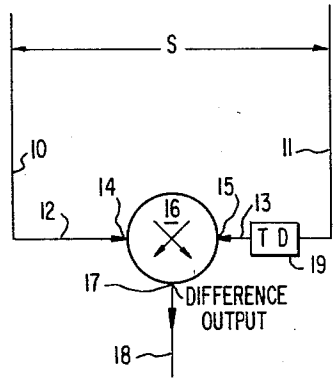
Aug. 6, 1968 J. H. DUNLAVY, JR 3,396,398

SMALL UNIDIRECTIONAL ANTENNA ARRAY EMPLOYING SPACED ELECTRICALLY ISOLATED ANTENNA ELEMENTS

Filed Aug. 25, 1964 3 Sheets-Sheet 1

FIG.1



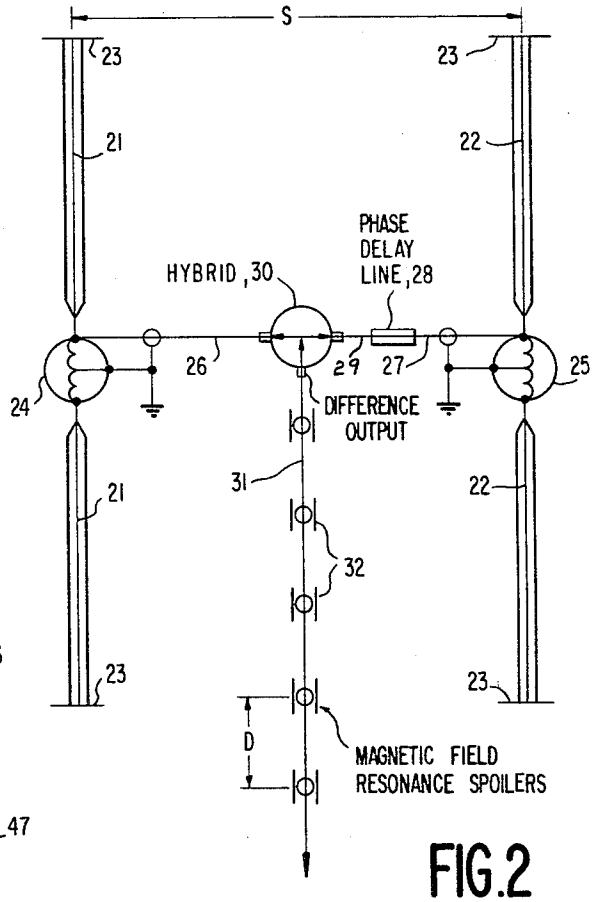


FIG.2

FIG.3

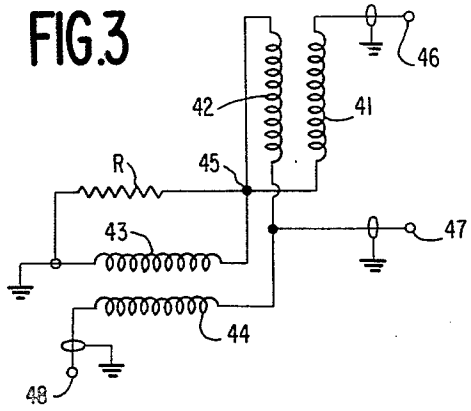
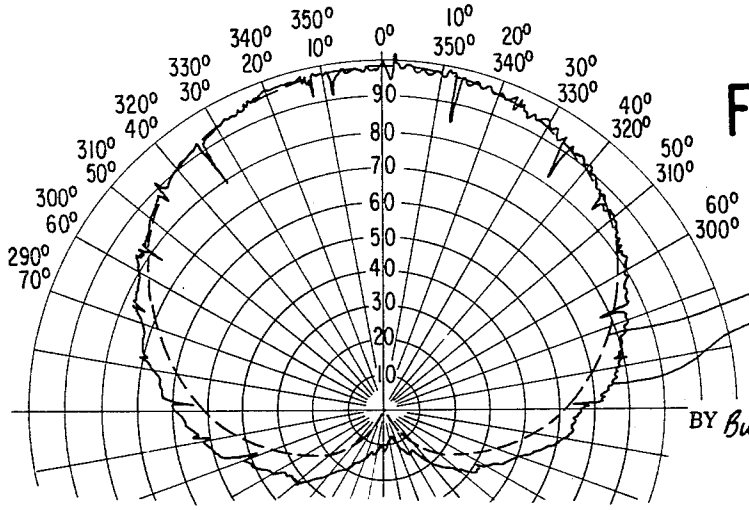


FIG.4



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ATTORNEYS

Fig. 5.

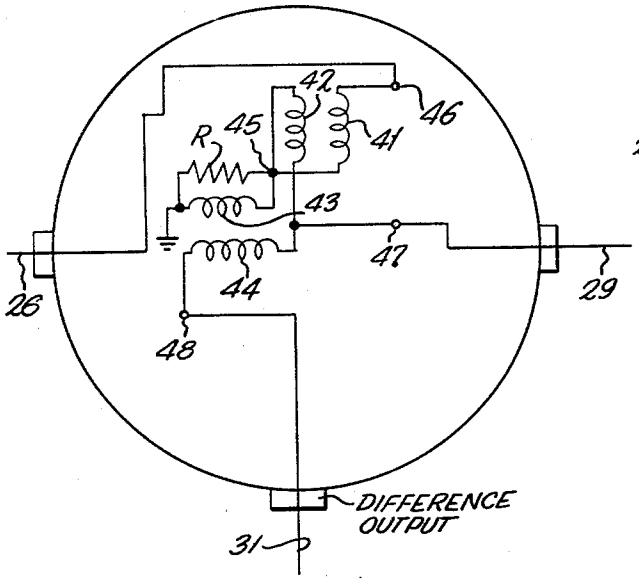


Fig. 6.

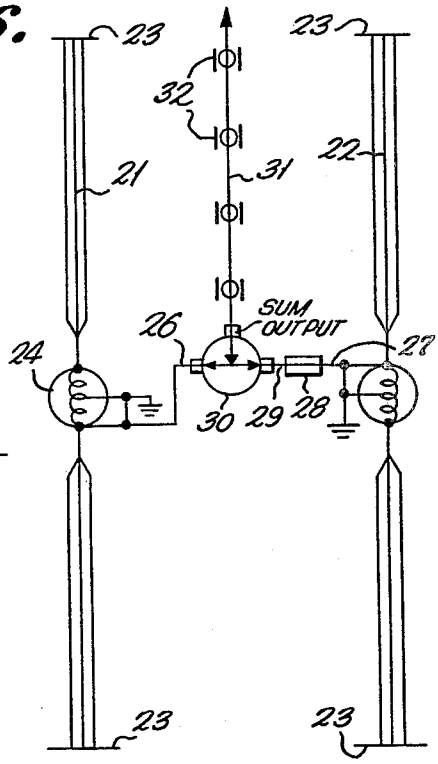
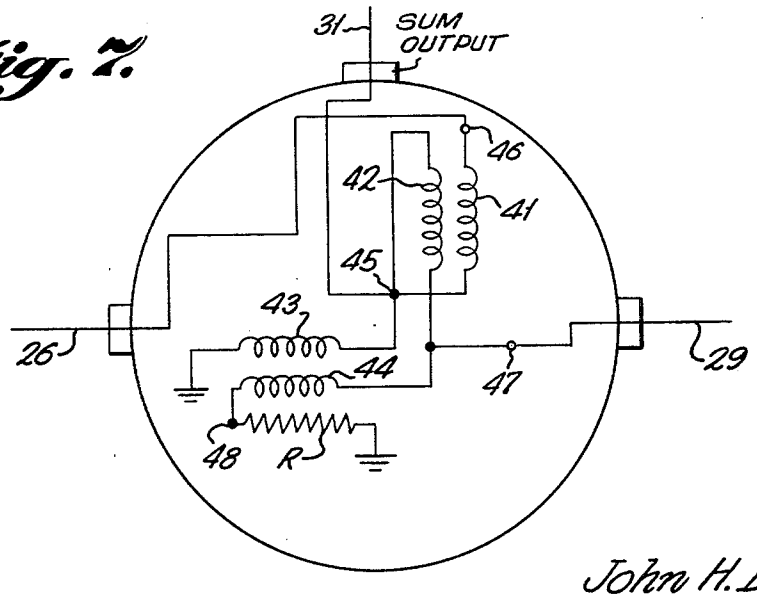
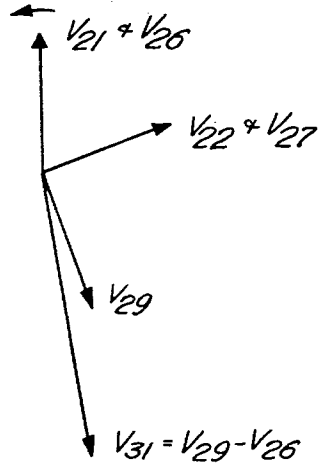


Fig. 7.



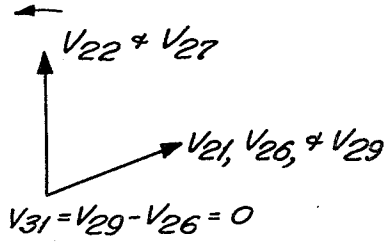
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Fig. 8.



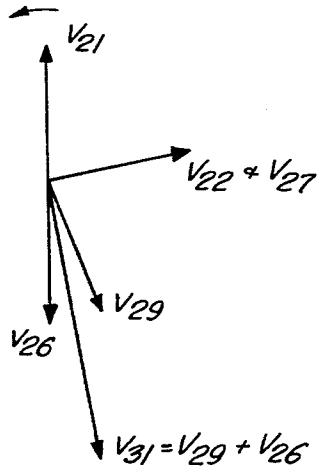
RADIANT ENERGY APPROACHING FROM LEFT IN FIG. 2.

Fig. 9.



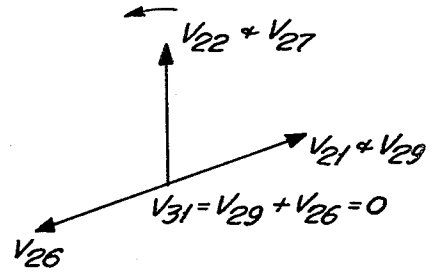
RADIANT ENERGY APPROACHING FROM RIGHT IN FIG. 2.

Fig. 10.



RADIANT ENERGY APPROACHING FROM LEFT IN FIG. 6.

Fig. 11.



RADIANT ENERGY APPROACHING FROM RIGHT IN FIG. 6.

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3,396,398

SMALL UNIDIRECTIONAL ANTENNA ARRAY EMPLOYING SPACED ELECTRICALLY ISOLATED ANTENNA ELEMENTS

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Filed Aug. 25, 1964, Ser. No. 391,860
10 Claims. (Cl. 343—814)

ABSTRACT OF THE DISCLOSURE

An antenna array is disclosed in which a pair of antenna elements are connected to a common feed line through a unidirectional coupling hybrid to suppress mutual currents between the dipoles. A differential time delay related to the spacing between antenna elements is introduced into the signals received from the respective antenna elements to provide a broad-band characteristic with a unidirectional pattern.

Background of the invention

Most receiving antennas designed for use in the high frequency range are larger and costlier than is required. One reason for this is that the designs have been intended primarily to provide the efficiency necessary for transmitting purposes. For most high frequency receiving applications where the signal received is greater than the atmospheric noise background level, the antenna need be only large enough to receive sufficient atmospheric noise to mask the receiver input noise to obtain optimum efficiency.

The signal-to-noise ratio will not be impaired if the receiver noise is small compared to the atmospheric noise. Consequently, small antenna sizes are possible because of the intensity of ambient atmospheric and man-made noise in the high frequency range.

Further, in the high frequency range, the atmospheric noise received at a particular location may result from either a local atmospheric disturbance or may have been propagated by means of the ionosphere from some far distant locations experiencing thunderstorm activity. Thus, at any given time, atmospheric noise may arrive from one or more directions of azimuth with varying degrees of intensity but not from all directions simultaneously with equal intensity. Because of this characteristic of atmospheric noise, a directional antenna, and more particularly a directional antenna capable of being rotated in azimuth, may be employed to null out the most objectional noise source, thereby realizing an effective gain or improvement in system sensitivity that exceeds the simple directivity gain of the antenna. This same degree of improvement may be realized by nulling out objectional man-made noise sources and interfering carrier signals arriving from directions of azimuth not coinciding with the direction of the desired signal.

Many successful antenna designs have been proposed and employed in the past making use of an array of multiple elements in various configurations and sizes dimensioned to secure effective directivity at a single design frequency. However, wide band operation over several octaves of frequency has been unobtainable with such antennas due to the destructive effects of the mutual coupling between the antenna elements. Mutual coupling gives rise to what may be termed mutual currents which flow through the feeder circuit of the array from element to element and thereby alter the individual input impedance of each of the elements as a function of the equivalent mutual impedance. Since the magnitude and the phase angle of the mutual impedance varies as a function

of the spacing of antenna elements, it has been considered nearly imposible to compensate for the changing ratio of the effective input impedance of one element to that of the other in an attempt to preserve equal element currents over a wide range of frequencies.

For this reason, the utility of normal two-element arrays has been limited to a relatively narrow bandwidth of approximately 10% of the design frequency over which good directivity and a high front-to-back can be realized.

An antenna known as the log periodic dipole array provides essentially frequency independent operation by utilizing a planar array of elements differing in length by approximately 10%, such that at any given frequency there exists a set of two or more elements with currents of the proper phase and amplitude to generate a unidirectional pattern with good characteristics and with high efficiency. For high frequency receiving applications, however, such an array is wasteful of space due to its large overall size and unnecessarily high efficiency.

It is an object of this invention to provide directional receiving antenna systems of unusually small size which provide directivity characteristics, i.e., unidirectional patterns and a high front-to-back ratio, essentially independent of frequency and with an efficiency sufficient only to meet the necessary criterion of masking the receiver noise with atmospheric noise.

A further object of this invention is to provide miniaturized directional antenna arrays having performance characteristics which equal or exceed those obtainable with optimized log periodic arrays many times larger in size due to the practicality of rotating the smaller antenna in azimuth to null out specific noise sources varying in azimuth direction.

A further object of the invention is the provision of vertically polarized unidirectional antenna arrays of small size which may be designed to be essentially perfectly balanced with respect to ground and thus exhibit an unusually high inherent immunity with respect to locally generated man-made noise compared to larger antenna systems which are impractical to effectively balance with respect to ground.

Yet another object of this invention is the provision of multiple element directional antenna systems constructed to combine the signals received by each of the antenna elements with minimum electrical coupling between antenna elements to obtain a substantially uniform directivity characteristic over several octave bands of frequencies.

A further object of the invention is the provision of antenna systems of simple configuration employing only passive network elements to achieve directivity characteristics essentially independent of frequency.

Summary of the invention

By way of a brief summary of a preferred embodiment of the invention, an invention capable of a substantial number of variations, an antenna array is constructed with two closely spaced end-loaded monopole elements coupled to a transmission line by coaxial feedlines through a hybrid transformer. The hybrid transformer, using only passive elements, combines two signal inputs received by it into a single output while maintaining substantial electrical isolation between the two inputs. Consequently, mutual current flow between the two monopoles is suppressed and wide band operation results. An electrical delay line interposed between one of the monopoles and its input to the hybrid transformer introduces a phase displacement into the signal from its associated monopole. The constant time delay inserted by the delay line is selected to cause a phase displacement of any signal wavelength equal to the phase displacement between antenna elements. If the signal is extracted from the difference port of the hybrid, an additional phase difference

of 180 electrical degrees is inserted into the feed circuit such that the total delay between the antenna elements is equal to 180 degrees minus the electrical length of the delay time. As the operating wavelength of the antenna system varies, the total phase displacement varies in a complementary manner such that signals of identical amplitude and proper phase are combined in the output of the hybrid transformer independently of their frequency, thus satisfying the conditions necessary for unidirectional patterns over an indefinitely wide band of operation.

Brief description of the drawings

Although the scope of this invention is not be limited except by the appended claims, further details of the invention as well as additional objects and advantages will be better understood in connection with the following more detailed description taken together with the accompanying drawings wherein:

FIGURE 1 is a partially schematic, partially pictorial plane view of a simplified antenna system constructed in accordance with the principles of this invention;

FIGURE 2 is a view similar to that of FIGURE 1 illustrating a more elaborate and preferred embodiment of the invention;

FIGURE 3 is a schematic diagram of one form of hybrid which may be employed in a combination such as that illustrated in FIGURE 2 to combine signals from separate antenna elements while maintaining substantial electrical isolation between antenna elements;

FIGURE 4 is relative voltage plot in polar coordinates of the signal strength delivered by the antenna system of FIGURE 2 from a distant transmitter as the antenna is rotated through 360° of azimuth;

FIG. 5 illustrates in detail how the hybrid of FIG. 3 is connected into the embodiment of FIG. 2;

FIG. 6 illustrates an alternative embodiment of the invention;

FIG. 7 illustrates in detail how the hybrid is connected in the embodiment of FIG. 6; and

FIGS. 8–11 are vector diagrams representing signals produced in the embodiments of FIGS. 2 and 6.

Detailed description

In FIGURE 1 is shown a simplified form of the invention for illustration purposes. The end fire antenna array shown therein comprises a pair of closely spaced antenna elements **10** and **11**, which, in this form of the invention, are simple vertically disposed monopole elements although antenna elements of other forms such as conical could be substituted therefore. The antenna elements **10** and **11** are short in relation to the wavelengths of the operational band of the antenna system. The spacing S between antenna elements is fixed at some distance which is preferably less than 0.3 times the length of the shortest wavelength handled by the system. For any particular operating frequency the distance S may be expressed in electrical degrees. Signals received by antenna elements **10** and **11** are fed over coaxial transmission lines **12** and **13** to inputs **14** and **15** respectively of a hybrid output transformer **16**. The hybrid transformer is connected as an equal impedance unidirectional coupler such that signals at inputs **14** and **15** are effectively isolated from each other but are coupled into a single output **17** which is the difference port output. At the output **17** of the hybrid transformer **16**, the input signals are combined algebraically, i.e., subtracted, minus only the losses experienced internally and are fed over transmission line **18** to a utilization circuit for further mixing, if necessary, and amplification.

A time delay device **19**, which may take the form of an additional length of coiled coaxial feed line, is inserted in feed line **13** for the purpose of introducing a relative phase displacement in the signal transmitted therethrough. The lag provided by the time delay device **19** introduces a constant time delay which, like the distance between antenna elements, may be expressed in electrical degrees for any particular operating frequency. The time lag is selected to provide a phase displacement of a predetermined amount. Signals arriving in the plane of the drawing from the right or from the left are captured by antenna elements **10** and **11** at phase angles which differ by S degrees. Consequently, in order to combine the two received signals subtractively in the hybrid, the time delay provided by the delay line **19** should compensate for this phase angle difference by an amount sufficient to bring the two signals into phase coincidence when arriving from a signal source in the plane of the drawing from the right. Signals arriving from the opposite direction will not be cancelled subtractively in the hybrid because the phase difference between the received signals would in such an eventuality be enlarged still further by the time delay device **19**. The combination of the inserted time delay, the electrical isolation between antenna elements, and the phase reversal provided by the hybrid **16** results in the delivery of signals of identical root-mean-square or average amplitude to each of the hybrid inputs **14** and **15** regardless of the frequency of the received signals and wide band operation is achieved.

With this general understanding of the invention in mind, attention may now be turned to the preferred and somewhat more elaborate embodimets of the invention shown in FIGURE 2. The particular form of the invention illustrated herein is intended for use over a broad frequency range from approximately two megacycles to thirty megacycles and it should be understood that the dimensions referred to hereinafter are intended for use in this range. In FIGURE 2 the antenna elements **21** and **22** are shown as vertically polarized dipoles, although horizontally polarized dipoles may also be used. The physical length of the dipoles is short in comparison to the wavelengths in the operational band of the antenna system. Although the physical length of the dipole elements is only twelve feet overall, an equivalent electrical length of approximately **25** feet is achieved by the use of end loading elements **23** affixed at the extremities of the dipoles. These end loading elements are preferably in the form of radiating finger-like projections about one foot in length, although other configurations such as that of a disc are also useful. These end loading elements also serve to mask the incremental capacitance of each side of each dipole element to ground and thus act to greatly improve the balance of the dipole with respect to ground.

The spacing S between antenna elements, preferably 8 feet, corresponds to a phase displacement between elements of approximately six degrees at two megacycles and ninety degrees at thirty megacycles.

Precision matched baluns **24** and **25** respectively are employed to convert the balanced output of the dipole elements to the coaxial feed lines **26** and **27** respectively. These baluns each employ a multi-turn bifilar winding on a high permeability toroidal core. The winding is constructed to yield an impedance transfer preferably of four to one with a balanced input and an unbalanced output. The two baluns should have exactly the same VSWR, phase, insertion loss, and balance ratio characteristics as a function of frequency over the entire two to thirty megacycle range. Consequently, the coaxial feed lines **26** and **27** receive signals through the baluns **24** and **25** from each of the dipoles which are identical to each other except for the phase displacement between them.

In the right hand transmission line **27** is inserted a coaxial delay line **28**, which may take the form of an additional length of coaxial cable having the same impedance characteristics as feed line **27** but packaged as a coil sealed in a tubular container to assure mechanical rigidity and electrical stability.

The signals delivered from the feed line **26** on the left and the signal delivered through the time delay feed line **28** by feed line **27** on the right are combined through a unidirectional coupler **30**. The portion of the feed line

providing the connection between the delay line **28** and the hybrid **30** is designated by the reference number **29**. The unidirectional coupler **30** is preferably in the form of a hybrid transformer with equal conjugate impedences. The hybrid combines two separate signal inputs into a single output while maintaining a high isolation between the two inputs. When connected as shown in FIGURE 2, the hybrid suppresses mutual current flow between antenna elements which would otherwise alter the individual input impedences of the elements as a function of the operational frequency. Elimination of the flow of mutual currents through the feeder circuit of the array between antenna elements permits the antenna array to be operated effectively over an indefinitely wide frequency band amounting to several octaves.

In FIGURE 3 may be seen a circuit diagram of a preferred hybrid transformer used in FIGURE 2 for combining the signals from the feedlines and introducing them into the transmission channel **31**. This hybrid, composed exclusively of passive elements, is of typical construction, including a pair of inductively associated windings **41** and **42** which may be wound as a bifilar coil on a ferrite core. A second pair of windings **43** and **44** are also wound in a similar manner on a second core. The first two windings **41** and **42** are not inductively related to the second pair of windings, and all four windings have preferably equal reactances. By virtue of the connection at **45** between windings **41** and **42** and because of the phase relationships between these windings, the input connections **46** and **47** from separate dipoles are effectively isolated from each other such that a signal introduced at input **46** is not coupled into input **47** and vice versa. The resistor R terminates the unused sum port represented by connection **45** of the hybrid and dissipates the power representing in-phase components of signals appearing at input connections **46** and **47** of the hybrid. In this embodiment a difference signal appears at output port **48** of the hybrid. FIG. 5 illustrates in detail how the hybrid circuitry of FIG. 3 is connected to the feed lines **26** and **27** and to the transmission channel **31**. The use of the difference signal output introduces a simple 180° phase reversal into one of the input signals. This same phase reversal can also be accomplished in another way by obtaining a sum signal from the hybrid at point **45** and by reversing the electrical connections between dipole **21** and its feedline **26**. FIG. 6 illustrates this alternative embodiment with the connections between the dipole **21** and the feed line **26** reversed and with the output being taken from the sum part of the hybrid. FIG. 7 illustrates in detail how the hybrid in the embodiment of FIG. 6 is connected to the feed lines **26** and **29** and to the transmission channel **31**. As shown in FIG. 7, the resistor R is connected between the terminal **48** and ground in order to dissipate the out of phase components from the antenna elements.

It should be understood that the nature of the hybrid shown is not in and of itself the subject of this invention except in its overall relationship to the antenna systems discussed herein. In the practice of this invention the hybrid may take many other forms, inductive as well as resistive. Indeed a Wheatstone bridge of purely resistive elements with conjugate electrically isolated inputs may be employed to mix the signals from the antenna elements while preventing the flow of mutual currents between antenna elements. Inductive hybrids are preferred for most applications, however, because of the generally lower power losses therein. The term hybrid as used herein is intended to signify those passive electrical networks of whatever form which are capable of mixing electrical input signals to obtain a combined output signal while maintaining a high degree of electrical isolation between the input signals.

The output signal from hybrid **30** is fed over a channel represented by transmission line **31** to a utilization system where it may be amplified and/or combined with other signals from similar antennas. To prevent coupling of externally induced signals from the outside of the transmission line **31** into the dipoles **21** and **22** which would destroy the directivity of the array, magnetic field insulators **32** are placed at spaced intervals along the transmission line **31**. These magnetic field insulators **32** are preferably in the form of small diameter cylindrical ferrite cores having a length of approximately two or more inches. These are arranged concentrically around the outside of the coaxial transmission line **31** preferably at two-foot intervals and make no electrical contact with the outer or inner conductor thereof. Each ferrite core **32** acts as a lossy one-turn magnetic loop, effectively preventing the magnetic component of any electromagnetic wave from propagating further along the outside of the transmission line. They thus serve to prevent the transmission line from achieving resonance within the operational range of the antenna array and reradiating signals which would destroy the directivity of the array.

An antenna of this configuration and construction is capable of realizing excellent directivity gain, and a high front-to-back ratio with an unusually small aperture over a very broad band. The response pattern exhibited by the antenna in the horizontal plane is essentially in the shape of a cardioid, regardless of the wavelength of the received signal. The frequency independence of the antenna system is attested by the distinct null point which appears on the response pattern at 180 degrees of azimuth throughout the operational band of the antenna system. The relative sizes of the cardioidal response patterns may vary at different frequencies, but the shape of the curve remains essentially the same with a distinctive cardioid null.

The shape of the response pattern is given by the general expression for a two element array:

$$F_\theta = K \cos\left(\frac{S^\circ}{2}\cos\theta + \frac{\alpha}{2}\right)$$

Where θ is the angle with respect to lobe maximum in standard polar coordinates; S° is the spacing between the dipole elements in electrical degrees; and α is the phase angle between the currents in the elements, assuming dipole currents of equal magnitude. By analysis it can be seen that a unidirectional cardioid pattern results when the phase angle α equals 180 degrees minus the element spacing S°. This relationship in effect is achieved over a broad band in the practice of this invention by the unique time delay relationship introduced in the feedlines from antenna elements in combination with the passive unidirectional coupling network which assures equal currents in the antenna elements. In FIGURE 4 is shown a typical plot of the measured pattern for an antenna array of the type described in connection with FIGURE 2. The calculated pattern is shown by the dotted line curve superimposed upon the graph. It can thus be seen that there is a very close approximation between the measured and calculated values for such an antenna system. This pattern will also be achieved by the embodiment of FIG. 6.

The vector diagrams of FIGS. 8–11 all represent conditions when the received radio signal has a wavelength four and a half times the spacing between the elements so that the antenna elements are 80 electrical degrees apart relative to the received radio signal. In each of the vector diagrams, the signals received by the antenna elements **21** and **22** are represented by the vectors V_{21} and V_{22}. The signal on the feed line **26** is represented by the vector V_{26}; a signal on the feed line **27** before passing through the delay line **28** is represented by the vector V_{27}; the signal on the connection **29** between the delay line **28** and the hybrid **30** is represented by the vector V_{29} and the resulting signal at the output of the hybrid on transmission channel **31** is represented by the vector V_{31}. FIGS. 8 and 9 are vector diagrams for the embodiment of FIG. 2 and FIGS. 9 and 10 are vector diagrams for the embodiment of FIG. 6.

When the radio signal is received by the array shown in FIG. 2 in alignment with the antenna elements **21** and

22 from the left as shown in the drawing, signals corresponding to the vectors of FIG. 8 will be produced. As shown in FIG. 8, the signal received by the antenna element 21 and on the feed line 26 leads the signal received by antenna element 22 by 80 degrees because of the spacing between the antenna elements. Accordingly, the signal on feed line 26 leads the signal on feed line 27 before passing through the delay line 28 by 80 degrees. The signal on the connection 29 lags the signal on the feed line 27 before passing through the delay line by 80 degrees due to the delay provided by the delay line 28 and accordingly lags the signal on feed line 26 by 160 degrees. Thus, when the hybrid 30 subtracts the signal on feed line 26 from the signal on connection 29, an increased output signal is produced at the hybrid output on transmission channel 31 as represented by the vector V_{31}.

FIG. 9 represents the signals produced when the radio signal is received by the antenna arrangement of FIG. 2 in alignment with the antenna elements from the right as viewed in the drawing. As shown in FIG. 9, the signal received by antenna element 21 and on feed line 26 will lag the signal received by antenna element 22 and on feed line 27 before entering the delay line 28 by 80 degrees due to the spacing between the antenna elements. The signal on the connection 29 will also lag the signal on the feed line 27 before entering the delay line 28 by 80 degrees due to the delay provided by the delay line. Accordingly, the signal on connection 29 will be in phase with the signal on feed line 26 and accordingly the resulting substraction provided by the hybrid 30 will theoretically result in an output signal of zero magnitude. This same result is obtained for different wavelengths because the delay provided by the delay line is constant in time and accordingly the delay in electrical degrees will equal the displacement in degrees between the signals received by the spaced antenna elements. Thus, the antenna array of FIG. 2 is unidirectional in that it will receive signals from the left but signals received from the right will cancel themselves out.

FIG. 10 is a vector diagram representing signals produced in the embodiment of FIG. 6 when the radio signal is received from the left as viewed in the drawing in alignment with the antenna elements. As shown in FIG. 10, the signal on feed line 26 is 180 degrees out of phase with the signal received by the antenna element 21 due to the phase reversal provided by the balun 24. The signal received by antenna element 22 and on the feed line 27 before entering the delay line lags the signal on antenna element 21 by 80 degrees due to the spacing between the antenna elements. The signal at the connection 29 lags the signal on the feed line 27 before entering the delay line by 80 degrees due to the delay provided by the delay line. Accordingly, the signal at the connection 29 leads the signal on the feed line 26 by 20 degrees. Thus, when the hybrid adds the signal on feed line 26 to the signal on the connection 29, an increased signal corresponding to the vector V_{31} is produced.

FIG. 11 is a vector diagram representing signals produced in the embodiment of FIG. 6 when the radio signal is received from the right as viewed in the drawing in alignment with the antenna elements. As shown in FIG. 11, the signal received by the antenna element 21 lags the signal received by the antenna element 22 by 80 degrees due to the spacing between the antenna elements. The signal on the feed line 26 is reversed 180 degrees from the signal received by the antenna element 21 as the result of the phase reversal provided by the balun 24. The signal on connection 29 lags the signal received by the antenna element 22 by 80 degrees as a result of the delay provided by the delay line. Accordingly, the signal on the feed line 26 is 180 degrees out of phase with the signal on connection 29 so that when the balun adds the signals on feed line 26 and on connection 29, the signals will cancel themselves out. Thus, the antenna array of FIG. 6 is unidirectional in that the antenna will receive signals from the left but signals from the right will cancel themselves out.

Rotatable receiving antenna systems of this type with the 8 by 12 foot dimensions indicated supported at the center on a 20 foot mast are capable of providing coverage over the two to thirty megacycle high frequency range at least equivalent to that obtained from a rosette of four log-periodic monopole antennas requiring a 130 foot tower and four acres for its installation.

In the use of such antennas as those described herein, it has been found that the directivity gain of the array is most evident in the improvement of the signal-to-noise ratio of weak signals as compared to that obtained with an omnidirectional, vertically polarized reference antenna. As an example of the overall effectiveness of the antenna in terms of having sufficient aperture to meet the efficiency criterion mentioned earlier, such a system has been successfully used to determine the general direction of arrival of atmospheric noise signals from far distant thunderstorms at frequencies as low as two megacycles and as high as thirty megacycles during all seasons of the year at those periods of time when the ionosphere is effective in propagating such signals.

Although but two embodiments of the invention have been shown and described, it should be understood that certain variations, obvious to those skilled in the art to which the invention pertains, may be made without departing from the principles of this invention in its broader aspects. In addition, the basic two element design may be considered a building block for more elaborate antenna arrays. One such more complex array might consist of a four element end-fire array using two passive network antenna systems of the type described herein arrayed in a plane and fed 180 degrees out of phase. The basic passive network array described herein may also be used, for example, as an element of a large circularly disposed array or a Wullenweber array. A cross-polarized version with two sets of elements arranged orthogonally on a single boom would allow the use of polarization diversity from a single antenna structure.

It is intended that the following claims should cover these and all other such variations as come within the true spirit and scope of the invention.

What is claimed is:

1. A broad band unidirectional antenna array comprising:
   - a pair of laterally spaced antenna elements;
   - a transmission channel;
   - a passive, unidirectional, coupling network having two independent inputs with high isolation therebetween for receiving signals from said antenna elements and an output for delivering to said transmission channel a combined signal representing the two input signals; and
   - differential time delay means inserted between said antenna elements and said transmission channel, said time delay means and the interconnection between said antenna elements and said transmission channel introducing a relative phase displacement between signals of any wavelength received by said antenna elements of 180 electrical degrees minus the separation between antenna elements in electrical degrees.

2. A broad band unidirectional antenna array comprising:
   - a pair of antenna elements spaced laterally apart;
   - a transmission channel for delivering radio frequency energy from said antenna elements;
   - a unidirectional coupling hybrid having two independent inputs with high isolation therebetween for receiving signals from said antenna elements and an output for delivering to said transmission channel a signal representing the algebraic difference of the signals applied to said inputs; and
   - feed lines connecting said antenna elements to said transmission channel through said unidirectional coupling

hybrid to introduce a fixed time difference phase displacement into the signals received from said antenna elements to compensate for the phase separation between said antenna elements such that the signal components delivered to said transmission channel from said antenna elements regardless of frequency are out of phase with respect to signals received from sources 180° from the directionally sensitive line of said antenna array.

3. A broad band unidirectional antenna array comprising:

a pair of antenna elements spaced laterally apart;

a transmission channel for delivering radio frequency energy from said antenna elements;

a unidirectional passive coupling network hybrid having two independent inputs with high isolation therebetween for receiving signals from said antenna elements and an output for delivering to said transmission channel a signal representing the algebraic difference of the signals applied to said inputs; and

time delay means inserted between at least one of said antenna elements and said transmission channel for introducing a phase displacement into a signal of any wavelength received from said one antenna element equal to the separation between antenna elements in electrical degrees.

4. A broad band unidirectional antenna array comprising:

a pair of parallel spaced apart antenna elements;

a passive network directional coupling hybrid having two mutually isolated inputs and an output coupled such that signals introduced at either input are not transmitted to the other input and signals at both inputs are combined electrically at said output to provide a signal representing the algebraic sum of the signals applied to said inputs; and

feedline means connecting said antenna elements to respective ones of said hybrid inputs and introducing a fixed time delay relative phase shift into one of the input signals received from said antenna elements of 180 electrical degrees minus the physical separation between such elements expressed in electrical degrees.

5. A broad band unidirectional antenna array comprising:

a pair of laterally spaced apart antenna elements;

a directional coupling hybrid having two independent input ports with high isolation therebetween and an output port for delivering algebraically combined input signals to a transmission channel;

time delay means having a predetermined phase shift characteristic in combination with the electrical connections between portions of said array, said phase shift characteristic being equal at any operating frequency of said array equal to 180 electrical degrees minus the spacing between said elements in electrical degrees;

first transmission means connecting one of said antenna elements to one input of said hybrid; and

second transmission means connecting the other of said antenna elements to the other input port of said hybrid through said time delay device.

6. A broad band directional antenna array comprising:

a pair of parallel spaced apart antenna elements;

a time delay means having a phase shift characteristic at any operating frequency of said array equal to the spacing between said elements in electrical degrees;

first feed line means connected to receive signals from one of said antenna elements;

a second feed line means including said time delay means connected to receive signals from the other of said antenna elements; and

a directional coupling hybrid having two independent input ports with high isolation therebetween connected respectively to said first and second feed line means and an output for algebraically combining input signals, whereby the flow of mutual currents between said antenna elements through said feed line means is prevented by the electrical isolation between the input ports of said hybrid, the circuit connections between parts of said array in combination with said time delay means introducing in said output a phase displacement between signals received by said antenna elements of 180° minus the spacing between elements expressed in electrical degrees.

7. A broad band directional antenna array comprising:

a pair of antenna elements spaced laterally apart;

a transmission channel for delivering radio frequency energy from said antenna elements;

a unidirectional coupling hybrid having two independent inputs with high electrical isolation therebetween for receiving signals from said antenna elements while preventing the flow of mutual currents therebetween and an output for delivering to said transmission channel a signal representing the algebraic sum of the input signals; and

a feed lines of differing effective lengths connecting each antenna element to a respective one of said hybrid inputs for introducing a phase displacement into the signals received from said antenna elements and combined in the output of said hybrid of 180 electrical degrees minus the separation between antenna elements in electrical degrees, whereby signal components received by each of said antenna elements from signals arriving from the back side of said array undergo a phase cancellation in the output of said hybrid regardless of the wavelengths of such signal components.

8. A broad band directional antenna system comprising:

a pair of vertically disposed dipoles short in relation to signal wavelengths in the band of operation of said antenna system;

means supporting said dipoles a fixed distance apart;

end loading elements affixed at the extremities of each dipole to increase the effective electrical length thereof and to equalize the capacitance to ground between the opposite ends of said dipoles;

a pair of matched baluns each connected to a respective one of said dipoles at the feedpoint thereof;

a pair of coaxial feedlines of differing effective lengths connected to said baluns respectively for receiving signals coupled through said baluns from said dipoles, and for introducing a fixed time delay displacement between said signals equal at any wavelength within the band of operation of said antenna system to the separation between said dipoles in electrical degrees; and

a broad band unidirectional coupling hybrid transformer having a pair of mutually isolated inputs connected to respective ones of said coaxial feedlines to prevent the flow of frequency-variable mutual currents between said dipoles through said feedlines, and having an output for algebraically combining input signals with a relative phase displacement between input signals from said dipoles of 180° minus the separation between antenna elements expressed in electrical degrees.

9. A broad band directional antenna system comprising:

a pair of dipoles short in relation to signal wavelengths in the band of operation of said antenna system;

means supporting said dipoles a fixed distance apart;

end loading elements affixed at the extremities of each dipole to increase the effective electrical length thereof;

a pair of matched baluns each connected to a respective one of said dipoles at the feedpoint thereof;

a pair of coaxial feedlines of differing effective lengths connected to said baluns respectively for receiving

signals coupled through said baluns from said dipoles, and for introducing a fixed time delay displacement between said signals in an amount sufficient to deliver in-phase signal components from said feedlines at any wavelength within the band of operation of said antenna system;

a broad band unidirectionally coupling hybrid transformer having a pair of mutually isolated inputs connected to respective ones of said coaxial feedlines to prevent the flow of frequency-variable mutual currents between said dipoles through said feedlines, and having an output for producing an algebraic difference between signals introduced into said inputs.

10. A broad band directional antenna system comprising a pair of spaced antenna elements, and coupling means connected to said elements electrically isolating said elements from one another and algebraically combining the signals received by said elements into an output signal, said coupling means including means to reverse the phase of one of said signals and to delay one of said signals relative to the other by an amount corresponding to the spacing between said antenna elements expressed in electrical degrees.

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