Aug. 15, 1933. J. W. GREIG ET AL 1,922,677

RADIO DIRECTION FINDING SYSTEM

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FIG. 1

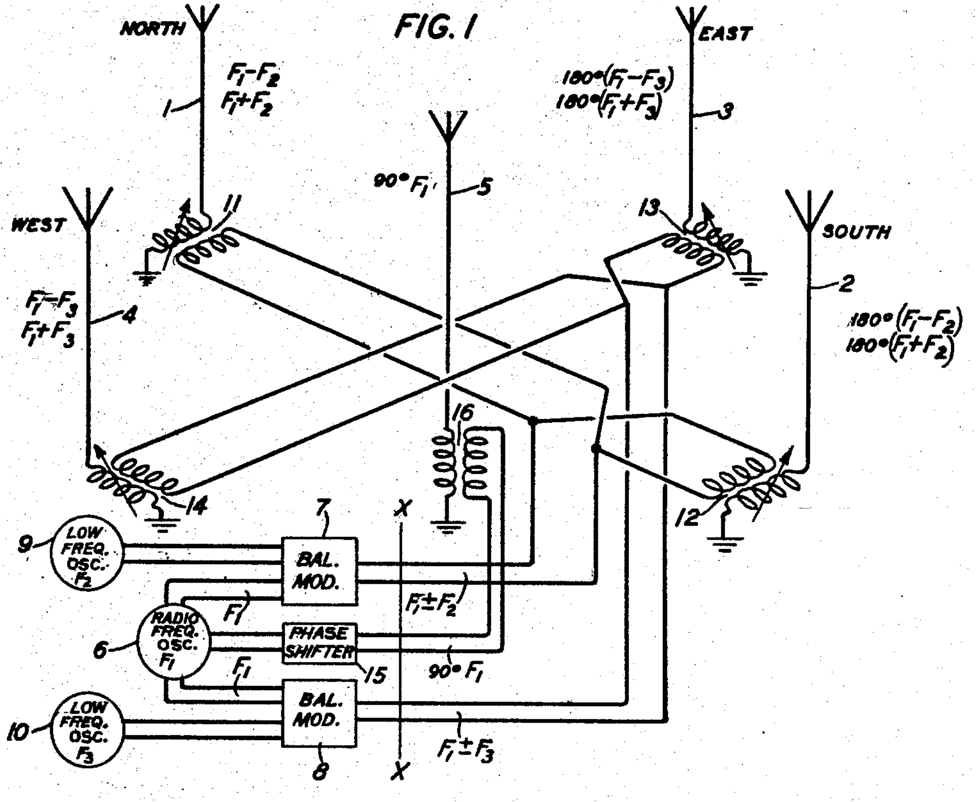

FIG. 2

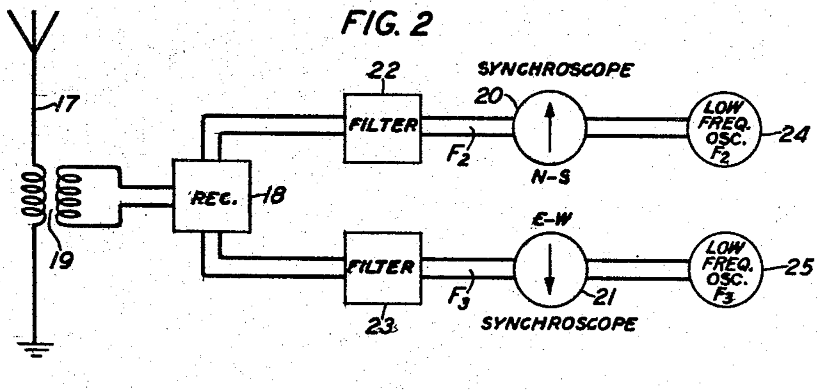

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FIG. 3A

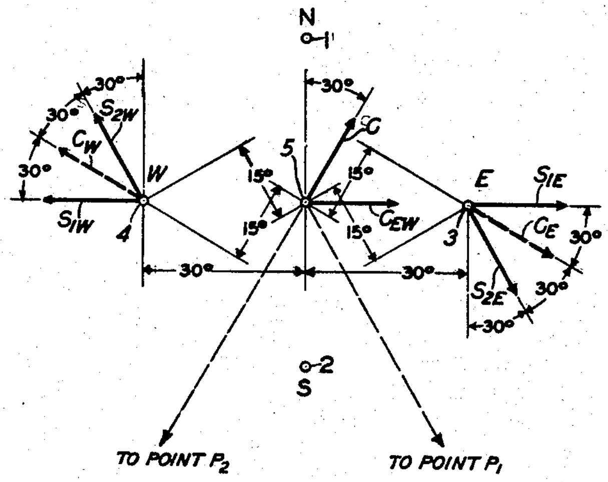
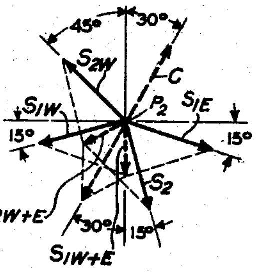


FIG. 3B



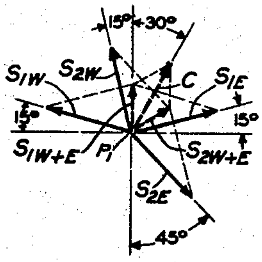


FIG. 3C

FIG. 4

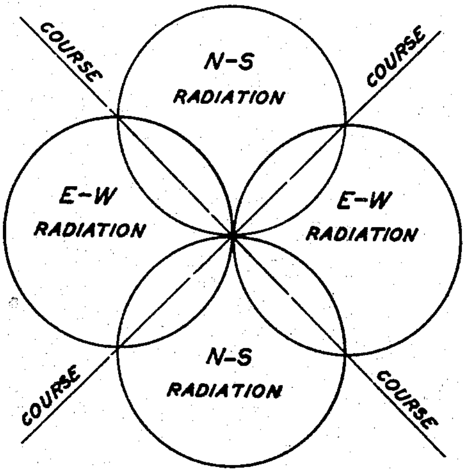


FIG. 5

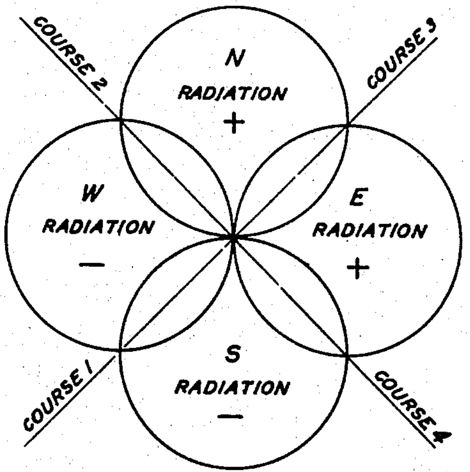


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FIG. 6

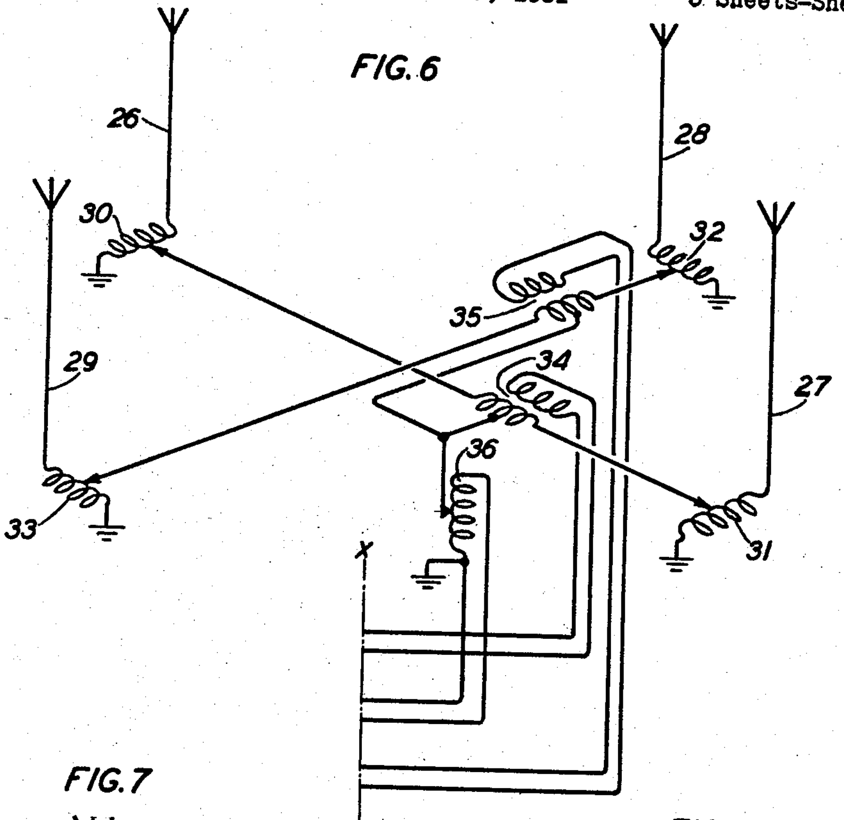


FIG. 7

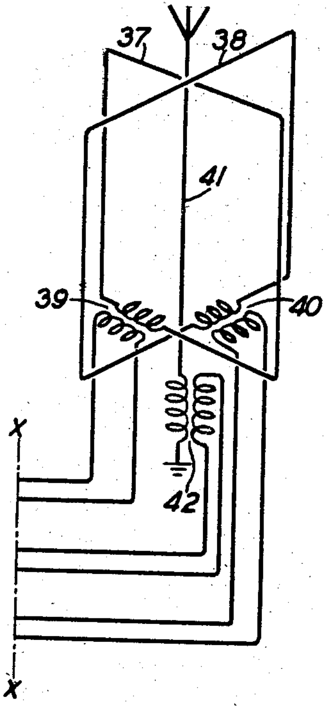
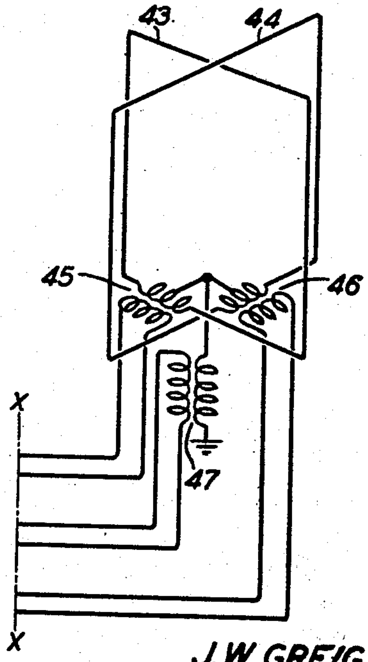


FIG. 8



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RADIO DIRECTION FINDING SYSTEM

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13 Claims. (Cl. 250—11)

This invention relates to methods of, or means for, radio direction finding and more especially to directive finding systems in which modulated waves and carrier waves are transmitted from a fixed or radio beacon station for the purpose of enabling a pilot at a mobile station, such as an aircraft, to determine his position with respect to the beacon station.

In certain direction finding systems in use at the present time which utilize a transmitter at the fixed or beacon station and a receiver at the mobile station, the pilot determines his course from the phase relation between two sets of waves transmitted from the beacon station. One phase discriminating system in which a rotating beam is used to introduce the desired phase-space characteristic is disclosed in Patent 1,815,246 to Englund. In this and in similar systems a beam comprising a rotating single side bound and a non-directional carrier is transmitted and, at the mobile station, the low frequency component obtained by combining these waves is compared as to phase with a similar component obtained from a non-directional side band and a non-directional carrier also transmitted from the beacon station. For purposes of accuracy and better modulation, and for other reasons as discussed below, it is clearly desirable in such a system to employ double instead of single side bands and this invention is particularly suitable for use in such a system for transmitting rotating double side band frequencies and a non-directional carrier wave having a special phase relation with the side band frequencies so that modulation at the mobile station is easily effected.

In a somewhat different type of system the intensities of two bi-lateral waves transmitted from a beacon station in directions perpendicular to each other are compared, there being four directions or predetermined courses along which the pilot of the mobile station receives the same indication. One important disadvantage of this system is that the pilot must have some knowledge of his position with respect to the beacon station in order to successfully navigate the aircraft and it is clearly desirable in such a system to provide a different indication for each of the courses associated with the beacon station.

It is one object of this invention to provide means for determining the direction of a radio beacon in a more efficient manner than heretofore practiced.

It is another object of this invention to insure effective modulation at the mobile station between the received waves in a system in which a carrier wave and side band frequencies are independently transmitted from the beacon station for direction finding purposes.

It is still another object of this invention to enable a pilot to differentiate between the various courses associated with a radio beacon station.

According to one embodiment of this invention five antennæ are employed at the beacon station, four being positioned at the corners of a square as, for example, the north, south, east and west corners, and the fifth being centrally located with respect to these antennæ. Side band frequencies with suppressed carrier are radiated from the diagonally opposite antennæ, the modulation for one such pair of antennæ being different in frequency or phase or continuity from that used for the other pair. The currents supplied to the diagonally opposite antennæ are 180° out of phase with each other so that the side band frequencies radiated in opposite directions are of opposite phase. A carrier wave is radiated by the central non-directional antenna which wave is in phase quadrature with the carrier used in the production of the side band frequencies. The last mentioned carrier is preferably suppressed.

At the mobile station, the carrier and the side band frequencies radiated from one pair of antennæ, say the east-west antennæ, are combined to reproduce the original audio frequency envelope whose phase is dependent upon the phase of the side band frequencies. The phase relation, that is, the phase similarity or opposition as determined at the mobile station, between the reproduced audio envelope and the envelope radiated from one, say the east, antenna of the said pair indicates the position, east or west, of the mobile station from the beacon station. Similarly, the north-south position of the mobile station is determined from the other, differently modulated, side band frequencies. When the invention is employed in conjunction with the four-course system referred to above, or with similar systems, the various courses may be easily distinguished.

The invention will be more fully understood from the following description taken in connecton with the drawings in which:

Fig. 1 illustrates a radio beacon transmitter employed in one embodiment of the invention;

Fig. 2 illustrates a receiver at the mobile station arranged to cooperate with the transmitter of Fig. 1;

Figs. 3—A, 3—B and 3—C are vector diagrams used in explaining the operation of the invention;

Figs. 4 and 5 are directive diagrams also used in explaining the operation of the invention; and

Figs. 6, 7 and 8 illustrate antenna systems, any one of which may be substituted for that portion of the transmitter shown in Fig. 1 at the right of line X—X.

Referring to Fig. 1, reference numerals 1 and 2 designate vertical antennæ positioned respectively, at (say) the north and south corners of a square and numerals 3 and 4 denote vertical antennæ positioned, respectively, at the east and west corners of the square. Numeral 5 denotes a vertical antenna positioned at the center of the square. Reference numeral 6 designates a radio frequency oscillator generating a wave of frequency F_1 and connected to balanced modulators 7 and 8. Numeral 9 designates a low frequency oscillator generating a wave of frequency F_2 and connected to balanced modulator 7; and numeral 10 denotes a low frequency oscillator generating a wave of frequency F_3 and connected to balanced modulator 8. Balanced modulator 7 is inductively associated with antennæ 1 and 2 by means of transformers 11 and 12, respectively, the connections being such that oppositely phased currents are supplied to antennæ 1 and 2. Similarly, balanced modulator 8 is inductively associated with antennæ 3 and 4 by means of transformers 13 and 14, respectively, the connections for the two antennæ being reversed. Reference numeral 15 denotes a 90° phase shifter connected to oscillator 6 and inductively associated with antenna 5 through transformer 16.

In Fig. 2 reference numeral 17 denotes a receiving antenna which is associated with the receiver 18 by means of transformer 19. Two synchroscopes 20 and 21 are connected, respectively, through filters 22 and 23 to the receiver 18, the filter 22 being adjusted to pass only currents of frequency F_2 and filter 23 being adjusted to pass only currents of frequency F_3. Reference numeral 24 designates a low frequency oscillator generating a frequency F_2 in phase with the current generated at the transmitter in low frequency oscillator 9. Numeral 25 designates a low frequency oscillator which generates a wave of frequency F_3, this wave being in phase with the current generated at the transmitter in low frequency oscillator 10. Oscillator 24 is associated with synchroscope 20 and oscillator 25 is connected to synchroscope 21. A system for supplying each synchroscope with current synchronous with that generated in oscillators 9 and 10 is described in Englund Patent 1,815,246 supra.

The operation of the direction finding system comprising the transmitter shown in Fig. 1 and the receiver shown in Fig. 2 may be briefly described as follows. Referring to Fig. 1 side band waves F_1-F_2 and F_1+F_2 with negligible carrier are supplied in opposite phase relation to antennæ 1 and 2. Side band waves F_1-F_3 and F_1+F_3 with suppressed or negligible carrier are supplied through transformers 13 and 14 to antennæ 3 and 4, respectively, and in opposite phase relation. A carrier wave shifted approximately 90° by means of phase shifter 15, with respect to that employed in producing the above side band frequencies is supplied through transformer 16 to antenna 5. This carrier is designated on the drawings by 90° F_1. Since the side band frequencies in the north antenna are reversed in phase from those in the south antenna as shown by the designations F_1-F_2, F_1+F_2 and 180° (F_1-F_2), 180° (F_1+F_2) on the drawings the resultant radiation in the north direction will have an audio frequency envelope which is in reverse phase to that in the south direction. The phase designations on the drawings are, of course, only relative. Similarly the double side band radiation in the west direction will be in a sense reversed in phase from that in the east direction as indicated on the drawings. It is this difference in phase in the opposite directions which provides the means of distinguishing between the various directions. This may be more clearly understood from a consideration of the vector diagrams shown in Figs. 3—A, 3—B and 3—C.

In Fig. 3—A a plan view of antennæ 1, 2, 3, 4 and 5 is shown. For convenience only the waves radiated from the east, west and central antennæ, that is, antennæ 3, 4 and 5, are considered. The carrier supplied to modulator 8 in Fig. 1 is shown by vector C_{EW} at antenna 5. The upper and lower side band frequencies in the east antenna are represented by vectors S_{1E} and S_{2E} and the same side bands in the west antenna are represented by S_{1W} and S_{2W}. The vectors C_E and C_W show the relative phase which the carrier would have in these antennæ if it were not suppressed. It should be noted that the two side band vectors are symmetrical about the carrier vector so that their vector sum is in phase with the carrier. This condition is necessary for effective demodulation at the fundamental audio frequency. Vector C shows the carrier current in the center antenna. No side bands are supplied to this antenna and the phase of this carrier is adjusted by means of phase shifter 15 to be in quadrature to the phase of the vectors C_E and C_W. Assuming the feed line causes a phase shift of 30° vector C_E lags vector C_{EW} by 30° and vector C_W of opposite phase with respect to C_E is retarded a similar amount. Consequently vector C is adjusted to lag the position it would have if there were no phase shift over the feed line.

Now consider any distant point P_1 in space, as shown in Fig. 3—C, chosen for convenience at a distance which is an integral multiple of a wave length from the center antenna 5. Any other distance would only produce a rotation of the vectors without changing their relation to each other. Fig. 3—C shows the vector S_{1E} leading by 15° its position at the east antenna and the vector S_{1W} lagging by 15° its position at the west antenna, the lead and lag being due to the difference in distance along the path between the receiver and the antennæ 3, 4 and 5. It will be seen that the sum S_{1W+E} of the vectors S_{1W} and S_{1E} at point P_1 is in quadrature to the position of the component vectors at the antennæ 3 and 4. Furthermore, the sum S_{2W+E} of the side band vectors S_{2W} and S_{2E} is in quadrature to the position of these component vectors at these same antennæ. It may be stated, therefore, that if two like antennæ are excited in opposite phase by equal currents, the vector sum at a remote point in space at a distance an integral number of wave lengths from the center of the antenna system will be in phase quadrature to the currents in the two antennæ. The carrier wave C arrives at point P_1 without effective phase change and, since its vector is symmetrical with respect to the vector sums of the side band radiations, it is in proper phase to produce effective modulation. More specifically, at the point P_1 the resultant of the side band vector sums S_{1W+E} and S_{2W+E} is in phase with the carrier vector.

If the distant point is nearer to the west antenna than to the east antenna as shown by point P_2 in Fig. 3—B the carrier and side band components, when demodulated, will produce an audio frequency opposite in phase to that produced at point P_1.

Thus in Fig. 3—B vector S_{1W} leads by 15° its position at antenna 4 and vector S_{1E} lags by 15° its position at antenna 3. Similarly vector S_{2W} leads by 15° its position at antenna 4 and vector S_{2E} lags by 15° its position at antenna 3. The carrier vector C is symmetrical with respect to the side band vector sums S_{1W+E} and S_{2W+E} and it is 180° out of phase with the instantaneous vector resultant of the side band vector sums.

Referring to Fig. 2 the position of the mobile station is determined in the following manner. The two sets of double side bands and the quadrature carrier are received and demodulated in receiver 18. The phase of the low frequency modulation component F_3 in the output of filter 23, obtained by demodulation in receiver 18 of the double side bands $F_1 \pm F_3$ radiated by antennæ 3 and 4 and the carrier 90° F_1, is compared in synchroscope 21 with the phase of the reference current established by oscillator 25, the waves generated by oscillator 25 being in phase with those generated in oscillator 10. A similar phase indication indicates that the mobile station is east of the beacon station and an opposite phase indication denotes that the mobile station is west of the beacon station. In a similar manner, but utilizing the side bands radiated by antennæ 1 and 2, the position of the mobile station, north or south, with respect to the beacon station is indicated by synchroscope 20.

Fig. 4 is a directive diagram for a radio beacon system in which the intensities of two directive waves are compared for direction finding purposes. Such a system is described in the article "Development of the Visual-Type Airway Radio Beacon System" by Messrs. J. H. Dellinger, H. Diamond, and S. W. Dunmore, published in the Proceedings of the Institute of Radio Engineers for May, 1930. In a system having a directive diagram similar to that shown in Fig. 4 there are four courses along which the pilot of a mobile station receives the same indication. By means of the present invention the several courses may easily be distinguished. The directive diagram for such a combined system is shown in Fig. 5.

The transmitting and receiving apparatus employed in the combined system for determining both a particular course to the beacon and the bearings of the mobile station with respect to the beacon may be separate and distinct, or the equipment shown in Figs. 1 and 2 for determining the direction to the beacon may be modified so as to give a course indication to the pilot. By adjusting oscillators 9 and 10 in Fig. 1 to generate suitable frequencies as, for example, 65 cycles and 85 cycles, respectively, and connecting between the output terminals of filters 22 and 23 in Fig. 2 a visual indicator comprising vibrating reeds tuned to these two frequencies the intensities of the two sets of modulated waves transmitted from the beacon station may be compared. The pilot, by observing the visual indicator, may follow one of the four courses shown in Fig. 5 and, by noting the indication of synchroscopes 20 and 21, he may easily determine which of the four courses he is following.

The antenna system shown in Fig. 6 is similar to that shown in Fig. 1 except that no individual central antenna is employed, an equivalent effect, however, being achieved by the conjoint use of the other antennæ. Reference numerals 26, 27, 28 and 29 designate vertical antennæ positioned at the corners of the square and numerals 30, 31, 32 and 33 denote terminating impedances connected between the ground and these antennæ, respectively. Reference numeral 34 designates a transformer, the primary winding of which is associated with the balanced modulator 7 and the secondary winding of which is associated with the diagonally opposite antennæ 30 and 31, one terminal of the secondary winding being connected to impedance 30 and the other terminal being connected to impedance 31. In like manner reference numeral 35 designates a transformer, the primary winding of which is connected to the output of modulator 8, one terminal of the secondary winding being connected to impedance 32 and the other terminal being connected to impedance 33. Reference numeral 36 designates an impedance connected across the output of the phase shifter 15. The midpoint of the secondary windings of transformers 34 and 35 are adjustably connected to impedance 36.

The antenna system shown in Fig. 6 produces the same directive diagram as that shown in Fig. 1. The double side bands F_1-F_2 and F_1+F_2 in the output of modulator 7 are supplied through transformer 34 and impedances 30 and 31 to the radiating antennæ 26 and 27 in opposite phase relation, the carrier being suppressed. Similarly the side bands F_1-F_3 and F_1+F_3 from balanced modulator 8 are supplied through transformers 35 to antennæ 28 and 29 in opposite phase relation. Quadrature carrier currents from the phase shifter 15 are supplied through winding 36 and the secondary winding of transformers 34 and 35 to the antennæ 26, 27, 28 and 29 in phase so that non-directional radiation of the quadrature carrier occurs.

The antenna system of Figs. 7 and 8 both of which employ crossed loops instead of four vertical antennæ are very similar, the chief difference being that the quadrature carrier is radiated from the loops in the system shown in Fig. 8, the entire structure acting as a simple vertical antenna as in Fig. 6 while in the system of Fig. 7 an individual antenna is used for that purpose. In Fig. 7 reference numerals 37 and 38 designate two crossed loops positioned at right angles to each other, loop 37 being associated with modulator 7 by means of transformer 39 and loop 38 being associated with modulator 8 by means of transformer 40. A vertical antenna 41 centrally located with respect to the two loops is associated with the phase shifter 15 by means of transformer 42. In Fig. 8 reference numerals 43 and 44 designate two crossed loops similar to those shown in Fig. 7, loop 43 being associated with modulator 7 by means of transformer 45 and loops 44 being associated with modulator 8 by means of transformer 46. Reference numeral 47 designates a transformer the primary winding of which is connected to the output of phase shifter 15 and the secondary winding of which has one terminal grounded and the other terminal connected to the midpoints of the secondary windings of transformers 45 and 46.

Oppositely-phased double side band waves $F_1 \pm F_2$ are radiated from the vertical portions of loop 37 in Fig. 7 and loop 43 in Fig. 8; and oppositely-phased double side band waves $F_1 \pm F_3$ are radiated from the vertical portions of loop 38 in Fig. 7 and loop 44 in Fig. 8. In Fig. 7 the quadrature carrier waves supplied from phase shifter 15 through transformer 42 to antenna 41 is radiated non-directionally from antenna 41 and in Fig. 8 the quadrature carrier currents induced in the secondary winding of transformer 47 are supplied through the secondary windings of transformers 45 and 46 to the loops 44 and 45 so that the quadrature carrier current is radiated non-directionally.

Although the invention has been described in connection with certain antenna arrangements and other apparatus it is not to be limited to such arrangements and apparatus and it is to be understood that other antenna systems and apparatus may be employed in carrying out the invention without exceeding its scope.

What is claimed is:

1. In a radio system, means for transmitting bi-laterally double side band waves, and means for transmitting non-directionally a carrier wave in quadrature to that employed for producing the side bands.

2. In a radio system, means for transmitting bi-laterally double side band waves with suppressed carrier, means for transmitting bi-laterally and at an angle to the first transmission different double side band waves with suppressed carrier, and means for producing and transmitting non-directionally a carrier wave substantially in phase quadrature to the carriers employed for producing the double side band waves.

3. In a radio system, antenna structure for transmitting a carrier wave of a particular wave length and double side band waves with negligible carrier comprising a plurality of elements spaced a fraction of said wave length, and means for energizing at least two of said elements with double side band currents of opposite phase and said structure with carrier current in quadrature with the negligible carrier.

4. In a radio system, four radiating elements positioned at the corners of a square, means connected to one pair of diagonally opposite elements for energizing said elements with double side band currents of opposite phase, means connected to the other pair of elements for energizing said elements with different double side band currents of opposite phase, and means connected to the elements for supplying carrier current in quadrature to the carriers employed in producing the side bands.

5. In a radio system, four radiating elements positioned at the corners of a square, means connected to one pair of diagonally opposite elements for energizing said elements with double side band currents of opposite phase, means connected to the other pair of elements for energizing said elements with different double side band currents of opposite phase, another radiating element, and means connected to said last mentioned element for supplying carrier current in quadrature to the carrier employed for producing the side band currents.

6. In a radio system, two crossed loops positioned at right angles to each other, means connected to one loop for energizing the vertical portions thereof with double side band currents of opposite phase, means connected to the other loop for energizing the vertical portions thereof with different side band currents of opposite phase, a non-directional antenna, and means connected to said antenna for supplying carrier current having a quadrature relation to the carriers employed for producing the side bands.

7. In a radio system, four radiating elements positioned at the corners of the square, a source of radio frequency energy, a source of low frequency energy, a balanced modulator connected to said sources, the output terminals of said modulator being connected to one pair of diagonally opposite elements, a second source of low frequency energy, a second balanced modulator connected to the second source of low frequency energy and the source of radio frequency energy, the second balanced modulator having its output terminals connected to the other pair of elements, another radiating element positioned at the center of the square and connected to the radio frequency source, and wave shifting means included between the radio frequency source and the last mentioned radio element.

8. In a radio system, four radiating elements positioned at the corners of the square, a source of radio frequency energy, a source of low frequency energy, a balanced modulator connected to said sources, the output terminals of said modulator being connected to one pair of diagonally opposite elements, a second source of low frequency energy, a second balanced modulator connected with the second source of low frequency energy and the source of radio frequency energy, the second balanced modulator having its output terminals connected to the other pair of elements, a phase shifter connected to the radio frequency source, said phase shifter having one output terminal connected to the radiating elements and its other terminal associated with ground.

9. In a direction finding system, two spaced elements radiating bi-laterally oppositely-phased side band waves, said elements also radiating a non-directional carrier wave in quadrature to the carrier waves employed for producing the side band waves, a mobile wave receiving means comprising a modulator, means associated with the modulator for comparing the phase direction of the low frequency current in the modulator output and the side band envelope of the current in one of the elements.

10. In a direction finding system, a beacon station comprising four radiating elements, means connected to one pair of diagonally opposite elements for energizing said elements with oppositely-phased modulated waves comprising a carrier and a low frequency current, means connected to the other pair of elements for energizing said elements with oppositely-phased modulated waves comprising a carrier and a second low frequency current, means connected to the elements for producing a nondirectional carrier wave in quadrature to the carriers employed in producing the modulated waves, a mobile receiving station comprising means for demodulating the waves received from the beacon station, means for comparing the phase direction of the low frequency current obtained from demodulation of the first set of modulated waves and the modulated envelope of the current in one of the first pair of elements, means for comparing the phase direction of the low frequency current ob-

tained from demodulation of the second set of modulated waves and the modulated envelope of the current in one of the second pair of elements.

11. In a radio system, means for producing a double side band with negligible carrier, transmitting means connected thereto for radiating bi-laterally said band, and means connected to the transmitting means for producing a carrier in quadrature to the negligible carrier as radiated.

12. In a bearing determining system, means for producing a double side band with negligible carrier and a carrier in quadrature with the negligible carrier, a plurality of radiators connected thereto and arranged to transmit in opposite phase each single side band and non-directionally the quadrature carrier, and means for receiving and modulating said double band and quadrature carrier.

13. In a single course-indicating system, means for producing a plurality of double side bands, each comprising the same negligible carrier component and a dissimilar low frequency component, means for transmitting each double band bi-laterally and said double bands along different paths, means connected to the transmitting means for producing a carrier in quadrature to the negligible carrier as transmitted, means for receiving and modulating the double bands and quadrature carrier, means connected to said last means for comparing the phase of each low frequency component as received and as employed in producing the double side band and for comparing the intensities of the dissimilar low frequency components.

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