Nov. 16, 1965 H. W. EHRENSPECK 3,218,646

ENDFIRE ANTENNA CONSTRUCTION

Filed Feb. 19, 1964 3 Sheets-Sheet 1

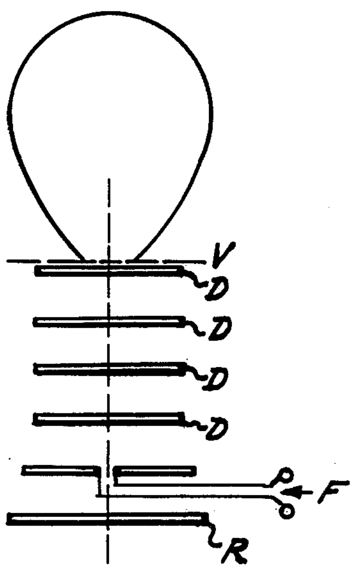

Fig. 1 PRIOR ART

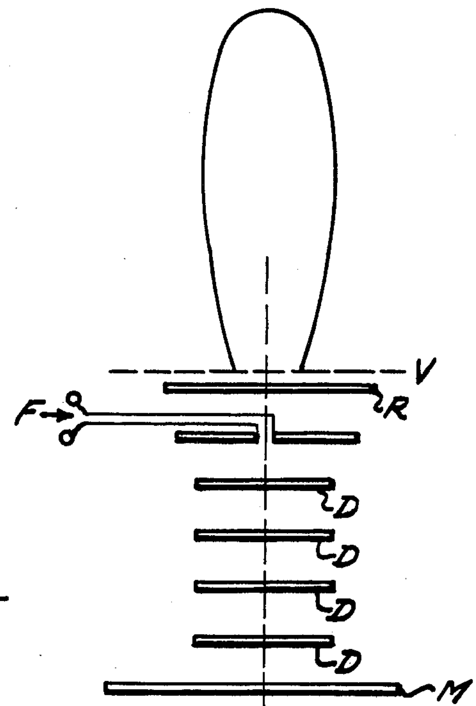

Fig. 2

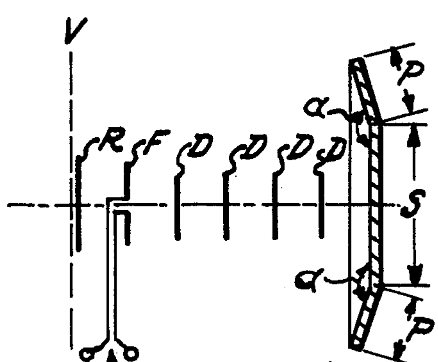

Fig. 3

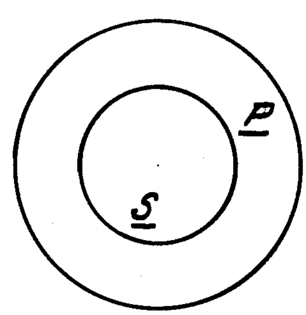

Fig. 3a

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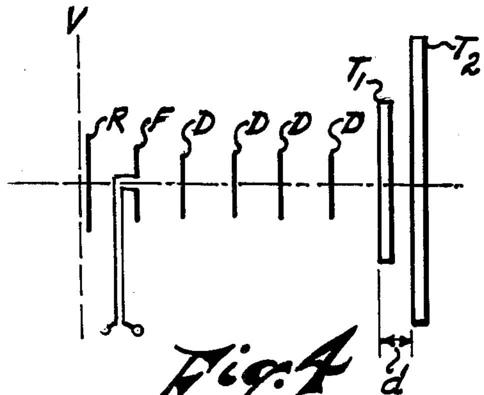

Fig. 4

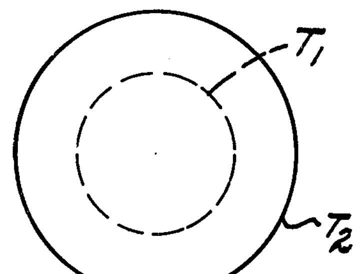

Fig. 4a

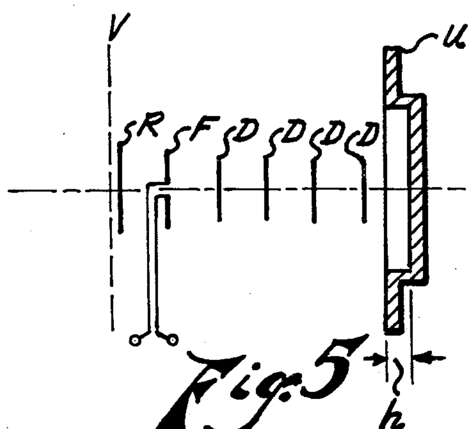

Fig. 5

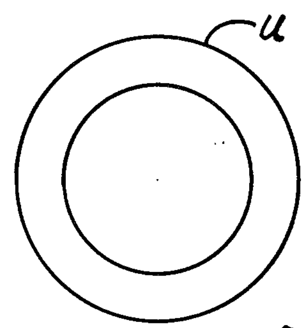

Fig. 5a

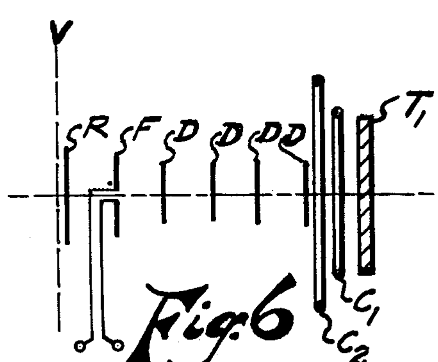

Fig. 6

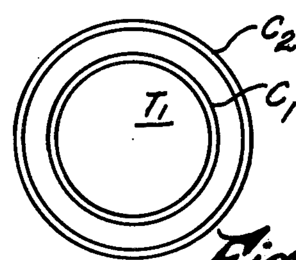

Fig. 6a

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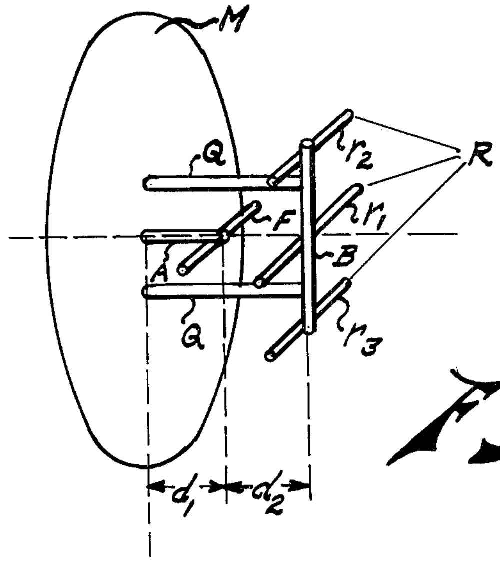

Fig. 7

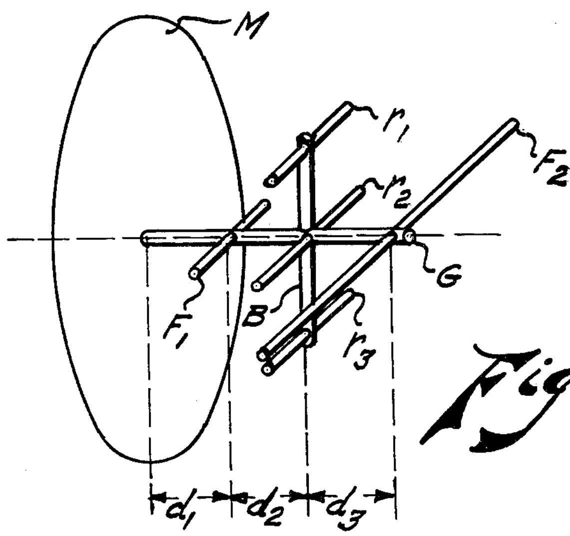

Fig. 8

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United States Patent Office

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ENDFIRE ANTENNA CONSTRUCTION

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Filed Feb. 19, 1964, Ser. No. 346,050
8 Claims. (Cl. 343—819)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without payment to me of any royalty thereon.

This application is a continuation, in part, of my copending application Number 812,565, filed May 11, 1959, now Patent No. 3,122,745, issued on February 25, 1964.

This invention relates generally to directional antennas and more particularly to a modification of directional antennas to produce a reflection of energy from an array to cause it to traverse the array at least once before it is radiated and thereby increase gain.

The gain of directional antennas depends on the phase velocity of the surface wave travelling along it and the length of the antenna; however, for a given length there is an optimum phase velocity beyond which the gain decreases, therefore, for adjustment of antennas at optimum phase velocity, the gain becomes proportional to the antenna length.

The utilization of the concept of this invention whereby the use of a reflection arrangement to cause a traverse of at least part of the energy of an endfire directional array back along the array has been found to increase the effective length of the array and, therefore, cause an increase in antenna gain. The gain increase thus achieved is accomplished without extensive modification of the antenna or physically increasing the length.

In the drawings:

FIG. 1 is a schematic representation of a conventional endfire antenna with the main lobe of its pattern;

FIG. 2 is a schematic representation of the backfire antenna embodiment of my invention with the main lobe of its pattern;

FIGURES 3 and 3*a*, FIGURES 4 and 4*a*, FIGURES 5 and 5*a* and FIGURES 6 and 6*a*, show various other embodiments of this invention as applied to endfire antennas; and

FIGURES 7 and 8 illustrate the application of the principle of backfire antennas to non-slow wave structures.

The gain of a reflection antenna according to FIG. 2 (identical with FIG. 2 of the aforementioned copending patent application) is mainly a function of the antenna length and the size of the plane reflector M, provided that the directors D, feed F, and reflector R are adjusted to their optimum height. The gain of such antennas, however, cannot be continuously increased by increasing the reflector size. Rather, there is an optimum size for reflector M and increases beyond that size lead to a decrease in gain.

This behavior of the reflection antenna is caused by the fact that the field radiated from the virtual aperture V (see FIG. 2) is the vector sum of two components called E_1 and E_2, whose amplitude and phase are a function of the size of reflector M. E_1 is the field of the slow wave traveling along the structure from the feed towards reflector M with a phase velocity smaller than light. After impinging on M with a plane phase front it is reflected back towards the virtual aperture V. E_2 is that portion of the field which, having been radiated directly by the feed towards the reflector M (without being bound to the slow wave structure) is thence reflected back to the virtual aperture V. Maximum gain is obtained when E_1 and E_2 are in phase in the virtual aperture, minimum gain if they are out of phase by 180°.

When a conventional slow wave structure, for example of the type illustrated in FIG. 1 (identical with FIG. 1 in the aforementioned copending patent application) is adjusted for optimum performance (by appropriate adjustment of height and spacing of the elements and antenna length), the energy associated with field E_1 travels in what is called a virtual wave channel, starting from the feed in direction towards the opposite end of the antenna from where it is radiated into space from the virtual aperture V as from the mouth of a horn. The wave channel has an approximately circular cross section with the energy strongly concentrated around its longitudinal axis and decaying approximately exponentially in the direction normal to the axis. The concept of the virtual aperture and wave channel is more fully explained in U.S. Patent No. 3,096,520, entitled "Endfire Array," wherein the virtual aperture at the end of an array is defined to include the field at which power levels are from maximum to 20 db below maximum. In many practical cases of such conventional slow wave structures the enery density has already decreased to this 20 db limit at a distance of about 0.75 to 1.00 wavelength from the axis. One can say, therefore, that practically the entire energy of E_1 is contained in a wave channel of 1.5 to 2.0 wavelengths diameter. Consequently, for the reflection of component E_1 a reflector of this size is sufficient.

If now we return to the structure of FIG. 2 above, it is seen that any increase of the reflector size beyond a diameter of 1.5 to 2.0 wavelengths will have practically no effect on the contribution of E_1 to the radiation pattern of the reflection antenna. On the other hand, any further increase of the size of reflector M does result in the interception of more energy of the directly radiated field E_2, which after its reflection towards the virtual aperture does increase the contribution of E_2 to the radiation pattern. Taking into account the phase shift between E_1 and E_2, the gain of the reflection antenna first increases rapidly with increase of reflector size, reaches a maximum when E_1 and E_2 are in phase, decreases to a minimum when E_1 and E_2 are out of phase by 180°, then increases once more to another maximum, etc. The second and further maxima, however, are not too important for practical applications, because the reflector dimensions have then become unnecessarily large. What is important, however, is that an increase of the size of reflector M, which is often desired for maximum possible suppression of backward radiation, may decrease the antenna gain.

According to the invention, this disadvantage of a reflection antenna can be overcome by shaping the reflector M so that E_1 and E_2 are effectively reflected from different parts of the reflector so that they are always in phase in the virtual aperture. Even if it is not possible to treat both components completely independently of each other, the application of this method to reflection antennas results in essential improvements with respect to gain as well as to the suppression of side- and backlobes in their radiation patterns. This goal can be reached in various ways, all of which are based on the phase adjustment of E_1 and E_2 in the virtual aperture after reflection at reflector M has taken place.

One approach is schematically shown in FIG. 3 with its end view, FIGURE 3*a*. R, F, D, and V have the same meaning as in FIG. 2. Reflector M of FIG. 2 here consists of two parts, a plane center part S of circular shape and an exterior ring P, forming an angle α with S. The ring P may be plane or curved as a spherical or parabolic sector ring. S is extended out to the limits of the virtual aperture. Ring P should, for best antenna performance, be inclined at such an angle α with S, that E_2 is reflected towards the virtual aperture in a direction parallel to the longitudinal axis of the antenna. As the antenna is increased in length, both S and P have to be extended also.

According to another method, instead of a single reflector M two separate plane reflectors T_1 and T_2 may be used, as schematically shown in FIG. 4 taken together with FIGURE 4*a*. T_1 again should have the dimension of the virtual aperture, and T_2 about twice to three times the area of T_1. This arrangement offers the advantage that the components E_1 and E_2 after their reflection at T_1 and T_2 can, by change of spacing d between T_1 and T_2, simply be adjusted in phase such that maximum gain is obtained in the direction of the antenna axis. In a similar way, more than two plane reflectors can also be used and adjusted for optimum performance of the reflection antenna. This method may be of special interest if extremely low backward radiation is desired.

It has been found that practically the same results can be obtained if reflector T_2 is only a flat ring with its interior diameter equal to the outside diameter of T_1. Reflector ring T_2 may be arranged behind or in front of reflector T_1. In the later case the radiation pattern has a lower sidelobe lever than in the first. T_1 and T_2 can be connected by fixed or adjustable spacers made from metal or plastic material.

Still another way combines T_1 and T_2 into a single stepped reflector U as schematically shown in FIG. 5 taken together with end view, FIGURE 5*a*. This circular reflector has the form of a shallow pot with a bottom of the size of T_1, with the side walls of height h and a flange-like edge with an outside diameter of T_2. Reflector U may also be used in a position opposite to that shown in FIG. 5.

For obtaining extremely low backward radiation all these shapes and forms of reflectors may have a ring of about ¼ wavelength width surrounding the edge and connected with it such that it is perpendicular to the reflector plane or forms an angle α with it, as indicated in FIG. 3. All reflectors may be made of sheet metal or may consist of narrowly spaced rods, concentric rings, or wire mesh. Also the surrounding rings may be fabricated of sheet metal, one or more parallel rings, or wire mesh.

It has been found that also a reflector combination consisting of a plane center part T_1 and two concentric metal rings C_1 and C_2, as schematically shown in FIG. 6 taken together with end view, FIGURE 6*a*, give radiation patterns similar to those obtained from reflection antennas with reflector types according to FIG. 3 to FIG. 5. For a circularly shaped reflector combination, for example, best results are achieved provided that C_1, having about the same diameter as the edge of T_1, is arranged in a distance of about 0.25 wavelength from T_1, and C_2 is variable in its distance from T_1 so that it can be adjusted for optimum performance of the antenna.

According to the description in the aforementioned U.S. Patent No. 3,122,734, column 4, lines 7 through 10, reflector R may be made of narrowly spaced rods. It has been found that by changing the length and spacing of these rods the field distribution in the virtual aperture of a reflection antenna can be changed very effectively, and thus its radiation pattern can be given different shapes. Two extremes are patterns with highest gain and a sidelobe level up to 10 db below maximum, and patterns with extremely low side- and backlobes and a somewhat decreased gain. On an experimental model all sidelobes in the sector ±90° from the forward direction were at least 20 db, and in the sector ±90° from the backward direction even more than 30 db below the maximum in the H- and E-plane patterns. It should be mentioned that all the proposals discussed with reference to FIG. 2 can also be applied to reflection antennas according to FIG. 4 of the above-mentioned patent application, wherein the reflectors R and M have been reversed in position with respect to the feed F.

Even if reflection antennas according to the invention can be constructed for any length, the different types discussed so far were mostly assumed to have a length of more than one wavelength. It was thought that gain figures obtainable from still smaller reflection antennas can also be obtained with endfire antennas without a plane reflector, for example, with the usual Yagi antennas. Later experiments, however, have shown that smaller reflection antennas are also of great interest, especially because of their very low side- and backlobe level, the adjustability of their radiation patterns in the H- and E-plane, and their extremely simple and sturdy construction. A reflection antenna with a length of only about a half wavelength, for example, consists only of reflectors M and R and the feed dipole F between them. Because of the small distance between M and R no further elements are needed to make the combination perform as a reflection antenna according to the principle described in the patent application mentioned above.

A schematic sketch of such a short reflection antenna is shown in FIG. 7. M marks a circular plane reflector, F the feed, supported by a piece of tubing A with the energizing cable inside, and R the reflector built as a combination of three dipoles r_1, r_2, r_3 which are mounted on a supporting rod B at a distance of about ⅓ wavelength from each other. For obtaining patterns with low side- and backlobes the dipoles r_2 and r_3 are by about 10% shorter than the center dipole r_1; Q indicates two metal or plastic rods which hold the reflector combination R at a certain distance from, and parallel to, the plane reflector M; d_1 marks the spacing between M and F, d_2 between F and R. For obtaining maximum gain d_1+d_2 should be about 0.50 wavelength. By varying d_2 within limits of about 0.10 to 0.50 wavelength the radiation pattern can be adjusted for equal halfpower beamwidth in H- and E-plane, or for the smallest possible half power beamwidth in the H- or E-plane. By arranging an adjusting device for d_2 in the antenna construction, for example length-adjustable supporting rods Q, these variations in the radiation pattern can be obtained even after the antenna has been mounted in its working position. The reflector combination can be fabricated as one unit.

Furthermore, it has been found that variations in d_1 and/or d_2 can be used for changing the input impedance of feed F, thus giving a simple method for obtaining best matching between transmission line and feed. Because of the very complicated interaction between all elements, however, the optimum adjustment can so far only be found experimentally.

An experimental model of a short reflection antenna according to FIG. 7, consisting of a circular reflector of two wavelengths diameter, a feed dipole at $d_1=0.25$ wavelength distance from M, and a three-reflector combination at $d_2=0.32$ wavelength distance from F, showed the following results when used for receiving a horizontally polarized field:

Half power beamwidth in horizontal plane ------ 30.5°
Half power beamwidth in vertical plane -------- 30.5°

For an adjusting range $d_2=0.15$ to 0.45 wavelength, the half power beamwidth could be varied as follows:

In the horizontal plane from 27° to 37°
In the vertical plane from 48° to 26°

Over the entire adjusting range the first sidelobe always remained at least 10 db, mostly 15 to 20 db, and all lobes within ±90° from the backward direction in both planes 25 to 35 db below the maximum.

The short reflection antenna can be converted into an antenna which covers two discrete frequency ranges if a second feed, optimized for the lower of the two frequency ranges, it attached in front of reflector R. A schematic sketch of a useful configuration is shown in FIG. 8. M, r_1, r_2, r_3, d_1, d_2, and B have the same meaning as in FIG. 7. G is a rod or tube supporting all elements of the antenna, F_1 marks the feed for the higher, F_2 for the lower frequency range. This antenna represents a combination of a short reflection antenna for the higher frequencies, consisting of reflector M, feed F_1 and the reflector dipoles r_1, r_2 and r_3, and of a reflector antenna for the lower frequencies, consisting of reflector M and feed F_2. d_3 indicates the spacing between r_1 and F_2. In the higher frequency range, feed F_2 cannot cause any essential perturbations because it is located outside the reflection antenna; at the lower frequency range, the dipoles F_1, r_1, r_2, and r_3 practically do not disturb the pattern because they are short compared to the wavelength.

It has been found that reflector r_1, if it is given the appropriate length and shape, can serve as reflector for the reflection antenna and as feed for the reflector antenna at the same time. Best results are obtainable from a folded dipole with its centerpoint connected to the supporting rod G, and the two open ends used as feed terminals for the lower frequency range. In this configuration the two frequency ranges have a ratio of 2:1 provided r_1 is optimized for half the center frequency of the reflection antenna. If the dimensions of r_1 are chosen such that the two frequency ranges are overlapping, an antenna combination with a fairly broad bandwidth is obtained. Antennas with two discrete frequency ranges having their center frequency in the ratio of 3:1 or 4:1 can be achieved provided $d_3=d_2=d_1$ or d_2+d_1, respectively, and provided the feed F_2 is optimized for ⅓ or ¼ of the center frequency of the reflection antenna, respectively.

Many more combinations can be thought of. For example, in addition to the feed of the reflection antenna, two or more feeds can be arranged on a more widely extended supporting rod G. These feeds have to be optimized for the appropriate frequency and mounted at the corresponding spacing. A limit is, however, imposed by the size of reflector M, which has to be large enough to act as an efficient reflector for the lowest frequency to be covered.

What I claim is:

1. A slow wave endfire antenna array having a feed, a partial reflector at one end of said array, planar reflector means at the other end of said array of a size substantially equal to the virtual aperture of said array, and additional reflector means of a size greater than the virtual aperture of said array at said other end of said array.

2. A slow wave endfire antenna array as defined in claim 1 wherein said planar reflector means and said additional reflector means are arranged such that the energy in the field of the slow wave travelling along said array is reflected by said planar reflector means and the energy radiating from said feed which is not bound to the slow wave array is reflected by said additional reflector means.

3. A slow wave endfire antenna array as defined in claim 2 wherein said planar reflector means and said additional reflector means are oriented with respect to one another to produce an in-phase relationship in the virtual aperture with respect to energy reflected from each of said planar reflector means and said additional reflector means.

4. An endfire antenna array as defined in claim 2 wherein said additional reflector means is in the form of a ring at an angle to said planar reflector means.

5. An endfire antenna array as defined in claim 2 wherein said planar reflector means and said additional reflector means are in the form of plates spaced one from the other.

6. An endfire antenna array as defined in claim 2 wherein said planar reflector means is in the form of a plate and said additional reflector means is in the form of a ring.

7. An endfire antenna array as defined in claim 6 wherein said planar reflector means and said additional reflector means are spaced and interconnected.

8. An endfire antenna array as defined in claim 2 wherein said additional reflector means is in the form of multiple rings.

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