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H. E. BARTLETT ET AL

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REFLECTOR ANTENNAS

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Sheet 1 of 2

FIG. 1

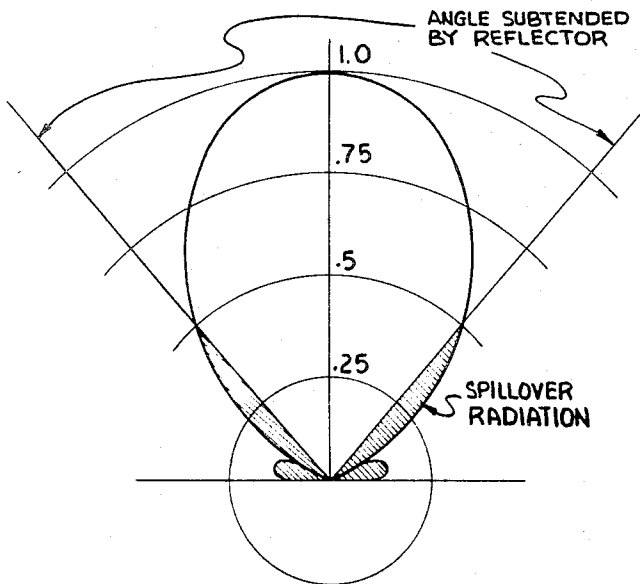
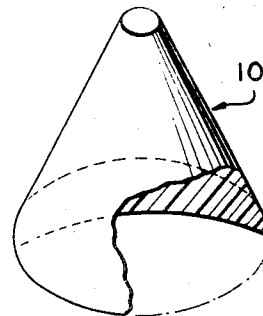


FIG. 2

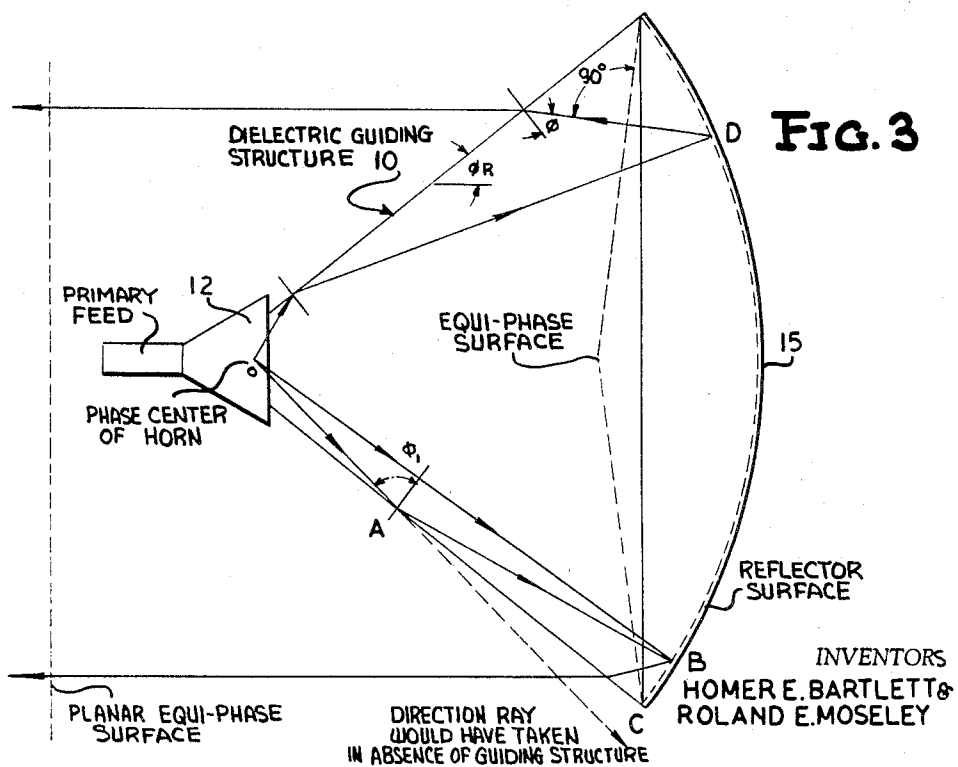


FIG. 3

INVENTORS
HOMER E. BARTLETT &
ROLAND E. MOSELEY

BY

Hurwitz & Rose

ATTORNEYS

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REFLECTOR ANTENNAS

Homer E. Bartlett, Melbourne, and Roland E. Moseley, Indialantic, Fla., assignors to Radiation Incorporated, Melbourne, Fla., a corporation of Florida

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ABSTRACT OF THE DISCLOSURE

A reflector antenna has a directive feed separated from the surface of a reflector, and a solid dielectric guiding structure interposed between the feed and the reflector for directing substantially all of the radiation emanating from the feed that would otherwise produce spillover lobes, onto the reflector surface.

The present invention relates to antennas of the reflector type and more particularly to improved reflector-type antennas wherein spillover reduction apparatus is employed to increase efficiency and to reduce noise.

Reflector antennas are often utilized where it is necessary or desirable to produce a highly directive antenna pattern analogous to the sharply defined beam of light produced by a searchlight. Such spatial patterns are of prime importance in radar, microwave, and space communications applications, for example, and may generally be obtained in accordance with principles analogous to those applicable to optical systems.

In the basic reflector-type antenna case, energy is radiated from a primary feed to a reflector, and reflected therefrom. The amplitude and phase distribution across the reflector can be determined from the primary feed characteristics and the system geometry. From a knowledge of these amplitude and phase distributions, coupled with knowledge as to the primary feed radiation which fails to illuminate the reflector, the spherical pattern of the system, and hence the directivity and aperture efficiency, can be completely determined.

That radiation of the primary feed which is directed at such an angle that it falls outside the edge of the reflector results in the presence of spillover lobes, which cause decreased aperture efficiency. Aperture efficiency is defined as the ratio of directivity of the antenna of interest to that of a perfect antenna having the identical aperture size and shape, with a uniform amplitude distribution and no spillover radiation. The maximum attainable aperture efficiency for aperture type antennas is 100%. For a receiving antenna, there is the additional undesirable effect of a decrease in system signal-to-noise ratio, because of thermal noise from the earth received through the spillover lobes.

In accordance with the present invention, the properties peculiar to a dielectric boundary are utilized to advantage in the provision of a dielectric guiding structure which substantially reduces spillover radiation and simultaneously creates a more nearly uniform amplitude distribution across the reflector-type antenna.

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It is, therefore, a primary object of the present invention to provide an improved reflector-type antenna.

Another object of the present invention is to reduce undesirable radiation spillover in reflector-type antenna systems.

It is a further object of the present invention to increase the directivity and aperture efficiency of reflector antennas.

Other objects, features, and attendant advantages of the present invention will become apparent from a consideration of the following detailed description of specific embodiments thereof, taken in conjunction with the accompanying drawings in which:

FIGURE 1 represents a typical primary feed radiation distribution pattern;

FIGURE 2 is a perspective view of an exemplary dielectric guiding structure in accordance with the present invention;

FIGURE 3 is a planar diagram of an apex-fed reflector antenna employing the guiding structure;

FIGURE 4 shows the relation of the primary feed pattern to the dielectric guiding structure geometry;

FIGURE 5 is a planar diagram of a guiding structure which allows use of conventional reflector shapes by phase correcting in the guiding structure;

FIGURE 6 is a planar diagram of a dual reflector antenna system with guiding structure; and

FIGURE 7 is a planar diagram of a dual reflector antenna with dual guiding structure.

The loss in directivity (and hence aperture efficiency) can be understood by reference to the radiation pattern of a typical primary feed shown in FIGURE 1.

The energy radiated within the angle subtended by the reflector is incident on and illuminates the reflector; that radiated outside this angle is lost in spillover radiation.

The taper of the amplitude distribution across the reflector is the ratio of the amplitude of the illumination at the reflector edge to that in the center of the reflector. The taper can be calculated as the reduction in amplitude of the primary feed pattern in the direction of the reflector edge (normalized to the pattern maximum) multiplied by ΔA_s , the difference in space attenuation between that for a path from the primary feed to the center of the reflector and that for a path from the primary feed to the edge of the reflector. ΔA_s is simply the inverse ratio of the squares of these two path lengths. In the case of the typical primary feed pattern shown in FIGURE 1, the amplitude taper across the reflector would be $(0.5)\Delta_s$.

As can be seen from FIGURE 1 the spillover radiation can be reduced by narrowing the beamwidth of the primary feed. However, this increases the amplitude taper across the reflector (see FIGURE 1), and the aperture efficiency decreases with increasing amplitude taper, as is well known. The optimum taper for a particular reflector is derived from a compromise between spillover reduction and directivity due to amplitude taper.

Referring now to FIGURE 2, there is illustrated a dielectric guide 10 which is suitable for use with the reflector-type antenna systems shown in FIGURES 3, 6 and 7, for example. Typically, such a structure will have

the form of a solid cone, or frustum thereof, adapted to guide the energy radiated from a feed in the direction of increasing diameter. The guide structure may be fabricated from any suitable dielectric material, such as Styrofoam, in accordance with principles which will hereinafter be discussed. In addition to natural dielectrics, artificial dielectrics may be used where insertion loss and weight are important. It will be understood that the conical configuration of the dielectric guide is purely exemplary, and that the structure may take other forms, such as a pyramidal shape, as necessitated by the particular reflector application.

FIGURE 3 illustrates the manner in which the dielectric guiding structure of FIGURE 2 is used with an apexed reflector antenna. In this embodiment, the primary feed is illustrated as a horn 12, but any suitable feed having a pattern shape in accordance with requirements given below may be employed, as desired.

For the purpose of analyzing the operation of microwave antennas, it is customary to make use of what is called ray-tracing theory. This consists of drawing vectors perpendicular to surfaces of equal phase, and applying to these vectors, called rays, the optical laws governing light rays. This technique yields admirable results where antenna dimensions are large in terms of wavelengths.

Accordingly, ray-tracing techniques will be employed in the several figures of the drawings to illustrate the manner in which the dielectric guiding structure reduces spillover radiation. Energy radiated by horn 12 may be characterized as a plurality of such rays emanating from the phase center thereof and illuminating the reflector surface 15. Normally, a substantial portion of the radiation would fall outside the reflector as indicated by ray O-A-C, for example, resulting in spillover lobes and a consequent reduction of gain or directivity. These undesirable results are overcome by use of dielectric guiding structure 10, the small end of which is placed adjacent the mouth of the primary feed element 12, and the large end adjacent reflector surface 15.

Substantially all of the energy radiated from the horn which is not directly incident upon the reflector will be totally reflected at the guiding structure boundary to fall within the angle subtended by the reflector surface.

The mechanism by which that energy is reflected from the guiding structure boundary is the phenomenon known as "total internal reflection." This phenomenon is described below.

In accordance with known optical principles, a ray traveling through a first optical medium having a refractive index n_1 and incident upon a boundary separating medium 1 from a second medium of refractive index n_2 , will either be refracted, reflected, or partially refracted and partially reflected. The amount of refraction and/or reflection of the ray will depend upon the angle at which the ray is incident upon the boundary. As is well known, the angle of incidence is defined as the angle between a normal to the boundary and the path of the incident ray. If the angle of incidence has a value greater than $\arcsin n_2/n_1$, there is a total reflection of the wave from the surface of the boundary. This value is defined as the critical angle of the boundary.

In accordance with Maxwell's relation between dielectric constant and refractive index, the dielectric constant ϵ of a medium is related to its refractive index n by $\mu\epsilon = n^2$. The constant μ is the relative permeability of the dielectric, which is unity for most dielectrics. If the second dielectric medium is air, which has a dielectric constant approximately equal to one, the critical angle ϕ_{cr} is determined by $\sin \phi_{cr} = 1/\sqrt{\epsilon_1}$ where ϵ_1 is the dielectric constant of the first medium. Total internal reflection will thus occur at angles of incidence greater than the critical angle for materials having a dielectric constant greater than one.

These principles are embodied in the structure of the

present invention by which spillover is reduced in reflector antennas for electro-magnetic waves of relatively short wavelength, as will be better understood by reference to FIGURE 3. A ray, which may be representative of the Poynting vector of an electromagnetic wave, originating at the focus O of parabolic surface 15, coincident with the phase center of the horn 12, is incident upon the dielectric medium-air medium boundary at point A. In the absence of a guiding structure, the ray OA would continue along the original path and, as shown by the line OAC, would fall outside the reflector surface. If the dielectric constant of the guiding structure is greater than one, and the flare angle of the conical structure is properly chosen, as indicated above, OA is incident at the boundary of the media at an angle ϕ_1 , greater than the critical angle of the boundary. The ray OA will thus be totally reflected from the guide surface, as at OAB, striking the parabolic surface at B.

The amplitude and phase distributions across the reflector result from the summation of waves radiated directly to the reflector and those reflected from the boundary of the guiding structure to the reflector. The reflector surface is shaped to produce a phase distribution resulting in an equiphase surface as shown in FIGURE 3. Rays drawn perpendicular to this equiphase surface will intersect the guiding structure boundary at an angle less than the critical angle and will thus pass freely through the boundary. There will be a slight bending of the ray at the boundary away from the surface normal, so that the rays finally are parallel, which is the same as saying that a planar equiphase surface exists.

Up to this point only spillover reduction has been discussed. It has been determined experimentally that, when the primary feed is properly chosen, and properly adjusted relative to the guiding structure, there results a nearly uniform amplitude distribution across the reflector. The primary feed requirements are given below.

Examination of the geometry of FIGURE 3 shows that the spillover rays that are reflected by the dielectric boundary are those falling approximately between the angle ϕ_r (as measured from the primary feed boresight axis), intercepted by the reflector edge, and

$$\phi_r + (\pi/2 - \phi_{cr})$$

where ϕ_{cr} is the critical angle of the dielectric. Rays at an angle greater than $\phi_r + (\pi/2 - \phi_{cr})$ intersect the guiding structure boundary at an angle less than the critical angle of the dielectric, and hence are not totally reflected.

FIGURE 4 illustrates the manner in which the immediately preceding matter is related to the primary feed pattern. The angle subtended by the reflector is $2\phi_r$. The energy reflected from the guiding structure boundary is that falling between the angles ϕ_r and $\phi_r + (\pi/2 - \phi_{cr})$.

In order that substantially all the energy radiated by the primary feed be incident on the reflector, the angle $\phi_r + (\pi/2 - \phi_{cr})$ should fall approximately at the first null of the primary feed radiation pattern, as shown. Simultaneously, as has been found by experimentation, a nearly uniform amplitude distribution across the reflector results when $\phi_r + (\pi/2 - \phi_{cr})$ is approximately twice ϕ_r . The above requirements result in optimum aperture efficiency and spillover reduction. Various degrees of improvement in aperture efficiency and spillover reduction are obtainable when $\phi_r + (\pi/2 - \phi_{cr})$ falls at an angle different from that of the first null of the primary feed pattern; and/or $\phi_r + (\pi/2 - \phi_{cr})$ is greater or less than twice ϕ_r .

Instead of using a reflector of specialized shape, as indicated above, conventional shapes such as the paraboloid can be used if proper adjustment of the phase distribution is obtained by shaping the base of the guiding structure.

An exemplary guiding structure configuration is shown

in FIG. 5. The concave surface at the large diameter end of the guiding structure in conjunction with paraboloidal reflector shape re-direct the rays so that after reflection from the reflector surface and bending at the dielectric boundaries, the rays emerge parallel as shown.

In the dual reflector (Cassegrain) embodiment of FIGURE 6, the antenna system comprises a feed 12, sub-reflector 14, and a main reflector 15. The feed again may, for example, be a horn, placed along the axis of reflectors 14 and 15. The location of the feed will depend almost entirely on the shape of the subreflector surface. The dielectric guiding structure 10 is arranged between the mouth of the feed 12 and the convex surface of subreflector 14, to guide substantially all of the energy radiated by the feed which would otherwise fall outside the subreflector surface (as ray OAX), toward the sub-reflector (as ray OAB). Almost all of the energy is thus directed toward the subreflector surface, reflected, passing through guide 10 at angles less than the critical angle (as does ray BC).

Thus, the angle subtended by the conical guide 10 will again be selected in accordance with knowledge of the critical angle, as hereinabove explained, of the guide material, and in accordance with dimensional factors such as shape and area of the subreflector and position of the feed. Ray OA strikes the boundary of the guide at an angle greater than the critical angle and is thus totally reflected to the surface of the subreflector as AB.

The amplitude and phase distributions across the sub-reflector result from the summation of waves radiated directly to the subreflector and those reflected from the boundary of the guiding structure to the subreflector. The subreflector surface is shaped to produce a phase distribution such that rays drawn perpendicular to equiphasic surfaces will intersect the guiding structure boundary at an angle less than the critical angle and will thus pass freely through the boundary. There will be a slight bending of the ray away from the surface normal, but this is also compensated for in the subreflector shape so that the rays finally assume the proper angles for correct illumination of the main reflector.

Here again, as in the case of the apex-fed reflector, conventional subreflector shapes can be used instead of the specialized subreflector shapes indicated if the necessary phase adjustment is accomplished by shaping the base of the guiding structure.

A very small portion of the radiation reflected from the subreflector will fail to strike the main reflector because of the finite size of the subreflector. In cases where very low noise temperatures are desirable, this spillover past the main reflector may be further reduced by an additional dielectric guiding structure employed with the system illustrated in FIGURE 6. Such an arrangement is shown in FIGURE 7. Rays striking the subreflector 14 which, upon reflection, would otherwise fail to impinge upon the surface of the main reflector 15, will be appropriately guided by the dielectric structure 18. The principles previously discussed with respect to the other embodiments are applicable to the dual reflector-dual guide antenna system of FIGURE 7.

It is to be emphasized that the particular shape of the dielectric guide and the reflectors will depend upon the requirements for the specific antenna application. For example, where the main reflector has a substantially rectangular aperture as in the case of a semi-cylindrical parabolic reflecting surface, the guide may have the form of a pyramid to direct the feed radiation against the surface of the reflector. Other guide configurations will become immediately apparent. It is also to be emphasized that it is not entirely necessary for the guiding structure to extend all the way to the subreflector. However, the quality of the antenna performance decreases as the distance between the guiding structure base and the sub-reflector increases.

Thus while certain preferred embodiments have been

shown and described, it will be clear that various changes and modifications may be effected without departing from the true spirit and scope of the invention. It is therefore desired that the present invention be limited only by the appended claims.

We claim:

1. An antenna system comprising a feed for radiating electromagnetic energy, energy reflecting means, and means interposed between said feed and said reflecting means for guiding substantially all of said energy radiated by said feed upon said reflecting means, said guiding means comprising a solid dielectric structure having a surface contour tapered to provide total internal reflection of energy radiated by said feed incident on said surface toward said energy reflecting means, said guiding means surface contour cooperating with the contour of said energy reflecting means to permit passage therethrough of energy reflected from said energy reflecting means.

2. A reflector antenna comprising energy radiator means, reflector means arranged to receive and reflect energy emanating from said radiator means, and dielectric wave guide means for directing substantially all of said energy against said reflector means, wherein said wave guide means is a solid dielectric structure having a monotonically increasing cross-sectional area from one end at which said radiator means is located to the other end at which said reflector means is located, said structure defining a boundary, at the surface thereof, between the dielectric material of the structure and that of the surrounding medium, said boundary continuously presenting a critical angle for total internal reflection of electromagnetic energy which is less than substantially every angle of incidence thereon of said energy emanating from said radiator means and which is greater than substantially every angle of incidence thereon of energy reflected from said reflector means.

3. The combination according to claim 2 wherein said dielectric structure has a conical shape, said surrounding dielectric medium is air, and said structure dielectric material has a dielectric constant greater than that of air.

4. An antenna system comprising an antenna feed, means having a defined surface for reflecting energy radiated by said feed, and means interposed between said feed and said reflecting means for preventing said energy radiated by said feed from falling outside the boundary of said surface, such that substantially all of said radiated energy is incident upon said reflecting means, said last-named means further permitting passage therethrough of substantially all of said energy reflected from the reflector surface.

5. The combination according to claim 4 wherein said last-named means is a solid dielectric structure having a linearly increasing cross-sectional area in the direction from said feed to said reflecting means, said structure defining a boundary at the surface thereof between the dielectric material of the structure and that of the surrounding medium, said boundary of said structure continuously presenting a critical angle for total internal reflection of electromagnetic energy, which is less than angles of incidence of energy radiated by said feed and which is greater than angles of incidence of energy reflected by said reflecting means, said dielectric material of said structure having a dielectric constant greater than that of said surrounding dielectric medium.

6. The combination according to claim 5 wherein said dielectric structure has a conical shape, said feed being positioned at the smaller diameter end of said structure, and said reflecting means being positioned at the larger diameter end of said structure.

7. The invention according to claim 5 further including another reflector for reflecting energy incident thereon from the first-named reflecting means; and another solid dielectric structure for receiving the first-named dielectric structure in a cavity thereof; said another di-

electric structure having a linearly increasing cross-sectional area in the direction from the first-named reflecting means to said another reflector, and defining a boundary relative to the surrounding air continuously presenting a critical angle, for total internal reflection of electromagnetic energy, less than angles of incidence of energy reflected by the first-named reflecting means and greater than angles of incidence of energy reflected by said another reflector, said another dielectric structure having a dielectric constant less than that of the first-named dielectric structure and greater than that of air.

8. The invention according to claim 7 wherein each of said dielectric structures has a conical shape, said feed positioned at the smaller diameter end and the first-named reflecting means positioned at the larger diameter end of the first-named dielectric structure, said first-named reflecting means positioned at the smaller diameter end and said another reflector positioned at the larger diameter end of said another dielectric structure.

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15 ELI LIEBERMAN, *Primary Examiner.*

W. H. PUNTER, *Assistant Examiner.*

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