Jan. 30, 1962 H. J. REIS ETAL 3,019,439

ELLIPTICALLY POLARIZED SPIRAL ANTENNA

Filed Sept. 19, 1957 4 Sheets-Sheet 1

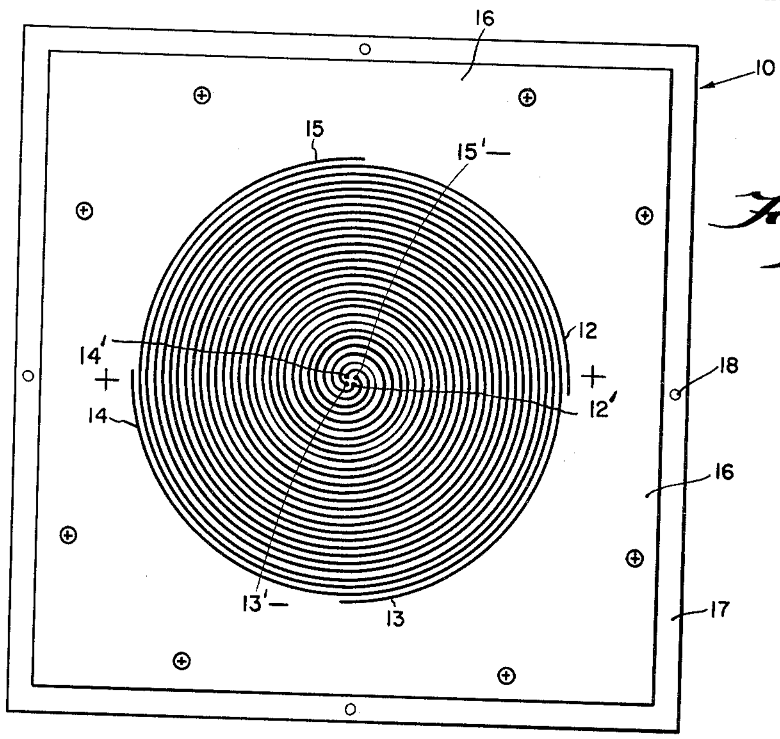


Fig.1.

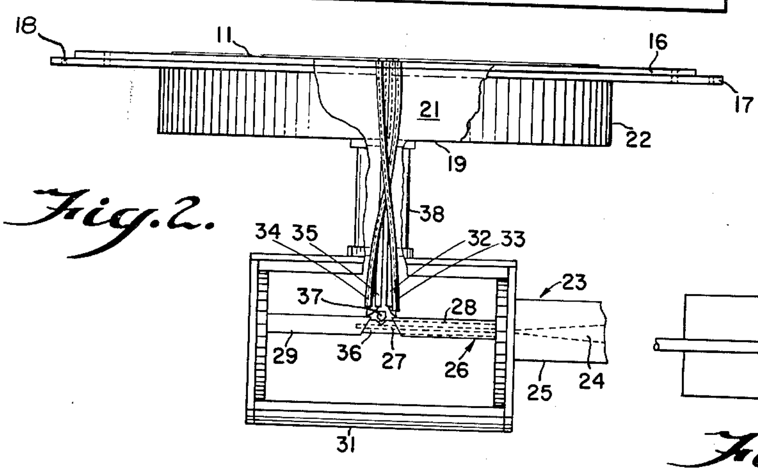


Fig.2.

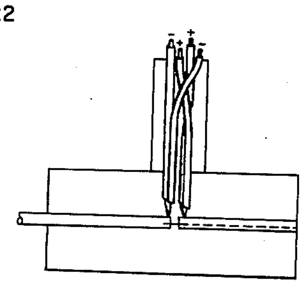


Fig.3.

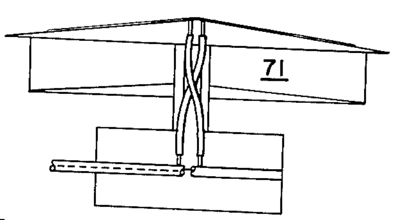
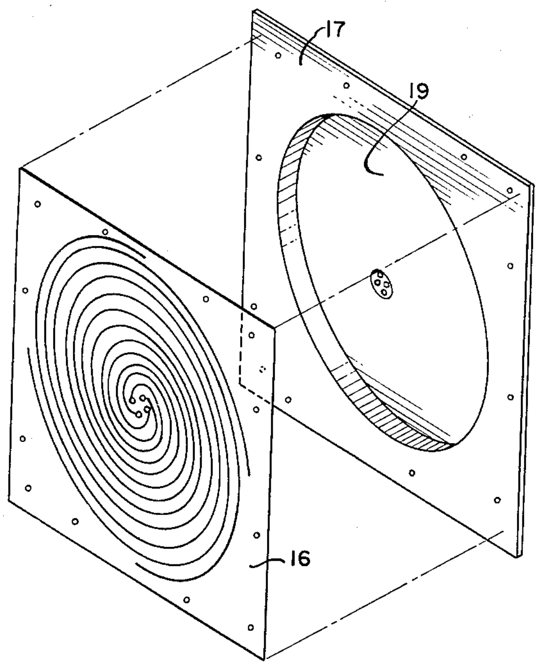


Fig.11.

INVENTORS
HERBERT J. REIS
FRANCIS M. KUDO
BY
Julian C. Renfro
ATTORNEY

Fig. 4.



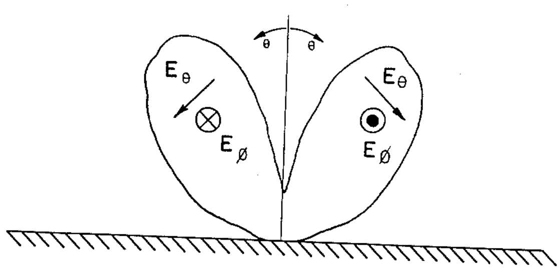


Fig. 7.

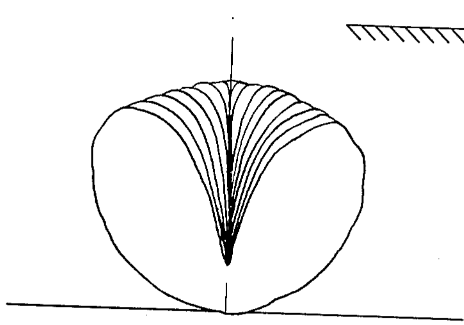


Fig. 6.

INVENTOR.
HERBERT J. REIS
FRANCIS M. KUDO
BY
Julian C. Renfro
ATTORNEY

Fig. 5.

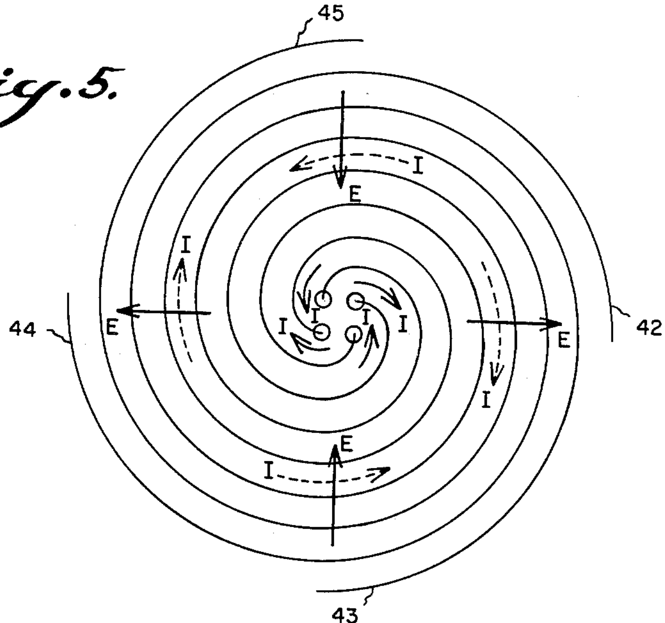
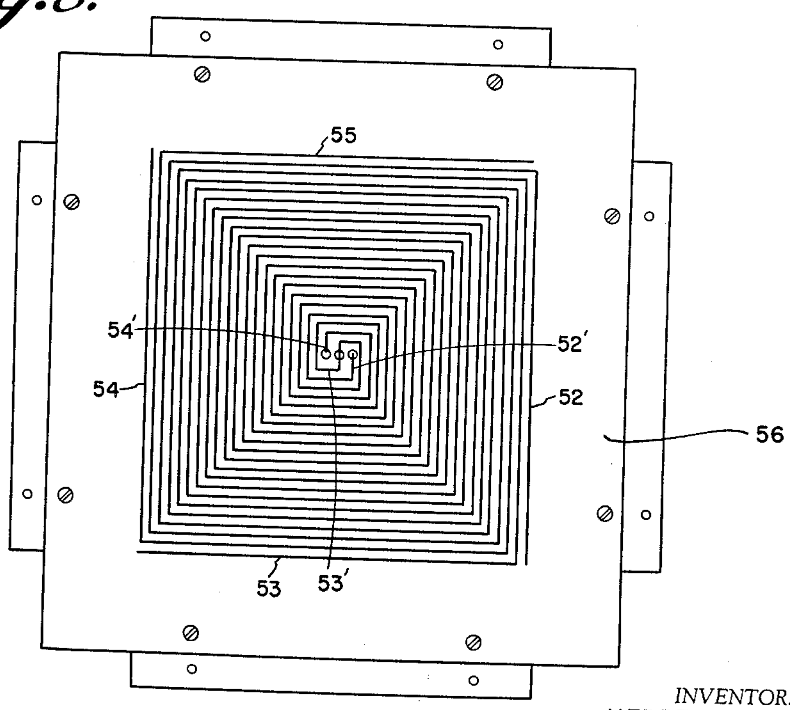


Fig. 8.



INVENTOR.
HERBERT J. REIS
FRANCIS M. KUDO
BY
Julian C. Renfro
ATTORNEY

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ELLIPTICALLY POLARIZED SPIRAL ANTENNA

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4 Sheets-Sheet 4

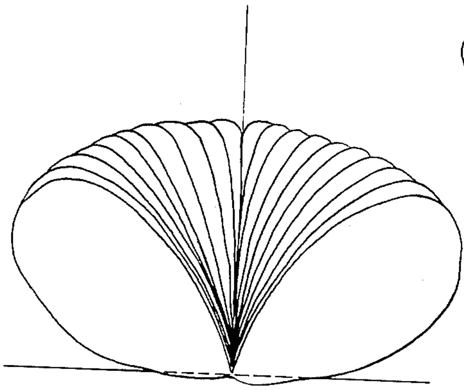

Fig. 12.

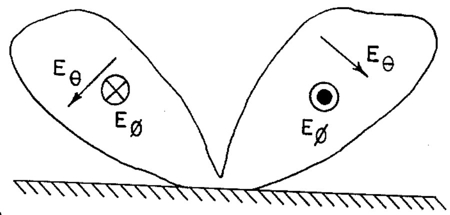

Fig. 13.

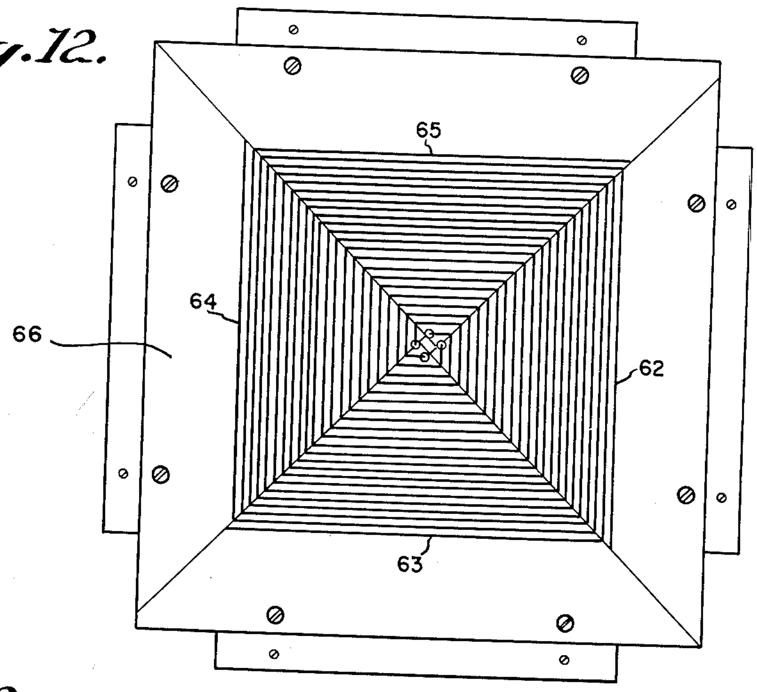

Fig. 9.

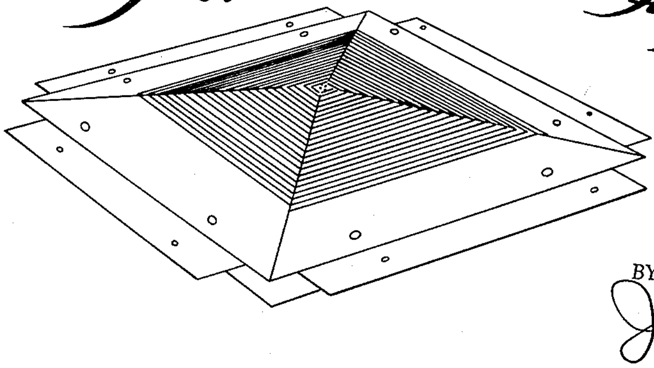

Fig. 10.

INVENTOR.
HERBERT J. REIS
FRANCIS M. KUDO

BY Julian C. Renfro

ATTORNEY.

United States Patent Office 3,019,439

Patented Jan. 30, 1962

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ELLIPTICALLY POLARIZED SPIRAL ANTENNA

Herbert J. Reis, Middle River, and Francis M. Kudo, Kenwood, Md., assignors to Martin-Marietta Corporation, a corporation of Maryland

Filed Sept. 19, 1957, Ser. No. 684,876
19 Claims. (Cl. 343—853)

This invention relates to an antenna of generally spiral construction, flush mounted with the surface of a ground plane, and more particularly to an antenna adapted to transmit or receive elliptically polarized electromagnetic waves in an efficient manner and over a wide range of frequencies.

In the past, so-called stub antennas have been employed with a moderate degree of success for communication purposes, such as for communication between an aircraft and a ground station. Stub antennas, however, have only limited usefulness in the field of electronic countermeasures since they are efficient for the transmission and reception of only linearly polarized energy, and for only a limited frequency range, i.e., a small part of an octave. Furthermore, a stub antenna when used in an aircraft must necessarily project through the surface or skin of the aircraft, and therefore may be responsible for additional drag. Other known antennas have suffered similar disadvantages.

According to the present invention we have provided a novel and improved travelling wave antenna which, because of its wide frequency range and polarizations in both the horizontal and vertical planes, is ideally suited for use in electronic countermeasures equipment and ground based weapons systems. The antenna is small, compact, and capable of operating over a frequency range of more than one octave, and quite satisfactory results have been obtained in tests conducted in the 2,000 to 4,000 mc. frequency range. It may advantageously be flush mounted on the underside of an aircraft so as to radiate energy in a pattern extending downwardly and to all sides of the aircraft in a highly desirable manner.

In the preferred form of the invention, the antenna is of generally spiral construction and principally comprises a plurality of interwound conductors or radiating elements disposed substantially in a common plane, with one end of each element terminating in a central area of the face of the antenna. Four radiating elements are preferably employed, although a larger even number of elements may be used. Appropriate feed means are connected to each radiating element, and the outer ends of the radiating elements terminate at radially outer portions of the antenna face. The radiating elements are electrically isolated from each other and a cavity may be defined on the underside of the antenna so that the energy will be expended in the desired direction and in an efficient manner.

Depending upon the use to which the antenna is to be placed and the radiation pattern desired, any one of several embodiments of an antenna according to this invention may be selected. According to a first embodiment, the radiating elements are in the form of interwound spirals formed about a common axis and located in a substantially common plane, with balanced feed means connected to the radially inner ends of the elements whereby a balanced and symmetrical wave pattern may be transmitted. As an alternative, the radiating elements can form a substantially square configuration, with each element being bent approximately 90° in a number of locations in the process of winding across the face of the antenna. As a further modification, the central portion of the face of the antenna may be raised somewhat, this having the result of producing radiation closer to the ground plane rather than in modifications not having the raised central portion. Spiral radiating elements may be employed in the modification having the raised central portion, as may radiating elements of essentially square configuration previously described.

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Since the mean diameter of the radiating circumferential zone varies with frequency, a broad frequency range of operation is possible with an antenna of suitable diameter. Because of the orientation and distrbiution of field vectors, a null is produced in a direction normal to the plane of the antenna, with consequent radiation extending in a lateral, encircling direction above (or below) the ground plane of the antenna. Due to the many windings of the antenna, a traveling wave exists along the turns to yield omniazimuthal radiation along a wide frequency range.

The above and other features in this invention will become apparent upon reference to the following detailed description and accompanying drawings in which:

FIGURE 1 is a plan view of a first embodiment of a multi-conductor spiral antenna according to this invention;

FIGURE 2 is a side view of the antenna according to FIGURE 1, partly in section to reveal internal construction;

FIGURE 3 is a simplified view revealing details of the feed means and the polarities associated with the coaxial conductors employed in the antenna according to this modification;

FIGURE 4 is an exploded view of the antenna according to FIGURES 1 and 2 revealing inner construction;

FIGURE 5 is a simplified diagram of the radiating elements of the antenna of FIGURES 1 and 2, revealing direction of current flow through the radiating elements at a given instant and the direction of the generated electric field in the circumferential region from which radiation originates;

FIGURE 6 is a typical conical radiation pattern of the type obtained by the use of an antenna of the type shown in FIGURES 1 and 2;

FIGURE 7 is a view taken through the radiation pattern of FIGURE 6, revealing the manner in which a given section of the radiation pattern is polarized according to components at one instant;

FIGURE 8 is a plan view of a second embodiment according to this invention in which the radiating elements are of substantially square configuration;

FIGURE 9 is a plan view of a third embodiment of this invention in which the radiating elements are similar to those of the second embodiment, but with the central portion of the antenna raised;

FIGURE 10 is a perspective view of the antenna according to FIGURE 9;

FIGURE 11 is a simplified view similar to FIGURE 3 revealing how the feed means are connected to the radiating elements of an antenna in which the central portion is raised;

FIGURE 12 is a conical radiation pattern similar to FIGURE 6, this pattern being obtained from an antenna having a raised central portion; and

FIGURE 13 is a view taken through the antenna pattern of FIGURE 12, revealing the components of polarization of a given section thereof at a given instant.

Referring initially to FIGURE 1, there is illustrated an antenna **10** constituting a first embodiment of this invention wherein the radiating portion or face **11** consists of radiating elements **12, 13, 14** and **15** in the form of interwound spirals formed about a central axis and disposed in a common plane. The inner ends of these elements terminate in a common central area at feed points **12′, 13′, 14′** and **15′** respectively. The outer ends of these elements may terminate adjacent the outer edge of the antenna in any convenient manner such as the 90° relationships shown.

The radiating elements are electrically isolated from each other, and accordingly printed circuitry techniques may be employed in the illustrated embodiment for the creation of radiating elements upon a dielectric sheet **16**. The sheet **16** may be structurally mounted by suitable screws or the like upon a mounting plate **17**, which in turn may be provided with mounting holes **18** to enable the antenna to be secured in the desired operating position, such as to the underside of an aircraft. Radiating elements of other construction may of course be employed if desired.

In FIGURE 2 a cavity **21** is defined on the side of the dielectric sheet that is remote from the radiating elements, and to this end, a cavity plate **19** is secured to the underside of mounting plate **17** in the illustrated manner. The cavity plate is provided with circumferential edge portions **22** located radially outwardly of the radial portion of the antenna so as to define a closed cavity and to properly support plate **19** with respect to mounting plate **17**. If desired, members **17**, **19** and **22** can be of integral construction, such as by the employment of metal stamping techniques.

Although there is no definite size for cavity **21**, the best results have been obtained when the depth of this cavity is slightly less than a quarter wave length at the high frequency end of the band of operation. The cavity **21** acts as a reflector to direct radiation outwardly from the face of the dielectric sheet in which the radiating elements are disposed, for without the presence of the cavity, an antenna of this type would tend to radiate energy both below and above the ground plane, thereby dissipating its power in an undesirable direction and decreasing its range and overall efficiency. Other details of this construction may be observed by referring to FIGURE 4.

Centrally mounted on the lower side of cavity plate **19** is a connector **38** through the interior of which are located a plurality of coaxial lines for supplying energy to the radiating elements. Inasmuch as four radiating elements **12** through **15** are employed in this embodiment, the lines **32** through **35** are connected to these elements, respectively, at feed points **12'**, **13'**, **14'** and **15'** as previously mentioned.

Since coaxial lines **32** through **35** are to be connected to coaxial feed cable **23** in a balanced arrangement, a broad band balun **31** is preferably secured to the lower end of connector **38**. This type of balun is described at some length by Nathan Marchand in his article entitled, "Transmission-Line Conversion," in Electronics December 1944 issue, pages 142 through 145. As brought out in the article, whenever it is necessary to use a balanced two wire line over one part of a system and a coaxial transmission line over another part of the system, a conversion transformer is often necessary at the juncture of the two types of lines in order to maintain currents on the two types of lines in their proper relations.

In FIGURE 2, the balun **31** is generally of the type shown in Figure 6 of the Marchand article and employs a solid stub **29** centrally disposed in one end of the balun, and extending for approximately one half the length thereof. Coaxial feed line **23** is attached to the opposite end of the balun, with outer conductor **25** being secured to the continuous shield forming the exterior of the balun, and the inner conductor **24** being tapered to a size commensurate with the size of coaxial line **26** located in the balun in aligned relationship with solid stub **29**. The inner conductor **24** is connected to inner conductor **27** of line **26**, and conductor **27** in turn is connected to solid stub **29** by a suitable electrical connection. Outer conductor **28** of line **26** terminates approximately at the midpoint of the balun but spaced somewhat from the stub **29**. Dielectric portion **36** of line **26** separates conductors **27** and **28**, continues past the termination of outer conductor **28** into contact with stub **29**, although dielectric **36** is apertured to receive a small block of dielectric **37** on its upper side. The dielectric **37** is inserted in this gap between conductor **28** and stub **29** so as to increase the dielectric strength of the medium in the gap, thereby increasing the power handling capabilities of the balun.

The four coaxial lines **32** through **35** are connected in a particular arrangement as illustrated in FIGURES 2 and 3 so as to achieve a balanced arrangement. The center conductor of each lines **32** and **33** is connected to the outer conductor **28** of coaxial line **26**, and the center conductors of lines **34** and **35** are connected to the solid stub **29**. Balance is achieved by crossing over two of the lines as shown in FIGURES 2 and 3 so that polarities are attained for the antenna feed terminals as shown in FIGURES 1 and 3. In other words, when terminals **12'** and **14'** are positive, terminals **13'** and **15'** will be negative and vice versa. Preferably the top and bottom ends of the outer conductors of lines **32** through **35** are connected to ground for shielding purposes, this also causing the capacity from center conductors to ground for all four lines to be equal.

FIGURE 5 is illustrative of the theory of operation associated with this antenna. The four radiating elements **42** through **45** correspond with radiating elements **12** through **15** of FIGURE 1. When these elements are energized in the manner indicated by the inner arrows I, the current vectors I indicated by dotted lines will be established at radially outer locations on the radiating elements. Since each radiating element is typically many wave lengths long and radiation originates in a mean circumferential region equaling two wave lengths, the direction of the arrows representing current in the radiating region is approximately as shown. Electric field vectors E are produced in a circumferential zone with orientation similar to that shown in this figure, lying substantially at right angles to the current vectors I. Also, since the mean diameter of the radiating circumferential zone varies with frequency, a broad range of operation is achieved by the use of an antenna of suitable diameter. Because of the orientation and distribution of the field vectors, a null is produced in a direction normal to the plane of the spiral, with energy being radiated toward all sides.

FIGURE 6 is illustrative of the type of radiation pattern produced by an antenna as described. Elliptically polarized energy is radiated or received in all directions on the side of the ground plane upon which the antenna is mounted. FIGURE 7, which is a typical section taken through the radiation pattern of FIGURE 6, reveals the polarization of two components of the radiated electric field at any one instant. More particularly, due to the current distribution at the antenna in the horizontal plane as shown in FIGURE 5, horizontally polarized components of the radiating electric field are achieved in space. Two of these components are shown in FIGURE 7 by the vectors E_ϕ where the vector in the left lobe is entering the plane of the page, whereas the other vector is coming out of the page in the right lobe, this corresponding with the phasing of diametrically opposite current vectors at the antenna.

Due to the radial electric field distribution at the antenna as shown in FIGURE 5, electric field radiation polarized in the θ-direction is also achieved. In FIGURE 7, two θ components of the electric field are shown by vectors E_θ which point downwardly at a slant angle corresponding to the θ-direction, this also corresponding with the electric field vectors pointing outwardly in FIGURE 5. This polarization bears a resemblance to that obtained from radiation by an annular slot antenna in a finite ground plane where the electric field at the antenna is also radial. As a result of the radial electric field at the antenna, the polarization of the radiated field from the annular slot antenna is also in the θ-direction.

A spiral type antenna as described herein differs from the annular slot, loop, and other resonant antennas wherein standing waves exist, for the spiral type antenna contains traveling waves along the radiating elements. Because of the configuration of the antenna, and more specifically the four conductors, spacing between conductors, many turns, and polarities of the feed terminals, the current and electric field distributions shown in FIGURE 5 are achieved in a region corresponding to a mean circumference of two wave lengths, this accounting for the orientations of the current and electric field vectors illustrated in the latter figure. Since traveling waves exist in the antenna, nearly equal radiation is achieved along circles parallel to the face of the spiral with centers along the perpendicular axis of the spiral. Elliptical polarization is obtained because the E_ϕ and E_θ components are about 90° out of time phase.

Referring to FIGURE 8, another embodiment according to this invention is shown, with the radiating elements **52** through **55** corresponding to elements **12** through **15** and **42** through **45** of earlier figures, and preferably being located upon a similar dielectric sheet **56**. The radiating elements in FIGURE 8 form an essentially square configuration, with each element being bent approximately 90° at a number of locations in the process of winding across the face of the antenna. Feed points **52'** and **54'** of elements **52** and **54** are connected to the outer conductor of a coaxial line, and feed point **53'** is connected to the center conductor. Although a balun is not used in the illustrated embodiment, a shallow cavity (not shown) is mounted on the underside of the antenna in a manner similar to that shown in FIGURE 2. The cavity is square to conform to the square configuration of the radiator, but it can be circular if desired. A feed arrangement can consist of a single coaxial line passed through the bottom center of the cavity and electrically connected to the radiating elements in the aforementioned manner.

A study of feed points shows that current distribution at the center of this antenna embodiment is similar to that shown in FIGURE 5 since, when current is flowing toward **53'** in conductors **53** and **55**, current will flow away from **52'** and **54'** because these points are of opposite polarity with respect to that of feed point **53'**. Current and electric field distributions in the circumferential radiating zones are similar to that achieved in the embodiment shown in FIGURE 1, because of the similar current distribution at the center and the generally spiral type configuration of the radiator. However, due to the unbalanced feed arrangement shown in FIGURE 8, radiation in azimuth is not as symmetrical as that obtained from the antenna shown in FIGURE 1, wherein a balun was employed. If the balanced feed arrangement be indicated, a balun may of course be employed with the antenna illustrated in FIGURE 8.

Referring now to FIGURES 9 and 10, an embodiment is illustrated in which the central portion of the face of the antenna is raised to form a somewhat pyramidal configuration. However, as an example, the central portion of the face of the antenna may be raised in the order of magnitude of ⅝", so that the radiating elements **62** through **65** of this embodiment are still disposed in a substantially common plane upon dielectric sheet **66**. Therefore the increase, if any, in aerodynamic drag of this embodiment when employed in an aircraft is small. Although the desired type of feeding arrangement may of course be employed with this embodiment as with the earlier embodiments, a balun is preferably used, with the feed lines preferably being crossed as shown in FIGURE 11 in order that balance will be achieved. In the latter figure, cavity **71** is defined by a tapered bottom surface that agrees fairly closely with the configuration of the radiating surface of the antenna.

Since the mean diameter of the radiating circumferential zone varies inversely with frequency, radiation at the high frequency end of the operating band originates near the apex of the pyramid to produce radiation closer to the ground plane than radiation from a flat spiral antenna. However, the reduction in angle of radiation at the low frequency end of the operating band is not as significant because radiation originates near the base of the pyramid where the diameter of the pyramid is greater.

The radiation patterns obtained by the use of the embodiment according to FIGURES 9 and 10 are shown in FIGURES 12 and 13, which correspond comparatively closely with the radiation pattern illustrated in FIGURES 6 and 7 but with the radiation being somewhat closer to the ground plane because of the raised central portion of the antenna.

The described embodiments of an antenna according to this invention are merely exemplary, and other configurations and other feeding arrangements are possible within the orbit of this invention. As an example, the balun could be eliminated and a balanced arrangement nevertheless obtained if separate generators are used to energize the radiating elements, the generators being phased so as to present appropriate polarities. By the selection of the desired configuration, various radiation patterns may be obtained which advantageously are elliptically polarized and designed for operation over a wide frequency range.

We claim:

1. A flush mounted elliptically polarized omniazimuthal antenna having a face, and a plurality of at least four conducting elements electrically isolated from each other and interwound in a common direction across said face so that the introduction of electromagnetic energy to said antenna will produce apparent current vectors at quadratic points around the means circumferential region of said elements, the apparent current vector at any one quadratic point being circumferentially opposed to the apparent current vectors at the adjacent quadratic points, whereby said antenna will have an elliptically polarized omniazimuthal pattern.

2. A flush mounted elliptically polarized omniazimuthal antenna having a face and an underside, a plurality of at least four conducting elements electrically isolated from each other and interwound in a common direction across said face so that introduction of electromagnetic energy to said antenna will produce apparent current vectors at quadratic points around the mean circumferential region of said elements, the apparent current vector at any one quadratic point being circumferentially opposed to the apparent current vector of the adjacent quadratic points, balanced coupling means mounted on said underside, with the radially inner ends of said radiating elements connected to said coupling means, whereby a balanced and symmetrical wave pattern may be transmitted.

3. The antenna as defined in claim 2 in which mounting means for said antenna are provided, said mounting means defining a cavity on the underside of said antenna of a depth approximately ¼ wave length, whereby a radiation pattern is principally formed on the face side of said antenna.

4. A flush mounted elliptically polarized omniazimuthal antenna of generally spiral construction having a face, a plurality of at least four conducting elements interwound about a common axis in the same direction across a portion of said face, said conducting elements being electrically isolated from each other and disposed substantially in a common plane, and balanced feed means connected to the radially inner ends of said elements so that when energy is coupled into said antenna through introduction of electromagnetic energy apparent current vectors will be produced at quadratic points around the mean circumferential region of said elements, the apparent current vector at any one quadratic point being circumferentially opposed to the apparent current vector at the quadratic points adjacent thereto, whereby a balanced and symmetrical wave pattern may be transmitted by said antenna.

5. The antenna as defined in claim 4 in which said conducting elements are in the form of interwound spirals.

6. The antenna as defined in claim 4 in which said conducting elements form an essentially square configuration, with each element being bent approximately 90° in a number of locations on the face of the antenna.

7. The antenna as defined in claim 4 in which a central portion of said face is slightly raised, with said feed means connected at said raised portion to the inner ends of said elements.

8. The antenna as defined in claim 4 in which said conducting elements are disposed upon dielectric material, and said feed means includes a balun connected to said elements by means of a plurality of balanced output conductors connected in an electrically symmetrical arrangement.

9. An elliptically polarized omniazimuthal antenna adapted to be flush mounted on the surface of an aircraft or the like comprising a plurality of at least four interwound conducting elements disposed in a generally spiral arrangement upon dielectric material, mounting means for said antenna including means defining a cavity of a depth of approximately ¼ of a wave length on the side of the antenna opposite the surface of said elements, and feed means including a balun for energizing said elements so that the introduction of electromagnetic energy to said antenna will produce apparent current vectors at quadratic points around the mean circumferential region of said elements, the apparent current vector at any one quadratic point being opposed in a circumferential direction to the apparent current vectors at the quadratic points adjacent thereto, and a plurality of balanced output conductors connecting said elements with said balun in an electrically symmetrical arrangement.

10. The antenna as defined in claim 9 in which said conducting elements each are formed with a number of 90° bends so that said elements define a substantially square configuration on the face of said antenna.

11. The antenna as defined in claim 9 in which the central portion of said antenna is raised somewhat so as to cause the radiation pattern of the antenna to occur closer to the ground plane of the antenna.

12. An antenna mounted flush with the surface of a ground plane for transmitting and receiving electromagnetic energy in an elliptically polarized pattern comprising a face, and four radiating elements interwound about a common axis in the same direction across a portion of said face, said radiating elements being electrically isolated from each other and disposed substantially in a common plane, and coupling means connected to the first and third of said four conducting elements in a first phase relation and connected to the second and fourth of said elements in a second phase relation displaced substantially 180 electrical degrees from said first phase relation, whereby introduction of electromagnetic energy to said antenna will produce apparent current vectors at quadratic points around the mean circumferential region of said elements, the apparent current vector at any one quadratic point being circumferentially opposed to the apparent current vectors at the quadratic points adjacent thereto.

13. The antenna as defined in claim 12 in which said radiating elements are disposed upon dielectric material.

14. The antenna as defined in claim 12 in which said radiating elements are in the form of interwound spirals.

15. The antenna as defined in claim 12 in which said radiating elements form an essentially square configuration, with each element being bent approximately 90° in a number of locations on the face of the antenna.

16. The antenna as defined in claim 12 in which a central portion of said face is slightly raised, with said feed means connected at said raised portion to the inner ends of said elements.

17. An antenna in accordance with claim 12 in which said coupling means is a two-wire transmission line.

18. An antenna in accordance with claim 12 which includes means for matching impedances between said coupling means and the ultization circuitry, and mounting means on the underside of said face defining a cavity thereunder for concentrating the radiation pattern of said antenna on the other side of said face.

19. An antenna in accordance with claim 18 in which said means for matching impedances is a balun, and the said first and third elements are electrically shorted, and the said second and fourth elements are electrically shorted together, said coupling means being connected to said elements at the radially inner ends thereof.

References Cited in the file of this patent

UNITED STATES PATENTS

2,509,903	Brode et al.	May 30, 1950
2,616,046	Marston	Oct. 28, 1952
2,640,928	Kandoian	June 2, 1953
2,746,018	Sichak	May 15, 1956
2,773,254	Engelmann	Dec. 4, 1956
2,863,145	Turner	Dec. 2, 1958

FOREIGN PATENTS

411,888	Italy	July 19, 1945

OTHER REFERENCES

Marchand: "Transmission-Line Conversion," Electronics, December 1944, pages 142–145.

Antenna Systems, AF Manual 52–19, 1953, pages 227, 228,

Klass: "Airborne Spiral Antennas Minimize Drag," Aviation Week, July 14, 1958 pages 75–82.