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ELECTRIC CIRCUITS FOR EMPLOYING CAPACITATIVE CURRENTS

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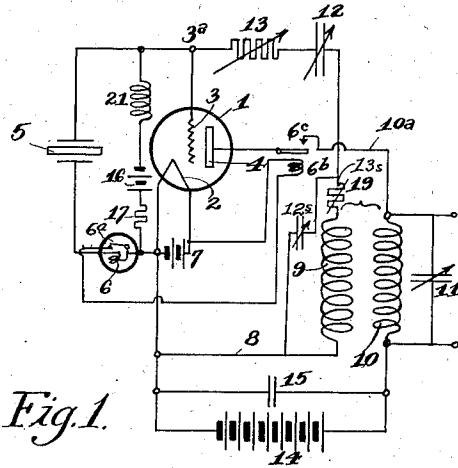


Fig. 1.

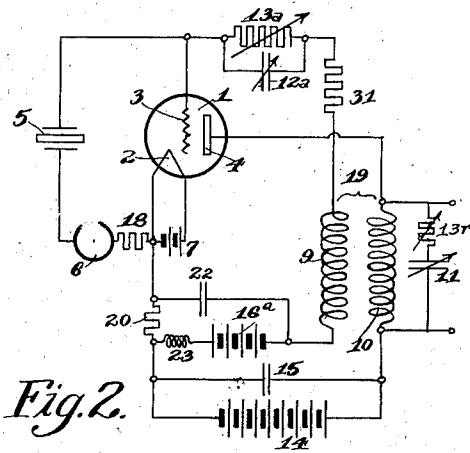


Fig. 2.

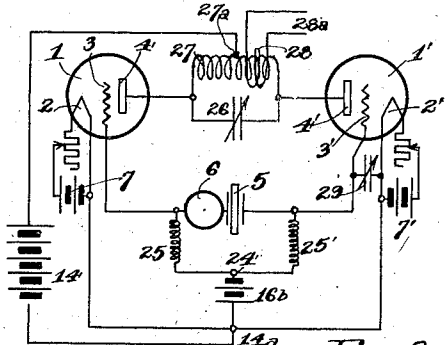


Fig. 3.

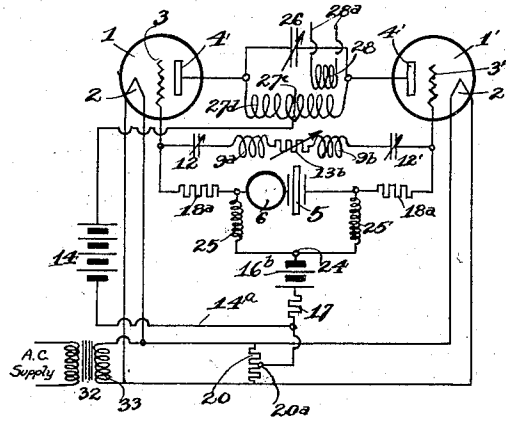


Fig. 4.

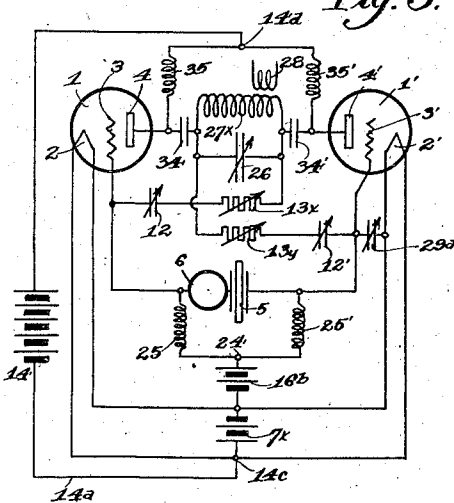


Fig. 5.

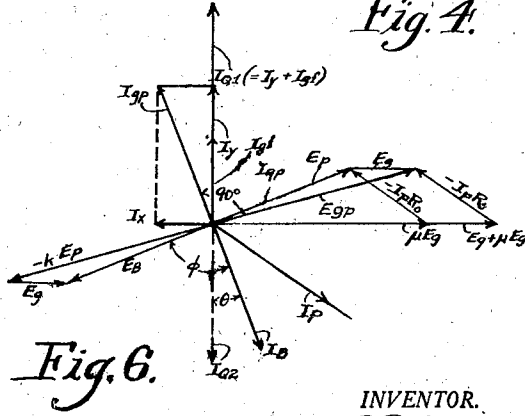


Fig. 6.

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ELECTRIC CIRCUITS FOR EMPLOYING
CAPACITATIVE CURRENTS

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9 Claims. (Cl. 250—36)

This invention relates to improvements in electrical circuits involving the employment of capacitative currents, and more particularly concerns circuits for electron discharge tubes in which a relatively weak capacitative current may be employed for controlling the operation of an electron discharge tube requiring a greater current application to its control element for its controlled operation.

An illustrative form of employment of such circuits is with piezo-electric elements intended to control the frequency of oscillations generated by electron discharge tubes. Other instances of such employment are with resistively coupled radio frequency amplifiers and with microphone modulation circuits.

One object of the present invention is to provide means for obtaining a greater output from an electron discharge tube, controlled by the means passing the weak capacitative current, than has heretofore been accomplished without the employment of succeeding steps of amplification.

Another object of the invention is to provide a novel circuit arrangement whereby the capacitative current is caused to act symmetrically and reciprocally upon a pair of electron discharge tubes connected in what might be called "a push-pull" arrangement, and wherein each tube operates at a greater power output than can be controlled by the weak capacitative current involved.

Still another object of the invention is to provide a circuit arrangement in which a pair of electron discharge tubes may be employed and in which the connection to these tubes for current of useful output frequency shall be symmetrical with respect to ground or cathode potentials or shall provide a substantial approximation to this condition.

A further object of this invention when employed with piezo-electric elements for controlling the frequency of electron discharge tubes, is the provision of means whereby the mechanical vibrations in a piezo-electric element may be sustained by the power component of electric oscillations occurring in the electron discharge tube circuits while a quadrature current component from such circuits is employed to limit and reduce the quadrature current passing through the piezo-electric elements.

A further object of the invention is to provide a circuit arrangement of electron discharge tube generators with the employment of a piezo-electric element to control the frequency of the generated oscillations and the provision of stabi-

lizing or limiting devices separate from the electron discharge tube for governing the amplitude of the generated oscillations so that large electron discharge tubes may be operated at normal or higher than normal anode potential, such tubes being larger than have heretofore been competent to direct control by piezo-electric means.

In the accompanying drawing:—

Figure 1 shows a simple circuit including an electron discharge tube with oscillatory circuits and a piezo-electric control element, along with the operator of the present invention.

Fig. 2 is a view of a modified circuit using a single electron discharge tube and modified type of control means.

Fig. 3 is a diagram showing two electron discharge tubes mounted symmetrically with respect to a single piezo-electric element.

Fig. 4 is a modified form of circuit employing two tubes mounted symmetrically with respect to the piezo-electric element.

Fig. 5 is a further modified form showing the use of two electron discharge tubes with a single piezo-electric element.

Fig. 6 is a vector diagram conventionally explaining the operation of a single circuit such as that in Fig. 1.

Considered broadly, it is proposed according to this invention to provide circuits involving at least one electron discharge tube having anode, cathode and grid electrodes, in conjunction with a relatively weak source of capacitative current, i. e. a current of such nature that it may flow through a condenser under the conditions of operation and in which the intensity of current usually leads the potential or voltage. According to this invention, means are provided whereby a control E. M. F. is applied to the grid portion of the tube system. Such means likewise is connected to derive excitation from the output circuit or circuits of the tubes and by the action of suitable phase shifting elements to deliver a current to the aforesaid grid system in substantial quadrature with the control E. M. F. This quadrature current is brought by the phase shifting elements into such quadrant or angular relationship and electrical vector magnitude that its value will be subtracted from the quadrature current which would otherwise have to be supplied by the source providing the control voltage. Thus, the E. M. F. source is relieved of a greater or lesser part of the quadrature current load which it would otherwise be obliged to carry, making possible the control of the operation of the entire system by a much weaker source of

control voltage. At the same time, any power component of current flowing in said means toward the grid system is so reduced that it does not operate upon the grid to determine the operation of the circuit.

In the form set forth in the drawing, such a circuit arrangement has been illustrated in conjunction with the employment of a piezo-electric element for controlling the operation of a generating tube system. In this invention, it is proposed to employ the piezo-electric element in conjunction with one or more discharge tubes having control and output circuits so that the control and output circuits are coupled for the generation of sustained oscillations. It is further proposed to segregate the in-phase and quadrature components of currents flowing in the associated circuits so that the in-phase or power component is employed to maintain the piezo-electric element in oscillation while requiring relatively little quadrature current to pass through this element, a parallel path carrying the major portion thereof to maintain the necessary grid charging current to keep the discharge tube in oscillation, and to provide a useful output therefrom. The quadrature component is employed to regulate the effective potential in the control circuit.

In the drawing, Fig. 1 shows an electron discharge tube 1 of the three electrode type including a cathode 2, grid 3, and anode 4. The piezo-electric element 5 in practice is usually a plate cut from a quartz crystal and mounted between conductor plates. The frequency control or piezo input circuit extends from the cathode 2 through an indicator 6 which may be an alternating current milliammeter to indicate qualitatively the load carried by the piezo-electric element 5, through the piezo-electric element 5 to the tap 3a and thence to the grid 3. The quadrature feedback circuit extends from the cathode 2 by conductor 8 and the secondary coil 9 to the high frequency transformer 19 to condenser 12, and thence through resistance 13 to tap 3 and to the grid 3. In this figure also, the secondary coil 9 is shown to be connected in series with a variable resistance 13s, and a loop comprising the coil 9, resistance 13s, and a variable condenser 12s is connected between the grid 3 and cathode 2 of the electron discharge tube 1, in series with the condenser 12 and resistance 13. This figure likewise shows the indicator device 6 as including a coil energized by the current flowing to the piezo-electric element 5, so that when the radio-frequency components of this current become excessive, and upon the flow of direct current as when a breakdown of the system may occur, the coil would operate to close the contacts 6a and establish a circuit including the coil 6b of a relay having its contacts 6c in the anode circuit of the tube 1.

The anode or output circuit of the tube 1 extends from the cathode 2 through anode or plate battery 14 which is shunted by a high frequency bypass condenser 15 to the parallel loop circuit comprising the primary 10 of high frequency transformer 15 and tuning condenser 11, by conductor 10a to the anode 4. Space paths through the electron discharge tube 1 exist from the cathode 2 to the grid 3 and plate 4 and from the grid 3 to the plate 4.

In actual values, the coupling between coils 9 and 10 was relatively the same as in the well-known neutrodyne circuits. The capacity of condenser 12 is larger than is required for bal-

ancing a neutrodyne arrangement. In a particular case, the condenser 12 had a capacity of approximately 0.00005 mf. when the circuit was adjusted for operation. It might be indicated that with the same circuit the neutrodyne balance adjustment required a capacity for the condenser 12 of about 0.00002 mf. The impedance 13 employed was a commercial compression type rheostat having a resistance which could be varied from 100 to 5,000,000 ohms; and which was adjusted at such an intermediate point that it operated as a phase adjusting device. The operation of the circuit according to Fig. 1 may be described as follows:—

With the device adjusted in operating condition for a given frequency, any momentary impulse will cause the generation of oscillations in the output circuit through coil 10 in the usual manner, with a quadrature feed-back to coil 9 in the input circuits. The alternating current potential produced in the coil 9 and applied in series with the series connected assemblage of coil 9, condenser 12 and impedance 13, may be considered as producing currents across three paths, (1) the space path of the discharge tube 1 between cathode 2 and grid 3; (2) the piezo-electric element 5 in series with the load indicator 6; and (3) a shunt bias circuit comprising the resistance 17, biasing battery 16 and choke coil 21.

The current passing through the piezo-electric element 5 may be considered as resolvable into two components: (a) a power component derived from the anode circuit of tube 1 by coupling between the grid 3 and anode 4 of the tube 1; and (b) a quadrature component originating within the piezo-electric element 5 and employed in whole or in part to charge the capacity from the grid and grid leads to the filament and anode. In practice, it has been found that the quadrature current that may be drawn from a piezo-electric element 5 must be limited to a rather small value in order to avoid the rupture of the particular crystal, and that such a small value is not sufficient to adequately excite the grid of a discharge tube of large power rating; the present invention proposes to permit a portion of this quadrature current to be supplied to the grids and connections without passing through the element 5.

The normal phase relationship of the E. M. F. across the coil 10 will cause power to be fed from the anode to the grid through the internal capacity between the grid 3 and anode 4 in the tube; and obviously an E. M. F. of opposite phase supplied across the condenser 12 would result in power being drawn from the grid circuit through this condenser. This tendency for power to pass in this direction is to be reduced so that no interference will be presented to the maintenance of oscillations in the piezo-electric element. This reduction of the power passing through the capacity 12, resistance 13, coil 9 and conductor 8 is produced by the employment of the phase shifting impedance 13, which is roughly of a non-reactive nature.

If for any reason the flow of current to the piezo-electric element 5 becomes excessive, then this fact will be made known by the indicator 6; and further in the particular form described in conjunction with Fig. 1, a circuit will be closed from the filament heating battery 7 through the contacts 6a of the indicator 6, the coil 6b of the anode relay, and back to the battery 7. This coil

The operation of this circuit is substantially the same as before, and it will particularly be noted that the phase shifting device 13b has the same function here as the phase shifting devices 13, 13a described above; and the regulating impedances 18a, 18a may be of the same character as the regulating impedance 18 described in respect of Fig. 2 and serves to prevent more than a predetermined maximum current from flowing through the piezo-electric element 5.

A further development of the present invention is shown in Fig. 5, in which the respective discharge tubes 1, 1' are heated by a common filament battery 1x. The tubes are symmetrically arranged as before, and the direct current anode component circuit of either tube may be traced, for example, between cathode 2 by one cathode conductor to the symmetrical tap 14c and thence by a conductor 14a and common space current battery 14 to a symmetrical tap 14d between the high frequency choke coils 35, 35' through the respective choke coil as 35 to the anode 4. The anodes 4, 4' are directly connected through the blocking condenser 34, the output parallel resonance circuit comprising the coil 27x and condenser 26, the blocking condenser 34' to the anode 4'. A shunt path, whereby to bypass a part of the quadrature current component (required for charging the grids) around the piezo-electric element 5, is provided through the parallel resonance elements 26, 27x by connecting the terminals of these elements through respective phase shifting impedances 13x and 13y and the balancing condensers 12, 12' to the respective grids 3, 3' of the tubes 1, 1'. As before, a final balancing condenser 29a is preferably connected between the cathode and grid of one tube. The output inductance 27x is coupled to the output coil 28 as before. The piezo-electric control circuit for the grids is connected directly between these and comprises the indicator 6 and the piezo-electric element 5 in series. The individual grids are afforded proper bias by being connected in circuits, for example, from the cathode 2 through the heating conductors and the common grid biasing battery 16b to a symmetrical tap connection 24 and thence by the respective high frequency choke coil 25, to the respective grid 3.

A method of calculating the dimensions of the respective parts, and of indicating the operation of an apparatus according to this invention, is shown by the vector diagram of Fig. 6, which is based upon the equivalent circuit operation of a distortionless amplifier. Corrections for a particular device operating with distortion similarly may be computed, by taking into account the dimensions of the distortions. This vector diagram is a qualitative indication of the nature of operation of the circuit. The controlled E. M. F., which is applied between the grid and the cathode, is taken as the reference vector and marked μE_g . μE_g is then the fictitious E. M. F. which, if acting within the tube in series with the anode-cathode path, through the electron stream, would produce the alternating current component found to exist as a result of the application of the control E. M. F. The amplification factor μ of the tube, under the conditions of operation, is a constant, and hence this reference vector is in phase with the control E. M. F.

I_p is the alternating current carried by the electron stream between anode and cathode, and is shown as lagging behind the control E. M. F. since this is the necessary condition for transfer of energy from the anode to the grid through the

inherent capacity therebetween, this transfer being in turn necessary for the operation of the type of piezo-electrically controlled oscillator commonly used. This transfer of energy is also relied upon for the maintenance of oscillations of the piezo-electric element in all of the circuits shown herein. $I_p R_o$ is the particular IR drop that occurs within the tube due to the passage of the alternating current component carried by the electron stream. R_o is commonly referred to as the internal impedance of the tube, and is of the nature of a pure resistance. The voltage across the capacity existing between anode and grid may be obtained by subtracting $I_p R_o$ from $E_g + \mu E_g$, that is, $(1 + \mu) E_g$. The vector result is shown as E_{gp} on the diagram. The current through this capacity leads the voltage across it by 90° , and is indicated by the vector I_{gp} on the diagram: it is also shown as resolved into two components, I_x and I_y , which are respectively in line with and at right angles to the control E. M. F. E_g ; of these components I_x is the power component of current and represents power transferred from the anode to the grid and used to maintain the piezo-electric element in oscillation, and to overcome any other power losses associated with the flow of the alternating current in the elements associated with the grid circuit, while I_y is the component of the current I_{gp} which is at 90° from the control E. M. F., and represents a quadrature or wattless component required to charge the grid-anode capacities. These charging currents necessarily complete their path by returning in some manner to the cathode. I_{gr} is another quadrature component of grid current which represents all of the charging current required to charge capacities between grid and anode except the aforementioned I_y which goes to the cathode by way of the anode. $I_y + I_{gr}$ then gives the total quadrature current which must be supplied to the grid by some means in order that its voltage may be E_g . This sum is marked I_{q1} on the diagram.

Since one of the objects of this invention is to provide means which will relieve a piezo-electric element, used for the determination of the frequency of the E. M. F. E_g , of a portion or all of the quadrature load represented by I_{q1} , means are provided including a phase reversing device shown as a simple transformer or autotransformer, and including a tunable element. This transformer is caused to function by the voltage E_p from anode to cathode, which may be found on the diagram by subtracting $I_p R_o$ from μE_g , this voltage being represented by the vector E_p on the diagram. The result of reversing this E. M. F., utilizing an ideal means, would be $-kE_p$, where k is some constant employed to show that the means may change the amplitude of the E. M. F. at the same time that it reverses it. This E. M. F., $-kE_p$, is for example, the one which acts in coil 9 of Figs. 1 and 2 due to transformer action from the coil 10, across which E_p exists. The total alternating current component of E. M. F. acting on the portion of the circuit through the conductor 8, coil 9 and elements 12 and 13 is the vector sum of $-kE_p$ and E_g , and is shown on the diagram as E_B . The current which will flow through this portion of the circuit is shown as I_B , leading E_B by the angle ϕ . In the above ideal case, if the resistive element 13 is reduced to zero, the angle ϕ will be 90° and, as explained elsewhere, I_B will have a component (opposite to I_x) which will abstract power from the grid circuit. For the operation of the circuits here disclosed, this power

6b will operate to open the contacts 6c in the anode circuit. This effect will occur whether the actuation of the contacts 6a is produced by an excessive flow of radio frequency current components through the piezo-electric device 5, or if a direct current should flow as by a break-down or short circuit in some part of the system; thus providing a safety device to prevent overloading of the piezo-electric element 5.

In Fig. 2 the elements are substantially the same as set forth with respect to Fig. 1, except that a resistance 31 is provided in series with the secondary coil 9 of the high frequency transformer 19, and with a loop circuit comprising the condenser 12a and impedance 12 and 13a. In this case also, a resistance 13r is shown as connected in series with the variable condenser 11 in parallel to the primary coil 10 of the transformer 19, as a further means for controlling the phase shift. The bias battery 16a is here connected likewise in series with the coil 9 and with a small high frequency choke coil 23; while the biasing battery 16a, choke coil 23 and impedance 20 are shunted by a high frequency bypass condenser 22. The output circuit from the cathode 2 extends through the impedance 20 in series with the plate battery 14, while the frequency controlling input circuit including the piezo-electric element 5 and the indicator 6 passes through an impedance 18: the impedances 18 and 20 being of substantially non-reactive nature. The impedance 18 to be effective must have a resistance which in the neighborhood of desired current through the piezo-electric element 5 will increase rapidly with increase of current whereby to limit the maximum current which may be passed through the piezo-electric element 5. One such means is an iron wire ballast resistor which may have a value of several hundred ohms when the current through the piezo-electric element 5 is normal, but rising abruptly to a very high value as the current through the piezo-electric element 5 exceeds a predetermined maximum permissive value. The impedance 20 is preferably of the same nature as the impedance 18 but will give some limiting action by change of grid bias, even if its resistance is constant, and in a practical example this resistance was a constant one of approximately one thousand ohms. The impedance 13a was of such character that direct current could pass through it, so that this path is employed to supply the desired direct current operating bias to the grid 3 of the tube; as before, a resistance which here could be varied between 200 and 5000 ohms, was employed, to accomplish the phase adjustment of the current through the coil 9. The operation of this device was in effect the same as that described for Fig. 1.

Fig. 3 is a modification of the device in which two electron discharge tubes are employed as generators of alternating current with a frequency control by a single piezo-electric element. The tubes 1, 1' having the cathodes 2, 2', grids 3, 3' and anodes 4, 4' are supplied with heat-current for the filamentary cathodes by the batteries 7, 7' and with space current from a common battery 14. The anode circuit of either tube may be traced, for example, from the cathode 2 to a symmetric central tap 14a, thence through the space battery 14 to a central tap 27a on an output inductance coil 27, back to the anode 4: the respective anodes 4, 4' being connected to opposite ends of the output coil 27,

which in turn is shunted by a tuning condenser 26 and delivers an output of current through a coupled coil 28 to the output connection 28a. The grid bias circuits of the tubes are symmetrical and have parts in common and may be traced, for example, from the cathode 2 to the common tap 14a, thence by a common grid biasing battery 16b to a common tap connection 24, the respective choke coil 25 and thence to the respective grid 3. The piezo-electric element 5 is again connected in series with the indicating device 6 and the two are connected directly between the two grids 3, 3'. For controlling and balancing the circuit, it is found desirable to employ a small condenser 29 connected between the grid and filament of one of the tubes.

The operation of the device of Fig. 3 is as follows:—

The piezo-electric element 5 is located in a circuit which may be traced from anode 4 through parallel loop 27—26 to anode 4', grid 3', piezo-electric element 5, indicating device 6, back to grid 3 and anode 4. The piezo-electric element 5, therefore, acts to reduce the effect at the grid 3 at the same time that it acts to increase the effect at the grid 3': so that, in effect, the same current is employed at the two grids, and hence the total effect is twice as great in the production of amplitude of oscillation in the parallel resonance circuit 26, 27 between anode 4 and anode 4'.

In the circuit shown in Fig. 4, an alternating current supply is connected to the low frequency transformer 32 having a secondary coil 33 to deliver alternating current to the cathodes 2, 2' of the tubes 1, 1'. A point of symmetry between the cathode heating conductors is established by a resistance 20 connected across the same with a central tap 20a. The anode circuit of either tube may be traced as follows: from the cathode 2, for example, by the heating conductors in parallel to the shunting resistance 20 and the symmetrical tap 20a of the same to conductor 14a, through the space current battery 14 to the central tap 27c of the output inductance coil 27d and thence through half of this coil 27d to the anode 4. It will be noted that as with Fig. 3, a direct connection exists between anode 4 across the parallel loop circuit comprising the two sections of the coil 27d and the condenser 26 to the other anode 4': and as before a coil 28 is coupled to the coil 27d to obtain an effective output by conductors 28a. The grid biasing circuit of either tube may be traced, for example, from the cathode 2 by the heating conductors in parallel to the symmetrical tap 20a on the resistance 20 and thence by the common leak resistance 17, and common biasing battery 16b, the respective high frequency choke coil 25, respective impedance 18a, to the grid 3. The piezo-electric element 5 and indicating device 6 are here connected in series in a circuit extending from the grid 3 of one discharge tube through the impedance 18a of the respective grid circuit, the indicating device 6 (which may operate an anode circuit relay as in Fig. 1), the piezo-electric element 5, the impedance 18a of the other discharge tube, the grid 3' of this other tube 1', and back through the space paths of the tubes and by the cathode heating conductors of these tubes. A direct shunt connection between the two grids 3, 3' also exists across the balancing resistance 13b between these sections, all in series, to establish an external circuit connection between the anode and the grid circuits.

component must be so reduced that it does not determine the operation of the circuit. This reduction of the power components of I_B may be accomplished by any means which shifts I_B clockwise in the vector diagram of Fig. 6 without materially disturbing other operations of the circuit. It may be accomplished by causing E_B to shift clockwise, or by reducing the angle ϕ . The first of these may be accomplished by change of the resistance in the primary circuit of the coupling element, such as the transformer 19 in Fig. 1, and since in practice there is always some resistance present in these windings, a certain amount of this shift is obtained due to the inherent characteristic of circuit elements. Experience indicates that the magnitude of this shift, however, is small so that the angle θ is reduced approximately to zero due to this only with other circuit adjustments closely approaching a condition of instability where the generated frequency abruptly changes to some value different from that normally maintained by the piezo-electric element. It is therefore usually preferred to locate the means employed to cause the angle θ to approximate or equal zero in the secondary circuit at a point such as indicated by element 13 in Fig. 1. At the same time that phase adjustments of I_B are made, the impedance of the elements 12 and 13, or the magnitude of $-kE_p$, or both, should be so adjusted that the magnitude of I_B will be equal to, or preferably slightly less than that of I_{q1} . When so adjusted, I_B lies in the direction of I_{q2} on the diagram. I_{q2} is preferably slightly smaller than I_{q1} because the apparent input impedance of the grid circuit of the tube increases rapidly as the total quadrature component approaches zero, with the result that the frequency of the crystal may be forced, to an undesirable extent, to depart from its normal frequency for free oscillation.

It will be understood that this vector diagram is employed to indicate the vector relationships of the electric quantities and dimensions, and that the operation of other circuits employing this invention may be predicted and computed in a corresponding manner.

It is obvious that the invention is not limited to the forms of execution shown, but that it may be practiced in many ways within the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent is:—

1. In a piezo-electrically controlled apparatus, a piezo-electrically responsive element, two electron discharge tubes each having cathode, anode and grid electrodes, an anode conductor connecting said anodes and including branch portions respectively containing inductance and capacitance to form a parallel resonant circuit, a first grid conductor including in series said piezo-electric element and connecting said grids, a second grid conductor establishing a shunt around said piezo-electric element and including a coil in inductive relation with said inductance, a third grid conductor in shunt of said piezo-electric element and including inductance, an anode connection between a midpoint of said first inductance and a midpoint of said third grid shunt conductor inductance, and a cathode connection between said midpoint of said third grid shunt conductor and the cathodes.

2. An electrical apparatus comprising a piezo-electrically controlled element, two electron discharge tubes each having anode, cathode and grid electrodes, a conductor including said piezo-electric

element for connecting said grids, a conductor including an inductance and a condenser in parallel for connecting said anodes, a conductor for connecting said cathodes, individual conductors for connecting the grid of a said tube to the anode inductance terminal remote from the anode of said tube and each including a resistance and a condenser, a second conductor including inductance in shunt of said piezo-electric element, a source of current connected to tap connections on said anode inductance and said second conductor inductance, and output means actuated by the current flowing between said anodes.

3. An electrical apparatus comprising a piezo-electrically responsive element, two electron discharge tubes each having anode, cathode and grid electrodes, a conductor including said piezo-electric element for connecting said grids, a conductor including an inductance and a condenser in parallel for connecting said anodes, a conductor for connecting said grids in shunt of said piezo-electric element and including in series a further inductance in inductive relation to said anode inductance, a resistance and a condenser, a further conductor including inductance in shunt of said piezo-electric element, a source of current connected to tap connections on said anode inductance and said further conductor inductance, and output means actuated by the current flowing between said electrodes.

4. An electrical apparatus including elements for providing interconnected first and second sources of alternating current of the same frequency but differing in phase, and a common load of low power factor at such frequency, said first source having a high impedance and adapted to pass only a low current intensity at such frequency; said elements including means for energizing said sources, means for maintaining said second source at the same frequency as said first source so that said second source operates as a relay for said first source, and also means for connecting said sources in multiple to said load and supplying to said load from said second source a current component substantially in quadrature to the output voltage of the said first source to relieve said first source at least in part from the delivery of quadrature current to said load.

5. An electrical circuit comprising an electron discharge tube having anode, cathode and control elements, means for connecting said elements to provide input and output circuits, a device of high impedance and low current capacity for delivering electric oscillations, means for connecting said device to the input circuit so that the tube operates as a relay for said device, and means energized by said output circuit for supplying a current component substantially in quadrature to the potential drop between the control and cathode elements to said connecting means so that the device is relieved at least in part of delivering quadrature current to said input circuit.

6. An electrical circuit comprising an electron discharge tube having anode, cathode and control elements, means for connecting said elements to provide input and output circuits, a device of high impedance and low current capacity for delivering electric oscillations, means for connecting said device to the input circuit so that the tube operates as a relay for said device, and means energized by said output circuit for supplying to the connecting means between the device and control element, a current component

substantially in phase opposition to the current flowing between the grid and cathode elements.

7. An electrical circuit comprising an electron discharge tube having anode, cathode and control elements, means for connecting said elements to provide input and output circuits, a device of high impedance and low current capacity for delivering electric oscillations, means for connecting said device to the input circuit so that the tube operates as a relay for said device, and means energized by said output circuit for supplying current to said device for maintaining the same in oscillation, and to the connecting means between the device and control element a current component substantially in quadrature to the potential drop between the control and cathode elements so that the device is relieved at least in part of delivering quadrature current to said input circuit.
8. An electron discharge tube relay apparatus comprising an electron discharge tube having input and output circuits, the input circuit in-

cluding a device having lower current capacity than the remainder of the input circuit, a phase reversing device supplied from said output circuit, and circuit means connected to said phase reversing device and said input circuit for feeding current to said input circuit in opposition to the quadrature current flowing from said input device and including means for producing a further phase shift thereof to substantially quadrature relation to the input voltage.

9. An electron discharge tube relay apparatus comprising an electron discharge tube having input and output circuits, the input circuit being connected for imposing an input voltage on said tube and including a device having lower current capacity than the remainder of the input circuit, a phase reversing device supplied from said output circuit, and circuit means supplied from said phase reversing device for feeding said input circuit with current having substantially a quadrature lag with relation to the input voltage.

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