United States Patent

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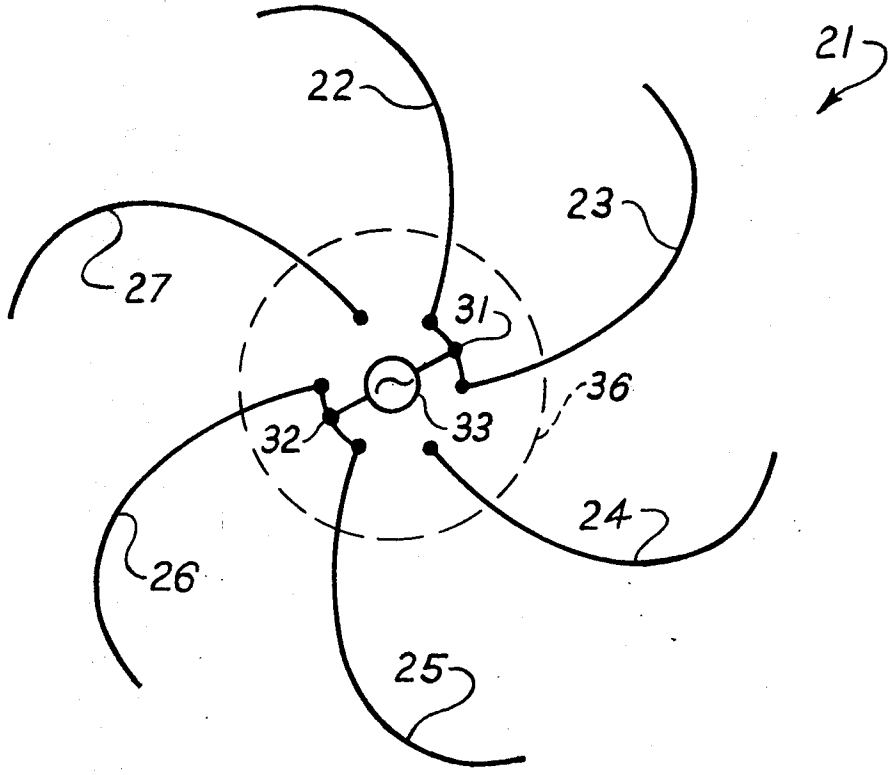
[54] **BROADBAND SPIRAL ANTENNA WITH PROVISION FOR MODE SUPPRESSION**
8 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **343/895,** 343/739
[51] **Int. Cl.** **H01q 1/36**
[50] **Field of Search** 343/895, 739

[56] **References Cited**
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ABSTRACT: A six-arm spiral antenna backed by a reflective surface is energized to activate four arms with the other two arms being parasitic and Mode 5 radiation is suppressed to achieve broadband operation.



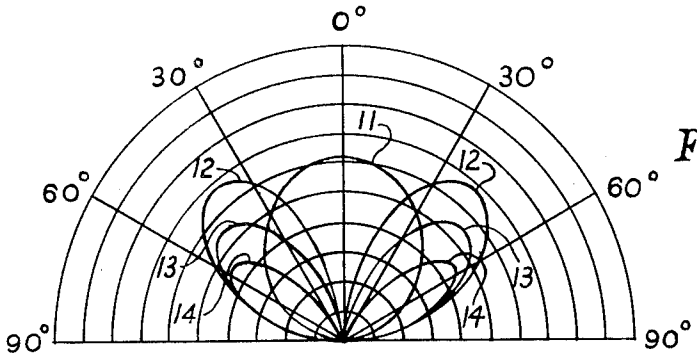


FIG. 1

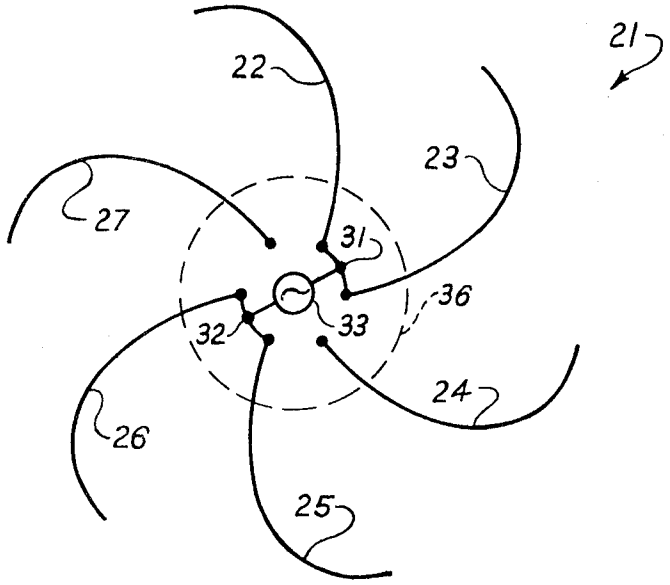


FIG. 2

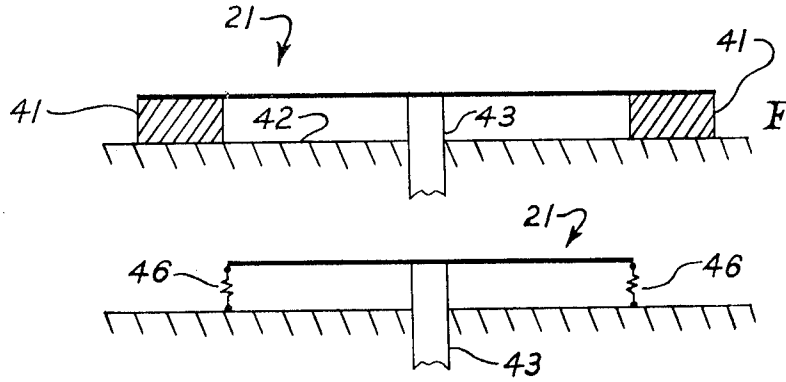


FIG. 3

FIG. 4

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BROADBAND SPIRAL ANTENNA WITH PROVISION FOR MODE SUPPRESSION

BACKGROUND OF INVENTION

There have been developed a class of antennas which are oftentimes termed "frequency-independent antennas" inasmuch as they are relatively insensitive to frequency variations above some minimum frequency. Such structures were originally proposed by V. H. Rumsey and reference in this respect is made to page 33 of the publication "The Encyclopedia of Electronics," copyright 1962 by Reinhold Publishing Corporation. Although these types of antennas are considered to be relatively independent of variations in energization frequency, it is realized that electrically conducting bodies disposed in proximity thereto materially varies their characteristics. In particular, problems oftentimes arise in the physical mounting of frequency-independent antennas.

One type of frequency-independent antenna is the spiral antenna, as it is commonly termed. Generally the curvature of the arms of a spiral antenna may be properly delineated as an Archimedean spiral or as a logarithmic spiral; however, in the following discussion the term "spiral" is taken to denominate an antenna having curved arms of these general types.

In the utilization of spiral antennas many applications require the mounting of same relatively close to a ground plane or in front of a shallow cavity and this then creates a frequency dependency which is generally considered to be highly undesirable. One such situation in which this type of mounting occurs is the provision of antennas upon aircraft structures.

There has been carried out a variety of investigations of frequency-independent antennas including spiral antennas of a variety of different configurations. For a discussion of at least one such series of investigations, reference is made to an article by R. Sivan-Sussman entitled "Various Modes of the Equiangular Spiral Antenna" and appearing in IEEE Transactions on Antennas and Propagation, pages 533 to 539, Sept. 1963. Experimental data on a substantial number of different equiangular spiral antenna configurations and modes of energization is set forth in the foregoing article. Such article does not, however, attempt to propose practical solutions to the problems identified above. Insofar as practical operating antennas of this general type are concerned, there have been issued a number of U.S. Pats. such as, for example, U.S. Pat. Nos. 2,990,548 and 3,131,394 to Wheeler, as well as others. Conventional prior art spiral antennas do, however, still suffer from the difficulty of frequency dependency when the spiral is operated at a close distance from the ground plane and beam pattern variations with frequency occur.

SUMMARY OF INVENTION

The antenna of the present invention is comprised as a six-arm spiral comprising a unidirectional radiator backed by a cavity or ground plane that may be in close proximity to the antenna arms. The antenna produces a highly desirable radiation pattern which is stable over a substantial bandwidth or frequency variation.

The six-arm spiral antenna hereof has the first and second arms thereof electrically connected together and energization applied between such connection and a connection between the fourth and fifth arms. The third and sixth arms of the antenna are parasitically excited to thereby produce only Mode 1 and Mode 5 radiation. The invention furthermore provides for suppression of Mode 5 radiations either by the utilization of an absorber or resistive terminations at a predetermined antenna radius. This then substantially eliminates the variation in radiation pattern with frequency change caused by the otherwise present Mode 5 radiation. Other radiation modes are not present so that substantially only Mode 1 radiation occurs.

DESCRIPTION OF FIGURES

The present invention is illustrated as to particular preferred embodiments thereof in the accompanying drawings wherein:

FIG. 1 illustrates the patterns of radiation of various harmonics for a spiral antenna;

FIG. 2 is a schematic illustration in plan view of an antenna in accordance with the present invention;

FIG. 3 is a central sectional view of one embodiment of the present invention, such as illustrated in FIG. 2; and

FIG. 4 is a schematic illustration of an alternative embodiment of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention comprises a six-arm spiral antenna having a pair of opposed arms of the antenna parasitically excited and being backed by a reflecting surface. Investigations of spiral antennas which, as noted above, are one form of what is generally termed "frequency-independent antennas," has shown that the radiation pattern thereof is formed of patterns resulting from the various independent excitation voltages or currents whose phases are harmonically related. In this respect, reference is made to FIG. 1 of the drawings of this application wherein there is shown a plot of radiation patterns as presented in the publication "Frequency-Independent Antennas" by Victor H. Rumsey, Academic Press, 1966, page 122. To those knowledgeable in the art, it is recognized that the first harmonic produces a single-lobe radiation pattern which is highly advantageous for many applications. The radiation pattern resulting from a mixture of the various harmonics may be of theoretical interest but, in general, are detrimental to the desired result from a frequency stability point of view. Extensive investigation has been made of this general type of antenna, as noted above. However, to date, there appears to have been developed no antenna of this general categorization producing a stable radiation pattern over an appreciable bandwidth with a simple feeding arrangement, for example, a bandwidth of 4:1 or greater.

Particularly under those circumstances wherein a conventional two-arm spiral antenna is operated over a ground plane at a small electrical distance therefrom, the beamwidth of the radiation pattern has been found to fluctuate rapidly with frequency for frequency bandwidths in excess of 2:1. Investigation of this phenomenon has indicated that the range of half-power beamwidth fluctuation is typically in the area of 35° to 110°.It will be appreciated that such fluctuations are intolerable for many applications.

Careful consideration of the reasons for the above-noted radiation pattern fluctuations indicates that same are caused by simultaneous presence of more than one mode of radiation and, in general, it is the presence of Modes 1 and 3 which pose the problems. It may be postulated and has, in fact, been established that the Mode 3 radiation is present because of insufficient radiations from the Mode 1 region of the antenna so that the remainder of the energy to be radiated by the antenna occurs in the Mode 3 region.

Referring to FIG. 1 of the drawing, there is shown a single lobe of radiation **11** resulting from the primary or first harmonic and double-lobes **12** and **13** and **14** which are the result of second, third and fifth harmonics, respectively. For many applications the presence of more than one mode of radiation is highly undesirable as, for example, the presence of Modes 2, 3 or 5 are the cause of beamwidth fluctuations with frequency variations. The present invention provides for the suppression of these higher modes of radiation.

Referring now to FIG. 2 of the drawing, it will be seen to be schematically illustrated an equiangular spiral antenna **21** having six spiral arms **22** to **27** extending outwardly from a central excitation area in numbered order and equal spacing about such area. The arms of the antenna in themselves may be conventional and may, for example, be formed by copper plating on very thin Teflon-impregnated Fiberglas having a copper thickness, for example, of the order of 0.002 inch.

The present invention provides for particular energization of the antenna hereof and, referring to FIG. 2, it will be seen that arms **22** and **23** are electrically connected together as by a connection **31** and that arms **25** and **26** are electrically con-

nected together as by a connection **32**. Energization of the antenna is then accomplished by application of high-frequency energy between the connections **31** and **32**, as schematically illustrated by the generator **33**. It will be seen that this then leaves intermediate spiral antenna arms **24** and **27** electrically unconnected and these are thus parasitically excited by current flowing in the other arms of the antenna. It will be realized that parasitic excitation of antenna elements is well known in the art.

It can be established that with the antenna configuration of FIG. **2** and the type of energization employed therein, there will be radiated from the antenna electromagnetic energy from Modes 1 and 5 with no radiation occurring from Modes 2, 3 or 4. The foregoing can be established theoretically by a consideration of current vectors and a determination therefrom that Mode 2, Mode 3 and Mode 4 currents are multiplied by vanishing coefficients with only Mode 1 and Mode 5 excitation currents being multiplied by finite coefficients. While this is advantageous over conventional spiral antennas, the present invention proceeds further to suppress Mode 5 radiation, as described below, to then consequently attain substantially pure Mode 1 radiation to achieve operation over a frequency band of approximately 4:1.

Mode 5 radiation is herein suppressed by the utilization of absorbers or resistors particularly located with respect to the spiral arms. It can be established that Mode 1 radiation occurs substantially within a central area of the antenna of FIG. **2**, as generally indicated by the dotted line **36** therein. This area has a circumference of λ which is the wavelength of the highest operating frequency of the antenna and thus the radius of the circular area is $\lambda/2\pi$. Mode 5 radiation will begin to occur radially outward from a circular area having a circumference of approximately 4λ with full development of this mode at a circumference of 5λ. The present invention thus proceeds, for example, as illustrated in FIG. **3** to provide an absorber of high-frequency radiation **41** in engagement with the antenna in the Mode 5 region thereof. As noted above, the Mode 5 region commences radially outward from a circular area having a circumference of approximately 4λ which then is equivalent to a radius of $2\lambda/\pi$ or about 0.6λ. Thus the radius of the inner circumference of the absorber **41** is approximately 0.6λ wherein again λ is the wavelength at the highest operating frequency of the antenna.

As a practical matter the radial extent of the absorber **41** may be as large as desired but, at any rate, it should extend radially outward sufficiently to encompass the entire Mode 5 region which extends outwardly to between 0.8λ and 0.9λ. The actual physical extent of the antenna arms **22** to **27** radially outward from the center of the antenna may be limited to the above-noted 0.6λ radius where resistive termination is provided as set forth below, or, alternatively, the arms may continue further out from the center. It is noted that the absorber **41** is formed of a material having a high loss tangent such as, for example, materials sold under the trademark "Eccosorb" such as "Eccosorb" LS 26, "Eccosorb" AN 72 through AN 79 and "Eccosorb" NZ. Referring further to FIG. **3**, it is noted that the antenna is mounted above a ground plane **42** which may, for example, be planar or, if desired, may be formed of a conical shape in accordance with antenna practices. Antenna energization is herein accomplished by a conventional balun **43** feeding the antenna from a microwave generator, in the instance of a transmitting antenna. It is to be appreciated that the antenna of the present invention may be operated at a variety of different frequencies but it is particularly useful in the VHF and UHF region. As an example, an antenna in accordance with the present invention designed to operate at a minimum frequency of 100 MHz. would have a diameter of the order of 3 to 4 feet and might have a ground plane spacing of only an inch to 1½ inches rather than the normal $\lambda/4$ because of space limitations, for example.

As noted above, the present invention proceeds to suppress Mode 5 radiation either by the utilization of an absorber or by resistive termination of the arms. Referring to FIG. **4** there will be seen to be schematically illustrated the six-arm antenna of the present invention having the arms physically terminated at a distance radially outward from the center of the antenna that is substantially the above-noted 0.6λ. At the outer end of each arm there is provided a resistor **46** connected between the end of the arm and the ground plane **42**. This then provides a return path for Mode 5 current so that same does not reflect from the ends of the spiral arms, and again this configuration of the present invention provides a substantially pure Mode 1 radiation. It will be appreciated that the embodiments of FIGS. **3** and **4** are electrical equivalents insofar as the objects of the present invention are concerned.

It has been noted above that, in order to preclude or suppress Mode 5 radiation, there shall be employed either an absorber or resistors located at an appropriate radius of the antenna. This radius has been calculated above as a minimum of 0.6λ but it is to be appreciated that this dimension may be somewhat increased to increase the antenna bandwidth at the low frequency end, for it is radially outward of such distance that Mode 5 intensive radiation occurs. Thus, for example, it is quite practical to place the resistors **46**, for example, at a radial distance outward from the center of 0.8λ. It is also to be particularly noted that the presence of the ground plane, even disposed immediately behind the antenna, is not deleterious to operation of the antenna in the manner described above. Prior art limitations of radiation pattern fluctuations for frequency bandwidths in excess of 2:1 are overcome by the present invention.

What is claimed is:

1. An improved spiral antenna comprising six equiangular arms equally spaced circumferentially apart about a center, first means electrically connecting together the inner ends of a pair of adjacent arms, second means connecting together the inner ends of the pair of arms opposite to the first connected pair of arms, means applying high-frequency energization between said first and second means to energize the antenna for producing electromagnetic radiation therefrom, and suppression means disposed substantially at a radius of 0.6 wavelength of antenna energization from the antenna center about the center adjacent each arm for suppressing electromagnetic radiation at a radius greater than 0.6 wavelength to thus suppress Mode 5 radiation from the antenna.

2. The antenna of claim **1** further defined by means defining an electrically conducting ground plane in close proximity to one side of said antenna adjacent each arm thereof whereby said antenna radiates away from said plane.

3. The antenna of claim **1** further defined by said suppression means comprising an annular absorber of a material absorbing electromagnetic radiation disposed against one side of the antenna and having an inner diameter in the range of 0.6 to 0.8 wavelength.

4. The antenna of claim **2** further defined by said suppression means comprising a plurality of resistors connected one between each antenna arm and said ground plane at a radius in the range of 0.6 to 0.8 wavelength and said arms terminating at such connections.

5. An improved unidirectional frequency-independent antenna comprising six equiangular spiral antenna arms disposed in substantially planar array and spaced equally apart about a center, means electrically connecting together a first pair of antenna arms adjacent said center and connecting together the pair of antenna arms opposite said first pair, means applying high-frequency electrical energization between said connections to directly energize said two pairs of arms and parasitically energize the two remaining unconnected antenna arms whereby said antenna is energized to radiate in Mode 1 and Mode 5 regions, means defining an electrically conducting ground plane in close proximity to one substantially planar side of the antenna, and radiation suppression means disposed between said antenna and ground plane radially outward of the Mode 1 radiation region of the antenna and suppressing Mode 5 radiation whereby substantially only Mode 1 radiation occurs.

6. The antenna of claim 5 further defined by said radiation suppression means being disposed radially outward of the antenna from the center thereof substantially 0.6 wavelength of the highest operating frequency of energization of the antenna.

7. The antenna of claim 6 further defined by said radiation suppression means comprising a material having a high loss tangent for high-frequency energization disposed in a ring between said antenna arms and said ground plane and extending radially outward from substantially 0.6 wavelength to 0.9 wavelength of the highest operating frequency of energization of the antenna.

8. The antenna of claim 5 further defined by said suppression means comprising resistors connected between said antenna arms and said ground plane and said arms terminating at said resistor connections.

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