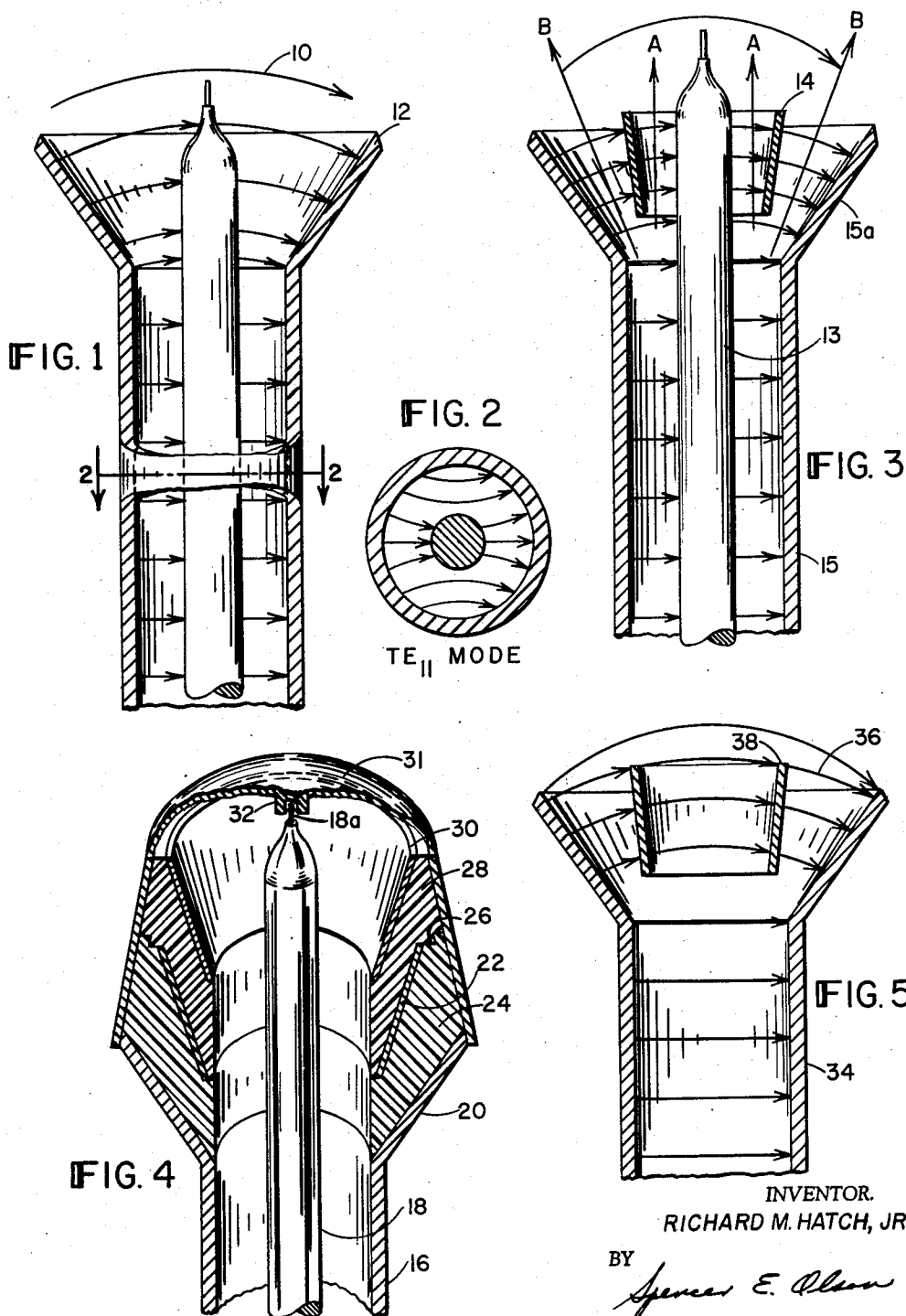


March 8, 1960

R. M. HATCH, JR
ELECTROMAGNETIC LENS
Filed Oct. 9, 1957

2,928,092



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2,928,092

ELECTROMAGNETIC LENS

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Application October 9, 1957, Serial No. 689,092

7 Claims. (Cl. 343-753)

This invention relates to antenna systems for radiation and/or reception of ultra high frequency electromagnetic waves, and more particularly to antenna systems for maintaining a wide radiation beam over a broad band of frequencies.

As is well known in the art, electromagnetic horns of various configurations have long been used as impedance transformers between the wave guide systems of microwave apparatus and free space. The more conventional configuration consists of a section of rectangular wave guide flared at one end in one or both planes to provide a rectangular aperture lying in a flat plane. While radiators of this type are useful in certain applications, and by suitable modification, as by insertion of septa and the like, can be made to provide specific radiation patterns, their radiation patterns are very sensitive to changes in frequency. The radiation beam width of a simple horn type radiator depends upon the electrical dimensions of the horn, and thus for a given horn, a change in wave length of the transmitted or received signal results in a corresponding change in the width of the beam. Thus, a change in wave length of 2:1 would result in roughly a 2:1 change in beam width. Accordingly, radiators heretofore available are unsatisfactory in certain communications and radar applications where it is desirable to maintain a wide radiation beam over a large frequency range.

Accordingly it is a primary object of the present invention to provide a radiator for electromagnetic radiation having a wide beam width which is maintained over a wide range of frequencies.

Another object of the invention is to provide an electromagnetic lens having a wide beam width maintainable over a broad band of frequencies and which is useful with linearly, elliptically or circularly polarized waves.

Another object of the invention is to provide an antenna having the foregoing characteristics which is relatively simple to manufacture and sufficiently rugged to withstand the environmental conditions encountered in modern high speed, high altitude aircraft.

The invention is based in part upon the fact that the phase of field in a space bounded on at least two sides by conductive walls placed substantially parallel to the electric field progresses at a velocity greater than the velocity in free space, this increase in velocity resulting from the interaction of waves reflected from the boundary walls. This field velocity or phase velocity may be controlled by controlling the spacing of the boundary walls. This phenomena is applied to a horn radiator of the coaxial waveguide type, normally consisting of a coaxial line the outer conductor of which is flared to provide an aperture, with the inner conductor coextensive with the flared outer conductor so that the aperture lies in a flat plane. When a horn of this type is excited in the dominant TE mode, the equiphas surfaces of radiant energy become increasingly flat as the electrical dimension of the aperture becomes larger with the consequence that the radiation beam becomes narrower. Ac-

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cording to the main feature of this invention, a radiator of the type just described is modified by a conducting cylinder disposed in the aperture effectively to divide the aperture into two concentric wave guides having by virtue of their different diameters, different propagation velocities. With proper relative spacing between the cylindrical conductor and the inner and outer conductors of the coaxial conductor horn, the relative phase of the energy passing through the central portion of the aperture may be made to advance with respect to that near the outer region of the aperture, thus advancing the center of the equiphas surface. As a result, the total surface becomes nearly spherical with the consequence that the radiation beam is widened. Further control of the radiation pattern may be achieved by insertion of additional cylindrical conductors in the aperture, the relative diameters of the conductors and their relative lengths and positions in the aperture determining the radiation characteristics of the total lens structure. Variations in these parameters also determine the relative amounts of energy transmitted and reflected by the structure; i.e., the match of the antenna to the associated apparatus and free space. Further adjustment of the propagation characteristics of the various portions of the lens may be obtained by the insertion of dielectric materials having dielectric constants greater than that of free space in one or more of the concentric wave guides. In a preferred embodiment, the dielectric material also functions as the support for the cylindrical conductors to provide an integral rigid structure.

The foregoing and other objects of the present invention will now become apparent, and a better understanding of its construction and applications had from the following detailed description when taken in connection with the accompanying drawing in which:

Figs. 1 and 2 are diagrams illustrating the field patterns encountered in a coaxial waveguide type of electromagnetic radiator;

Fig. 3 is a cross-section view of the electromagnetic lens in its most basic form illustrating the principal of the invention;

Fig. 4 is a cross-section view of a preferred embodiment of the invention; and

Fig. 5 is a cross-section view illustrating the invention as applied to a circular waveguide horn radiator.

With reference now to the drawing and more particularly to Figs. 1 and 2, in a simple horn radiator of the coaxial waveguide type excited in the dominant TE mode (illustrated in Fig. 2) the equiphas surfaces 10 of radiant energy emanating from the aperture 12 become increasingly flat as the dimension of the aperture becomes larger with the consequence that the resulting radiation beam becomes narrower. At constant frequency, of course, the beam width is constant at a width determined by the dimension at the aperture, but should the frequency of transmitted or received radiation increase, the electrical dimension of the aperture likewise increases causing the beam to become narrower.

In accordance with the present invention, a conducting cylinder 14, preferably of metal, is disposed in the aperture of the radiator concentrically with the inner conductor 13 and the outer conductor 15 of the coaxial waveguide. As shown in Fig. 3, the cylinder 14 may be tapered slightly in the same direction as the taper of the flared opened end 15a of the outer conductor 15 of the waveguide, and is of such a dimension that the coaxial waveguide formed by inner conductor 13 and cylinder 14 is of smaller dimension than the waveguide formed by cylinder 14 and the flared portion 15a. Thus it is seen that cylinder 14 divides the aperture into two concentric waveguides, which by virtue of their different diameters have different propagation velocities. The smaller inner

guide has a greater propagation velocity than the concentric outer guide, and therefore advances the relative phase of energy passing therethrough, that is, along the path A, with respect to that in the outer guide, designated by the arrows B. The center of the equiphase surface emanating from the lens is thus advanced and the total surface becomes more nearly spherical with the result that the radiation beam is widened. By proper selection of the length, diameter, and position of a single cylinder 14 in the aperture, it is possible to maintain a beam width of approximately 70° substantially constant over a range of frequency of 2:1.

While the structure illustrated at Fig. 3 is useful in explaining the principle of operation of the antenna, and has utility in certain applications, to maintain substantially uniform band width over a wide frequency range the diameter of cylinder 14 necessarily is so small that the cutoff frequency of the inner waveguide is approached within the operating frequency range of the antenna. At frequencies near or below the cutoff frequency, the cylinder introduces objectionable reflections, obviously an undesirable condition. This disadvantage is overcome by an extension of the basic concept hereinabove described, and the introduction of means to delay the field at the periphery of the aperture and not the field at the center of the aperture. In a preferred embodiment, illustrated in Fig. 4, this is accomplished by the introduction of dielectric materials having relatively high dielectric constant near the periphery of the aperture, and the use of concentric conducting cylinders to divide the aperture into concentric waveguides in the manner discussed in connection with Fig. 3.

More specifically, the electromagnetic lens of Fig. 4 comprises a coaxial waveguide having an outer conductor 16 and inner conductor 18, the outer end of the outer conductor being flared as shown at 20. Instead of the single cylinder of Fig. 3, the embodiment of Fig. 4 includes two conducting cylinders mounted within the aperture concentrically with inner conductor 18. A first of these cylinders, designated 22, is of frusto-conical shape and has a flare angle somewhat less than that of the flared open end 20 of the outer conductor 16. Cylinder 22 is supported relative to the flare 20 by a mass of rigid dielectric material 24 of generally torroidal shape, which is in turn, supported inside the flange 20. Dielectric material 24 may be Teflon or polystyrene, which have dielectric constants of approximately 2.0-2.5, or preferably a metal powder loaded plastic foam material, which has recently become available, and whose dielectric constant may be adjusted to any value between 1.0 and about 4.0 by controlling the proportions of the plastic-metal mixture. It will be noted that the diameter of the smaller end of cylinder 22 is slightly larger than the inner diameter of conductor 16, and that the dielectric material 24 extends radially beyond the larger diameter of cylinder 22.

Fitted within cylinder 22 and supported on the cylinder and on a portion of dielectric 24 along the surface 26 is a second mass of similar dielectric material 28, also of generally torroidal form, on which is supported a second cylinder 30 also of frusto-conical shape. The smaller diameter of cylinder 30 is substantially equal to the smaller diameter of cylinder 22 and has a similar angle of flare whereby cylinders 22 and 30 together define a passage for wave energy having substantially parallel sides. It will be evident that in fabrication, dielectric material 24 may be deposited in the flared open end of the coaxial waveguide and the cylinder 22 fitted in place, and the dielectric member 28 and its associated cylinder 30 separately fabricated and machined and then inserted in place within cylinder 22. The outer surface of dielectric members 24 and 28 are similarly tapered as shown.

From the foregoing description, it is seen that the cylinders 22 and 30 together with the conductors of the coaxial waveguide divide the aperture of the radiator into three concentric waveguides; namely, a first guide between

inner conductor 18 and cylinder 30, a second guide between cylinders 22 and 30, and a third guide between the flared portion 20 and the cylinder 22. The first-mentioned waveguide is unloaded, and is of such dimensions that of the three it has the highest propagation velocity. The third contains more dielectric material or material of higher dielectric constant than the second whereby energy at the periphery of the aperture is delayed more than in either of the second or first guides. As a consequence, the total radiation pattern from the lens has a wide beam and substantially spherical wave front. The lens structure being circularly symmetric, the polarization of the energy may rotate about the axis of the structure without effect upon the radiating properties of the lens, and is thus equally well adapted to elliptically or circularly polarized waves as to linearly polarized waves.

In applications of the antenna where dust may be encountered, it may be preferable to cover the aperture, a cap 31 formed of thin, radiation permeable plastic material being shown for this purpose. Internally of its crown, the cap is preferably provided with a boss 32 having an opening therein for receiving the tip 18a of the center conductor of the coaxial waveguide. Thus, in addition to sealing the lens, the cap provides lateral support for conductor 18.

The invention has been described in connection with two possible physical embodiments; namely the single conducting cylinder of Fig. 3 and the double-cone, dielectric-loaded embodiment of Fig. 4. It will be understood that in arriving at a desired radiation pattern it may be possible to devise many alternative combinations. For example, a two-cone lens without dielectric loading may be useful in some applications, and it will be appreciated by those skilled in the art that considerable adjustment of the angle of taper of the conducting cylinders, their locations relative to each other and relative to the flared open end of the coaxial waveguide, and the angle of flare of the coaxial waveguide (as well as the number of conducting cylinders) are subject to individual adjustment without departing from the spirit of the invention. Likewise, the structure of Fig. 4 is subject to modification, such as the relative angles of flare of the outer conductor and the two cylinders, as well as the external shape of the dielectric material.

Although the circular cylindrical conductors positioned in the aperture have been described as rigid elements, it is within the contemplation of the invention to deposit conductive material on the surfaces of dielectric members 24 and 28 on which the cylinders 22 and 30 are positioned, such as by plating or painting. It can be expected that in certain applications it may be desirable to have a very thin conducting boundary for one or more of the concentric transmission lines; it is possible with this technique to reduce the overall weight of the antenna system. Accordingly, it is intended that the term "cylinder" should cover this alternate construction.

It will now be recognized by ones skilled in the art that the principles of the invention may also be applied to a horn radiator of the type shown in Fig. 5 comprising a flared hollow circular waveguide 34. In this configuration also, when excited in the dominant TE mode, the equiphase surfaces of wave energy emanating from the aperture 36 become increasingly flat as the diameter of the aperture increases, resulting in a narrowing of the beam. This effect can be minimized and the beam width maintained substantially constant over a wide range of frequencies by the insertion of one or more conducting cylinders, such as 38, in the aperture of the horn to divide the aperture into concentric waveguides having relative propagation velocities so as to produce the desired phase distribution across the aperture. As in the coaxial waveguide embodiment, a two-cone lens may be used, with or without dielectric loading, with the angle of flare and position of the cylinders in the aperture subject to considerable modification.

While the invention has been described primarily with reference to the transmission of radio energy it will be apparent to those skilled in the art that the constructions described herein may also be used for the reception if desired since a radio horn is in essence a reversible device.

Further modifications of the inventive concepts disclosed herein may now become apparent to those skilled in this art. It will be understood that the scope of the present invention is to be regarded as subject only to those limitations of the appended claims.

What is claimed is:

1. An electromagnetic lens comprising, a coaxial waveguide having an outer conductor of circular section, an open end of which is flared to provide an aperture, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared open end of said outer conductor, and a pair of hollow conductors of frusto-conical shape disposed in said aperture coaxially with said inner and outer conductors with the smaller ends thereof directed inwardly and spaced apart along the extending portion of said inner conductor, said hollow conductors being insulated from each other and from said inner and outer conductors and spaced to divide said aperture into three concentric waveguides having successively increasing propagation velocities from the outer portion of the aperture to the inner portion of the aperture.

2. An electromagnetic lens comprising, a coaxial waveguide having an outer conductor of circular section, an open end of which is flared to provide an aperture, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared open end of said outer conductor, a pair of hollow conductive cylinders of substantially frusto-conical shape both flared in the same direction as the flared open end of said outer conductor disposed in said aperture coaxially with said inner and outer conductors, the smaller ends of both said cylinders being substantially the same diameter as said outer conductor and the larger ends of both having smaller diameters than that of the flared open end of said outer conductor, said cylinders being spaced apart along the extending portion of said inner conductor and separated from the flared open end of said outer conductor by a rigid dielectric material having a dielectric constant greater than 1.0, said dielectric material extending beyond the outer diameter of said concentric cylinders and having an outer surface tapered inwardly from the periphery of the flared open end of said outer conductor to the periphery of the larger end of the furthest extending of said cylindrical conductors.

3. An electromagnetic lens comprising, a coaxial waveguide having a hollow outer conductor of circular section, one end of which is flared to provide an aperture, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared end of said outer conductor, a pair of hollow conductive cylinders of substantially frusto-conical shape both flared in the same direction as the flare on the outer end of said outer conductor disposed in said aperture coaxially with said inner and outer conductors, said cylinders being spaced apart along the extending portion of said inner conductor to divide said aperture into three concentric waveguides, the outer two of said three concentric waveguides being filled with rigid dielectric material having a dielectric constant greater than 1.0, the outer surface of said dielectric material being flared inwardly from the periphery of the flared open end of said outer conductor to the outer periphery of the furthest extending one of said cylindrical conductors.

4. An electromagnetic lens comprising, a coaxial waveguide having a hollow outer conductor of circular section, an open end of which is flared outwardly to provide a circular aperture, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared open end of said outer conductor, and

at least one hollow cylindrical conductor of substantially frusto-conical shape flared in the same direction as the flared end of said outer conductor disposed in said aperture coaxially with said inner and outer conductors and insulated therefrom, the smaller diameter of said frusto-conical conductor being substantially equal to the diameter of said outer conductor and the larger diameter thereof being slightly smaller than the diameter of said aperture whereby said conical conductor divides the aperture into at least two concentric waveguides, the smaller and larger diameters of said frusto-conical conductor being so related to the diameters of said outer conductor and said aperture that the innermost of said concentric waveguides has the higher propagation velocity.

5. An electromagnetic lens comprising, a coaxial waveguide having a hollow outer conductor of circular section, an open end of which is flared outwardly to provide a circular aperture, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared open end of said outer conductor, a pair of similar hollow conductive circular cylinders of substantially frusto-conical shape both flared in the same direction as the flared end of said outer conductor disposed in said aperture coaxially with said inner and outer conductors, the smaller diameter of said cylinders being substantially equal to the diameter of said outer conductor, said cylinders being spaced apart along the extending portion of said inner conductor and from the flared open end of said outer conductor by a rigid dielectric medium having a dielectric constant greater than 1.0.

6. An electromagnetic lens comprising, a coaxial waveguide having a hollow outer conductor of circular section, an open end of which is flared outwardly to provide a circular aperture, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared open end of said outer conductor, a pair of similar hollow conductive cylinders of substantially frusto-conical shape both flared in the same direction as the flared end of said outer conductor disposed in said aperture coaxially with said inner and outer conductors, the smaller diameter of said cylinders being substantially equal to the diameter of said outer conductor and the larger diameter of said cylinders being approximately equal to the diameter of said aperture, said cylinders being spaced apart along the extending portion of said inner conductor and from the flared open end of said outer conductor by a dielectric medium having a dielectric constant greater than 1.0, the spacing between the first of said cylinders and the flared open end of said outer conductor being greater than the spacing between said cylinders and between the second cylinder and said inner conductor thereby to divide said aperture into three concentric waveguides having successively increasing propagation velocity from the outer portion of said aperture to the inner portion of said aperture.

7. An antenna for the production of a wide beam radiation pattern having a substantially spherical wave front comprising, in combination, a coaxial waveguide having a hollow outer conductor of circular section, an open end of which is flared outwardly to provide a circular aperture of diameter greater than the diameter of said outer conductor, and an inner conductor of circular section coaxial with said outer conductor and extending beyond the flared open end of said outer conductor, a pair of hollow conductive cylinders of substantially frusto-conical shape both flared in the same direction as the flared open end of said outer conductor disposed in said aperture coaxially with said inner and outer conductors and spaced apart along the extending portion of said inner conductor, the smaller diameter of said cylinders being substantially equal to the diameter of said outer conductor and the larger diameter of said cylinders being substantially equal and somewhat smaller than the diameter of said aperture, said cylinders being separated from each other and from the flared portion of said outer con-

ductor by a rigid dielectric material extending inwardly to the cylindrical plane of said outer conductor and extending beyond the outer diameter of said concentric cylinders and having an outer surface tapered inwardly from the periphery of the flared open end of said outer conductor to the periphery of the larger end of the furthest extending of said cylindrical conductors, the dielectric constant of said material being greater than 1.0, and a radiation permeable cap closing the open end of said furthest extending cylindrical conductor.

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