Aug. 3, 1948. K. RATH 2,446,390

POTENTIOMETRIC AMPLIFIER

Filed Sept. 28, 1943 2 Sheets-Sheet 1

Fig. 1

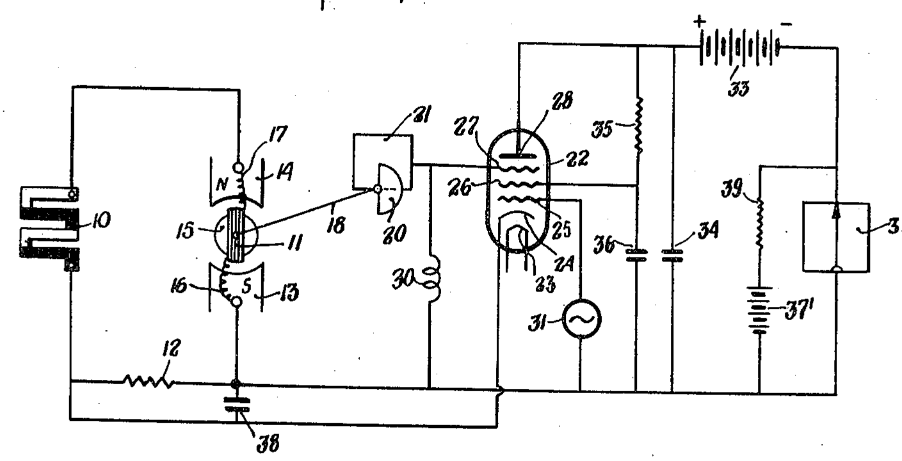


Fig. 2

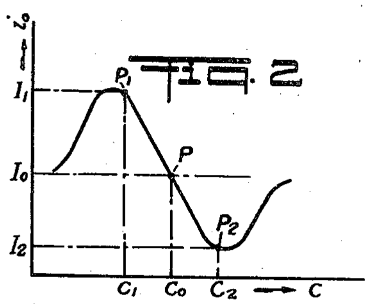
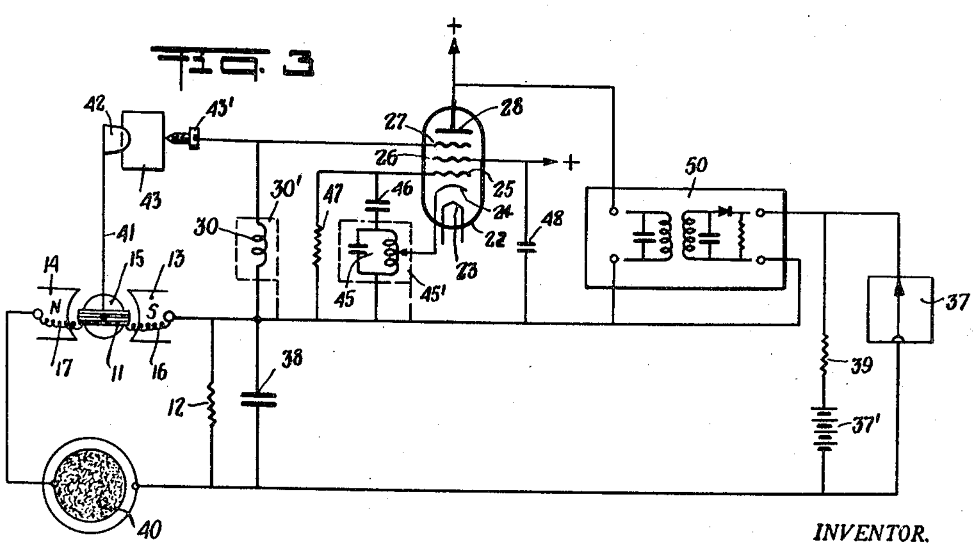


Fig. 3



INVENTOR.

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K. RATH

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2 Sheets-Sheet 2

Fig. 4

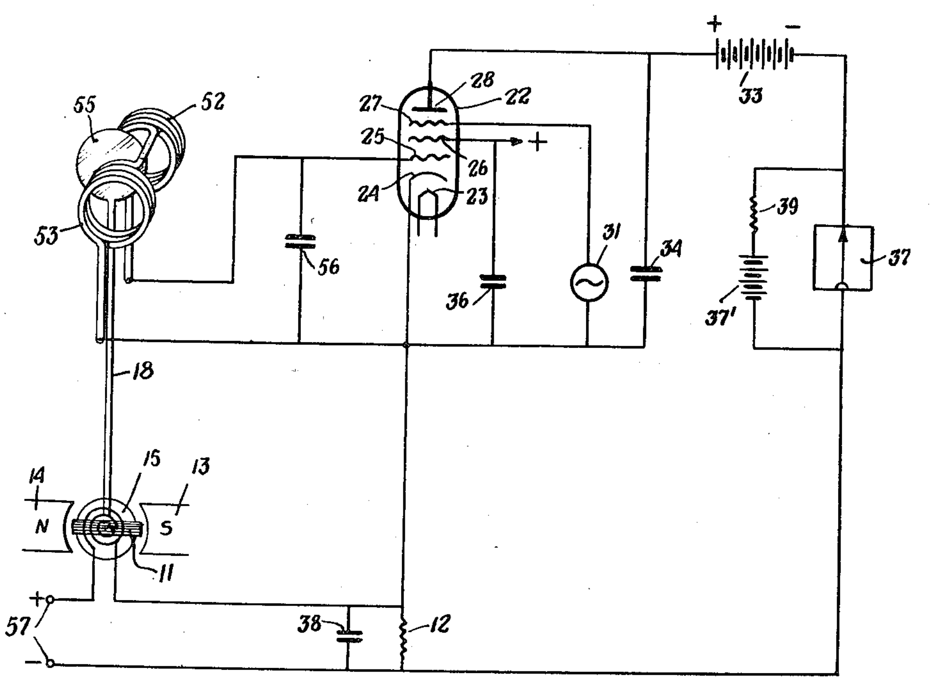
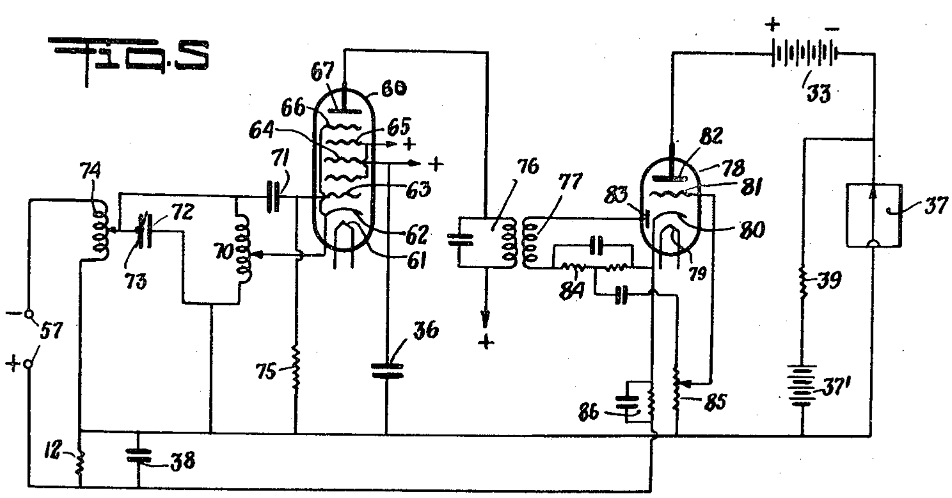


Fig. 5



INVENTOR.

Karl Rath

Patented Aug. 3, 1948

2,446,390

UNITED STATES PATENT OFFICE

2,446,390

POTENTIOMETRIC AMPLIFIER

Karl Rath, New York, N. Y., assignor to Radio Patents Corporation, New York, N. Y., a corporation of New York

Application September 28, 1943, Serial No. 504,107

8 Claims. (Cl. 171—95)

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My invention relates to potentiometric or follow-up type translating systems or amplifiers for amplifying small input currents or potentials normally insufficient for exciting the grid or other input element of a standard amplifier tube, such as the current or potential supplied by photovoltaic cells, thermo-electric elements or any other weak current or potential changes obtainable in response to any variable magnitude or condition to be indicated, recorded or otherwise utilized for operating an output or translating device.

Known arrangements of this type make use of a balanced photoelectric translating system adapted to be unbalanced in accordance with the initial variations of the magnitude or condition to be indicated or translated, such as by the aid of a sensitive galvanometer serving as a detecting and unbalancing means. The off balance or output current upon adequate amplification is utilized to counteract or compensate the initial variation, whereby to restore and maintain the balance of the system. As a result, the output current will be an exact replica of the initial current variations and may be utilized to operate a recorder or meter of substantially reduced sensitivity.

An object of the present invention is to provide a system of the above character which is both simple in design as well as highly sensitive and stable in operation compared with potentiometric balancing devices known according to the prior art.

Another object is to provide a system of this character wherein the mechanical parts and elements are reduced to a minimum, being in fact constituted solely by the galvanometer or other initial current responsive device excited by the weak input current or potential.

A further object is the provision of a device of the above character which can be easily balanced or adjusted to suit existing conditions or requirements substantially without expert knowledge or skill.

These and further objects and novel aspects of my invention will become more apparent from the following detailed description taken in reference to the accompanying drawings forming part of this specification and wherein:

Fig. 1 is a circuit diagram illustrating a simple

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potentiometric translating arrangement embodying the principles of the invention;

Fig. 2 is a graph illustrative of the function and operation of Fig. 1; and

Figs. 3, 4 and 5 are diagrams illustrating various modifications of my invention embodying the basic principle thereof.

Like reference characters identify like parts throughout the different views of the drawings.

With the aforementioned objects in view, the invention involves the use of a tuned or resonant electric circuit embodying means responsive to the variations of the initial magnitude or condition to be translated to vary the tuning or resonant frequency of said circuit in relation to a fixed or predetermined reference frequency. The varying relative departure of the tuning frequency with respect to said reference frequency is translated or converted into corresponding variations of output current of a translating vacuum tube or frequency detector of high response sensitivity. The output current of said frequency detector or discriminator is then utilized by an inverse or negative feed-back arrangement to counteract the initial variations or frequency modulation of said circuit in such a manner as to instantly restore or maintain the balance between the resonant frequency of said circuit and said predetermined reference frequency. As a result, the discriminating or output current which may have many times the intensity of the original input currents, will vary substantially in exact synchronism with the latter and is utilized to operate a suitable output device, such as a meter, recorder or the like of substantially reduced sensitivity compared with the original current responsive device such as a highly sensitive galvanometer, micro-ammeter or the like.

Referring to Fig. 1, I have shown a simple potentiometric amplifier or translating arrangement embodying the principle of the invention and utilizing a so-called space charge type discriminator or translating device disclosed in greater detail in U. S. Patent 2,208,091, to I. Zakarias, issued July 16, 1940, as a means for translating or converting the variations of the initial magnitude or condition into corresponding amplified output current changes. In the diagram shown, numeral 10 represents, by way of example, a thermo-electric element normally producing a current of insufficient potential for direct amplification by a standard vacuum tube amplifier. The element 10 is shown connected directly to the low resistance moving coil 11 of a galvanometer type instrument in series with a small fixed compensating resistance 12 to be described presently. The galvanometer comprises the usual pole pieces 13 and 14 and magnet core 15 arranged to provide an air gap for the moving coil 11. The terminals of the latter are connected through suitable flexible leads 16 and 17 commonly in the form of a pair of spiral balancing springs to the fixed terminal posts of the instrument.

The moving coil 11 carries a pointer or other coupling element 18 to which is secured the movable electrode 20 in the form of a thin metal vane or blade of a variable condenser element having a further fixed plate or electrode 21 suitably arranged for micrometric adjustment relative to the adjustable electrode 20. Thus, under normal conditions, the moving coil 11 excited by the current supplied by the thermocouple 10 will be deflected proportionally, resulting in corresponding variation of the capacity of the condenser element 20, 21.

This varying capacity is utilized in accordance with the invention to control or modulate the resonating frequency of a tuned electric circuit and the variable tuning departure of said circuit with respect to a predetermined reference frequency is translated or converted into corresponding amplified current variations by the frequency detector or discriminator tube 22. The latter, in the example shown, comprises a heater 23, an equipotential cathode 24, a first or inner control grid 25, an accelerating or screen grid 26, a second or outer control grid 27 and an anode or plate 28, all arranged substantially in the order mentioned. The electrode 21 of the translating condenser is connected to the outer grid 27 and the cooperating electrode 20 is connected to the cathode by way of pointer 18, flexible lead 16 connected to said pointer in any suitable manner and resistance 12. The translating condenser 20—21 is shunted by an inductance coil 30 to form a parallel-tuned or antiresonant circuit connected between the grid 27 and the cathode 24. The inner control grid 25 is shown excited by a source 31 of high frequency energy of substantially constant or invariable frequency supplied by an oscillator or high frequency generator of any suitable type known in the art, preferably a crystal controlled vacuum tube oscillator of known construction.

Item 33 represents the plate potential source shown in the form of a battery for simplicity's sake, the plate 28 being connected to the cathode through by-pass condenser 34 for the high frequency current. The accelerating or screen grid 26 is shown connected to the positive side of the source 33 through a voltage drop resistance 35 and is also by-passed to the cathode for high frequency currents by way of by-pass condenser 36 in a manner well known in the art. The circuit for the steady or direct plate current is completed through the indicating, recording or other output device 37 and the aforementioned compensating resistance 12 inserted in the input circuit of the thermocouple and galvanometer. Condenser 38, besides completing the connection of the resonating circuit 20—21—30 to the cathode, acts as a further by-pass condenser to prevent residual high frequency currents from entering the input circuit. The output device 37 is shown by-passed by a compensating battery 37′ in series with a resistance 39 to balance the constant or steady output current through the meter or recorder.

In a frequency modulator-detector system of the type shown in Fig. 1, the direct output current i_0 of the tube 22 varies in the manner indicated by the graph according to Fig. 2 as a function of the relative departure between the exciting frequency impressed upon grid 25 and the natural or tuning frequency of the resonant circuit 20—21—30 connected to the grid 27 and cathode 24. If the frequency of the resonant or discriminating circuit is equal to the operating or exciting frequency, corresponding to a capacity C_0 of the condenser element 20, 21, then the direct or steady output current of the tube assumes a normal value I_0 equal to the plate current if the resonant circuit 20—21—30 were omitted or the grid 27 disconnected entirely. If the resonant frequency of the circuit 20—21—30 increases beyond or decreases below the exciting frequency supplied by the source 31, or in other words, if the capacity of the condenser element 20—21 varies in either direction from its normal value C_0 as shown in Fig. 2, then the direct plate current i_0 it will vary substantially linearly between upper and lower values I_1 and I_2 corresponding to the operating points P_1 and P_2 and capacity values C_1 and C_2, respectively, of condenser 20—21.

By feeding back the steady or direct current of tube 22 to the compensating resistance 12 so as to counteract or substantially balance the initial potential supplied by the thermocouple 10, and by proper design of the parameters and circuit constants of the system, an automatic balance or substantial compensation of the input voltage applied to the galvanometer may be effected and maintained in such a manner as to cause the output current through the translating device 37 having many times the value of the current supplied by the thermocouple 10 to follow the potential variations of the latter substantially instantly and in exact synchronism therewith.

The adjustment of the system according to a preferred embodiment is such that with a potential e of medium value supplied by the thermocouple 10, the output current of the discriminator or detector tube 22 has a value I_0 as shown in Figure 2. Furthermore, the value R of the resistance 12 is so designed that the voltage drop RI_0 caused by the output current substantially balances said input potential e. This balance condition $e=i_0R$ will be automatically maintained as the input potential changes, resulting in a variation of the output current i_0 in synchronism with the input potential variations. In other words, any tendency of the galvanometer to deviate from its normal or balance position is instantly counteracted by a flow of off-balance current in the input circuit resulting in a balancing potential drop or torque to return the moving coil 11 to the balance position. The balancing operation is continuous and instantaneous to changes of input current or potential. All other circuit components subject to variation do not affect directly the operation of the system which is maintained at an inherently stable balance position with only the output current of the discriminator subject to change in producing the off-balance current flow.

If under the conditions outlined, the battery 37′ and resistance 39 are designed to balance the mean output current I_0 through the device 37, the latter may be of the zero-center type for indicating or recording deviations of the input from an average or mean value. If an indication or record between zero and maximum current is desired, battery 37' and resistance 38 should be adjusted to balance the current I_2 through the device 37, whereby the current through the output device 37 will vary between zero and maximum in synchronism with the input voltage change, such as the potential supplied by the thermocouple 10 in the example shown. As an example, the amplification may be so chosen, such as by the proper design of the resonant circuit (Q-value of the inductance coil 30, etc.) and by the employment of an additional direct coupled amplifier interposed between the detector 22 and output device 37, that a change of one microampere in the input circuit will result in a change of one milliampere off balance current in the output circuit, in which case the device 37 may be directly calibrated in microamperes or other input units.

In order to avoid the use of a multi-stage direct coupled amplifier with its inherent defects and drawbacks due to drift, instability, etc. when higher output powers are required, the invention makes it possible to use an R. F. amplifier of high stability to secure a desired output current by means of the system described hereinbefore. An arrangement of this type is shown in Fig. 3, which otherwise differs from Fig. 1 by showing a photovoltaic cell 40 as an input device. The latter, as is well known, supplies a potential unsuited for direct amplification similar to the current and potential supplied by a thermo-electric device as shown in Fig. 1. I have furthermore shown in Fig. 3 a modified detecting condenser associated with the galvanometer and comprising a pointer 41 carrying a blade or vane 42 of suitable configuration and arranged to cooperate with a fixed plate 43 mounted for micrometric adjustment indicated by an adjusting screw 43'. By properly shaping the movable blade 42 any desired initial response characteristic may be obtained, as is understood.

I have furthermore shown in Fig. 3 an oscillator circuit associated with the detector tube 22 itself, whereby to avoid a separate source or oscillator as shown in Fig. 1. For this purpose the cathode 24, inner control grid 25 and screen grid 26 are utilized as a normal triode having associated therewith a regenerative feed-back circuit to produce continuous or sustained electrical oscillations. In the example shown, the resonant or tank circuit 45 has one end connected to the control grid 25 through coupling condenser 46 and has its other end connected to the screen grid 26 through the coupling or by-pass condenser 48. A suitable tap point of the inductance circuit 45 is connected to the cathode 24, and grid 25 is by-passed to cathode through a grid leak resistance 47, whereby the system will function to generate sustained oscillations having a frequency determined by the resonant frequency of the circuit 45 in a manner well understood. In order to insure proper function and stability of the system, the oscillator circuit and the resonant or discriminating circuit should be carefully shielded to avoid magnetic and other mutual coupling such as by the provision of grounded metal shields 30' and 45' well known to those skilled in the art.

In a discriminator of this type the output or plate current, in addition to the steady or direct current component as shown by Fig. 2, contains a high frequency component which in the case of Fig. 1 is by-passed to the cathode through condenser 34, but in the embodiment of Fig. 3 is utilized for amplification by a stabilized high frequency amplifier and detector shown at 50. As explained in detail in my Patent No. 2,248,197, issued July 8, 1941, this high frequency component in the plate circuit is amplitude-modulated in accordance with the relative tuning departure between the operating frequency applied to grid 25 and the resonating frequency of circuit 30—42—43 connected to grid 27. As a result, the demodulated current obtained from the output of the amplifier and detector 50 will vary in a manner similar to the direct plate current of the tube 22 and is utilized to operate the output device 37 and to provide the off balance current for the potentiometric balance by returning it through the balancing resistance 12 in a manner similar to Fig. 1 and understood from the above.

Referring to Fig. 4 I have shown a further modification of my invention. This arrangement is similar to that according to Fig. 1, with this difference that the exciting high frequency current is applied to the outer control grid 27, while the resonating or discriminating circuit is shown connected between the inner control grid 25 and cathode 24. Under these conditions, the system operates in substantially the same manner as in the case of Fig. 1 with the only difference that the plate current change will be in a direction opposite to the change as shown in Fig. 2. This can be compensated for by the design and choice of the winding sense of the galvanometer coil 11.

Moreover, in the embodiment of Fig. 4, the resonating circuit is shown to consist of a fixed condenser 56 and a variable inductance element controlled in accordance with the galvanometer deflection. For this purpose, I have shown a split inductance coil having elements 52 and 53 and a metal vane or blade 55 carried by the pointer 18 and arranged to move within the space between said inductance elements, whereby to vary the inductance thereof in a manner well known. This arrangement has the advantage that no electrical connection has to be made through the pointer 18 to the metal vane 55 which preferably consists of copper or other high conducting material.

The design and adjustment of the system shown in Fig. 4 is such that in the balance position the metal vane 55 which may be of circular shape as shown or of any other suitable configuration, assumes a mean position within the space between the inductance elements 52 and 53 to provide an inductance value resulting together with the fixed condenser 56 in a resonating frequency equal to the operating or exciting frequency supplied by the source 31. The potentiometric resistance 12 is again designed in such a manner as to produce a potential drop by the steady plate current I_0 to substantially balance a predetermined input potential supplied from a suitable device connected to terminals 57 and exciting the galvanometer winding 11 in a manner similar to that described in connection with Fig. 1. An initial deviation of the input current or potential from an existing value in either direction will then result in an unbalance and subsequent instantaneous increase or decrease of the off balance output current to maintain the balance condition in a manner understood from the foregoing. By proper design and adjustment by the balancing battery or other source 37', the output device 37 may be of the ordinary or zero-center type in substantially the same manner as described hereinbefore.

In the preceding examples, the capacity or inductance variations effected by the initial detecting means such as a galvanometer or microammeter serves to modulate the natural or resonating frequency of a tuned circuit of a frequency detector or discriminator excited by a source of substantially constant frequency, whereby to derive an output current varying in proportion to the relative departure of said tuning frequency with respect to said constant exciting frequency. In the embodiment shown in Fig. 5, the varying reactance produced in accordance with the input potential or other condition to be translated, serves to frequency modulate a self-excited high frequency oscillator, the output of which is then detected by means of any known frequency discriminator to produce an amplified direct current varying exactly as the initial input changes and serving to operate both the output device and to provide the off balance or negative feed-back current for the input circuit necessary to maintain the balance condition of the system.

For this purpose, I have shown in Fig. 5 a multi-electrode vacuum tube **60** of the penta-grid converter type comprising in a known manner, a heater **61**, an equi-potential cathode **62**, a first control grid **63**, an accelerating or anode grid **64**, a screen grid **65** enveloping said accelerating grid, a suppressor grid **66** internally connected to the cathode in a known manner and a plate **67**, all arranged substantially in the order mentioned. A tuned resonant or tank circuit comprising an inductance coil **70** shunted by a variable condenser having electrodes **72** and **73** is connected to the control grid **63** through coupling condenser **71** and to the accelerating grid **64** by way of decoupling condenser **36**. The cathode **62** is shown connected to a suitable tap point on the inductance **70** and a grid leak resistance **75** is connected between control grid **63** and cathode **62**, whereby to provide a self-oscillating regenerative circuit capable of producing sustained oscillations having a frequency determined by the capacity of the condenser **72**, **73**. The oscillations are transmitted to the output or plate circuit **76** by electron coupling in a manner well known and understood by those skilled in the art.

The variable condenser in the example shown comprises a fixed plate or electrode **72** and a movable electrode blade **73** carried by the torsion string or wire of a normal string galvanometer having an exciting coil (not shown). In other words, blade **73** takes the place of the usual mirror provided in galvanometers of this type.

In an arrangement of this type, the varying input current supplied by the source **57** tends to deflect the galvanometer electrode **73** to approach or recede from the fixed electrode **72**, whereby to vary the electrical capacity between said electrodes in a manner well understood. As a result, the frequency of the oscillations generated tends to change in the one or other direction from a center or normal frequency. In order to detect the frequency changes any known type of frequency detector or discriminator may be connected to the output circuit. In the example shown the discriminator comprises the resonant circuit **76** which is detuned relative to the frequency of the oscillator in the balance condition so as to operate along one branch of its resonance curve to convert the frequency modulation into corresponding amplitude changes of the output current. The latter are then detected or demodulated by means of any suitable amplitude modulation detector such as a diode-triode vacuum tube **78** shown in the example illustrated and comprising a heater **79**, a cathode **80**, a control grid **81**, an amplifier plate or anode **82** and a rectifier plate **83** adjacent to the cathode **80**. The high frequency output currents are applied from the circuit **76** by way of coupling coil **77** to the diode plate **83** and to the cathode **80** through a diode load resistance **84** by-passed for high frequency current by a condenser in a manner well known. A portion of the rectified current is applied from the diode resistor **84** to a coupling resistor **85** by way of a coupling condenser and a suitable portion of the rectified potential developed by the coupling resistor **85** is shown applied to the control grid **81** for further amplification by the triode section of the tube. Item **86** represents a biasing network comprising a condenser-shunted resistance in the cathode return lead of the tube to provide suitable steady operating bias for the control grid **81** in a manner well known. The amplified output current of the tube **78** is applied to the output device **37** and passed through the potentiometric balance resistance **12** in substantially the same manner as shown and understood from the preceding exemplifications of the invention.

Arrangements of the type described, besides being simple from a mechanical standpoint in requiring a minimum of mechanically moving parts and adjustments, have the advantage of extreme sensitivity by the utilization of the resonance effect affected by the initial input variations and resulting in increased stability and operating safety as well as low manufacturing and maintenance cost of instruments of this type.

The operating frequency used in arrangements aforedescribed may be chosen to suit any existing and special requirements. Practical considerations have shown that a frequency between about 1 to 10 mc. and higher results in an efficient and mechanically simple construction, since the size and weight of the adjusting element (**21**, **42**, **55** and **73**) decreases as the operating frequency is increased. As an example, when using a variable condenser of about one to $\frac{1}{10}\mu\mu f$ and a frequency of about 5 mc., the adjusting element will be of such small size and weight as not to impair the accuracy and sensitivity of galvanometer of known construction.

The oscillator or operating frequency used should be maintained constant to insure accuracy and reliability of the indication or record. When lower frequencies are used, the oscillator may be stabilized by the aid of a piezo-electric crystal or equivalent device, or any other well known means of frequency stabilization may be employed for the purpose of the invention. If a double-grid electron tube is used as a frequency detector as shown in Figures 1, 3 and 4 which as is well known functions on the basis of two control potentials at operating frequency being set up upon said grids which potentials have a relative phase relation varying in proportion to the input current changes to be translated, the system may be checked and/or rebalanced at any time in a simple manner for optimum operating efficiency and accuracy.

Thus, if the balance condition is chosen to correspond to the condition of tuning of the resonant discriminating circuit to the operating frequency, the grid potentials in a detector tube of this type will be in quadrature or at a relative 90° phase difference, resulting in no effect on the direct or steady plate current of the tube (see current I_0 according to Figure 2). If, under this condition, the operating or oscillator frequency should have slightly changed due to drift or other causes, temporary disconnection of the resonant circuit by means of a suitable test button or the like will indicate a slight change of the direct plate current. In this case, all that is necessary to rebalance the system is to readjust the variable condenser or induction coil by operating the micrometric adjustment and/or to readjust the operating frequency, until the steady plate current again remains the same in both the on or off-position of the resonant circuit.

As is understood, condenser 20—21 in Figure 1 and condenser 42—43 in Figure 3, may be provided with two stationary plates arranged on opposite sides of the movable electrode to obtain an increased initial capacity if desirable.

It will be evident from the foregoing that the invention is not limited to the specific details, arrangement of parts and constructions shown and disclosed herein for illustration, but that the underlying thought and basic principle are susceptible of numerous variations and modifications coming within the broader scope and spirit of my invention as defined in the appended claims. The specification and drawings are accordingly to be regarded in an illustrative rather than in a limiting sense.

I claim:

1. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising a resonant impedance means, a source of auxiliary high frequency voltage having a frequency normally relatively equal to the resonant frequency of said impedance means, coupling means between said resonant impedance means and said source to develop a secondary high frequency voltage by said impedance means having a phase normally at 90° with respect to the phase of said source voltage and varying in sense and magnitude in proportion to the relative frequency departure between said source and the resonant frequency of said impedance means, and further means for combining said secondary high frequency voltage with said source voltage to produce a direct output current having an amplitude varying in sense and magnitude in proportion to said frequency departure; a current responsive device connected to said input device and means operatively associated therewith to effect a relative frequency departure between said source and the resonant frequency of said impedance means; a resistance traversed by said direct output current and connected in series with said input device and said current responsive device to produce a potential drop substantially counterbalancing said input voltage, whereby to restore the frequency balance between said source and the resonant frequency of said impedance means and to maintain a condition of electrical equilibrium between said direct current input voltage and said output current; and translating means responsive to said output current.

2. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising a resonant impedance means, a source of auxiliary high frequency voltage having a constant frequency normally equal to the resonant frequency of said impedance means, coupling means between said resonant impedance means and said source to develop a secondary high frequency voltage by said impedance means having a phase normally at 90° with respect to said source voltage and varying in sense and magnitude in proportion to the relative frequency departure between said source and the resonant frequency of said impedance means, and further means for combining said secondary high frequency voltage with said source voltage to produce a direct output current of amplitude varying in sense and magnitude in proportion to said frequency departure; a galvanometer connected to said input device and having a movable element adapted to control the resonant frequency of said impedance means, to effect a relative frequency departure between said source and the resonant frequency of said impedance means; a resistance traversed by said output current and connected in series with said input device and said galvanometer to produce a potential drop substantially counterbalancing said input voltage, whereby to restore the balance between the frequency of said source and the resonant frequency of said impedance means and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

3. In an electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising a resonant circuit including an induction coil and a variable condenser having a fixed electrode and movable electrode, a source of auxiliary high frequency voltage having a constant frequency normally equal to the tuning frequency of said circuit, coupling means between said circuit and said source to develop a secondary high frequency voltage by said circuit having a phase normally at a 90° angle with respect to said source voltage and varying in sense and magnitude in proportion to the relative frequency departure between said source and the tuning frequency of said circuit, and further means for combining said secondary high frequency voltage with said source voltage, to produce a direct output current of amplitude varying in sense and magnitude in proportion to said frequency departure; a galvanometer connected to said input device and having a movable element actuating said movable electrode, whereby to vary the tuning frequency of said circuit and to effect a relative frequency departure therebetween and said source; a resistance traversed by said output current and connected in series with said input device and said galvanometer, to produce a potential drop substantially counterbalancing said input voltage, whereby to restore the frequency balance between said source and the resonant frequency of said circuit and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

4. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising a resonant circuit including a condenser and an induction coil, a source of auxiliary high frequency voltage having a constant frequency normally equal to the tuning frequency of said circuit, coupling means between said circuit by said source to develop a secondary high frequency voltage by said circuit having a phase normally at a 90° angle with respect to said source voltage and varying in sense and magnitude in proportion to the relative frequency departure between said source and the tuning frequency of said circuit, and further means for combining said secondary high frequency volt-

age with said source voltage to produce a direct output current of amplitude varying in sense and magnitude in proportion to said frequency departure; a galvanometer connected to said input device and having a movable element carrying a metallic member arranged to cooperate with said induction coil to vary the inductance thereof, to thereby effect a relative frequency departure between said source and the tuning frequency of said circuit; a resistance traversed by said output current and connected in series with said input device and said galvanometer to produce a potential drop substantially counterbalancing said input voltage, whereby to restore the frequency balance between said source and the tuning frequency of said circuit and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

5. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising an electronic tube having at least a cathode, an anode, a pair of control grids and a screen grid interposed between said control grids, a resonant impedance means connected between said cathode and one of said control grids, a source of auxiliary high frequency voltage having a frequency normally relatively equal to the resonant frequency of said impedance means and connected between the other of said control grids and said cathode, said source being substantially exteriorly decoupled from said impedance means, to produce a direct anode current having an amplitude varying in sense and magnitude in proportion to the relative frequency departure between said source and the resonant frequency of said impedance means; a current responsive device connected to said input device and having means operatively associated therewith to effect a relative frequency departure between said source and the resonant frequency of said impedance means; means including a balancing resistance in series with said input device and said current responsive device to produce a voltage drop varying in proportion to said direct output current and substantially counterbalancing said input voltage, whereby to restore frequency balance between said source and said resonant impedance means and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

6. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising an electronic tube having at least a cathode, an anode, a pair of control grids and a screen grid interposed between said control grids, a resonant impedance means connected between said cathode and one of said control grids, a source of auxiliary high frequency voltage of substantially constant frequency normally equal to the resonant frequency of said impedance means and connected to the other of said control grids and said cathode, said source being substantially exteriorly decoupled from said impedance means, to produce a direct anode current having an amplitude varying in sense and magnitude in proportion to the relative frequency departure between said source and the resonant frequency of said impedance means; a galvanometer connected to said input device and having movable means adapted to control the resonant frequency of said impedance means; means including a balancing resistance in series with said input device and said galvanometer, to produce a voltage drop varying in proportion to said direct output current and substantially counterbalancing said input voltage, whereby to restore the frequency balance between said source and said resonant impedance means and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

7. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising an electronic tube having at least a cathode, an anode, a pair of control grids and a screen grid interposed between said control grids, a resonant circuit comprising an induction coil and a variable condenser having a fixed electrode and a movable electrode, said resonant circuit being connected to one of said control grids and said cathode, a source of auxiliary high frequency voltage having a constant frequency normally equal to the tuning frequency of said circuit and connected to the other of said control grids and said cathode, said source being substantially exteriorly decoupled from said resonant circuit, to produce a direct anode current having an amplitude varying in sense and magnitude in proportion to the relative frequency departure between said source and the tuning frequency of said circuit; a galvanometer connected to said input device and having a movable element actuating said movable electrode, whereby to vary the resonant frequency of said circuit and to produce a relative frequency departure between said source and the tuning frequency of said circuit; means including a balancing resistance in series with said input device and said galvanometer and adapted to produce a voltage drop varying in proportion to said direct output current and substantially counterbalancing said input voltage, whereby to restore the frequency balance between said source and the tuning frequency of said circuit and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

8. An electrical system comprising an input device supplying a relatively weak direct current input voltage; a frequency converter comprising an electronic tube having at least a cathode, an anode, a pair of control grids, and a screen grid interposed between said control grids, a resonant circuit including a condenser and an induction coil and connected to one of said control grids and said cathode, a source of auxiliary high frequency voltage of constant frequency normally equal to the tuning frequency of said circuit and connected between the other of said control grids and said cathode, said source being substantially exteriorly decoupled from said circuit, to produce a direct anode current having an amplitude varying in sense and magnitude in proportion to the relative frequency departure between said source and the tuning frequency of said circuit; a galvanometer connected to said input device and having a movable element carrying a metallic element actuated thereby and cooperating with said induction coil to control the inductance thereof to thereby effect a relative frequency departure between said source and the tuning frequency of said circuit; means including a balancing resistance in series with said input device and said galvanometer for producing a voltage

drop varying in proportion to said output current and substantially counterbalancing said input voltage, whereby to restore the frequency balance between said source and the tuning frequency of said circuit and to maintain a condition of electrical equilibrium between said input voltage and said output current; and translating means responsive to said output current.

KARL RATH.

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