Dec. 14, 1965 D. C. HOGG 3,224,006

HORN REFLECTOR ANTENNA WITH CONCENTRIC CONICAL REFLECTORS AT MOUTH TO INCREASE EFFECTIVE APERTURE

Filed March 30, 1962

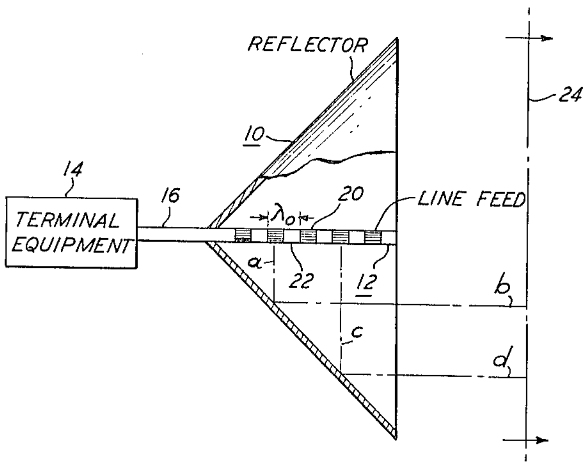



FIG. 1

FIG. 3

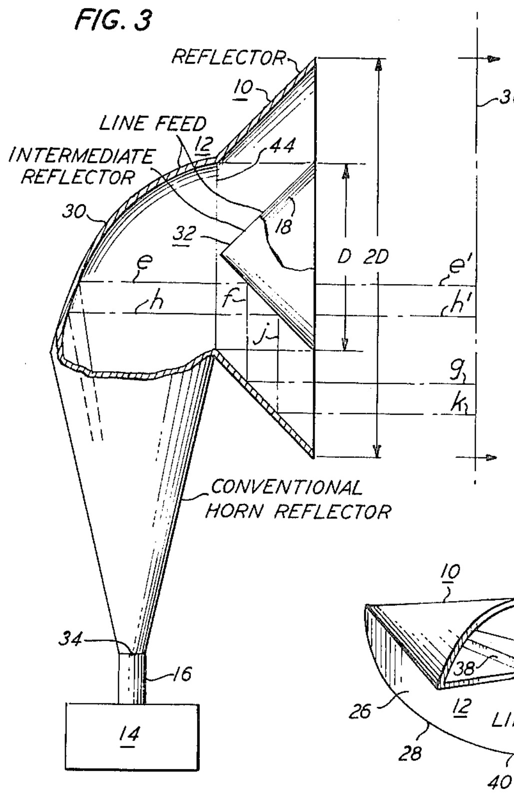
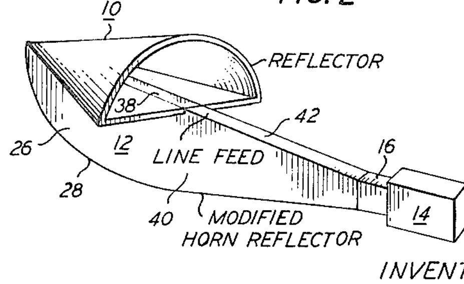



FIG. 2

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United States Patent Office

3,224,006

Patented Dec. 14, 1965

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3,224,006

# HORN REFLECTOR ANTENNA WITH CONCENTRIC CONICAL REFLECTORS AT MOUTH TO INCREASE EFFECTIVE APERTURE

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Filed Mar. 30, 1962, Ser. No. 183,955

6 Claims. (Cl. 343—781)

This invention relates to antenna systems and, more specifically, to directional antennas of the type having at least one passive reflector and an active feed element.

Directional antennas are frequently employed in line-of-sight communication systems operating between two geographically separated points, as for example radio relay networks, and in radar installations. The characteristics of the directional antennas used largely determine the range of such systems. Hence, the larger the gain of a directional antenna the more signal energy it is capable of intercepting from the surrounding medium when operating as a receiving antenna and the greater proportion of the total available signal energy it can direct toward a desired target when functioning as a transmitting antenna. Particularly important in determining the ultimate effective range of antenna systems are the wide angle side lobes of the directional pattern of the receiving antenna. If the wide angle side lobes are large, an inordinate proportion of the total energy intercepted by the receiving antenna comprises atmospheric noise which tends to degrade the intelligibility of the signal. Ultimately, in view of recent advancements in other areas of receiver technology, the signal-to-noise ratio of the energy intercepted by the receiving antenna is the limiting factor in sensitivity capabilities of radio receivers. High receiver sensitivity is, in turn, a weighty factor in achievement of long range performance.

Perhaps the most commonly used types of directional antennas are the horn reflector and the passive paraboloidal dish reflector having an active feed element located at its focus. Both these antennas employ a paraboloidal reflector or segment thereof to focus electromagnetic waves having a plane wavefront to a point and to transform electromagnetic waves diverging radially from a point into a plane wavefront. This practice requires a reflecting surface which is "doubly" curved. Being formed by revolving a parabola about an axis, the paraboloidal surface projects a parabolic curve in planes containing the axis of revolution and a circular curve in planes perpendicular to the axis of revolution, hence the description doubly curved. Requirement of a doubly curved surface makes these reflectors, particularly in the huge sizes coming more into demand for current applications, difficult to fabricate. Moreover, to achieve the dimensional tolerances for both degrees of curvature which are required to obtain the directional characteristics sought in present applications, resort is had to elaborate and time consuming manufacturing practices. These problems of fabrication, the quantity of material consumed in manufacture, and the space requirements of the assembled antenna, all of which may generally be classified as mechanical factors, are directly related, of course, to the cost of constructing the antenna.

The horn reflector exhibits small wide angle side lobes and therefore is capable, when functioning as a receiving antenna, of delivering received signals to its output terminals with a large signal-to-noise ratio. In order to achieve this desirable result, the horn reflector, considering its aperture area, occupies an extremely large space and consumes quite a large quantity of material due to its horn-like structure. Unfortunately, the antenna gain

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of a directional antenna is proportional to the aperture area, and the advantages of the horn reflector are thus obtained at the expense of increased space and material requirements and/or decreased antenna gain capability.

The paraboloidal dish having a feed element at its focus, on the other hand, provides large antenna gain for the space consumption and material required to fabricate it. It does not have good wide angle side lobe characteristics, however, because the electromagnetic waves are radiated without shielding between the feed and paraboloid, a condition conducive to "spillover" radiation from the paraboloidal dish. On the other hand, in the horn reflector the horn shields the electromagnetic waves. To reduce spillover radiation from the paraboloidal dish, the edge or periphery of the paraboloid may be extended to create a deeper dish which more satisfactorily encloses its focus. As the paraboloidal dish is deepened, however, the aperture area of the paraboloid does not increase in proportion to the added dish surface area. Hence, an inefficient use of materials and space comparable to the inefficiency arising in the case of the horn reflector takes place when it is attempted to improve the wide angle side lobe characteristics of a paraboloidal dish with a feed element at its focus.

It is, therefore, the object of the present invention to alleviate the mechanical problems, and consequently reduce the fabrication costs, encountered in building directional antennas of the type having a passive reflector and active feed element without thereby introducing a corresponding degradation in antenna electrical characteristics.

In accordance with the above object, a passive reflector, the operative surface of which forms the inside surface of a circular cone or segment thereof, is fed by an active line feed situated on the axis of the cone. The feed is distributed along the axis of the cone and is designed to accommodate electromagnetic waves propagating at an angle to the surface of the cone equal to one half the apex angle of the cone. Electromagnetic waves generally emanate from the feed in a conical wavefront (cylindrical wavefront in the special case of a 90 degree conical reflector) and are reflected from the conical reflector to form a plane wavefront propagating in the direction of the axis of the cone in a fashion analogous to the way electromagnetic waves emanating from a point source at the focus of a paraboloidal reflector are reflected therefrom into a plane wavefront. Conversely, an electromagnetic wave of plane wavefront impinging upon the conical reflector in the direction of the conical axis is focused onto the line feed by the conical reflector.

A circular conical surface is "singly" curved, i.e., it projects a circular curve in planes perpendicular to the axis of the cone but straight lines in planes containing the axis of the cone. Such a reflective surface is easier to construct with specified tolerances than doubly curved, paraboloidal reflective surfaces. Moreover, unlike the paraboloidal dish, the conical reflector can be deepened without limit and the aperture area still increases proportionately with surface area of the reflector, thus permitting a reduction in spillover radiation without inefficient use of space and materials.

According to another feature of the invention, particularly applicable when the reflector surface comprises only a segment of a 90 degree cone, the reflector is fed by a rectangular horn reflector of a special type, the aperture of which forms a long slot lying on the conical axis. In cross section the horn is much larger on the sides perpendicular to the plane containing the aperture than on the other sides, and the reflecting section has a surface which is a portion of a cylindrical parabola, as distinguished from the paraboloidal segment which is employed in conventional horn reflector antennas.

Still another feature of the invention adapts a reflector having a surface in the shape of the inside surface of a truncated circular cone for use with a conventional horn reflector to increase the aperture area, and thus the gain, of the horn reflector up to fourfold without expanding the dimensions of the horn reflector itself. In this arrangement the smaller base of the truncated cone faces the horn reflector aperture. A second reflector having an operative surface in the shape of the outside surface of a circular cone whose walls are parallel to the surface of the truncated cone is situated on the axis and inside of the truncated conical reflector with its apex facing the horn reflector aperture.

The above and other features of the invention will be discussed in detail in the following specification taken in conjunction with the drawings in which:

FIG. 1 shows in partially cut away side elevation an antenna comprising a passive circular conical reflector and an active line feed;

FIG. 2 depicts in perspective view a circular conical reflector section fed by a modified horn reflector; and

FIG. 3 illustrates in partially cut away side elevation a truncated circular conical reflector and a conical reflector adapted to function with a conventional horn reflector antenna.

In FIG. 1 a reflector **10** comprising the inside surface of a 90 degree right circular cone is fed by a line feed **12**, which is situated on the axis of the cone. A 90 degree cone is one in which the axis forms an angle of 45 degrees with the conical surface. Line feed **12** may be any variety of the radiating elements commonly called line sources. With a 90 degree right circular cone forming the surface of reflector **10**, as in FIG. 1, line feed **12** radiates and intercepts electromagnetic waves propagating in a direction perpendicular to its length and uniformly around the axis of the cone. To achieve this characteristic, line feed **12** is shown as a circular waveguide **22** having annular slots such as **20** spaced apart one wavelength of the electromagnetic wave to be accommodated. Terminal equipment **14**, which may be transmitting and/or receiving circuitry depending upon the capacity in which the antenna system is operating, is connected to line feed **12** by a waveguide section **16**, which passes through conical reflector **10** at its apex.

Line feed **12**, as shown in FIG. 1, may be constructed of a single, long cylindrical piece of dielectric material of outside diameter slightly smaller than the inside diameter of waveguide **16** inserted inside waveguide **16** at the end near the apex of conical reflector **10**. Rings of conductive material may then be placed over the dielectric at the proper spacing, viz., one wavelength, $\lambda_0$, of the electromagnetic wave to be accommodated, to permit line feed **12** to accommodate electromagnetic waves propagating in a direction perpendicular to the length of line feed **12** and to the axis of conical reflector **10**.

The combination of reflector **10** and line feed **12** is capable of transmitting and receiving electromagnetic waves having a plane wavefront that is propagating in the direction of the axis of reflector **10**. That this is so can be seen from consideration of the following: If the antenna system is viewed as functioning in the capacity of a transmitting antenna, two rays of electromagnetic energy, designated *a* and *c*, emanating from arbitrarily-chosen points on line feed **12** impinge upon conical reflector **10** at an angle of 45 degrees to its surface, i.e., generally at an angle equal to the angle between the axis and surface of the cone. The continuation of rays *a* and *c*, designated rays *b* and *d*, respectively, are also reflected from conical reflector **10** at an angle of 45 degrees to its surface and parallel to the axis of conical reflector **10**. Geometrical considerations establish that the pathlength between line feed **12** and a plane perpendicular to the axis of conical reflector **10**, $a+b$, equals the pathlength between line feed **12** and plane **24**, $c+d$. Likewise, all rays emanating from line feed **12** perpendicular to the axis of conical reflector **10** combine in phase, to form a plane wavefront propagating in the direction of the axis of conical reflector **10**.



Despite the fact that the above-described conical reflector performs the same function as a paraboloidal reflector, improved antenna characteristics are feasible at a saving in materials, space and manufacturing complexity over the horn reflector and the paraboloidal dish fed from its focus.

Practice of the invention is not limited to 90 degree conical surfaces. The surface of reflector **10** may form a cone of larger than 90 degrees if more gain is desired from the antenna system and a cone of smaller than 90 degrees if the spillover of the antenna system is to be diminished. In both of these cases the design of line feed **12** must be modified so that it accommodates electromagnetic waves propagating at an angle that is not perpendicular to the axis of the cone. In general to operate as a directional antenna in combination with any circular cone, line feed **12** handles electromagnetic waves propagating at an angle with the conical surface of reflector **10** equal to the angle between the axis and the conical surface, i.e., one half the apex angle of the cone. By way of example, to accommodate electromagnetic waves when functioning with a cone of larger than 90 degrees, line feed **12** could comprise a waveguide having two longitudinal slots opposite each other. The size of the waveguide and frequency of operation determine the angle at which waves are accommodated by the line feed.

The line feed shown in FIG. 1 is somewhat limited in the frequency band within which it operates successfully because it requires that annular slots **20** be one wavelength apart. In some communication systems, a line feed capable of accommodating a wider frequency band of signals will be desired. FIG. 2 illustrates an embodiment of the antenna system of the invention wherein the surface of reflector **10** is in the shape of a segment only of the inside surface of a 90 degree right circular cone and line feed **12** takes the form of a horn reflector **26**, modified in some respects from the conventional horn reflector. Horn reflectors do not exhibit the narrow frequency band characteristics of waveguides radiating from annular slots, and the system of FIG. 2 accordingly possess wide frequency band capabilities.

The cross section of horn reflector **26** is rectangular and sides **40**, perpendicular to the plane of a radiating aperture **38**, are very wide with respect to the width of the remaining sides **42**. An additional modification is that the inner surface of reflecting section **28** is a concave cylindrical parabola whereas in the conventional horn reflector, the reflecting section has a paraboloidal surface. As before, line feed **12**, in the form of modified horn reflector **26**, is connected to terminal equipment **14** by waveguide section **16**, which is in this embodiment rectangular in cross section.

Aperture **38** of horn reflector **26** is long and thin, and its length is oriented along the axis of conical reflector **10**. It has a radiation pattern that is perpendicular to the axis of conical reflector **10** in planes containing the axis of conical reflector **10** and has a somewhat semicircular radiation pattern in the plane perpendicular to the axis of conical reflector **10**. Accordingly, to prevent spillover and still efficiently illuminate conical reflector **10**, conical reflector **10** should constitute a sufficiently large segment of a right circular cone to permit substantially the entire radiation pattern of horn reflector **26** to subtend its surface.

Another embodiment of the invention, disclosed in FIG. 3, adapts truncated conical reflector **10** and conical reflector **32** for use with conventional horn reflector **30**, where such horn reflector radiates from its aperture a plane wavefront of electromagnetic energy having a predetermined wavelength. This adaptation effects an increase in the aperture of horn reflector **30**, and therefore its gain, without calling for an expansion of the dimensions of horn reflector **30** itself, thus economizing on material and space. Conical reflector **10** here has a reflecting surface in the shape of the inside surface of a truncated 90 degree right circular cone. The smaller base of conical reflector **10** is connected to the wall of horn reflector **30** defining an aperture **44**, both of which have a diameter of D. Conical reflector **10** tapers outward away from horn reflector **30** to the larger base, having a maximum diameter of 2D. An intermediate reflector **32**, having a reflecting surface in the shape of the outside surface of a 90 degree right circular cone, is located inside of conical reflector **10**, its axis coinciding with the axis of conical reflector **10**. The surface of intermediate reflector **32** is caused to be only partially reflective by well-known techniques, as for example, by depositing a thin metallic coating by sputtering on a dielectric support member of the proper shape, so that about one half the incident electromagnetic energy is transmitted directly through intermediate reflector **32**. The apex of intermediate reflector **32** lies at aperture **44** and its coincal sides extend parallel to those of conical reflector **10** to a maximum base diameter D. The position of intermediate reflector **32** is maintained by supports (not shown) connecting it to conical reflector **10**. Intermediate reflector **32** and horn reflector **30** function together as line feed **12**, accommodating electromagnetic waves propagating perpendicular to the axis of the cones.

The operation of this structure as a transmitting antenna may be understood by following two arbitrarily-selected rays of electromagnetic energy designated *e* and *h*, originating from throat **34** of horn reflector **30** and emanating from aperture **44** parallel to the axis of reflector **10**. Rays *e* and *h* impinge upon intermediate reflector **32** at an angle of 45 degrees to its surface. Part of the impinging energy, represented by rays *f* and *j*, respectively, is reflected from intermediate reflector **32** also at an angle of 45 degrees to the surface of conical reflector **10** and part, represented by rays $e'$ and $h'$, respectively, is transmitted directly through intermediate reflector **32** to an arbitrarily-selected plane **36** lying perpendicular to the axis of reflector **10** and reflector **32**. Rays *f* and *j* impinge upon conical reflector **10** at an angle of 45 degrees to its surface and are reflected therefrom, in the form of rays *g* and *k*, respectively, at an angle of 45 degrees to the surface of conical reflector **10**. Rays *g* and *k* are also parallel to the axis of reflector **10**. Geometrical principles establish that the pathlength $e+f+g$ equals the pathlength $h+j+k$ and, accordingly, all rays of electromagnetic energy emanating from throat **34** and arriving at plane **36** via intermediate reflector **32** and conical reflector **10** are in phase with one another. The pathlengths to plane **36** for rays transmitted through intermediate reflector **32**, such as $e'$ and $h'$, are less than those reflected from intermediate reflector **32** by a factor equal to the pathlength of ray *f* or *j*. A layer of dielectric material **18** of thickness to delay the rays of electromagnetic energy transmitted through intermediate reflector **32** sufficiently to arrive at plane **36** in phase with the rays reflected from intermediate reflector **32** is placed along the inside surface of intermediate reflector **32**. Thus all the rays of electromagnetic energy emanating from the aperture of reflector **10** are in phase to form a unified plane wavefront propagating in the direction of the axis of the conical reflectors.

As with the embodiment of FIG. 1, conical reflector **10** need not have a 90 degree conical surface. So long as the reflecting surfaces of conical reflector **10** and intermediate reflector **32** are parallel to each other, the adaptation of FIG. 3 provides the desired effect of enlarging the aperture of horn reflector **30** in the fashion described above for 90 degree conical reflectors.

By modifying the conventional horn reflector as described above, increased gains are possible from the horn reflector without necessitating the consumption of material



and space to the extent which would be required were the horn reflector itself to be expanded to provide the same gain. Furthermore, the added gain is accomplished with singly curved reflectors, namely reflector **32** and reflector **10**. In this respect an additional saving is realized because an expanded paraboloidal surface area is also obviated.

Alternatively, intermediate reflector **32** may be made completely reflective, in which case a shadow appears in the beam of the antenna and the maximum increase in gain over the conventional horn reflector is somewhat less than in the partially reflective case.

What is claimed is:

**1.** In an antenna system, a reflector the reflective surface of which is the inside surface of at least a segment of a circular cone, terminal equipment, and feed means adapted to accommodate nonplanar electromagnetic waves propagating within an arc substantially coextensive with the projection of said segment on a plane perpendicular to the axis of said cone and propagating at an angle to said surface equal to the angle formed between said axis and said surface, said feed means comprising at least a horn reflector connected to said terminal equipment.

**2.** Antenna apparatus as defined in claim **1** in which said feed means comprises a horn reflector of rectangular cross section, the reflective section of said horn reflector having a concave parabolic cylindrical inner surface and the sides of said horn reflector lying perpendicular to the plane of the horn reflector aperture being many times the width of the other two sides of said horn reflector.

**3.** Auxiliary equipment for increasing the effective aperture of a radiator of electromagnetic waves having a predetermined wavelength and having a plane wavefront comprising a first reflector having an inside surface conforming to the surface of a truncated circular cone and a second reflector having an outside surface conforming to the surface of a circular cone situated within said first reflector, the respective inside and outside surfaces of said first and second reflectors being parallel to each other and spaced at least several of said wavelengths from each other so that transmission therebetween takes place in a free-space mode.

**4.** In an antenna system in combination with a horn reflector antenna for electromagnetic waves having a predetermined wavelength, said horn reflector antenna having a circular aperture and producing a plane wavefront, a first reflector having a reflective surface in the shape of the inside surface of a truncated circular cone, the truncated portion of said first reflector abutting the aperture of said horn reflector, and a second reflector having a reflective surface in the shape of the outside surface of a circular cone, the axis of said first reflector coinciding with the axis of said second reflector, the apex angle of said first reflector being equal to the apex angle of said second reflector, and the spacing between said first reflector and said second reflector being at least several of said wavelengths to ensure that transmission between said first reflector and said second reflector takes place in a free-space mode.

**5.** A combination as defined in claim **4** in which the apex angles of said first and second reflectors are 90 degrees, the larger base of said first reflector has a diameter that is twice the diameter of the aperture of said horn reflector antenna, the diameter of the base of said second reflector is equal to the diameter of the aperture of said horn reflector antenna, the common axis of said first reflector and said second reflector is perpendicular to the plane wavefront emanating from the aperture of said horn reflector antenna, and the apex of said second reflector is located at the geometric center of the aperture of said horn reflector antenna.

**6.** Auxiliary equipment for increasing the effective aperture of a radiator of electromagnetic waves having a plane wavefront comprising a first reflector having a surface conforming to the inside surface of a truncated circular conical surface and a second reflector having a surface conforming to the outside surface of a circular cone situated within said truncated conical surface, said second reflector transmitting a portion of the electromagnetic energy incident upon its outside conical surface, and means for delaying the portion of electromagnetic energy transmitted through said second reflector to bring it in phase with the portion of electromagnetic energy reflected by said second reflector, the conical surfaces of said first and second reflectors being parallel to each other and spaced such a distance from each other relative to the frequency of said electromagnetic waves that transmission therebetween takes place in a free-space mode.



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