Dec. 27, 1949 H. G. BUSIGNIES 2,492,354

DIPOLE ANTENNA DIRECTION FINDER

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Fig. 1.

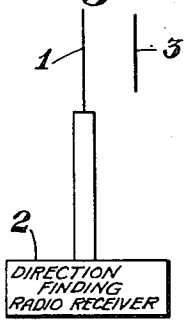


Fig. 2.

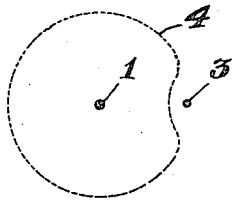


Fig. 3.

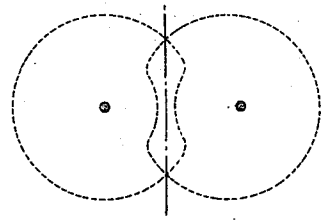


Fig. 4.

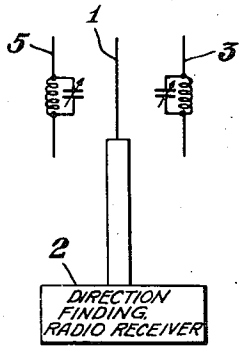


Fig. 4A.

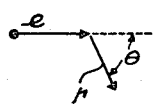


Fig. 4B.

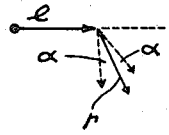


Fig. 5.

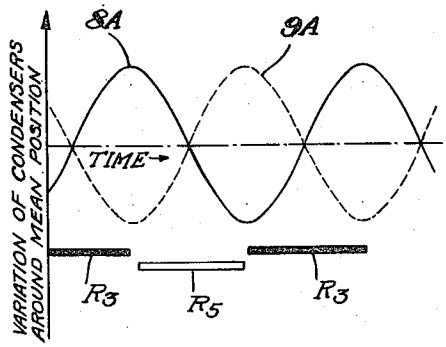


Fig. 6.

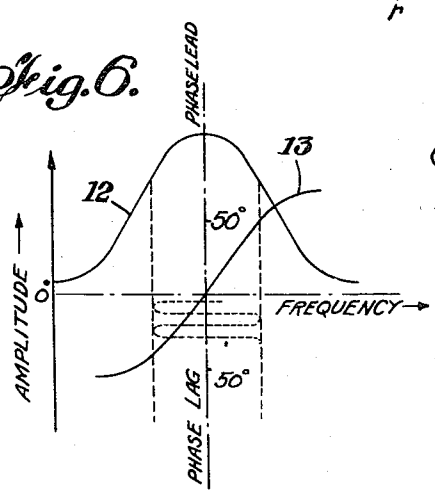


Fig. 7.

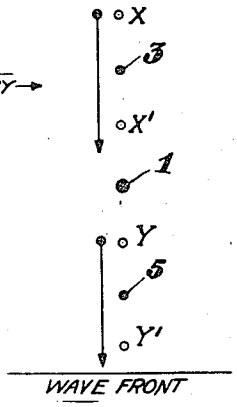
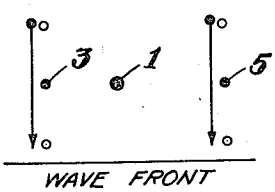


Fig. 8.



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Fig. 9.

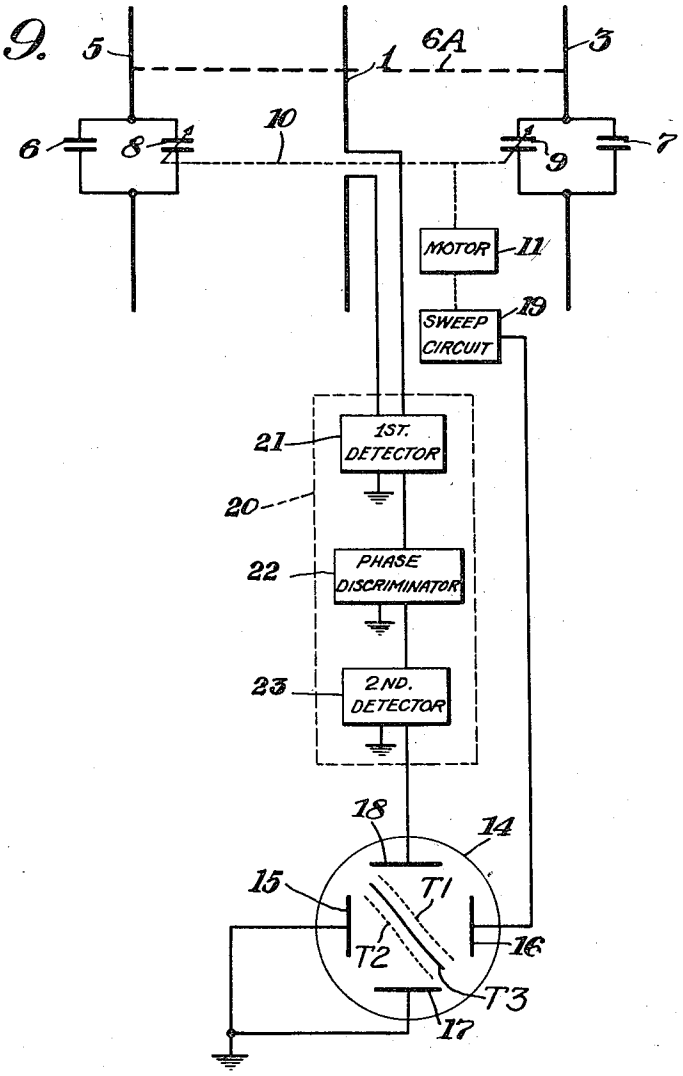
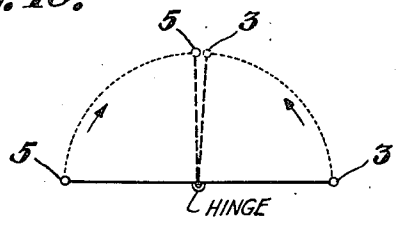


Fig. 10.



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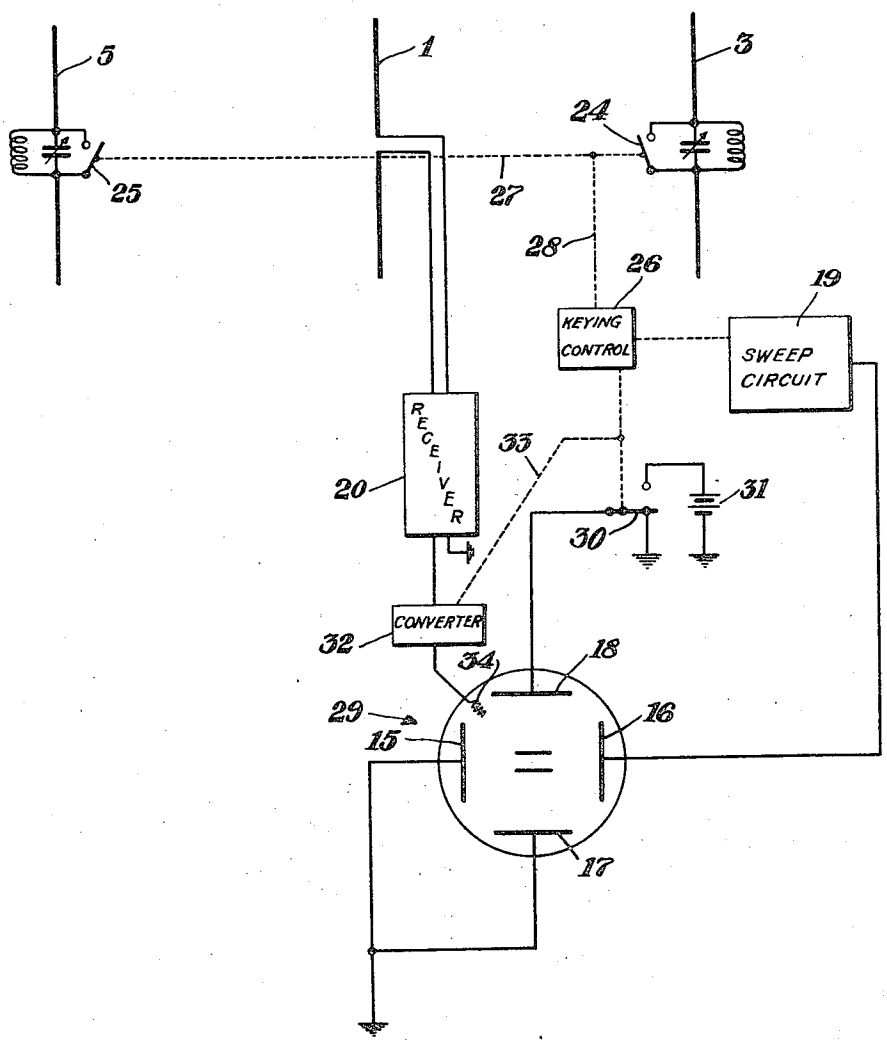
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Fig. 11.



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DIPOLE ANTENNA DIRECTION FINDER

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Application April 9, 1945, Serial No. 587,242

15 Claims. (Cl. 343—113)

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This invention relates to direction-finding systems and more especially to antenna arrays to produce crossed-field diagrams.

A principal object of the invention is to provide a direction-finding system employing a dipole array wherein certain errors caused by undesired polarization effects are avoided.

It has been proposed heretofore to employ for direction finding, a so-called elevated H antenna system usually consisting of a pair of substantially parallel elevated dipoles. It has been found that in such systems there exists an error factor caused by the horizontal connecting member which extends between the dipoles. This connecting member has usually been of conducting material, and various proposals have been made to eliminate the effect of this conductor upon the desired crossed-field diagram. The present invention provides a direction finder employing dipoles or tuned antennae and has for its object effectively to reduce, if not entirely eliminate, the above-mentioned undesired polarization effect. In achieving this object, it is proposed to employ a central or main receiving antenna and to employ in conjunction therewith a pair of laterally-spaced auxiliary tuned antennae, preferably dipoles. These auxiliary dipoles however are used as localized reradiators to give the desired crossed diagram effect so that the array can be used to determine the bearing and direction of a distant transmitter or radiation source. Merely for purposes of explanation, the auxiliary dipoles will be referred to as free dipoles in that their effect on the direction-finding radio receiver which is connected to the main antenna, is substantially entirely by reason of space induction and radiation from the auxiliary dipoles to the main antenna.

Accordingly, it is another principal object to provide a direction-finding system employing a main direction-finding antenna in conjunction with a plurality of free dipole antennae for producing a direction finder system of the crossed diagram type.

A feature of the invention relates to a direction finder employing a main receiving antenna unit and a plurality of auxiliary antenna units coupled thereto substantially entirely by space radiation or induction, together with means to render said auxiliary units alternately effective as reradiators in setting up a crossed diagram field effect.

Another feature relates to a direction-finding system employing a main direction-finding antenna and a plurality of spaced dipoles which act as auxiliary radiators to the main antenna,

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the auxiliary radiators being timed and phased so as to produce an equivalent crossed diagram effect for direction finding.

A further feature relates to a direction finder employing a main receiving dipole with a pair of auxiliary tuned reradiating dipoles and a receiver and indicating system connected to the main dipole. The dipoles are positioned and spaced apart relatively to each other so that the resultant effect on the direction-finding indicator corresponds to the bearing and direction of a distant radiation source.

A further feature relates to an improved direction finder employing a plurality of free dipoles and which is substantially free from horizontal polarization errors.

A still further feature relates to a novel method of controlling a cathode ray tube oscilloscope to produce visual signals indicating the bearing and direction of a distant radiation source.

Other features and advantages not particularly set forth, will be apparent from the following descriptions and the appended drawing wherein,

Figs. 1 to 4 are rudimentary diagrams used in explaining the invention.

Figs. 4A and 4B are vector diagrams explanatory of Fig. 4.

Fig. 5 is a set of curves to illustrate the timed operation of the reradiating antenna units according to the invention.

Fig. 6 is a resonance and phase diagram useful in explaining the invention.

Figs. 7 and 8 are other schematic explanatory diagrams.

Fig. 9 is a composite schematic diagram of a direction-finding system embodying features of the invention.

Fig. 10 is a diagrammatic plan view of a modified manner of supporting the auxiliary dipole antennae according to the invention.

Fig. 11 is a schematic diagram of a further direction finding system embodying features of the invention.

It is known that when a vertical receiving antenna such as the antenna 1 (Fig. 1) is connected to any well-known direction-finding radio receiver 2, and a length of vertical conductor 3 is moved around the antenna in a cylindrical path, negligible effect is produced upon the field affecting the antenna 1. This is true when the conductor 3 is short with respect to the wave length of the main field affecting antenna 1 and when the conductor 3 is detuned with respect to the received frequency. When, however, the conductor 3 is tuned to the received frequency, the effect on

antenna 1 of the auxiliary field reradiated from antenna 3 is a substantial percentage of the effect produced by the main or primary field on antenna 1. If such a tuned conductor is rotated around antenna 1, it causes variation of the polar diagram 4 as shown in dotted outline in Fig. 2. If a similar tuned conductor 5 (Fig. 4) were also rotated around antenna 1 and tuned in timed relation with respect to conductor 3 so that the two tunings are respectively 180° out of phase, the combined result would be a crossed-field diagram such as shown in Fig. 3. This would enable the combination to be used as a direction finder. Such an arrangement of main antenna and auxiliary free reradiating antennae has the advantage of substantially eliminating polarizing errors which would unavoidably arise if the auxiliary antennae 3 and 5 were connected by conductors to the antenna 1, as is the case in so-called elevated H antennae.

Ordinarily, the conductors 3 and 5 are in the form of dipoles and in accordance with the invention they are tuned in any suitable way as schematically represented by the parallel inductances and capacities connected between their adjacent arms. However, one of the practical difficulties with such an arrangement is that of requiring a high degree of accuracy in the tracking of the tuning of the two auxiliary dipoles. Furthermore this tuning must be effected without using a conducting shaft or beam extending between the antennae 3 and 5.

In accordance with one aspect of the invention, the two dipoles 3 and 5 are located at the ends of a non-conductive horizontal beam member. When the two auxiliary dipoles are tuned to the frequency being received by the main antenna 1, and are located at relatively short distances therefrom, e. g., of the order of 2.5 meters, sufficient current will be set up in the auxiliary dipoles to induce in, and reradiate a field to, the main antenna 1, which field is of the same order of strength as the main or primary field from the distant source whose direction is to be determined. In order to tune the dipoles, an inductance and variable condenser can be connected, as shown in Fig. 4, in each dipole. At frequencies for which each dipole is materially less than one-half wave length, the radiation resistance of each dipole system will be very small, and if high quality reactance elements are used for tuning, the Q of the resonant circuit will be high. In fact, at all those frequencies for which there is a pronounced undesirable horizontal polarization effect in the equivalent elevated H antenna, the Q of each of the reradiating dipoles according to the invention will be fairly high, e. g., above 20. This relatively high Q causes the tuning of the dipoles to be very sharp. Consequently small variations in values of tuning capacitance cause comparatively large variation in phase angle between voltage and current. That is, there is a large variation in the phase of the primary electric field which acts on each dipole and the electric field reradiated therefrom. In the vicinity of resonance, the phase angle is the arctan $Q+C/C_0$ where C_0 is the capacitance at resonance. In accordance with one feature of the invention, the resonance of the two reradiating dipoles is controlled so as to minimize the critical effect of the resonance tuning thereof.

It is well-known that a resonant dipole located in an electric field has set up therein a current which is in phase quadrature with the primary electric field acting thereon. This current flowing in the dipole is itself a source of electric field which, for purposes of analysis, can be considered to be made up of two components, the reradiation field and the inductance field. When the dipoles 3 and 5 are located at a distance approximating a small fraction of a wave length, the two components are of substantial magnitude, and therefore the reradiated field must be considered as made up of space induction and radiation. Consequently the phase between the primary or main field acting on antenna 1 and the field from each of the dipoles will vary from 0° to 180°. For purposes of explanation the expression "primary field" as used herein refers to that field emanating from the distant source whose bearing and direction is to be determined according to the invention.

Let it be assumed for example, that the dipoles 3 and 5 are spaced apart about five meters and each is tuned exactly to resonance with the frequency of the primary field. Then it is possible to determine the total difference in phase between primary field and reradiated field by adding to the actual electrical phase difference between the fields, the difference in space phase corresponding to the distance between each dipole and the main antenna, and also by adding the space phase corresponding to increased length of primary wave path to each dipole in excess of the length of the primary wave path to antenna 1 when the assembly 3 and 5 is rotated at an angle to the primary wave front. Fig. 4A shows the vector relations when the line joining dipoles 3 and 5 is parallel to the wave front of the primary field, and Fig. 4B shows the vector relation when it is at an angle. In each of these figures the vector e indicates the primary field and the vector r represents the reradiated field, and the angle α is the space phase angle lag above mentioned. In Fig. 4A the amplitude of the demodulated signal in receiver 2 is the sum of the two vectors e and r. In Fig. 4B the amplitude of the demodulated signals is the sum of all the vectors. The resultant phase angle in Fig. 4B is given by $(2\pi d/\lambda) \sin \theta$ where d equals the distance from antenna 1 to each dipole, λ is the wave length of the primary field, and θ is the angle through which the antenna system has been rotated.

In accordance with the invention, special means are provided to determine and produce an indication when the phases of the two reradiated fields respectively from 3 and 5 are equal. The direction of the wave propagation from the distant source can then be determined as perpendicular to the azimuthal angle of the line connecting dipoles 3 and 5 provided, of course, the dipoles are identical and are off resonance by exactly the same amount.

In order to avoid the difficulty of accurate tracking of the tuning of each dipole, a preferred arrangement such as shown in Fig. 9 is employed, wherein the auxiliary dipoles 3 and 5 are supported on a suitable non-conducting beam indicated by dash line 6A and are tuned each by a fixed condenser 6, 7 and by an associated adjustable trimmer condenser 8, 9. The rotors or adjusting shafts of condensers 8 and 9 are coupled to a non-conductive rotatable shaft 10. The condensers 6 and 7 are roughly adjusted near the tuning resonance point and the condensers 8 and 9 are arranged to be displaced around a mean resonance value at a low frequency rate, e. g. twenty or fifty times per second under control of shaft 10 which is driven by a suitable motor 11.

In order to produce the effect of alternating switching in and out of the antennae 3 and 5, each antenna is arranged to be tuned to resonance at approximately 180° lag with respect to the other. Fig. 5 shows graphically the rate and timing of the variation of the condensers 8 and 9, curves 8A and 9A, and blocks R3 and R5 represent the effective phase periods of the two dipoles. It will be noted from Fig. 5 that the condensers 8 and 9 are rotated so that their effects on the mean resonance frequency of the respective dipoles are 180° out of phase. The curve 12 of Fig. 6 shows the resonance characteristic for each dipole, and the curve 13 shows the resultant phase angle change in each dipole as it is being tuned into and out of resonance, the resultant phase variation would be approximately between 50° to 70°.

The electrical phase variation thus produced is equivalent to a corresponding spacial displacement of the antennae 3 and 5 as represented for example in Figs. 7 and 8. Fig. 7 represents diagrammatically the equivalent apparent displacement of antennae 3 and 5, when the beam of the direction-finding antenna array is perpendicular to the wave front from the distant source; while Fig. 8 represents the equivalent apparent displacement when the antenna array is parallel to the wave front. Near the null point this apparent displacement is analogous to the displacement used in an ordinary cross loop direction finder. It will be seen that by suitable design of the electric parameters, the apparent displacements X to X', and Y to Y', can be larger than the actual physical spacing between antennae 3 and 5. The electric spacing between antennae 3 and 5 may be between 25° and 120°.

If the electric spacing between the antennae 3 and 5 is of the order of 90°, that is a quarter wave length spacing, the electric equivalent motion corresponding for example to displacements XX' and YY' would be of the same order of magnitude, namely 90°.

For the purpose of determining the relative phase of the radiations from the two antennae 3 and 5 at the antenna 1, a suitable phase indicating device such as a cathode-ray tube oscilloscope 14, having the usual horizontal deflecting plates 15 and 16 and the usual vertical deflecting plates 17 and 18, may be employed. The plates 15 and 16 are energized at the desired horizontal sweep rate, for example by means of a saw-tooth wave generator 19, which is operated or controlled preferably at twice the rate of rotation of a shaft 10. Thus, the cathode-ray beam will pass through one complete horizontal sweep cycle for each resonant tuning period (R3, R5, Fig. 5), corresponding to the reradiation from antennae 3 and 5.

The main antenna 1 is excited by the resultant energy derived from the primary field and by the energies reradiated alternately from antennae 3 and 5. A suitable radio receiver 20, such as is generally used in radio direction finders, is connected to antenna 1 and is preferably of the superheterodyne type. The first detector 21 of the receiver feeds a phase discriminator 22 of any well-known type such as disclosed. The discriminator 22 feeds a second detector 23 whose output is applied across the vertical deflector plates 17 and 18.

When the antenna array 1, 3, 5, is not aligned perpendicularly to the transmitting source, the energies reradiated by dipoles 3 and 5 will be out of phase with respect to each other. Accordingly, the signal, after passage through the discriminator 22, will vary in amplitude in accordance with the relative phase displacements of the reradiations. This difference in phase will appear on the screen of the oscilloscope 14 in the form of two traces T1, T2. On the other hand, when the antenna array is adjusted perpendicularly to the distant source, the two traces T1, T2, coincide and appear as a single trace T3. It will be clear that the invention is not limited to the particular type of trace that is produced on the oscilloscope screen. For example, instead of relying upon a coincidence of the two traces to indicate a null point, a fixed cross-point on the screen may correspond to the null point, and when the two traces pass through this point, it is an indication that the null position is reached. Therefore, the trace can be used to show the phase variation of the high frequency signals from the distant transmitter as a function of the scanning, or time rotation of condensers 8 and 9; and also as a function of the position of the direction-finding beam which carries the antenna array.

While in the foregoing the free dipoles have been described as being preferably effectively "switched-in" under control of the 180° displaced resonance tunings, it will be understood that any other well-known switching method may be employed. For example, in Fig. 11, each dipole 3, 5 may be provided with an individual switch 24, 25 and the switches may be alternately opened and closed at the required rate. These switches will then be controlled from a keying control means 26 by a non-conducting control such as rotatable Bakelite rods 27, 28. Synchronized with the switching mechanisms is an indicating mechanism which will cause the amplitudes of the demodulated signals to be indicated separately when each of the dipoles is reradiating. The cathode-ray tube oscilloscope 29 is provided with a switch 30 coupled alternately between ground and a potential source 31 in synchronism with operation of switches 24 and 25. The length of these traces are determined by the signal output from receiver 20 proportional to the amplitudes of the demodulated signals when each of the dipoles is reradiating. The signals of different amplitudes are converted into signals of corresponding different lengths in converter 32, which may be of any known form, such as resistant capacity time control circuits. The switching in converter 32 is likewise controlled by keying control 26 through means 33. These output voltages are applied to a control grid 34 rendering the beam visible for a length of time depending upon the signal duration. When the fields of the two dipoles are in equal phase, the primary field or the distant transmitter would have added to it, alternately, two fields which are lagging by a certain angle as mentioned above. Rotating the dipole array about a perpendicular axis will then cause one reradiated field to lag by a smaller angle, and the other by a larger angle, resulting respectively in a smaller and larger amplitude of the demodulated signal. The effect on amplitude of the demodulated signal by change of phase lag is most pronounced when the reradiated field lags the primary field by approximately 90°. At frequencies when the lag is too far from 90°, the two dipoles 3 and 5 can be equally detuned to change the phase relationship between current and voltage. As shown in Fig. 4B, the effect on demodulated signal amplitude is greatest when the angle between primary and reradiated fields is near 90°.

In order to permit operation over a wide band

of frequencies it will be necessary to provide some method of avoiding tracking errors caused by a difference in tuning of the two dipoles 3 and 5 for the various frequencies. One solution for effecting the tracking of the condensers would be as follows. The condensers 8 and 9 would be controlled by a Bakelite rod as above described. After a signal is tuned-in on the receiver 20 and approximately tuned on the dipoles by means of the condensers 6 and 7, the dipoles must be trimmed to exact resonance or to an equal amount of off resonance. In order to simplify this adjustment, the beam which carries the two antennae 3 and 5 can be hinged at its center so that the two dipoles can be swung substantially adjacent to each other as represented diagrammatically in Fig. 10. Thus, after a signal is tuned-in, the two dipoles would be swung together to occupy approximately the same location and space and with no phase difference between them. Then one or the other of the dipoles can be trimmed until the suitable phase indicator such as 14 showed equal phases for each dipole. The dipoles could then be swung apart to the full-line position shown in Fig. 10 preparatory to taking the bearing.

It might at first seem that the proximity of the two dipoles during the trimming operation would so change their electrical characteristics that upon separating them they would fall out of exact resonance. While it is true that the setting for resonance would be different when the two dipoles were in very close proximity, the subsequent separation of the dipoles would detune both of them exactly the same amount, and it is necessary only that they be tuned alike, not necessarily to exact resonance—provided only that they are not so far from resonance that their reradiated fields are too weak to affect the total energy in the central antenna. Moreover, if the ganged tuning were performed while the two dipoles were still separated, and only the trimming were carried on while they were close together, the subsequent separation would return the conditions for optimum signal reradiation.

Tracking errors may likewise be cancelled out by obtaining direct and reciprocal readings from the antenna unit, and balancing these indications against one another.

While certain particular embodiments have been disclosed herein, it will be understood that various changes and modifications may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. A direction-finding arrangement comprising a main wave pickup, at least one auxiliary pickup mounted for excitation by waves from a source whose direction is to be determined and adapted to reradiate waves to said main pickup, means to adjust the phasing of said pickups to produce a crossed diagram directional radiation characteristic, and means to obtain a determination of any one of a range of phase relations among the reradiations to said main pickup and the waves received directly by said main wave pickup.

2. A direction-finding arrangement comprising a main wave pickup, a plurality of auxiliary wave pickups, all said pickups arranged to be excited by radiations from a transmitting source whose direction is to be determined, said pickups constituting a movable array, said auxiliary pickups being coupled to the main pickup substantially entirely by space induction and reradiation derived from said source, and a phase translating and indicating system coupled to said main pickup for producing an indication of the angular relation between said array and said source.

3. A direction-finding arrangement comprising a main wave pickup, a plurality of auxiliary wave pickups mounted in the vicinity of the main pickup and arranged to be tuned to the frequency of the waves from a source whose direction is to be determined whereby they act as substantial reradiators to said main pickup, means to control alternately the reradiation from said auxiliary pickups, and a translating and indicating system connected to said main pickup to produce an indication of the relative phases of the reradiations from said auxiliary pickups.

4. A direction-finding arrangement comprising a main directional antenna, a plurality of auxiliary antennae coupled to said main antenna substantially entirely by space induction and reradiation derived from a distant source whose direction is to be determined, means to control said auxiliary antennae so that they effectively reradiate to said main antenna alternately at a predetermined rate, a translating system connected to said main antenna and including means to provide a signal whose amplitude corresponds to the phase difference between the waves acting directly on said main pickup and the waves reradiated thereto from said auxiliary pickups.

5. A direction-finding arrangement according to claim 4 in which the last mentioned means includes a phase discriminator which converts phase differences in the waves impressed thereon into corresponding voltage amplitude variations.

6. A direction-finding arrangement according to claim 4 in which said auxiliary antennae are tuned dipoles.

7. A direction-finding arrangement according to claim 4 in which said auxiliary antennae are dipoles each having a tuning unit, and means for adjusting said units at a predetermined rate to vary the resonance of each dipole around a mean value.

8. A direction-finding arrangement comprising a dipole antenna array consisting of a central main dipole and a pair of auxiliary dipoles, means to support said array for angular adjustment with respect to a source whose direction is to be determined, said means including a non-conductive beam extending between said auxiliary dipoles, means to tune said auxiliary dipoles, means to render said auxiliary dipoles alternately effective as reradiators to said main dipole, a wave detector connected to said main dipole, a cathode-ray tube oscilloscope having a plurality of coordinate beam deflector controls, a phase discriminator connected to said detector, a sweep circuit for one of said controls, means to energize the other of said controls by the output of said phase discriminator, and means to control said sweep circuit in timed relation with the said alternate effectiveness of said auxiliary dipoles.

9. A direction-finding arrangement according to claim 8 in which the said means to tune the auxiliary dipoles includes a tuning condenser for each dipole and non-conductive means for adjusting said condensers from a central point to resonate the associated dipoles approximately in opposite phase.

10. A direction-finding arrangement according to claim 8 in which each of the said auxiliary dipoles has a pair of tuning condensers one condenser of each pair being an adjustable trimmer,

and non-conductive means for operating the trimmers in unison so as to tune the associated dipoles approximately in opposite phase a predetermined amount on either side of a mean resonance value.

11. The method of determining the direction from a point of observation to a source of energy radiation which comprises directly receiving energy from said source, setting up a source of energy reradiation in a direction other than that of said first named source, and comparing the effect produced at said point of observation by phasal relations between the direct received energy radiated from said first source with that produced by the energy reradiated from said second source.

12. The method of determining the direction of a source of wave radiation which comprises collecting at a given location directly waves from said source, reradiating at one or more points adjacent said location and mixing with said collected waves waves received also from said source, adjusting the phase relation between the directly collected waves and the reradiated waves, and producing therefrom a determination of any phase relation in a given range between said waves as indicative of direction.

13. The method according to claim 12, wherein the reradiation takes place at two points and the reradiated waves are oppositely phased.

14. The method according to claim 12, wherein the phase relations between the mixed waves is intermittently controlled.

15. The method of determining the direction of a source of wave radiation which comprises collecting at a given location directly waves from said source, reradiating at one or more points adjacent said location and mixing with said collected waves waves received also from said source, adjusting the phase relation between the directly collected waves and the reradiated waves, and producing therefrom a determination of any phase relation in a given range between said waves as indicative of direction, the reradiation taking place at two points and the reradiated waves being oppositely phased, and the phase determination taking place when the phase between waves directly collected and those received for reradiation is equal.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,739,520	Potter	Dec. 17, 1929
1,944,563	Kruesi	Jan. 23, 1934
2,133,615	Gerhard	Oct. 18, 1938
2,141,247	Kramar et al.	Dec. 27, 1938
2,151,922	Kramar	Mar. 28, 1939
2,207,263	Nass	July 9, 1940
2,234,654	Runge	Mar. 11, 1941