SPIRAL ANTENNA MOUNTED ON OPENWORK SUPPORT

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This invention relates to broadband antennas and has reference to a recticular construction for circularly polarized short wave antennas. While technical advances have recently led to the development of broadband antennas for operation in the V.H.F. and U.H.F. ranges, attempts to achieve comparable results in the lower frequencies have heretofore encountered structural and dimensional barriers. Rhombic configurations with satisfactory stability in radiation characteristics and impedance uniformity are limited to a frequency range on the order of 2 or 3 to 1. The bandwidth limitation of single dipoles and tuned arrays are even more restrictive. While much can be said for the directional characteristics of a rhombic system, the area of land it occupies is a detrimental economic factor and the physical dimensions of the antenna, itself, make the cost of constructing a rotatable unit prohibitive for most applications. Both the rhombic and the dipole have the further disadvantage of plane polarization. Ionospheric reflection is an important factor in signal propagation at frequencies from 2–30 mc./s. Although the variations and transient properties of ionospheric reflection are not completely understood, it is known that elliptical polarization is a normal characteristic of the reflected wave and that orientation of the principal axis of polarization varies with time. As will be shown, circular polarization leads to improved signal reception in this frequency range. Great progress has been made in the development of so-called frequency independent configurations for very high frequency operation, but unfortunately these advances have generally not been paralleled in the 2–30 mc. range. Of particular interest has been the equiangular and Archimedean spirals. Theoretically, it can be shown that an equiangular spiral of finite length would have uniform impedance and radiation characteristics over an infinite bandwidth. It follows logically that an equiangular spiral of finite length would have substantially uniform characteristics over a finite bandwidth and that the bandwidth would be a function of the length. For the U.H.F. band, pure spirals of this type with a frequency ratio of 20–1 have been constructed. Archimedean spirals with advantages over conventional configurations have also been made. Thus, for antennas of small size, spirals cut from sheet metal or deposited upon flat surfaces can be made to serve as practical structures. Since the effective range of an equiangular spiral lies above the frequency where the arm length equals approximately one wave length and since wave length is inversely proportional to frequency it is easily seen that the physical dimensions of a spiral reach appreciable and heretofore prohibitive size at the lower frequencies where some of its characteristics could be used to most advantage. The physical size of low frequency spirals as known heretofore has constituted a major deterrent to their use in the 2–30 mc. range. Considering wind resistance alone, it is seen that a sheet metal spiral made to operate at 10 mc. would present a surface of approximately 1500 sq. ft. without allowing for the surface area of a supporting structure; the problems of rigidity and weight are equally challenging.

The present invention is directed to skeletal construction for an equiangular spiral antenna and provides means whereby strands approximating the essential elements of configuration are supported by and affixed to a planar recticular member of minimum wind resistance and low weight. More particularly, it has been discovered that a solid planar spiral arm may be simulated by three strand members, two of which are formed as the edges of a spiral arm and the third of which is positioned equidistantly between the other two. Accordingly, an object of the present invention is to provide a broadband antenna for operation within a 5:1 range within the 2–30 mc. frequency band with uniformity of input impedance and radiation characteristics. Another object of the invention is to provide means for reducing signal fading in long distance reception (and transmission) of short wave transmissions.

A further object of the invention is to provide a light weight antenna of equiangular or Archimedean spiral characteristics. A particular object of the invention is to provide a circularly polarized broadband antenna which may be effectively mounted in a vertical plane. An additional object of the invention is to provide an antenna of the type described which is substantially unidirectional in its reception or transmission.

These and other objects will become apparent from the following description and the accompanying drawings, wherein:

FIGURE 1 is a front elevation view of an antenna as defined herein and shown supported within a peripheral frame.

FIGURE 2 is an enlarged and fragmentary view of a portion of the invention shown in FIGURE 1.

FIGURE 3 is a broken side elevation view of a supporting structure for antennas of the type defined herein.

FIGURE 4 is an enlarged elevation view of a clamp of the invention.

FIGURE 5 is a comparative graph of variations in signal intensity with time taken simultaneously from the invention and an optimized rhombic through identical receivers.

FIGURE 6 is a graphical plot of VSWR (logarithmically scaled) versus frequency (linearly scaled) of the invention as actually measured in tests of a prototype.

In the illustrated embodiment of the invention two peripheral frames 10 and 11 are held in spaced and parallel relationship to one another by a plurality of horizontal spacer bars 12. Each of the peripheral frames is comprised of a plurality of articulated segments 13 each attached by pivotal connections 14 to a preceding segment and a succeeding segment of the frame and arranged as one of a continuous chain of segments. A plurality of flexible lines 15 are respectively attached to each pivotal connection 14 of an adjacent pair of segments 13 and extend radially therefrom to connection with a central hub 16; the various flexible lines 15 are equal in length and are secured in substantially equal tension between a frame 10 and its hub 16 so that the various segments 13 are each positioned within a substantially circular perimeter of the frame 10 and are there held in longitudinal compression. It is to be understood that each frame is provided with a hub 16 and radial flexible lines 15 and that the hub and flexible lines of one frame 10 differ from the other 11 only that materials of construction of one are electrically conducting whereas those of the other are non-conducting. The present invention relates to the construction of an antenna particularly adapted for support by a recticular structure providing two expensive parallel planes; a suitable structure of this type is more particularly described and claimed in my pending application, Serial No. 31,589, filed May 23, 1960.

A central feed arm 17 cut from a sheet of wire mesh in the general shape of a spiral is positioned with its inner termination adjacent a portion of the circumference of
the non-conducting hub 16 and is attached to those non-conducting flexible lines 15 which it intersects. The width of the feed arm 17 is greatest in the immediate vicinility of the hub 16 whereas opposite sides of the outwardly projecting end of the feed arm converge with increased distance from the center of the mounting frame 10. The material of construction of the wire mesh is an electrical conductor and is unirule 18 having the same dimensions and hand of lay as the first 17 is positioned in the plane of the forward frame 10 with its enlarged end adjacent a portion of the circumference of the hub opposite the enlarged end of the first feed arm 17 and with its converging end disposed 180° from the converging end of the first. Thus, the two feed arms 17 and 18 are located on the forward frame 10 and are there oriented one-half of a revolution apart with respect to the hub 16 and flexible lines 15. Each of the feed arms 17 and 18 is physically and electrically separated from the other.

From the feed arms 17 and 18 spiral arms 19 and 20 respectively extend angularly and outwardly toward the forward peripheral frame 10. Each spiral arm 19 and 20 is comprised of a plurality of strands which lie in the plane of the feed arms 17 and 18 and are attached to the flexible lines 15 in such arrangement that the strands approximate regularly spaced logarithmic spirals. For purposes of identification, strands comprising separate spiral arms are identified by lines of different width in FIGURES 1 and 2. With reference to those figures, one end of an outer strand member 21 of one arm 19 is attached to the enlarged portion of the first feed arm 17 and is preferably soldered to the feed arm to establish electrical contact therewith. At a point where one of the flexible lines 15 intersects an outer edge of the first feed arm 17, the strand 21 is secured to the flexible line 15 by a clamp 22. The clamp 22 is constructed of two opposed rhomboidal plates having corresponding openings in opposite ends of the major diagonal thereof receiving threaded opposite ends of a U-bolt 23. A crosswise arch 24 is formed in one of the plates of the clamp 22 and is adapted to receive a flexible line 15; an opposed archway 25 is formed in the other plate of the clamp 22 in an angular relationship to the first archway 24 which is secured at the center of the clamp 22 and is adapted to receive the strand 21. Nuts 26 and 27 engaging opposite ends of the U-bolt 23 urge the plates of the clamp 22 toward one another and force the strand 21 to bear upon the enclosed portion of the flexible line 15. Since the sole purpose of the clamp 22 is to secure a strand 21 to a flexible line 15 at a predetermined point of intersection, it should be understood that features of the clamp’s construction are here recited by way of example and that other means of attachment may be used without departing from the scope of the present invention. From a clamp 22 on one flexible line 15, the strand 21 extends to a point of intersection with the next succeeding flexible line 15 where it is likewise secured by a second clamp 22b in the manner described above. The second clamp 22b is positioned at a greater radial distance from the hub 16 than is the first clamp 22a. Let r represent the distance from the first clamp 22a to the center of the hub 16 and r1 represent the distance from the second clamp 22b to the center of the hub, and r1<r. The strand extends from the second clamp 22b to a third clamp 22c secured to the next flexible line 15b at a location thereon of distance r2 from the center of the hub 16 such that r1/r2=rk where k is a proportionality constant (0<k<1) defining the ratio of radial distances of clamps 22 on next adjacent flexible lines 15. The strand 21 extends to clamps 22 on successive flexible lines 15 and the radial distances rk of each clamp is likewise defined as r1rk=rk−1.

One of an inner strand member 28 of one arm 19 is soldered to the first feed arm 17 at a location intermediate the ends of the feed arm. A clamp 22, as previously described, secures the inner strand 28 to a flexible line 15 immediately adjacent the inner edge of the feed arm 17 and the inner strand extends from its first clamp 22 to another clamp secured to the next adjacent flexible line. If r1 be designated as the distance from the center of the hub 16 to the first clamp of the inner strand and if r2 is the radial distance to the second clamp then the relationship of r1 to r2 is r1/r2=rk where k is the proportionality constant previously defined. The radial distance r1 of the point of clamped attachment of the inner strand 28 to the next succeeding flexible line, may similarly, be determined as r1=rk−1 and the radial distances of subsequent clamps 22 on succeeding flexible lines are described by the definition

\[ r_{k} = r_{2}^{k} \]

By the foregoing definition of successive points of attachment to the forward frame 10 of two strand members 21 and 28 in terms of a single proportionality constant k it will be seen that approximations of identical curves are formed thereby. By the congruence of their respective configurations it will readily be seen that the distance between the strands 21 and 28 at any location on the forward frame may be expressed as either an angular distance θ measured between equivalent points of the hub 16 to the respective strands or as a constant k representing the ratio of distances measured along a single radius; it should be noted, however, that θ or k hold exactly only if r equals r1. This is because the segments between points of attachment of both strands are straight lines and, hence, the course of each strand is only an approximation of a curve; the error in the approximation is a function of the number of flexible lines 15 in the frame 10. If r1=r2 then the configurations are similar instead of congruent although the validity of k still holds. Under this circumstance the distance between the two strands may be expressed precisely if θ is taken as the angular distance between congruent curves which the separate strands approximate.

An intermediate strand 29 is soldered to the outer end of the first feed arm 17 and is secured by a clamp 22 to a flexible line 15 there adjacent. With the same hand of lay as outer and inner strands 21 and 28 of the first spiral arm 19, the intermediate strand is clamped to positions on successive flexible lines 15 so that r1=kr2, r2=kr3, and r3=kr4 where r1, r2, r3, r4 are radial distances for successive flexible lines and k is the previously defined proportionality constant. In its relationship to the inner and outer strand lengths of the intermediate strand 29 may be determined as θ/k where θ is the angular distance between the inner and outer strands.

The second spiral arm 20 is likewise comprised of outer 30, inner 31 and intermediate 32 strand members which are respectively soldered at their inner ends to the second feed arm 18 in the manner previously described for strands of the first spiral arm 19 to its feed arm 17 and which extend to successive clamped connections on the flexible lines 15. The configuration and position of each of the strand members 30, 31 and 32 of the second spiral arm 20 may be defined as being positioned equidistantly with and 180° from a corresponding point on its opposite member of the first spiral arm. Whereas the inner and outer strand member 30 and 31 of the second spiral arm 20 are substantially identical in construction with all strand members of the first spiral arm 19, the whole spiral arm 20 is constructed as coaxial cable. The outer conductor of the coaxial cable is soldered to the second feed arm 18, but the center conductor of the cable is insulated from the second feed arm and extends across the hub 16 where it is electrically connected to the first feed arm 17. Outer ends of all described strands extend to and are electrically connected with segments 13 of the frame 10.

As has been stated previously, the flexible lines of the
rearward frame 11 are made of metal and constitute a reflector behind the spiral antenna arms 19 and 20 of the forward frame 16. A series of cross members (not shown) approximating concentric circles may be attached in cobweb like arrangement to the flexible lines of the rearward frame to enhance the efficiency of its reflection. Generally, the spacing between the reflector and the forward frame 16 should be between 0.1 and 0.2 of a wave length of the lowest frequency at which the antenna is to be operated.

The two opposed spiral arms within the forward frame may be defined by three parameters: Λ, a constant describing the ratio of radii between the center of the hub and clamps attaching any strand to next adjacent flexible line; θ, the angular distance between corresponding points of inner and outer strands of spiral arm; and R, which will denote the length of a flexible line on the frame. It should also be noted that the constant k may be replaced by an expression ψ defining the angle formed by the bisector of the angle between next adjacent flexible lines 15 with any strand fastened therebetwixt; since all strand segments extending between next adjacent lines are attached at radial distances in the ratio k, the angle ψ holds for the junction of the bisector with each segment it intersects and this relationship holds for the bisector of all next adjacent pairs of flexible lines. It is thus seen that the only necessary dimensional consideration is the radius of the frame. From the constant angle ψ made by discretely and regularly spaced successive lengths it is further seen that the described configuration approximates an equiangular spiral wherein a radius vector forms a constant angle with tangents to the curve.

In theory, if the configuration of an infinitely long antenna could be entirely defined by angular relationship the propagation characteristics of the radiating body would operate independently of frequency. Further, if all dimensions of an antenna were to expand in linear proportion to wave length, the impedance of the antenna would remain constant for all frequencies. A dipole having infinitely long planar arms with edges defined as logarithmic spirals would meet these specifications. It follows that such a dipole with arms of finite length could be made to operate advantageously over a finite band of frequencies. It has been seen that the described antenna approximates a logarithmic spiral and that only dimensional parameter is R, the radius of its supporting frame. As a practical matter, the arm thickness, the diameter of the hub and structurally permissible spacing between forward and rear frames impose an additional dimensional limitation so that the present invention may be said to approximate the theoretically specified radiator between fixed upper and lower frequency limits. Assuming that the antenna may be fed efficiently, the theoretical performance of radiating arms or their complementary slots in a conducting plane, are identical.

Admittedly, the described construction is not a true spiral but only a segmented approximation thereof. The nature of its deviation from a true expanding equiangular curve is, however, an important feature of the present invention. Expressed in polar coordinates, the length of the radius vector ρ of a logarithmic spiral of several turns is ρ = aekρ where a and k are positive constants; ρ at each complete turn is thus equal to a constant multiplier aekρ at each succeeding turn. Similarly, it can be shown that the length of the spiral for each turn is equal to the same common multiplier times the length of the spiral in a preceding turn. In like manner, the length of any segment of any strand extending between next adjacent flexible lines is proportional to its distance from the center of the hub 16 and the length of a segment at the center of the hub equals a constant multiplier times the length of a segment of the same strand at a preceding turn. It can then be stated that the distance of any (all) clamps 22 from a true spiral connecting points of intersection of the bisectors B with the various strand segments is constant with respect to the length of their adjacent strand segments. Since frequency is a function of arm length it can be seen that functional deviations resulting from the departure from a true spiral are evenly distributed and substantially uniform over the band of frequencies covered by the antenna. FIGURE 6 shows the plotted result of actual measurement of the voltage standing wave ratios for a frequency range of 6-30 mc./sec. in a full scale test antenna conforming to the present disclosure and mounted with a forward frame measuring 70 feet in diameter.

A favorable radiation characteristic of the invention is elliptical polarization which varies with frequency in orientation of its major axis but which tends toward small eccentricity within the frequency limits of the antenna. Near circular polarization is particularly advantageous for reception in the short wave band because ionospheric reflection has a tendency to distort and rotate plane polarized transmissions into elliptical components. It has long been thought that a major factor in the fading noted in short wave transmissions is due to polarization shifts caused by natural changes in the F layers of the ionosphere; typical reception data illustrated in FIGURE 5 wherein performance of the antenna described herein is compared with an optimized rhombic would seem to bear out this supposition as well as demonstrate the value of the polarization characteristics of the invention. From this figure it will be noted that the fade periods are of relatively short duration for the invention and that the fade periods of the two antennas do not coincide. It is believed that the occasional sharp dips in signal strength of the elliptically polarized antenna are due to polarization components with a direction opposite to the hand of lay of the antenna. The coaxial cable constructed as one of the strands 32 serves as a feed system for the antenna, and acts as an infinite balun in that it follows a neutral course with respect to radiation of the inner and outer strands. To those skilled in the art it will be readily apparent that other feed systems such as a balanced line extending from the reflector side of the antenna may also be employed.

As the angle ψ made by the bisector B of the angle between two flexible lines 15 with a strand segment 19 is made to approach π/2 in radian measure the essential differences between approximations of equiangular, Archimedean and other spiral forms tend to become negligible for strands of finite length. It is thus seen that design and economic considerations for a particular antenna could result in the approximation of any of a variety of curves or in a compromise between two or more approximated spiral forms.

The invention is not limited to the exemplary construction herein shown and described, but may be made in various ways within the scope of the appended claims. What is claimed is:

1. A combination with a plurality of coplanar and regularly spaced electrically insulating radial supporting members, an antenna for operation within the 2-30 mc. range comprising: a first flexible strand connected adjacent one end thereof to one of said radial supporting members forming a first connection and extending directly outward and angularly therefrom to successive points of connection on successively next adjacent supporting members such that r_{n}=r_{n+1}; k where r is the distance from the point of origin of said radial members to a respective point of connection and n is an integer representing the number of connections to said radial members from said first point of connection to said respective point of connection; and k is a proportionality constant having a value between 0 and 1.

2. The invention as defined in claim 1 and including a second strand connected to said radial supporting members at points equidistant with but 180° apart from said connecting points of said first strand.
3. In combination with a plurality of radial supporting members, an antenna for operation within the 2-30 mc. range comprising: a first plurality of strands each connected adjacent one end thereof to a respective one of said radial supporting members forming a respective first connection and extending between and connected to successively next adjacent radial supporting members at points thereon such that \( r_n = r_{n+1}, \) where \( r \) is the distance from the point of origin of said radial members to corresponding points at equal radial distances on said respective strands and \( n \) is the number of connections of each respective strand with said radial members between said respective corresponding points and said respective first connection, and \( k \) is a constant having a value between zero and one, adjacent ones of said corresponding points being spaced from one another by a constant angular distance \( \theta; \) means electrically connecting said first plurality of strands to one another at their end portions closest to said point of origin of said radial supporting members; a second plurality of strands each extending between and connected to successively next adjacent radial supporting members at points thereon equidistant with but 180° apart from points of connection of a corresponding member of said first plurality of strands; and means electrically connecting said second plurality of strands to one another at their end portions closest to said point of origin of said radial supporting members.

4. The invention as defined in claim 3 and wherein said means electrically connecting said respective pluralities of strands include wire mesh members supported by said radial supporting members and respectively extending to electrical contact with the end portions of the strands of said respective first and second pluralities of strands.

5. The invention as defined in claim 3 and including an electrically conducting peripheral frame connected to outer ends of said radial supporting members, and means electrically connecting the outer end portion of each said strand to said peripheral frame.

6. In an antenna including a peripheral frame, elongate flexible supports of non-conductor material extending in tension radially in regular angular spacing from one another across the area of said peripheral frame, a first flexible strand connected adjacent one end thereof to one of said elongate flexible supports forming a first connection and extending directly outward and angularly therefrom to successive points of connection on successively next adjacent elongate flexible supports in successive orientations such that \( r_n = r_{n+1}, k, \) where \( r \) is the distance from the point of origin of said support to a respective point of connection and \( k \) is a proportionality constant having a value between 0 and 1.

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