Sept. 20, 1960 L. O. KRAUSE 2,953,786

ANTENNA FOR POLARIZED PROPAGATION

Filed June 4, 1958 2 Sheets-Sheet 1

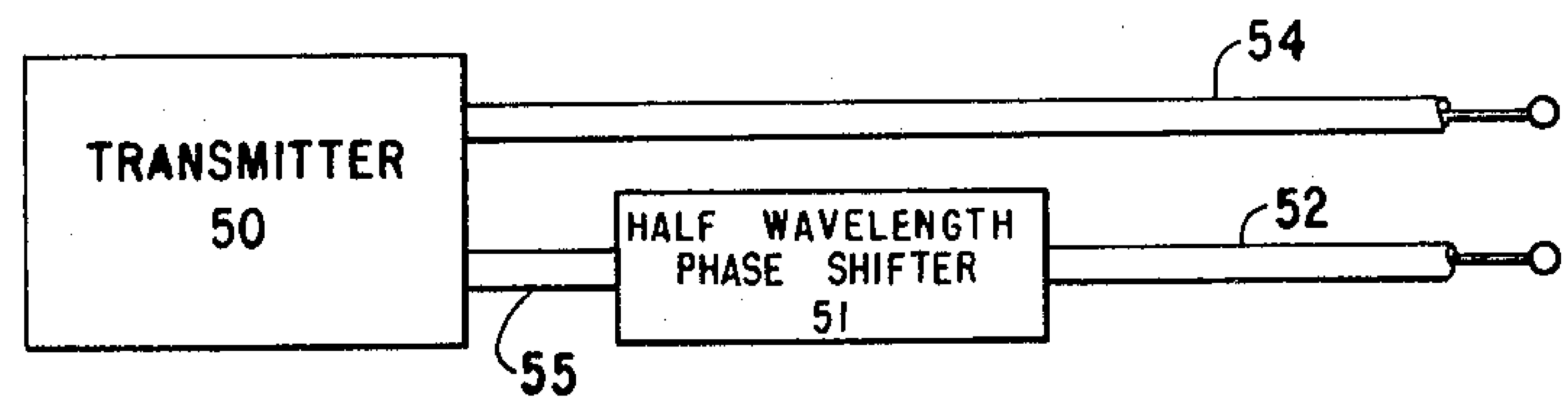

FIG. 2

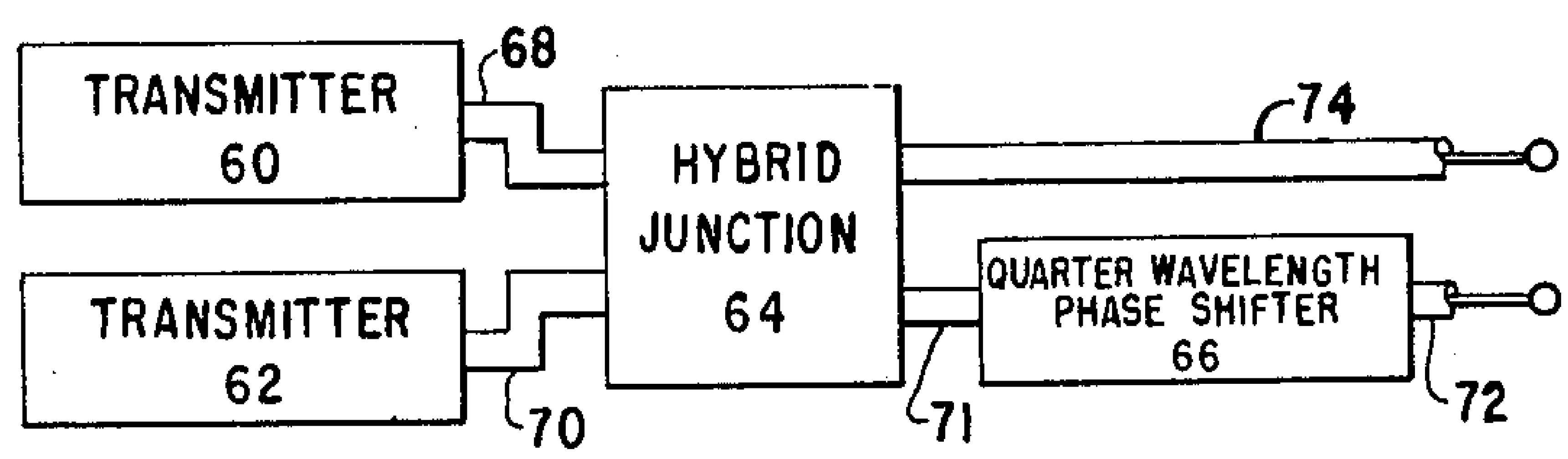

FIG. 3

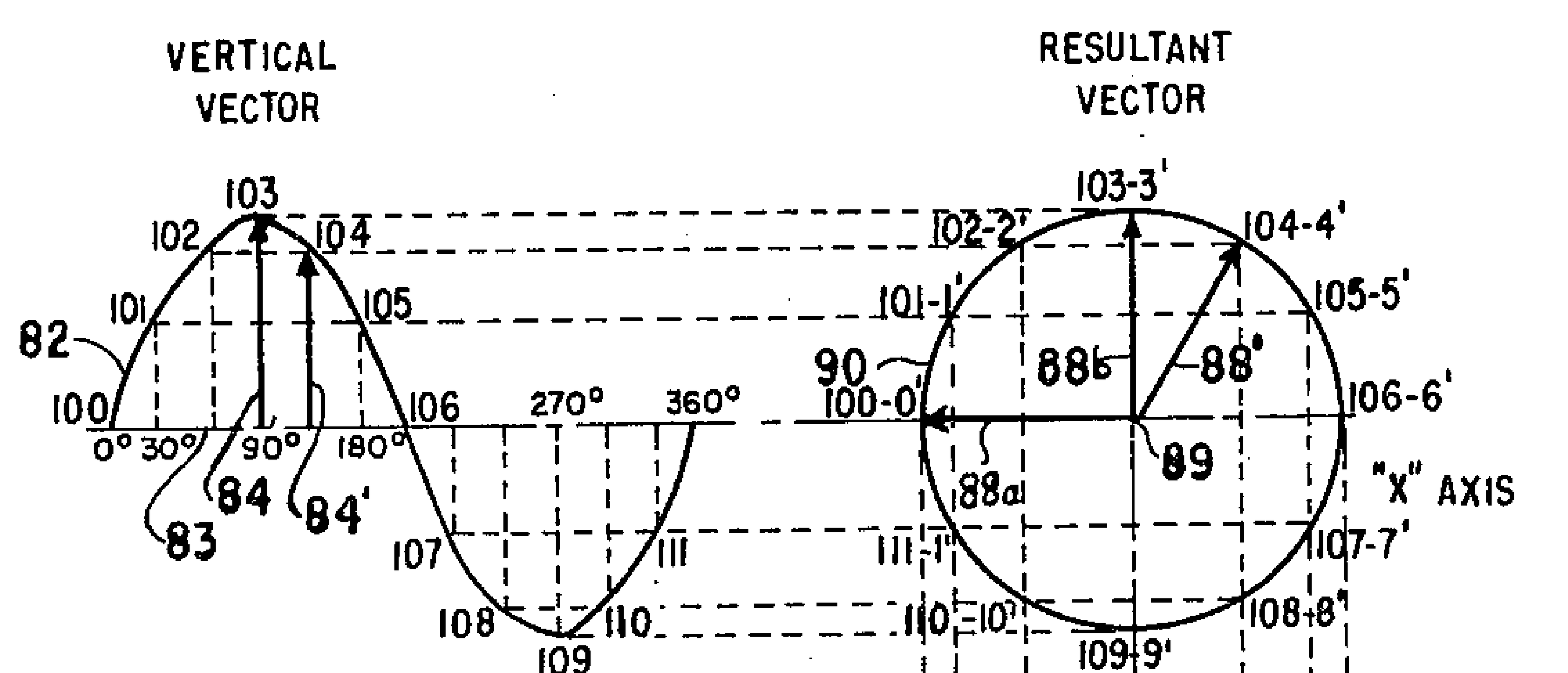
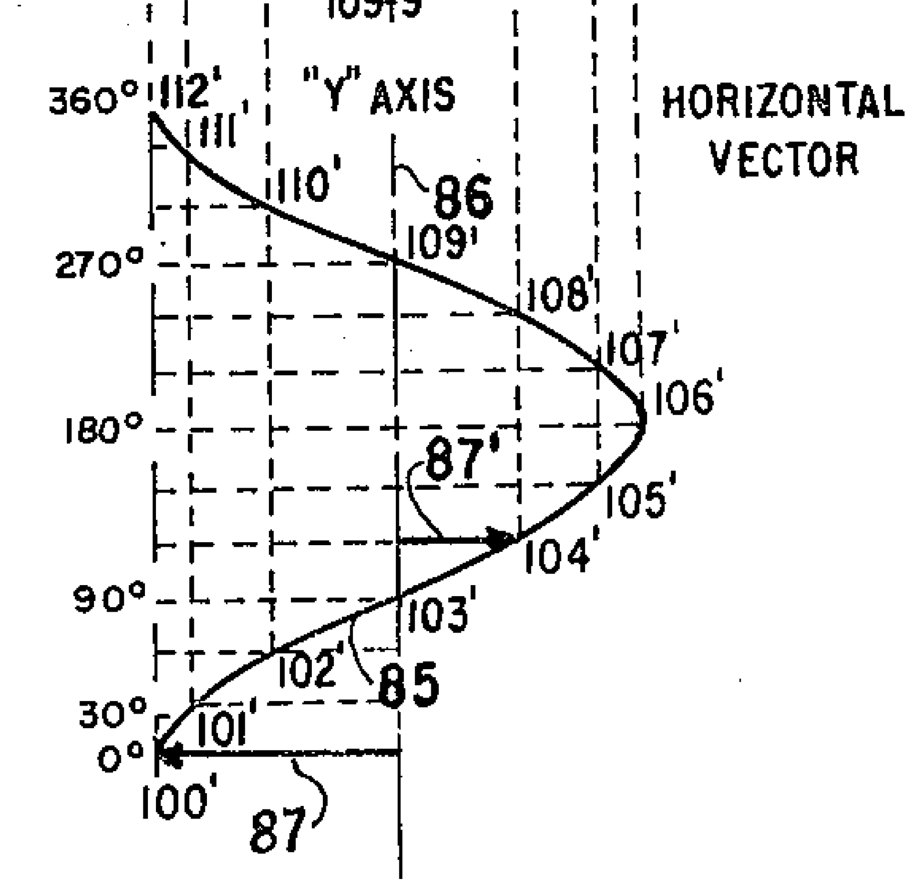

FIG.5

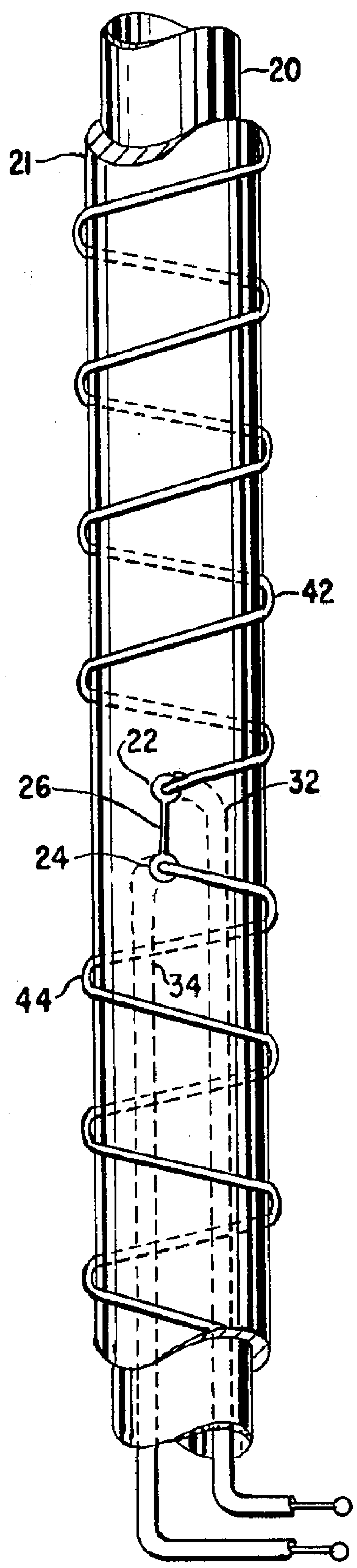

FIG. 1

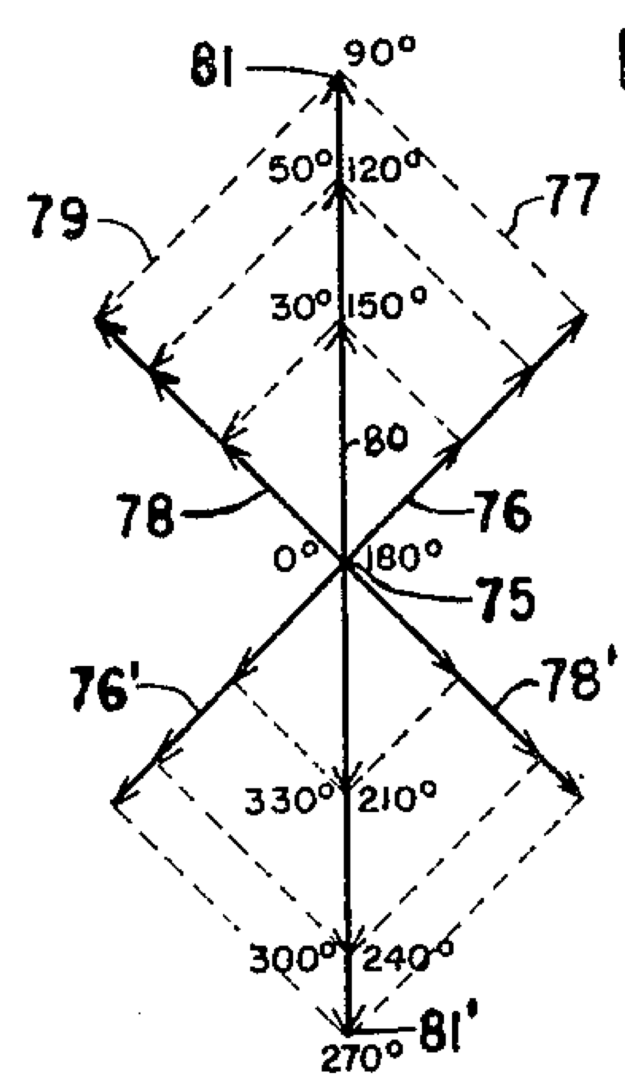

FIG. 4

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Sept. 20, 1960 L. O. KRAUSE 2,953,786

ANTENNA FOR POLARIZED PROPAGATION

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0° PHASE DIFFERENCE

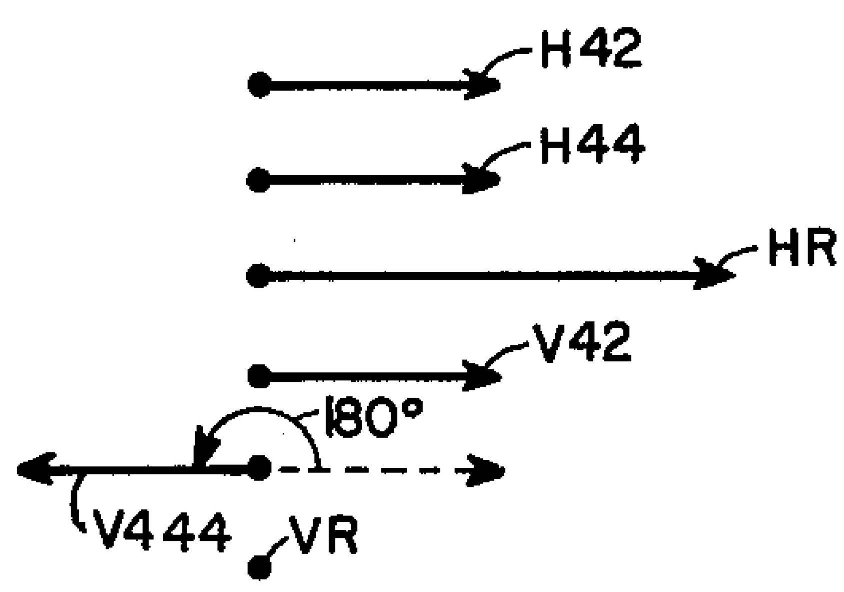

FIG. 6

90° PHASE DIFFERENCE

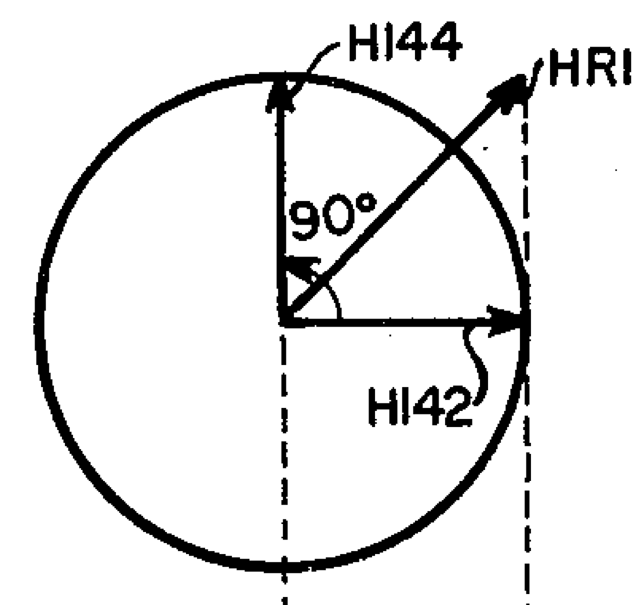
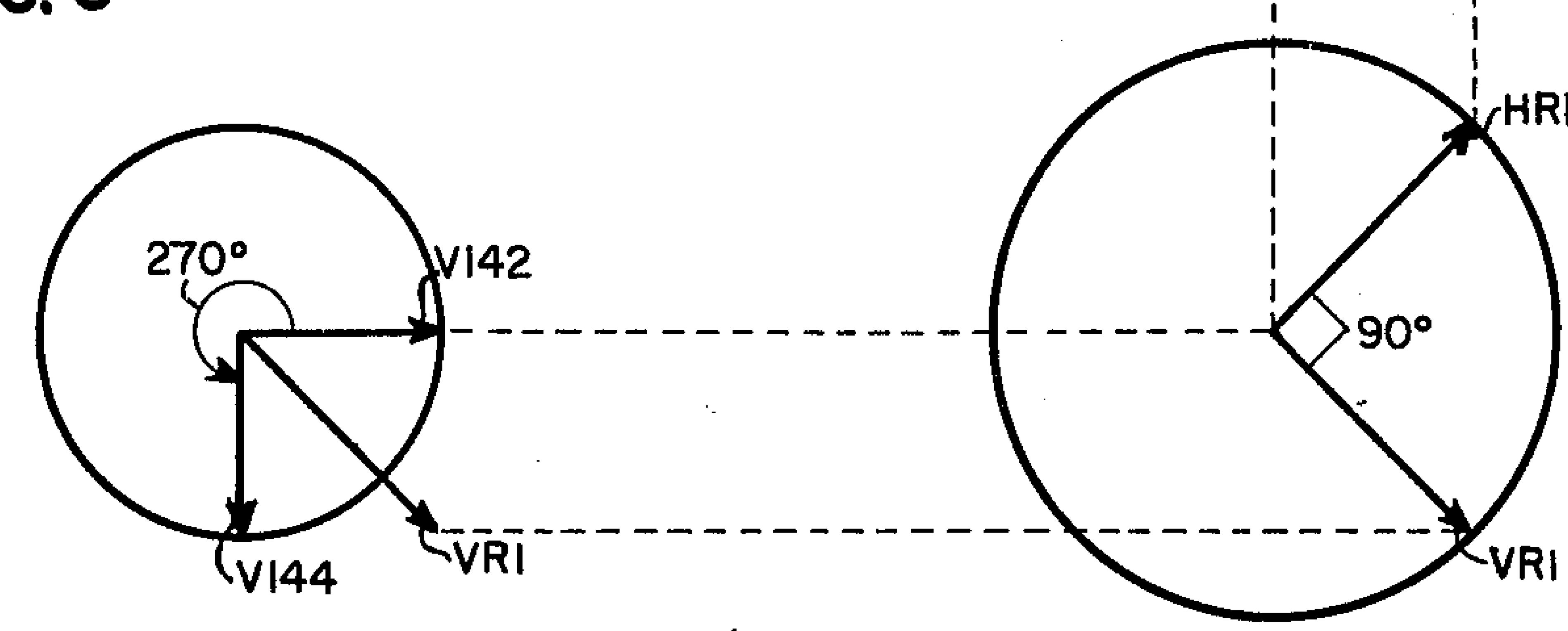

FIG. 7

180° PHASE SHIFT

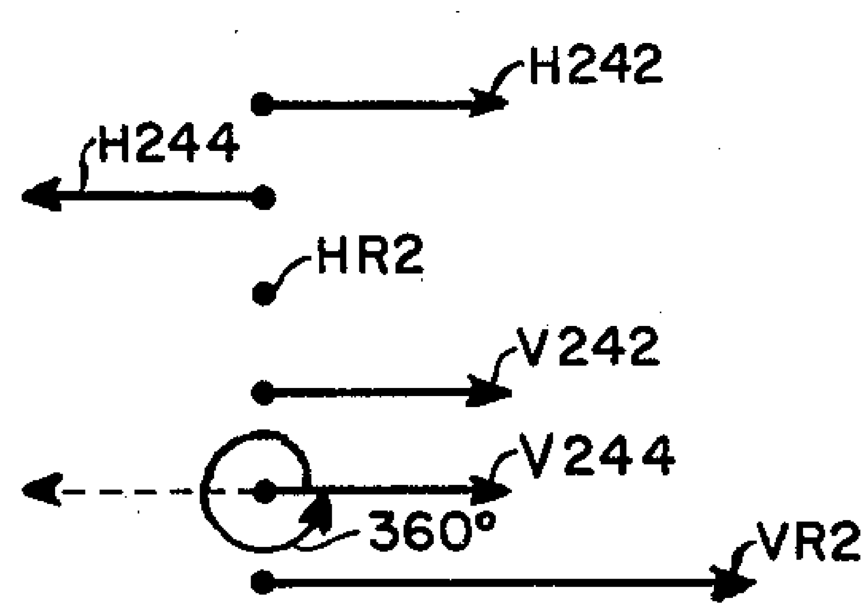

FIG. 8

225° PHASE SHIFT

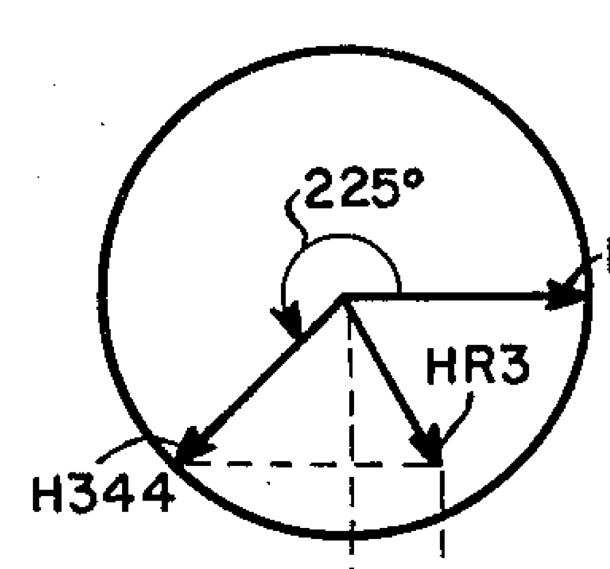
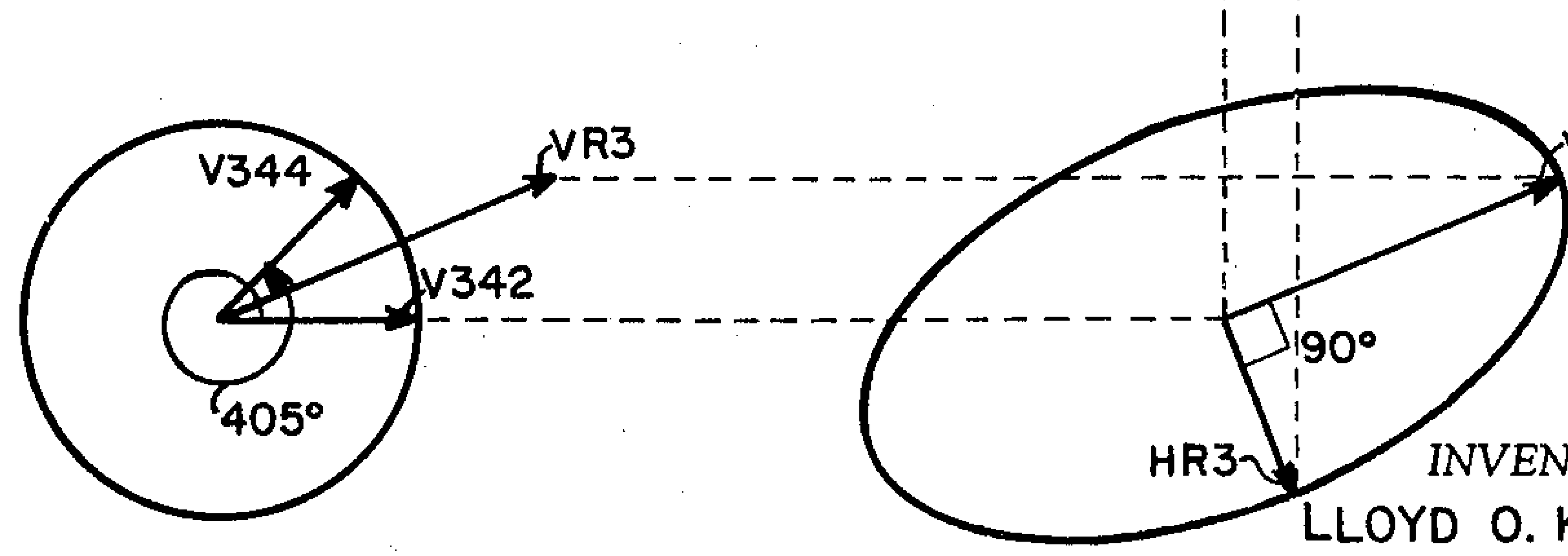

FIG. 9

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ANTENNA FOR POLARIZED PROPAGATION

Lloyd O. Krause, North Syracuse, N.Y., assignor to General Electric Company, a corporation of New York

Filed June 4, 1958, Ser. No. 739,748

12 Claims. (Cl. 343—895)

This invention relates to antenna structures of the kind used for the radiation and reception of electromagnetic energy and more particularly to antenna systems for radiating and receiving high frequency energy having a broad azimuth directivity.

In many communication and television applications, there is a need for radiating electromagnetic energy from a central source to a plurality of fixed or mobile receivers at any azimuth position about the central source. The radiation should be omnidirectional to permit the uniform distribution of the radiant energy to all points in circles concentric with the central source. Such a distribution affords the most efficient utilization of the available electromagnetic energy when the receivers are uniformly distributed over a given area or when the mobile receivers have equal probabilities of being at any position within the area. Unfortunately, many of the available communication antenna systems have limited directivity. The radiation patterns of such antennas show directions wherein the signal strength at particular azimuth angles is greater than the signal strength at other azimuth angles. Therefore, mobile receivers may go between areas of low signal strength and areas of high signal strength thereby affecting proper operation of the mobile receivers.

Although there are available communication antenna systems which are substantially omnidirectional, their radiation efficiency is limited by the spread in the elevation distribution of the electromagnetic energy. The elevation distribution may be defined as distribution in planes normal to the surface of the earth. When communication antenna systems transmit line of sight range signals, i.e., F.M. or television, most of the electromagnetic radiation transmitted in directions above the horizon is incapable of reception and therefore wasted. To minimize the amount of unavailable radiation transmitted by such antenna systems, it is necessary to decrease the angular spread of the radiation elevation distribution.

Many techniques employing complicated arrays and stacks have been employed in obtaining more desirable elevation directivity characteristics. The resultant antenna systems are usually complex and expensive. However, a very satisfactory solution of the problem is obtained by using a helical antenna described and claimed in the copending United States application of Lloyd O. Krause and Howard G. Smith, Serial No. 732,482, filed May 2, 1958, as a continuation of Serial No. 271,374, filed February 13, 1952, now abandoned, which is assigned to the same assignee. The above cited helical antenna is of the side fire type. However, the helical antenna, besides being of the side fire type, radiates electromagnetic energy having its active component polarized normal to the antenna axis. Since a side fire antenna has a radiant energy flow normal to (radially from) the axis of the antenna, the vertical mounting of such an antenna yields the desired omnidirectional radiation pattern. However, since the active component (electric field component) of the radiation is normal to the antenna axis,

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vertical mounting results in what is known as horizontally polarized electromagnetic radiation. Horizontally polarized radiation has many useful applications, for example, in the transmission of television signals, but there are instances when vertical or circular polarization are more desirable.

In the mobile communications art, vertically polarized radiation is less susceptible to certain types of interference. Therefore, many mobile systems employ such radiation. Further, the vertical mounting of a whip antenna on a vehicle is much simpler than the mounting of a horizontal antenna. Vertically mounted antennas are highly sensitive to vertically polarized electromagnetic radiation.

It is accordingly a general object of the invention to provide an improved antenna system.

It is a more specific object of the invention to provide an improved antenna system which, while having broad azimuth distribution characteristics, has a desirable minimum of elevation distribution.

It is a more specific object of the invention to provide an antenna system which has a high efficiency of radiation.

It is an object of one aspect of the invention to provide a highly efficient antenna system for radiating over a broad azimuth range vertically polarized electromagnetic radiation.

It is another object of this aspect of the invention to provide an improved directional antenna system for radiating vertically polarized electromagnetic radiation.

Briefly, in accordance with a general aspect of the invention, an antenna system is provided which includes a linear conductor. A second conductor is developed about the linear conductor in a given direction. The second conductor extends from a first point along the length of the linear conductor toward a first of its ends. A third conductor is also developed in the same direction about the linear conductor. The third conductor extends from a second point along the length of the linear conductor towards its other end. The first point is disposed between the second point and the first end of the linear conductor. A first energization terminal is coupled to the linear conductor. Second and third energization terminals are respectively coupled to the second and third conductors (preferably but not necessarily at said first and second points respectively) for receiving signals to be radiated by the second and third conductors.

In accordance with a specific aspect of the invention, the azimuth orientation of the first and second points is predetermined. A signal is fed between the first and second energization terminals and the same signal with a time phase relation is fed between the first and third energization terminals so that the energy radiated from the second and third conductors interacts to establish resultant vertically polarized electromagnetic radiation.

In some communication systems or in some military applications, it is highly desirable to transmit first and second classes of information signals from an antenna system. It has been the usual practice to provide an antenna system having separate antennas for radiating the energy associated with the two classes of information. Attempts to radiate the energy associated with both classes of information often result in interferences between the two signals.

Furthermore, to increase their versatility these systems often require that the electromagnetic radiation associated with each class of information be transmitted in mutually orthogonal modes of polarization. That is, the radiation associated with the first class of signals be vertically polarized while the radiation associated with the second class of information be horizontally polarized.

It is, therefore, an object of a second specific aspect of the invention to provide an antenna system which requires a single antenna structure to radiate the energy associated with two classes of information signals.

It is another object of this second specific aspect of the invention to provide an antenna system which, while employing a single antenna structure, permits the radiation of electromagnetic energy associated with two classes of information within a minimum of mutual interference.

It is a further object of this aspect of the invention to provide an antenna system which permits the radiation of energy associated with two classes of information signals wherein the electromagnetic radiation associated with one class of information is vertically polarized and the electromagnetic radiation associated with the other class of information is horizontally polarized.

Briefly, in accordance with this second aspect of the invention, the above described antenna system is employed with a modified signal feeding means. The signal feeding means permits the feeding of the information signals of the first class between the first and second energization terminals of the antenna system in a given time phase, while feeding the same information signals between the second and third energization terminals in an out-of-phase relationship so that the resultant electromagnet radiation is vertically polarized. At the same time the signal feeding means permits the feeding of the information signals of the second class between the first and second terminals in a given time phase and feeding the same information signals in the same time phase between the first and third energization terminals so that the resultant electromagnetic radiation associated with the second class of information signals is horizontally polarized.

It should be noted that such a system minimizes the interaction between the electromagnetic radiation associated with the first and second classes of information signals when the operating frequencies associated with these information signals are different from each other.

Although linear polarization, whether horizontal or vertical, is desirable in communication and military applications, there is often a need for circularly polarized electromagnetic radiation. For example, circular polarization has been found particularly valuable in VHF FM communication systems and of possible value in television systems. One reason is that linearly polarized electromagnetic radiation when reflected changes polarization to some extent. Therefore, if the receivers are surrounded by high objects which prevent line of sight reception, the electromagnetic radiation initially transmitted with a predetermined linear polarization may be received by a correspondingly oriented antenna after reflection at a different polarization. However, when circularly polarized electromagnetic radiation is reflected there is usually a strong enough linear component to ensure adequate reception under most conditions. It is therefore an object of another specific aspect of the invention to provide an improved antenna system for radiating circularly polarized energy.

It is another object of this aspect of the invention to provide an improved antenna system for radiating over a broad azimuth range circularly polarized electromagnetic energy.

It is a further object of this aspect of the invention to provide an improved omnidirectional antenna system for transmitting circularly polarized electromagnetic radiation.

Briefly, in accordance with this third specific aspect of the invention, the antenna system of the second specific aspect of the invention handles a single kind of information signals. Thus, when the signal feeding means feeds the information signals to the energization terminals in the above described manner, there is an interaction between the electromagnetic radiation transmitted from the second and third conductors. Since the antenna system is now radiating both horizontally and vertically polarized radiation of the same frequency, the resultant polarization will be circular when there is a ninety degree time phase displacement between the linearly polarized electromagnetic waves.

Additional objects, features and advantages of the invention will be apparent from the following detailed description when read with the accompanying drawings in which:

Figure 1 shows an antenna structure which permits the radiation of electromagnetic energy with predetermined polarization in accordance with a general aspect of the invention as determined by the signal feeding means coupled to the antenna structure;

Figure 2 shows a signal feeding means for coupling to the antenna structure of Figure 1 to permit the radiation of vertically polarized electromagnetic energy in accordance with a specific aspect of the invention;

Figure 3 shows a signal feeding means for coupling to the antenna structure of Figure 1 to permit the transmission of either crossed polarized electromagnetic energy related to two classes of information signals or the transmission of circularly polarized electromagnetic energy related to a single information signal in accordance with further aspects of the invention;

Figure 4 is a vector diagram to show the interaction of the electromagnetc radiation transmitted by the antenna structure of Figure 1 when coupled to the feeding means of Figure 2 to establish a vertically polarized electromagnetic wave;

Figure 5 is another vector diagram to show the vector interaction required to establish circularly polarized radiation;

Figures 6 to 9 are alternate vector diagrams using time as a parameter to show the vector interactions required to establish different forms of polarized energy. In particular, Figure 6 shows the interaction which produces horizontal polarization; Figure 7 the interaction for circular polarization; Figure 8 for vertical polarization; and Figure 9 for elliptically polarized radiation.

I. *General description of helical antenna systems*

Helical antenna systems may be grouped into two characteristic types, side fire and end fire.

In the side fire type with which the subject application is concerned, the antenna system is vertically mounted with respect to the earth, and the radiation pattern may be either linearly or circularly polarized. More exactly, the volumetric radiation pattern of the side fire type is a solid of revolution about the antenna axis of a directive lobe normal to the axis. The radiation from an end fire helical antenna system such as is described and claimed in the copending United States application of Paul M. Pan, Serial No. 646,837 filed March 18, 1957, and assigned to the same assignee, is concentrated along the axis of the helical antennas. The radiation may also be either circularly or linearly polarized.

The side fire type is particularly useful in television broadcasting and in communication systems where receiving locations are in various directions. The end fire type is particularly useful for directed communications and in radar systems.

Side fire types may be arrayed; that is, a number of helical antennas may be supported end to end along a common axis. The side fire types when arrayed (stacked) produce a more concentrated radiation pattern in directions normal to the common axis.

Each helical antenna comprises a series of single turns or helices. When the helical circumference is approximately some integral number of operating wavelengths, for example, two or four wavelengths, and is driven between a point on the helix and a concentric conducting mast, the normal mode of radiation dominates; that is, the helical antenna is of the side fire type.

Each of the various embodiments of the invention has one major characteristic in common; each comprises at least two radiating conductors which are wound in the same circumferential direction and in opposite axial directions about a concentric conductor and each of the radiating conductors has a separate feeding means.

II. *Antenna system* (*Fig. 1*)

A single bay system for radiating electromagnetic energy in which two helical antennas are arranged coaxially about a concentric central conductor is shown in Figure 1. It should be noted, however, that in some installations it may be desirable to axially stack several of the single bay systems to form a multi-bay system.

The system generally comprises a central conductor **20**, which may also serve as a mast. The central conductor **20** is mounted on a support means (not shown) which may be a tower or the top of a high building. An insulator **21** sheaths the central conductor **20**. A first energization terminal **22**, mounted in the insulator **21**, insulatively extends through the central conductor **20** for connection to the inner conductor of the coaxial line **32**. A second energization terminal **24**, mounted in the insulator **21**, also insulatively extends through the central conductor **20** to connect to the inner conductor of the coaxial line **34**. Each of the outer conductors of the coaxial lines **32** and **34** may be coupled to the central conductor **20** in a conventional manner. It should be noted, however, that these separate connections of the outer conductors are equivalent to a single connection to the central conductor **20**, which is hereinafter termed a third energization terminal **26**.

The energization terminals **22**, **24** and **26**, and the coaxial lines **32** and **34** can be considered as a coupling system for coupling energy from an energy source to the radiating conductors **42** and **44**.

Insulating means, such as the insulator **21** or the equivalent, disposed about the central conductor **20**, support the radiating conductor **42** which is connected to the first energization terminal **22** and the radiating conductor **44**, which is connected to the second energization terminal **24**. The radiating conductors **42** and **44** are of the helical type which respectively extend in opposite axial directions from the energization terminals **22** and **24**.

In particular, the radiating conductor **42** and the radiating conductor **44** are helical radiative conductors which extend in axially progressive turns about a circular central conductor **20**, which functions as a conductive support structure. The radiating conductor **42** is shown as a right-handed helix, that is, it is developed about the central conductor **20** from its starting point opposite the energization terminal **22**, in the same manner as the threads of a right-handed screw. Similarly the radiating conductor **44** is a left-handed helix; that is, tracing it from its starting point opposite the energization terminal **24**, it follows a path similar to the path of threads of a left-handed screw.

The radiating conductors **42** and **44** each has an axial helical length (aperture) preferably in the range between one and one-half and five operating wavelengths and a helix diameter and pitch such that the circumference of each turn preferably equals an integral number of operating wavelengths. The radiating conductor **42**, connected at one end to the energization terminal **22**, winds in one direction around the insulator **21** which encircles the central conductor **20**. The radiating conductor **44**, which is connected at one end of the energization terminal **24**, winds in the same direction. The ends of each of the radiating conductors **42** and **44** may be supported free or in contact with the central conductor **20**.

The energization terminals **22** and **24** preferably have the same azimuth position and arbitrary axial displacement so that the radiating conductors **42** and **44** are symmetrical on either side of a plane located midway between the energization terminals **22** and **24**, and perpendicular to the axis of the central conductor **20**. Such a symmetry permits the interaction of the electromagnetic energy radiated from each of the radiating conductors **42** and **44** to provide for controlled polarization of the resultant radiation.

Further, by providing equicircumferential turns each of an integral number of operating wavelengths, all points on the radiating conductors **42** and **44** having the same azimuth direction radiate the same phase of signal. The electromagnetic radiation from these points interact with each other to provide an equiazimuth distributed radially propagated resultant electromagnetic wave which has a controlled elevation distribution.

There is a relationship between the radial spacing between a radiating conductor and central conductor and the length of the radiating conductor. There is a further relationship between these two dimensions and the helical pitch of the radiating conductors. In general, the radial spacing between a radiating conductor and central conductor determines the characteristic impedance of the radiating system. Also, the smaller the spacing between the central conductor and a radiating conductor, the smaller the radiation per unit length of radiating conductor. Therefore, given a specific attenuation per unit length, it is possible to choose the length of the radiating conductor commensurate with radial spacing to insure that any signal propagated along a radiating conductor is substantially completely attenuated upon reaching the end remote from its energization terminal. Thus the termination of radiating conductors **42** and **44** is neither important nor critical.

A further understanding of these relations may be obtained by considering the radiating conductors and the central conductor to form sections of a radiating transmission line. Electromagnetic energization applied between adjacent ends of the radiating conductors and the central conductor cause electromagnetic waves to travel along the length of the radiating conductors away from the points of energization. In order to constrain the propagation to travel in the helical path instead of the axial path as in a coaxial transmission line, the coupling between a turn of the radiating conductor and the central conductor must be greater than the coupling between adjacent turns of the radiating conductor. In general, the radiating conductor pitch is greater than the radial spacing between the radial conductor and the central conductor. Furthermore, as the electromagnetic waves travel along the radiating conductors, they gradually decay due to the radiation of the electromagnetic energy from the radiating conductors. Therefore, by making the radiating conductors of sufficient length, reflections of electromagnetic waves from remote ends of the helical conductors can be made substantially insignificant in effect. Typical values for a specific case would be 0.1 operating wavelengths radial spacing, 2 operating wavelengths per helical turn, .5 operating wavelengths helical pitch, 5 turns per helix, with 20–26 decibels of attenuation to the end.

Since the radiating conductors **42** and **44** and the central conductor **20** can be considered as a pair of radiating transmission lines being fed from adjacent ends, the coaxial lines **32** and **34** are respectively coupled between the energization terminals **22** and **26** and **24** and **26** in the following manner. The inner conductor of the coaxial line **32** is coupled via the energization terminal **22** to the radiating conductor **42**, while the outer conductor of the coaxial line **32** is coupled via the energization terminal **26** to the central conductor **20** to provide a feeding means for the upper radiating transmission line which comprises the radiating conductor **42** and the central conductor **20**. Similarly, the inner conductor of the coaxial line **34** is coupled via the energization terminal **24** to the radiating conductor **44**, while the outer conductor of the coaxial line **34** is coupled via the energization terminal **26** to the central conductor **20** to provide a feeding means for the lower radiating transmission line which comprises the radiating conductor **44** and the central conductor **20**.

The apparatus so far discussed provides an omnidirectional side fire antenna system. The polarization of the electromagnetic radiation is dependent on the signals (particularly their phasing) transmitted to the feed means. Several types of linear and circular polarization are obtainable.

III. *Generation of linearly polarized electromagnetic radiation*

In general, the electric field component of an electromagnetic wave radiated from a linear conductor is parallel to the length of the linear conductor and has an amplitude and direction related to the amplitude and direction of signal current flowing in the linear conductor. As the electromagnetic field radiates from the linear conductor, the orientations are maintained. Since incremental lengths of the radiating conductors **42** and **44** may be considered as small linear conductors, the electric field components associated with their radiation should have a similar parallelity. Thus the electric field components should be linear and making an angle with the axis of the central conductor which is the same as the pitch angle of the radiating conductors.

Electric field components have the property of interacting with each other. They are vector quantities which are governed by the laws of vector algebra. Since examples associated with these vector interactions are hereinafter more fully described and shown, it will for the present be stated that when the electric field components radiated from the radiating conductors **42** and **44** have direction symmetry about the horizontal plane, but opposite senses, they interact to produce resultant electric field components that are vertically polarized. The structural symmetry of the radiating conductors **42** and **44** ensure that the electric field components have directional symmetry. Their sense is determined by the instantaneous polarity of the signal current flowing in the radiating conductors. Thus, when there are opposite polarities of signal currents at corresponding points on the radiating conductors, the electric field components will have opposite senses. To produce the opposite polarity signal currents it is necessary to feed each radiating conductor with the same signal but completely out of phase, i.e., one radiating conductor receives the signal and the other radiating conductor receives the same signal, but one hundred and eighty degrees out of phase. In other words, the radiating conductors **42** and **44** of Figure 1 are fed in push-pull.

Accordingly, Figure 2 shows apparatus for generating the desired out of phase signals. The apparatus includes a transmitter **50** and a half wavelength phase shifter **51**. One output terminal of the transmitter **50** is coupled via the coaxial line **55** to the half wavelength phase shifter **51**. The coaxial line **54** is coupled to another output terminal of the transmitter **50**, while the coaxial line **52** is coupled to the output terminal of the half wavelength phase shifter **51**. To transmit vertically polarized electromagnetic radiation, it is only necessary to couple coaxial lines **52** and **54** respectively to the coaxial lines **32** and **34** of Figure 1.

Since transmitters and half wavelength phase shifters are well known in the art, only their general requirements will be discussed. It should be noted that by using a conventional push-pull amplifier for the output of the transmitter **50**, there is no need for a phase shifting circuit. If a phase shifting circuit is employed, it is necessary to ensure that signal attenuation of any consequence introduced by the phase shifting circuit, such as the half wavelength phase shifter **51**, be compensated. One method is to introduce an attenuator at either end of the coaxial line **54**. However, a more satisfactory means of compensation is to feed a greater amplitude signal to the coaxial line **55** than to the coaxial line **54**.

There has thus been shown means for generating out of phase signals which produce electric field components of opposite sense to yield a resultant electromagnetic field having vertical polarization, in accordance with one embodiment of the invention.

When the electric field components are in the same direction and have the same sense, the resultant radiation is horizontally polarized. Again, since the antenna system of Figure 1 will radiate electric field components having the same direction, it is necessary to provide for a similarity of sense. In other words, the polarities of the signals on corresponding points of the radiating conductor must be the same. In accordance with another embodiment of the invention, to provide for the same polarity it is necessary to feed the same signal without any relative phase shift (push-push) to each of the radiating conductors.

By providing predetermined relative phase shifts of the two signals fed to the antenna system of Figure 1, it is possible to produce radiation having a corresponding angle of polarization, in accordance with other embodiments of the invention.

IV. *Generation of crossed polarized electromagnetic radiation*

It has been shown in section III that by feeding the radiating conductors in push-pull, the resultant electromagnetic radiation is vertically polarized and by feeding the radiating conductors in push-push, the resulting electromagnetic radiation is horizontally polarized.

If a first frequency signal is fed to the radiating conductors in push-pull and a second frequency signal is fed to the radiating conductors in push-push, crossed polarized electromagnetic radiation is radiated by the antenna system, i.e., there will be vertically polarized radiation of the first frequency signal and horizontally polarized radiation of the second frequency signal.

The first and second frequency signals may be fed alternately or simultaneously. Simultaneous feeding permits the transmission of two classes of information from the same antenna system. A possible application could be in television wherein the audio signals and the video signals might be simultaneously transmitted over different carriers.

There is little interaction of the two signals provided suitable diplexing means are used in the feed system.

Figure 3 shows apparatus for coupling to the antenna system of Figure 1 for transmitting two cross polarized electromagnetic waves. The apparatus includes first and second transmitters **60** and **62**, a hybrid junction **64**, and a quarter wavelength phase shifter **66**. The transmitters **60** and **62** are respectively coupled via the coaxial lines **68** and **70** to the hybrid junction **64**. A first output terminal of the hybrid junction **64** is coupled via the coaxial line **74** to the coaxial line **34** (Fig. 1), and a second output terminal of the hybrid junction **64** is coupled via the coaxial line **71**, the quarter wavelength phase shifter **66**, and the coaxial line **72** to the coaxial line **32** (Fig. 1).

Each of the transmitters **60** and **62** may be of conventional design for transmitting two forms of signal intelligence. The hybrid junction **64** may be of the well-known "ring" variety, having the following properties: Signals received via the coaxial line **68** are transmitted in the same phase via the coaxial line **74** and via the coaxial line **71** lagging in phase by a quarter of an operating wavelength. Similarly, signals received via the coaxial line **70** are transmitted in the same phase via the coaxial line **71** and via the coaxial line **74** lagging in phase a quarter of an operating wavelength. The quarter wavelength phase shifter **66** may be one of the many well-known in the art. The basic function of the phase shifter **66** is the introduction of a lagging phase shift of a quarter of an operating wavelength in the signals received via the coaxial line **71**.

In operation, a signal is transmitted from transmitter **60** via the coaxial line **68** to the hybrid junction **64**. The hybrid junction **64** transmits this signal without relative phase shift to the coaxial line **74**. The signal is also transmitted to the coaxial line **71** with a quarter of an operating wavelength phase delay. The delayed signal is further phase delayed another quarter of an operating wavelength by the quarter wavelength phase shifter **66**. It is therefore transmitted via the coaxial line **72** to the coaxial line **32**, phase-shifted half an operating wavelength. Since the signal on the coaxial line **74** has no phase shift and the signal on the line **72** has a half an operating wavelength phase shift, the signal from the transmitter **60** is fed to the antenna system in push-pull and the resultant electromagnetic radiation is vertically polarized.

At the same time, a signal is transmitted from the transmitter **62** via the coaxial line **70** to the hybrid junction **64**. This signal is transmitted from the hybrid junction to the coaxial line **71** without relative phase shift and to the coaxial line **74** with a quarter of an operating wavelength lagging phase shift. The quarter wavelength phase shifter **66** introduces a quarter of an operating wavelength lagging phase shift in the signal on the coaxial line **71** during its transmission to the coaxial line **72**. The signals from the transmitter **62** which are now present on the coaxial lines **72** and **74**, both have a phase delay of a quarter of an operating wavelength and are therefore in phase with each other. Thus, the signals from the transmitter **62** are fed to the antenna system in push-push and the resultant electromagnetic radiation is horizontally polarized.

It has therefore been shown that by using apparatus of Figure 3 to feed the antenna system of Figure 1, it is possible to generate two electromagnetic waves that are crossed polarized, that is, one electromagnetic wave is horizontally polarized while the other is vertically polarized.

V. *Generation of circularly polarized electromagnetic radiation*

As is hereinafter more fully described, there are three basic requirements for producing circularly polarized electromagnetic radiation. There must be a vertically polarized electromagnetic wave and a horizontally polarized electromagnetic wave, both electromagnetic waves must have the same operating frequency and amplitude, and there must be a quarter of an operating wavelength phase difference between the two electromagnetic waves.

In section IV there has been described apparatus for simultaneously transmitting horizontally and vertically polarized electromagnetic waves. By suitably modifying the apparatus of Figure 3, the remaining requirements for producing circularly polarized electromagnetic radiation are satisfied. First, the transmitters **60** and **62** must generate the same signal. It may be more desirable to use a single transmitter such as the transmitter **60**, and feed both coaxial lines **68** and **70**, in parallel. To ensure that equal amplitude signals are transmitted to the antenna system, it may be further necessary to introduce a conventional attenuator in the coaxial line **74**, to compensate any attenuation of consequence in phase-shifter **66**. Additionally the antenna helix pitch angles must be suitably adjusted for equal horizontal and vertical components. With these modifications, the electromagnetic radiation from the antenna system will be circularly polarized.

There has thus been shown apparatus for transmitting circularly polarized omnidirectional electromagnetic radiation.

VI. *Vector algebra*

Many physical quantities are best represented by vectors or directed line segments which both indicate magnitude and direction. These physical quantities include forces, velocities, and the electric field component of an electromagnetic wave.

Vectors may be added by means of several graphical methods. Figure 4 shows the parallelogram method. A first vector **76** extends from a point **75** while a second vector **78** also extends from the same point. A line **79** is drawn from the arrowheaded tip of the vector **78** parallel to the vector **76**. Another line **77** is drawn from the tip of the vector **76** parallel to the vector **78** to form a parallelogram. The resultant vector is the diagonal of this parallelogram drawn from the point **75** to point **81**.

The vectors shown in Figure 4 actually represent the electric field components of the antenna system of Figure 1 when it is fed a sinusoidal signal in push-pull. The points shown are for one cycle of the sinusoidal signal at thirty degree intervals. It should be noted at each thirty degree point that the resultant vector is vertical. Thus the resultant of the electric field component of the electromagnetic radiation is vertically polarized.

Figure 5 shows the vector addition which produces a rotating vector. The curve **82** which is disposed about the horizontal (X) axis **83** represents the instantaneous magnitudes of a sinusoidally varying vertically directed vector **84**, while the curve **85** disposed about the vertical (Y) axis **86** represents the instantaneous magnitudes of a horizontally directed vector **87**. It should be noted from the angular coordinates along each axis that there is a ninety degree (quarter operating wavelength) phase difference between the two vectors. It should be further noted that the maximum amplitudes of both of the vectors **84** and **87** are equal and their sinusoidal periods (frequency) are also the same.

At the beginning of the sinusoidal period (zero degrees), the vertically directed vector whose amplitude is represented by the point **100** has zero amplitude while the horizontally directed vector **87** has a maximum positive value (point **100′**). The resultant vector **88*a*** is shown on the circle **90** as a line from the center **89** of the circle to the point **100–0′**. Consequently, the resultant electric vector is horizontal as indicated.

During the first quarter cycle, the vertically directed vector increases in magnitude while the horizontally directed vector decreases in magnitude and the resultant vector rotates. Its amplitude remains constant but its direction sweeps out ninety degrees of arc on the circle **90**. The points **101–1′**, **102–2′** and **103–3′** represent the resultant directions respectively for the 30, 60 and 90 degree points in the sinusoidal cycle. The resultant vector **88*b*** is the resultant at the 90 degree point. It is basically the vertically directed vector **84**, since at this point the horizontally directed vector has zero amplitude. During the second quarter cycle, the vertically directed vector decreases in amplitude and the horizontally directed vector increases in amplitude in an opposite direction. The resultant vector sweeps out another ninety degree arc on the circle **90**. For example, the vector **88′** represents the resultant of the vertically directed vector **84′** and the horizontally directed vector **87′** at the 120 degree point in the sinusoidal cycle. The process continues for the complete sinusoidal cycle and a complete circle is traced out.

There is an alternate way of visualizing the interaction of the electric field components radiated from the radiating conductors **42** and **44** (Fig. 1). The radiating conductor **42** is a right-handed helix extending toward one end of the central conductor **20** and the radiating conductor **44** is a left-handed helix extending toward the opposite end of the central conductor **20**. Incremental lengths of the radiating conductors radiate electric field components that are parallel to their length. When there is symmetry of the radiating conductors **42** and **44** about the horizontal plane which bisects the space between the energization terminals **22** and **24**, no relative time phase shift is introduced between the electric field components radiated from the incremental lengths of the radiating conductors 42 and 44 which are the same distance from their associated energization terminals. Since energy introduced at the energization terminals 22 and 24 is radiated while traveling toward the ends of the radiating conductors 42 and 44, the direction of travel of energy along the incremental lengths determines the sense of the electric field components.

Each of the incremental lengths makes an angle with the horizontal plane. Thus, the electric field component associated with each incremental length makes a corresponding angle. Each of the electric field components can be separated into a horizontal and a vertical component. The sense of the horizontal components from each of the incremental lengths is the same, but the sense of the vertical components is opposite. Thus, when viewed from a point external to the antenna system it appears that there is a relative hundred and eight degree time phase shift introduced by the geometry of the helices on the vertical components but no time phase shift on the horizontal components. It should be noted that this effective time phase shift of the vertical components is also introduced regardless of the relative time phase relationship of the signals fed to the radiating conductors 42 and 44 by the associated energization terminals 22 and 24.

Figures 6–9 have been provided to more clearly point out the interaction of the electric field components of the radiating conductors 42 and 44 in terms of the time phase relationship of their horizontal and vertical components and several examples will be given. Each of the examples uses time as the variable to control the relationship of equal amplitude vectors instead of physical direction as heretofore described in Figures 4 and 5.

The vectors of Figs. 6–9 will be designated by an "H" or "V" representing the horizontal or the vertical component of the electric field component radiated by the radiating conductors 42 and 44 followed by a number indicating the radiating conductor. Thus, the vector H42 is the horizontal component of the electric field component radiated by the radiating conductor 42.

Figure 6 shows the vector diagram of the electric field components when there is no time phase difference between signals transmitted from the energization terminals 22 and 24. Since there is no time phase difference, the vector H42 has the same direction as the vector H44. Since the vector V42 is in time phase with the vector H42 it is similarly directed. However, the vector V44 is oppositely directed because of the effective one hundred eighty degree time phase shift introduced by the geometry of the helices. The vector HR is the resultant horizontal component and the vector VR is the resultant vertical component. It is seen that the horizontal component vectors H42 and H44 and to produce a resultant of double amplitude and the vertical component vectors subtract to yield a zero or null resultant. Thus, the electric field for push-push feed is linear polarization in the horizontal direction.

Figure 7 shows the vector diagrams when a ninety degree time phase shift exists between equal amplitude signals fed from the energization terminals 22 and 24. The vector H144 (the horizontal component of the electric field component radiated by the radiating conductor 44) lags by ninety degrees in time phase the vector H142 (the horizontal component of the electric field component radiated by the radiating conductor 42). The vector V144 lags the vector V142 by two hundred and seventy degrees (ninety degrees from the time phasing introduced at the energization terminals and one hundred and eighty degrees from the geometry of the helices). The resultant vectors of the sumations of the horizontal components is vector HR1 and of the vertical components is vector VR1. Vectors HR1 and VR1 are ninety degrees out of time phase. Since the resultant vectors HR1 and VR1 are of equal amplitude and in time phase quadrature, they interact to produce circularly polarized radiation, as previously described. It should be noted, however, that if the original horizontal and vertical components were of different amplitudes the resultant polarization would be elliptical.

Figure 8 shows the vector diagram when the signals feeding the energization terminals 22 and 24 are one hundred and eighty degrees out of time phase or push-pull. The vector H244 cancels the vector H242 because of the phase opposition relationship. However, the vector V244 reinforces the vector V242 because they are three hundred and sixty degrees out of time phase or effectively in phase since the vector V244 lags the vector V242 by one hundred and eighty degrees because of the time phase shift introduced in the signals fed to the energization terminals and lags another one hundred and eighty degrees because of the geometry of the helices. The resultant electric field component is therefore vertically polarized, as heretofore described for push-pull feed.

Figure 9 shows the vector diagram when the signals feeding the energization terminals 22 and 24 are two hundred and twenty-five degrees out of time phase.

The vector H344 lags the vector H342 by this two hundred and twenty-five degrees, and the vector V344 lags the vector V342 by four hundred and five degrees (two hundred and twenty-five degrees from the time phase shift introduced by the feeding means and one hundred and eighty degrees from the helical geomery). The resultant vectors HR3 and VR3 are of different amplitude and ninety degrees out of time phase to yield an elliptically polarized electric field component. However, it should be noted that for unequal amplitudes of the horizontal and vertical components the degree of ellipticity of polarization would be different. For example, for the case of Figure 9 with a 225° phase shift, a reduction in the amplitude of the vertical component yields a less elliptically polarized resultant.

In summary, it may be stated, that with equal amplitude components for time phase differences other than multiples of ninety degrees the polarization is elliptical. Circular polarization occurs for a ninety degree phase difference. Linear polarization occurs when the time phase differences are multiples of one hundred and eighty degrees.

It should be further noted that the above descriptions and explanations are related to the interactions of the electric field components at points in a plane bisecting the junction of the two helices and normal to their colinear axes. At other elevation angles there will be an apparent increasing or decreasing phase shift between the upper and lower helices because of the differences in space phase delay. Therefore, circular polarization in the above-mentioned plane will become more elliptical at points elevationally displaced from this plane.

VII. *Conclusion*

There has thus been shown an improved omnidirectional antenna system for efficiently radiating electromagnetic waves having predetermined polarizations. One embodiment of the invention comprises apparatus for transmitting omnidirectional vertically polarized electro-magnetic radiation. Further embodiments have been disclosed for transmitting crossed polarized electromagnetic radiation representing two kinds of intelligence from the same antenna structure. The crossed polarized radiation is transmittable over a broad azimuth range. Other embodiments of the invention comprise apparatus for radiating linearly polarized electromagnetic waves and apparatus for radiating circularly polarized electromagnetic waves having an omnidirectional radiation pattern.

While a number of specific embodiments of the invention have been described in detail, it should be apparent that many modifications and changes may readily be made without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a first conductor, a second conductor developed in a given direction about said first conductor and extending toward a first end of said first conductor, a third conductor developed in the same given direction about said first conductor and extending toward the opposite end of said first conductor, a first energization terminal coupled to said first conductor, a second energization terminal electrically insulated from said first energization terminal and coupled to said second conductor, and a third energization terminal coupled to said third conductor.

2. The antenna system of claim 1 wherein said second and third conductors are helical radiative conductors.

3. A side fire antenna comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix developed about said central conductor extending from a first point along the length of said central conductor toward one end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix developed about said central conductor extending from a second point along the length of said central conductor toward the other end of said central conductor, said first point being disposed between said second point and said first end of said central conductor, a first energization terminal coupled to said first radiative conductor, a second energization terminal electrically insulated from said first energization terminal and coupled to said second radiative conductor, a third energization terminal coupled to said central conductor, means for feeding a first kind of signal energy to said first and third energization terminals, and means for feeding a second kind of signal energy to said second and third energization terminals.

4. A side fire antenna comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix developed about said central conductor and extending from a first point along the length of said central conductor toward a first end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix developed about said central conductor and extending from a second point along the length of said central conductor toward the second end of said central conductor, said first point being disposed between said second point and the first end of said central conductor, each turn of each helix being an integral number of operating wavelengths, first feeding means coupled to the portion of said first radiative conductor adjacent to said first point, and second feeding means electrically insulated from said first signal feeding means and coupled to the portion of said second radiative conductor adjacent to said second point whereby electromagnetic energy to be radiated travels along the length of said first and second radiative conductors.

5. A side fire antenna to radiate electromagnetic radiation of predetermined polarization comprising a cylindrical conductor, a first radiative conductor, said first radiative conductor being a right-handed helix of given pitch developed about said cylindrical conductor and extending from a first point along the length of said cylindrical conductor and extending toward one end of said cylindrical conductor, a second radiative conductor, said second radiative conductor being a left-handed helix of the same given pitch developed about said cylindrical conductor and extending from a second point along the length of said cylindrical conductor toward the other end of said cylindrical conductor, said first point being disposed between said second point and the first end of said cylindrical conductor, each of the turns of each of the helices of said radiative conductors having the same integral number of operating wavelengths, first feeding means coupled to the portion of said first radiative conductor adjacent to said first point and adapted to feed signal energy to said first radiative conductor, and a second feeding means electrically insulated from said first signal feeding means, said second signal feeding means being coupled to the portion of said radiative conductor adjacent said second point and adapted to feed signal energy to said second radiative conductor so that the electromagnetic radiation radiated by said first and second radiative conductors interacts to produce a resultant electromagnetic radiation having a predetermined polarization.

6. A side fire antenna to radiate electromagnetic radiation of predetermined polarization comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix of given pitch developed about said central conductor and extending from a first point toward one end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix of the same given pitch developed about said central conductor and extending from a second point along the length of said central conductor toward the other end of said central conductor, said first point being disposed between said second point and the first end of said central conductor, each of the turns of each of the helices of said radiative conductors having the same integral number of operating wavelengths, a signal source, first signal feeding means responsive to said signal source for feeding signal energy to the portion of said first radiative conductor adjacent to said first point, and second signal feeding means responsive to said signal source for feeding signal energy to the portion of said second radiative conductor adjacent to said second point in a relative time phase displacement with respect to the signal energy fed from said first signal feeding means so that the electromagnetic radiation radiated by said first and second radiative conductors interacts to produce a resultant electromagnetic radiation that is vertically polarized.

7. A radiating system to radiate electromagnetic radiation of predetermined polarization comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix of given pitch developed about said central conductor toward a first end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix of the same given pitch extending from a second point along the length of said central conductor toward the other end, each of the turns of each of the helices of said radiative conductors having the same integral number of operating wavelengths, said first point being disposed between said second point and said first end of said central conductor, first feeding means coupled to the portion of said first radiative conductor adjacent to said first point and adapted to feed signal energy to said first radiative conductor, a second signal feeding means coupled to a portion of said second radiative conductor adjacent to said second point and adapted to feed signal energy to said second radiative conductor, a transmitter, and a half wavelength phase shifter, said transmitter being coupled to said first feeding means, and to said second signal feeding means via said half wavelength phase shifter, so that the electromagnetic radiation radiated from said first and second radiative conductors interacts to produce resultant vertically polarized electromagnetic radiations.

8. A side fire antenna system to radiate electromagnetic radiation of predetermined polarization comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix of given pitch developed about said central conductor and extending from a first point toward a first end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix of the same given pitch extending from a second point along the length of said central conductor towards the other end, each of the turns of each of the helices of said radiative conductors

having the same integral number of operating wavelengths, said first point being disposed between said second point and said first end of said central conductor, first feeding means coupled to the portion of said first radiative conductor adjacent to said first point for feeding signal energy to said first radiative conductor, a second signal feeding means coupled to the portion of said second radiative conductor adjacent to said second point for feeding signal energy to said second radiative conductor, a first signal source of signal energy of a first frequency, a second signal source of signal energy of a second frequency, and coupling means for coupling said first and second signal sources to said first and second signal feeding means whereby the electromagnetic radiation radiated by said first and second radiative conductors interacts to produce resultant electromagnetic radiations having predetermined polarizations.

9. The apparatus of claim 8 wherein said coupling means couples signal energy from said first signal source to said first signal feeding means and in the same time phase to said second signal feeding means to produce an electromagnetic radiation having a horizontal polarization and said coupling means couples signal energy from said second signal source to said first signal feeding means and the same signal energy in time phase opposition to said second signal feeding means to produce vertically polarized electromagnetic radiation.

10. A radiating system to radiate electromagnetic radiation of predetermined polarization comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix of given pitch developed about said central conductor extending from a first point toward a first end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix of the same given pitch extending from a second point along the length of said central conductor toward the other end, each of the turns of each of the helices of said radiative conductors having the same integral number of operating wavelengths, said first point being disposed between said second point and said first end of said central conductor, first feeding means coupled to the portion of said first radiative conductor adjacent to said first point for feeding signal energy to said first radiative conductor, second signal feeding means coupled to a portion of said second radiative conductor adjacent to said second point for feeding signal energy to said second radiative conductor, a transmitter, junction means, means for coupling said transmitter to said junction means, and means for coupling said junction means to said first signal feeding means and said second signal feeding means so that the electromagnetic radiation radiated from said first and second radiative conductors interacts to produce resultant circularly polarized electromagnetic radiations.

11. A radiating system to radiate electromagnetic radiation of predetermined polarization comprising a central conductor, a first radiative conductor, said first radiative conductor being a right-handed helix of given pitch developed about said central conductor extending from a first point toward a first end of said central conductor, a second radiative conductor, said second radiative conductor being a left-handed helix of the same given pitch extending from a second point along the length of said central conductor toward the other end, each of the turns of each of the helices of said radiative conductors having the same integral number of operating wavelengths, said first point being disposed between said second point and said first end of said central conductor, first feeding means coupled to the portion of said first radiative conductor adjacent to said first point for feeding signal energy to said first radiative conductor, second signal feeding means coupled to a portion of said second radiative conductor adjacent to said second point for feeding signal energy to said second radiative conductor, first and second transmitters, junction means, phase shifting means, and means for coupling said first and second transmitters to said first feeding means via said junction means and to said second feeding means via said junction means and said phase shifting means, so that signals from said first transmitter are radiated from said first and second conductors with a given polarization and signals from said second transmitter are radiated from said first and second conductors with a polarization different from said given polarization.

12. The radiating system of claim 11 wherein said phase shifting means is a quarter wavelength phase shifter and said signals from said first and second transmitters are radiated with horizontal and vertical polarizations respectively.

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