Aug. 4, 1936. W. W. MACALPINE 2,049,712

ELECTRICAL CONTROL SYSTEM

Filed Sept. 8, 1931 4 Sheets-Sheet 1

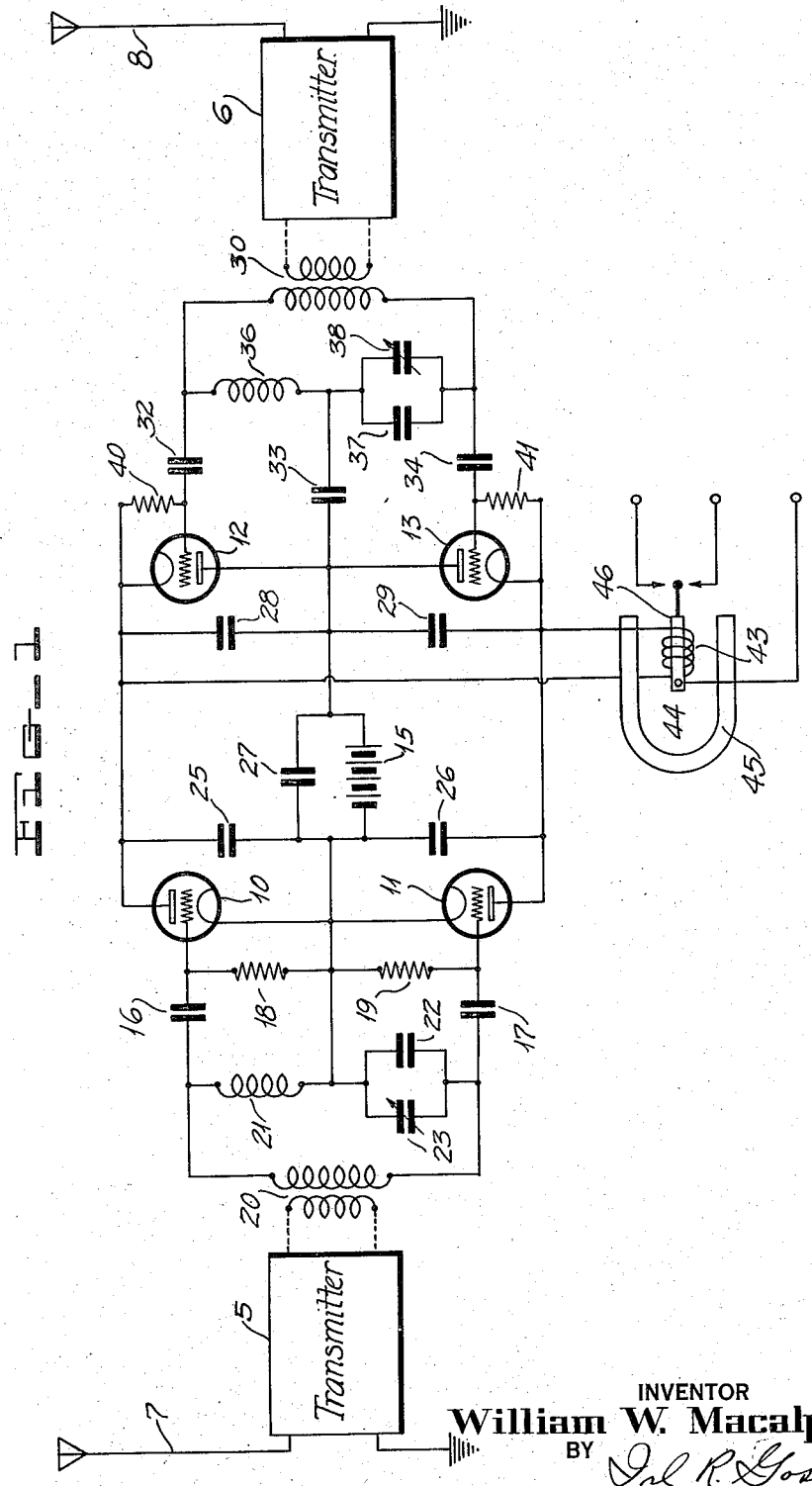


Fig. 1

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ELECTRICAL CONTROL SYSTEM

Filed Sept. 8, 1931 4 Sheets-Sheet 2

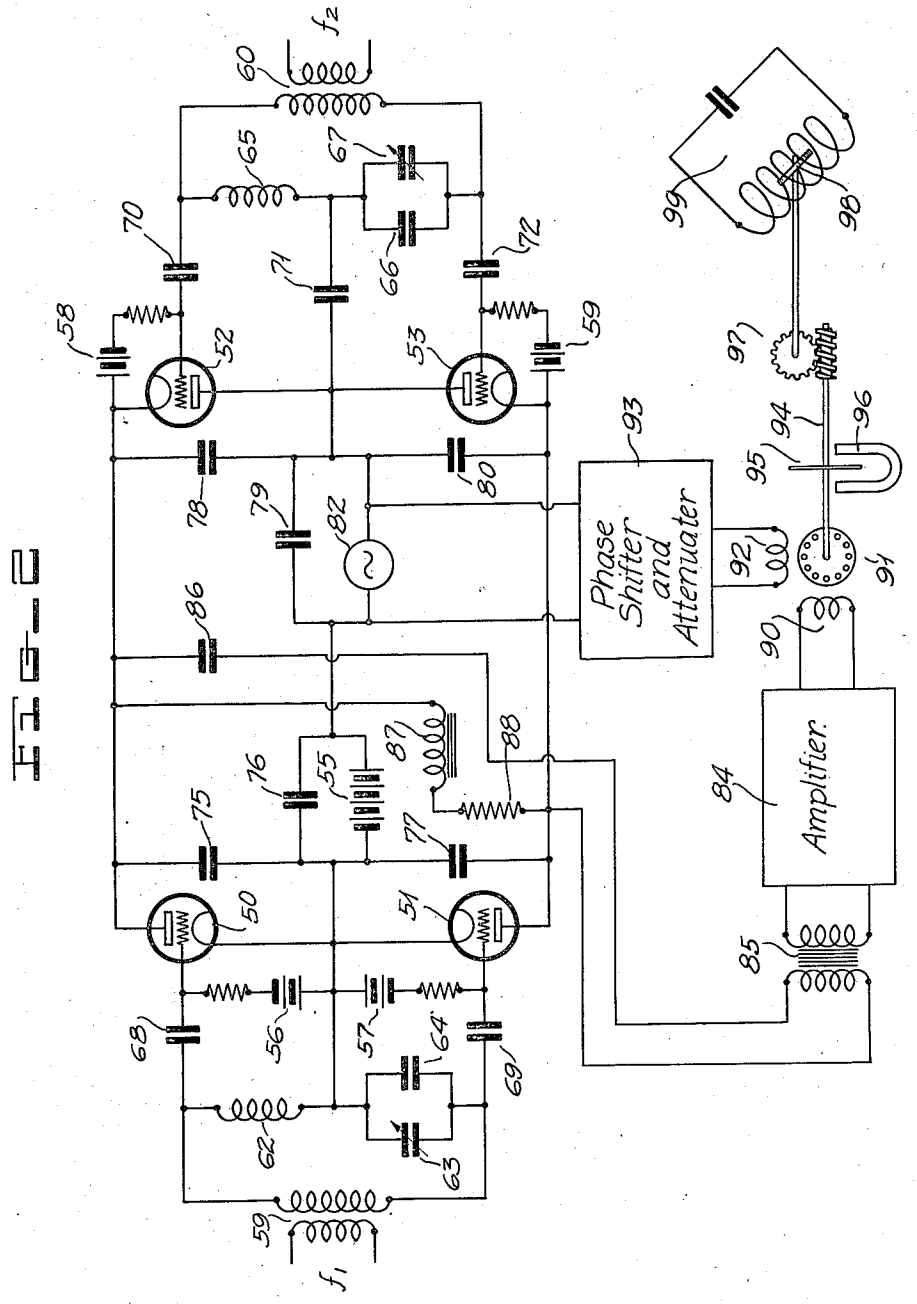


FIG. 2

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ELECTRICAL CONTROL SYSTEM

Filed Sept. 8, 1931 4 Sheets-Sheet 3

Fig. 3

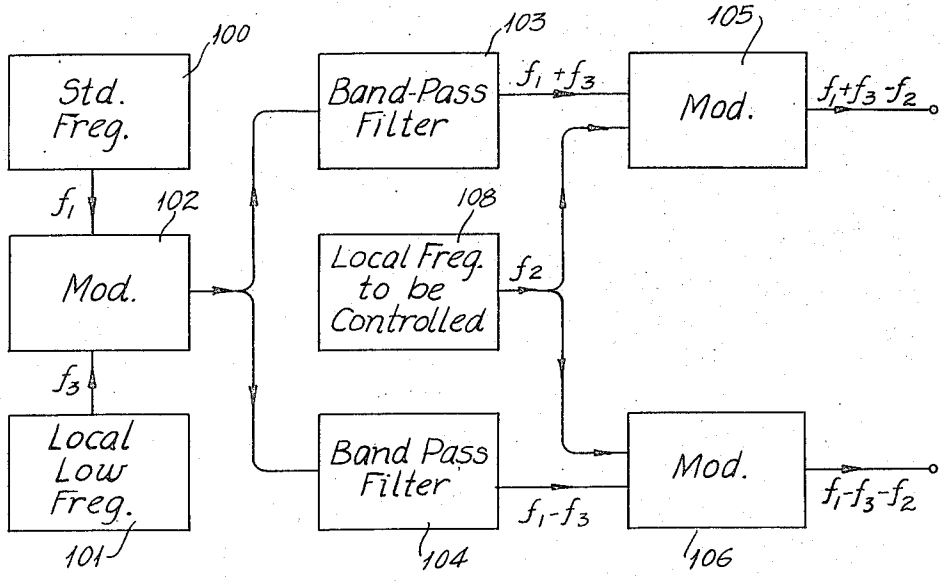
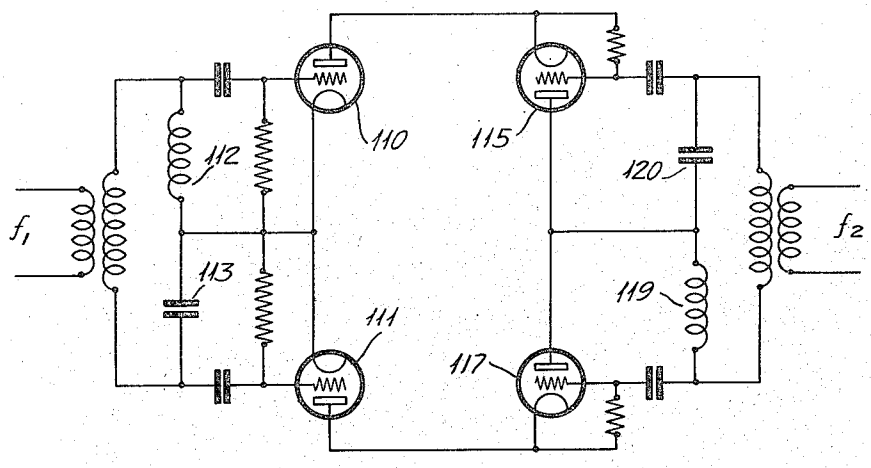


Fig. 4



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ELECTRICAL CONTROL SYSTEM

Filed Sept. 8, 1931 4 Sheets-Sheet 4

Fig. 5

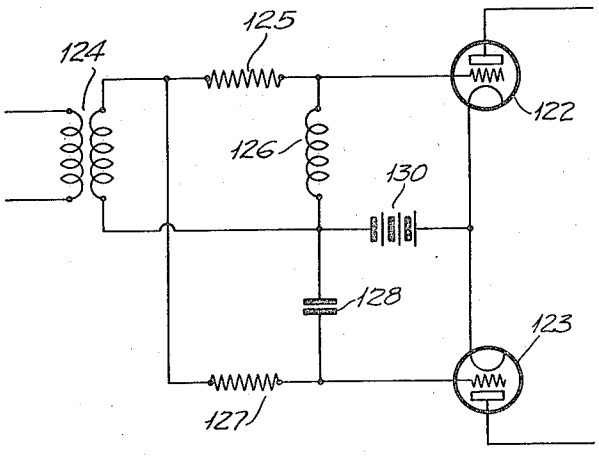
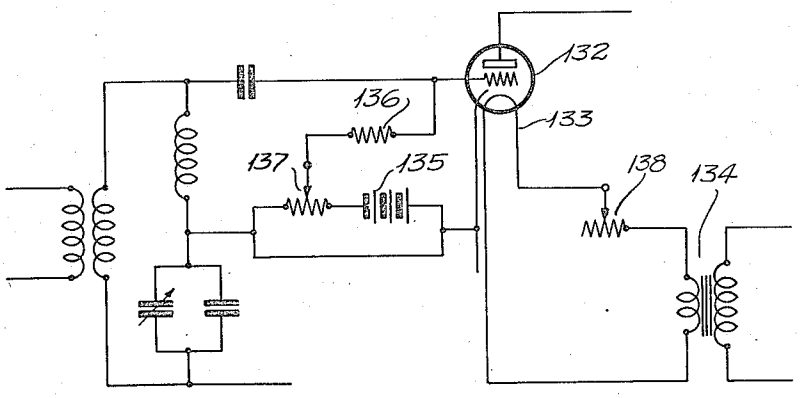


Fig. 6



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UNITED STATES PATENT OFFICE

2,049,712

ELECTRICAL CONTROL SYSTEM

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Application September 8, 1931, Serial No. 561,610

11 Claims. (Cl. 250—36)

This invention relates to control systems and particularly to control systems employed with communication and signalling systems in which high frequency currents are employed.

There are many systems of communication which depend upon the synchronization of certain moving elements either mechanical or electrical for satisfactory operation. A few of the systems of this type are automatic telegraph transmitters and receivers, television systems and radio broadcasting networks. In the case of chain broadcast systems wherein several stations operate on the same frequency carrier current, it is of prime importance that the transmitters at each station be synchronized as to frequency of the broadcast carrier to prevent heterodyning noises which interfere with reception in areas where both stations are effective.

The present invention contemplates controlling the generated currents at certain stations and to cause this generation in accordance with the frequency of the current at a master station. It is to be understood, of course, that this is not the sole use of this invention and that it is applicable to any electrical system wherein it is desired to maintain synchronism between any two elements located in different systems.

An object of this invention is to control the operation of an electrical or mechanical system.

Another object of this invention is to maintain a predetermined relationship between two oscillating or rotating systems.

A further object of the invention is to maintain synchronism between two electrical oscillating systems by automatically varying the generated frequency of one of the systems in accordance with the variation of the other system.

A still further object of this invention is to enable an accurate adjustment to be made of a high frequency oscillating system by the introduction of secondary currents to produce a suitable control current.

Other objects and certain advantages of this invention will be obvious from the following description when read in conjunction with the accompanying drawings in which:

Fig. 1 is a schematic drawing of a control circuit in accordance with one embodiment of the invention.

Fig. 2 is a schematic drawing of another embodiment of the invention illustrating diagrammatically means for controlling a local generating system.

Fig. 3 is a diagrammatic drawing of the general method of controlling a high frequency current; and

Figs. 4, 5, 6, are schematic drawings of modifications of certain features of Figs. 1 and 2.

Referring specifically to Fig. 1, two transmitters 5 and 6, having antennae 7 and 8, respectively, may be two broadcast stations or other generating plants, which are operating on the same carrier frequency. These transmitters or plants, are located at separated positions and may be representative of a plurality of broadcast transmitters, the control output circuits of which are represented in dotted lines to denote their separation. The control apparatus shown in the body portion of the drawings may be located at either one of the transmitters, the signals from the distant transmitter being transmitted thereto by wire or through space. This apparatus may also be located at any intermediate point between the two transmitters, transmission thereto being accomplished as stated above.

The circuit which determines any change in frequency between the transmitters 5 and 6 includes four vacuum tubes 10, 11, 12, and 13, having appropriate electrode energy sources, the supply for the filaments not being shown but which may be either direct or alternating current. The plate potential source 15 is common to all four tubes, tubes 10 and 12 being in series as well as tubes 11 and 13, the two series pairs being in parallel.

Tubes 10 and 11 on the left hand side are in a bridge circuit arrangement with blocking condensers 16 and 17, and grid leaks 18 and 19, respectively. The input of these tubes is through a transformer 20 coupled to the output of the transmitter 5. An inductance 21 and condensers 22 and 23 form a series tuned circuit connected across the input circuits of tubes 10 and 11, the tuning of this circuit being substantially to the frequency of the transmitter 5. This tuned circuit may be adjusted by means of the variable condenser 23.

The common terminal of inductance 21 and the condensers 22 and 23 is connected to the filament of the tubes 10 and 11 so that inductance 21 determines the high frequency voltage on the grid of tube 10 and condensers 22 and 23 determine the high frequency voltage of the grid of tube 11.

A plurality of condensers 25, 26, 27, 28, 29, and 33 are by-pass condensers having a low reactance at the frequencies of the transmitters 5 and 6. The transmitter 6 is coupled to the input circuits of tubes 12 and 13 by a transformer 30. Blocking condensers 32 and 34 are shown connecting the

grids of the tubes 12 and 13 to a second series tuned circuit comprising inductance 36 and condensers 37 and 38. The grid leaks for the tubes 12 and 13 are resistances 40 and 41, respectively.

Similarly to the input for tubes 10 and 11, the inductance 36 determines the high frequency voltage of the grid of tube 12, and condensers 37 and 38 determine the high frequency voltage on tube 13, the tuned circuit 36, 37, 38, being tuned to the frequency of transmitter 6. With the tubes matched and the series circuits above mentioned tuned to the frequency of the respective transmitters, the tube bridge will be balanced with no current flowing in an output circuit including a polarized relay 44. If however, the frequency at either one of the transmitters 5 and 6 varies, an unbalance of the circuit will occur, operating the relay 44. The relay 44 is composed of a permanent magnet 45, armature 46 and coil 43. The direction of flow of current in the coil 43 is determined by the direction of change of the frequency at either transmitter. That is, should the frequency of the current at the transmitter 5 decrease or the frequency of the transmitter 6 increase, the relay will be thrown to one position, while if the frequency of transmitter 5 increases and the frequency of the transmitter 6 decreases, the armature of the relay will be thrown in the opposite direction. The contacts on the relay may control a motor circuit for tuning one of the generators, the temperature of a frequency determining crystal, or any other control arrangement desired for a change of frequency.

The relay 44 may be any type of polarized relay such as a Weston model 30 galvanometer relay, which is similar to a microammeter with its pointer replaced by an arm with associated contacts. This relay only requires a current of 20×10^{-6} amperes to close either contact according to the direction of the current in coil 43. Between these limits the armature assumes an intermediate position.

It is to be noted that by impressing the currents from each station on two tubes in a bridge arrangement such as shown, the bridge balance is practically independent of any fluctuations which may be expected in the supply voltage from transmitters 5 and 6. It is also independent of variations in the plate voltage source 15, or in the filament supply voltage not shown, provided all the filaments or heaters are supplied from a single source. Another advantage of this bridge circuit is the additional sensitivity obtained by the use of four tubes instead of two, the system being capable of operating, however, with two tubes only, but less accurately.

Referring to Fig. 2 a bridge arrangement similar to that shown in Fig. 1 employs vacuum tubes 50, 51, 52 and 53 which have an alternating anode potential supply 82 supplemented by a direct current source 55. Batteries 56, 57, 58 and 59 respectively are the grid biasing sources. The cathode heating supply is not shown but may be from either a direct or alternating source. The input circuit for tubes 50 and 51 includes a transformer 59, the primary of which may be connected to any desired source of frequency to be controlled while the input circuit of tubes 52 and 53 includes a transformer 60, the primary of which is connected to a second frequency source which is to be synchronized with the source connected through transformer 59. Across the secondary of the transformer 59 is a series tuned circuit including inductance 62 and condensers 63 and 64, this circuit being tuned to the input frequency arriving at 59. A similar tuned circuit across the secondary of transformer 60 includes inductance 65 and condensers 66 and 67. Blocking condensers 68 and 69 are shown in the grid circuits of tubes 50 and 51 respectively and similar condensers 70 and 72 are shown in the input circuits of tubes 52 and 53. By-pass condensers 71, 75, 77, 78, 79 and 80, have a low reactance to the currents of the frequencies to be synchronized.

This circuit differs from the one shown in Fig. 1 by having as the anode potential supply, an alternating current source 82 which may comprise the sole source of anode potential for the tubes, the source 55 being employed to bring the system to a better operating point. The by-pass condenser 76 shown shunting source 55 has a low impedance to the current generated at 82, while the other by-pass condensers, namely 71, 75, 77, 78, 79 and 80 have a medium impedance to the frequency of generator 82, but low with respect to that of the sources to be synchronized.

The bridge output is impressed upon an amplifier 84 through input transformer 85 and over a circuit including blocking condenser 86. A circuit paralleling this output circuit includes inductance 87 and resistance 88 providing a direct current path across the tubes 50 to 53 and in which may be inserted any direct current device to be operated in addition to the other apparatus shown. As shown, this shunt path serves as a balancing medium for the plate currents of the tubes.

The output of the amplifier 84 is impressed upon one winding 90 of a two phase motor 91, the other winding 92 of this motor receiving energy through a phase shifter 93 which is connected to the alternating current source 82. Windings 90 and 92 are so wound as to produce a quadrature field for rotating a shaft 94 of the motor. Mounted on the armature 94 is disk 95 adapted to rotate between the poles of a permanent magnet 96 to provide a damping effect on the rotating portions of the motor. At the end of the shaft 94 is a worm and gear combination 97 which rotates a disk 98 within the inductance of a tuned circuit 99, the disk operating to adjust the tuning of the circuit in the well known manner. This tuned circuit may be the frequency determining unit of one of the oscillating generators, but it is to be understood that other means of adjusting the generated frequency at either source may be employed, such as varying the capacity of a condenser by rotating a plate thereof, or by varying the coupling between two coils in the tuning circuit.

The worm and gear combination 97 reduces the speed of the rotor of the motor 91, the rotor being of the squirrel cage or any other suitable type. The disk 98 in the inductance of the tuned circuit 99 may be a copper disk or metallic ring placed so that a rotation of 180° varies its position from a normal or 90° position to the shaft, to a position in which the axis of the ring is coincident with the axis of the coil.

In operating this embodiment of the invention, an unbalance of the vacuum tube bridge in one direction caused by a relative variation in the frequency of one of the sources will produce a flow of current in the winding 90 at 90° lead to that in winding 92 causing the disk 98 to rotate in a direction to increase the inductance of coil 58. When the bridge is unbalanced in the opposite direction, however, the currents in coil 50 will lag those in coil 92 by 90° producing an opposite

motion of the disk 98. It is to be understood that the invention is not limited to cases in which the frequencies to be synchronized are equal, but that it is applicable to systems wherein the frequencies are different, the same percentage change being maintained at each station. It is also adaptable to inverse proportional changes as will be explained hereinafter. In a case where two currents of different frequencies are to be controlled so as to maintain their frequencies proportional to each other, inductance 21 and the capacitances 22 and 23 are tuned to one frequency while inductance 36 and capacitances 37 and 38 are tuned to the other frequency. If the transmitters 5 and 6, respectively, are operating at the frequencies at which the tuned circuits 21, 22, 23 and 36, 37 and 38 are tuned the vacuum tube bridge will be balanced. If however, the frequency of 5 changes by a small percentage the vacuum tube bridge will become unbalanced and will not be balanced again until the frequency of transmitter 6 is changed by the same percentage. Thus it is seen that the operation in this case is analogous to that where the two frequencies are the same.

In Fig. 3 is a diagram of a system for making the bridge circuits above described more sensitive and stable. By introducing another frequency, the bridge is not directly operated with the frequencies of the sources to be controlled but with lower frequencies which vary by much greater percentages than the controlled frequencies. In the diagram, a standard frequency is shown at 100, this frequency being combined with a local low frequency current source 101 in a modulator 102. The side bands produced are passed to filters 103 and 104, which separate the side bands. In other words, the standard frequency f_1 and the local frequency f_3 will arrive at a modulator 105 as f_1+f_3 frequency and at a modulator 106, as f_1-f_3 frequency. These side bands are now combined with the local frequency source 108 which is to be controlled, the results of this modulation being a frequency $f_1+f_3-f_2$ at the output of modulator 105 and a frequency of $f_1-f_3-f_2$ at the output of modulator 106.

As a practical example of the operation of this method, we may assume f_1 to be a current at a frequency of 1000 kilocycles which is in the broadcast carrier range, and the frequency of source 101 to be 1000 cycles or one kilocycle. Then the output of band pass filter 103 is 1001 kilocycles and the output of band pass filter 104 is 999 kilocycles, the percentage change being comparatively small. Now should f_2 be different from f_1 by .7 of a kilocycle so that its frequency is 999.3 kilocycles, then the result of modulation at 105 produces a frequency of 1.7 kilocycle and that at modulator 106 will be .3 of a kilocycle. Since the difference between 1.7 and .3 kilocycles, or 1.4 kilocycles, is large with respect to 1.7 and .3 kilocycles, a very accurate adjustment may be made with small percentage changes in the frequencies to be controlled. With such an arrangement, therefore, the small percentage changes in frequency are amplified at the controlling circuits.

In Fig. 4 a modification of the circuits of Figs. 1 and 2 is shown in which the frequencies are not controlled by direct proportionality but in an inverse relationship. In the input circuits of tubes 110 and 111 is shown a series tuned circuit comprising inductance 112 and capacity 113 while across the input of tubes 115 and 117 is a similar tuned circuit including inductance 119 and capacity 120. The general input arrangement is the same as shown in Figs. 1 and 2 except that the inductance 112 is in the input of tube 110 while the condenser 120 determines the voltage on tube 115 in series with tube 110. There is produced therefore, on tube 110 a voltage which increases with increase in f_1 while that on tube 115 increases with decrease in f_2. Similarly the elements determining the voltages on tubes 111 and 117 are the condenser 113 and inductance 119, providing voltages on these tubes whose relationship to the frequencies is opposite to that of tubes 110 and 115, respectively. The output relationship of this circuit, therefore, will be that

$$f_1=\frac{K}{f_2}$$

so that an increase in frequency of one source will produce a proportional decrease in frequency at the other source.

Fig. 5 shows a modification of the input circuit of the balanced tubes 122 and 123 in which the input transformer 124 is connected across two parallel circuits, one including resistance 125 and inductance 126 and the other resistance 127 and condenser 128. A battery 130 provides a grid bias through resistance 125 for tube 122 and through resistance 127 for tube 123 causing the tubes to function as grid biased detectors in this circuit. By the use of such an input circuit arrangement the impedance looking from the supply line may be made to remain constant during variations in input frequency. This is in contrast to the circuits of Figs. 1, 2 and 4 where the impedances looking from the supply line vary considerably with frequency.

The tubes used in the above embodiments should have the same characteristics. This is not always possible from a practical standpoint, but the circuit of each tube may be adjusted so that the tubes have the same operating characteristics. One method of accomplishing this result is shown in Fig. 6 in which an indirectly heated cathode tube 132 has an alternating current supplied to its heater 133 through transformer 134 and adjusting rheostat 138. The grid biasing circuit for this tube includes a battery 135, resistance 136 and a variable potentiometer 137. By varying the grid potential on the grid of tube 132 and/or the rheostat 138 the output impedance may be adjusted to match the other tubes in the circuit.

The above control circuits for synchronizing two current sources of either like or unlike frequencies, may be employed for other purposes than above set forth, such as the temperature control of crystals and the like, for synchronizing mechanical moving elements for television systems, or for controlling any physical quantities through the medium of frequencies dependent on the physical quantities. It is to be understood however, that these equivalent systems are contemplated to be within the scope of the appended claims.

What is claimed is:

1. In combination, a source of current having a certain frequency, a second source of current having a certain frequency, a plurality of detectors, a tuned circuit interconnecting one of said sources and a certain plurality of said detectors, a tuned circuit interconnecting the other of said sources and the remaining plurality of said detectors, the output of said detectors being impressed on a common circuit and balanced when the frequencies of the currents of said sources are

at a predetermined frequency, said circuits being series tuned to maintain said output currents constant when the voltages of said sources vary, but destroying said balance when the frequencies of either of said sources varies, and means operated by the output of said detectors.

2. In a synchronizing system, a plurality of current sources to be synchronized, a plurality of vacuum tubes connected to one of said sources, a second plurality of vacuum tubes connected to the other of said sources, a common output circuit for all of said vacuum tubes, a tuned circuit positioned between each of said vacuum tubes and said sources, each of said circuits being series tuned for determining the voltage impressed upon its respective tube so that variations in voltage in either of said sources does not change the output current from said tubes, while variations in frequency varies the voltage of the tubes connected to one of said sources and thereby changes the output current of said tubes, and means for utilizing the output current of said tubes for controlling the frequency of the generated current at one of said sources.

3. In a control system for maintaining a source of alternating current at a constant frequency, a plurality of detectors the space path of one detector being arranged in each of the four arms of a quadrilateral bridge circuit, a series tuned circuit connected to the input of each of a pair of said detectors, said tuned circuit being connected to said source of alternating current, a second source of current having a certain frequency, a series tuned circuit connected to the input of each of said other pair of detectors and to said second source of current, the tuned circuits of each of said detectors being adjusted to provide definite current outputs when the current of said first source is at a predetermined frequency, means for combining the output of all of said detectors in a common circuit, and a device operative from the output current of said bridge for adjusting one of said alternating current sources when the frequency thereof tends to vary.

4. In a control system for maintaining a source of alternating current at a constant frequency comprising a quadrilateral bridge circuit including the space path of a detecting vacuum tube in each arm thereof, means for impressing said alternating currents on the input of a pair of said tubes, a second source of current, means for impressing the current from said second source on the input of the other pair of said tubes in said bridge circuit, a series tuned circuit forming the input of each pair of tubes and their respective source of current, said tuned circuits being adjusted to impress on each pair of tubes connected to each source equal voltages when the frequency of said first source is at a predetermined value and different voltages on the inputs of said tubes when the frequency of said current tends to vary, and means connected in said bridge circuit for varying the frequency of said first source when the frequency thereof tends to vary.

5. In a frequency control system, two current sources having different frequencies, a detector circuit forming a quadrilateral bridge having a detector in each arm thereof, a pair of said detectors having their anodes connected together and their inputs connected together by a series tuned circuit for detecting the current impressed thereon from one of said sources, a second pair of said detectors having their cathodes connected together and their inputs connected together by a series tuned circuit for detecting the current impressed thereon from the other of said sources, a common output circuit for said detectors, and means operated by the unbalanced current caused by a frequency variation in the current of either of said sources for restoring at least one of said frequency sources to its proper frequency relation with respect to the other.

6. In a system for synchronizing the frequencies of two current sources, a pair of tubes having their cathodes connected together, a second pair of tubes having their anodes connected together, the anode of each tube of said first pair being connected to the cathode of one tube of said second pair of tubes, a source of current connected between the cathodes of said first pair of tubes and the anodes of said second pair of tubes, a series tuned circuit connected between the grids of said first pair of tubes, a second series tuned circuit connected between the grids of the second pair of tubes, and means for impressing each current from each of said sources on a respective tuned circuit.

7. In a system for synchronizing a plurality of alternating current sources, a bridge circuit having the output circuit of a vacuum tube in each arm, a series circuit tuned substantially to the frequency of one of said sources connected between the control electrodes of a pair of said tubes, said tubes having their cathodes connected together, a second series circuit tuned substantially to the frequency of another of said sources connected between the control electrodes of a second pair of said tubes, said tubes having their anodes connected together, the anode of each tube of said first pair being connected to the cathode of one tube of said second pair, means for impressing the output of each of said sources on one of said series tuned circuits, respectively, and means for utilizing the output current of said bridge to control the difference in frequency between said sources.

8. In combination, a source of current having a certain frequency, a second source of current having a certain frequency, a plurality of vacuum tubes, means for connecting a pair of tubes to each of said current sources, means in the input circuit of each of said tubes for dividing the input voltages equally between the tubes of each pair when the voltages of said currents are equal and the frequencies of said currents are in synchronism, said means further dividing the voltages of said currents equally when the voltages of said currents vary, but varying the voltages on said pair of tubes when the frequencies vary, and means for combining the output currents to said tubes for controlling the frequency of the current of at least one of said sources.

9. In combination, a source of current having a certain frequency, a second source of current having a certain frequency, two pairs of vacuum tubes, one pair being connected to each of said frequency sources for detecting said current sources, a common output circuit for said pairs of tubes, and means in the input circuits in each of said pairs for separating the voltage on the tubes of each pair in accordance with the frequency of said sources, said voltage separation increasing with increasing frequency separation.

10. In a frequency control system, a source of current having a certain frequency, a second source of current having a certain frequency, a bridge circuit including two pairs of vacuum tubes, one pair having their cathodes connected

together and the other pair having their anodes connected together, both pairs having series tuned input circuits, means for energizing the anode of one tube of each pair in series with the cathode of one tube of the other pair, means for impressing the output of one of said sources on the input circuits of one pair of said vacuum tubes, means for impressing the output of said second source on the input circuits of the other pair of said vacuum tubes, and a work circuit connected to said bridge circuit, said work circuit including means for varying the frequency of the current of one of said sources in an inverse relationship to the change in frequency of said other source.

11. In a synchronizing system for controlling the frequency of generation of a source of electrical currents, a bridge arrangement including the space path of a vacuum tube in each arm thereof, a pair of said tubes having their cathodes connected together and a second pair of said tubes having their anodes connected together, the anode of each tube of said first pair being connected to the cathode of one tube of said second pair, a series tuned circuit connected to the input of a pair of said tubes for varying the voltages thereon during a shift in the frequency of the current from said source, said circuit being tuned substantially to the frequency impressed thereon, means for connecting the other pair of said vacuum tubes to a second source of current, and means for utilizing the unbalanced current produced by a frequency shift of one of said sources for adjusting the frequency of one of said sources.

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