Sept. 21, 1948. H. F. PENFOLD ET AL 2,449,859

AUTOMATIC RADIO COMPASS

Filed Jan. 27, 1944 3 Sheets-Sheet 1

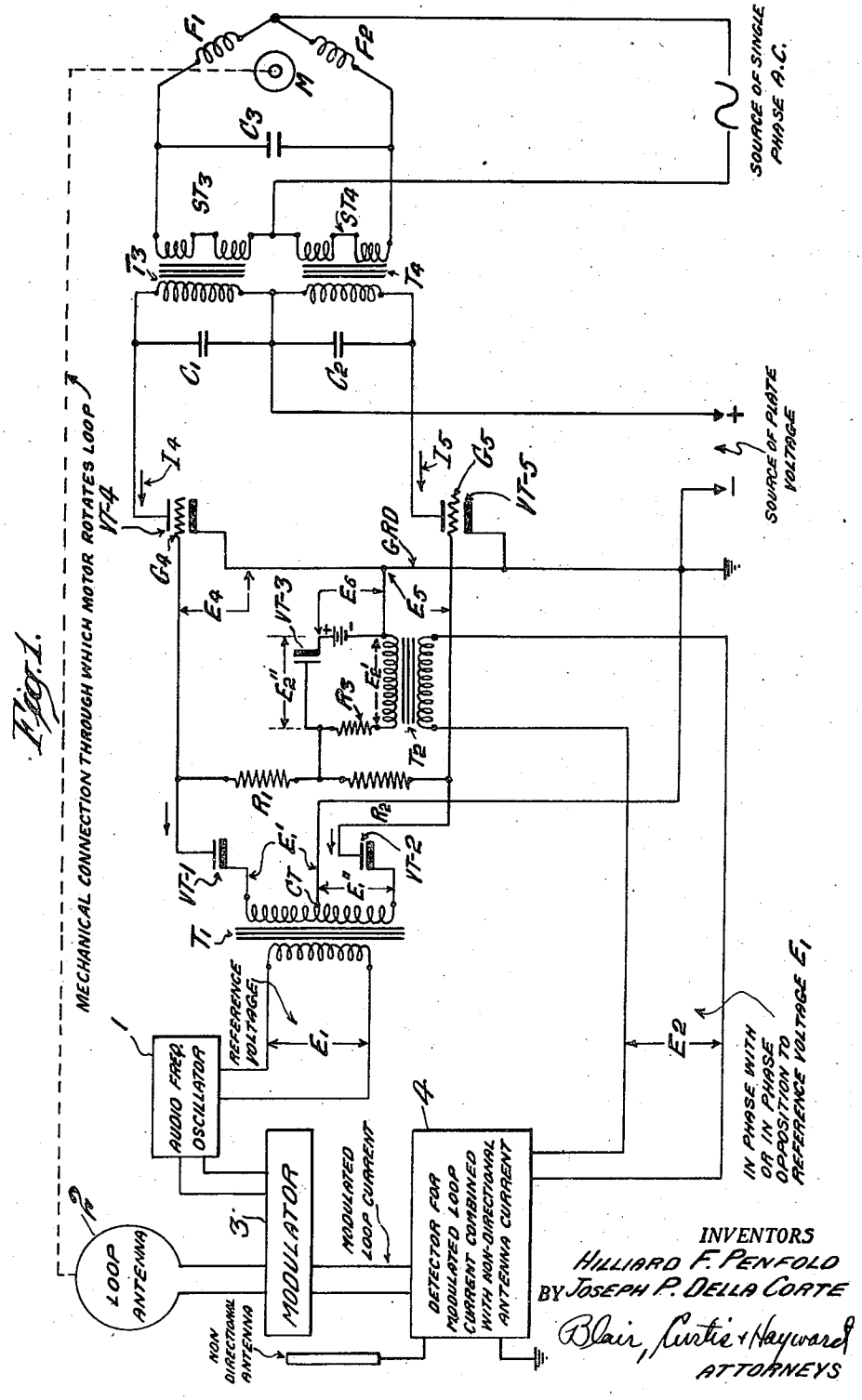


Fig. 1.

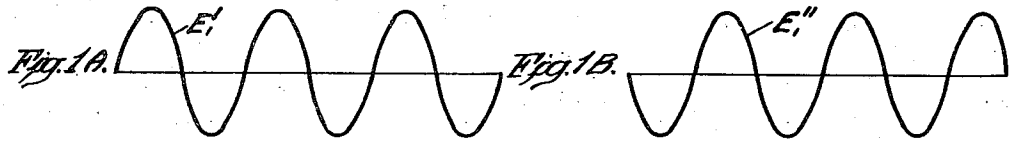
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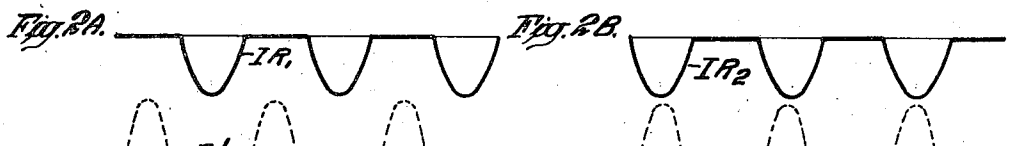
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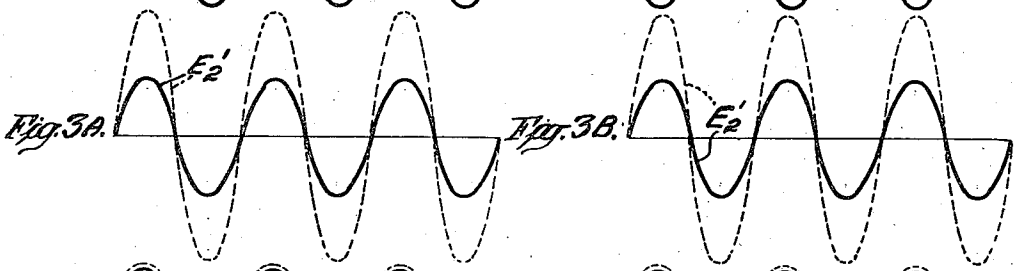
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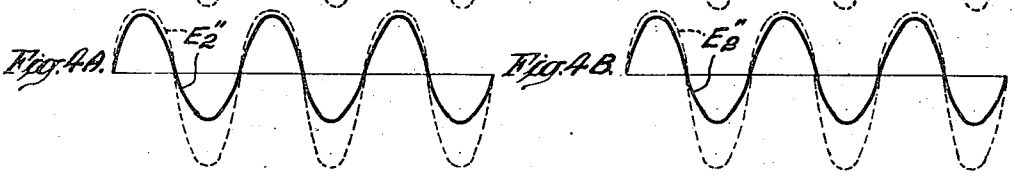
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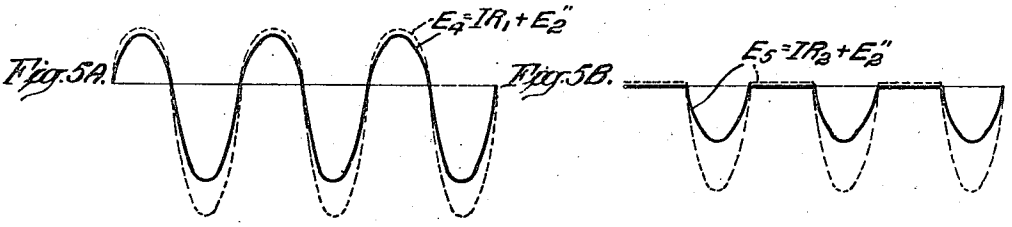
LOOP TO LEFT OF "ON COURSE POSITION"















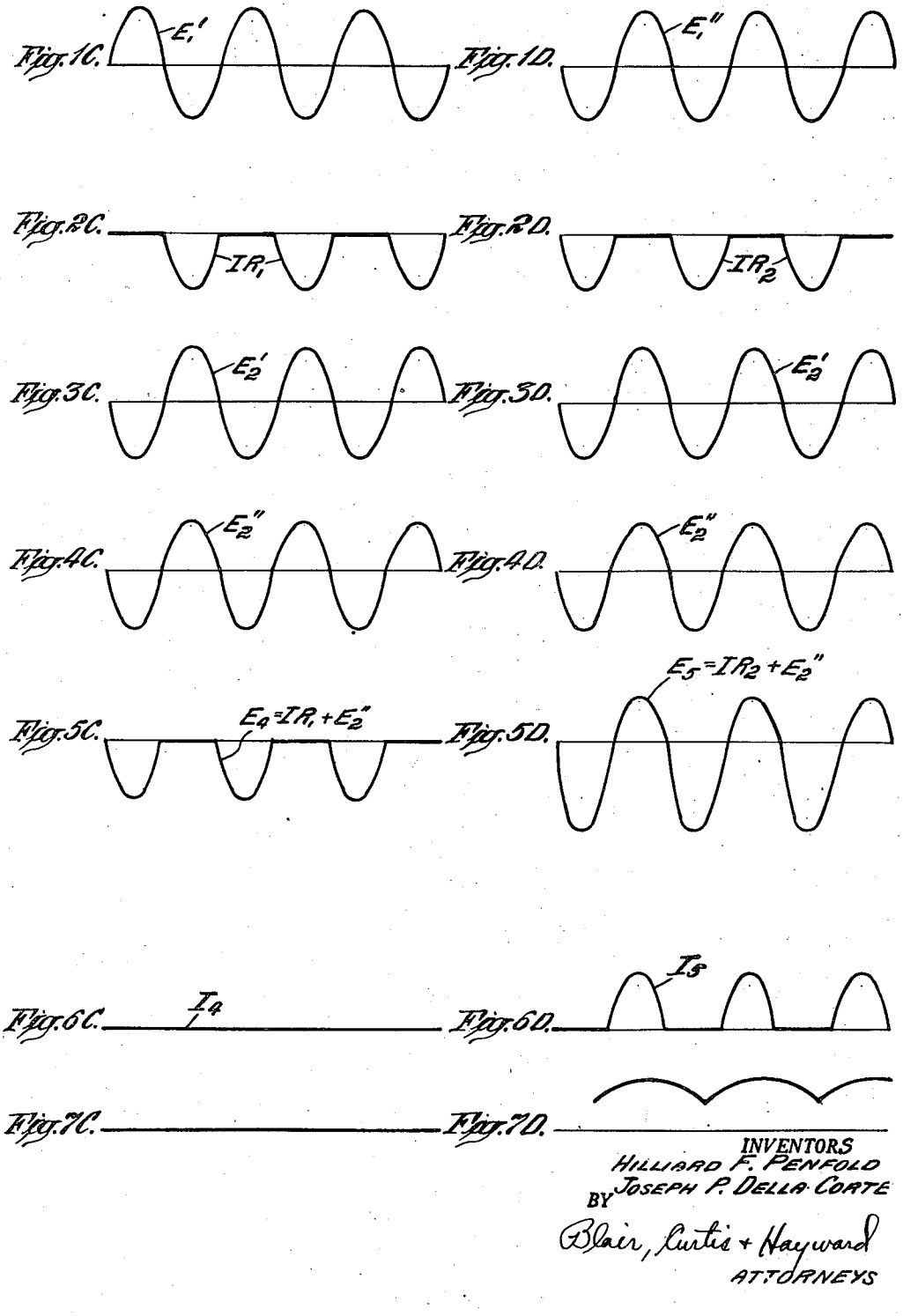
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AUTOMATIC RADIO COMPASS

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LOOP TO RIGHT OF "ON COURSE POSITION"



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2,449,859

AUTOMATIC RADIO COMPASS

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6 Claims. (Cl. 343—117)

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This invention relates to a follow-up system applicable to various uses. It is well adapted for use as an automatic loop director for radio compasses, and it will be disclosed and discussed in that connection.

Radio compasses of known type receive on two antennae the incoming signal to which the compass is tuned. One antenna is non-directional; the other is a directional or loop antenna. With an incoming signal of given strength, the loop antenna current varies as the plane of the loop is shifted to different angular positions with respect to the direction from which the signal is arriving. A radio compass utilizes this well-known effect to determine or indicate the signal's direction. The output of the compass circuit varies in distinctive manner (e. g. phase reversal) as the plane of the loop is shifted to and slightly past the "on course" position in which it is at right angles with the signal direction. Associated with the loop is an azimuth indicator which, when the loop is "on course," points in the direction from which the signal is arriving. When applied to a radio compass, the present invention utilizes the phase of the loop current in governing the rotation of the loop to "on course" position. The phase reversal as the "on course" position is passed is utilized to return the loop to "on course."

A general object of the invention is to provide an accurate, sensitive follow-up system which provides ample power for follow-up purposes, in response to variations in weak or lower level energy.

Another object of the invention is to provide a follow-up system which provides substantially full follow-up power the instant such power is called for by the change in the conditions which initiates the follow-up.

A further object of the invention is to provide a sensitive, accurate, and reliable follow-up system for automatically directing the loop antenna of a radio compass.

A still further object of the invention is to provide a follow-up system providing ample follow-up power in response to even relatively weak initiating current, the direction of the follow-up action being determined by the phase of such current.

Various additional objects of the invention will be apparent to those skilled in the art, from a consideration of the following disclosure.

Fig. 1 of the drawings is a schematic diagram showing a follow-up system or circuit of the present invention applied as an automatic loop director for a known type of radio compass.

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Figs. 1A through 7A show related voltages or currents in that part of the control circuit which leads to one saturable control reactor that is connected into the motor-circuit of the follow-up motor. These curves apply when the loop is to the left of "on course" position.

Figs. 1B through 7B show similarly related voltages or currents in that part of the control circuit which leads to the other saturable control reactor that is connected into the motor circuit. These curves also apply when the loop is to the left of "on course" position.

Figs. 1C through 7C correspond respectively to Figs. 1A through 7A, but apply when the loop is to the right of "on course" position.

Figs. 1D through 7D correspond respectively to Figs. 1B through 7B, but apply when the loop is to the right of "on course" position.

A brief preliminary outline of the manner in which the invention operates, will be helpful in understanding the detailed description which follows later.

A local audio frequency oscillator 1 is used as a source of fixed phase-reference voltage. The energy received by the loop antenna 2 is modulated at 3 by a voltage obtained from local source 1. The modulated radio frequency loop voltage is combined with the radio frequency voltage from the non-directional antenna, and then detected at 4. The means for carrying out these steps are known in the art.

The detected modulating voltage E_2 issues either in phase with or in phase opposition to the reference voltage E_1 depending upon whether the normal to the plane of the loop is to the left or right of the line on which the signal is arriving. Voltages derived from the detected modulating voltage E_2 and the reference voltage E_1 are combined in phase or in phase opposition to supply a differential bias to the grids of the two electronic tubes VT—4 and VT—5 such that the plate current of one or the other, but not both, increases depending on whether the loop is to the left or to the right of the "on course" bearing. The plate current is made to flow through and saturate a control reactor T_3 or T_4, in series with one field of a balanced two phase motor M causing upset of the balance and consequent rotation of the motor in the direction necessary to move the loop to the correct bearing or "on course" position. The motor M is, of course, mechanically connected to loop 2, so as to rotate the loop. This is indicated schematically in Fig. 1 of the

drawing, it being evident that such reducing gears and other mechanical devices as may be found necessary may be employed.

In lieu of modulating the loop radio frequency voltage with the local audio frequency voltage, as above described, the non-directional antenna voltage may be modulated with the reference voltage and a similar result achieved.

The reference voltage E_1 is fixed in magnitude and phase. The voltage E_2 is zero when the loop antenna is in "on course" position. If the loop varies from "on course" position, voltage E_2 has a value and it is either in phase with or in phase opposition to reference voltage E_1, depending upon whether the loop is to the left or to the right of "on course" position.

The reference voltage E_1 is applied to transformer T_1 whose center tapped secondary provides voltages E_1' and E_1''. Figures 1A and 1B (also Figs. 1C and 1D) show three cycles of sinusoids E_1' and E_1'', respectively. The voltages E_1' and E_1'' are applied to rectifiers VT—1 and VT—2 in phase opposition with respect to the center tap CT of the transformer T_1. The rectifiers VT—1 and VT—2 are so poled as to rectify those pulses of E_1' and E_1'' which are negative to the point CT. Figures 2A and 2B illustrate the voltages developed across resistances R_1 and R_2 respectively by the rectified current. These voltages IR_1 and IR_2 are applied respectively to grid G_4 of vacuum tube VT—4 and grid G_5 of vacuum tube VT—5. All the voltages shown in Figs. 1A, 1B, 2A and 2B have as their base or reference, point CT, which, is the same as ground point GRD. The relationship set forth in this paragraph apply regardless of whether the loop is to the left or the right of the "on course" bearing. Thus Fig. 1C is a duplicate of Fig. 1A, and Fig. 1D is a duplicate of Fig. 1B.

Voltage E_2, the nature of which has been already explained, is applied to transformer T_2. To the secondary of transformer T_2 is connected a series circuit of resistor R_3, a rectifier VT—3 and a battery B. The solid line curves of Figs. 3A and 3B illustrate the voltage E_2' which is developed directly across the secondary of transformer T_2 and which is phased for the displacement of the loop to the left of the "on course" position. The control voltage E_2'' which develops across the rectifier VT—3 is illustrated in both Figs. 4A and 4B. This voltage E_2'' is added vectorially to the voltages developed across resistances R_1 and R_2 (see Figs. 2A and 2B) to produce a differential bias on grids G_4 and G_5 of vacuum tubes VT—4 and VT—5.

Comparing the dotted curve of Fig. 4A with the dotted curve of Fig. 3A, or that of Fig. 4B with the dotted curve of Fig. 3B, it will be apparent that voltage E_2'' has had its positive half cycles partly suppressed. This suppression is effected by resistance R_3, the delay voltage battery and rectifier VT—3, this rectifier being poled to pass current which is positive with respect to GRD. During the negative half cycles no significant amount of current flows through rectifier VT—3, which permits voltage E_2'' to reach its normal maximum value. The positive half cycles also pass through unattenuated by the rectifier so long as their peak value remains less than the delay voltage E_6. This is readily seen by comparing the solid curves of Figures 3A and 4A and those of Figures 3B and 4B. However, if the peak exceeds the delay voltage, during that portion of the positive cycle when the delay voltage is overcome, the impedance of the rectifier VT—3 is lowered. Thus the positive half cycles of voltage E_2'' are suppressed to a magnitude just slightly larger than that of E_6, the delay voltage. The purpose of this suppression is to prevent large positive peaks of E_2'' from exceeding the peaks of IR_1 or IR_2 and making conductive that tube which should be biased to cutoff. It can be seen from Figure 5D that if the dotted curve were permitted to have a significant positive excursion, current I_5 would flow interfering with the action of current I_4 in unbalancing the motor bridge circuit which is to be explained later.

The control voltage E_2'' is vectorially added to the voltage developed across resistance R_1 to produce voltage E_4, which is applied to grid G_4. Additionally the same voltage E_2'' is vectorially added to the voltage developed across resistance R_2 to produce voltage E_5, which is applied to grid G_5. Voltage E_4 is shown in Fig. 5A, being the vector sum of the voltages of Figs. 2A and 4A. Voltage E_5 is shown in Fig. 5B, being the vector sum of the voltages shown in Figs. 2B and 4B.

The vacuum tubes VT—4 and VT—5 are normally blocked, i. e., pass very little or no current. This may be effected by suitable negative bias on the grids or by the use of tubes whose plate current is nil with zero grid bias. As shown in Fig. 5B voltage E_5 has no positive portion, and hence no significant amount of current flows in the plate circuit of tube VT—5. This is indicated in solid lines in Fig. 6B which shows the plate current I_5 in solid lines. However, voltage E_4 does have positive half cycles, and these applied to grid G_4 result in plate current I_4 shown in Fig. 6A. Condensers C_1 and C_2 partially smooth out the currrent delivered to the primaries of the saturable control reactors T_3 and T_4, e. g. to the form shown in Fig. 7A. With the loop to the left of "on course" position the current delivered to the primary of reactor T_4 is zero, as shown in solid line in Fig. 7B.

The energization of reactor T_3, with no energization of reactor T_4, causes motor M to rotate in the direction to move the loop to the right, to bring the loop "on course." The motor action will be described later.

If the loop be to the right of "on course" position, Figs. 1C through 7C and 1D through 7D will apply. In this case the loop current is reversed 180° and accordingly voltage E_2' is likewise reversed 180°, as shown in Figs. 3C and 3D. Control voltage E_2'' is then as shown in Figs. 4C and 4D. The vector sum of voltage E_2'' (Fig. 4C) and voltage IR_1 (Fig. 2C) gives the voltage E shown in Fig. 5C. This has no positive portion and hence the plate current I_4 of tube VT— is very small or practically nil, as shown in Fig. 6C. However, the vector sum of voltage E_2' (Fig. 4D) and voltage IR_2 (Fig. 2D) give voltage E_5 as shown in Fig. 5D. This produces plate current I_5 (Fig. 6D) which is smoothed by condenser C_2 and energizes the primary of reactor T_4 as indicated in Fig. 7D. The motor now rotates in the direction to move the loop 2 to the left, to bring the loop "on course."

The motor M is a two-phase motor having field F_1 and F_2 connected in balanced bridge relationship with the secondaries of the saturable control reactors T_3 and T_4. Condenser C_3 aids in phasing the voltage applied to the second phase of the motor. Reactors T_3 and T_4 are so wound that their windings which are in series with fields F_1 and F_2 produce zero flux in the respective primary windings when the A. C. supply voltage is applied to the motor. This precludes the possi-

bility of any A. C. motor supply voltage developing in the plate circuits VT—4 and VT—5 and interfering with their operation.

The bridge formed by field windings F_1 and F_2 and reactor secondaries ST_3 and ST_4 is balanced when plate currents I_4 and I_5 are either the same or zero. In this condition motor M is not effectively energized and hence it remains stationary. When plate current I_4 flows, it saturates the core of reactor T_3, thereby lowering the impedance of its secondary winding ST_3. This so unbalances the bridge that field F_1 receives a voltage approximately equal to but out of phase with that of field F_2; and the motor M rotates in the proper direction. When plate current I_5 flows (current I_4 then being small or zero), the core of reactor T_4 is saturated, and the bridge is similarly unbalanced in the opposite direction. Thus, the motor rotates in the opposite direction.

In compliance with the patent statutes we have disclosed the best form in which we have contemplated applying our invention, but it will be realized that the disclosure is illustrative and not limiting.

What we claim is:

1. An automatic loop director for a radio compass, comprising: an alternating current power source; a reversible motor for turning the loop in either direction to place it on course; a motor circuit connecting the motor to the power source, the motor circuit being normally balanced for keeping the motor operatively deenergized; a source of phase-reference voltage separate from said alternating current power source; an intermediate circuit connecting the phase-reference source to the motor circuit, said intermediate circuit being normally balanced for maintaining the balance of the motor circuit; means for deriving a control voltage in phase with the reference voltage when the loop is off course in one direction and in phase opposition to the reference voltage when the loop is off course in the other direction; and means for applying the control voltage to the intermediate circuit for upsetting the balance of the motor circuit in one direction when the control voltage is in phase with the reference voltage and for upsetting the balance of the motor circuit in the other direction when the control voltage is in phase opposition to the reference voltage, whereby the motor is energized for rotation in either direction as required to place the loop on course.

2. An automatic loop director for a radio compass, comprising: a reversible electric motor for turning the loop in either direction to place it on course, said motor having two field windings; a pair of plural-winding saturable-core reactors; a four-arm bridge circuit having said motor windings connected into two of the arms and having windings of the respective reactors connected into the other two arms; a source of electric power connected to a diagonal of the bridge, the bridge being normally balanced for keeping the motor operatively deenergized; a source of phase-reference voltage; a normally balanced intermediate circuit connecting the reference voltage source to windings of both reactors; means for deriving a control voltage in phase with the reference voltage when the loop is off course in one direction and in phase opposition to the reference voltage when the loop is off course in the other direction; and means for impressing the control voltage on the intermediate circuit for selectively increasing the saturation effect of said reactors according to the aforesaid phase relation between the control voltage and the reference voltage, whereby the bridge is unbalanced when the loop is off course in either direction and the motor is energized for rotation to place the loop on course.

3. An automatic loop director for a radio compass, comprising: an electric power source; a reversible motor for turning the loop in either direction to place it on course; a motor circuit connecting the motor to the power source, the motor circuit being normally balanced for keeping the motor operatively deenergized; a pair of saturable-core reactors connected into the motor circuit and operative when selectively energized to unbalance the motor circuit in opposite directions; a pair of grid-controlled electric valves connected to the reactors for energizing the same; a source of phase-reference voltage; an intermediate circuit connecting the reference voltage source to the grids of the electric valves and operable to impress on the grids of the respective valves negative half cycles of voltage 180 degrees out of phase; means for deriving a control voltage in phase with the reference voltage when the loop is off course in one direction and in phase opposition to the reference voltage when the loop is off course in the other direction; and means responsive to the control voltage for applying positive half cycles of voltage to the grid of one valve only when the loop is off course in one direction and positive half cycles of voltage to the grid of the other valve only when the loop is off course in the other direction, whereby the reactors are selectively energized when the loop is off course in either direction and the motor is energized for rotation to place the loop on course.

4. An automatic loop director for a radio compass, comprising: a motor for turning the loop in either direction to place it on course; a source of power for the motor; a motor circuit connecting the source of power to the motor, the motor circuit being normally balanced for keeping the motor operatively deenergized; a pair of normally blocked grid-controlled valves connected to unbalance the motor circuit in opposite directions when the valves are rendered conducting selectively; a source of phase-reference voltage, said source being independent from said source of power; means for deriving a control voltage in phase with the reference voltage when the loop is off course in one direction and in phase opposition to the reference voltage when the loop is off course in the opposite direction; and a circuit for vectorially combining the control voltage and the reference voltage and applying a positive resultant thereof to the grids of the valves selectively according to the aforesaid phase relation of the control voltage to the reference voltage, whereby the valves are rendered conducting selectively when the loop is off course in either direction and the motor is energized to place the loop on course.

5. An automatic loop director for a radio compass, comprising: a motor for turning the loop in either direction to place it on course; a source of power for the motor; a motor circuit connecting the source of power to the motor, the motor circuit being normally balanced for keeping the motor operatively deenergized; a pair of saturable-core reactors connected into the motor circuit, said reactors being operative when selectively energized to unbalance the motor circuit in opposite directions; a pair of normally blocked grid-controlled valves connected to the

reactors respectively for selectively energizing them when the valves are rendered conducting selectively; a source of phase-reference voltage; means for deriving a control voltage in phase with the reference voltage when the loop is off course in one direction and in phase opposition to the reference voltage when the loop is off course in the opposite direction; and a circuit for vectorially combining the control voltage and the reference voltage and applying a positive resultant thereof to the grids of the valves selectively according to the aforesaid phase relation of the control voltage to the reference voltage, whereby the valves are rendered conducting selectively when the loop is off course in either direction and the reactors are energized selectively and the motor is energized to place the loop on course.

6. An automatic direction finding system, comprising: a directional rotatable antenna; a reversible motor connected to said antenna; a first source of alternating voltage for driving said motor; a second source of alternating voltage separate from said first source for phase reference; means responsive to the position of said antenna relative to the direction of propagation of a received signal for producing a control signal having the same frequency as said second source and having a phase angle of zero or 180 degrees relative thereto depending upon the rotational position of said antenna; a comparison circuit including rectification means for producing from said second source of alternating voltage a first and a second comparison voltage, said first voltage constituting negative pulses each separated by an interval of time substantially equal to the duration of one of said pulses, said second voltage constituting similarly spaced negative pulses occurring during the interval of time between successive pulses of said first comparison voltage, and means for vectorially combining said

control voltage with each of said first and second comparison voltages thereby producing two resultant signals one or the other of which has its positive peaks suppressed in accordance with the phase relationship between said control voltage and said comparison voltages and consequently in accordance with the rotational position of said antenna; a bridge circuit comprising at least two windings of said motor and two similar variable impedance elements and connected to said first source of alternating voltage whereby the rotation and direction of rotation of said motor are controlled by the relative impedances of said variable impedance elements; and two impedance control means each coupled to one of said resultant signals and each operative to vary the impedance of the one of said impedance elements associated therewith in accordance with the magnitude of the positive peaks of the respective resultant signal.

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