92/02384 SAE 66196

In diesem Anhang sind die Mitglieder
der Patentfamilien der im obenge-
nannten internationalen Recherchenbericht
angeführten Patentedokumente angegeben.
Diese Angaben dienen nur zur Unter-
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This Annex lists the patent family
members relating to the patent documents
cited in the above-mentioned inter-
national search report. The Office is
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La présente annexe indique les
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Im Recherchenbericht angeführtes Patentedokument Patent document cited in search report Document de brevet cité dans le rapport de recherche	Datum der Veröffentlichung Publication date Date de publication	Mitglied(er) der Patentfamilie Patent family member(s) Membre(s) de la famille de brevets	Datum der Veröffentlichung Publication date Date de publication
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US A 3914769	21-10-75	keine - none - rien	
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GB A 1125828		keine - none - rien	
US A 2835891		keine - none - rien	