

March 11, 1941.

H. T. BUDENBOM

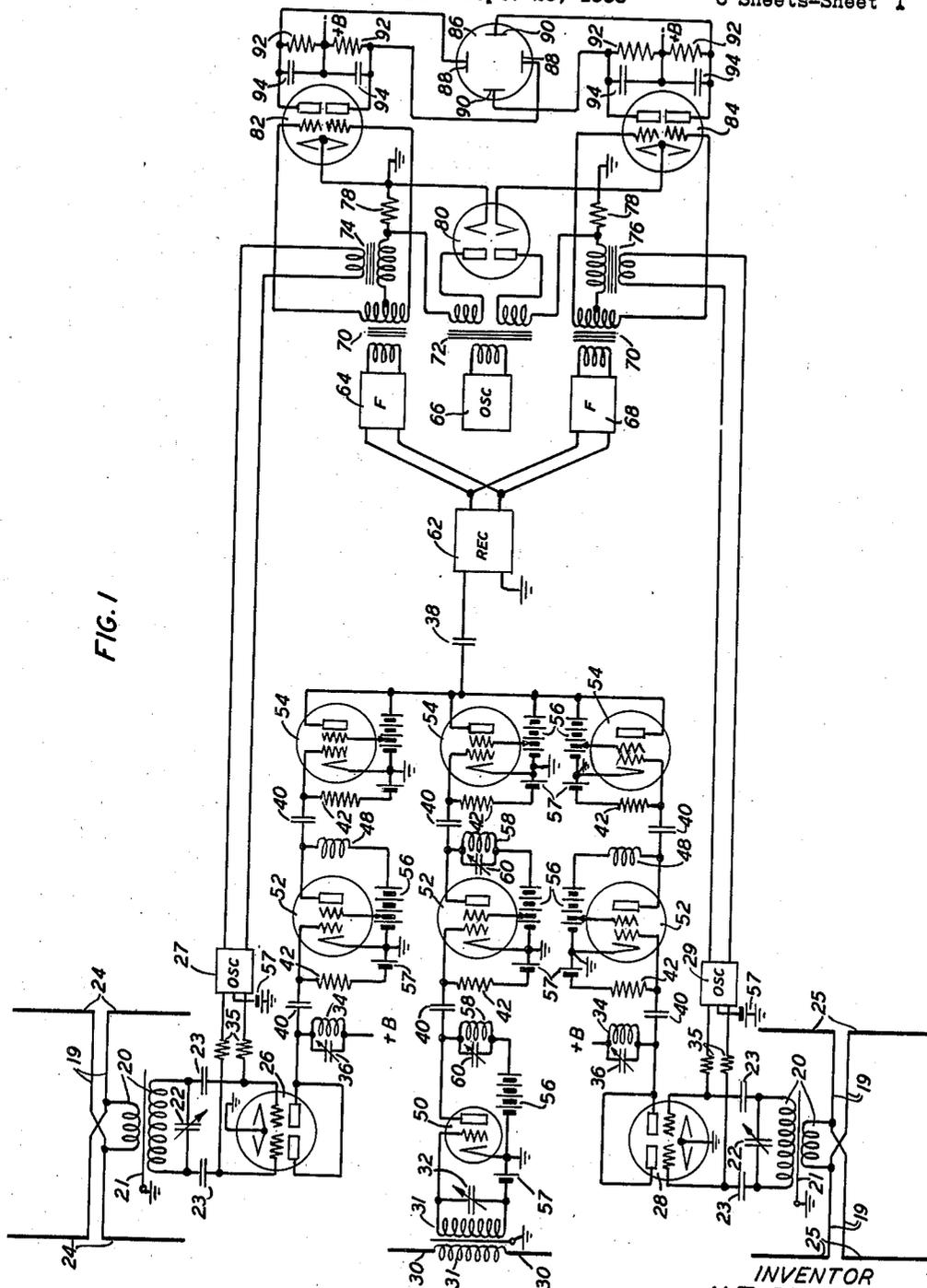
2,234,587

RADIO DIRECTION FINDING SYSTEM

Filed Sept. 23, 1938

6 Sheets-Sheet 1

FIG. 1



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6 Sheets-Sheet 2

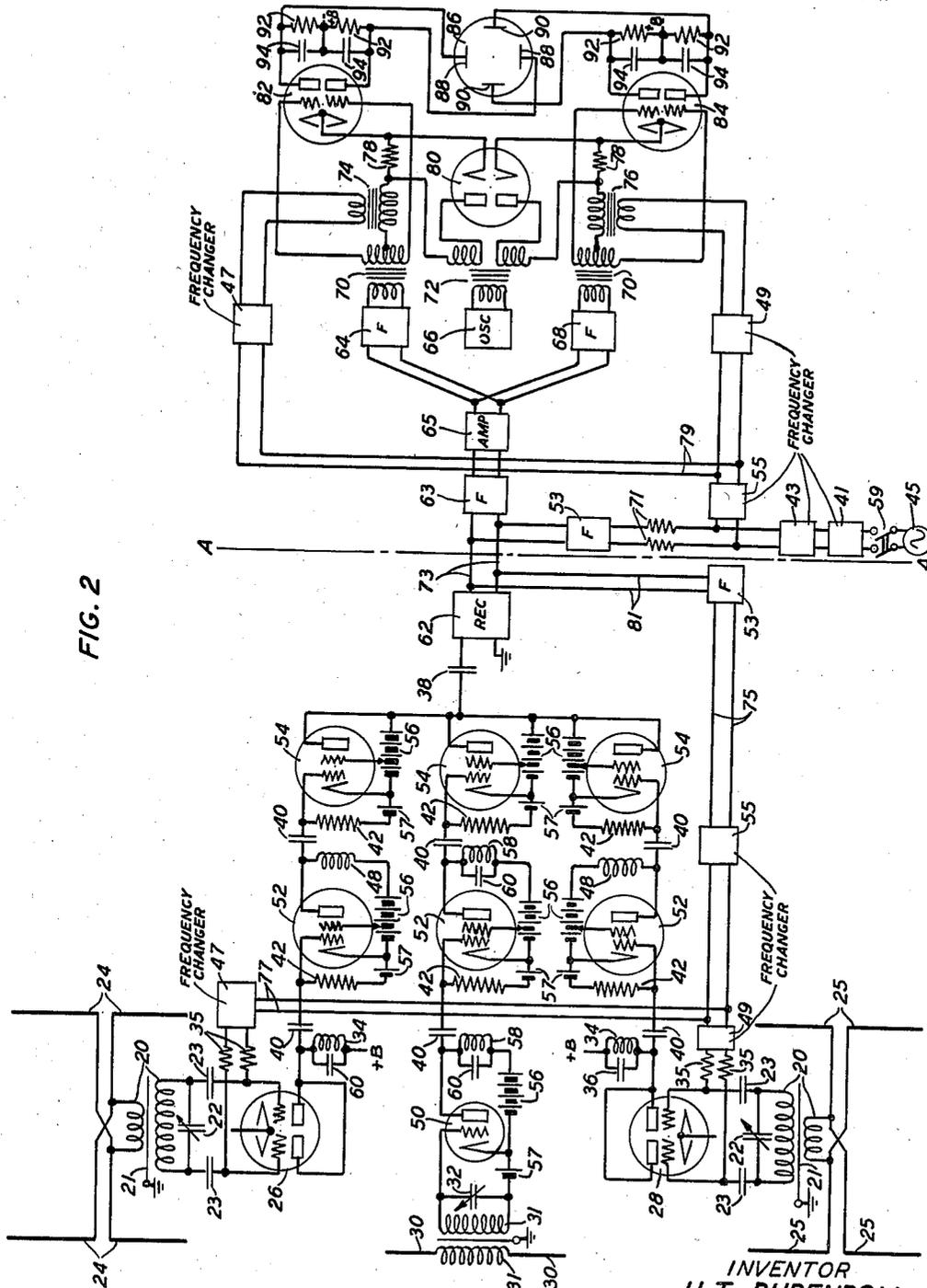


FIG. 2

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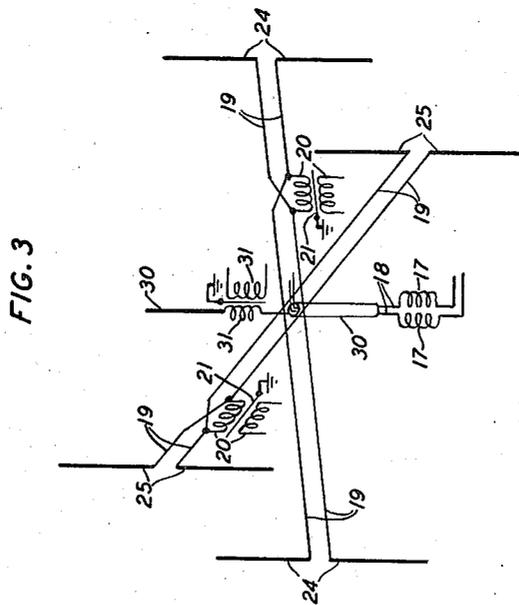
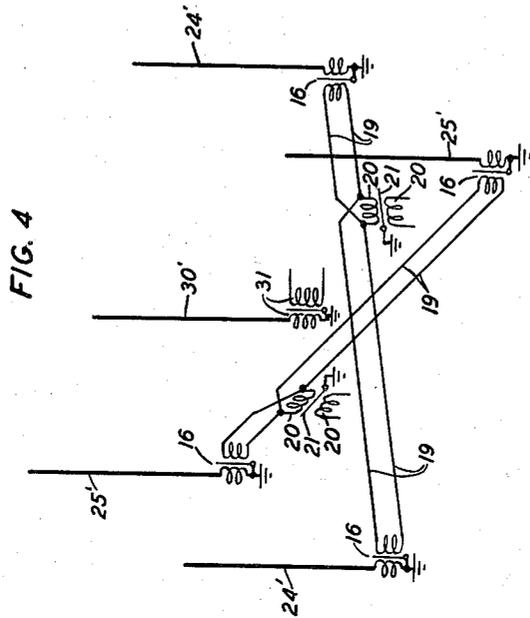
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RADIO DIRECTION FINDING SYSTEM

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6 Sheets-Sheet 3



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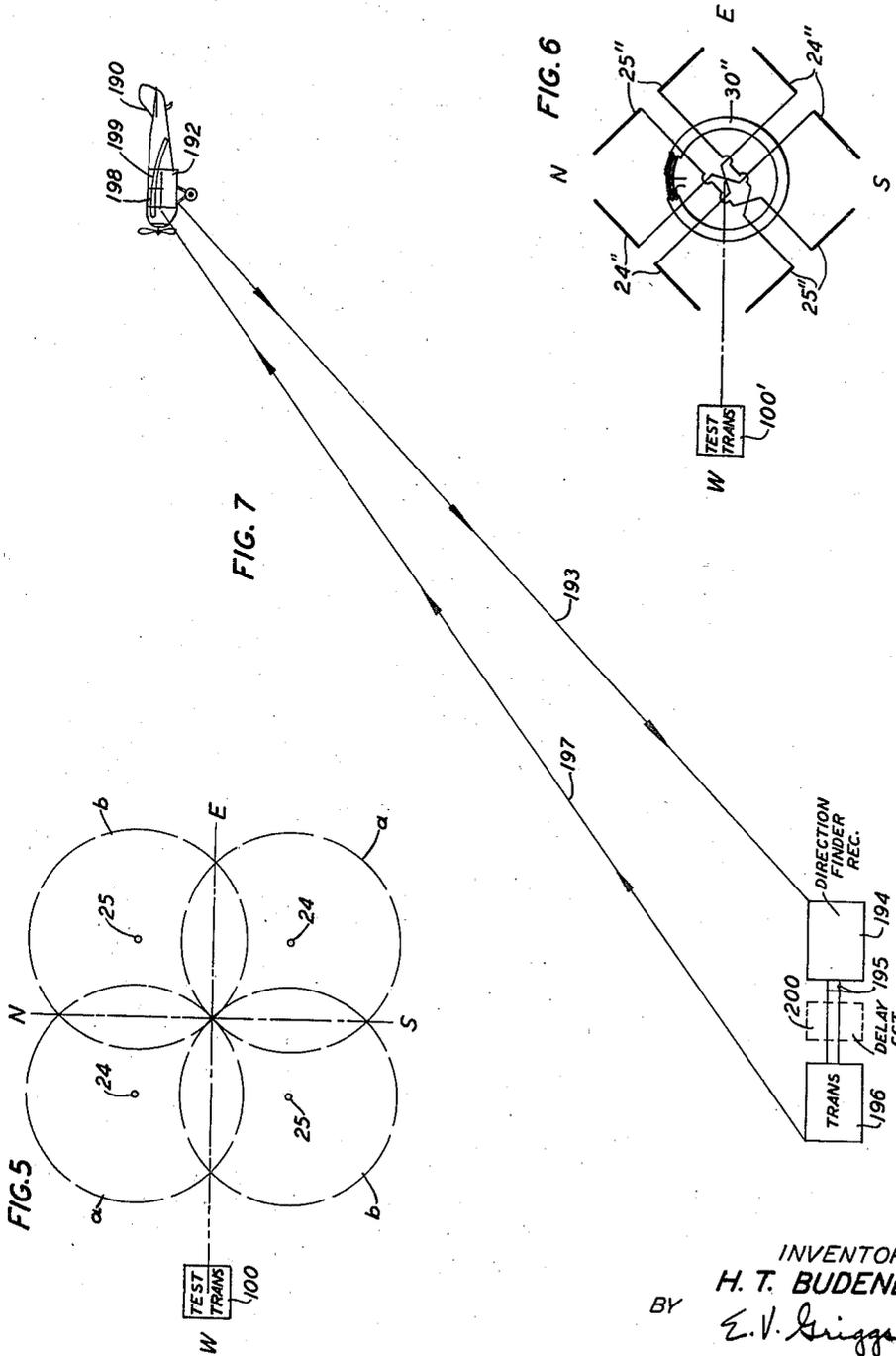
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6 Sheets-Sheet 4



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RADIO DIRECTION FINDING SYSTEM

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6 Sheets-Sheet 5

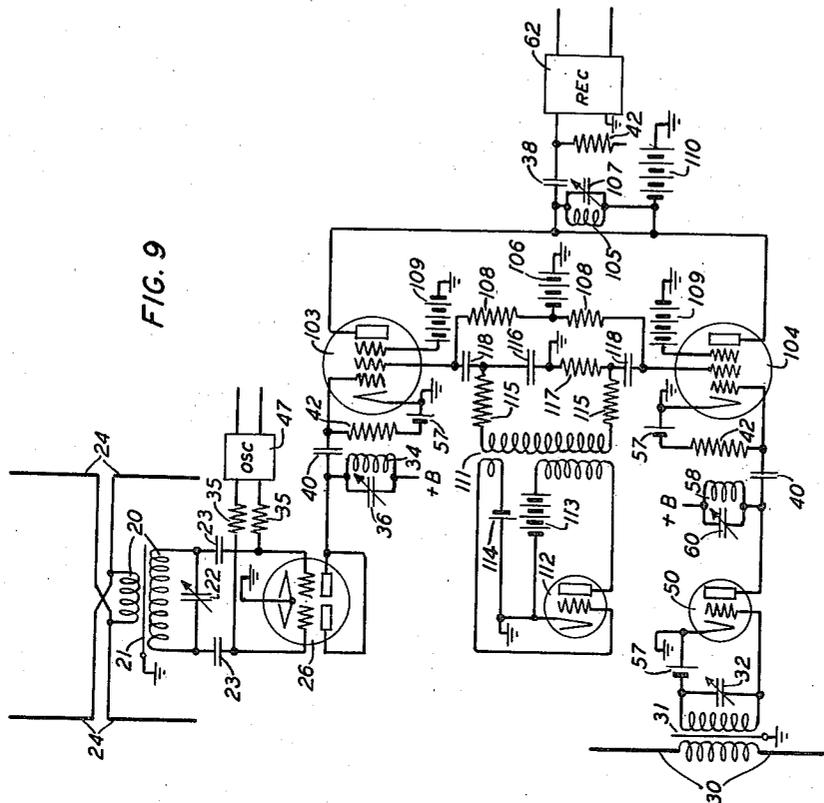


FIG. 9

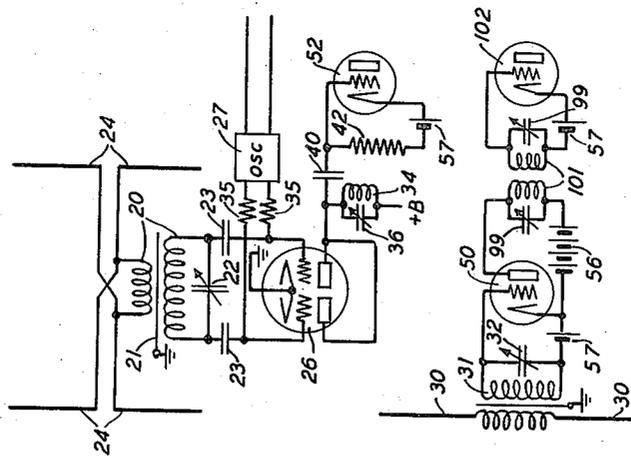


FIG. 8

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RADIO DIRECTION FINDING SYSTEM

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6 Sheets—Sheet 6

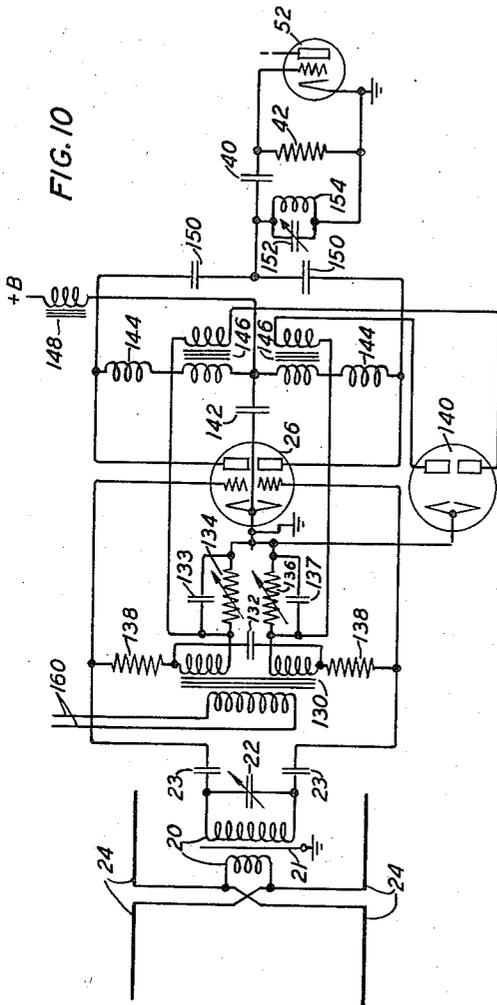


FIG. 10

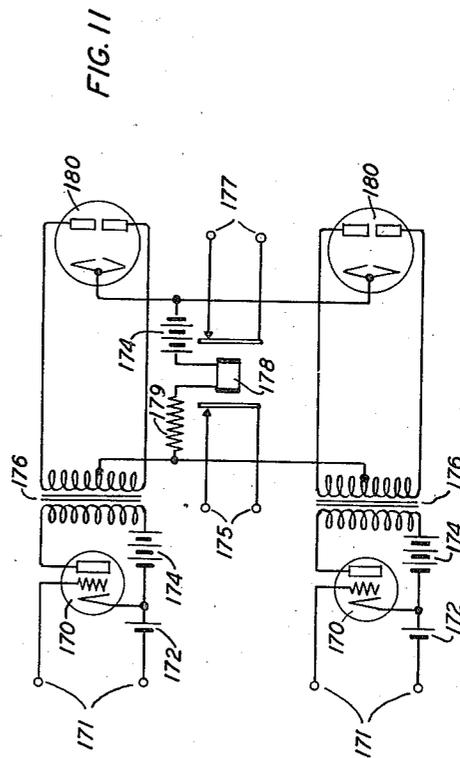


FIG. 11

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UNITED STATES PATENT OFFICE

2,234,587

RADIO DIRECTION FINDING SYSTEM

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Application September 23, 1938, Serial No. 231,333

5 Claims. (Cl. 250—11)

This invention relates to improved radio direction-finding systems and apparatus therefor. More particularly, it relates to improved radio direction-finding systems and apparatus therefor to determine instantaneously and without ambiguity the direction from which a radio wave approaches the receiving station of the system by comparing the relative characteristics of certain components of the wave, the components being obtained by receiving the wave on several antenna systems, the several antenna systems having predetermined characteristics and orientations. The systems of the invention may, furthermore, be readily adapted to provide directional indications at points remote from the receiving apparatus of the system.

Broadly stated, the method of directional determination proposed in this invention contemplates receiving a radio wave on a plurality of directional antennas or antenna arrays, said antennas or antenna arrays having particular directional properties which impart phase and amplitude variations to the components of the radio wave received by them, the variations being a function of the direction from which the radio wave approaches the particular antenna or array. The directional antenna systems employed in the specific embodiments of this invention disclosed hereinafter are of the type in which signals received from one side of the antenna are 180 degrees out of phase with those received from the other side. It is obvious, however, as will become apparent during the course of the following description, that antenna systems having other phase characteristics may equally well be used. The several antennas or arrays are given different particular orientations, a symmetrical arrangement being usually employed, so that the respective components of any given radio wave received by them will in general have different phases and amplitudes and a comparison of the phases and amplitudes of the several components will indicate the direction from which the radio wave approaches the antennas.

To facilitate this comparison each component of the radio wave after being received is modulated by a low frequency. Preferably different low audible or sub-audible frequencies are employed for each component, for purposes of ready identification, to permit the use of a single detector for all components and to avoid the duplication of other apparatus and circuits, as will become apparent hereinafter. These low frequencies will, for convenience, be referred to as poling frequencies.

In the specific embodiments illustrated, balanced modulators are employed so that the radio and poling frequencies balance out and the side-band frequencies, only, appear in the modulator output, provided the balance of the modulator is maintained. It is obviously feasible to employ any of numerous other well-known modulating means and to select at the output thereof, by means of appropriate filters or selective networks, the desired side-bands.

By reintroducing an appropriate carrier frequency the side-bands may be detected. The poling frequencies, modified in phase and amplitude to an extent determined by the particular radio wave component with which each was combined in the process of modulation, are thus again obtained.

The carrier frequency necessary for the process of detection may be obtained by receiving the radio wave on a simple non-directional antenna and adjusting its phase, or the phase of the side-bands by 90 degrees, to avoid the quadrature relation which would otherwise exist, or an appropriate frequency may be locally generated and furnished to the detector with the side-bands.

Having obtained the modified poling frequencies, each is introduced, in conjugate relation with energy of like frequency but of approximately the original phase and amplitude of the particular poling frequency, in a common frequency, conjugate input, balanced demodulator. The phase relation between the detected and the original poling frequency, in the case of each poling frequency, determines the polarity, and the amplitudes of the two determine the magnitude, of the direct electromotive force developed in the output of the balanced demodulator associated therewith. These demodulators are arranged to rectify the applied frequencies so that their outputs may be more readily compared and a relatively steady indication obtained.

In the particular systems to be described, the phase change is a simple sense reversal as the orientation varies.

The direct electromotive forces developed in the several demodulators are then applied to an indicating device, such as a cathode ray oscillograph, having a pair of deflecting plates for each electromotive force, the arrangement of the several pairs of deflecting plates preferably corresponding to that of the several directional antenna systems from the signals of which the poling frequencies derive their directional characteristics, respectively. The device will then

indicate the relative polarities and magnitudes of the above-mentioned direct electromotive forces in proper relation to each other, from which indication the direction of the received signals will usually be apparent. When a cathode ray oscillograph is employed, as above suggested, and the pairs of deflecting plates are arranged (as is also suggested as preferable above), in the same manner as the directional antennas with which the respective poling frequencies are associated, the position to which the ray is deflected may readily be made to directly indicate the direction from which the radio wave approaches the antennas.

A line pointing toward the transmitting station may be obtained by blocking the balanced demodulators simultaneously in the order of ten or more times per second. If this is done, the ray of the oscillograph will return each time the demodulators are blocked to its central, or no signal, position and thus trace the desired line. With either a symmetrical or non-symmetrical system a calibrated scale may be furnished with the indicating device from which the direction of the received signal may be read.

The specific embodiments of the invention employed for illustrative purposes herein comprise quadrature systems, that is, systems employing two directional antennas or antenna arrays in quadrature relation. Such systems employ two poling frequencies and two pairs of deflecting plates of the cathode ray indicator, placed in space quadrature relation.

It is obvious that more complex systems, for example, a hexagonal system employing three antenna systems in hexagonal relation, with three poling frequencies and a cathode ray indicator having three pairs of deflecting plates also placed in hexagonal relation with the appropriate apparatus associated with each antenna system as for the quadrature system could readily be devised by one skilled in the art and such a system would represent but another embodiment of the principles of this invention.

Also where maximum accuracy and sensitivity to waves approaching from particular areas are desired unsymmetrically arranged antenna arrays may well be employed. In such instances the arrangement of the cathode ray deflection plates may be similar to that of the antenna systems or a symmetrically arranged cathode ray tube may be specially calibrated to indicate positions within the limited area of particular interest.

An increase in the complexity of the system tends to eliminate areas in which the accuracy or sensitivity of the system may be impaired because of broad minimum or maximum response characteristics of the component antenna arrays. On the other hand it introduces additional apparatus with a corresponding increase in the number of apparatus difficulties which may be encountered.

While the specific embodiments disclosed hereinafter are designed to indicate the azimuth angle of the transmitting station with respect to the receiving station, it is obvious that by merely turning the antenna system so that its central horizontal plane is perpendicular to the earth's surface the system may be employed to obtain the vertical angle at the receiving station, of an aircraft in a known vertical plane with respect to the surface of the earth. By the use of auxiliary antenna systems of this character ground

station observations may be used to determine the altitude of aircraft.

A large number of radio direction-finding systems have been suggested heretofore. Numerous difficulties giving rise to incorrect indications have been encountered in these systems. Such difficulties include night errors, ambiguity of indication, inequality of amplification and/or phase shift within the system for systems in which several components are compared, broadness of indication, probable errors in manipulation and others.

It is a primary object of this invention to provide a radio direction-finding system which will be substantially free from error and ambiguity.

A further object is to provide an automatic system requiring no manipulation to obtain the directional indication.

A further object is to provide an accurate, direct and instantaneous indication of the direction of the transmitting station from which radio waves are being received.

A further object is to provide systems in which the indicating devices may conveniently be located at points far removed from the receiving stations.

A further object is to provide systems in which directional indications may be furnished mobile craft with a minimum amount of apparatus on the craft.

Other objects will appear during the course of the following description and in the appended claims.

In the accompanying drawings:

Fig. 1 illustrates, in schematic diagram form, one embodiment of a system employing the principles of this invention;

Fig. 2 illustrates, in schematic diagram form, a second embodiment of a system of this invention which has been modified so that the indicating device may more conveniently be located at a point far removed from the receiving station;

Fig. 3 illustrates an antenna arrangement employing dipole antennas, the arrangement being suitable for use with systems of this invention, and being designed to operate on the vertically polarized component of the received electromagnetic waves;

Fig. 4 shows an alternative antenna arrangement differing from that of Fig. 3 chiefly in that Marconi antennas are employed in place of dipole antennas;

Fig. 5 shows a suitable horizontal plan view of the antennas of Figs. 3 and 4, and also illustrates an appropriate method of locating a local test transmitter for checking and aligning the channels of the system carrying different components of the received signal wave;

Fig. 6 illustrates an antenna arrangement, suitable for use with systems of this invention, differing from the arrangement in Fig. 3 principally in that it is designed to operate on the horizontally polarized component of the electromagnetic wave;

Fig. 7 illustrates, in diagrammatic form, the system for furnishing a directional indication to a mobile craft, contemplated in connection with this invention;

Figs. 8 and 9 illustrate additional and alternative methods for obtaining appropriate phase relations between non-directionally and directionally received signal components;

Fig. 10 illustrates a balanced modulator circuit in which the gain of each side of the circuit is independently controlled by automatic means to

maintain the two sides of the circuit in balance; and

Fig. 11 illustrates a signal controlled relay circuit which short-circuits the inputs of the indicator when no signals are being received.

In the system of Fig. 1, antennas 24 and 25 are of the dipole type and are arranged in pairs to provide directional antenna systems of the well-known "Adcock" type. The antenna arrangement is completed by a simple non-directional antenna 30. Several appropriate antenna arrangements for the systems of this invention will be discussed in detail hereinafter in connection with Figs. 3 to 6, inclusive.

Referring again to Fig. 1, the energy received on each pair of dipole antennas 24 and 25 is passed through transformers 20 to balanced modulators 26 and 28, respectively. Transformers 20 are provided with interwinding electrostatic shields 21, the use of which is well known in the art.

The secondary circuit of each transformer is tuned to the frequency of the electromagnetic wave, whose direction is to be determined, by a variable condenser 22. Series condensers 23 permit the passage of the received radio frequencies but block lower frequencies from the antenna circuits. The energy from the respective antenna pairs 24 and 25 is modulated, in each instance, by a different low frequency, commonly designated as a poling frequency. Suitable low frequencies are generated by oscillators 27 and 29, respectively.

To be suitable for this purpose, the two low frequencies chosen should preferably not be harmonically related to each other, since if they are harmonically related, harmonics of one frequency may cause objectionable cross-talk into the circuits of the other. While this difficulty may be minimized by shifting the phase of one low frequency to be in quadrature with the other, it is preferable to avoid it if conveniently possible. The two frequencies should differ sufficiently in frequency so that filters to separate them may be readily designed and constructed. They should be of sufficiently low frequency that they may readily be transmitted over ordinary communication circuits of great length and should preferably not fall within the band of frequencies usually employed in transmitting speech so that the operation of the system will not be affected by the presence of speech modulations of the wave whose direction is being determined. A second reason for employing frequencies other than those within the band usually employed for speech is that then the same circuit between the receiving and indicating apparatus of the system may carry both the directional signals and, in addition, speech currents for communication between persons located at the two points.

Obviously, the oscillators 27 and 29 may be replaced by any other devices capable of generating currents of suitable low frequencies. Frequencies between 10 and 500 cycles per second have been found suitable for this use, bearing in mind the several desiderata involved.

Resistances 35 pad the respective oscillator impedances to an appropriate value for use in the grid circuits of the balanced modulator tubes 26 and 28. Appropriate grid bias 57 for the balanced modulator tubes may be introduced as indicated between the mid-points of the outputs of the oscillators 27 and 29 and ground. As is well known with balanced modulators, such as 26 and 28 arranged as shown in Fig. 1, the radio frequency

carrier and the low modulating frequency will both balance out leaving in the output only the "side-band" frequencies, that is, frequencies equal to that of the carrier plus and minus the low modulating frequencies. Should the modulators become unbalanced some radio and low frequency carriers will appear in the output. A novel method of maintaining the modulators in balance is described hereinafter in connection with Fig. 8. The side-band frequencies provided by the modulators will have phases and amplitudes determined by those of the original frequencies from which they were formed.

Adjustable tuned circuits, comprising a coil 34 and a variable condenser 36 in parallel, included in each of the balanced modulator plate potential circuits, serve to exclude the alternating currents from the plate supply circuits and to enhance the amplification and selection of the incoming wave.

As is well known, a carrier received on a loop antenna or on an array such as that indicated by the pairs of antennas 24 or 25 of Figs. 1 and 2, will be in quadrature with a carrier received on a non-directional antenna such as antenna 30. In order to detect the side-bands in the radio receiver 62, the systems of Figs. 1 and 2 introduce, with the side-bands, carrier energy non-directionally received on antenna 30. To avoid the quadrature relation, as is obviously desirable, either the side-bands or the non-directionally received carrier must be given an additional 90-degree phase shift. To accomplish this, several artifices may be employed. One convenient method is illustrated in Figs. 1 and 2 and two other methods are illustrated in Figs. 8 and 9. These latter will be described in detail hereinafter. The method of Figs. 1 and 2 consists of coupling two stages of side-band amplification, employing vacuum tubes 52 and 54, by a radio frequency choke coil 48 operated above its resonant frequency, that is, the frequency at which its distributed capacity, together with the circuit capacity, resonates with its inductance. In such an arrangement the choke coil 48 provides a direct current path for the plate supply current and, at the radio frequencies employed, appears as a capacitive reactance. Its resonant frequency, above mentioned, should be sufficiently lower than the radio frequencies employed so that at the latter frequencies the phase angle of the choke coil when shunted by the tube and wiring capacity in the circuit is within approximately 10 degrees of that of a pure capacitive reactance.

The number of stages of amplification employed and the gain to be introduced by them is, of course, within wide limits, optional and is determined in general by the strength of the received radio waves whose direction it is desired to determine. In the systems of Figs. 1 and 2 the two sets of side-band frequencies pass through a modulator and two stages of amplification comprising, in addition to the modulating circuits described above, coupling condensers 40 and coupling resistors 42, vacuum tubes 52 and 54 and appropriate sources of plate and grid potentials 56 and 57, respectively. Representations of cathode heating current sources have been omitted to avoid further complication of the drawing. Any of the well-known conventional means of heating the cathodes of vacuum tubes in similar circuits may be employed.

The non-directionally received carrier from antenna 30 is passed through three tuned stages of amplification comprising antenna transformer

31 and tuning condenser 32, interstage coupling resistors 42, vacuum tubes 50, 52 and 54 and appropriate sources of plate and grid potentials 56 and 57, respectively. Cathode heating current sources have again been omitted to avoid unnecessary complication of the drawings, as above explained.

Except for the 90-degree phase shift, deliberately introduced into each side-band circuit as above described, the three circuits should have substantially the same phase characteristics so that relative differences in phase of the several components received on the several antennas will be maintained until the components are combined and introduced into radio receiver 62. The two side-band amplitudes must be approximately equal at any "45-degree" point, but the carrier amplitude should, to prevent over-modulation, be at least twice either side-band amplitude maximum.

The radio receiver 62 is so designed and the modulating frequencies of oscillators 27 and 29 are so chosen that the side-bands formed in the outputs of both balanced modulator tubes 26 and 28 will, after detection in receiver 62, be passed with substantially equal amplification and phase shift so that the relative phases and amplitudes of the several components as originally received will be maintained. Receiver 62 detects the input signal and its output comprises the low frequencies of oscillators 27 and 29 modified in phase and amplitude by the respective components of the directionally received radio frequency waves with which each was associated.

Band-pass filter 64 selects the frequency generated by oscillator 27 and band-pass filter 63 selects that of oscillator 29. The output of filter 64 is introduced through transformer 70 into the input circuit of the common-frequency, conjugate-input, balanced demodulator circuit including vacuum tube 82. Energy of like frequency but having the phase of the original low modulating frequency is introduced directly from oscillator 27 into a portion of the grid filament circuit of vacuum tube 82 common to both grids. The amplitude impressed on the common leg should equal or exceed the maximum amplitude impressed on the input through transformer 70. The tube 82 should be biased as a demodulator. The relative poling of these two energies determines the sign of the voltage developed across resistors 92 in the plate circuits of vacuum tube 82. The amplitudes of these energies determine the magnitude of the latter voltage.

Analogously the output of filter 68 and energy of like frequency from oscillator 29 are introduced into the input circuit of the common-frequency, conjugate-input, balanced demodulator circuit including vacuum tube 84 and by their relative polings determine the polarity of the voltage across resistances 92 in the plate circuits of vacuum tube 84 and by their amplitudes determine the magnitude of this voltage.

The voltage developed across resistors 92 in the plate circuits of tube 82 is then impressed on deflecting plates 88 and that developed across resistors 92 in the plate circuits of tube 84 is impressed on deflecting plates 90 of the cathode ray tube 86.

Oscillator 66 furnishes a low frequency current of the order of 10 cycles per second which acting through transformer 72, the balanced rectifier 80 and resistors 78, serves to block vacuum tubes 82 and 84 during half of each cycle of oscillator 66. The two secondary windings of transformer 72

should be poled so that both sides of balanced rectifier 80 operate on the same half cycle. The interruption thus caused permits the cathode ray to return to its central position and the ray, therefore, traces a radial path extending from the center to a point determined by the relative polarities and magnitudes of the voltages developed across resistors 92 of vacuum tubes 82 and 84. Oscillator 66 and the apparatus immediately associated therewith may be omitted, if desired, in which case the ray will remain in its deflected position during the reception of the radio wave and a point indication will be obtained. Obviously, also other methods of interrupting the application of the potentials to the cathode ray tube deflecting plates may readily be devised, such for example as a mechanically rotating or oscillating four-circuit interrupter.

From the above description of the circuit, it is apparent that the polarities of the voltages depend upon the phases of the signals received on antenna pairs 24 and 25 and the magnitudes of the voltages depend upon the amplitudes of these signals. Therefore, the angle of the radial line traced by the cathode ray, or its position of deflection if point indications are used, as above described, is an index of the direction from which the radio waves approach the antenna system. By placing an appropriate scale adjacent to the screen of the cathode ray tube, the direction or azimuth angle of the received signal may be directly read. The response of the system is automatic and effectively instantaneous. The indication is unambiguous and observational errors are not likely to occur. It should be noted that in the system of Fig. 1 to the right of the output side of the radio receiver 62 only the frequencies generated by oscillators 27 and 29 are employed. The significance of this is that the indicating apparatus and connecting circuits carry only low frequency currents, and the connecting circuits may, therefore, be almost indefinitely extended without serious difficulties being encountered. The system of Fig. 1, as shown, requires three pairs of conductors to connect the receiving system with the indicating system. A particular advantage of the general system, however, is the relative ease with which it may be made to operate on a remote basis, using only one pair of conductors. One such arrangement is shown in Fig. 2.

The arrangement of Fig. 2, then, differs from that of Fig. 1 primarily in the manner in which suitable low frequency modulating currents are supplied, the arrangement being such that the receiving apparatus to the left of line A—A is connected to the indicating apparatus to the right of line A—A by a single pair of conductors 73, only.

In Fig. 2 a suitable source of substantially constant frequency alternating current 59 of convenient frequency, such as 60 cycles per second, is selected. This source may, as will be obvious from the following description, be located either at the indicating station as shown in Fig. 2 or at the receiving station, its location being solely a matter of convenience. In Fig. 2 the 60-cycle source is connected through switch 59, frequency doubler 41, multivibrator 43, impedance matching resistors 71, and low-pass filter 53 to line 73. The doubler 41 produces 120 cycles and the multivibrator 43 produces the fifth subharmonic, or 24 cycles, which has the advantage of having no harmonic relation to the 60-cycle source.

High-pass filter 63 prevents this frequency (24 76

cycles) from entering the indicating apparatus, but it may pass to the left along pair 73. It will be blocked by radio receiver 62 but may pass along conductor pair 81, through a second low-pass filter 53 and along conductor pair 76 to frequency doubler 55. The output of frequency doubler 55 is 48 cycles which is again doubled in frequency doubler 49 to 96 cycles for use as one of the low frequency modulating currents and is employed in modulating tube 28 of Fig. 2 for that purpose. A portion of the output of frequency doubler 55 is led along conductor pair 77 to a frequency tripler 47, the output of which is 144 cycles used as the second low frequency modulating current, and is employed in modulating tube 26 of Fig. 2 for that purpose. The fourth and sixth harmonics are chosen rather than the second and third (the lowest inharmonic pair) for ease in filtering.

Analogously, at the indicating apparatus, to the right of line A—A, the 24-cycle current from multivibrator 43 enters frequency doubler 55 which produces 48 cycles which is then doubled by doubler 49 to produce the same frequency 96 cycles as is supplied to modulating tube 28. This frequency is then employed in the input circuit of tube 84. A part of the output of doubler 55 is also led along pair 79 to frequency tripler 47 to produce a current of like frequency, 144 cycles, as that supplied to modulating tube 26. This modified current is then introduced into the input circuit of tube 82. If necessary, phase adjusting networks may be employed at either the indicating or the receiving stations to maintain the reference frequencies in proper phase alignment.

The output of radio receiver 62 includes, of course, low frequencies arising out of the modulating arrangements beginning in modulating tubes 26 and 28, respectively. The system is designed, therefore, so that these frequencies will not pass through low-pass filters 53 but will pass through high-pass filter 63.

Frequency doublers 41, 49 and 55 may conveniently be, for the particular arrangement shown in Fig. 2, push-pull vacuum tube circuits operated to produce second harmonics as described by C. H. W. Nason in Radio Engineering for August 1931 at page 23. Frequency triplers 47 may be of the types described in U. S. Patent 1,885,728, issued November 1, 1932, to C. R. Keith, or in U. S. Patent 2,022,968, issued December 3, 1935, to D. T. May. Multivibrator 43 may be of the type described in U. S. Patent 2,022,969, issued December 3, 1935, to L. A. Meacham.

Alternative systems for supplying the low frequency modulating currents, employing devices described in U. S. Patent 1,908,249, issued May 9, 1933, to A. Hund, or any one of numerous other frequency changing devices, including small motor-generator sets synchronously driven from a common alternating current supply of substantially constant frequency, may also obviously be readily devised, by one skilled in the art, in accordance with the principles above disclosed.

From the above discussion and an inspection of Fig. 2, it is evident that the system of Fig. 2 operates in a manner equivalent to that of Fig. 1. Since, however, as above mentioned, only one pair of conductors is required by the system of Fig. 2 to connect the receiving apparatus of the system with the indicating apparatus and since only low frequencies need be transmitted over this pair of conductors, the indicating apparatus may readily be located at a point far removed

from the receiving apparatus. Furthermore, the poing frequencies employed in Fig. 2 are well below the frequency band normally employed for speech transmission so that simultaneous telephonic communication between the receiving and indicating stations may readily be provided over the single pair connecting them.

Obviously, also, systems employing the general principles of this invention, in which a radio communication channel is employed in place of the pair of conductors 73 can be readily devised. In such systems indicating apparatus can, for example, be placed on mobile craft to advise the craft, when transmitting radio signals, of their directions relative to the receiving station of the system and the directions of other mobile or fixed transmitting stations, during their respective transmitting periods, from the receiving station. The salient features of such systems are indicated in Fig. 7 in which 194 is a receiving station such as that to the left of line A—A in Fig. 2. 196 is a radio transmitter, the carrier wave of which is modulated by the low frequency currents brought from directional receiving station 194 over conductor pair 195 upon which the directional characteristics of the components of the radio wave 193, received from an aircraft 190, have been impressed. The carrier emitted by transmitter 196 is also modulated by a base frequency, such as the 24-cycle frequency employed in Fig. 2, from which the low frequency modulating frequencies for the common legs of the indicator demodulators on the aircraft may be derived. If desired, this carrier may in addition be modulated by a band of voice frequencies for telephonic communication with the aircraft. If difficulties are encountered because of interference between the signals transmitted from the craft to the receiving station and the signals transmitted from transmitter 196 to the craft, delay may be introduced by a time delay device 200 between the receiving station 194 and transmitter 196 so that the direction indicating signals will arrive at the mobile craft after transmission from the craft has ceased.

The aircraft 190 should carry a radio receiver and detector 198 and indicating apparatus 199 having essentially the features of the apparatus to the right of line A—A of Fig. 2. Obviously, the indicator on the aircraft may be made to show the bearing of the craft relative to the ground station 194. Also, the indicator may be poled in reverse sense to show the reciprocal bearings, that is, the bearing of the station relative to the plane. By obtaining bearings from several ground stations, the craft may readily determine its position. Where the ground stations have suitable auxiliary antenna systems, as mentioned above, the altitude of the craft may also be determined.

If speech is also transmitted to the craft, suitable selective networks to separate the speech and the directional signals from each other should be provided on the craft. Obviously, it is preferable that the carriers of radio waves 193 and 197 should differ sufficiently in frequency to avoid interfering with each other.

Obviously, too, the features of the system indicated in Fig. 7 may be employed to simultaneously advise several listening radio stations equipped with the indicating apparatus, above described, of the direction of a particular transmitting station from the directional receiving station 194.

The arrangement of the antennas for the systems of Figs. 1 and 2 is indicated diagrammatically in Fig. 3 in which the two like Adcock systems comprising vertical dipole pairs 24 and vertical dipole pairs 25, respectively, are shown in quadrature relation and the non-directional antenna 30 is centrally located with respect to the directional antenna systems.

The total height of each vertical dipole is preferably of the order of a quarter of the mean wave-length on which the system is intended to operate. The centers of the dipoles may be at the same order of distance above the ground. Results published by R. H. Barfield in 1935 in volume 67 of the Journal of the British Institute of Electrical Engineers indicate that the "standard wave error" is inversely proportional to the ratio of the height of the lower ends of the dipoles above ground to the height of their mid-points above ground. The apparatus to the left of line A—A of Fig. 2, or the equivalent apparatus of Fig. 1, is preferably mounted in a centrally located housing also supported at the height of the dipole centers so that the leads 19 may be maintained in a common horizontal plane.

To avoid distortion of the receiving characteristic of non-directional antenna 30, the lower half of antenna 30 is made hollow and power leads 18, and other leads to the apparatus, such as pair 73 of Fig. 3, in installations where the indicating apparatus is remotely located, are passed through the lower half of antenna 30. Radio frequency chokes 17 are placed in such leads to prevent the circulation and loss of radio frequency energy in these circuits. Non-directional antenna 30 is thus effectively made an elevated dipole.

The spacing of the antennas of Fig. 3 is usually determined chiefly with a view to obtaining a high degree of accuracy in the directional indications to be obtained by the system. From this standpoint, the diagonals of the square on whose corners the vertical dipole antennas 24 and 25 are placed may be of the order of one-tenth of the wave-length of the signals whose direction it is desired to determine.

Should optimum sensitivity be desired the diagonals of the above-mentioned square should be increased to approximately one-quarter of the wave-length of the signals whose direction it is desired to determine. Such spacing will involve some sacrifice in accuracy.

Fig. 4 shows an alternative antenna arrangement employing Marconi antennas 24', 25' and 30' in place of the dipoles 24, 25 and 30 of Fig. 3 and permitting the receiving apparatus to be located on the ground. In this arrangement transformers 16 are introduced so that the horizontal leads from the antennas 24' and 25' may be balanced lines and the arrangement may, therefore, be made more closely equivalent to that of Fig. 3.

Fig. 1 shows a suitable horizontal plan view of an antenna arrangement such as that of Fig. 3. In Fig. 5 in addition to the two Adcock antenna systems comprising antennas 24 and 25, respectively, and the non-directional antenna 30, there is shown a small local check transmitter 100.

The check transmitter 100 should be placed along one of the axes of equal receptivity for the two Adcock antenna systems which in Fig. 5 are the E—W and N—S axes. It may conveniently be at a distance of approximately one wave-length of the signals whose direction is to be determined and should when in operation produce

a low field strength in order not to cause interference. Its field at the antennas 24 and 25 may well be of the same order as the minimum signal field strength on which bearings are to be taken. The function of the check transmitter, as its name implies, is to facilitate a calibration of the system by producing a signal of known directivity. By providing an emission strength of the order indicated, the check transmitter will cause minimum interference, and, in addition, the ability of the apparatus to take a satisfactory bearing on such a field provides a good operating sensitivity check. It should, of course, for systems employing vertical antennas, emit vertically polarized waves.

In Fig. 5 the figure 8 pattern *a—*a** represents the directive characteristic of antenna pair 24 and *b—*b** that of antenna pair 25 when employed in their respective Adcock systems.

In Fig. 6, as mentioned above, is shown a horizontal plan view of an arrangement of antennas suitable for use with systems of this invention. This arrangement of antennas is designed for operation with horizontally polarized waves. Since an appreciable number of aircraft employ trailing antennas of types which emit substantially horizontally polarized waves, it may obviously, in some instances be essential that direction-finding systems such as those of this invention be designed to efficiently operate on such waves. The modifications necessary in an antenna arrangement such as that shown in Fig. 3 to adapt it to use with horizontally polarized waves are relatively simple. In Fig. 6, for example, we find that the dipole antenna pairs 24'' and 25'' are equivalent in all respects to pairs 24 and 25 of Fig. 3 except that the former pairs are arranged in a common horizontal plane, and the non-directional antenna 30'' is a simple loop antenna situated concentrically with respect to the antenna system in the same horizontal plane, instead of being a simple vertical antenna such as antenna 30 of Fig. 3. Check transmitter 100' may be the same as check transmitter 100 of Fig. 5, except that it should be arranged to emit horizontally polarized waves. With the above modifications the antenna arrangement of Fig. 6 is closely equivalent, for use with horizontally polarized waves, to the arrangement of Fig. 3 for use with vertically polarized waves.

Non-directional antenna 30'' is preferably an electro-statically-shielded circular loop, a type well known in the art, and should have as high an efficiency as the over-all requirements of the antenna arrangement will conveniently permit. The over-all operation of complete systems of this invention, such as those illustrated in Figs. 1 and 2, will obviously be the same whether the antenna system responds to vertically or horizontally polarized components of the received wave, the direction of which is to be determined. Of course, the actual polarization of a particular received wave may lend itself to more efficient reception by one antenna system than the other. Manifestly also a composite antenna system including both arrangements could be constructed, and the system could then operate efficiently on horizontal, vertical or composite polarization.

As mentioned above, Figs. 8 and 9 illustrate two other methods of obtaining an additional phase shift of approximately 90 degrees to avoid the quadrature relation of the non-directionally received carrier to the directionally received carrier. Only sufficient detail is shown in Figs. 8 and 9 to illustrate the methods and their application to

systems of the type shown in Figs. 1 and 2. To further simplify Figs. 8 and 9 only one of the two pairs of directional antennas and associated apparatus is shown. Obviously, the other pair and the associated apparatus may be evolved in like manner to the one shown.

In Fig. 8 the additional phase shift is introduced only in the non-directionally received carrier, by coupling two stages of the vacuum tube amplifier associated with the non-directional antenna through the mutual inductance between the two inductances 101 of two tuned circuits, each tuned circuit comprising one of the inductances 101 and a variable condenser 99. As is well known to the art, if, with such an interstage coupling, the mutual inductance between the two inductance coils is made small and both tuned circuits are tuned to the desired frequency, the frequency will suffer substantially a 90-degree change in phase in passing from the first to the second of the stages so coupled.

Obviously, if the non-directional carrier is given an additional phase shift, as described above, the directionally received signals need not be given additional phase shifts and the artifice employed in Figs. 1 and 2 involving the use of radio frequency choke coil 48 would not be necessary.

In Fig. 9 the additional phase shift is introduced by providing an intermediate frequency, which may be the beating oscillator frequency, to the vacuum tubes of the second stages of both of the circuits carrying the directionally received wave and to the circuit carrying the non-directionally received wave but with the intermediate frequency supplied to the circuit carrying the non-directionally received wave in quadrature with that supplied to the two other circuits. The features of the arrangement are apparent from an inspection of Fig. 9 in which vacuum tube 112, transformer 111 and sources of potential 113 and 114 comprise the oscillator providing the desired intermediate frequency. This frequency is supplied through impedance matching resistances 115 to condenser 116 and resistance 117 which are in series across the intermediate frequency oscillator output. The voltage developed across condenser 116 is then supplied to vacuum tube 103 comprising the first intermediate frequency stage of the circuit carrying the directionally received wave from antennas 24 and the voltage developed across resistance 117 is supplied to vacuum tube 104 comprising the first intermediate frequency stage of the circuit carrying the non-directionally received wave from antenna 30. Condensers 118 are blocking condensers to isolate the phase-splitting circuit comprising condenser 116 and resistance 117 from the grid biasing battery 106. Resistances 108 preserve the proper impedance relations in their respective circuits. Potential sources 109 provide the proper potentials for their respective grids of tubes 103 and 104 and tuned circuit comprising inductance 105 and capacity 107 isolates plate potential source 110 from the high frequencies present in the plate circuits at that point of the system.

To avoid unnecessary complication, as above explained, only one of the two circuits carrying the directionally received waves is shown. In connection with Fig. 9 it should be noted that only one intermediate oscillator (tube 112 and associated apparatus) is required for both circuits carrying the directionally received waves as the modulating grid of the tube in the second

circuit (corresponding to the central grid of tube 103 in Fig. 9) may be connected directly to the central grid of tube 103 of Fig. 9.

Additional stages of amplification may also, obviously, be added as desired, when either of the arrangements of Figs. 8 and 9 is employed in a system of this invention.

Fig. 10 illustrates an arrangement which may be employed to maintain the two halves of the balanced modulators, employed with the directional antenna arrangements of this invention, in balance. It may also be employed to maintain the balance between halves of any of numerous "push-pull" vacuum tube circuits commonly employed in the art. The arrangement is in effect the independent application of automatic volume control to each side, or half, of the balanced circuit.

In systems of this invention it is important to maintain the balance of the balanced modulators since if they become unbalanced, the carriers, of both high and low frequency, will not balance out but will appear with the sidebands in the modulator outputs and may give rise to erroneous indications.

In Fig. 10, then, a radio frequency wave is received on a pair of dipole antennas 24, passed through transformer 20 to the grid circuits of a balanced modulator tube 26, and a low modulating frequency is introduced into these same grid circuits through pair 160, transformer 130 and resistors 138. In the plate circuits of tube 26 we find, in the plate potential supply circuits for each side of the modulator, a radio frequency choke coil 144 and a low frequency transformer 146. Chokes 144 will exclude the radio frequencies from these supply circuits but the second harmonic of the low modulating frequency will pass freely through them and will induce currents in the secondary windings of transformers 146. These are then separately rectified in balanced rectifier tube 140 and passed as unidirectional currents through resistors 134 and 136 which contribute to the biases of the upper and lower grids of tube 26, respectively. Resistors 134 and 136 may be adjusted until the modulator tube is balanced. The currents from transformers 146 when separately rectified and fed back to their respective control resistors 134 and 136 are arranged to maintain the gain of their respective sides or halves of the modulator appreciably constant thereby maintaining the balance of the modulator, after adjustment. It will be appreciated that the tube functions here as a modulator by virtue of the same coefficient of its characteristic as that which produces the second harmonics employed in this arrangement of Fig. 10 to maintain the gain of each side of the modulator circuit constant.

Choke 148 excludes alternating currents from the plate potential source. Condenser 142 drains off noise currents which may develop across the plate potential source. Condensers 150 freely pass the side-band frequencies to the first amplifying tube 52, the tuned circuit comprising condenser 152 and coil 154 tunes the input of the amplifier tube 52 to the desired frequencies and coupling condenser 40 and coupling resistor 42 complete the input circuit to this tube. As stated above, the principles disclosed in connection with Fig. 10 may be applied to maintain the balance of numerous other "push-pull" type circuits well known to the art. In some instances it may be desirable to employ different

harmonics to maintain the gain of the several sides of the circuit.

The direction-finding systems of this invention obviously may be used to advantage to furnish at a single control point simultaneous directional indications from several widely separated receiving points simply by installing receiving apparatus for a system of this invention at each of the desired widely separated receiving points and locating the indicating apparatus of all the systems at the control point in such manner that all the indicators may be simultaneously observed. Also, any of numerous well-known methods of triangulation may be employed in conjunction with such an arrangement to determine from the several directional indications the location of the transmitting station. Again, multiple indications, at physically separated points, may, if desired, obviously be furnished from a single receiving station. Finally, by the use of a multiple beam indicator with the spot rest positions situated on the screen at points relatively corresponding to the known positions of the several direction-finding receivers, the multiple beam indicator can be caused to completely locate the transmitting station relative to the receiving stations.

In Fig. 11 a signal operated relay system is shown, the object of which is to short-circuit the two signal input circuits of the indicator of Figs. 1 and 2 when no signal is being received in either circuit so that static or other stray impulses will not deflect the ray of the indicator tube. It is applicable to the systems of Figs. 1 and 2 when, in order to increase the sensitivity of the system, individual amplifiers (not shown in Figs. 1 and 2) are inserted in the two branches to the indicator circuit respectively, that is between filter 64 and its associated transformer 70 and between filter 68 and its associated transformer 70 in Figs. 1 and 2. Under these circumstances, terminals 171 of the circuit of Fig. 11 are connected across the input terminals of one amplifier and terminals 173 across those of the other, and terminals 175 are connected across the output of one amplifier and terminals 177 across the output of the other. When a signal is received in either branch, it is amplified in the associated vacuum tube 170 of Fig. 11, rectified in the associated rectifier tube 180 and passed through the winding of relay 178, operating it to remove the short circuits from the outputs of both amplifiers and thus placing the indicating circuit in operating condition. Appropriate sources of plate and grid potentials 174 and 172, transformers 176 and resistor 179 complete the circuit of Fig. 11 and are employed for their respective obvious purposes in conventional manners.

The systems and arrangements above described by no means exhaust the possible applications of the principles involved but are merely illustrative thereof. Accordingly, it is anticipated that numerous applications of these principles will occur to those skilled in the art. The scope of the invention is defined in the following claims.

What is claimed is:

1. In a radio directional system including a receiving station and an indicating station remote therefrom, means for providing at both said sta-

tions from a source of alternating current of a given low frequency located at one of said stations, two other low frequencies bearing no harmonic relation to said source or to each other, without transmitting between said two stations a current of the frequency of said source, a harmonic thereof or the said two other low frequencies, said means comprising at the station at which said source is located a first frequency changer for producing the second harmonic of said source, a second frequency changer for producing the fifth subharmonic of said second harmonic, said fifth subharmonic being then transmitted to said other station and at both of said stations frequency changing devices producing fourth and sixth harmonics respectively of said fifth subharmonic.

2. In a radio direction finding system comprising a receiving station and an indicating station, said system being of the type in which two components of a radio wave are directionally received at the first said station and modulated by two different low frequency currents, respectively, the low frequency currents being then detected and transmitted to said indicating station where they are separated and each is combined with a low frequency current of its respective frequency but having substantially the phase and amplitude of the corresponding low frequency current employed in the aforesaid modulating process, and the combinations thus formed are employed to provide an indication at said indicating station of the direction from which the radio wave approached the said receiving station; means at one of said stations for obtaining a third low frequency current and transmitting it to the other station, means at both said stations for obtaining from said third low frequency current, currents of said first-mentioned two different low frequencies, and means for adjusting said two currents so obtained to be substantially of like phase and amplitude, respectively, at both said stations.

3. The arrangement of claim 2, all three of said low frequencies being below the range of frequencies normally employed for the transmission of speech.

4. The arrangement of claim 2, the said third frequency being a subharmonic of a source of alternating energy located at one of said stations and the said means for deriving the said first-mentioned two frequencies providing frequencies which bear no harmonic relation to each other or to the frequency of said source.

5. In a radio direction finding system, including a receiving station and an indicating station remote therefrom, means for providing at each of said stations two different low frequency currents of like frequencies, phases and amplitudes, respectively, said means comprising a source of a third different low frequency current at one of said stations, means for transmitting said third low frequency to the other of said stations, means at both said stations for deriving from said third low frequency the currents of the first-mentioned two low frequencies, and means for adjusting the phases and amplitudes of said two frequencies, respectively, to be alike at the two said stations.

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