Jan. 27, 1953 W. B. NOWAK 2,627,028

ANTENNA SYSTEM

Filed July 3, 1945

FIG. 1

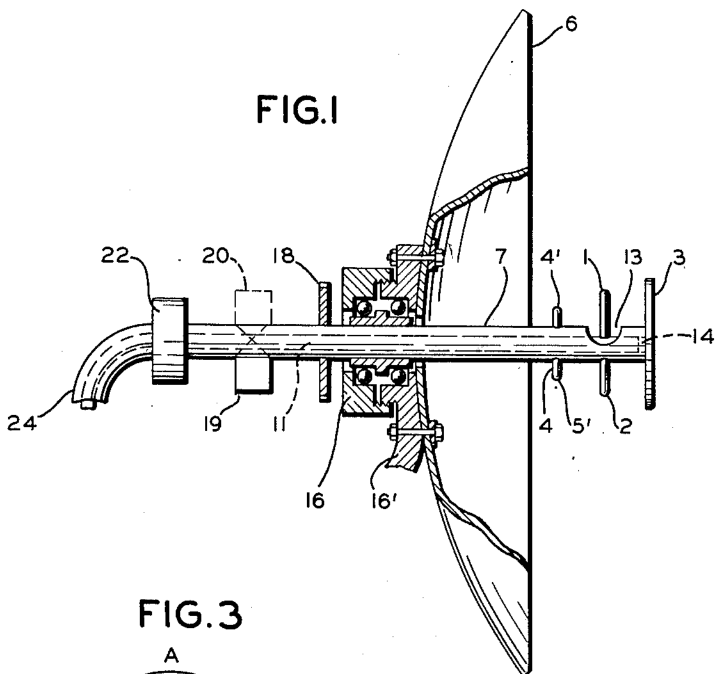


FIG. 3

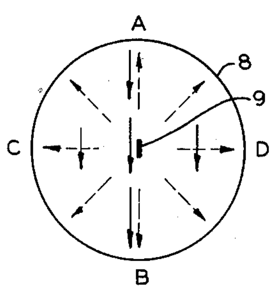


FIG. 4

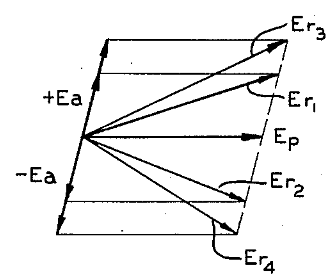
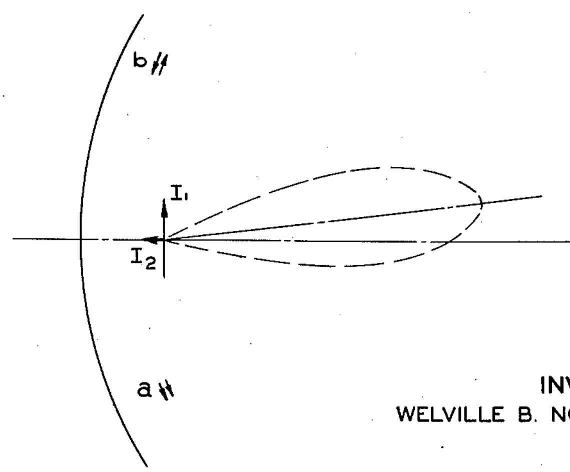


FIG. 2



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ANTENNA SYSTEM

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2 Claims. (Cl. 250—33.65)

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This invention relates to directional microwave antenna systems and in particular to an antenna system having physical symmetry about an axis but productive of a radiation beam with the direction of maximum radiation at a definite angle with this axis so that when a suitably symmetrical portion of the system is rotated a zone shaped scanning will result.

It is one object of this invention to provide an antenna system having almost complete physical symmetry about an axis but with a beam pattern unsymmetrical with respect to this axis in that the direction of maximum radiation is at an angle with this axis.

It is a further object to make certain portions of the antenna rotatable so that as a consequence of rotation the off-axial beam will generate a cone.

It is another object to provide an antenna system with a minimum of physical asymmetry in which it is possible in the manufacture or in the operation of the system to fix or adjust the degree of electrical asymmetry of the beam pattern at some desired value within a substantial range.

An additional object is to provide an antenna system for cooperation with a parabolic reflector for the formation of a highly concentrated directional radiation beam pattern.

Also an object is to provide an antenna system making use of metallic supporting structures of electrically resonant length integrated into the system and dispensing with insulating beads, spacers or other supports of such type and therefore capable of handling larger amounts of power.

Other objects and features will become apparent from consideration of the following detailed description taken with the drawings which are to be deemed exemplary and not limitational.

Fig. 1 shows partly in section a typical embodiment of this invention including a parabolic reflector and also that portion of the system which serves to illuminate the reflector in such a way as to produce a relatively narrow beam deflected from the direction of the reflector axis.

Fig. 2 is a diagram showing reference directions and the off-center pattern produced by the antenna system of Fig. 1.

Fig. 3 and Fig. 4 are diagrams for the purpose of illustrating a possible theoretical explanation which is believed to account for the phenomena with which the invention is concerned.

The type of construction of an antenna system preferred for the practice of the invention is

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shown in Fig. 1. There is shown the principal parabolic reflector 6 along the axis of which is positioned a coaxial conductor feed line having inner conductor 11 and outer conductor 7 suitable for connection with a radio transmitting and receiving system. Near its extremity is connected an antenna dipole having arms 1 and 2 the arms preferably being slightly shorter than a quarter wave length each. Dipole arm 1 is mounted on the inner conductor 11 and passes through a cut-out shown at 13 provided in the outer conductor 7. The clearance should be sufficient to prevent corona discharges at the edge of the cut out. The dipole arm 2 is mounted on the outside of the outer conductor 7 on the same axis as dipole arm 1. The dipole 1, 2 should be near the focus of the reflector 6.

The feed line 7, 11 is continued for a distance beyond its connection with the dipole 1, 2. At its extremity a short-circuiting plug 14 is inserted (and preferably soldered in place) thus furnishing a point of support for the inner conductor 11 relative to the outer conductor 7 of the feed line. The inner face of the short-circuiting plug 14 is approximately a quarter-wave length distant from the axis of the dipole 1, 2. Thus the forward extension of the feed line is enabled to act as a resonant supporting stub line which serves to support the inner conductor 11 and the dipole arm 1. If the antenna element used were not inherently well matched, in terms of impedance, to the feed line, the forward extension of the feed line might be used to improve the impedance match or to constitute one element of a matching transformer arrangement. In practice an antenna element such as the dipole 1, 2, when properly located with respect to the parabolic reflector with which it is adapted to be associated, is rather well matched to the feed line, so that it is preferred to provide the forwardly extending stub line with an electrical length of substantially a quarter-wave length.

The auxiliary reflector 3 is a metallic disk simply mounted on the end of the feed line perpendicular to the axis and at a suitable distance from the dipole 1, 2, and should be substantially greater in radius than the length of the dipole antenna arms. The disk reflector is to prevent direct forward radiation from the dipole antenna 1, 2 and the same function may be accomplished by a reflector dipole instead of a complete disk. For best focussing effect from such combination of dipole and reflector the focus should be between the two. Matching impedance must also be considered and it is also expedient to locate the effective center of radiation if possible at distance from the reflector equal to some multiple of a half-wave length.

A director dipole 4 with arms 4′ and 5′ on the outer conductor 7 and located between the reflector 6 and the dipole 1, 2 acts as a resonant or reactive element to cause standing waves on the outside of the feed line and produce a convenient amount of offsetting of the directivity of the radiated beam. The dipole 4 is somewhat shorter than the primary antenna dipole 1, 2 and is located about a quarter wave length away from it toward the reflector 6. The outer conductor 7 serves to connect the two arms 4′ and 5′.

The length and location of the director dipole 4 tends to determine the amount of offsetting. With the dipole 4, arranged as shown in Fig. 1, overall operation is quite satisfactory compared with other types of antenna systems, the beam being slightly broader for the usual size of parabolic reflector because of the less uniform illumination of the parabolic reflector resulting from the more directive qualities of the antenna arrangement. The latter properties arise from the fact that the dipole 4 acts as a director type of parasitic element, as well as functioning in the other respects above mentioned. On the other hand, lower side lobe intensities are to be expected for the same reason. The apparatus of Fig. 1 is believed to have some advantage over earlier apparatus of Rufus W. Wright (Serial No. 511,868, November 26, 1943) because the dipole 4 does not involve the narrow clearances and the consequent risks of corona discharges which are inherent in the operation of a quarter wave cylindrical choke resonator. This may be particularly important at high power operation or for operation at high altitudes.

Because the effect of the dipole 4 of Fig. 1 tends to vary rather strongly with the length of such dipole and with its spacing from the antenna dipole 1, 2, the dipole 4 may be included in the generic designation "resonant element" or "resonant structure" (with respect to the frequency of operation of the apparatus).

Fig. 1 also shows one way in which such an antenna system may be arranged for obtaining the antenna dipole on the axis of the parabolic reflector in order to produce a directive beam of radiation in which the direction of maximum intensity revolves to describe the surface of a cone about the axis of the parabolic reflector. The parabolic reflector is shown at 6 and may be supported in any suitable manner such as by a mount 16′ in order that it may be steerable and it may be provided with means to cause it to scan over a given area. For this purpose the mount 16′ providing for motion about two axes, as in the case of the search light mount or a gun mount, may be used, and motors, not shown, may be associated with the said axes for providing the desired scanning motion. The feed line 7 is supported by a housing structure 16 which is in turn supported by mount 16′ thus holding the feed line 7 centered on the axis of the parabolic reflector and permitting it to be rotated about such axis. A gear wheel 18 is fixed on the outside of the feed line 7, and the feed line and the antenna apparatus carried at its righthand extremity may be rotated by a suitable motor (not shown), geared to the gear wheel 18. Such motor may be conveniently carried on the same mount as the parabolic reflector 6. A supporting stub 19 is provided near the lefthand end of the feed line 7, 11 for supporting the inner conductor 11 of the said feed line. Similar support is provided at the right-hand end by the forward extension of the feed line beyond the antenna dipole 1, 2 and the shorting plug 14. If desired, a second stub 20, shown in dotted lines, may be provided directly opposite the stub 19 in order to provide dynamic balance so that the feed line 7, 11 may be rotated at relatively high speeds without substantial vibration. Instead of a second stub 20 a simple counter-weight may be used.

The use of stub supports as shown, by replacing insulators which would otherwise limit the safe power-handling capabilities, permits the antenna to be used for transmission at very high power levels. Operation at a peak power of 400 kilowatts is practical with a feed line having an outer diameter of only ⅞ inch with apparatus of the type shown in Fig. 1. Since the stub created by plug 14 and the conductors 7, and 11 extending forwardly of the antenna may have a diameter of almost a quarter-wave length (or even more in some cases), it is important that this stub should be properly located, for it might otherwise excessively disturb the radiation pattern of the antenna system. With the stub as arranged as described herein no such excessive disturbance is produced.

At the left of Fig. 1 the feed line 7, 11 is connected to a rotating joint 22, which may be of one of the forms shown in the patent of W. W. Salisbury, No. 2,451,876, issued October 19, 1948, through which the feed line 7, 11 connects to another coaxial transmission line 24. The rotating joint 20 is adapted to permit axial rotation of the feed line 7, 11 with respect to the feed line 24 without interference with transmission of radio frequency energy between them. The transmission line 24 is adapted to connect the feed line 7, 11 with a radio transmitting or receiving system (not shown) and may for that purpose pass through additional rotating joints in order to provide such connections continuously while the parabolic reflector 6 is being steered about or scanned as aforesaid.

Experimental work by Rufus W. Wright as described in his patent application, Serial No. 511,868, dated November 26, 1943, had indicated that when such antenna systems were arranged with a coaxial feed line along the axis of a parabolic reflector and with the focus of the reflector located at some point between the antenna element and the auxiliary reflector, the beam of radiation produced would, due to the presence of the resonator, generally have its maximum direction at some substantial small angle to the axis of the parabolic reflector instead of coincident with it as might normally have been expected. The resonator used by Wright was substantially a quarter wave length cylindrical resonant choke on the outside of the feed line. This invention consists in the substitution of auxiliary director dipole element 4 for the cylindrical choke resonator used by Wright.

It has been discovered that the axial position of the resonant element 4 of Wright's choke will control the amount of the electrical offsetting of the directivity the entire system reducing it to zero in some cases and extending it to several degrees in other cases.

This electrical offsetting is made use of by providing for axial rotation of at least part of the antenna system in order to produce a revolution of the offset directional characteristic about the axis of the parabolic reflector, thus adapting the system for highly accurate direction finding applications. The rotating portions of the system, because of the fact that the offsetting is produced electrically with a minimum of physical asymmetry, have a relatively high degree of dynamic balance.

A possible theoretical explanation of the directivity offset noted has been noted in aforesaid patent application of Wright, but it is to be understood that the invention is not limited by the suggested theory which is included here only as an aid in the appreciation and application of the principles of the invention.

This explanation is partly illustrated by the diagrams, Fig. 3 and Fig. 4, and is based upon the deduction previously made that standing electrical waves occur on the outside of the outer conductor of feed line 7 forward of the resonator element 4.

These standing waves constitute a source of radiation just as the standing waves on the dipole arms 1 and 2 are a source of radiation. However, the standing waves on the feed line being less effectively coupled to the inside of the feed line are much weaker and the radiation therefrom is much less intense than from the dipole arms 1 and 2. The primary antenna system may therefore be considered as if it included a fully excited dipole perpendicular to the axis of the parabolic reflector and another dipole oriented along the axis of the parabolic reflector excited at relatively much lower power, both dipoles being substantially at the focus of the parabolic reflector.

Fig. 2 illustrates the theoretical operation of such a system. The presence or absence of the auxiliary reflector may be neglected for the purposes of this explanation, and also the effect of the action of the element 4 as a second antenna element perpendicular to the axis may be neglected since the primary dipole and the director dipole jointly act to produce a resultant varying electrical field in the vertical plane which can be considered to cooperate with an axially oriented dipole to produce in the manner hereafter described a deflection of the beam from the axial direction.

Two dipoles seem to be radiating, one polarized vertically and one polarized axially as shown in Fig. 2. Designate the current in the imaginary vertical dipole as I_1 and in the imaginary axial as I_2. Then whatever the magnitude and phase of I_2 with respect to I_1 (and this would depend upon the position of the resonator), on the time diagram the contributions from the two dipoles at points such as *a* have to be added vectorially, whereas at points such as *b* they are subtracted vectorially since the reference directions (not the fields) are opposite to each other. The magnitudes and phases of the resultant fields at *a* and at *b* are therefore different and the source therefore does not send out radiation in all directions in a single time phase. Consequently the plane of the parabola opening is not a constant phase surface. The pattern can be determined by dividing the plane of the parabola opening into strips such that all points on one strip radiate in phase but the several strips are not in phase with one another. The resultant lobe is pulled toward the strips which are lagging in phase as in the case of ordinary arrays. The angle that the axis of the lobe makes with the axis of the parabola can be adjusted by axially varying the position of the resonator 4 of Fig. 1.

Fig. 3 illustrates the theory of operation of such an antenna system of a parabolic reflector, a perpendicular dipole antenna element and also an axial dipole. The presence or absence of an auxiliary reflector may be neglected for the purposes of this explanation. The parabolic reflector is represented by 8 and the antenna dipole by 9. The electric field produced by the antenna dipole 9 at a certain given instant is indicated by the solid arrows. The solid arrows show that a single beam is produced having the same polarization throughout, the polarization being in the direction of orientation of the dipole 9 (polarization being defined in terms of the electric vector, as is the practice in the electrical art). The effect of the axial dipole not represented on Fig. 3 is indicated by the dotted arrows which show the electric field produced thereby for some particular instant. It will be seen that radially polarized components are produced and because of the radiation characteristics of a dipole itself, there will be a null at the center of the pattern, there being no radiation along the axis of the parabolic reflector resulting from the axial dipole.

In general the excitation of the axial dipole and that of the perpendicular dipole are not exactly in phase. For the condition in which these oscillations are in phase, it will be seen that in the region indicated at A the radiation from the two dipoles will directly cancel in part (or directly add, according to how the condition of co-phasing is defined), whereas in the region indicated at B the radiation from the two dipoles will reinforce each other. At C and D the effect of the radiation from the axial dipole will be to cause the plane of polarization to deviate from that determined by the radiation from the dipole 9. At A and B the plane of polarization is unaffected. Now, for the case in which the radiation from the axial dipole and the radiation from the perpendicular dipole 9 are not in phase, the effect at A and B will be to shift the phase of radiation and, as will be seen from the opposite direction of the dotted arrows at A and B respectively, the phase will be shifted in one direction at A and in the opposite direction at B. Thus the phase might be shifted ahead in time at A and retarded in time at B. At C and D, the polarization of the wave, instead of being merely rotated in direction, will become more or less elliptic (becoming circular if the phase difference is 90° and the magnitude of the two components of the resultant radiation is equal). As previously mentioned, the contribution of the axial dipole is relatively small, so that the slight change in the polarization characteristics at C and D will hardly be noticeable. The effect on the phase in the regions A and B, however, is important.

Because of the usual characteristics of a dipole radiator such as a dipole arranged axially of a parabolic reflector, the illumination of the reflector by such a dipole will be a minimum at the center of the reflector and will increase gradually toward the edges. Usually the parabolic reflector will intercept only a fairly small solid angle of the radiation from the axial dipole—it is common to use reflectors intercepting considerably less than a hemisphere about the focus. Thus a progressive phase shift in the regions A and B can be expected which will increase at a fairly constant rate with increasing radius across the face of the reflector 8 (in a plane perpendicular to its axis). The linearity of this increase in phase shift with radius across the aperture of the reflector in a direction parallel to the dipole 9 may be increased by the slight falling off of the illumination of the parabolic reflector by the perpendicular dipole towards the edges of the aperture. Thus the surfaces of equal phase across the aperture of the parabolic reflector, in the portion not far from the diameter parallel to the dipole 9, will be approximately planes, the normals to which are inclined at a small angle to the axis of the parabolic reflector in the plane of polarization of the radiation from the dipole 9. This means that the radiation from the antenna system as a whole will go off at a small angle to the axis of the parabolic reflector, and because the surfaces of constant phase are approximately plane, the directive characteristics of the antenna system will be substantially unaffected in other respects, such as gain and beam width. This inclination of the surfaces of constant phase will decrease on both sides of the axis away from the diameter parallel to the dipole 9, but the decrease will be in proportion to a cosine curve and will therefore be quite gradual in the portion of the aperture forming a wide strip centered on the said diameter.

It will be seen from the foregoing consideration that if the explanation given corresponds to facts, the maximum deviation of the beam from the axis of the parabolic reflector which should be obtainable would be that for which the maximum phase shift at the edges of the aperture is respectively plus and minus 90 electrical degrees. Such a phase shift would give a deviation of

$$\frac{\lambda}{2D}$$

where λ is the free space wave length and D is the diameter of the aperture. Thus about ½ of the beam width measured at the half power level. In fact this theoretical limit has been quite closely approached, for deviation of as much as 2° or slightly more has been observed with antenna systems having a half power beam widths of the order of 8° or 10°. The achieving of maximum deviation, according to the explanation just set forth, would involve a suitable adjustment of the phase and the intensity of the radiation from the axial dipole. To some extent the adjustment of one of these factors might be expected to compensate for limitations in the range of adjustment of the other. It is naturally desirable to keep down the power level at the axial dipole.

Although the attainment of maximum deviation according to this invention may be of some theoretical interest, it is not of great practical consequence, because smaller deviations are usually sufficient for practical purposes, such as for highly accurate locating and directing service. If the theoretical maximum deviation were used and the antenna proper were spun on the axis of the parabolic reflector, the "cross-over" (power level on the axis) would be the half power point. In practice the "cross-over" is usually made to occur at 80% of peak power and therefore at an angle considerably less than half of the half-power beam width.

For a further amplification of the above given explanation of the phenomena upon which this invention depends, one may consider the vector diagram shown in Fig. 4 which is adapted to show the time relation of the various oscillations, the magnitude of the oscillations being indicated by the length of the vectors and the phase relation by the angular displacement between them. The vector E_p represents the radiation from the perpendicular dipole 9 and its phase may be used as a reference phase for the other vectors. The vector $+E_a$ represents (at an amplitude considerably magnified for purposes of illustration) the radiation from the axial dipole at a given point, while the vector $-E_a$ represents the radiation from the axial dipole at a corresponding position on the other side of the axis of the parabolic reflector. The resultant radiation at the two points considered will be E_{r1} and E_{r2} respectively. If another pair of points further away from the axis of the parabolic reflector should be considered, they might be found to have oscillating electric fields corresponding to the vector E_{r3} and E_{r4}. The deviation in phase between these last two vectors and reference vector E_p will be increased because of the greater magnitude of the contribution from the axial dipole at points farther away from the axis of the parabolic reflector.

For some purposes it may be desirable to swing the beam of the antenna directivity characteristic back and forth instead of around in a circle. This may be accomplished by a periodic variation over a small range of the frequency, at which the antenna system is excited and without rotating the feed. The resonator will remain substantially resonant throughout such small frequency range, but the electrical distance between the antenna system and the resonator, and consequently the standing wave pattern there will be varied, with the result that the tilt or deviation of the beam with respect to the axis of the parabolic reflector will be varied by changes of frequency. Variation of frequency may be combined with rotation of the antenna to produce a spiral scan effect.

Antenna systems constructed in accordance with this invention are particularly well adapted for operation in radio transmitting and receiving systems employing a single antenna for both transmission and reception. In such a system a small amount of offset of the direction of maximum radiation is of practically no consequence when the antenna system is not being rotated about the axis of the parabolic reflector, because it introduces at most a fixed error in aiming the parabolic reflector of which account need not be taken because it enters into both transmission and reception. At the same time, such offset may be used to advantage when it is desired to make precise determinations of the direction of an object by simply causing the portion of the antenna system mounted on the feed line to be rotated about the axis of the parabolic reflector. Such an antenna system can therefore be used to advantage in a double purpose apparatus for both ordinary detecting and locating and for more accurate direction finding operations.

In such a double-purpose apparatus, instead of discontinuing the axial rotation of the antenna proper with respect to the parabolic reflector when the apparatus is employed for general search or warning purpose, it may be advantageous to continue the said axial rotation. If the axial rotation is thus continued while the entire system, including the parabolic reflector, is rotated about suitable axes, either by manual steering or by a mechanically driven scanning motion, the radiated beam will describe a coiled path and will thus act as a broadened beam, which is more useful for general search purposes than the extremely sharp beam desired for accurate location operations such as are necessary for the directing and aiming of searchlights and guns. With this type of a broadened beam a fairly large solid angle can be effectively searched with a relatively small number of traverses of the field in search.

For the purpose of general search the indicating apparatus need not take account of the axial rotation of the antenna proper with respect to the parabolic reflector and need only show the position of the parabolic reflector corresponding to the detected object. More accurate locating operation could be initiated after a period of general search has revealed a target, by simply substituting other analysing or indicating apparatus for the general search indicator and employing the information obtained for following the target.

In apparatus in which the offset of the beam from the axis of the parabolic reflector is undesired, advantage can be taken of the present invention to set the resonant structure **4** of Fig. 1 at such a position that the offset equals zero. This would usually require setting the resonant structure somewhat farther back of the antenna dipole than is shown in Fig. 1.

What is claimed is:

1. Apparatus for producing a narrow, directive beam of radiation and causing the axis thereof to describe a cone comprising, a stationary parabolic reflector, a dynamically balanced spinnable antenna including a coaxial cable feed line extending through said reflector and rotatable relative thereto on the axis of said reflector, a radiating dipole having first and second elements secured to the inner and outer conductors of said feed line, respectively, and located substantially at the focus of said reflector, a circular conducting disc mounted at the extremity of said feed line in a plane perpendicular to the axis of said feed line and a director dipole having first and second elements secured to the outer conductor of said feed line rearwardly of said radiating dipole and in a plane including the axis of said feed line and said radiating dipole, the radiation pattern produced by said combination of radiating dipole, conducting disc and director dipole having an electrical asymmetry to said reflector; means for spinning said feed line, said disc and said dipoles mounted thereon about the axis of said feed line; and means including a rotatable transmission line joint for supplying electromagnetic energy to said feed line.

2. Apparatus for producing a narrow, directive beam of radiation and causing the axis thereof to describe a cone comprising, a stationary parabolic reflector; a coaxial feed line disposed coaxially with said reflector and passing through the vertex of said reflector, said feed line being dynamically balanced and mounted for rotation about the axis thereof relative to the said reflector, a radiating dipole mounted on said feed line near the extremity thereof and located substantially at the focus of said reflector, said radiating dipole including a first element secured to the inner conductor of said coaxial feed line and passing through a cut-out in the outer conductor thereof and a second element secured to the outer conductor and disposed coaxially with said first element, said radiating dipole being disposed perpendicularly to the axis of said feed line, a circular conducting disc mounted at the extremity of said feed line and disposed parallel to said radiating dipole, and a director dipole secured to the outer conductor of said feed line rearwardly of said radiating dipole in a plane including the axis of said feed line and said radiating dipole, the combined radiation produced by said radiating dipole and the portion of the feed line disposed between said radiating dipole and said director dipole having an electrical asymmetry to said reflector; means for spinning said feed line about its axis; and means including a rotatable coaxial transmission line joint for supplying electromagnetic energy to said feed line.

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