

Jan. 18, 1966

T. C. CHESTON

3,230,536

BEAM FORMING LENS

Filed April 13, 1962

FIG. 1.

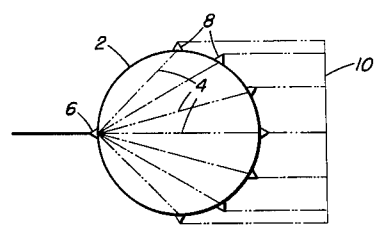


FIG. 2.

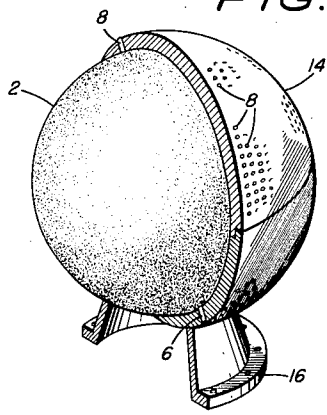


FIG. 3.

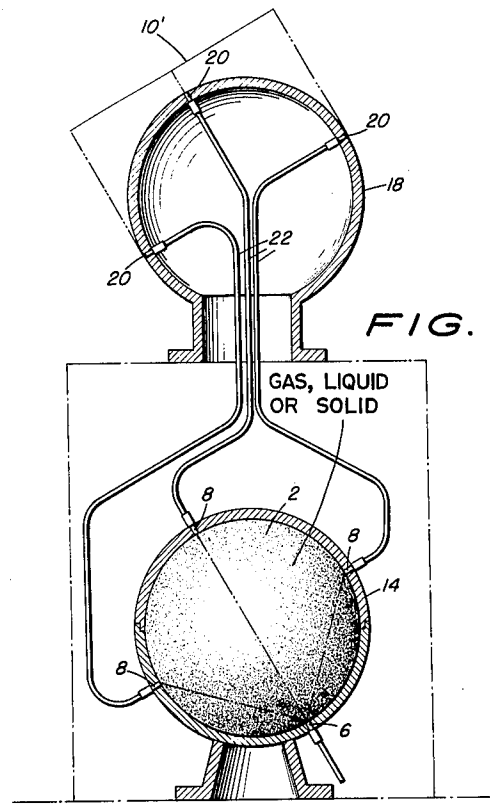
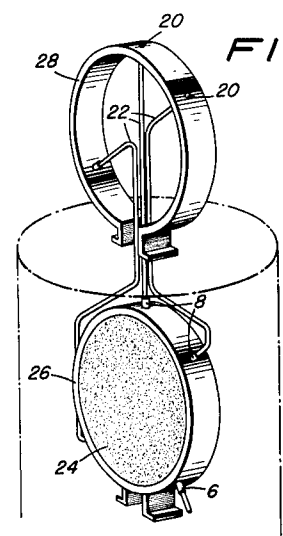


FIG. 4



THEODORE C. CHESTON
INVENTOR

BY

Claude Funkhouser

ATTORNEY

1

3,230,536

BEAM FORMING LENS

Theodore C. Cheston, Bethesda, Md., assignor to the United States of America as represented by the Secretary of the Navy

Filed Apr. 13, 1962, Ser. No. 187,441

11 Claims. (Cl. 343-754)

This invention relates in general to spherical antennas and more particularly to a spherical antenna system utilizing a lens as a beam forming device. More specifically the invention relates to a dielectric lens having the characteristics of the "Luneberg lens" described by R. K. Luneberg in "Mathematical Theory of Optics," Brown University Advanced Instruction and Research in Mechanics, Providence, Rhode Island, summer of 1944.

In a tracking radar system, a highly directional radiation pattern is required to obtain a high degree of sensitivity. Rather than to allow even a unidirectional radiation pattern, the transmitted energy of such systems is confined to a beam. Furthermore, an added requirement of such radar systems is the necessity for providing an omnidirectional scanning capacity.

The need for a highly directional signal could be satisfied through the use of a spherical antenna having the properties of the aforesaid Luneberg lens. However, of practical necessity, the power level in such a beam forming device must be far below that required for long range operation. Therefore, it is necessary to provide a separate beam forming device in addition to the spherical antenna. This device has the beam bending properties of the Luneberg lens, but additionally has many collecting elements distributed about its surface. The signal to be radiated is injected into the spherically shaped lens at one point on its surface and expands within the sphere from that point into many individual portions which are separately picked up by the collecting elements located about the opposite surface of the lens. The signal picked up by each collecting element is first amplified and then transferred to the antenna by transmission lines. All of the collected signals are then radiated into space providing a highly directional concentrated beam. In effect the signal derived by the lens and present at its surface is divided into several component portions by the lens allowing amplification of each portion so as to preserve the characteristics of the beam for radiation from a separate spherical surface.

The antenna requirements for providing omnidirectional scan are achieved through electronic switching. That is, the signal is injected at different points on the surface of the sphere and will form a beam in the direction dictated by the point of signal injection. Therefore, the mechanical rotation of the normal radar antenna system is no longer required since the electronic switching performs the same function in a more advantageous way.

The beam bending property of the Luneberg lens is attributed to the dielectric material from which the lens is made. This dielectric material has an index of refraction, N , which is functionally related to the radius r , within the lens, by the equation:

$$N = \sqrt{2 - \left(\frac{r}{r_0}\right)^2}$$

where r_0 = the outer radius of the sphere. As is evident from the equation this lens will comprise a dielectric filled sphere having a continuously varying dielectric constant from its center to its outer surface.

Because of the great difficulty associated with the manufacture of a dielectric lens having a constantly varying index of refraction, various methods have been proposed to simulate a continuously varying index of refraction. Examples of two such approximations are explained in

2

U.S. Patents 2,849,713 to G. P. Robinson, Jr. and 2,943,358 to S. F. Hutchins et al.

Notwithstanding the various attempts to minimize the expense of manufacturing an approximation of the Luneberg lens, the expense has remained high because of the close tolerances that must be achieved during the manufacturing process.

One object of the present invention, therefore, is to provide a simplified lens for a radar transmitting antenna system.

Another object of the present invention is to provide a lens constructed of a homogeneous dielectric material having a uniform index of refraction.

A further object of the invention resides in the provision of a lens which is constructed in the form of a sphere and that has air as its dielectric.

A still further object of the invention is to provide a lens for low frequency waves having a very high index of refraction with a comparative reduction in size.

Other objects and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a schematic representation of the wave shaping characteristics of a lens of the instant invention;

FIG. 2 illustrates an embodiment of the lens of the instant invention;

FIG. 3 shows a schematic representation of the lens in combination with a spherical antenna; and

FIG. 4 shows a schematic representation of the invention for a two dimensional scan where linear polarization may be used.

This invention may be used, for example, to replace the transmitter lens required by the system of John B. Garrison, described and illustrated in his application Serial No. 20,231, filed April 5, 1960, and assigned to the U.S. Government.

The formation of a beam having parallel rays from an omnidirectional signal injected at a point source on the surface of a Luneberg lens is caused by the beam bending property of the lens which continuously adjusts the phase and amplitude of the individual portions of the injected signal and provides the proper phase relationship between all of the portions of the signal on the opposite side of the lens from the point of signal injection so that radiation into space of a plane wave results at its exit aperture. It has been discovered that a spherically shaped dielectric lens with an invariant dielectric constant of $3.5 \pm 10\%$ approximates the beam forming properties of the aforesaid Luneberg lens. These invariant dielectric constant lenses perform well in sizes up to at least a diameter of 30 wavelengths and may be used in the same way as Luneberg lenses.

Referring to the schematic representation of the lens 2 shown in FIG. 1, the signal phase produced by the lens can be seen to be dependent solely upon the electrical path length through the lens, as designated by the length of a line 4 between a radar transmitting feed 6 and one of the radar collectors 8. The length of a line 4 determines the amount of adjusted phase for that collector.

Each collector 8 receives a signal whose phase, relative to its phase at the radar transmitting feed 6, is given by the equation:

$$\Phi = \frac{2\pi}{\lambda} L \sqrt{\epsilon}$$

where

Φ = the relative phase at the collector,

L = the physical path length between the collector and the feed,

ϵ =the assigned value of the dielectric constant of 3.5;
and
 $2\pi/\lambda$ =a well-known constant in optics.

If radiated from this surface, all of the individual signals would combine to form a wave having an equi-phase wave front at the exit aperture designated by line 10.

As long as the product $L\sqrt{\epsilon}$ in the aforementioned equation remains constant the path length, L, and the dielectric constant ϵ , may be varied. An embodiment of the instant invention for use with low frequency waves is derived by increasing the value of ϵ . This is accomplished by utilizing a solid dielectric material having a relatively high refractive index. The radius of the resulting lens will then be reduced correspondingly. By reducing the value of ϵ , a lens will result of correspondingly larger dimensions. In such an embodiment even a liquid such as paraffin oil can be used and will perform as well as the solid dielectric material. If ϵ is reduced to unity, it is possible to use air as the dielectric material. Compensation for this change is made by increasing the value of L by the factor of $\sqrt{3.5 \pm 10\%}$. The resultant lens will then have a radius that is increased by a factor of $\sqrt{3.5 \pm 10\%}$ and this will eliminate the need for a homogeneous dielectric material other than air.

The above-mentioned equation assumes the form

$$R = R_o \frac{\sqrt{Z}}{K}$$

when written in terms of physical size, where

R=the radius of the lens having a homogeneous dielectric material,

R_o =the radius of antenna used with the radar system,

K=the refractive index of the lens having a radius R; and
 $Z=3.5 \pm 10\%$.

The lens 2 employed in the instant invention is shown in FIG. 2 wherein a spherical mounting shell 14, formed of a high loss material such as a metal covered with iron oxide, is used to support a plurality of radar transmitting feeds 6 and radar collectors 8. There can be any reasonable number of radar transmitting feeds and radar collectors distributed on the surface of the shell. The number is limited only by the physical size of the feeds themselves. The mounting shell 14 is supported on a pedestal 16 or any other physical means of support which will not interfere with the proper operation of the lens.

Referring to FIG. 3, there is seen a schematic representation of the lens 2 of the instant invention in combination with a spherical radar antenna 18 having, located on its surface, radiating elements 20 which correspond to those on lens 2 and which are connected to their respective radar collectors 8 on the surface of the lens 2 by a plurality of transmission lines 22, all of which are of equal length. For the sake of clarity, the intervening power amplifiers are not shown. An equiphase wave front 10' is radiated from the surface of the antenna 18.

Referring to FIG. 4, there is seen a disk shaped lens 24 enclosed by a mounting shell 26 having a radar transmitting feed 6 and a plurality of radar collectors 8 mounted thereon. This embodiment of the invention shows the adaptation of the principles of the invention to a cylindrical lens 24. The transmission lines 22 are all of equal length and transpose the signals collected by the collectors 8 to corresponding radiators 20 mounted on a similarly oriented radiating disk 28. This configuration produces a fan shaped beam of radiation having its width in the plane at right angles to the plane of the disk 28 and is defined by the size of the radiators 20 in that plane. Linear polarization is permissible for this configuration.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within

the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. In combination with a radar system including a spherical antenna, a spherical lens for focusing and refracting waves having a given wavelength, said lens comprising, a shell, a plurality of radar transmitting feeds distributed adjacent the surface of said lens and mounted in said shell for injecting a wave into said lens from any selected feed, a plurality of radar collector means uniformly distributed over the remaining portion of said lens diametrically opposite said plurality of feeds, said plurality of collectors serving to collect a wave emergent from said lens, and said lens being constructed of a homogeneous dielectric material having a uniform refractive index.

2. In combination with a radar system including a spherical antenna, a lens as claimed in claim 1, wherein the homogeneous dielectric material is a gas.

3. In combination with a radar system including a spherical antenna having a radius R_o , a lens as claimed in claim 1, wherein the dielectric material has a refractive index K greater than 1 and the radius R of the lens is functionally related to the radius R_o according to the relationship

$$R = R_o \frac{\sqrt{3.5}}{K}$$

4. In combination with a radar system including a spherical antenna having a radius R_o , a lens as claimed in claim 1, wherein the dielectric material has a refractive index K greater than 1 and the radius R of the lens is functionally related to the radius R_o according to the relationship

$$R = R_o \frac{\sqrt{Z}}{K}$$

where $Z=3.5 \pm 10\%$.

5. In combination with a radar system including a spherical antenna having a radius R_o , a lens as claimed in claim 1, wherein the dielectric is air and the radius R of the lens is functionally related to the radius R_o according to the relationship $R = R_o \sqrt{3.5}$.

6. In combination with a radar system including a spherical antenna, a lens as claimed in claim 1, wherein the homogeneous dielectric material is a liquid.

7. In combination with a radar system including a spherical antenna, a lens as claimed in claim 1, wherein the homogeneous dielectric material is a solid.

8. In combination with a radar system including a disk shaped antenna, a disk shaped lens for focusing and refracting waves having a given wave length, said lens comprising, a disk shaped shell, a plurality of radar transmitting feeds distributed adjacent the surface of said lens and mounted on said shell for injecting a wave into said lens from any selected feed, a plurality of radar collector means uniformly distributed over the remaining portion of said lens diametrically opposite said plurality of feeds, said plurality of collectors serving to collect a wave emergent from said lens, and said lens being constructed of a homogeneous dielectric material having a uniform refractive index.

9. In combination with a radar system including a disk shaped antenna, a lens as claimed in claim 8, wherein the radius of the disk shaped antenna is designated as R_o , the dielectric material has a refractive index K greater than 1, and the radius R of the lens is functionally related to the radius R_o according to the relationship

$$R = R_o \frac{\sqrt{3.5}}{K}$$

10. In combination with a radar system including a disk shaped antenna, a lens as claimed in claim 8, where-

5

in the radius of the disk shaped antenna is designated as R_o , the dielectric material has a refractive index K greater than 1, and the radius R of the lens is functionally related to the radius R_o according to the relationship

$$R=R_o\frac{\sqrt{Z}}{K}$$

where $Z=3.5\pm 10\%$.

11. In combination with a radar system including a disk shaped antenna, a lens as claimed in claim 8, where-
in the radius of the disk shaped antenna is designated as R_o , the lens has air as its dielectric and the radius R of

6

the lens is functionally related to the radius R_o according to the relationship $R=R_o\sqrt{3.5}$.

References Cited by the Examiner

5

UNITED STATES PATENTS

2,566,703	9/1951	Iams	-----	343—753
3,145,382	8/1964	Cuming et al.	-----	343—911 X

10

CHESTER L. JUSTUS, *Primary Examiner*.
ELI LIEBERMAN, *Acting Primary Examiner*.
M. KRAUS, *Assistant Examiner*.