

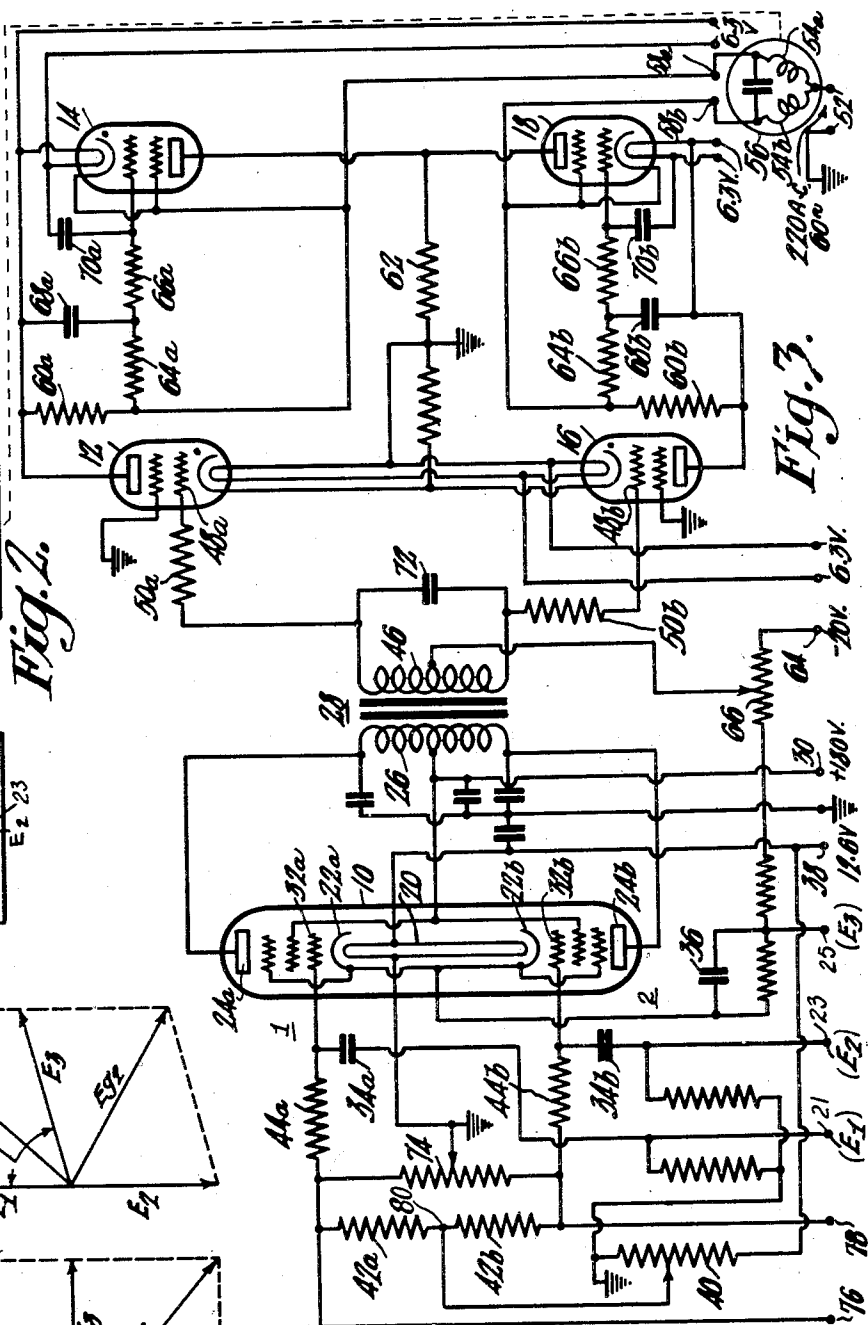
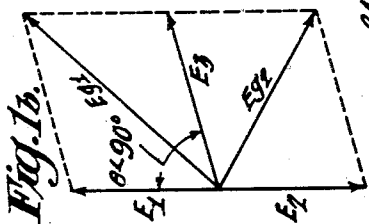
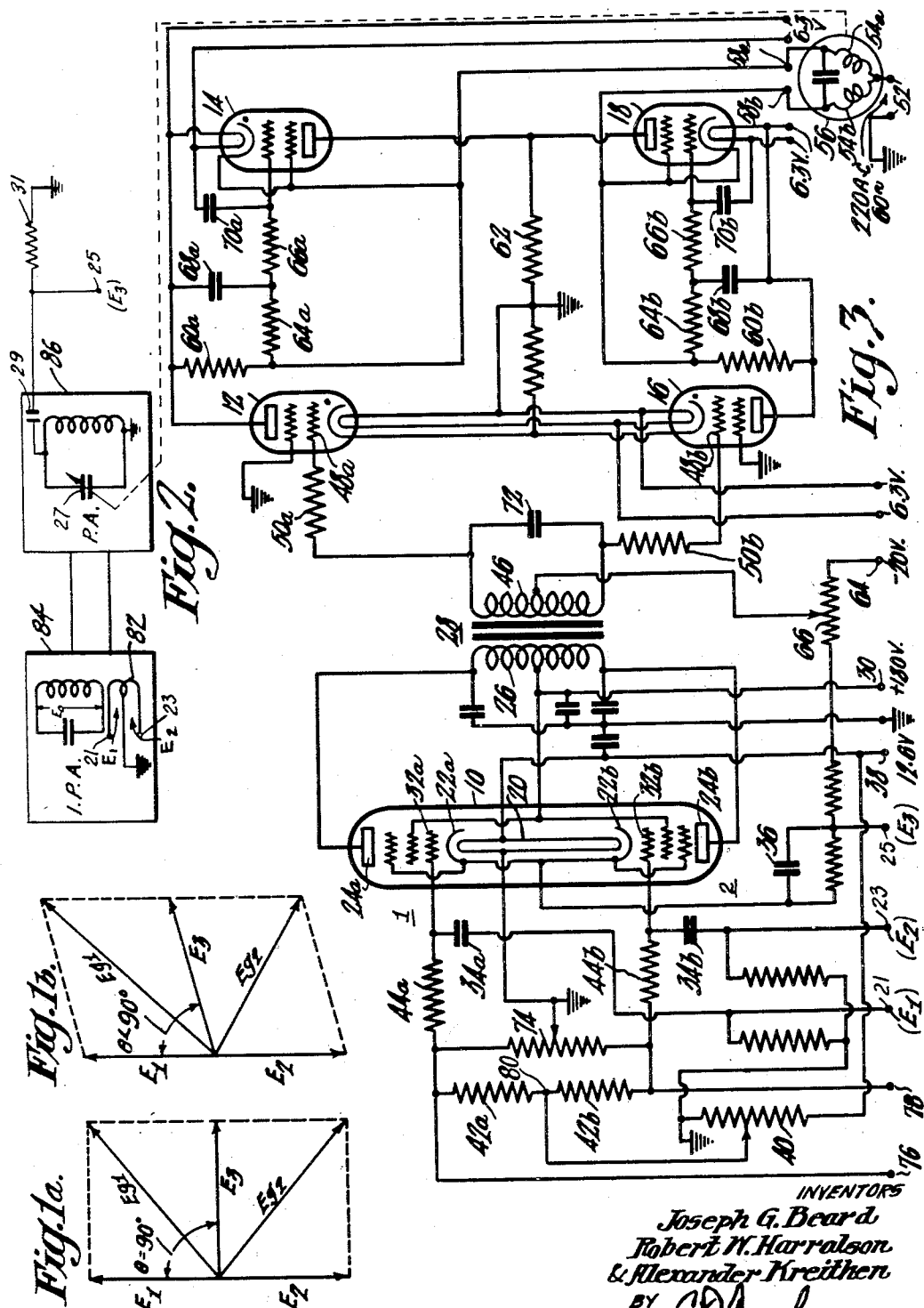
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PHASE RESPONSIVE CONTROL CIRCUIT

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PHASE RESPONSIVE CONTROL CIRCUIT

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This invention relates to a phase control system and particularly to a method of and means for maintaining two alternating signals in phase quadrature.

Among the objects of the invention is the provision of an improved phase detector and particularly of a method of and means for detecting any change in the phase relation of two signals which are normally in quadrature.

Another object is the provision of an improved phase control system and of sensitive accurate speedy and compact apparatus for maintaining two signals in quadrature.

According to the invention these objects are achieved by producing a pair of alternating currents which are balanced when the signals under control are in quadrature and by utilizing energy under the control of an unbalance of these currents for returning the signals to the desired phase relation.

In the accompanying drawing

Figures 1a and 1b are vector diagrams which illustrate the operation of the invention,

Figure 2 illustrates an application of the invention, and

Figure 3 is a circuit diagram of an embodiment of the invention.

In Figure 1a two signals in phase quadrature are represented by the vectors E_1 and E_3 and their vector sum by the vector E_{g1} . E_1 and E_3 are the signals whose relative phase is to be controlled or indicated. A third signal is represented by the vector E_2 . This signal has an absolute magnitude at any instant equal to that of one of the before-mentioned signals, say E_1 , but of opposite phase to E_1 . The vector sum of E_2 and E_3 is seen to be the vector E_{g2} . As long as the angle θ representing the phase difference between E_1 and E_3 remains at 90° then $E_{g1} = E_{g2}$, but when θ becomes greater or less than 90° then E_{g1} becomes less or greater than E_{g2} . In Figure 1b, for example, the phase difference between E_3 and E_1 is less than 90° and it will be seen that E_{g1} is greater than E_{g2} .

These principles are applied in the circuit of Figure 3, which consists basically of a phase detector tube 10, four gas tubes 12, 14, 16 and 18 and their associated circuits. The phase detector 10 includes identical amplifiers 1 and 2 with a common heater 20 and connected cathodes 22a, 22b, and is shown as a twin pentode which may be of RCA Type 1644. The two anodes 24a, 24b are connected by the primary winding 26 of an output transformer 28, and a center tap on this winding is connected to a terminal 30 at which

direct current potential for the anode and screen grids of the amplifiers is applied.

The signal E_1 , one of the signals whose relative phase is to be controlled, is applied to terminal 21, that is, between the control grid 32a of amplifier 1 and ground through a capacitor 34a, and the signal E_3 , the other signal whose phase is to be controlled with respect to the first signal E_1 , is applied to terminal 25, that is, between the connected cathodes 22a, 22b and ground through a capacitor 36. The potential of the grid 32a of amplifier 1, with respect to its cathode 22a, varies in accordance with the vector sum of E_1 and E_3 and may, therefore, be represented by the vector E_{g1} of Figure 1.

The signal E_2 is derived in any conventional manner from a reference voltage which will produce the required phase and amplitude relation with respect to E_1 . This may be accomplished either by deriving E_2 from E_1 by means of a phase inverter, or both signals E_1 and E_2 may be derived from some other voltage E_0 , as for example, by means of a center-tapped coil 82 coupled to a winding across which the voltage E_0 is available, as shown in Fig. 2. The signal E_2 is applied to the control grid 32b of amplifier 2 from terminal 23 through a capacitor 34b. Since E_3 has been applied to the connected cathodes, the potential of grid 32b with respect to its cathode 22b varies as the vector sum of E_2 and E_3 and may be represented by the vector E_{g2} .

An alternating voltage is applied to and amplified by each amplifier. This voltage may be from the commercial supply with a frequency of sixty cycles per second and may be taken from the same source as the current for the heater 20. It is applied between a terminal 38 and ground through a variable resistor 40 common to both units, and then to grid 32a through resistors 42a, 44a, and to grid 32b through resistors 42b, 44b of equal value with 42a, 44a. The two resistors 42a, 42b and the connection from the tap on the resistor 40 are joined at a terminal 80; the free terminals of the resistors 42a, 42b being connected to limit switches (not shown) by means of terminals 76, 78.

A resistor 74 connects the two grids 32a, 32b. This resistor is tapped, the tap being connected to the common heater 20 and to ground. If, owing to non-linearity of components or for some other reason, the gain of amplifiers 1 and 2 is not equal, the inequality may be compensated by adjustment of the tap on resistor 74.

We have seen that $E_{g1} = E_{g2}$ when E_1 is in quadrature with E_3 . In that event, the alternating

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voltage applied to each grid 32a, 32b is equally amplified by the amplifiers 1 and 2. Equal currents will therefore flow in each anode circuit and the resultant current through the primary winding 26 will be zero except for direct current from terminal 30. When therefore E_1 is in phase quadrature with E_3 no voltage will be induced in the secondary winding 46 of the transformer 30. However, if E_1 is not in phase quadrature with E_3 , E_{s1} will be greater or less than E_{s2} , the alternating voltage applied to grids 32a and 32b will not be equally amplified and the former balance of alternating current in winding 26 will be disturbed. Voltage is therefore induced in the secondary winding 46 and applied to the control grids 48a, 48b of the gas tubes 12 and 16 through resistors 50a, 50b respectively.

The four gas tubes which may be of RCA Type 2D21 are energized by alternating current from a source indicated at 52 and connected through the windings 54a, 54b of a split phase induction motor 56 to terminals 58a, 58b respectively. The source 52 may be from the same commercial supply from which alternating voltage is applied to the control grids of the two amplifier units of the phase detector tube, and therefore of the same frequency and in phase with that voltage.

The anode of gas tube 12 is connected to terminal 58a through a resistor 60a and the anode of gas tube 16 is connected to terminal 58b through a resistor 60b, while the cathodes of these two tubes are connected to ground. In the two gas tubes 12 and 16 this situation is reversed, the anodes being connected to ground through resistor 62 and their cathodes to terminals 58a, 58b respectively. A biasing potential is applied at terminal 64 to the grids of tubes 12 and 16 and prevents these two tubes from conducting during the half cycles when positive voltage from the source 52 is applied to their respective anodes. The biasing potential may be varied by adjustment of a resistor 66.

We have seen that when E_1 is not in phase quadrature with E_3 an alternating voltage is induced in the secondary winding 46 and applied during alternate half cycles to the grids of gas tubes 12 and 16. A capacitor 72 connected across the winding 46 is chosen of such value as to form with winding 46 a circuit resonant to a frequency of sixty cycles per second only, and eliminates harmonic frequencies which may have been introduced from the supply source, or which may result from distortion in the amplifiers 1 and 2.

The alternating voltages applied to the grids 48a, 48b are 180° out of phase with each other. The voltage applied to the grid of one of the gas tubes 12 and 16 will be in phase with the voltage applied to the anode of the same tube, while the voltage applied to the other tube is completely out of phase with the voltage applied to its anode.

By way of example, we will suppose that when the phase angle θ between E_1 and E_3 becomes less than 90° the voltage applied to the grid of gas tube 16 is out of phase with the voltage applied to its anode. The grid will, therefore, become more negative with respect to its cathode as the anode becomes more positive and the tube will not conduct under these conditions. At the same time in the gas tube 12, grid to cathode potential increases in synchronism with anode to cathode potential and the tube will, therefore, conduct during half cycles of positive anode voltage. During these half cycles, anode current will flow through the resistor 60a and thus through the winding

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54a of the motor 56 to drive the rotor of that motor in one direction.

During the half cycles when the anode of tube 12 is positive with respect to its cathode, the anode of tube 16 is negative so that tube 16 will not conduct when tube 12 does. The flow of anode current through resistor 60a creates a potential drop across that resistor with the positive terminal further from the anode of tube 12. The positive potential thus created is applied to the grid of tube 16 by means of the time delay combination constituted by resistors 64a, 64b and capacitors 68a and 70a, the values of which are so chosen as to create a delay of approximately 50° .

Thus at the time when the anode of tube 16 is becoming positive with respect to its cathode a positive pulse is applied to its grid, and the tube, therefore, conducts as soon as the anode reaches ionization potential. With tubes of 2D21 type, the ionization potential is approximately 10 to 12 volts above that of the grid. This potential is small by comparison with the peak value of approximately 300 volts for the supply voltage. The tube 16 will, therefore, conduct during substantially the whole of each half cycle of positive anode voltage. During these half cycles current flows to terminal 58a and thus through winding 54a of the motor.

By this means, as long as the phase angle between the signals E_1 and E_3 is less than 90° a full wave of alternating current, the value of which is determined only by the characteristics of the gas tubes employed, is applied to the motor 56 to drive it in one direction. The motor may now be employed to correct the condition causing a departure from phase quadrature between the signals E_1 and E_3 . This may be effected, for example, by causing the motor to tune a circuit in which those signals, or at least one of them, are generated, as indicated by the dotted line extending between motor 56 and capacitor 27. As soon as the signals return to phase quadrature, balance in the primary winding 26 will be restored, the gas tubes will be extinguished and the motor will stop.

If the phase angle between E_1 and E_3 becomes greater than 90° the action of the circuit is reversed. The polarity of the voltage induced in the secondary winding 46 is now such that tubes 16 and 12 are ignited, current flows through these tubes during alternate half cycles to terminal 58b and thus through winding 54b of the motor, the rotor of which is thereby driven in the opposite direction until phase quadrature is re-established and the balance of the circuit restored.

While the invention is of general application whenever two alternating signals are to be maintained in phase quadrature, a particular application is found in automatically tuned multi-stage radio communication transmitters. It is well known that the tank circuit of an amplifier which is tuned to resonance at the operating frequency is substantially a resistive load, since the inductive and capacitive reactances are equal and opposite. It is also well known that an amplifier tube produces a phase reversal, that is, the output or plate voltage is 180° out of phase with the input or grid voltage. In a perfectly tuned multi-stage amplifier, therefore, the voltage across any tank circuit will have either a 0° or 180° phasal relation with respect to a reference voltage such as the input or oscillator voltage. If the power stage becomes detuned, the voltage across the power amplifier tank circuit will vary from this

0° or 180° relation. The phase displacement, with respect to the reference voltage, will be leading or lagging according to the nature of the detuning. A control system based on this phase displacement for returning the circuit to exact resonance is much more sensitive than that which can be obtained by tuning the circuit to minimum plate current. It is therefore a further object of this invention to control the tuning of a power amplifier by comparing the phase of a voltage derived from and having a fixed phasal relation with respect to the amplifier tank voltage and a reference voltage obtained from a preceding amplifier stage or the oscillator. One of the two voltages which are to be compared will be shifted in phase by 90° by conventional means. The two voltages will then normally have a quadrature phase relation and may be considered as the signals E_1 and E_3 and applied to the phase responsive circuit of Fig. 3 as described above.

Figure 2 shows in block an intermediate power amplifier 84 and a power amplifier 86 of a transmitter. The two signals E_1 and E_2 are derived from the voltage E_0 across the tank circuit of the intermediate power amplifier by the phase inverter center tapped transformer 82, and E_3 is a derived voltage which is in phase quadrature with the voltage across the inductor in the tank circuit of the succeeding stage. The 90° phase shift is obtained by connecting a capacitor 29 and a resistor 31 across the tank coil. Signal E_3 is developed across the resistor, as is well known, and is available at terminal 25.

The sensitivity of the device may be varied by adjustment of the variable resistor 40 which determines the amount of alternating voltage applied to the grids of the two amplifier units.

While E_3 need not be equal in magnitude to E_1 , it will be seen from Figure 1 that the circuit of the invention has maximum sensitivity when E_3 is of the same order of magnitude as E_1 because then any departure from phase quadrature between these two signals causes maximum variation between E_{g1} and E_{g2} .

In motor control systems of the prior art the gas tubes conduct during only the positive half cycles of anode voltage, producing a wave of somewhat square shape. To round off the corners of this square-shaped wave, transformers have been conventionally connected between the gas tubes and the motor windings. The present system is more efficient electrically because the circuit produces a full wave of energizing current for the motor, the torque of the motor is instantly realized and the expense, weight and bulk of transformers is eliminated.

Part of the subject matter of the present application is disclosed in our copending application Ser. No. 570,706 for an Electronic Relay, filed concurrently herewith.

Since the balance of current in transformer 28 will be upset by a change in the phase of E_3 with respect to E_1 or by a change in the amplification of one of the two amplifiers 1 or 2, it follows that the system can be adjusted to respond to a phasal relation between E_1 and E_3 other than 90° by increasing the gain of one of the amplifiers. The system would then be balanced for that phase angle between E_1 and E_3 which would produce vectors E_{g1} and E_{g2} of such amplitudes that the resultant currents in the primary 26 would be equal.

There has thus been described a phase control system comprising a phase detector and a motor control system. In the phase detector, a

balance is maintained between a pair of alternating current when two signals are in phase quadrature and an unbalance of these currents in either direction is caused to ignite one of two pairs of gas tubes whereby to produce a full wave of alternating energy for correcting the condition causing the unbalance.

We claim as our invention:

1. A phase responsive device comprising the combination of a circuit for deriving a pair of balanced alternating voltages from two signals having a predetermined phasal relation to each other, and a network responsive to an unbalance in said voltages for producing a full wave of alternating current, said network being constituted by a circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as one of the voltages of said pair and by another circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as the other of the voltages of said pair.

2. A phase control comprising the combination of a circuit for deriving a pair of balanced alternating voltages from two signals in phase quadrature, and a network responsive to an unbalance in said voltages for producing a full wave of alternating current, said network being constituted by a circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as one of the voltages of said pair and by another circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as the other of the voltages of said pair.

3. A phase control comprising the combination of a circuit for deriving a pair of balanced alternating voltages from two signals in phase quadrature, a network responsive to an unbalance in said voltages for producing a full wave of alternating current, said network being constituted by a circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as one of the voltages of said pair and by another circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as the other of the voltages of said pair, and apparatus actuated by said alternating current for returning said signals to phase quadrature.

4. A phase control comprising the combination of a circuit for deriving a pair of balanced alternating voltages from two signals in phase quadrature, a network responsive to an unbalance in said voltages for producing a full wave of alternating current, said network being constituted by a circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as one of the voltages of said pair and by another circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as the other of the voltages of said pair, and a motor actuated by said alternating current for returning said signals to phase quadrature.

5. A phase control comprising the combination of a circuit including a pair of amplifiers with a common cathode circuit for deriving a pair of balanced alternating voltages from two signals in phase quadrature, and a network responsive to an unbalance in said voltages for producing a full wave of alternating current, said network being constituted by a circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as one of the volt-

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ages of said pair and by another circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as the other of the voltages of said pair.

6. A phase control according to claim 5, characterized in that said common cathode circuit includes a variable resistor.

7. Apparatus for detecting a variation in phase relation between a first and second signal normally in quadrature, said apparatus comprising a pair of amplifiers of equal transconductance having common cathode circuits, each of said amplifiers having at least one control electrode in addition to a cathode and an anode, an impedance connected between said anodes, means for obtaining a third signal of equal instantaneous absolute magnitude with said first signal and of opposite phase thereto, connections for applying said first and second signals between the control electrode and common cathode of one of said amplifiers and for applying said second and third signals between the control electrode and common cathode of the other of said amplifiers, connections for applying an alternating voltage to said common cathode circuit, and means responsive to the resultant voltage across said impedance.

8. A phase control comprising the combination of a circuit for deriving a pair of balanced alternating voltages from two signals in phase quadrature, and a network responsive to an unbalance in said voltages for producing a full wave of alternating current, said network being constituted

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by a first circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as one of the voltages of said pair and by another circuit which includes two gas tubes energized by an alternating supply of the same frequency and phase as the other of the voltages of said pair, each of said gas tubes having at least one control electrode in addition to a cathode and an anode, and the anode of one of said tubes in each of the circuits constituting said network being connected to the control electrode of the other tube in the same circuit.

9. A phase control according to claim 8, characterized in that each of the before-mentioned connections from the anode of one gas tube to the control electrode of the gas tube in the same circuit includes a time delay combination.

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