April 2, 1968 P. D. KENNEDY 3,376,577

VERTICAL RADIATION SPIRAL ANTENNA

Filed Nov. 15, 1965 3 Sheets-Sheet 1

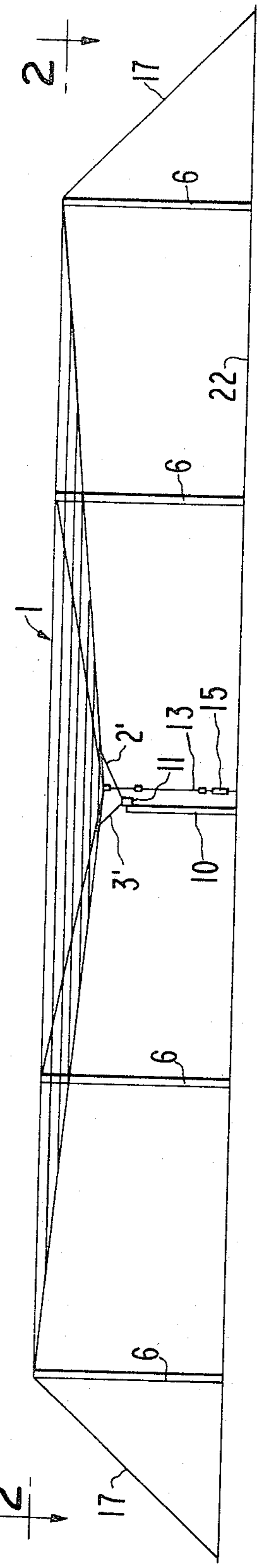

FIG. I

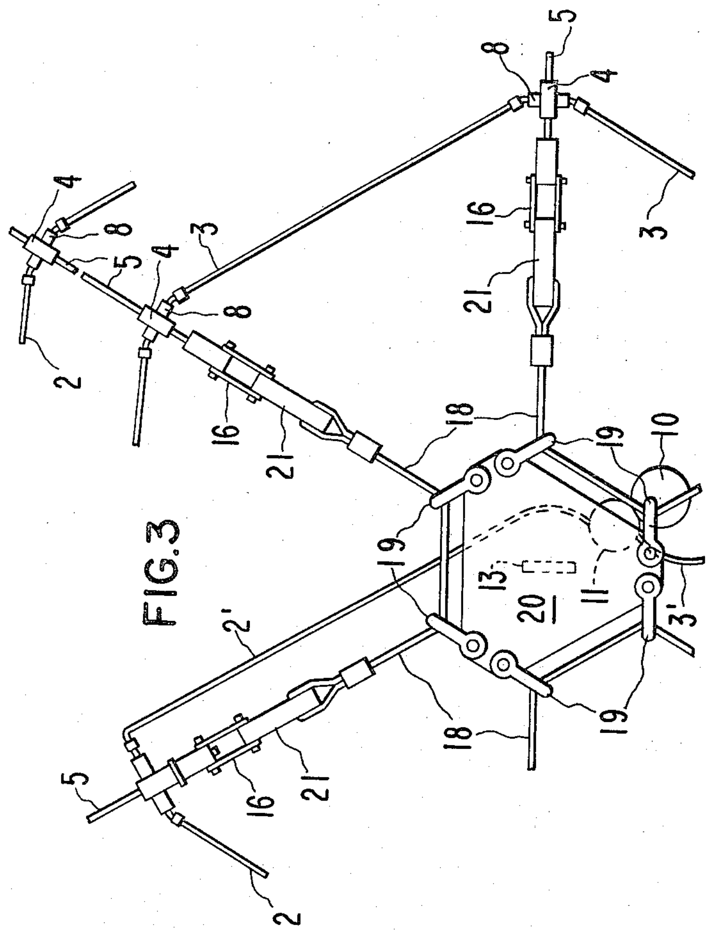

FIG. 3

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VERTICAL RADIATION SPIRAL ANTENNA

Filed Nov. 15, 1965 3 Sheets-Sheet 2

FIG. 2

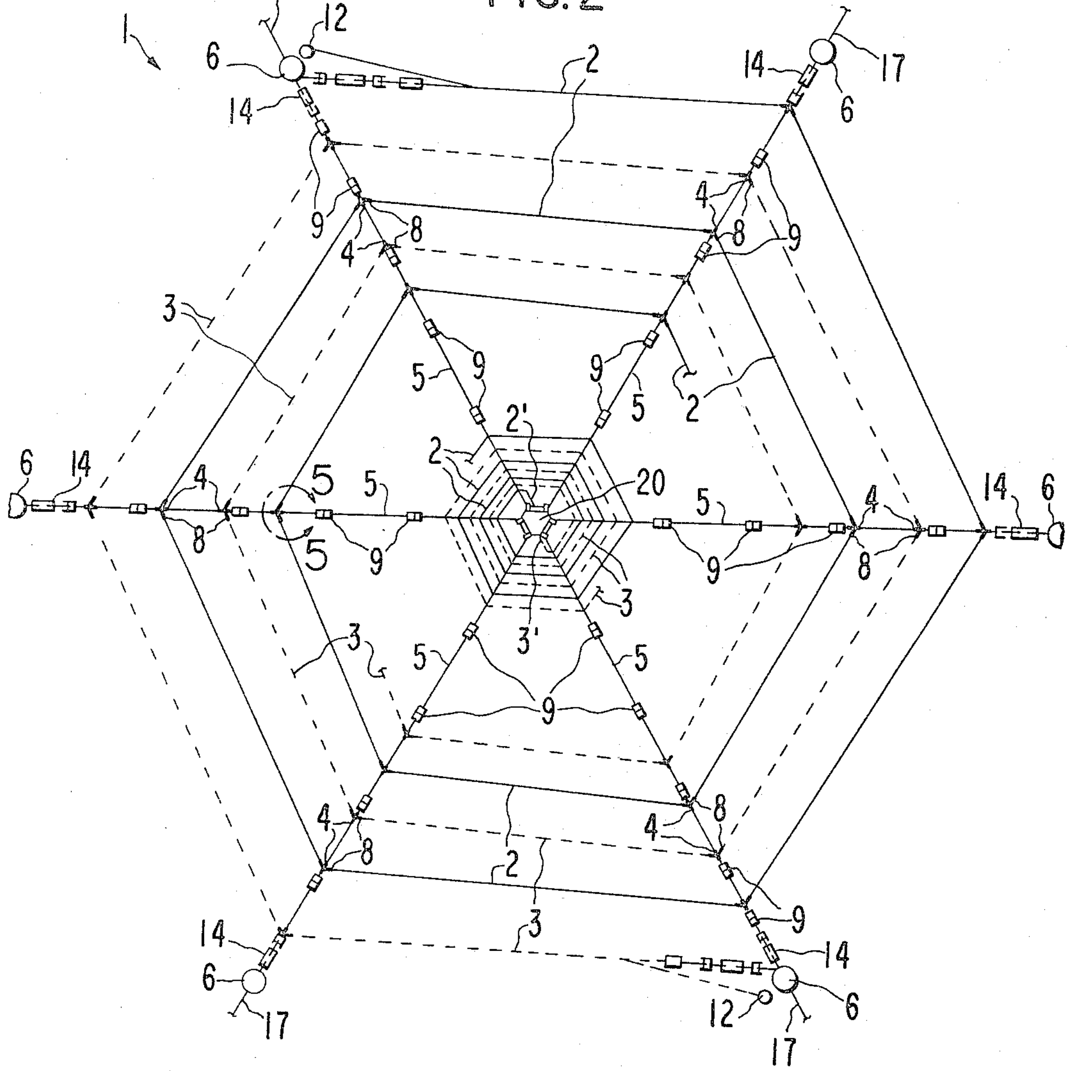

FIG. 5

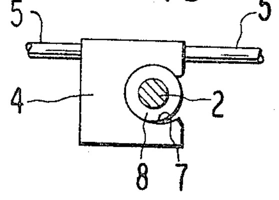

FIG. 5A

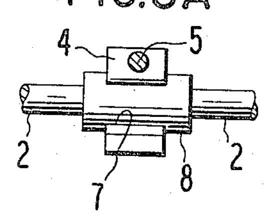

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FIG. 4

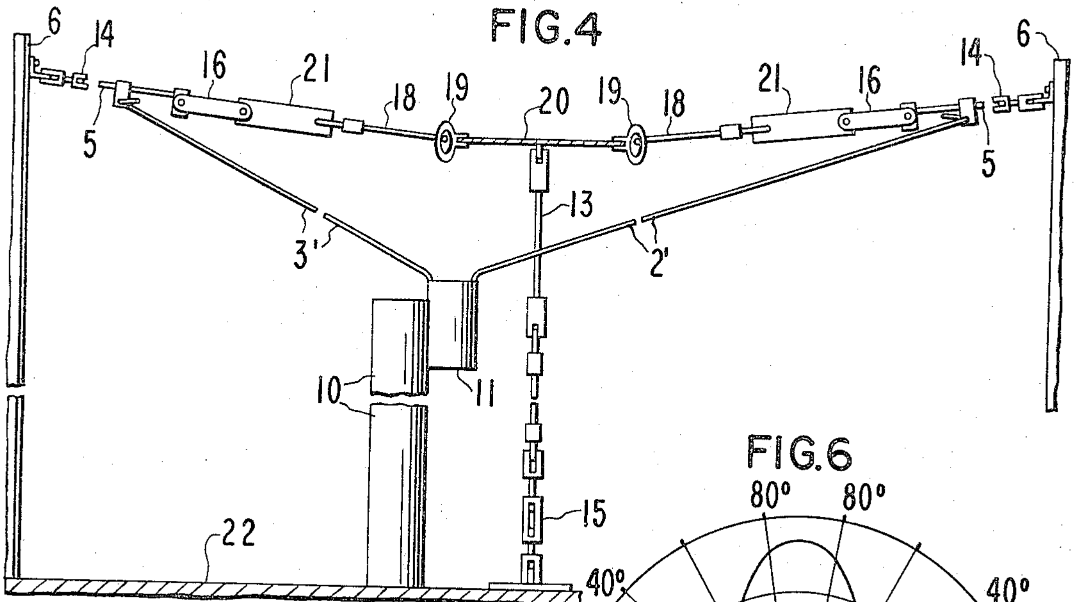


FIG. 6

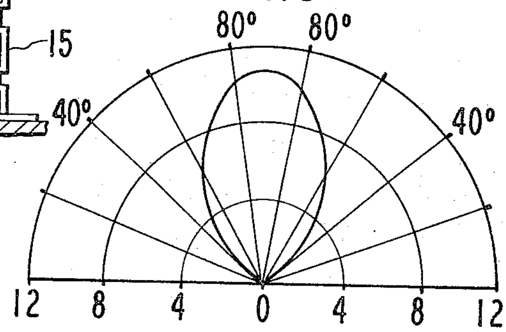


FIG. 7

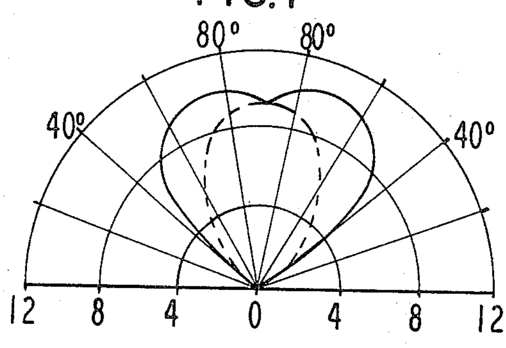


FIG. 8

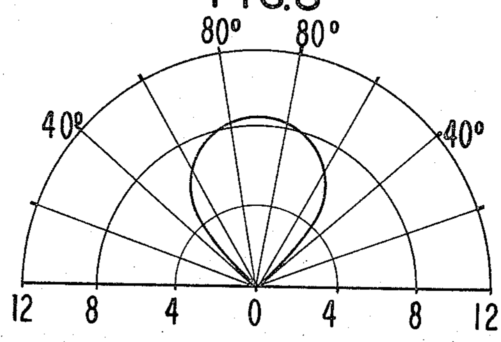
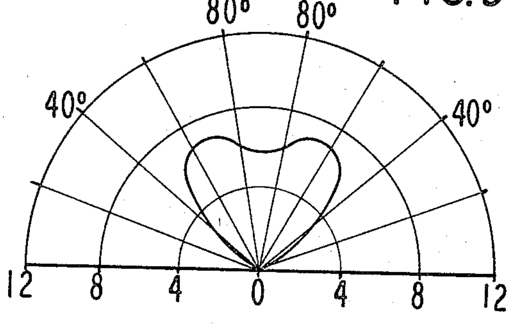


FIG. 9



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1

3,376,577
VERTICAL RADIATION SPIRAL ANTENNA

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3 Claims. (Cl. 343—886)

This invention relates generally to antennas, and the invention has reference, more particularly, to a novel spiral antenna effective over a wide frequency range for producing a substantially undistorted vertical radiation pattern throughout such frequency range.

It has been found by experimentation that, for short range communication by ionosphere reflections or for vertical incidence ionosphere sounding, an antenna with verticaly directed radiation and with a frequency range of approximately 2 to 15 megacycles per second is required. A simple horizontal dipole antenna placed one-quarter wavelength or less above the ground will radiate this way, but such an antenna is a narrow band device. However, for maintaining operation continuously throughout the year, adjustment of the operating frequency is required from time to time, and consequently a broadband antenna is necessary.

A log periodic dipole array with its apex pointed skyward while providing the necessary bandwidth would not be practical because of its large size. If the longest radiator of such an array is made to be, say 0.2 wavelength above the ground, the radiation patterns are entirely satisfactory at the lowest frequencies. However, if the frequency of the signal applied to the antenna is increased, the antenna radiates from a region which is closer to its apex and the separation between the center of radiation and the earth's surface increases. When this separation from the ground becomes one-half wavelength or more, radiation pattern distortion due to back radiation from the array being reflected from the ground will become objectionable. To reduce this effect, the array can be made more directive by reducing the apex angle and increasing the number of radiators. A fairly good array can be obtained, for example, by using a total apex angle of 30 degrees, but the structure would necessarily be very large if built for a lower frequency limit of 2 megacycles per second which would be a typical requirement for the intended application. Such a structure would be need to be approximately 600 feet high. Upward radiation can also be obtained by pointing the array downward. Here the principal radiation is the reflection from the ground, and it might be thought that the radiation patterns would be clean and constant with frequency change because the center of radiation stays a constant and small electrical distance above the ground. However, favorable characteristics are not actually obtained because of the parasitic excitation of the lower frequency radiators which occurs at higher frequencies.

Conical spiral antennas have been found useful for certain applications and the most obvious choice here for vertical radiation is an upward pointing conical spiral antenna such as disclosed in U.S. Patent No. 2,958,081 to J. D. Dyson. The radiator of this patent has good radiation patterns and impedance, but only when the apex angle is small. It has this general property, i.e., the smaller the apex angle, the better the antenna, in common with the log periodic dipole array. It has the same difficulty as the upwards pointing dipole array, namely that interference of back radiation reflected from the ground with the direct radiation causes pattern distortion unless the spiral is very directive. Since the base of such an array needs to be roughly one wavelength in circumference at the lowest operating frequency, a vertically radiating antenna of the Dyson type with a two megacycle lower frequency would be approximately 450 feet high which is impractical where economy is important.

2

By using a conical spiral antenna with a downwardly pointing apex, it might be thought possible to maintain a constant electrical height of the phase center and so to maintain a pattern which is invariant with frequency, even if it is affected to some extent by back radiation from the array. In the interest of economy, the cone angle would be made as large as possible so as to reduce the height of the antenna's supporting structure, and design approach for obtaining the same radiation patterns at all frequencies would be to place the apex of the cone at ground level. Since the active or radiation region of the antenna occurs at a radius from the center of the antenna which is a constant fraction of the wavelength, it might be thought that the active region of the antenna would remain at a constant fraction of a wavelength above the ground at all frequencies and so the radiation patterns would be essentialy identical to all frequencies. This approach, however, is actually unworkable. From scale model tests, it is found that the radiation patterns are as expected in the lowest frequency range of each particular model, but the patterns at higher frequencies are erratic and irregular. That is, multilobed and unsymmetrical patterns are obtained, and these vary greatly with small changes in the test frequency. Consequenty, it is apparent that such an antenna does not operate in the intended way.

The reason for the erratic high frequency performance of such an antenna can be understood from "near field" measurements on a model to determine the location and nature of its active region. The near-field reaches a maximum at a radius of about 0.1 wavelength. This would be called the center of the active region. If the antenna is large, the fields decay rapidly at larger radii because little current travels beyond the active region. If the spiral antenna is in free space, its performance is affected relatively little if the spiral arms are cut off just beyond the apparent active region. This behavior is similar to that of a log-periodic dipole antenna, where most of the energy is radiated from those dipoles which are about one-half wavelength long and little energy continues down the feedline beyond this region. However, near-field distribution measurements, made on a conical spiral antenna model having its apex coincident with a conducting ground plane at a high frequency for which erratic radiation patterns were obtained, proved that the fields do not decay beyond the normal radius of the active region, but that secondary maxima occur. In other words, the current flows along the arms of the spiral past the normal active region and radiates from higher order active regions; then the total radiation from the normal and the higher order regions combine to produce the totally undesirable characteristics that are observed.

The problem comes from placing the spiral too close to the ground plane and thereby making it an inefficient radiator. Because of the proximity to the ground plane, all of the energy applied to the antenna cannot leak off into space from the normal active region and significant current flow further along the spiral than is normally the case. At low frequencies, where the spiral is not larger than a normal active region, substantially regular radiation patterns are obtained because there is no conducting path of large radius in which the excess currents can flow, and consequently they cannot cause spurious radiation. Having recognized this, it might be thought that the spiral could be arranged so that the electrical height of the antenna would be a quarter-wavelength or so at all frequencies. For a 2 mc. antenna, this would require the outer turn to be about 125 feet above the ground and would defeat the original objective of an economical structure with a low silhouette.

These deficiencies of conical antennas of the prior art are substantially eliminated in the antenna of the present invention because it has been found that, since the region of the spiral which radiates at higher frequencies must be higher above the ground, the solution is to elevate the apex of the cone with the limitation that the active region of the antenna must not be appreciably higher above the ground plane than one-quarter wavelength at the highest operating frequency of the antenna. It is this novel compromise which makes the antenna of the present invention operate well over a useful wide range of frequencies.

The principal object of the present invention is to provide a novel spiral antenna having broad-band characteristics and wherein the radiation patterns of the antenna are directed upwardly and are substantially uniform throughout the useful frequency range thereof, the said antenna being economical to build and having a low silhouette.

A feature of the present invention is to provide a novel antenna of the above character having a frequency range of the order of two to fifteen megacycles and is suitable for communication by ionospheric reflections and for vertical incidence ionospheric sounding, the said antenna being of inverted conical shape and having a large angled apex positioned substantially one-quarter wavelength above ground at the highest operating frequency.

Other features and advantages of the present invention will become more apparent after a perusal of the following specification taken in connection with the accompanying drawings wherein:

FIG. 1 is a schematic elevational view of the novel antenna of this invention;

FIGURE 2 is a plan view with parts broken away of the structure of FIGURE 1 looking in the direction of the arrows **2—2**;

FIG. 3 is an enlarged fragmentary view of the apex region of the antenna;

FIG. 4 is an enlarged fragmentary view in elevation of parts of the antenna;

FIGS. 5 and 5A are side and end views respectively of antenna clamps used as viewed at **5—5** in FIG. 2; and

FIGS. 6, 7, 8 and 9 are graphs illustrating the radiation pattern of the antenna under different operating frequencies.

Similar characters of reference are used in the above figures to designate corresponding parts.

Referring now to the drawings, the reference numeral **1** designates the novel antenna of this invention comprising two spirally wound mutually spaced antenna wires or arms **2** and **3** (the latter being shown in dash lines in FIG. 2 for clarity). The wires or arms **2** and **3** are carried by clips **4** which in turn are supported by catenaries **5** carried at their outer ends by poles **6**, shown as six in number arranged substantially in a circle and equally spaced from one another, so that in plan the overall appearance of the antenna is a hexagon as shown in FIG. 2. The clips **4** may be of metal having cylindrical recesses **7** supporting the antenna wires **2** and **3**. If desired, cyilndrical spool shaped insulators **8** may surround the wires **2** and **3** which insulators can be snapped into the recesses **7** when assembling the antenna in the field.

Preferably, the catenaries **5** are of fiberglass and may be a series of rods interconnected by clevises **9** as shown in FIG. 2. These catenaries **5** are connected at their outer ends by turnbuckles **14** to the poles **6** at points substantially thirty feet above the ground, the radial length of each catenary being approximately 100 feet. Guy wires **17** support the poles **6** against the pull of the catenaries. The inner ends of the catenaries **5** are connected by links **16** and insulators **21** to stainless steel cables **18** threaded through C-clips **19** that are pivoted upon a substantially triangular apex plate **20** that is positioned at a desired length, i.e., approximately 20 feet above the ground, as determined by a central vertical cable **13** attached to ground and the plate **20** and adjustable as to length by a turnbuckle **15**. The catenaries **5** may be in the form of cables, if desired. The clips **4** are preferably cemented in desired position to the catenaries **5** at the factory and are arranged so that the path of each wire or arms **2** and **3** approximate a logarithmic spiral disposed on the surface of a shallow or flattened imaginary inverted cone when the antenna is assembled in the field, thus allowing rapid assembly. Thus, the radius of each turn, R_n for example, is related to the radius of an adjacent turn, R_{n+1}, by a constant factor such that:

$$R_n = kR_{n+1}$$

While other types of spiral could be used, such as the arithmetic spiral in which the radius of each turn is larger than the adjacent smaller turn by a constant difference, nevertheless the logarithmic spiral yields superior performance. The two wires or arms **2** and **3** of the antenna are identical in radius variation, but one is rotated 180° with respect to the other and consequently they are interleaved uniformly in all parts of the antenna. The wires **2** and **3** have input terminals **2'**, **3'** (see FIG 3) and these terminals are adapted to be supplied with balanced radio frequency current as from the balun transformer **11** (see FIG 4) carried by a post **10**. When the antenna is acting as a transmitter, the current flows out around the spiral arms until it encounters the group of turns which are between approximately 0.1 and 0.3 wavelength in radius. The relative phase shift between the currents in adjacent turns is correct for radiation to occur from this region, and, if the spiral were in free space, relatively little current would continue on to turns of larger radius.

The dimensions of this antenna are preferably chosen so that there are four modes of operation, each occurring in a different part of the frequency range. For successful operation in the frequency range of 2 to 15 megacycles and in order to keep the dimensions of the antenna within practical limits, a somewhat definite dimensioning of the antenna structure is necessary. Thus, the poles **6** are substantially thirty feet high. The radius of the largest turn of the antenna spiral is approximately 100 feet which is large enough so that a well-formed beam is obtained at the lowest frequency of operation (2 megacycles per second). Because of the proximity of the outer turns to the ground (30 feet), not all of the energy is radiated into space and is carried into terminating resistors **12** mounted on opposed poles **6** to be dissipated in the form of heat. This constitutes the first mode of operation.

At somewhat higher frequencies, the active region shrinks in size so that there are turns of larger radius beyond which undesired radiation can occur. This tendency is reduced to an acceptable amount in the present construction by raising the apex of the spirals **2**, **3** to a height of substantially 20 feet, thereby raising the height of the active region within the second mode of operation far enough above the ground that almost all of the energy is radiated into space. Consequently, relatively little current flows into the larger turns of the spiral, reducing distortion of the radiated patterns to substantially zero. At still higher frequencies, the active region is a larger fraction of a wavelength above the ground, the radiation process is very efficient, and the radiation patterns obtained in this third mode of operation are quite regular.

Finally, as the frequency is increased, the distance between the active region and the ground becomes greater than a quarter-wavelength and the beam maximum is no longer vertical. The frequency at which this occurs would represent the upper frequency limit of an antenna intended for vertical radiation. In the case of an antenna to be used for communication via ionospheric reflections, this upper frequency limit should be about 15 megacycles per second, as in the case of the present antenna.

The choice of the height of the spiral's center as determined by the length of the central vertical tie member **13**, having the turnbuckle **15** therein, is very critical. If it is placed too low, satisfactory operation cannot be obtained in the second mode as defined above; whereas. if it is placed too high, the condition giving the upper frequency limit as described above is reached at an excessively low frequency and the full potential of the antenna for communications cannot be realized.

The radiation patterns of FIGURES 6 to 9 illustrate the four modes of operation. At the low frequencies, the antenna is only as large as the normal active region, any energy reaching the ends of the spiral arms is absorbed by resistors **12**, and the radiation patterns are very well formed as shown in FIG. 6, even though the antenna is electrically close to the ground plane **22**. At somewhat higher frequencies, there is a transition range where the antenna is electrically large enough in radius and electrically close enough to the ground to show slight tendency toward erratic behavior. However, the compromise construction of the present invention is successful in that the radiation properties remain acceptable with this transition region as shown in FIG. 7. At still higher frequencies, the active region is electrically far enough from the ground plane to give regular and symmetrical patterns as shown in FIG. 8. Finally, the active region is greater than a quarter-wavelength above the ground plane and the beam maximum is no longer vertical. However, the antenna of this invention still behaves in a predictable and useful way as illustrated by the pattern in FIG. 9.

Since many changes could be made in the above construction of the novel antenna of this invention and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A broadband antenna having a frequency range

of the order of 2 to15 megacycles for producing an upwardly directed radiation lobe suitable for communications and ionosphere sounding comprising, two mutually spaced spirally-wound antenna wires, said wires laying in the surface of an imaginary inverted shallow cone, the apex of the cone serving as the input to said antenna wires and being elevated above ground substantially one-quarter wavelength of the highest operating frequency of said antenna, the apex ends of said antenna wires being angularly rotated 180° with respect to each other and the outer ends of said wires being higher above ground than said apex.

2. A broadband antenna as defined in claim **1** wherein a plurality of supporting catenaries are connected together adjacent the apex of said antenna and extended radially outwardly therefrom a distance of the order of one and one-quarter of the wavelength of the highest operating frequency of said antenna, posts supporting the outer ends of said catenaries at an elevation substantially equal to three-eights wavelength above ground of said highest operating frequency, and means attaching said antenna wires to said catenaries such that the path of each wire approximates a logarithmic spiral.

3. A broadband antenna as defined in claim **2** wherein an apex plate is provided at the apex of said antenna, said supporting catenaries being connected to said apex plate, a vertical tie member connecting said apex plate to ground, and means for changing the length of said tie member to determine accurately the height above ground of said antenna apex.

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ELI LIEBERMAN, *Primary Examiner.*