343-754 SEARCH ROOM

May 28, 1968 C. H. WALTER ETAL 3,386,099

MULTIPLE LUNEBERG LENS ANTENNA

Filed Feb. 11, 1965

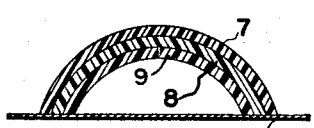


FIG. 1A

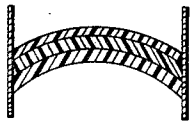


FIG. 2A

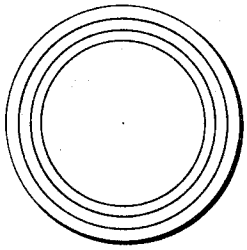


FIG. 1

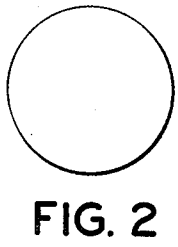


FIG. 2

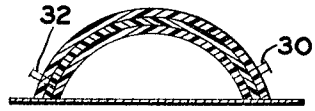


FIG. 5A

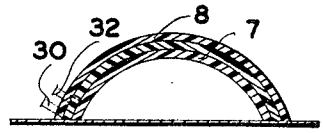


FIG. 5

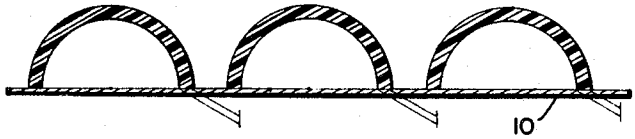


FIG. 3A

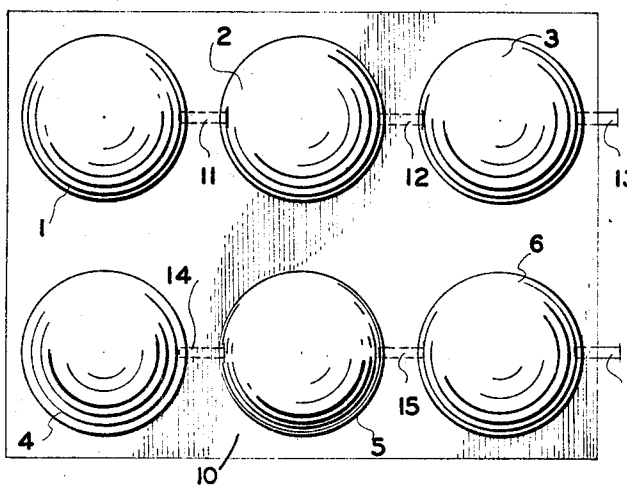


FIG. 3

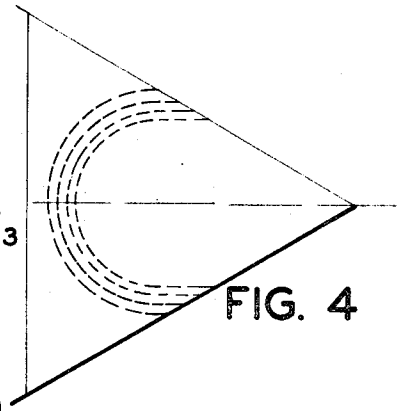


FIG. 4

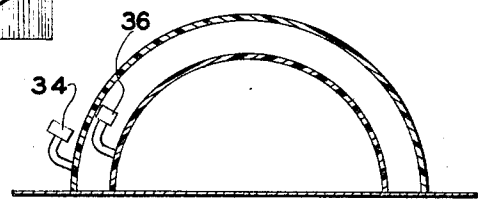


FIG. 5B

INVENTOR.
Carlton H. Walter
Roger C. Ruddick
BY
Anthony D. Cennamo

United States Patent Office

3,386,099

Patented May 28, 1968

3,386,099

MULTIPLE LUNEBERG LENS ANTENNA

Carlton H. Walter and Roger C. Rudduck, Columbus, Ohio, assignors to The Ohio State University Research Foundation

Filed Feb. 11, 1965, Ser. No. 431,902
11 Claims. (Cl. 343—754)

ABSTRACT OF THE DISCLOSURE

The invention is for a surface wave Luneberg lens antenna structure having a plurality of lenses positioned on a ground plane either in a side by side relationship or stacked one upon the other. Energy is then fed to the array.

In the patent issued to C. H. Walter, No. 3,108,278, for "Surface Wave Luneberg Lens Antenna System," there is disclosed a surface-wave structure that can be made to perform as a Luneberg lens. In particular, it was shown that the index of refraction of a surface-wave structure can be made to conform to the equation:

$$\frac{c}{v}=n=\sqrt{2-r^2}$$

where:

c=velocity of light in free space
v=phase velocity of the surface wave
r=normalized radius

It is further shown that a circular dielectric sheet on a ground plane can be made to perform as a Luneberg lens in the plane of the sheet and at the same time perform as an endfire antenna in the orthogonal plane.

In our co-pending application, S.N. 341,493, filed Jan. 28, 1964, as a continuation of S.N. 79,434, for "Non-Planar Surface-Wave Luneberg Lens Antenna," there is disclosed a surface-wave structure operable as a Luneberg lens although its contour may be other than planar. This antenna adapts the teachings of the prior patent to more practical applications. That is, the non-planar surface-wave structure may be fitted flush with the skin of the aircraft, vehicle or craft upon which the antenna is to be mounted.

We have found that the surface-wave antenna disclosed in the patent and in the application has its limitation that the radiated beam must lie in or near the plane of the rim of the lens. Therefore, if the surface-wave structure of either of our two co-pending applications is fitted directly to a vehicle, the radiated beam would only be in the one direction.

We further disclose in another co-pending application, S.N. 343,916, a continuation of S.N. 79,435, now Patent Number 3,255,454, for "Luneberg Lens Antenna System," a Luneberg lens similar to the non-planar structure with the improvement of beam steering in the orthogonal plane.

Although the antenna structures in the prior disclosures have proved to be quite successful, there are, nonetheless, applications for which these antennas are impractical or inadequate—for instance, various beam elevation positions, shaped vertical beams, simultaneous coverage over 360° in azimuth, simultaneous coverage in various frequency ranges, simultaneous transmit-receive capability, simultaneous dual polarization, and of most importance, volumetric coverage and beam shaping.

The present invention accomplishes these improved capabilities through the use of multiple lenses positioned

on or above a ground plane or in some instances with no ground plane at all.

It is, therefore, the principal object of the antenna of the present invention to utilize the teachings of the surface-wave Luneberg lens in accomplishing the improved capabilities.

Other objects and features of the present invention will become apparent from the following detailed description when taken in conjunction with the drawings in which:

FIGURE 1 illustrates multiple lenses on a ground plane with the lenses stacked one over the other;

FIGURE 1*a* is a side view of the lenses in FIGURE 1 in cross-section;

FIGURE 2 illustrates multiple lenses stacked in a cylindrical structure; wherein

FIGURE 2*a* is a side view of the lenses in FIGURE 2 in cross-section;

FIGURE 3 illustrates multiple lenses on a ground plane with the lenses individually positioned side by side;

FIGURE 3*a* is a side view of the lenses in FIGURE 3 in cross-section;

FIGURE 4 illustrates a cross-sectional view of a coaxial nose mount for the multiple lens of the present invention;

FIGURES 5, 5*a*, and 5*b* illustrate alternative feed arrangements for the stacked array.

There is described an antenna in our co-pending application, S.N. 343,916 wherein the radiated beam is steerable. There are also given calculations in that application for a typical constructed lens type antenna illustrating its capability of volumetric beam coverage. It has been found now that, although the single lens antenna of the co-pending application basically covers an extensive conical region about the lens axis, the beam shapes are poor for beam positions within about 10° of the lens axis. This is a result of the aperture polarization for feed positions near the center of the lens. It has been further found that the element pattern is also a practical limitation to using a single lens for wide coverage in elevation. The multiple lenses of the present invention overcome these particular difficulties.

Generally, the multiple lenses shown in FIGURES 1 through 4 are operative much in the same manner as the Luneberg type lenses of the co-pending applications. The particular choice of multiple lens antenna of the present invention is more attendant to the structural and environmental requirements. That is, in operation each lens in the stack or the array is operative independently as a single lens. The cooperation being in the radiation pattern having the improved capabilities not achievable with any one single lens set forth in the aforementioned co-pending applications.

The antenna of FIGURE 3 comprises a plurality of lenses, **1** through **6** shown, in a spaced arrangement on the ground plane **10**. The design and shape of these lenses conform to that taught in the aforementioned co-pending applications. The number of lenses employed and their spacing—uniform or non-uniform—relative to one another is, of course, dictacted by the desired shape of the beam pattern and by the beam position desired. Again referring to our co-pending application S.N. 343,916, there is given the development of the general equation for geodesic and non-planar Luneberg lenses— specifically the Equations 5 through 29. From these equations and utilizing

$$G'(\rho)=-\frac{\sqrt{1+\dot{z}^2}}{r}\frac{dr}{dp}=\frac{d}{dp}\left\{\ln[\cos^2\beta+\cos\beta\sqrt{\cos^2\beta-\rho^2}]^{1/2}\ln\rho-\Omega(p)\right\}$$

the following general equation for a single geodesic lens is obtained

$$\sqrt{1+\dot{z}^2}=\frac{n+r\dot{n}}{n}\left\{\frac{1}{2}+\frac{\cos\beta}{2\sqrt{\cos^2\beta-\rho^2}}\left[1-2F(\cos\beta)+\int_{\rho}^{\cos}\frac{KF'(K)}{\sqrt{K^2-\rho^2}}dK\right]\right\}=\frac{n+r\dot{n}}{n}\left\{\frac{1}{2}+\frac{\cos}{2\sqrt{\cos^2\beta-\rho^2}}-\frac{\cos^2\beta}{\pi\sqrt{\cos^2\beta-\rho^2}}\left[2\int_{\alpha}^{r_1}\frac{\sqrt{1+\dot{z}^2(r)}}{\sqrt{P^2(r)-\cos^2\beta}}\frac{dr}{r}+\int_{r_1}^{1}\frac{\sqrt{1+\dot{z}^2(r)}}{\sqrt{P^2(r)-\cos^2\beta}}\frac{dr}{r}\right]+\frac{\sqrt{\cos^2\beta-\rho^2}}{\pi}\left[2\int_{\alpha}^{r_1}\frac{P^2(r)\sqrt{1+\dot{z}^2(r)}}{(P^2(r)-\rho^2)\sqrt{P^2(r)-\cos^2\beta}}\frac{dr}{r}+\int_{r_1}^{1}\frac{P^2(r)\sqrt{1+\dot{z}^2(r)}}{(P^2(r)-\rho^2)\sqrt{P^2(r)-\cos^2\beta}}\frac{dr}{r}\right]\right\}$$

In the arrangement of lenses of FIGURE 3, the electromagnetic radiation is fed to each lens in a manner similar to that also taught in the co-pending application. That is the feed elements **11** through **16** each feed the respective lenses **1** through **6** at their rims.

To provide economy of space, such as in aircraft, it would be advantageous to concentrically stack the lenses one over the other in a manner shown schematically in FIGURE 1. The lenses **7**, **8**, and **9** are positioned one over the other and fixedly and electrically mounted to the ground plane **10**. Again, similar to the arrangement of FIGURE 3, each lens in the stacked array is operable in the same manner with the radiation pattern having the effective combined result.

In stacked lenses for coverage over a very wide angle sector in azimuth, the feeding of each lens in the stack requires that the feed lenses pass through other lenses in the stack. This may tend to somewhat degrade their electrical performance. In sectors of 90° wide, however, a stack of lenses may be fed without degradation of electrical properties. This feed arrangement is shown in FIGURE 5 wherein the feed **30** feeds the lens **8** and the feed **32** passes through the lens **8** to feed energy to lens **7**. Dependent upon the radiation pattern desired the feeds **30** and **32** may be positioned at either or at alternate rims. The alternate feed arrangement is shown in FIGURE *5a*. Again to overcome the degradation of electrical performance by the feed passing through lens, there is still a further arrangement of feed and lenses shown in FIGURE *5b*. In this array the lenses are not contiguous—that is they are spaced sufficiently apart to permit the receiving (or transmitting) apparatus **34** and **36** to be physically positioned between lenses.

There are two general types of mounting configurations for stacked lenses such as may be employed in aerospace vehicles. There is shown in FIGURE 4 a stack of lenses mounted coaxially with the nose axis of the vehicles; whereas in FIGURE 2 the stack of lenses is mounted in a cylinder. The type of mounting used would depend on the volumetric coverage required. For example, in a typical installation a stack of 4 to 8 lenses mounted on surface in the nose of an aerospace vehicle could be used to obtain coverage in a sector extending from the horizon down to −40° in elevation and 90° wide in azimuth. Each lens in the stack would cover a sector 5° to 10° wide in elevation. In this embodiment multiple fixed feeds of the narrow open-ended waveguide type could be mounted in 90° sectors in each lens.

Although certain and specific embodiments are shown, it is to be understood that modifications may be had without departing from the spirit and scope of the invention.

What is claimed is:

1. An antenna structure comprising a plurality of non-planar Luneberg type lenses having an index variation to give a beam position at angles from 0° to 90° from the plane of the rim, each of said lenses further comprising a geometrical configuration substantially semi-circular, said lenses arranged side by side in a spaced relationship, and feed means positioned at the focus of each of said lenses for coupling electromagnetic energy to each of said lenses at the focus of the lenses.

2. An antenna structure comprising a plurality of non-planar Luneberg type lenses having an index variation to give a beam position at angles from 0° to 90° from the plane of the rim, a ground plane structure, said lenses arranged in a spaced relationship on said ground plane, each of said lenses further comprising a non-planar configuration with a flat surface in coplanar relation to and in electrical contact with said ground plane structure and each having a free radiating surface with radial symmetry propagation capability; and feed means positioned at the focus of said lenses for coupling electromagnetic energy to said lenses at the focus of said circular lens.

3. An antenna structure as set forth in claim **2** wherein said lenses are positioned side by side in spaced relationship on said ground plane.

4. An antenna structure as set forth in claim **2** wherein said lenses are positioned one over the other on said ground plane.

5. An antenna structure as set forth in claim **2** wherein said lenses are positioned one over the other in spaced relationship on said ground plane.

6. An antenna structure as set forth in claim **2** wherein said non-planar configuration is of a circular configuration.

7. An antenna structure comprising a plurality of non-planar Luneberg type lenses having an index variation to give a beam position at angles from 0° to 90° from the plane of the rim, each of said lenses further comprising a geometrical configuration substantially semi-circular, said lenses arranged one over the other and in physical contact with one another, and feed means positioned at the focus of each of said lenses for coupling electromagnetic energy to each of said lenses at the focus of said lenses.

8. An antenna structure as set forth in claim **7** wherein said lenses are in spaced relationship with one another and said energy coupling means is positioned in said spacing.

9. An antenna structure as set forth in claim **7** wherein said geometrical configuration is substantially non-planar.

10. An antenna structure comprising a plurality of non-planar Luneberg type lenses having an index variation to give a beam position at angles from 0° to 90° from the plane of the rim, said lenses further comprising a geometrical configuration substantially non-planar, said lenses arranged one over the other and in physical contact with one another, and feed means positioned at the focus of said lenses for coupling electromagnetic energy to each of said lenses at the focus of said lens.

11. An antenna structure as set forth in claim **10** wherein said lenses are in spaced relationship with one another and said energy coupling means is positioned in said spacing.

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ELI LIEBERMAN, *Primary Examiner.*

PAUL GENSLER, *Examiner.*