CROSS REFERENCE

EXAMINER

Jan. 9, 1962 J. V. D'AGOSTINO ETAL 3,016,534

DUAL FUNCTION ANTENNA

Filed July 1, 1960 2 Sheets-Sheet 1

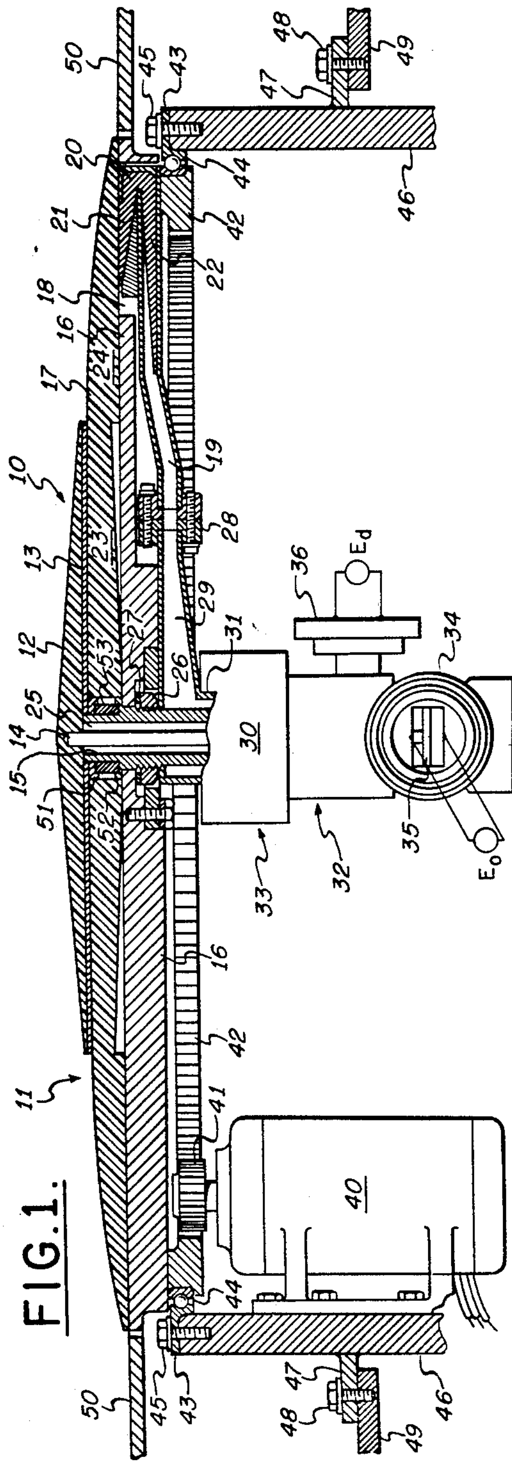

FIG. 1.

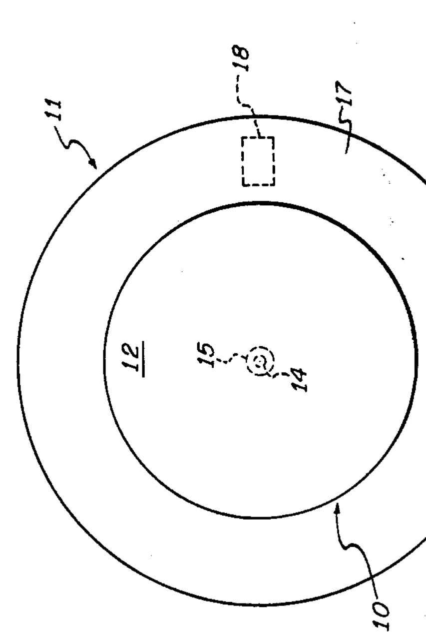

FIG. 2.

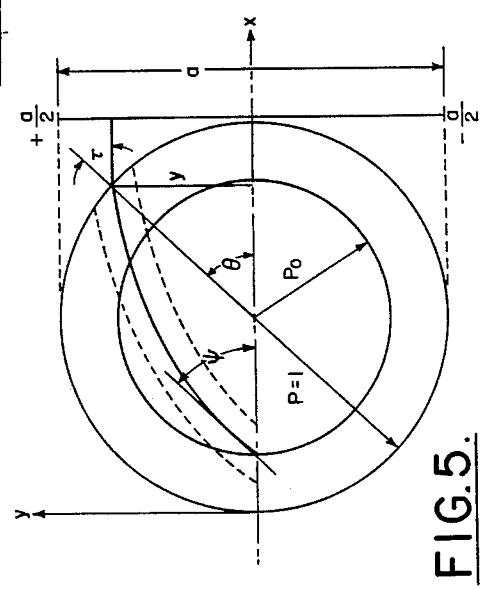

FIG. 5.

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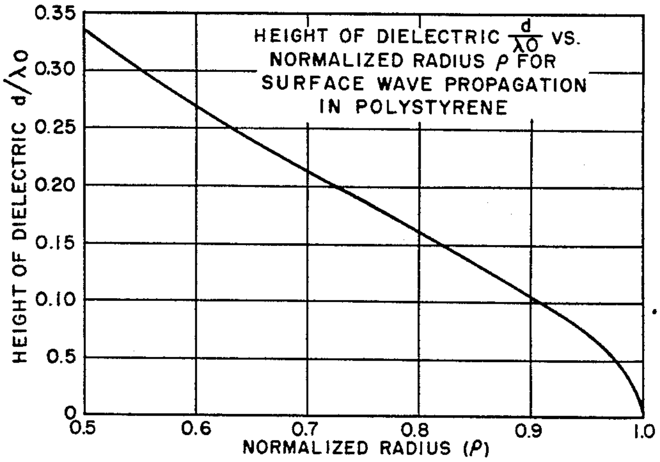

FIG. 3.

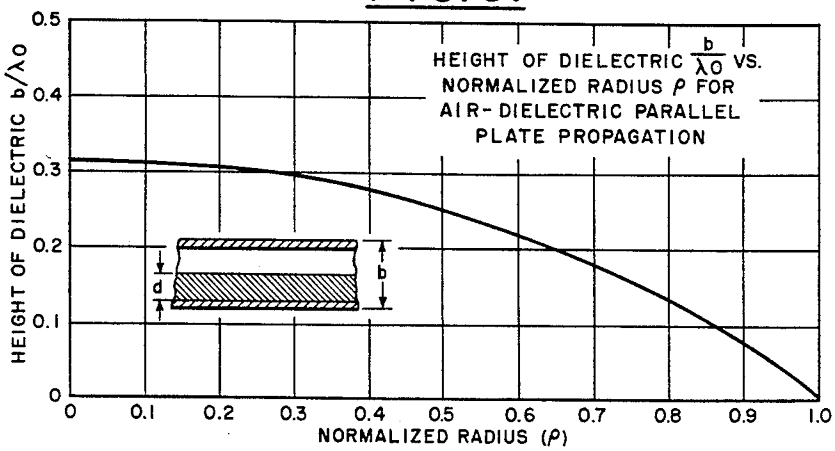

FIG. 4

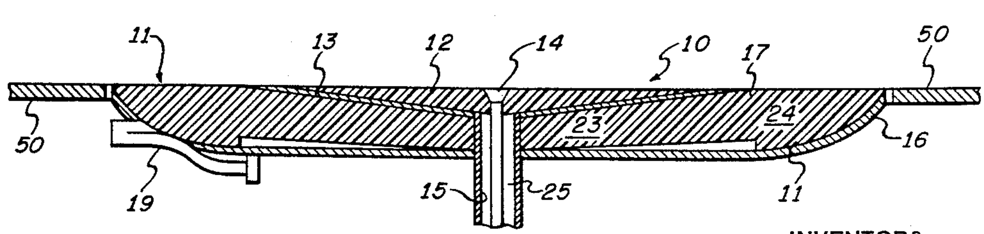

FIG. 6.

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3,016,534
Patented Jan. 9, 1962

3,016,534

DUAL FUNCTION ANTENNA

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Filed July 1, 1960, Ser. No. 40,377
9 Claims. (Cl. 343—725)

This invention relates to a dual function antenna, and more particularly to an antenna structure adapted for flush mounting on an aircraft and which is capable of simultaneously radiating and/or receiving microwave energy in both a rotatable directional antenna pattern and an omnidirectional antenna pattern.

It sometimes is required that an airborne communication system be capable of simultaneously radiating and/or receiving energy in both an omnidirectional pattern and a directional pattern. Because of space and weight limitations in an aircraft, it is necessary to provide antenna means which can accomplish both of these functions with a minimum amount of equipment. It also is required that the antenna structure be adapted for mounting on the aircraft in such a way as to interfere as little as possible with the aerodynamics of the aircraft.

It therefore is an object of the present invention to provide compact lightweight antenna means adapted for flush mounting on an aircraft and capable of providing both a rotatable directional antenna radiation pattern and an omnidirectional antenna pattern.

Another object of this invention is to provide a dual function antenna for mounting on an aircraft fuselage with a minimum of aerodynamic disturbance to said aircraft.

A further object of this invention is to provide a small compact antenna arrangement for simultaneously radiating energy in both an omnidirectional radiation pattern and a directional radiation pattern.

Still another object of this invention is to provide a relatively simple compact antenna structure providing an omnidirectional antenna pattern and a directional antenna pattern rotatable throughout 360° of azimuth.

These and other objects of the invention, which will become more apparent from the specification and claims below, are achieved by a structure comprising first and second centrally apertured conductive plates, vertically spaced from each other. Disposed above and in contact with the uppermost plate is a circular dielectric disc which tapers uniformly in thickness from its center to its edge. A coaxial transmission line extends through the center apertures of said two conductive plates, with the outer conductor of said line terminating on said uppermost plate and the center conductor of the coaxial line terminating within the dielectric disc. The uppermost conductive plate and the dielectric disc comprise a dielectric-disc antenna which is excited by the center conductor of the coaxial line and operates as a surface wave antenna to radiate microwave energy in an omnidirectional radiation pattern.

The lowermost one of said conductive plates extends radially beyond the outer edge of the upper conductive plate, and the region between the plates, from the central axis of the plates to the periphery of the lowermost plate, is filled with a dielectric medium having a radially monotonically decreasing effective index of refraction. A waveguide feed is positioned at a region near the periphery of the second conductive plate for launching microwave energy into the region between said two conductive plates. The two conductive plates with the varying effective index of refraction medium therebetween operate as a Luneberg lens type antenna which radiates microwave energy in a directional antenna pattern. The

feed lines of both of said antennas are coupled to a double concentric coaxial line section, which in turn is coupled to respective sources of microwave energy through a rotating coaxial line joint. The entire antenna structure is rotatable about the central axis of the conductive plates to provide 360° of azimuth scanning of the directional beam.

The present invention will be described by referring to the accompanying drawings wherein:

FIG. 1 is a sectional view, partially broken away, illustrating one embodiment of the dual function antenna of this invention;

FIG. 2 is a top view of the dual function antenna illustrated in FIG. 1;

FIGS. 3, 4 and 5 are curves used to help explain certain features of the antennas of this invention; and

FIG. 6 is an illustration of an alternative construction of the dual function antenna of this invention.

Referring now more particularly to FIGS. 1 and 2, the dual function antenna of this invention is comprised of integrally mounted omnidirectional antenna **10** and directional antenna **11**. Omnidirectional antenna **10** is comprised of a circular dielectric disc **12** having a uniformly decreasing taper from its center to its edge and is made of a low loss material whose dielectric constant is greater than that of air. Omnidirectional antenna **10** further includes an annular conductive plate **13** which functions as a ground plane and together with circular dielectric disc **12** operates as a surface wave type of antenna which is excited by the extended center conductor **14** of coaxial transmission line section **25**. In order to insure that only the lowest order surface wave mode is propagated by directional antenna **10**, the maximum thickness of dielectric disc **12** is made less than

$$\frac{\lambda_0}{4}\sqrt{e-1}$$

where λ_0 is the free space wavelength and ϵ is the relative dielectric constant of the disc. Omnidirectional antenna **10** radiates vertically polarized energy in an omnidirectional radiation pattern.

Directional antenna **11** is comprised of said centrally apertured conductive plate **13** and a second centrally apertured conductive plate **16** which is vertically displaced from plate **13** and extends radially beyond the edge of plate **13**. Disposed between the two conductive plates **13** and **16** is an annular sheet of homogeneous low loss dielectric material **17** which provides a radially monotonically decreasing index of refraction between the plates, as will be explained in detail hereinbelow. The bottommost conductive plate **16** has an aperture **18** near its periphery through which energy is coupled into directional antenna **11**. A tapered-depth wave guide feed **21**, which operates as an end fire waveguide antenna, is positioned in aperture **18** and couples microwave energy from waveguide **19** into directional antenna **11**. The reverse-bend portion **20** of waveguide **19** is filled with a dielectric material **22** to match the propagating characteristics of waveguide feed **21** to that of the lens of directional antenna **11**.

Directional antenna **11** is of the general type which has become known as a Luneberg lens antenna originally suggested by R. K. Luneberg in "Mathematical Theory of Optics," Brown University, 1944, pages 208–213, but modified in the manner suggested by J. E. Eaton in NRL Report 4110, "An Extension of the Luneberg Type Lenses," February 16, 1953. In this type of antenna lens, electromagnetic energy is directed across the lens from a radiator near the periphery and emerges as a collimated beam diametrically opposite the point of entrance of the energy.

The directional antenna of this invention may be considered as being comprised of two radially-adjacent lens regions 23 and 24. Region 23 will be referred to herein as the parallel plate region and is comprised of the parallel conductive plates 13 and 16 between which is disposed dielectric material 17 whose thickness varies in the manner to be described hereinbelow in order to provide the radially decreasing effective index of refraction. The second region 24 will be referred to herein as the surface wave region and is comprised of the outer portion of dielectric disc 17 and the portion of conductive annular plate 16 which extends radially beyond the periphery of the uppermost plate 13. This latter portion of the lens functions as a surface wave antenna which performs as an Eaton-Luneberg type lens in the horizontal plane, while operating as an end-fire antenna in the vertical plane.

For convenience in manufacturing, the dielectric material in both regions 23 and 24, that is, dielectric disc 17, is made from a single disc of homogeneous dielectric material whose cross-sectional contour is shaped in the respective regions 23 and 24 in a manner to be described hereinbelow.

Coaxial line section 25, which serves as a feed for surface wave omnidirectional antenna 10, extends through the central apertures of parallel plates 13 and 16 with the outer conductor 15 of said coaxial line terminating on the upper conductive plate 13 and the inner conductor 14 terminating within dielectric disc 12. Coaxial line 25 is secured in position by means of nut 26 which engages a threaded portion 27 of outer conductor 15. Nut 26 is housed within a recessed portion of bottom conductive plate 16 and is turned to engage the upper surface of said recessed portion. Conductive plate 16 is comprised of a relatively thick disc of aluminum, and structurally serves as a base plate for supporting the antenna structure.

Waveguide section 19 is coupled through flange joint 28 to a wave guide section 29 which in turn is coupled to the outermost coaxial line section of a dual concentric coaxial line section 30. In this dual line section, the outermost coaxial line section is comprised of outer conductor 31 and conductor 15. The innermost coaxial line section, which excites omnidirectional antenna 10, is comprised of inner conductor 14 and outer conductor 15. This dual concentric coaxial line section is joined to a dual waveguide feed 32 by means of a dual coaxial line rotating joint 33. The input wa eguide feed is comprised of two waveguide-to-coaxial line transitions of the type illustrated on page 357 of Microwave Transmission Circuits, by Ragan, McGraw-Hill Book Company, Inc., 1948. A source of microwave energy E_0 is coupled to input waveguide 34, and by means of cross bar transition 35, said energy is coupled to the innermost one of the concentric coaxial lines 25. A second source of microwave energy E_d is coupled through a second input waveguide 36 to the outermost concentric coaxial line, which is coupled by waveguide sections 29 and 19 to directional antenna 11. Rotating joint 33 and the dual coaxial line-to-waveguide transition section 32 are both components which are well known in the art.

By means of rotating joint 33 the entire antenna structure may be rotated about a vertical axis concentric with the longitudinal axis of center conductor 14. The antenna structure is rotated about said vertical axis by means of a motor 40 and pinion gear 41 which engages internally threaded gear 42. Internal gear 42 is secured to base plate 16, and is rotatably coupled to annular mounting flange 43 by means of ball bearing 44. Upon energization of motor 40, pinion gear 41 drives internal gear 32 and causes the entire antenna structure and associated transition line feeds to rotate, by means of rotating joint 33, about the vertical axis.

The manner in which the antenna structure is secured to the aircraft frame is illustrated on the right side of FIG. 1. Mounting flange 43 is secured by nut 45 to the end of a cylindrical can 46, and a radially extending flange 47 secured thereto is fixed by means of screws 48 to a bracket 49 which is secured to the aircraft frame. The antenna structure is mounted so that the top of conductive plate 16 is substantially flush with the skin 50 of the aircraft.

In the above-mentioned report by Eaton it is shown that in order to collimate the energy in a Luneberg lens having the waveguide feed near the periphery, the following relationships for the index of refraction of the lens must be satisfied,

$$\eta=\sqrt{\frac{2\rho_0-\rho^2}{\rho_0^2}} \text{ for } 0\leq\rho\leq\rho_0 \qquad (1)$$

$$\eta=\sqrt{\frac{2-\rho}{\rho}} \text{ for } \rho_0\leq\rho\leq 1 \qquad (2)$$

where ρ_0 is the normalized radius of the feed circle, ρ is the normalized distance from the center of the lens to a point within the lens, and η is the effective index of refraction.

For high aperture efficiency in a lens of the type under consideration, the feed horn 21, FIG. 1, should be close to the outer periphery of the lens. In an antenna constructed in accordance with the present invention a value of ρ_0 equal to .8 was chosen as a value which would provide high aperture efficiency and also would satisfy the mechanical requirement that the waveguide feed be entirely contained within the radius of the aperture circle. This latter feature reduces the size of the structure, and allows compactness of both the antenna structure and the microwave plumbing.

The surface wave portion 24 of directional antenna 11 provides means for obtaining a desired directivity in the vertical plane of the radiated pattern, while at the same time provides the varying effective index of refraction medium for satisfying the Equations 1 and 2 above to provide the Luneberg lens type of focusing in the azimuth plane. The necessary radial variation in the effective index of refraction in region 24 is obtained by varying the height of the dielectric material over the ground plate (conductive plate 16), and is determined according to the following equation.

$$\frac{d}{\lambda_0}=\frac{1}{2\pi\sqrt{e-\eta^2}}\tan^{-1}\left(\frac{e\sqrt{\eta^2-1}}{\sqrt{e-\eta^2}}\right) \qquad (3)$$

where

$$\frac{d}{\lambda_0}$$

is the height of the dielectric material in wavelengths, and e is the relative dielectric constant of the dielectric material 17. Obtaining the required values of effective index of refraction at various radii, as obtained from Equations 1 and 2, substituting these values into Equation 3 will give the contour of the dielectric material 17 between the outermost edges of plates 13 and 16. FIGURE 3 is a plot of Equation 3 for polystyrene dielectric material whose dielectric constant η is 2.54, and wherein ρ_0 is equal to .8.

The required varying effective index of refraction in the parallel plate region 23 of directional antenna 11 is obtained by varying the thickness of dielectric material 17 between parallel plates 13 and 16. The determination of the contour of this tapered dielectric region may be made by referring to pages 391–393 of Waveguide Handbook by Marcuvitz, McGraw-Hill Book Company, 1951, wherein the author describes the propagation characteristic in a rectangular waveguide having slabs of dielectric material whose faces are perpendicular to the electric field. By expanding the author's analysis to a parallel plate waveguide situation, the desired thickness of dielectric member 17 may be determined for providing the desired varying effective index of refraction. FIG. 4 is a graph showing the height of the dielectric material between the parallel plates 13 and 16; the dielectric material again being polystyrene.

The index of refraction of the dielectric medium of directional antenna 11 is a monotonically decreasing function from the central axis of the lens to the outer periphery of the lens, so that at the junction of the arbitrarily designated regions 23 and 24, no discontinuities will be present in a curve representing the varying index of refraction.

As just explained, the thickness of dielectric disc 17 varies in the parallel plate region 23 and in the surface wave region 24 in order to obtain the desired radial variation in the effective index of refraction. Other means may be employed to achieve this result. That is, concentric rings of dielectric materials having differing dielectric constants also may be employed to achieve this purpose. Alternatively, the lens structure may be constructed from compressed dielectric foam, wherein the degree of compression determines the index of refraction, such as described in "The Luneberg Lens of Continuous Varying Dielectric Constant," by Corkum et al., October 1954, Air Force Cambridge Research Center, Publication AFCRC -TR-54-103.

The elevational radiation patterns for omnidirectional antenna 10 and directional antenna 11 are functions of the radii of the respective antennas and may be approximately determined according to the following relationship which expresses the half-power beam width of the elevational patterns:

Elevation half-power beam width

$$\cong\frac{60}{\sqrt{\frac{l}{\lambda_0}}} \qquad (4)$$

wherein l is equal to the radius of the omnidirectional antenna and is equal to the difference between the radii of the two parallel plates 13 and 16 for the directional antenna 11, and λ_0 is the free space wavelength of the energy.

Although coaxial line 25 extends between the centers of conductive plates 13 and 16, any deleterious effect which it might have on the focussing action of directional antenna 11 is substantially eliminated by providing a tuned post about said coaxial line 25. The tuned post is of the type disclosed in U.S. Patent 2,528,367, and is comprised of short conductive annular cylinders 51 and 52 extending respectively from upper and lower conductive plates 13 and 16. A dielectric material 53 is disposed between and within said cylinders. Cylinders 51 and 52 comprise capacitive means and the dielectric 53 comprises inductive means therebetween. The dimensions of the respective capacitive and inductive means for optimum performance of directional antenna 11 are best determined experimentally.

The primary illumination function $S_0(\psi)$ of the waveguide feed horn 21 is modified in the directional antenna lens by the variable index of refraction medium. The aperture illumination function $S_0(\tau)$ of the directional lens antenna may be determined by considering that the energy flow through the lens is along a ray path (solid line) FIG. 5, and considering a cone of rays (dotted lines), the total energy through any cross sectional area perpendicular to the cone axis is constant. With this assumed condition, the power flow through the incremental angle $d\psi$ at the focus can be expressed as $S_0(\psi)_{d\psi}$ where $S_0(\psi)$ is the power level of the primary waveguide feed as a function of ψ. If $S_0(\tau)$ is the power level at the aperture, the power flow through the cone at this point is $S_0(\tau)\,dy$.

The far field radiation pattern in the plane of the antenna may be calculated once the amplitude distribution function of the antenna radiating aperture is known. The aperture illumination function $S_0(\tau)$ is related to the primary feed illumination $S_0(\psi)$ according to the expression

$$S_0(\tau)=\frac{S_0(\psi)}{[2\rho_0-\rho_0^2-\sin 2\tau]^{1/2}} \qquad (5)$$

where from FIG. 5 it may be seen that τ is the exit angle that the ray makes with a radius, and ρ_0 is the normalized radius of the feed circle. Because it is a characteristic of the Luneberg lens antenna that the energy is radiated in a plane wave front, the aperture illumination function of the antenna may be projected onto a plane normal to the $x=y$ plane (a plane containing the

$$\text{line } +a/2, \frac{-a}{2}$$

FIG. 5) to give the illumination function $S_0(y)$ at that plane. The far field radiation pattern $E(\theta)$ then may be calculated from the expression

$$E(\theta)=K\int_{-\frac{a}{2}}^{\frac{a}{2}} S_0(y)e^{iky\sin\theta}\,dy \qquad (6)$$

A detailed analysis of the far field mapping for the type of radiation under consideration is presented in section 6.6 of Microwave Antenna Theory and Design, by Silver, McGraw-Hill Book Co., 1949.

An alternative construction of the dual function antenna of this invention is illustrated in FIG. 6, wherein the same numerals used in FIG. 1 are used to designate corresponding parts. In this embodiment, the antenna structure will present even less of an aerodynamic disturbance than the embodiment illustrated in FIGS. 1 and 2, inasmuch as the surface of dielectric disc 12 of omnidirectional antenna 10 is exactly flush with the skin of the aircraft along a diameter of the disc. The tapered portion of dielectric disc 12 is on the bottom rather than the top as illustrated in FIG. 1, and similarly the tapered portion of dielectric disc 17 in the surface wave region 24 of directional antenna 11 is on the bottom rather than the top. Upper annular conductive plate 13 is slightly conical in shape in order to conform to the tapered dielectric disc 12. The bottom annular conductive plate 16 curves upwardly in the surface wave region 24 to contact the skin of the aircraft at its periphery. Despite the slightly conical shape of upper annular conductive plate 13, region 23 still may be considered as a parallel plate region. The operation of the dual function antenna constructed in accordance with FIG. 6 is substantially identical with the operation of the dual function antenna illustrated in FIG. 1, except that both the omnidirectional and the directional radiation patterns in the plane orthogonal to the plane of the antenna will be inclined more away from said plane of the antenna.

A dual function antenna constructed according to FIG. 1 of the present invention, and intended for operation in the X-band region of microwave frequencies, had the following approximate dimensions:

	Inches
Diameter of dielectric disc 12	8
Diameter of dielectric disc 17	15
Diameter of conductive plate 13	8
Diameter of conductive plate 16	15
Diameter of central aperture of plate 16	.4376
Radial extent of feed aperture 18	1.875
Normalized radius of feed circle	.8
Radial extent of waveguide feed aperture 21	1.125

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

We claim:

1. A dual function antenna for independently radiating electromagnetic energy both in a directional radiation pattern and in an omnidirectional pattern comprising first

and second spaced parallel conductive plates, the second one of said plates extending radially beyond the periphery of the first one of said plates and each of the plates having a central aperture, a first circular dielectric lens disposed between said plates and extending to the periphery of said second plate, a second circular dielectric lens disposed on the outer surface of said first plate coaxially with respect to said apertures, each of said lenses having a radially monotonically varying index of refraction, a coaxial transmission line extending transversely through said apertures with the outer conductor of said line terminating on said first plate and the inner conductor of said line extending through the aperture of said first plate and terminating within said lens, whereby said extended center conductor comprises a probe for launching waves into said first lens, and electromagnetic energy feed means positioned in an aperture in said second plate radially beyond the periphery of said first plate for feeding electromagnetic energy diametrically across said first lens.

2. The combination as claimed in claim 1 and further including a dual concentric coaxial transmission line wherein the inner one of said concentric coaxial lines is coaxial with and coupled to the coaxial line extending through said parallel plates and the outer one of said concentric lines is coupled to said electromagnetic energy feed means, whereby electromagnetic energy propagated on the inner one of said concentric lines is launched as surface waves in said second lens and electromagnetic energy propagated on the outer one of said concentric lines is launched into said first lens and propagates as a surface wave in the region thereof radially beyond the periphery of said first plate and propagates in a transverse electric mode in the region between said parallel plates.

3. The combination as claimed in claim 2 wherein said dual concentric coaxial transmission lines includes a rotating joint for permitting rotation of said dual function antenna about an axis concentric with the center conductor of the inner one of said concentric lines.

4. The combination as claimed in claim 1 including a tuned post disposed about the coaxial line extending between said parallel plates, said post being tuned to provide minimum perturbation to electromagnetic energy propagating through said first lens.

5. A dual function antenna for independently radiating electromagnetic energy both in an omnidirectional radiation pattern and in a directional radiation pattern comprising a pair of spaced, centrally apertured, substantially parallel circular conductive plates, a conically shaped disc of low loss dielectric material having a dielectric constant different from air symmetrically disposed on the outer plane surface of the first one of said plates, a coaxial transmission line extending through the central aperture of the second one of said parallel plates, the outer conductor of said line terminating on said first plate and the center conductor of said line passing through the aperture of said first plate and terminating within said dielectric disc, a dielectric lens disposed between said parallel plates and having a radially decreasing effective index of refraction, and an electromagnetic energy feed disposed adjacent the periphery of the second plate for launching electromagnetic energy diametrically across the lens disposed between said plates.

6. A dual function antenna for independently radiating electromagnetic energy both in an omnidirectional radiation pattern and in a directional radiation pattern comprising a thin circular lens having a radially varying effective index of refraction, electromagnetic energy feed means disposed adjacent the periphery of said lens for launching electromagnetic energy diametrically across said lens, a centrally apertured conductive plate disposed on an outer face of said circular lens, a disc of dielectric material having a radially varying index of refraction symmetrically disposed on the face of said plate opposite said lens thereby forming a dielectric-disc antenna, and a coaxial transmission line extending transversely through the central portion of said lens with the outer conductor of said line terminating on said plate and the center conductor extending through the central aperture of said plate and terminating within said dielectric disc for launching surface waves in said dielectric-disc antenna.

7. Integrally mounted omnidirectional and directional antennas for independently radiating electromagnetic energy in respective omnidirectional and directional radiation patterns, said omnidirectional antenna comprising a first thin circular lens having a radially monotonically decreasing effective index of refraction and a first centrally apertured, circular conductive plate disposed on a face of said lens, a coaxial transmission line extending normally away from said plate with the inner conductor of said line extending through said plate and terminating within said lens for launching electromagnetic waves therein, said directional antenna comprising said first conductive plate and a second centrally apertured, circular conductive plate coaxial with and axially spaced from said first plate and extending radially beyond said first plate, said coaxial line passing through the central aperture of said second plate, said directional antenna further including a second circular lens disposed between said two plates and extending to the periphery of said second plate, said second lens having a radially monotonically decreasing effective index of refraction, a feed aperture in said second plate at a radial distance beyond said first plate, and a waveguide feed coupled to said feed aperture for launching electromagnetic waves which propagate across the center portion of said second lens and are radiated from the side of said lens diametrically opposite said feed aperture.

8. An integrally constructed dual function antenna adapted for mounting on an aircraft exterior surface comprising first and second substantially parallel circular discs of dielectric material, a thin centrally apertured conductive plate having a radius substantially equal to that of said first disc separating said two discs, a coaxial transmission line extending through said second disc and terminating within said first disc for launching electromagnetic waves therein, a second centrally apertured conductive plate disposed on the surface of said second disc opposite said first disc and extending radially beyond the periphery of said first disc, a feed aperture in said second plate at a radial distance greater than the outer radius of said first plate, a waveguide feed coupled to said feed aperture for launching electromagnetic waves which propagate through said second disc and are radiated in a collimated beam on the side of said second disc diametrically opposite said feed aperture, first and second dual concentric coaxial transmission lines coupled respectively to the coaxial transmission line terminating within said first disc and to said waveguide feed, said concentric coaxial transmission lines being coaxial with the central axis of said discs and said plates, said concentric coaxial transmission lines having a rotating joint intermediate the respective ends thereof for permitting rotation of said discs and plates as a unit about an axis coaxial with said coaxial lines, and first and second sources of electromagnetic energy coupled respectively to the inner and outer ones of said concentric coaxial lines, whereby energy from said first source is radiated in an omnidirectional radiation pattern from said first disc and energy from said second source is radiated in a directional pattern from said second disc.

9. A dual function antenna for independently radiating electromagnetic energy both in a directional and an omnidirectional radiation patterns comprising a directional antenna comprised of first and second centrally apertured, circular conductive plates disposed coaxially and axially spaced with respect to each other, a first circular lens having a radially monotonically decreasing effective index of refraction disposed between said plates and extending radially to the periphery of the first of said plates,

whereby said directional antenna is comprised of a parallel plate region bounded by said plates and a surface wave region extending between the peripheries of said plates, a feed aperture in said first plate in the surface wave region thereof, a waveguide feed coupled to said aperture for launching electromagnetic waves which propagate from said surface wave region through said parallel plate region and are radiated in a collimated beam from the surface wave region diametrically opposite said feed aperture, an omnidirectional antenna comprised of the second one of said plates and a circular lens having a radially monotonically decreasing effective index of refraction disposed on the face of said second plate opposite said first lens, a coaxial transmission line extending through said directional antenna with the outer conductor of said line terminating within said second lens for launching surface waves of electromagnetic energy which are radiated in an omnidirectional radiation pattern by said second lens.

No references cited.