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E. BRUCE

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UNIDIRECTIONAL ANTENNA SYSTEM

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FIG. 1.

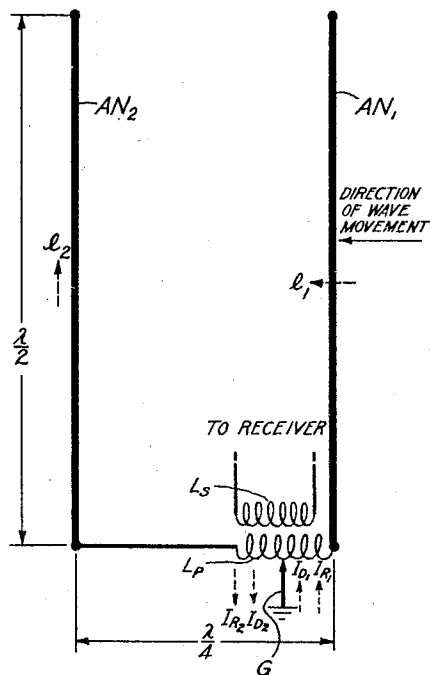


FIG. 2.

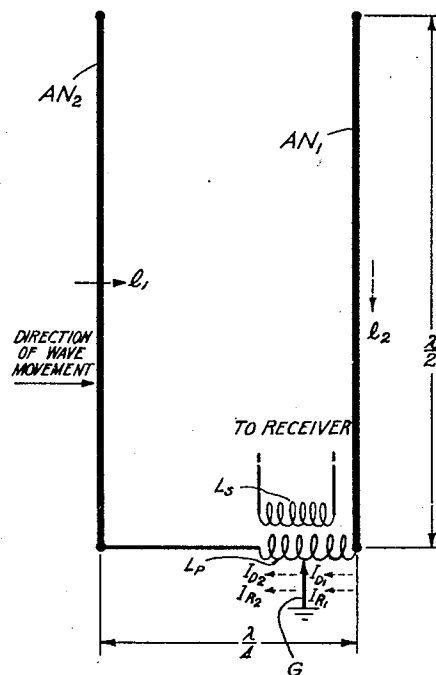
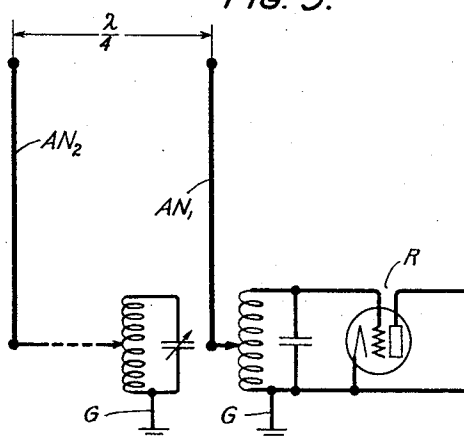


FIG. 3.



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UNIDIRECTIONAL ANTENNA SYSTEM

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This invention relates to unidirectional antenna systems, especially as adapted for transmission or reception of relatively short waves.

It has been known for some time that unilateral directivity may be achieved by a rectilinear antenna array, comprising two or more antennae extending in a direction parallel to the direction of propagation, the energizing or receiving circuit being directly associated with one only of the antenna units of the array, the other units (there may be but one) therefore functioning as reflecting or reradiating antennae. If the inter-antenna spacing is a quarter wave length or an odd multiple thereof, and if further the receiving or energizing circuit is connected to an end antenna unit there will be coincidence of phase at the receiver for waves propagated in one direction and opposition of phase for waves propagated in the converse direction, between the direct and reradiated waves, when account is taken of the phase reversal that occurs incidental to reflection or reradiation. Analogous conditions apply for transmission. Such systems are inherently directional and may be made strictly unilaterally directive if made to effect an amplitude as well as a phase balance. As an example of such an arrangement, reference may be had to applicant's Patent 1,813,143, granted July 7, 1931.

It is an object of the invention to secure unilateral directivity, using a system of spatially related antenna units broadly as above, under conditions which would make the achievement of unidirectivity difficult or impossible by such prior arrangements.

A qualification of perfection in prior systems of that general type as applied to short wave operation, relates to the effect of elevating the antenna units above the earth and to the variation of effect depending on such elevation. In fact where the elevation is comparable with the wave length it has been found that substantial unilateral directivity may not be achieved by the particular arrangement above explained or by other arrangements in the same category. By applicant's invention unilateral directivity may

be achieved entirely independently of such condition or other conditions affecting the geometry of the system except only the inter-spacing of the antenna units.

As compared with prior systems of the above type or other directive antenna systems or apparatus, it is believed that applicant's system excels in simplicity, economy of construction and efficiency of operation as well as in the quality of directivity and it is a further object of the invention to provide an aerial system for space propagated waves which will have such characteristics.

According to the present invention the wave corresponding to the reflected or reradiated wave of the above described unilateral directive antenna system, instead of being reradiated to the receiving antenna proper, is returned to such antenna by a conductive path interconnecting the antenna units at their lower terminals. This path constitutes a delay circuit for the wave propagated through it. The phase relation of the finally superposed waves depends on the electrical length of the connecting path in relation to the lengths of the antenna units through which also the currents corresponding to the elemental induced electromotive forces induced by the incident waves are propagated as a delay circuit. If the antenna units are each electrically half a wave length long and if they are spaced a quarter wave length or any odd multiple thereof, and if such interconnected circuit is electrically the same length as such spacing, the requisite conditions will be satisfied so that the resultant superposed waves will have the proper phase with respect to a properly related receiver. As a practical matter these conditions may be satisfied if with the antenna spacing as above, the antenna units are simple conductors so that waves are propagated therealong with the velocity of other waves and if the connection circuit is similarly constructed and is connected by the shortest path between the lower extremities of the antenna units.

The operation of the same principle may alternatively involve the use of different combinations of electrical and physical dimensions, especially depending on the position-

ing of the connecting path. The two antenna units may each have other forms than simple conductors, as above contemplated, so long as with respect to waves propagated in the direction corresponding to the above antenna spacing, they function similarly thereto. For example, each such unit may have the form of a broadside antenna array of the form disclosed in the above identified co-pending application. Also, by elaboration of detail, while preserving the principle, more than one unit in addition to that directly associated with the receiver, may be used. The principle is equally applicable to transmitting systems.

The invention will be better understood from the following description taken in connection with the accompanying drawings forming a part thereof and in which:

20 Figs. 1 and 2 each schematically illustrate a receiving system of the invention, and the electrical relations therein for a particular direction of wave incidence, the two figures respectively illustrating the condition most favorable for reception and least favorable for reception; and

Fig. 3 illustrates schematically an alternative means for associating the receiver with the remaining circuits.

30 Each of Figs. 1 and 2 represents symbolically a certain receiving antenna system of the invention, which is unilaterally directive with respect to incident waves propagated in two opposite directions in the plane of the two antenna units AN_1 and AN_2 . In Fig. 1, as indicated, the incident wave is assumed to be propagated from right to left and therefore impinges on antenna AN_1 before it impinges on antenna AN_2 , the converse being true with respect to Fig. 2.

The waves impinging on each elemental portion of each of antennae AN_1 and AN_2 generate an electromotive force therein which progresses as a wave in each direction to eventually reach ground at G, the wave which is propagated downwardly being directly so transmitted and the wave which is correspondingly propagated upwardly being reflected at the upper free end of the antenna in question, with a phase reversal, and thence being propagated downwardly throughout the length of the antenna and to ground. The path to ground from the lower ends of the antenna proceeds through the connecting circuit including a portion of inductance L_p . The receiver is connected to the secondary L_s of the transformer whose primary is constituted by the two portions of inductance L_p . The dimensions of inductance L_p are assumed to be small as compared with the antenna interspacing, that is, as compared with the length of the connecting circuit and to be positioned at the end thereof adjacent to the antenna AN_1 .

Of course a certain interval of time is re-

quired for the progression of an ether wave from a position in space corresponding to one antenna AN_1 the corresponding position in space of the other antenna AN_2 . In the example illustrated the inter-spacing is one quarter wave length as indicated, so that the difference in time between the successive incidence of a given wave on the two antennae is one quarter period. However, in this description what will be particularly had in mind is the phenomena occurring in the various parts of the system at a given instant of time. Therefore if at a certain instant of time a certain electromotive force is being generated in antenna AN_1 , at the same instant of time a corresponding electromotive force wave advanced 90° in phase therefrom is being generated in antenna AN_2 . The dashed arrows near the mid portions of the two antennae respectively indicate, as in accordance with the above, the vectors of the resultant electromotive forces e_1 and e_2 in antennae AN_1 and AN_2 , due to the composition of the corresponding electromotive forces for the various elemental portions of the respective antennae. It is proper and convenient to thus consider the effect as concentrated at the center. Of course the vectors are continuously rotating so that little significance attaches to the indicated position of each vector, per se, although their relation is definitive and is adequately shown. Counter-clockwise rotation is assumed to be positive so that the phase of the wave e_2 is indicated as being 90° in advance of the phase of the wave e_1 , as has been shown above to be correct. The antennae are assumed to be each half a wave length long, as indicated. This dimension is that for which the resultant electromotive force is a maximum. This is true for either short waves or long waves although of course, as a practical matter, this ideal is not attainable with long waves of the usual order. The fact is immediately apparent when account is taken of the time lag of the elemental waves from the various elemental portions progressing to the bottom of an antenna, that is, where the receiver is located, and there being superposed in the receiver.

It is an object of the invention to insure by proper geometrical and electrical dimensions of the elements of the circuit that the waves corresponding to e_1 and e_2 after propagation from the midpoints of the antennae to the receiver will be in phase with respect to waves propagated in a certain direction and will be opposite in phase with respect to waves propagated in the opposite direction. This condition defines unilateral directivity. The antennae and connecting circuit function as transmission lines for the propagation of these waves. As would be the case with simple linear conductors illustrated it is assumed that the waves will be propagated

over these conductors at the velocity of space waves so that a conductor of one quarter wave length will retard the wave as much as, or acquire the same time for propagation therealong as, an equal distance in etheric space.

The dashed arrow

I_{D_1} and I_{D_2}

shown adjacent to ground indicate the resultant phase at ground G of the propagated wave initiated in the corresponding antenna AN₁ and AN₂ respectively, and propagated directly to ground. Considering the conditions with respect to antenna AN₁ there will be retardation of 90° on account of the one quarter wave length of antenna through which the resultant electromotive force wave e_1 must progress, so that, at the time of incidence of the wave in the antenna and therefore when the phase of the electromotive force wave e_1 is that indicated by the dashed arrow at the mid point of the antenna the phase of the wave at the foot of such antenna, and therefore at ground, would have a phase advanced 90° from the phase of the wave e_1 , as indicated. Correspondingly the wave e_2 propagated from the mid portion of antenna AN₂ would be retarded 90° on account of such an antenna and another 90° on account of the connecting circuit. The phase vector

I_{D_1}

for that antenna is accordingly indicated as advanced 180° over the vector for e_2 . It is noteworthy that the two vectors

I_{D_1} and I_{D_2}

are in opposite phase at the ground, that is, in the ground lead. The corresponding currents would therefore flow in the same direction in the two portions of the inductance L_P on either side of the ground tap so that the waves propagated to ground add their effects in the receiver connected to the secondary L_S.

Following the same mode of reasoning with respect to Fig. 2, in which an opposite direction of incidence of the ether wave is assumed, it will be found that at ground the phases of the waves corresponding to those discussed in the above paragraph is the same for the two antennae and therefore opposite in the two portions of the primary L_P, so that their effects are opposed in the receiver connected to conductance L_S.

It has thus been demonstrated with respect to waves directly propagated from the antennae to the ground the system is unilaterally directive. It remains, however, to consider the effect of the waves propagated upwardly in the antennae and reflected at the free ends. These waves as measured at the

ground are illustrated by the dashed arrows

I_{R_1} and I_{R_2}

Considering the conditions with respect to antenna AN₁ of Fig. 1 the wave e_1 as thus propagated is retarded 90° in progressing to the free end of the antenna, is then effectively retarded 180° by reflection, and is then retarded 180° by propagation along the entire length of the antenna, so that the phase of the propagated current at ground is 450°, that is, effectively 90°, in advance of the phase of wave e_1 as indicated. By a similar course of reasoning it is apparent that the corresponding phase of the current propagated from the middle of antenna AN₂ is 180° in advance of the phase of the wave e_2 . This means that the two reflected waves, similarly as the two direct waves, are in opposite phase in the ground lead or in the same phase with respect to the receiver. It is also true that the reflected and direct waves are in the same phase. An analogous relation may easily be found with respect to the conditions illustrated by Fig. 2, that is, the reflected waves affect the receiver in opposite directions and have the same phase as the direct wave at the receiver. Accordingly it has been demonstrated that the system of Fig. 1 or Fig. 2 is unilaterally directive with respect to the reflected, as well as the direct waves and to such waves jointly and therefore with respect to all waves which may affect the receiver.

It is obvious that the principle applied above to a specific instance, is much more generally applicable. For example, the principle is equally operative if the spacing of the antennae is any other odd multiple of a one quarter wave length than the multiple one. Further it is possible to design the transmission line, comprising the connecting circuit and antenna proper, so that waves will be propagated there along at a velocity either greater or less than that of waves in space. Therefore it is possible to use antennae which are other than half a wave length long and a connecting circuit which is longer or shorter than the inter-antenna spacing. It is also obvious that the principle is equally applicable to a transmission system, the receiver in Figs. 1 and 2 being replaced by a transmitting source.

It has been assumed that the waves directly transmitted or reflected at the receiver will have the same amplitude, as they would tend to have with the conditions as illustrated. Of course unilateral directivity in a strict sense requires that these amplitudes should be the same. They may be made exactly the same by an adjustment of the ground tap toward or away from the center of the inductance L_P.

Fig. 3 illustrates an antenna system which is alternative to that of Figs. 1 and 2, the difference relating solely to the means or

method of associating the antenna-ground paths with the receiver. Each of the antennae is connected to ground through a resonant circuit as shown, which is tuned to the frequency of the incident wave. The coils of the two resonant circuits correspond to the two portions of the inductance L_p in Figs. 1 and 2 and are related in substantially the same way to ground, the two ground leads of Fig. 3 being equivalent to the single ground of Figs. 1 and 2. A difference in addition to the use of such resonant circuits relates to the means for affecting the amplitude adjustment, which in the circuit of Fig. 3 is accomplished by the variable tap from the antenna to the respective resonant circuit. Still a third difference relates to the connection of the receiver to these inductances. In Fig. 3 the receiver is directly connected to the inductance of one antenna and is magnetically coupled with the inductance of the other antenna instead of being magnetically coupled with each of the coils as in Figs. 1 and 2. The arrangement of Fig. 3 has been found to be perhaps more convenient and generally satisfactory than that of Figs. 1 and 2.

The system of Fig. 3 may be made unilaterally directive in the opposite direction by reversing the connections to either coil or, which amounts to the same thing, connecting the ground to the opposite end of either coil. Similarly the system of Figs. 1 and 2 may be made unilaterally directive in the opposite direction by connecting the coil L_p in the ground lead instead of in the position illustrated. These various changes have the common purpose and result of reversing the phase of one of the superposed currents with respect to the other.

By elaboration of detail the principle of the invention may be made applicable to a similar relation of more than two antennae although of course the quantitative effects would tend to be different so that there would be required quantitatively different values of the physical dimensions to give the requisite amplitude phase unbalance.

What is claimed is:

1. The method of unilaterally directive radio reception which comprises absorbing a portion of a radio wave when at a given position in space, absorbing an additional portion of the wave when at a different position in space, independently transmitting the absorbed wave portions to a given point and there receiving them and indicating their resultant effect, and shifting the phases of the respective absorbed portions by a critical amount such that the resultant effect is a maximum for a radio wave propagated in a desired direction through said positions and zero for a radio wave propagated in the opposite direction through said positions.

2. The method of unilaterally directive radio operation, utilizing a plurality of radio

antennae and a translating device, which comprises transmitting portions of a wave between said device and said antennae by as many independent paths as there are antennae guiding the wave portion over at least a part of each path and radiating it through the remaining part of the path, and effecting such a relative retardation of the wave portions in the respective paths that when said wave is transmitted outwardly from said device to said antennae and thence into space the resultant transmission is substantially zero in one direction and the maximum in the opposite direction, and so that similarly when said wave is absorbed from an ether wave by said antennae and is transmitted inwardly therethrough to said device the resultant wave at the device has substantially zero amplitude with respect to ether waves propagated in one direction and a maximum amplitude with respect to ether waves propagated in the opposite direction.

3. The method of unilaterally directive radio reception comprising absorbing radiant wave energy from two points in space, independently transmitting the energy absorbed from the respective points to a third point by wave propagated over different electrical distances whereby there tends to result a phase shift in the respective paths which is proportional to the corresponding electrical distance, and receiving and indicating the resultant effect of the transmitted waves at said third point, the relative electrical distances being such that the phases of the transmitted waves at the third point are alike when the original ether wave is propagated in one direction and opposed when the ether wave is propagated in the opposite direction.

4. A uni-directional antenna system comprising two antennae, a translating device, and an individual transmission line connecting said device with each of said antennae, the phase shift in the path between one antenna and the device by way of its transmission line being equal to the corresponding phase shift in the path between the same antenna and the device by way of the other antenna and its transmission line.

5. A uni-directional antenna system comprising two antennae, the electrical length of each antenna being an odd multiple of half a wave length of an ether wave to be used, said antennae also being parallel and spaced a multiple of one quarter wave length, a translating device, a transmission line connecting the lower ends of the two antennae, said device being coupled to said transmission line adjacent one end thereof whereby said device is connected to one antenna by a transmission line having substantially zero electrical length and to the other antenna by a transmission line whose electrical length is substantially equal to the antenna spacing.

6. The arrangement of claim 4 in which

the system is a receiving system, said device therefor being a receiving and indicating means.

5 7. The arrangement of claim 5 in which the system is a receiving system, said device therefor being a receiving and indicating means.

In witness whereof, I hereunto subscribe my name this 1st day of June, 1928.

10 EDMOND BRUCE.

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