March 11, 1952 W. P. BOOTHROYD ET AL 2,588,610

DIRECTIONAL ANTENNA SYSTEM

Filed June 7, 1946

FIG. 2.

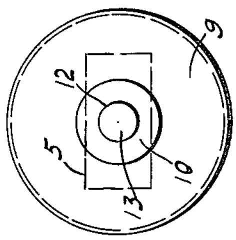


FIG. 4.

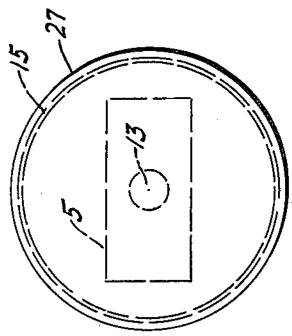


FIG. 1.

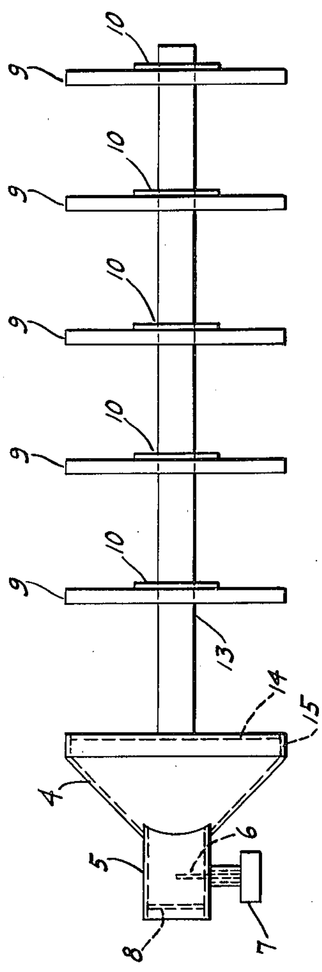
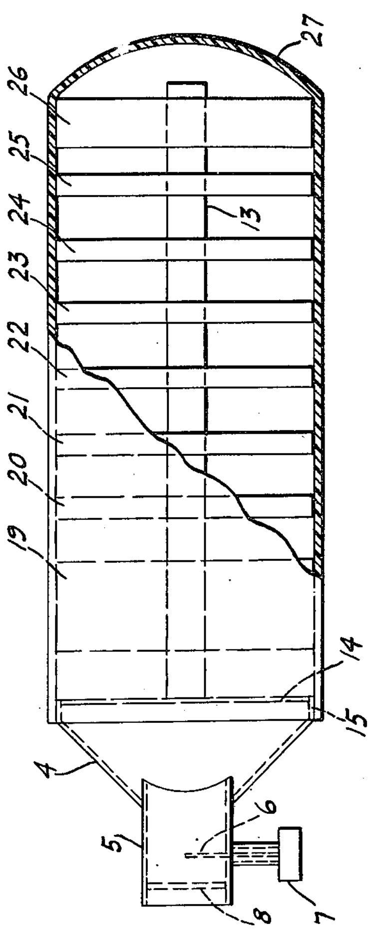


FIG. 3.



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Patented Mar. 11, 1952 2,588,610

UNITED STATES PATENT OFFICE

2,588,610

DIRECTIONAL ANTENNA SYSTEM

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Application June 7, 1946, Serial No. 674,951

11 Claims. (Cl. 250—33.63)

1

This invention relates to directional antenna systems adapted to radiate or receive ultrahigh-frequency electromagnetic wave energy. More particularly, the invention has to do with novel means for improving and/or modifying the directional properties of wave directive structures.

In consequence of the small physical dimensions of antennas and antenna systems available for use at ultrahigh-frequencies, directional propagation is preferably accomplished through the use of simple antenna structures, such as horn radiators and reflector type antennas, rather than by means of the more complicated and more critical arrays employed at the lower radio frequencies.

The manner in which horn radiators and reflector type antennas function as a means for propagating electromagnetic wave energy in a desired direction is considered to be sufficiently understood by those skilled in the art that only a brief reference to some of the physical considerations of such antenna systems will be given here.

The shape of the radiation pattern of a directive antenna system is primarily determined by the configuration of the wave front emerging from the system. Thus a wave front having a high degree of curvature will give a comparatively wide beam, while a wave front having a smaller curvature will produce a narrower beam. In horn radiators it has been found that the energy issuing from the mouth has a spherical wave front.

Highly directional radiation patterns may be obtained with simple horn radiators if the mouth or aperture is made large compared to the wavelength. Likewise, in a dipole and reflector type antenna system the width of the radiation pattern or beam becomes less as the diameter of the reflector mouth or aperture is increased. In practice, in order to obtain relatively narrow beam widths with these basic antenna structures, it has been necessary to employ large structures having apertures of inconveniently large diameter.

In a copending application of Oscar T. Simpson, Serial No. 657,691, filed March 28, 1946, Patent No. 2,556,046 granted June 5, 1951, and assigned to Philco Products Incorporated, there is described an antenna system utilizing phase modifying wave refracting means mounted wholly outside of and spaced from a wave directive structure for the purpose of modifying the wave front of the energy emerging from the structure. Such an antenna system may be arranged to give increased directivity over that obtainable from the wave structure alone, thereby permitting the use of a smaller wave directive structure than normally would be required to give a radiation pattern of specified beam width.

2

The present invention is directed toward an antenna system of the character described in the aforementioned copending application and is characterized by certain novel improvements in the phase modifying means whereby further control of the directional characteristics of such antenna systems is provided.

The improved antenna systems of the present invention may be used in conjunction with radar gun ranging equipment adapted for installation on aircraft. In aircraft installations it is particularly important that the antenna's physical dimensions and weight be kept as small as possible, and that the antenna have sufficient rigidity to withstand rough handling and vibration without variation in its electrical constants and hence in its radiation pattern.

It is therefore a general object of this invention to provide a novel means for controlling or modifying the directional characteristics of ultrahigh-frequency antenna systems.

Another object of this invention is to provide novel means for obtaining special radiation patterns from ultrahigh-frequency directive antenna systems.

A further object of the present invention is to provide an ultrahigh-frequency directional antenna system which is smaller, simpler and less costly to manufacture than previously known antenna systems of like directivity.

A more specific object of the present invention is to provide an antenna system for gun ranging equipment mounted on aircraft which, for the required beam width, is lighter, more compact, less costly to manufacture, and less subject to variation in its electrical characteristics when subjected to vibration than previously known antenna systems.

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

Figs. 1 and 2 are, respectively, side and front elevation views illustrating one embodiment of the invention; and

Figs. 3 and 4 are similar views illustrating another embodiment of the invention.

The drawings illustrate two specific antenna systems adapted for general use or with radar gun ranging installations on aircraft. Each antenna system includes, inter alia, a rectangular wave guide 5 terminated at its right-hand end in a conical horn 4. The wave guide 5 may be excited in any well known manner, such as by means of a capacity probe 6 extending into the wave guide from a coaxial cable input connection 7. Proper impedance match between the antenna system and a coaxial feeder cable attached to connection 7 may be obtained by any one of the usual matching methods. For example, the non-radiating end of the wave guide 5 may be closed by a conducting end plate 8, preferably movable within the guide, and positioned at the correct distance from the input connection 7 to give the desired impedance match. It will be understood, of course, that the position and extent of insertion of the probe 6 also affects impedance match. Since the above-mentioned elements, per se, are well known a detailed description thereof is deemed unnecessary.

In the embodiment of the invention illustrated in Figs. 1 and 2, five spaced wave-refracting elements are mounted in front of horn 4 along the principal axis of wave propagation thereof. Each wave refracting element comprises a dielectric disc 9 and may include, in addition, a preferably adjacent, and smaller, metallic disc 10. Preferably the wave refracting elements are spaced at approximately half wavelength intervals starting from the mouth of the horn. Any convenient and appropriate means may be employed to support the discs 9 and 10. By way of example, each disc may be centrally apertured, as indicated at 12, to engage dielectric supporting rod 13 which, in turn, is fixed to a dielectric plate 14 at the center thereof. As shown best in Fig. 1, the plate 14 is conveniently supported by means of an annular flange 15 formed around the aperture of horn 4. If desired the discs 9 and 10 may be slidably mounted on rod 13 so that their axial positions may be adjusted to produce a desired radiation pattern.

The dielectric elements 9, 13 and 14 should be composed of a substance or substances (e. g. a plastic or a ceramic) having low dielectric losses, i. e. low power factor, at the operating frequency. Polystyrene is an example of a suitable low loss plastic dielectric material. For mechanical protection the wave-refracting elements 9—10 may be enclosed in a tubular cover of suitable dielectric material, e. g. "Lucite" or the like (see Figs. 3 and 4).

A physical embodiment of the structure illustrated in Figs. 1 and 2 was constructed for operation at a frequency of 2550 megacycles. The wave guide 5, which was approximately 1.5 inches long and excited in the TE_{01} mode, drove a horn radiator having a flare angle of about 90 degrees and a comparatively small aperture measuring about 3.5 inches in diameter, i. e. approximately three-quarters of a wave length. Discs 9 were composed of polystyrene 0.25 inch in thickness and of the same diameter as the horn. The metal discs 10 were one thirty-second inch thick and about one and one-eighth inch, or one-quarter wave length, in diameter. The wave refracting elements 9—10 were spaced at half-wave intervals along the support rod 13.

The above described antenna system produced a radiation pattern which was essentially a figure of revolution and which had a beam width of 28 degrees at the half-power points. The only perceptible side lobe was a three-percent peak 70 degrees from the axis of revolution. Satisfactory operation of the system, including both impedance match and radiation pattern, was obtained over a band width of more than 100 mc.

To obtain the proper phasing of the wave energy required for destructive wave interference in planes transverse to the axis of the system it appears essential that the spacing between the pairs of elements closely approximate a multiple of a quarter wave length. Preferably the dielectric discs 9 should have a thickness of at least one-eighth inch, but the thickness within reasonable limits has been found to be not at all critical. Discs of larger diameter produce a narrower beam, and vice versa. By "tapering" the disc diameters so that the diameter of the last disc was half that of the first, the beam width — for a five-element array — was increased approximately two degrees. Increasing the diameter of the metal discs 10 produced a sharper beam but also increased the strength of the side lobes and caused a greater impedance mismatch between the horn and free space While some of the effects produced upon the radiation pattern by varying the diameters of the polystyrene and metal discs are mentioned above, it was found that within reasonable limits the dimensions of the discs were not critical, the shape of the radiation pattern being controlled primarily by the number of wave-refracting elements 9—10. Thus, in one experimental model, the horn alone produced a beam having a width of 60 degrees; the horn with three wave-refracting elements provided a beam having a width of 45 degrees; and the horn with seven wave-refractive elements provided a 22-degree beam. However, with arrangements employing more than five elements additional side lobes began to appear. For instance, with the seven pair array, a 25 percent lobe appeared 30 degrees from the axis while a 5 percent lobe appeared at the 70 degree points. As mentioned above, the lobe characteristic is also a function of the metal disc diameter.

The novel wave-refracting array of the present invention is not, of course, limited to use in combination with primary radiators of the horn type, it being apparent, as pointed out in the above-mentioned copending application, that other radiators (e. g. a dipole with spherical reflector) may be employed.

Instead of the pairs of dielectric and metallic discs shown in Figs. 1 and 2, other forms of wave refracting elements and other arrangements thereof may be employed to control the shape of the radiation pattern. A useful modification of the wave refracting array is illustrated in Figs. 3 and 4, in which Fig. 3 is a side elevation with a portion of a housing member broken away to facilitate illustration, and Fig. 4 is an end elevational view of the device shown in Fig. 3. This particular embodiment employs eight wave-refracting elements bearing reference numerals 19 to 26, mounted in front of horn 4, perpendicularly to and coaxially with the axis of the horn. The wave refracting elements, or discs, are composed of a suitable low-loss dielectric material, such as polystyrene. They may be supported in the manner previously explained in connection with the description of Figs. 1 and 2. The horn mouth or aperture, as well as the dielectric discs, measure about three-quarters of a wavelength in diameter. The first disc 19 is approximately one wave length thick with its center at a distance of about three-quarters of a wave length from the mouth of the horn. Discs 20 to 25 are approximately two-tenths of a wave length thick. The center of disc **20** is about three-quarters of a wave length from the center of disc **19**, while the spacing between discs **20** to **25** is approximately a quarter wave length. The last disc **26** is about a half wave length thick with its center approximately six-tenths of a wave length from the center of disc **25**. In the dimensions given above the disc thicknesses are in terms of wave length in the dielectric and the spacings between elements are in terms of free space wave length. Within limits the various disc thicknesses are not critical, the beam width being primarily an inverse function of the number of elements used.

The entire disc assembly may be enclosed in a protective cover **27** composed of a mechanically and electrically suitable dielectric material. "Lucite" has been used successfully for this purpose. For mechanical convenience in mounting the cover the discs may be of the same diameter as the horn. The presence of the cover tends to narrow the beam width.

A physical embodiment of the structure illustrated in Figs. 3 and 4 was constructed for operation at a frequency of 3285 megacycles. The horn **4** had a flare angle of 100 degrees and a mouth measuring two and three-quarter inches in diameter, disc **19** was one and seven-sixteenths inches thick, disc **26** was five-eighths of an inch thick, and discs **20** to **25** were each one-quarter of an inch thick. All of the discs, as well as rod **13** and plate **14** were polystyrene. Cover **27** was made from a piece of one-eighth inch thick "Lucite."

The radiation pattern of the above-described antenna system had a beam width of twenty-six degrees between half power points, with three percent side lobes at forty-five degrees from the axis of the horn. Although the frequency of the applied energy was varied over a hundred megacycle band the beam width varied but one degree, the side lobes increasing to a maximum of four percent at the ends of the band. Exceptionally good impedance match was maintained throughout this band, the standing wave ratio, looking into the antenna from the transmitter, being less than 1.2 over the band.

The antenna system illustrated in Figs. 3 and 4, may employ other driving or radiating means similar to those mentioned with reference to the system shown in Figs. 1 and 2. Various modifications may also be made in the number, diameter, and thickness of the discs **19** to **26** in order to produce radiation patterns of other configurations.

The principles underlying the present invention have not yet been fully determined. It appears however that the phase modifying elements, which may be termed "director discs" or "phase retarders," function as wave refracting bodies which alter the phase of portions of the electromagnetic wave energy with respect to other portions thereof and thus modify the radiation pattern. With specific reference to the embodiment of Figs. 3 and 4, for example, it appears that the discs **19** to **26** tend to retard the phase of the wave passing therethrough, or in the vicinity thereof, in such a manner as to more favorably phase the central portion of the radiated energy with respect to the outer portions thereof, and thus to convert the spherical wave front of the conventional horn to a more nearly plane wave front. The embodiment of the invention according to Figs. 1 and 2 may be considered to operate in a similar manner, with the metal and polystyrene discs acting to different degrees upon the wave front, the metal discs being more drastically effective than the polystyrene discs in retarding the phase of the wave.

It will be apparent to those skilled in the art that the structures herein described may be utilized in either the reception or transmission of wave energy, it being well understood that the characteristics of an antenna used to abstract energy from a passing wave are similar, in practically all respects, to those of the same structure used as a radiator.

Although this invention has been illustrated and described with reference to certain specific physical embodiments, it is to be understood that the invention is not limited to such embodiments and that other apparatus and arrangements may be utilized within the scope of the invention as defined in the appended claims.

We claim:

1. An ultrahigh-frequency antenna system comprising a hollow wave-directive structure having a principal axis, said structure terminating in an open mouth through which electromagnetic wave energy may pass in the direction of said axis, a plurality of dielectric plates mutually spaced along said axis, a plurality of conductive plates mutually spaced along said axis, the plane of each of said plates being perpendicular to said axis, and means supporting said plates in positions outside of and spaced from said structure, said plates being arranged coaxially with respect to said structure.

2. An ultrahigh-frequency antenna system comprising a conical horn radiator terminating in an open mouth and having a principal axis of wave propagation extending centrally through said mouth in a direction normal to the plane thereof, a dielectric rod, means supporting said rod on the line of said axis and in a position extending outwardly from said mouth, and a plurality of centrally-apertured dielectric discs through the apertures of which said rod extends whereby to support said discs in planes parallel to the plane of said mouth, said discs being mutually spaced along said rod in confronting relation with said mouth.

3. An ultrahigh-frequency antenna system as claimed in claim 2, characterized in that the diameter of at least certain of said dielectric discs is substantially equal to the diameter of the mouth of said horn.

4. An ultrahigh-frequency antenna system as claimed in claim 2, characterized in that the thickness of said discs is substantially less than the spacing therebetween.

5. An ultrahigh-frequency antenna system comprising a hollow wave-directive structure having a principal axis, said structure terminating in an open mouth through which electromagnetic wave energy may pass in the direction of said axis, and a plurality of dielectric plates each having parallel plane surfaces, the lateral dimensions and area of said plates being substantially equal to the lateral dimensions and area of said mouth, said plates being mutually spaced along said axis and disposed outside of and spaced from said structure in positions opposite the mouth thereof, the plane of each of said plates being perpendicular to said axis, said plates being arranged coaxially with respect to said structure, said plates being effective to modify the radiation pattern of said structure.

6. An ultrahigh-frequency antenna system as claimed in claim 5, characterized in that the spacing of at least certain of said dielectric plates is substantially an integral multiple of a quarter wavelength at the operating frequency.

7. An ultrahigh-frequency antenna system comprising a horn radiator terminating in an open mouth and having a principal axis of wave propagation extending centrally through said mouth in a direction normal to the plane thereof, and a plurality of dielectric plates each having parallel plane surfaces, the lateral dimensions and area of said plates being substantially equal to the lateral dimensions and area of said mouth, said plates being mutually spaced along said axis and disposed outside of and spaced from said horn radiator in positions opposite the mouth thereof, the plane of each of said plates being perpendicular to said axis, said plates being arranged coaxially with respect to said radiator, and the spacing of at least certain of said plates being substantially an integral multiple of a quarter wavelength at the operating frequency.

8. An ultrahigh-frequency antenna system comprising a horn radiator terminating in an open mouth and having a principal axis of wave propagation extending centrally through said mouth in a direction normal to the plane thereof, and a plurality of dielectric plates mutually spaced along said axis and disposed outside of and spaced from said horn radiator in a position opposite the mouth thereof, the plane of each of said plates being perpendicular to said axis, said plates being arranged coaxially with respect to said radiator, at least certain of said dielectric plates having conjoined therewith conducting metal plates, the dimensions of said metal plates being less than the corresponding dimensions of said dielectric plates.

9. An ultrahigh-frequency antenna system comprising a horn radiator terminating in an open mouth and having a principal axis of wave propagation extending centrally through said mouth in a direction normal to the plane thereof, and a plurality of dielectric plates each having parallel plane surfaces, the lateral dimensions and area of said plates being substantially equal to the lateral dimensions and area of the mouth of said horn, said plates being mutually spaced along said axis and disposed outside of and spaced from said horn radiator in positions opposite the mouth thereof, the plane of each of said plates being perpendicular to said axis, said plates being arranged coaxially with respect to said radiator, and the spacing of at least certain of said plates being substantially an integral multiple of a quarter wavelength at the operating frequency.

10. An ultrahigh-frequency antenna system comprising a horn radiator terminating in an open mouth and having a principal axis of wave propagation extending centrally through said mouth in a direction normal to the plane thereof, and a plurality of isotropic dielectric plates each having parallel plane surfaces, said plates being mutually spaced along said axis and disposed outside of and spaced from said horn radiator in positions opposite the mouth thereof, the spacing of at least certain of said dielectric plates being substantially an integral multiple of a quarter wavelength at the operating frequency, the plane of each of said plates being perpendicular to said axis, said plates being arranged coaxially with respect to said radiator, and the thickness of said plates, measured along said principal axis, being substantially less than the spacing between said plates.

11. An ultrahigh-frequency antenna system comprising a hollow wave-directive structure having a principal axis, said structure terminating in an open mouth through which electromagnetic wave energy may pass in the direction of said axis, and a plurality of dielectric plates each having parallel plane surfaces, said plates being mutually spaced along said axis and disposed outside of and spaced from said structure in positions opposite the mouth thereof, the plane of each of said plates being perpendicular to said axis, said plates being arranged coaxially with respect to said structure, and substantially all of the area of each of said plates directly confronting the open mouth of said wave-directive structure.

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