

[54] MODULATED ARM WIDTH SPIRAL ANTENNA

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[52] U.S. Cl. ....343/895

[51] Int. Cl. ....H01q 1/36

[58] Field of Search.....343/802, 895

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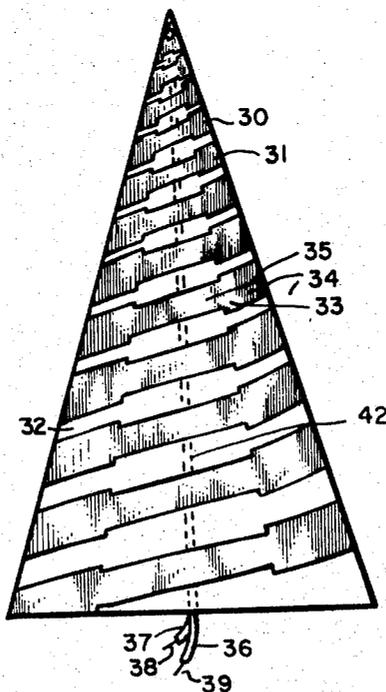
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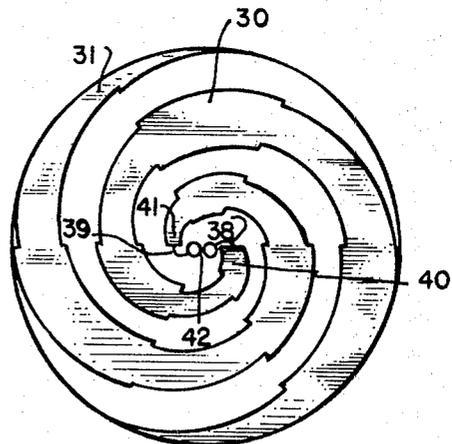
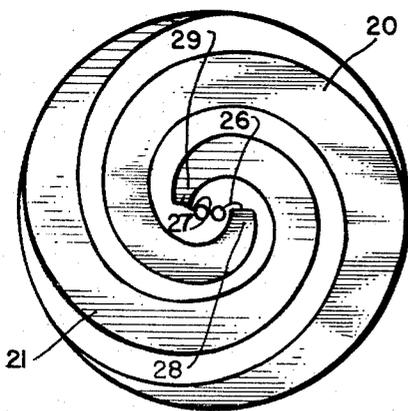
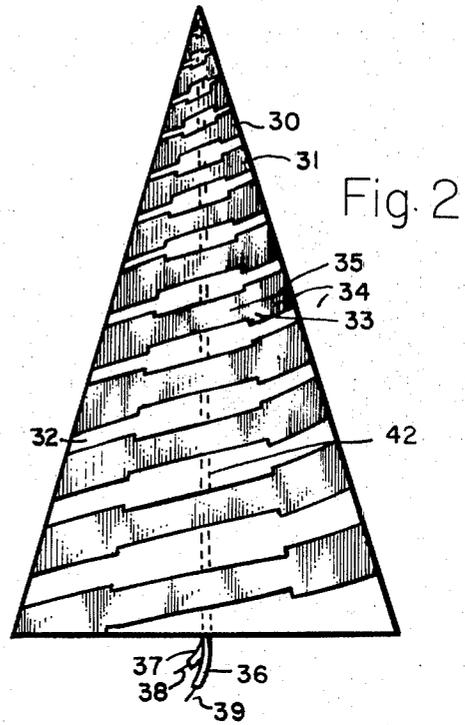
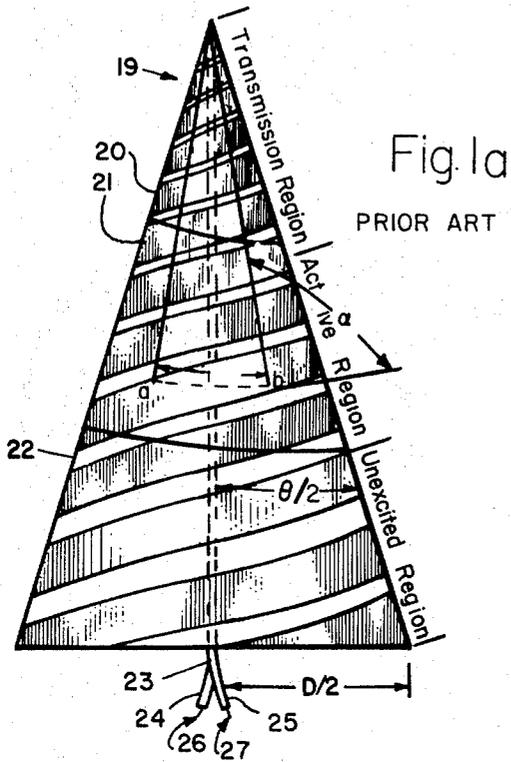
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[57] ABSTRACT

A multi-arm spiral antenna which allows unlimited broadband operation with dual senses of circular polarization. The antenna comprises spiral arms having width variations which are log-periodically scaled to produce local reflection (stopband) regions along the arms. The position of the stop-band regions is a function of the period and amplitude of width variations. Arm currents are produced by excitation of the antenna. These currents are reflected by the stopband regions. The relative phase of the reflected currents is a function of the relative scaling of the arms.

11 Claims, 10 Drawing Figures





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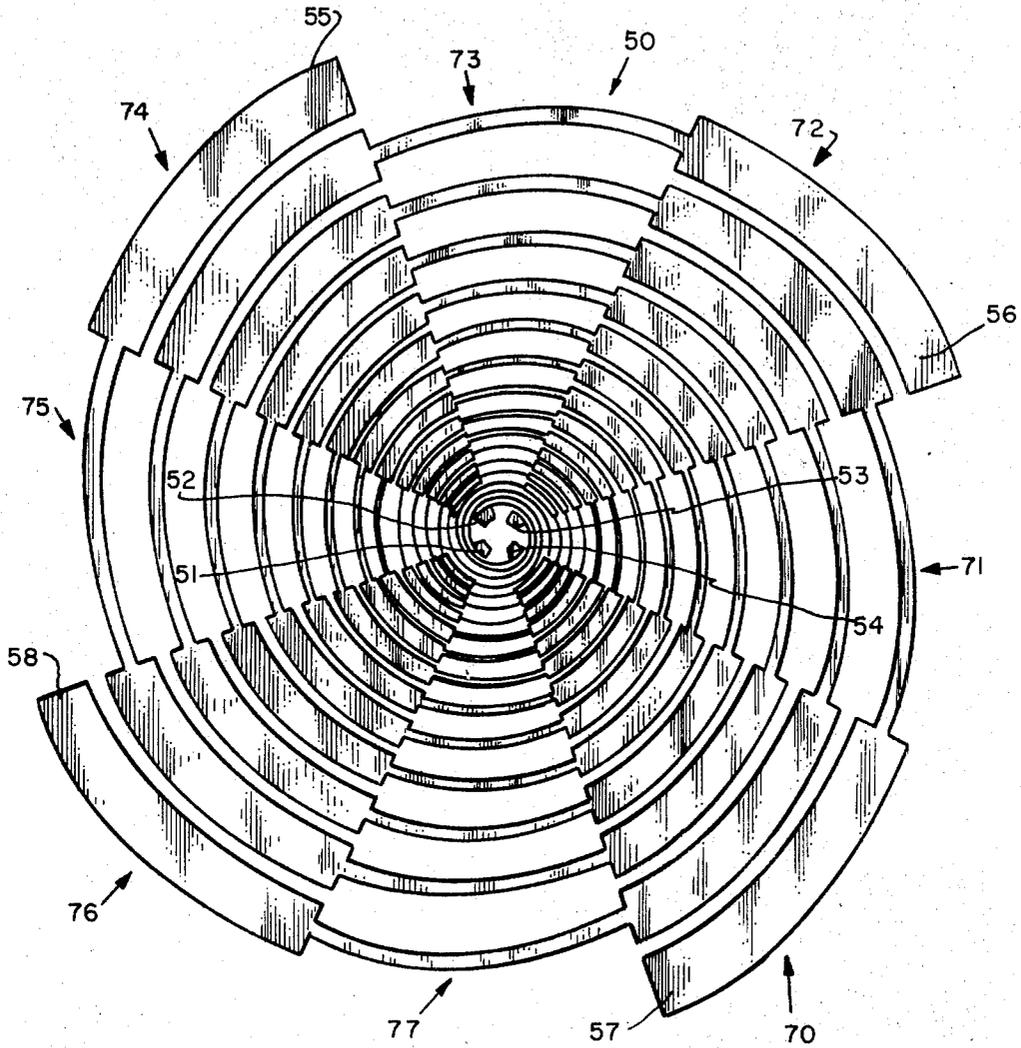


Fig. 4

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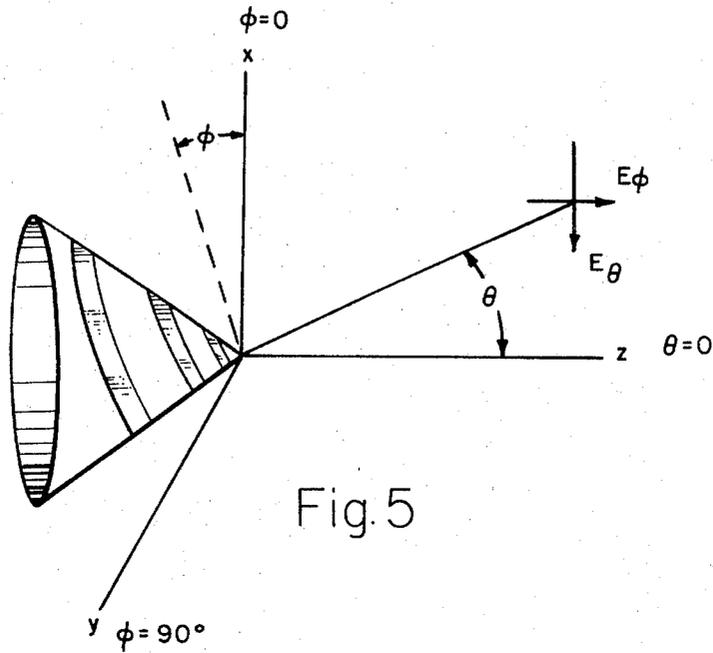


Fig. 5

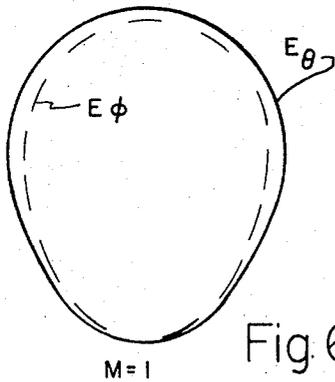


Fig. 6a

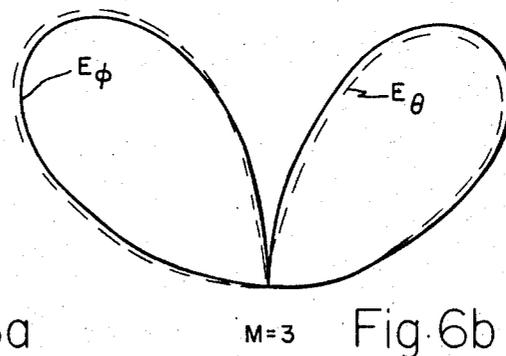


Fig. 6b

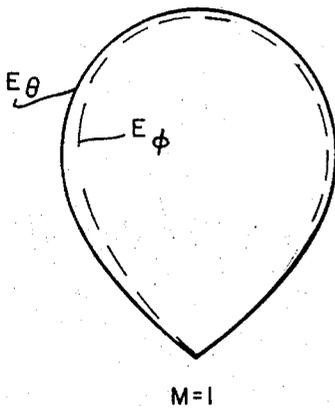


Fig. 7a

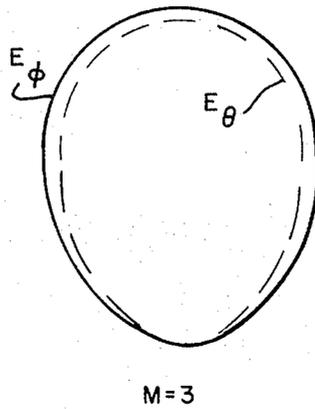


Fig. 7b

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## MODULATED ARM WIDTH SPIRAL ANTENNA

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

This invention relates to spiral antennas and specifically to multi-arm spiral antenna having both left-hand and right-hand circular polarization simultaneously produced over wide bandwidths.

## 2. Description of the Prior Art

The customary method of feeding broadband spiral antennas at the center terminals yields a radiation field which is elliptically polarized. If the parameters of the antenna are chosen properly, the radiation polarization can be made almost circular.

The sense of circular polarization (CP) is said to be right-handed circular polarization (RHCP) if the electric field vector rotates in the direction of the fingers of the right hand when the thumb points in the direction of propagation. Correspondingly, left-handed circular polarization (LHCP) is defined by an electric field vector rotating in the direction of the fingers of the left hand when the thumb points in the direction of propagation.

Spiral antennas are said to have a sense of wrap. The spiral sense of wrap is, in accordance with general practice, determined by the hand used when pointing the fingers in the direction of the arm current and the thumb in the direction of propagation of the radiated fields. Broadband operation of a spiral antenna yields the sense of polarization of the radiated field determined by the sense of wrap of the spiral.

Many applications of extremely broadband antennas require the ability to receive both RHCP and LHCP signals simultaneously over the entire bandwidth in a single antenna. One example where such a single antenna would be required is for the feed of a parabolic reflector. If the system is to be capable of receiving or transmitting both RHCP and LHCP, as well as any linear polarized signal without a loss in gain due to polarization, then the single feed of the parabolic reflector must be capable of RHCP and LHCP operation. Presently, such receiving or transmitting capability, has not been possible with the whole class of frequency independent spiral antennas. Some narrow band techniques are used whereby spiral antennas can be fed from the outside of the spiral in addition to feeding from the center. Since the direction of the current relative to the direction of propagation when fed from the outside is opposite to the direction of current, for the same direction of propagation when fed from the center, both senses of circular polarization can be obtained from a single spiral. This dual sense of polarization operation is bandwidth limited. If the ratio of the upper to lower frequencies of operation is used as a measure of bandwidth, this ratio will be less than 2 to 1 for the method of obtaining dual senses of CP from a single spiral antenna, where the antenna is fed from both the outside and center.

The present invention provides a new design of spiral antenna requiring only a center feed and which is capable of simultaneous dual circular polarization operation over any chosen bandwidth limited only by practical construction considerations in the feed region.

## BRIEF SUMMARY OF INVENTION

This invention relates to a multi-arm spiral antenna which is fed at the center of the spiral. Each of the spiral arms of the antenna have a cascade of cells, with each cell having a wide and narrow section along the lengths of the arms. The lengths of the sections increase for increasing distance from the center.

## BRIEF DESCRIPTION OF DRAWINGS

FIG. 1a shows an elevation view of a conventional 2 arm equiangular spiral;

FIG. 1b shows an enlarged plan view of the top portion of the conventional 2 arm equiangular spiral;

FIG. 2 shows an elevation view of a 2 arm equiangular modulated arm-width spiral embodying the invention;

FIG. 3 is an enlarged plan view of the top portion of the 2 arm spiral width self-complementary modulated arm width as shown in FIG. 2;

FIG. 4 is a plan view of a 4 arm equiangular modulated arm width spiral;

FIG. 5 illustrates the coordinate system;

FIG. 6a and 6b show typical radiation patterns of the electric field for two modes ( $M_1$  and  $M_3$ ) of feeding a four arm spiral using conventional antennas;

FIGS. 7a and 7b show the radiation patterns in the same modes of feeding ( $M_1$  and  $M_3$ ) as represented in FIG. 6 using the antenna of this invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1a and 1b show a conventional two arm conical spiral antenna 19 comprising two spiral arms 20 and 21 which are wound on the surface of an electrically nonconductive cone 22. A balanced feed line 23 is located at the cone axis of symmetry. The balanced feed line 23 comprises two coaxial transmission lines, 24 and 25. The outer shields of the coaxial lines 24 and 25 are electrically connected together in FIG. 1b, along their lengths. The center conductors 26 and 27 of the lines 24 and 25 are electrically connected to the feed terminals 28 and 29, respectively, as shown in FIG. 1b.

The parameters which define the equiangular conical spiral are also shown on FIG. 1a. These are: (1)  $\theta/2$ , the half-angle of the cone (2)  $\alpha$ , the angle of spiral wrap, which is the angle between a tangent to the edge of an arm and a line joining the tangent point and apex of the cone, and (3)  $\delta$ , the angular width of the spiral arms, found by the angular rotation needed to rotate the spiral defined by one edge a of the arm into congruence with the opposite edge b.

The customary method of feeding a broadband two-arm spiral at the center terminals yields two modes of operation whose sense of polarization depends on the sense of wrap of the spiral. In accordance with general practice, the polarization sense of the spiral antenna is determined from the hand used when pointing the fingers in the direction of the spiral arms current and the thumb in the direction of propagation of the radiated fields. Since the currents are assumed to travel away from the input terminal, right-hand circular polarization (RHCP) corresponds to progressive phase delay of the arm currents in the increasing  $\phi$  direction; left-hand circular polarization (LHCP) to progressive phase ad-

vance of the arm currents in the decreasing  $\phi$  direction; where  $\phi$  is the conventional polar coordinate and increases in the counter clockwise direction as shown in FIG. 5.

The push-pull mode, referred to herein as Mode 1, is obtained when the two spiral arms are fed  $180^\circ$  out of phase. The radiation patterns of Mode 1 are single beam patterns, which in the case of conical spirals are unidirectional and directed along the axis in the direction of the apex of the cone.

The push-push mode, referred to herein as Mode 2, is obtained when the arms are fed in phase, with a center post formed by the outer shields of the two feed lines, fed  $180^\circ$  out of phase.

The radiation pattern of Mode 2 is a toroid about the axis of the cone. The characteristic of this mode is a null in the radiation pattern along the axis of the spiral.

For analysis, the antenna is divided into three regions, "the transmission region," the "active region" and the "unexcited region." In the transmission region the arm currents travel along each arm with essentially free-space phase velocity and negligible radiation. The active region corresponds approximately to the region where the phase difference in the currents in the arm allows substantial radiation. If the active region is sufficiently wide to allow substantially total radiation of energy carried by the arm currents, the portion of the arms following the active region are essentially unexcited and hence constitute the unexcited region in a properly operating frequency independent antenna.

In Mode 1 ( $M_1$ ) the active region is approximately located at a diameter of the cone ( $D$ ) of  $\gamma/\pi$  (where  $\gamma$  is the wavelength at the given frequency) so that the currents in the arms are phased approximately an extra  $180^\circ$  each half turn and, hence, are in phase.

In Mode 2 ( $M_2$ ), the active region does not occur until  $D = 2\gamma/\pi$ . Hence, when the spiral's diameter is smaller than  $2\gamma/\pi$ , the incident energy into Mode 2 is not efficiently radiated.

FIG. 2 shows an embodiment of the invention which is a multi-arm conical spiral antenna having two arms. The arms 30 and 31 are wound on an electrically non-conductive cone 32. The arms, however, have periodic variations in the conductor arm width, called modulation. The arms of the antenna with such periodic variations can be thought of as being constructed from a cascade of cells, with a cell, for example 33, having a wide section, 34, and narrow section 35. Amplitude is defined as the ratio of the width of the wide section 34 to the width of the narrow section 35. The period is defined as the ratio of the lengths of adjacent cells. The lengths of the sections increase for increasing distance from the feed terminals 40 and 41 at the apex of the cone shown in FIG. 3. The antenna is fed by two coaxial lines 36 and 37, located on the axis of symmetry, whose outer shields are electrically shorted together along their lengths, as shown in FIG. 3. The center conductors 38 and 39 of the two lines 36 and 37, are connected at the top of the cone to the arms 30 and 31 at the terminals 40 and 41, respectively. When the arms 30 and 31 are fed  $180^\circ$  out of phase (Mode 1), the currents along the center post cancel each other. The Mode 1 method of feeding yields single beam patterns, which are essentially unidirectional and directed along the axis in the direction of the apex of the cone, as with

the conventional unmodulated arm width spiral, as illustrated in FIG. 1. In Mode 2 the arms are fed in phase with the center post 42 formed by the outer shields of the coaxial lines 36 and 37 fed  $180^\circ$  out of phase.

The energy in Mode 2 ( $M_2$ ) generally will not radiate efficiently until the circumference of the spiral is approximately 2 wavelengths. By making the variations in the arm width sufficiently large, it is possible to form reflection regions along the arms such that essentially all the incident energy along the arms is reflected by the arm impedance mismatch caused by these variations.

The maximum reflection along the arms is found to occur in that region where the length of the cells becomes approximately  $\frac{1}{2}\gamma$ . Further, the reflection from cells which are shorter than  $\frac{1}{2}\gamma$  is small. Hence, the reflection of the incident energy along the arms is confined to a region of the arms where the cells are approximately  $\frac{1}{2}\gamma$  long. This region is called a stopband region. By choosing the proper parameters of amplitude of the variations and the period of the variations, the stopband region can be placed at any desired diameter.

In the two-arm spiral case the stopband would be placed between the active regions of the  $M_1$  and  $M_2$  modes. Hence, the normal  $M_1$  mode would be unaffected if the  $M_1$  active region is efficient. The placing of the stopband ahead of the active region for the  $M_2$  mode assures that the structure when fed from the center in the  $M_2$  mode will not radiate efficiently, since the energy is reflected before reaching the required active region for substantial radiation.

If, further, the modulation of the arms is complementary, in the sense that the regions of modulation are opposite in the two arms at corresponding points, then the reflected energy will be  $180^\circ$  out of phase between the two arms. This is then the condition for substantial radiation of the reflected energy in the opposite sense of polarization to Mode 1 as discussed. If the spiral is an equiangular (logarithmic spiral), then log-periodically scaling the lengths of the cells, allows this region to move along the structure retaining its relative position between the active regions of the  $M_1$  and  $M_2$  modes. The self complementary geometry makes the relative phase of the reflected arm currents  $180^\circ$  out of phase, independent of frequencies. Hence, the antenna will now have broadband operation with both senses of circular polarization in a simple single beam, the  $M_1$  mode giving one sense of CP and the  $M_2$  mode the opposite.

In the general case of an  $N$  arm antenna, the phase change between successive arms would be

$$M \ 360^\circ/N$$

where  $M = 1 \dots N$ .

In general, only those choices which suppress radiation from the center feed post are used. Hence,  $M = N$  is in general not used since the arms would be fed against the feed post for this mode.

For a multi-arm spiral we can identify the modes by the excitation of the arms, and hence for  $M = 1, 2, 3$  we will refer to these as  $M_1, M_2,$  and  $M_3$  modes of excitation, respectively.

The principles may be applied to a multi-arm spiral having 4 spiral arms as follows. Assume the four arm spiral is initially a LH wound spiral as shown in FIG. 4. The normal feed for LHCP sum pattern (Mode 1) is

$$A_1 = (0, -90, 180, +90)$$

where

$A_m$  32 ( $I_{51}, I_{52}, I_{53}, I_{54}$ ) is the current vector notation for the phase of the excitation at the four input terminals 51, 52, 53, 54.

For the  $M=1$  Mode ( $M_1$ ), the four arm spiral gives a typical pattern shown in FIG. 6A. For the  $M=1$  mode ( $M_1$ ) of the four arm spiral, the active region still occurs at a diameter ( $D$ ) of about 1 wavelength. The  $M=3$  Mode ( $M_3$ ) has the excitation:

$$A_3 = (0, +90, +180, -90)$$

The active region for this mode will occur approximately at a diameter of 3 wavelengths. When the antenna is large enough ( $D > 3\gamma$ ) to support substantial radiation from this mode, the antenna gives a typical pattern shown in FIG. 6B.

If, however, the structure is not large enough to support substantial radiation of the  $M_3$  mode, simple reflection of the current at the ends of the structure 55, 56, 57, 58 produce a return excitation which efficiently radiates like the  $M_1$  mode, i.e. a smooth lobe pattern, but with the opposite sense of polarization.

Hence, introducing a modulation in the arms to effect a stopband region with the proper relative phasing between the arms after the  $M=1$  active region (i.e. at a diameter larger than  $1\gamma$ ), but before the normal  $M=3$  active region, is sufficient to give the required dual-polarization operation. With the relative phase of the reflected arm currents the same (all the reflection coefficients the same) it is possible to obtain the opposite polarization for the  $M_1$  mode; since, however, the excitation vector,  $A_1 = (0, 0, 0, 0)$  or  $(180, 180, 180, 180)$  is not useful if the modulation is scaled the same in each arm so that the arms are identical, a six arm spiral must be used to obtain multi-mode operation with dual polarization.

While the theory of log-periodically modulating the arm width of spiral antennas to effect stopband regions does not depend upon the proximity of the modulated sections between each arm, the actual construction for planar and conical spirals appears to be optimized by using a self-complementary arrangement i.e., a structure in which the metal area is identical in size and shape to the open area. This leads to dividing each turn of the spiral into  $2N$  equiangular segments. In the alternate sections the arm widths are made wide or narrow. A cell is, as defined before, composed of two sections of line—one section of wider width and one narrower. Since the maximum reflection along each arm occurs when the total length of a cell is approximately  $\frac{1}{2}\gamma$  long, the number of cells in circumference of the spiral in the region of maximum reflection will be  $N = 1, 2, 3$ , etc. By selecting  $N$  to be an integer, all the wide or narrow segments will lie in pie shaped wedges, shown as 70 - 77 in FIG. 4, allowing the most interaction of the wide portions of each arm, since they are then closest to each adjacent arm's wide segments over the longest distance. Correspondingly, the narrow portions have the least interaction over the longest distance. This then should allow the smallest modulation for a given size stopband region since the size of the stopband region in the periodically modulated transmission line structure appears to be maximized

when the change between the two impedance levels is a step function.

Thus, for the two arm spiral where the modulation of the arms themselves is to be opposite to give the reflected energy a relative  $180^\circ$  phase shift, the number of cells in circumference must be odd. This guarantees that the two arms will be physically complementary to each other. For a four arm spiral, using the  $M=1$  and  $M=3$  modes to obtain dual polarization, the arms will all be the same and, hence, an even number of cells will be used.

Since the location of the maximum reflection region occurs when the cell length is approximately  $\frac{1}{2}\gamma$  and the size of the stopband region is controlled by the amplitude of the modulation, it is apparent that the location and size of the stopband region can be selected by parameter choice.

The value of  $N$  is to be chosen so that the reflection region occurs between the active region of the selected modes on unmodulated armwidth spirals. Hence, in the two arm case,  $N=3$  seems appropriate while in the four arm case  $N=4$  for the  $M=1$  and 3 modes. This physical arrangement was used in FIGS. 2, 3 and 4 it is believed to be the optimum. The ratio of the angular width of the wide section of a cell to a narrow section is defined as the modulation ratio. It has been found that ratios of four are sufficient to form the necessary stopband regions when the other parameters of the spiral, i.e.  $\theta$  and  $\alpha$ , are selected to give good performance of the regular unmodulated spiral.

We claim:

1. A multi-arm spiral antenna capable of radiating circularly polarized electromagnetic energy with opposite senses of polarization, said antenna comprising:
  - a. at least two spiral arms, each arm consisting of a plurality of interconnected cells, each cell consisting of a wide and a narrow section along the length of its arm, the transition between adjacent wide and narrow sections being relatively abrupt, whereby to reflect electromagnetic energy, the sections of each cell increasing in length as the distance from the center increases, and
  - b. means for feeding said arms at the center of the spiral with electromagnetic energy.
2. The antenna of claim 1 wherein: the ratio of the lengths of adjacent arm-cells is constant.
3. The antenna of claim 2 wherein: the ratio of the widths of the wide section of adjacent arm-cells is constant.
4. The antenna of claim 3 wherein: the ratios of the widths of the wide sections of adjacent cells and the cell lengths of adjacent cells are equal.
5. The antenna of claim 3 wherein: the ratio of the width of the narrow section of adjacent arm cells is constant.
6. The antenna of claim 4 wherein: the ratios of the narrow sections of each cell are equal to the ratios of the cell lengths.
7. The antenna of claim 1 wherein: the said spiral is an equiangular spiral.
8. The antenna of claim 7 wherein: the number of said arms is four.
9. The antenna of claim 8 wherein: the arms are identical in size and shape.

10. An antenna as defined in claim 1 wherein the spacing between adjacent ones of said arms is nonuniform, thereby to provide a change of impedance in a direction along said arms.

11. An antenna as defined in claim 1 wherein said 5 arms are disposed on the surface of a cone.

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