Dec. 26, 1939. F. G. KEAR ET AL 2,185,059

MONITORING SYSTEM FOR ANTENNA ARRAYS

Filed April 26, 1938 2 Sheets-Sheet 1

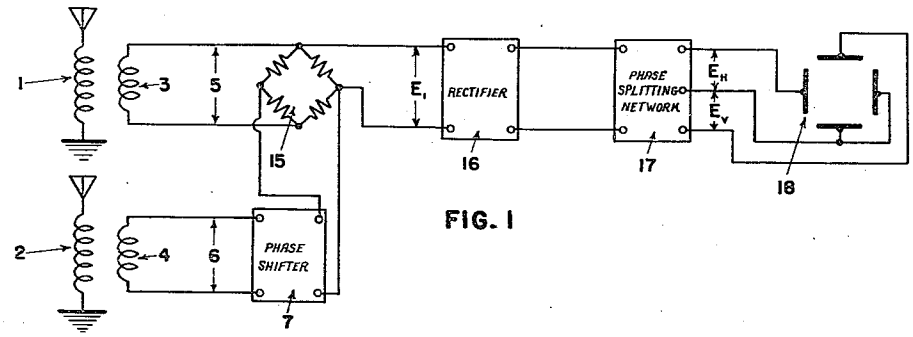


FIG. 1

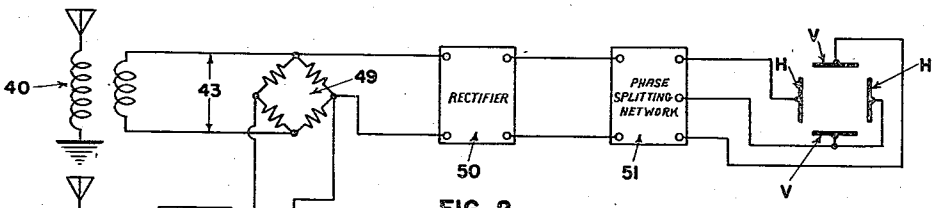


FIG. 2

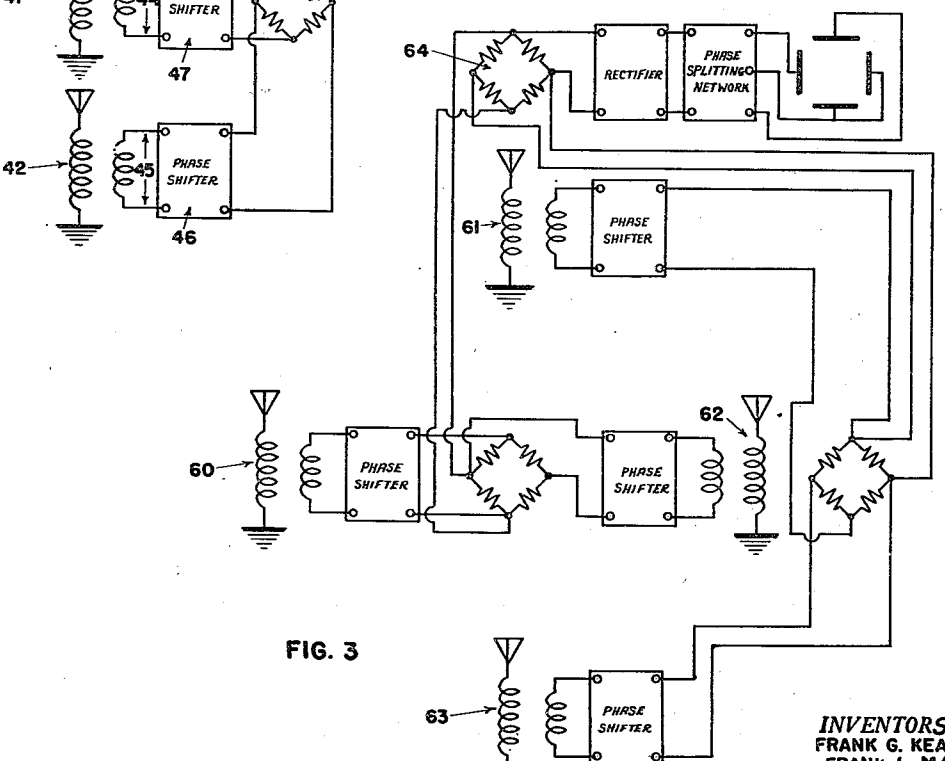


FIG. 3

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MONITORING SYSTEM FOR ANTENNA ARRAYS

Filed April 26, 1938 2 Sheets-Sheet 2

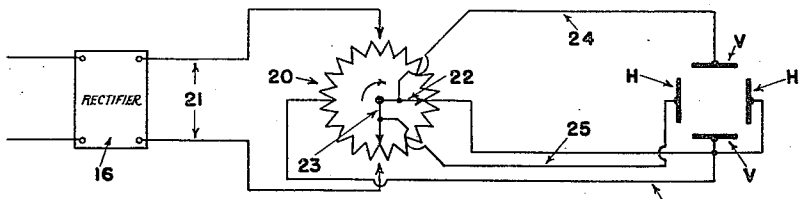


FIG. 4.

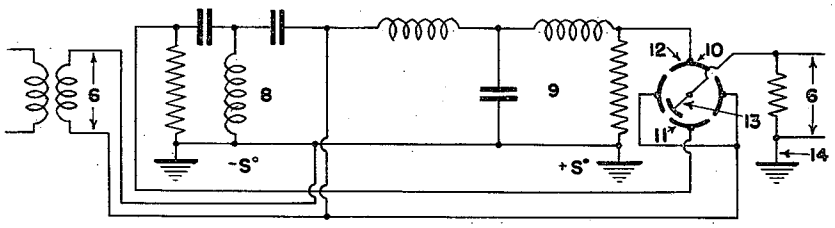


FIG. 5.

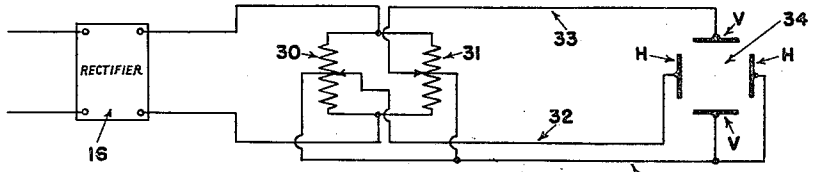


FIG. 6.

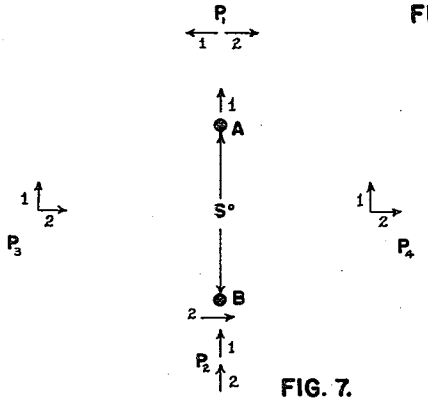


FIG. 7.

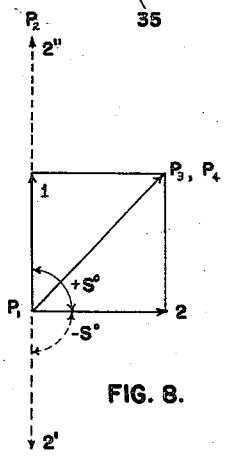


FIG. 8.

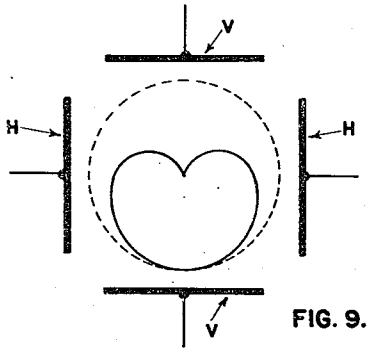


FIG. 9.

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MONITORING SYSTEM FOR ANTENNA ARRAYS

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Application April 26, 1938, Serial No. 204,422

10 Claims. (Cl. 250—11)

This invention relates to a method and apparatus for visually indicating the radiation pattern resulting from the transmission of radio signals from an antenna array.

It is the object of this invention to provide electrical means which will be operable to provide a visual representation, at any desired point, of the radiation pattern of an antenna array. A further object is to provide means operated by the current supplied to the antenna array for producing the radiation, for reproducing visually and continuously, the actual radiation pattern of the array with which the apparatus according to the invention is connected or operated. A still further object is to provide means which may be connected or operated with any antenna array and which will operate means, which may be located at any central or control point, for continuously and visually reproducing the radiation pattern of an antenna array, including any variations which may take place in such pattern as the array continues to be energized.

In observing or studying the radiation characteristics of an antenna array it is often necessary to know exactly or approximately the shape of the radiation or field pattern being produced. While the characteristic and conventional radiation patterns of different types of arrays are well-known, exact and perfect examples of these patterns are never produced in practise because of the imperfect conditions attending the transmission and surrounding the radiators. Further, and particularly with respect to commercial broadcasting stations, it is often necessary or desirable to adjust the radiation pattern of an array in order to regulate the effective coverage or to shift the directions of the maxima and minima of the pattern, this provided that the array is such as to produce directional radiation. In all of these and many other cases in which it has been necessary to know the shape of the radiation pattern, it has heretofore been possible to secure an approximation thereof only by the method of measuring the field strength of the radiations from the array at circumferentially spaced points about the array and then reducing these field strength measurements to graphical form by plotting them on paper. By this relatively laborious and difficult process the space pattern of the radiation from any array could be approximated.

As stated above, our present invention is intended to provide means for continuously and visually reproducing at a central or control or other point a representation of the radiation pattern of the antenna array with which the apparatus according to our invention is associated. In actually carrying our invention into effect we make use of the cathode ray oscillograph, and provide means for producing on the screen thereof the visual representation of the radiation pattern. As is well known, in a cathode ray oscillograph, a cathode ray or beam is thrown upon a tracing surface, which may be an observing screen or photosensitive film, and is deflected thereon by deflecting means such, for example, as voltages impressed upon deflecting plates, which cause the ray to bend or deflect in response to variations in the voltages. In this way curves are obtained which are representative of some phenomenon to which the deflecting voltages are responsive. In utilizing such an apparatus for our present purposes we vary the deflecting voltages in accordance with differences in phase, between the radiations from the several members of the radiating array, which exist at different circumferential points about the array. These deflecting voltages are functions of the phase difference at points about the array and their deflecting power will therefore provide a true measure of the intensity of the radiation at any point about the array, and the integration of all of these measurements by means of the oscillograph will hence produce a representation of the field pattern of the array.

The features of the method and apparatus according to our invention which we believe to be novel and patentable are set forth hereinafter in the appended claims. For an understanding of certain embodiments of our invention, reference is made to the following description and to the appended drawings, wherein similar reference numerals refer to like parts.

In such drawings:

Fig. 1 is a circuit diagram showing the application of the invention to an antenna array including two antennas;

Fig. 2 is a circuit diagram illustrating the application of the invention to an array including three antennas;

Fig. 3 is a circuit diagram illustrating the application of the invention to a four-antenna array;

Fig. 4 is a circuit diagram showing the phase-splitting network which is illustrated generally in Fig. 1;

Fig. 5 is a circuit diagram showing the phase-shifting network which is illustrated generally in Fig. 1;

Fig. 6 is a circuit diagram showing a second form of phase-splitting network;

Fig. 7 is a diagrammatic showing of the vector fields about an antenna array;

Fig. 8 is a vector diagram showing certain current relationships, and

Fig. 9 is a view showing the representation of a radiation pattern by means of the invention.

As stated hereinbefore, it is often necessary or desirable to know or have a reproduction of the radiation pattern of an antenna array. As also stated, it has heretofore been possible to secure this by measuring the field intensity of the radiation at circumferentially-spaced points about the array and by then reducing these measurements to graphical form by plotting them on paper. In effect, the circling of the array by the field intensity measuring means, which has heretofore been performed manually, is performed electrically and continuously by this invention, whereby a visual and continuous representation of the radiation pattern is provided.

In any antenna array including at least two spaced radiating elements, it has been observed that the phase relationship of the radiations from the spaced elements varies as the array is circled. This may be illustrated by reference to Fig. 7, wherein is illustrated an array consisting of two antennas A and B which are spaced S° apart and which are energized by currents displaced 90° in time phase and represented by the arrows 1 and 2. Referring to the field relations at a point P_1 which is in a prolongation of the line B—A and in the direction of antenna A, it will be seen that field from antenna A will have rotated S° with respect to the field from antenna B by the time that the field from antenna B has reached the point P_1 and that if S=90 the fields from the two antennas will be opposed in phase, as represented by the two arrows 1, 2. In the opposite direction, the field of antenna B will rotate through S° while the field from antenna A is reaching point P_2, whereby the two fields will be in-phase in the direction of antenna B, as represented by the two arrows 1, 2 at point P_2. In directions at right angles to the line between the antennas no variation from the original phase relation of the antenna currents will take place, as illustrated by the arrows 1, 2 at points P_3 and P_4 in Fig. 7. At other points about the array the phase relations of the fields from the two antennas will vary between the limits shown, i. e. between the 180° out-of-phase relation at P_1 and the 90° out-of-phase relation at P_3 and P_4, and between the in-phase relation at P_2 and the 90° displacement at P_3 and P_4.

It will be seen that at any point about the array the radiation intensity will be equal or proportional to the vectorial sum of the fields of the two antennas at that point. At any point, this vectorial sum will be dependent upon the phase relation of the two fields and we may therefore say that the radiation intensity or field strength at any point about the array is a function of the phase relation at that point between the fields radiated by the two antennas. The relative strengths of the radiation field at the points P_1, P_2, P_3 and P_4 are shown in the vector diagram of Fig. 8.

In our invention we utilize this known fact and, by means provided by the invention, we simulate the variation in phase relation between the radiations from the separate elements of the array in order to reproduce at one point the current relationships which exist at the infinite number of circumferentially spaced points about the array. After securing the resultant voltages for each point about the array, this is rectified and is then split into two voltages which are the vectorial components of the resultant voltage for each point about the array. These component voltages are employed as the deflecting voltages in a cathode ray oscillograph and cause the reproduction on the screen of the oscillograph of a representation of the resultant voltage at each point about the array. Proper adjustment and timing of parts of our invention will cause the representation of the intensity at successive points to be made so quickly that a continuous representation of the entire field pattern of the array will be presented.

In Fig. 1 of the drawings we have illustrated diagrammatically the adaptation of our invention to an array consisting of two radiating elements 1 and 2 which are spaced S° apart. These antennas are excited from a common radio frequency source, not shown, and a phase relation of ϕ degrees exists between the currents in the two antennas. Pick-up coils 3 and 4 bring radio frequency current from the two radiators to an observation point through transmission lines 5 and 6. One of these lines, such as 6, includes a phase-shifting network 7 which has an effective electrical length of $\pm$S°. The electrical lengths of the two lines 6 and 7 are adjusted to equality, this being done, if necessary, by artificial lines or other suitable means. In equalizing the electrical lengths of the two lines it should be remembered that the electrical length of line 5 should be equal to that of line 6 without regard to the electrical length added by network 7.

The phase-shifting network 7 is more particularly illustrated in Fig. 5 of the drawings and it will be seen from this figure that this network includes a network 8 having a negative phase angle and a network 9 having a positive phase angle, each phase angle being equal in magnitude to S°. Radio frequency current drawn from the antenna 2 through pick-up coil 4 is impressed across the common input terminals of these two networks, while the outputs of the two networks are connected respectively to two fixed plates 10 and 11 of a rotary condenser 12, the two remaining fixed plates of which are connected together and to the common input terminal of the networks 8 and 9. The rotary plate 13 of the condenser device is connected to one of the transmission lines 6 on the output side of the phase-shifting network, the other of the transmission lines being connected to ground at 14. A network providing the same function but employing balanced lines may be employed if desired.

It will be apparent that during energization of the antenna array 1, 2, radio frequency current will be continuously supplied to the networks 8 and 9 and the output voltages of these networks will be supplied to the two plates 10, 11 of the condenser device. If the networks 8, 9 are properly adjusted, the outputs thereof will differ in phase between the limits —S° and +S°. The rotary member of the condenser device will therefore deliver to transmission line 6, in making one complete revolution, currents which vary in phase relation between the limits —S° and +S°. In this manner energy passing through the phase-shifting network will be delayed or advanced in time by an amount depending upon

the adjustment of the network 8 and 9 and within the limits of −S° to +S°.

It will be seen that if the current output of network 7 is added vectorially to current drawn from antenna 1, the resultant current will represent, for one revolution of condenser device 12 and a corresponding variation of the output thereof from −S° to +S° to −S°, all of the resultant voltages at all circumferentially successive points about the antenna array. These currents are the equivalent of the fields which would be measured by an observer circling the array in order to secure a radiation pattern. According to the disclosed embodiment of our invention we combine the current from antenna 1 with the current output of the phase-shifting network 7 by passing these currents through current combining means such as the Wheatstone bridge 15.

The output of the Wheatstone bridge device 15 is a potential E of varying amplitude which represents the vectorial sum of current drawn from antenna 1 and current drawn from antenna 2, the latter being displaced in phase from current supplied to antenna 2 by an amount which continuously varies between −S° and +S°. This summation current, at voltage E, is rectified at 16 by any suitable rectifying device.

The output of the rectifier 16 consists of a direct current with or without tone modulation, and which fluctuates in accordance with variation in the output of the Wheatstone bridge. It will be seen that the variations in the direct current output of the rectifier will be in sequential accordance with and proportional to the vectorial sum of the currents from the two antennas at the different phase relationships thereof caused by the operation of the phase-shifting network 7. If desired, the rectifier 16 may be omitted and the voltage E supplied directly to the phase-splitting network. If the voltage at the output of the Wheatstone bridge is insufficient to operate the cathode ray oscillograph an amplifier may be introduced at this point.

Means are provided by the invention for causing the voltage output of the rectifier or of the Wheatstone bridge to be separated into vectorial components, and for supplying these component voltages alternately or simultaneously to the plates of a cathode ray oscillograph where they act to deflect the cathode ray produced by such device. A preferred means for so dividing the rectifier output and supplying the component voltages to the oscillograph plates is illustrated in Fig. 4. In this embodiment there is provided a toroidal form of potentiometer comprising the endless resistance coil 20, to diametrically separated points of which is applied the voltage E through leads 21. A rotary assembly is provided and consists of two arms 22, 23 which are permanently fixed at an angle of 90° with respect to each other and which are provided with brushes which are disposed in wiping relation to the coil 20. One of the arms, 22, is connected by lead 24 to one of the set of plates V of a cathode ray oscillograph device, while the other of the arms is connected by lead 25 to one of the set of plates H of the oscillograph. The remaining plates of the sets V and H are connected together and to diametrically opposed points of the coil 20 which are located midway between the connections thereto of the leads 21 through lead 26. The rotating arms 22, 23 are operatively connected to the rotary condenser device 12 of the phase-shifting network 7 in order that the two devices may be synchronously operated.

As stated, the output of the rectifier or of Wheatstone bridge consists of a fluctuating voltage E_1 and the operation of the phase-splitting network on this voltage is such as to divide the same into two vectorial components, which may be designated as E_V and E_H and which are, respectively, applied to the sets of plates V and H of the oscillograph device. These voltages across the output of the phase splitting network may be represented as

$$E_V = E_1 \sin wt$$

and

$$E_H = E_1 \cos wt$$

in which w is the angular velocity of the arms 22, 23 and t is time. If this relationship is maintained, and E_1 is constant then one revolution of the shaft carrying the arms 22, 23 will rotate the spot of the oscillograph in a complete circle. This rotation of the arms 22, 23 and of the spot of the oscillograph corresponds to a complete circuit in space about the antenna array. If E_1 is caused to vary in magnitude during this rotation by an amount directly proportional to the variation in field intensity which occurs in space during an actual circuit of the antenna array then the spot will describe a path which corresponds to the radiation pattern of the array. It will be apparent that if the phase-splitting network is so designed that its angular velocity w accounts for one complete cycle while the phase-shifter 7 is producing a phase shift of −S° to +S° to −S° then the spot of the oscillograph will describe a path which will represent the horizontal plane pattern of the radiation from the array. Networks 7 and 17 may be either electrically or mechanically controlled. If a screen of very high persistence is used in the oscillograph a very low frequency of sweep may be employed.

The synchronization of the operation of the phase-shifting and phase-splitting networks 7 and 17 is of importance as the alternate and simultaneous application of the voltages E_V and E_H to the plates of the oscillograph must be in the same sequence and at the same speed as the resultant field intensity voltages of the two antennas are changed by the variation in phase relationship therebetween as reproduced by the phase shifter 7. The rotating assemblies of the devices 7 and 17 are therefore operated in such a manner that this result is secured and this is preferably done by rotating these assemblies from the same shaft or prime mover. It will be seen that, under these conditions, when the rotary condenser 12 of the phase-shifter 7 is in such position that the output voltage thereof is displaced −S° with respect to the voltage supplied by antenna 1, the output E_1 of the rectifier will have a certain value and must be represented in one certain position on the screen of the oscillograph. This voltage is applied to the opposite terminals of the potentiometer 20 and, the arms 22, 23 having previously been adjusted to their proper relation and initial position, a potential is established between one of the arms, such as 22, and the common lead 26, this potential being transferred to plates V of the oscillograph, and a second potential is established between arm 23 and common lead 26, this potential being transferred to the plates H. There is therefore established between the two plates of each set a field which is proportional to the voltage applied

which is, itself, proportional to the vectorial sum of the current drawn from antenna 1 and that drawn from antenna 2, after shifting of the phase thereof at 7. This vectorial sum current is itself continuously changing due to the constant shifting of the phase of the current drawn from antenna 2 with respect to that drawn from antenna 1.

The potentials applied to plates V and H will cause the displacement of the spot of the oscillograph from the center of the screen thereof, and the amount of such radial displacement will be proportional to the voltage output of the Wheatstone bridge 15, while the direction of this displacement is determined by the angular position of the arms 22, 23 which has been made to correspond with the displacement of phase produced in phase-shifter 7. At any moment, therefore, the spot will occupy a position which will be dependent upon the magnitude of the voltage E_1 and the angular position of the arms 22, 23, which in turn represents a position in space about the antenna array.

An alternative form of phase-splitting network is illustrated in Fig. 6 of the drawings. In this embodiment of this part of the invention the potentiometer 29 of Fig. 4 is replaced by two resistances 30, 31 which are connected in parallel and along which resistances two slidable brushes or taps are mounted to reciprocate. These brushes are respectively connected by leads 32, 33 to one plate of each of the sets of plates V and H of a cathode ray oscillograph 34, the remaining plates of the two sets being connected together and to the midpoints of each of the coils 30, 31 through lead 35. The output of the rectifier 17 is connected in parallel to the coils 30, 31. The operation of this phase-splitting device is essentially the same as the operation of that illustrated in Fig. 4, the principal difference being in the necessary change in the means for operating the brushes which contact the coils 30, 31 synchronously with the rotary condenser of the phase-shifter 7. In function and electrical operation the networks disclosed in Figs. 4 and 6 are identical.

The method according to this invention may be employed with any antenna array, regardless of the number or type of the radiating elements which make up the array. In Fig. 2 of the drawings we have illustrated the application of our invention to an antenna system including three radiating elements 40, 41 and 42, which may be arranged or spaced in any desired manner. In adapting our invention to such an antenna array we take current from each of the antennas and lead this to an observation point by separate transmission lines 43, 44 and 45. The transmission line 45, carrying current from antenna 42 has connected therein a phase shifting network or device 46 which may be of the type illustrated in Fig. 5, while the transmission line 44, carrying current from antenna 42 has connected therein a separate phase-shifting network 47 of similiar type. The current outputs of the two phase-shifting networks 46 and 47 are supplied to the opposite terminals of some means for vectorially adding these currents, such as a Wheatstone bridge 48. The output terminals of this bridge are connected to two of the input terminals of a second bridge device 49, the other input terminals of which are connected to the transmission line 43 which carries current from antenna 40. It is important to note that the electrical lengths of the transmission lines 43, 44 and 45, exclusive of the effective electrical lengths of any phase-shifting networks therein, should be made equal, and this may be done by the use of artificial lines or other suitable means.

The output of the bridge 49 at any instant will consist of a potential which includes all of the currents from the three antennas at one of the various phase relationships between the fields radiated by the antennas which occur as the antenna array is circled. The output of the bridge 49 is supplied to a rectifier 50. The output of the rectifier is a fluctuating direct current which varies in accordance with the resultant of the currents from the three antennas as the antenna array is circled, this result being effected by the operation of the phase-shifting networks 46 and 47. This fluctuating current is supplied to the phase-splitting network 51 which may be constructed and operable in the same manner as the networks of either of Figs. 4 and 6. This network produces the equivalent of two-phase voltage and the component voltages which are produced by the network 51 are supplied to the plates V and H of a cathode ray oscillograph 52 in the manner and with the result set forth hereinbefore.

The synchronous operation of the phase-shifting networks 46 and 47 and the phase-splitting network 51 is required in this embodiment of the invention and this is effected by any suitable mechanical or electrical means.

In Fig. 3 of the drawings there is illustrated the application of our invention to an antenna array having four radiating elements 60, 61, 62 and 63. Current is drawn from each antenna by a suitable pick-up coil and is passed through transmission lines to an observation point. A phase-shifting network is connected in each transmission line and the output of two of such networks is vectorially added by one Wheatstone bridge, while the outputs of the other two networks are vectorially added by a second bridge device. The outputs of the two bridge devices are then combined in a third bridge 64, the output of which is supplied to a rectifier, phase-splitting network and the plate system of a cathode ray oscillograph in the manner hereinbefore set forth, to produce on the screen of the oscillograph a representation of the radiation pattern of the antenna array.

In any of the systems disclosed, it may be desirable to place a phase-shifting network in each of the transmission lines through which current is drawn from the antennas. In this event, the amount of phase shift introduced by each of the phase-shifting networks will be made equal to the electrical distance in degrees between the point chosen as the electrical center of the system and the antenna from which the phase-shifting network is energized.

While we have illustrated and described certain embodiments and circuits in and with which our invention may be practised, it will be apparent that improvements, modifications and further embodiments will be apparent to those skilled in the art. All of these may be practised without departing in any way from the spirit or scope of the invention, for the limits of which reference must be had to the appended claims.

We claim:

1. In combination with a radiating array comprising a plurality of antennas, means for producing a visual representation of the radiation pattern of the array comprising means for drawing current from said antennas, means for shift-

ing the phase of the current down from certain of the antennas and combining such current with that from the other antennas, means for rectifying the combined currents to produce a resultant current, means for splitting said resultant current into components, and means for causing said component currents to act upon and deflect the beam of a cathode ray oscillograph.

2. In combination with a radiating array comprising a plurality of antennas, means for producing a visual representation of the radiation pattern of the array comprising means which are operable by electric currents to produce a visual image, means for producing from energizing currents in said antennas a plurality of currents the phase relationship of which varies in the same manner and sequence as does the phase relationship of the radiated fields from said antennas as the radiating array is circled, means for combining said currents, means for producing from said combined currents a plurality of currents which vary in amplitude in proportion to the variations in amplitude of the combined currents, and means for causing said currents to operate said means for producing a visual image, to thereby produce a visual representation of the radiation pattern of said array.

3. Electrical means for producing a visual representation of the radiation pattern of a radiating array including a plurality of radiators, comprising means for drawing current from each of the radiators, means for constantly shifting the phase of the current drawn from at least one of the radiators with respect to the phase of the current drawn from another of the radiators, means for combining the currents drawn from the radiators of the array to produce a combined current which varies in amplitude in the same sequence as the field intensity of the radiation from the array varies as the array is circled and in proportion to such variations, means operable to produce a visual representation of a varying current, and means for causing the components of said combined current to operate said visual representation means to produce a visual representation of the radiation pattern of said array.

4. Electrical means for producing a visual representation of the radiation pattern of a radiating array including a plurality of radiators spaced S° apart, comprising means for drawing current from each of the radiators, means for constantly shifting the phase of the current drawn from at least one of the radiators between the limits and in the sequence −S° to +S° to −S° with respect to the phase of the current drawn from another of the radiators, means for combining the currents drawn from the radiators of the array to produce a combined current which varies in amplitude in the same sequence as the field intensity of the radiation from the array varies as the array is circled and in proportion to such variations, means operable to produce a visual representation of a varying current, and means for causing the components of said combined current to operate said visual representation means to produce a visual representation of the radiation pattern of said array.

5. Electrical means for producing a visual representation of the radiation pattern of a radiating array including a plurality of radiators, comprising means for drawing current from each of the radiators, means for constantly shifting the phase of the current drawn from at least one of the radiators with respect to the phase of the current drawn from another of the radiators, means for combining the currents drawn from the radiators of the array to produce a combined current which varies in amplitude in the same sequence as the field intensity of the radiation from the array varies as the array is circled and in proportion to such variations, means for separating said combined current into vectorial components, means operable to produce a visual representation of a varying current, and means for causing the components of said combined current to operate said visual representation means to produce a visual representation of the radiation pattern of said array.

6. Electrical means for producing a visual representation of the radiation pattern of a radiating array including a plurality of radiators, comprising means for drawing current from each of the radiators, means for constantly shifting the phase of the current drawn from at least one of the radiators with respect to the phase of the current drawn from another of the radiators, means for combining the currents drawn from the radiators of the array to produce a combined current which varies in amplitude in the same sequence as the field intensity of the radiation from the array varies as the array is circled and in proportion to such variations, means for rectifying said combined current, means for separating the rectified current into components, means operable to produce a visual representation of a varying current, and means for causing the components of said combined current to operate said visual representation means to produce a visual representation of the radiation pattern of said array.

7. Electrical means for producing a visual representation of the radiation pattern of a radiating array including a plurality of radiating elements, comprising means for producing from current supplied to the radiating elements a current which varies in amplitude in the same sequence as the field intensity of said array varies as the array is circled and in proportion to such variations, means for producing a visual representation of a varying current, and means causing the operation of said visual representation means by said current to thereby produce a visual representation of the radiation pattern of said array.

8. The method of producing a visual representation of the radiation pattern of an antenna array which comprises the steps of drawing current from each radiating element of the array, shifting the phase of the current drawn from certain of the radiating elements in a predetermined amount and sequence and combining such current after shifting of the phase thereof with current drawn from other antennas to produce a combined current which varies in amplitude in the same sequence as the field intensity of the array varies as the array is circled and in proportion to such variations, and causing such combined current to operate the deflecting means of a cathode ray oscillograph to thereby provide a visual representation of the radiation pattern of said array.

9. The method of producing a visual representation of the radiation pattern of an antenna array which comprises the steps of producing from the currents supplied to the separate antennas of the array a combined current which varies in amplitude in the same sequence as the field intensity of the radiation from said array varies as the array is circled and in proportion to such variations, and causing said com-

bined current to operate means for producing a visual representation of a varying current to thereby provide a visual representation of the radiation pattern of said array.

10. Electrical means for producing a visual representation of the radiation pattern of a radiating array including a plurality of radiators, comprising means for drawing current from each of the radiators, means for constantly shifting the phase of the current drawn from at least one of the radiators with respect to the phase of the current drawn from another of the radiators, means for combining the currents drawn from the radiators of the array to produce a combined current which varies in amplitude in the same sequence as the field intensity of the radiation from the array varies as the array is circled and in proportion to such variations, means for separating said combined current into vectorial components, means for synchronously operating said phase shifting means and said current separating means, means operable to produce a visual representation of a varying current, and means for causing the components of said combined current to operate said visual representation means to produce a visual representation of the radiation pattern of said array.

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