March 23, 1937. W. H. HOWE 2,074,396

IMPEDANCE VARIATION AMPLIFIER

Filed March 11, 1933 4 Sheets-Sheet 1

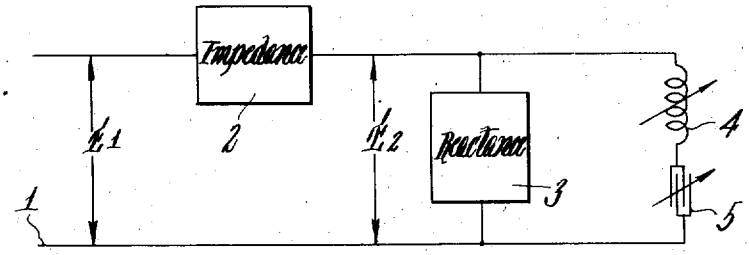


Fig. 1.

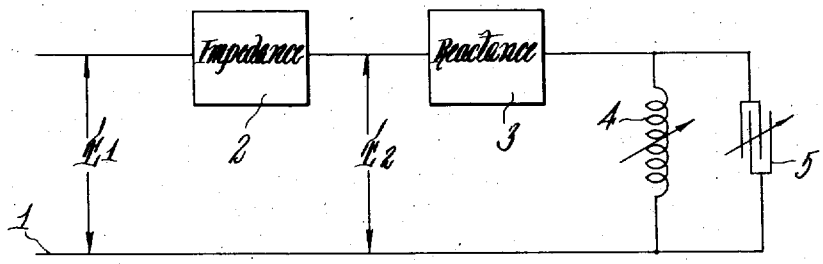


Fig. 2.

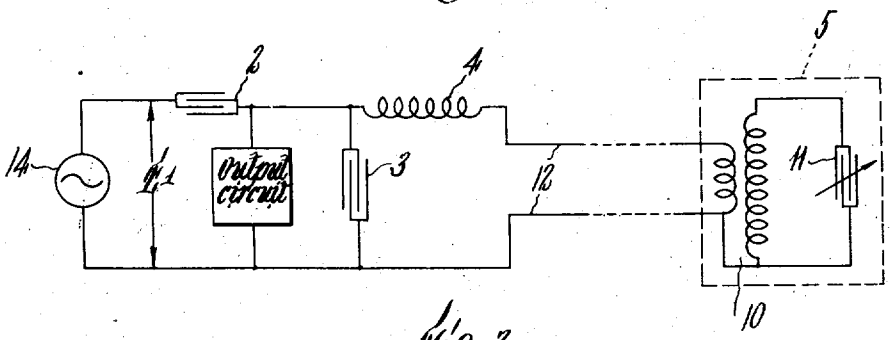


Fig. 3.

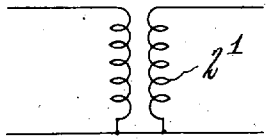


Fig. 4.

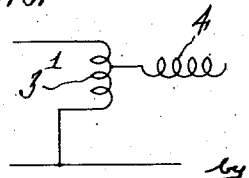


Fig. 5.

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Fig. 6.

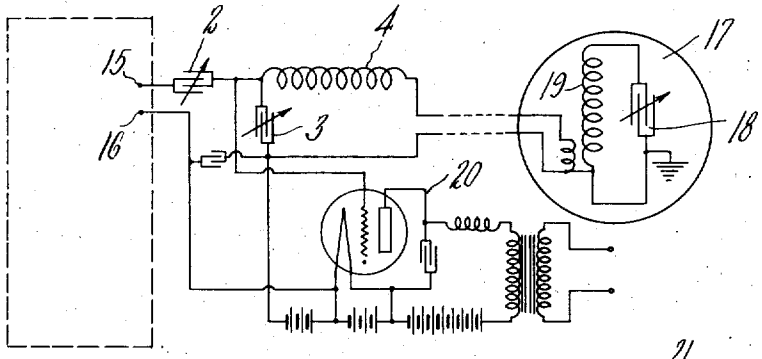


Fig. 7.

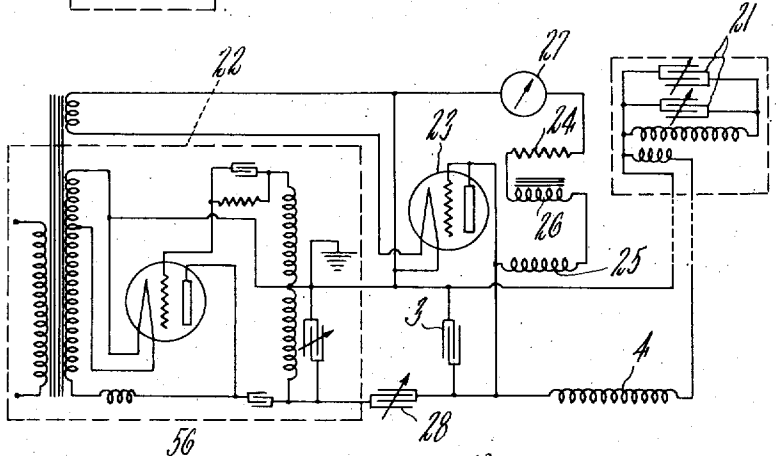
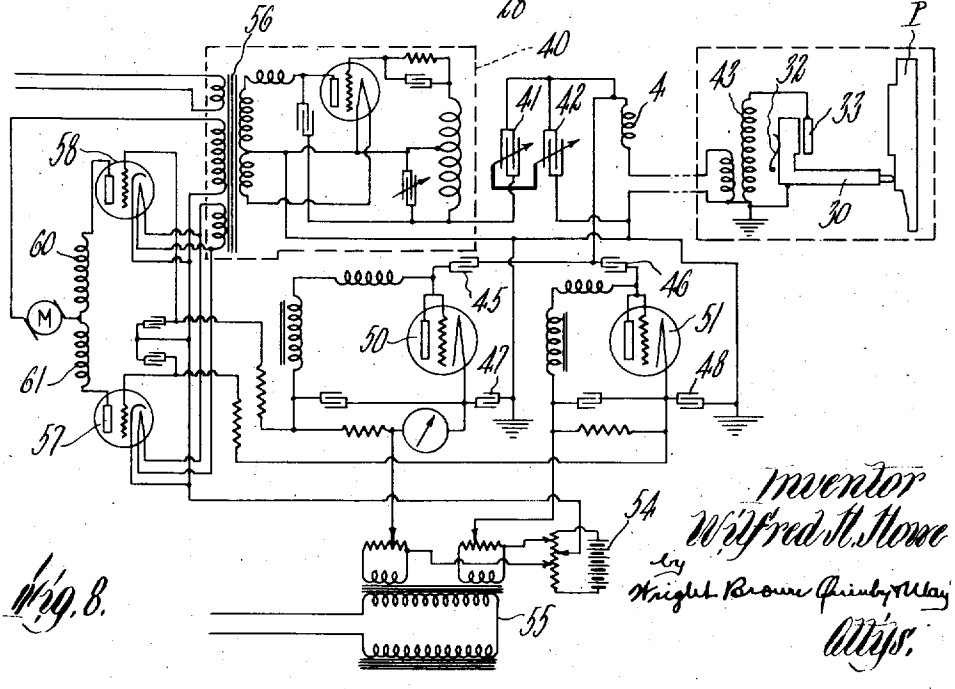


Fig. 8.



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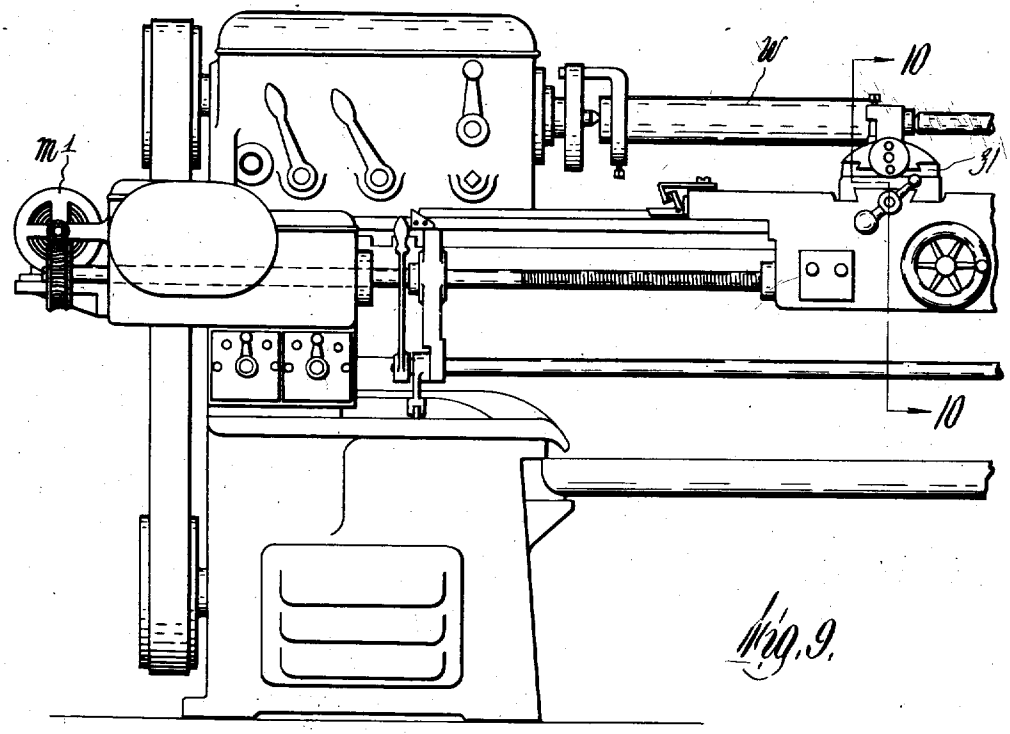


Fig. 9.

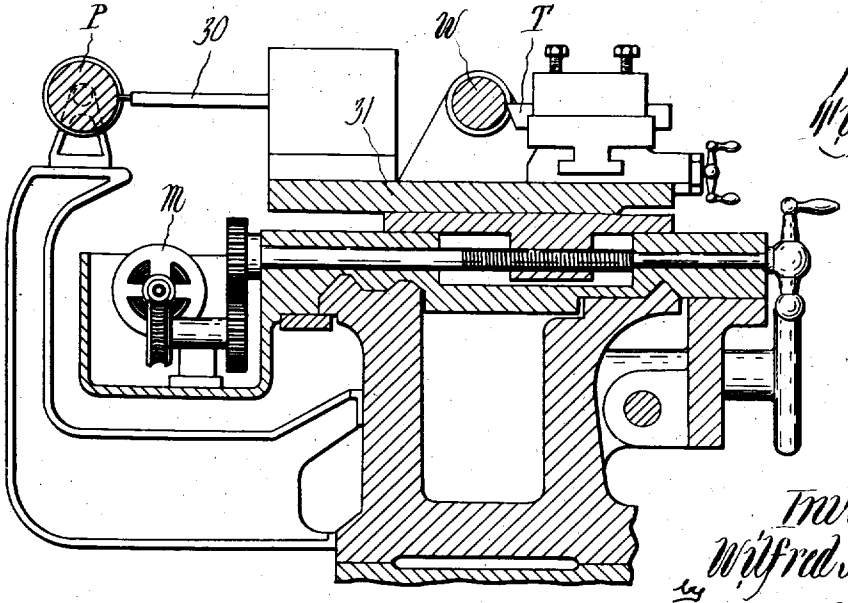


Fig. 10.

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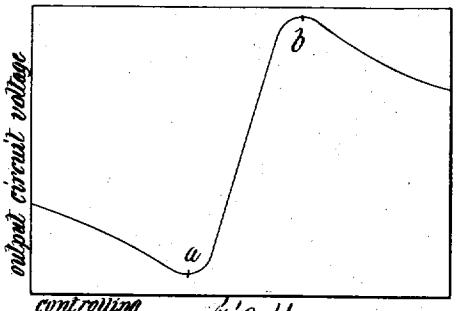


Fig. 11.

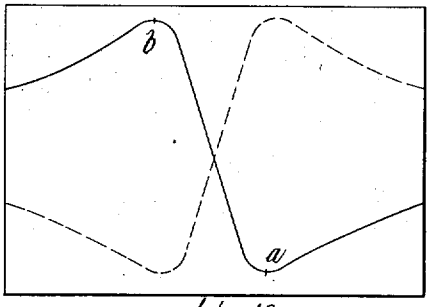


Fig. 12.

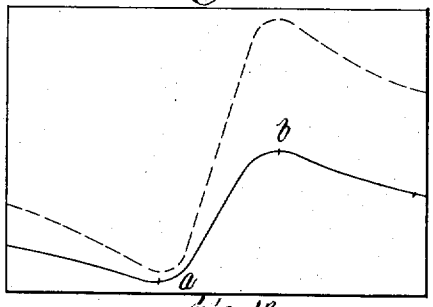


Fig. 13.

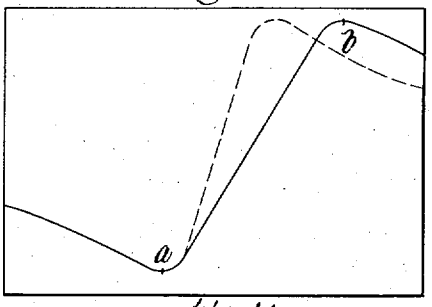


Fig. 14.

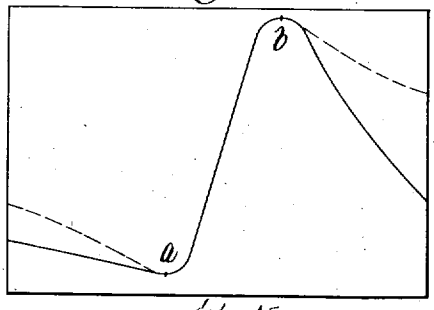


Fig. 15.

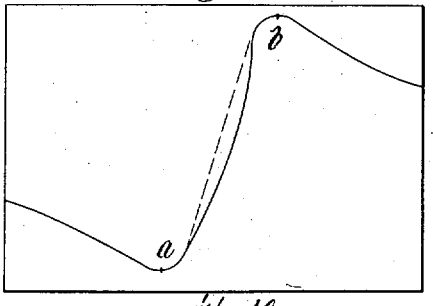


Fig. 16.

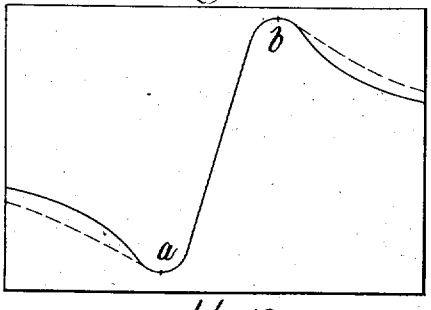


Fig. 17.

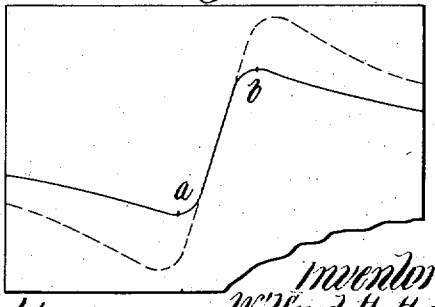


Fig. 18.

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UNITED STATES PATENT OFFICE

2,074,396

IMPEDANCE VARIATION AMPLIFIER

Wilfred H. Howe, Winchester, Mass., assignor, by mesne assignments, to The Cincinnati Milling Machine Co., Cincinnati, Ohio, a corporation of Ohio

Application March 11, 1933, Serial No. 660,429

22 Claims. (Cl. 82—14)

This invention has for an object to produce an amplifying effect on a controlled circuit similar to that which may be obtained by certain circuits employing vacuum tubes or other voltage or power amplifying devices, but without the use of such tubes or devices. This is accomplished according to this invention by variation of impedance suitably connected to a source of alternating power to control voltage to or through a circuit, the variations of this impedance being controlled by very much smaller variations in a controlling impedance. This may be accomplished entirely by suitable combinations of inductance, capacity and resistance designed for any desired single frequency, as will later more fully appear.

A simple resonant circuit with a single inductance and a single capacity, both of approximately the same impedance at the frequency at which they are operated, behaves as an impedance variation amplifier, a small change of inductance or capacity resulting in a large change of the effective impedance of the system. However, the ratio of change of total impedance to change of inductance or capacity cannot be maintained constant for any appreciable change of total impedance. The proportion varies according to the so-called resonance curve whose shape is not subject to control, except that as a whole by reducing the resistance of the system the curve can be made more sharply pointed. Furthermore, a simple resonant circuit is almost entirely an impedance amplifier and not an amplifier of power capacity. The out-put circuit, particularly if it contains resistance, very rapidly reduces the effectiveness of the simple resonance circuit as an amplifier of impedance variation.

For inductance and capacity in series the impedance of the total varies with a variation of either and reaches a minimum when the impedance of the capacity is equal to the impedance of the inductance. For an inductance and capacity in parallel the impedance of the total varies, reaching a maximum when the impedance of the capacity is equal to the impedance of the inductance. If the resistances of the inductance and capacity are small, that is, if the power factor is low, then the impedance at series resonance is much less than the impedance of either inductance or capacity, while the impedance at parallel resonance is much greater than that of either inductance or capacity.

By so arranging a circuit net work that a relatively small change of inductance or capacity will produce a change from a state of effective parallel resonance to effective series resonance, a condition is reached where the small change of reactance, either of capacity or inductance, produces a large change in impedance of the net work. It is upon this principle that the circuit of this invention operates. Such an arrangement is extremely flexible in operation. It is possible to so arrange the proportions that a very wide range of ratios between controlling and controlled impedance may be effected and this ratio may be adjusted at will. Within fairly wide limits the ratio of change of voltage or current to change of impedance may be made a constant, or it may be made to vary with change of controlling impedance. By connecting an out-put circuit even of relatively large power capacity in parallel with the controlled impedance, a relatively large change in the voltage, current, and power out-put of this circuit may be produced by a small variation in the controlling reactance which may be a relatively small inductance or capacity handling a relatively small amount of power, and the change in the power circuit may be produced in almost any desired ratio or variation of ratios. This circuit, then, has the advantage over a simple resonant circuit, first that the ratio of change of controlled network impedance to change of controlling inductance or capacity can be held constant through a wide range of controlled network impedance: second, that this ratio can be easily varied or may be caused to vary with changes in controlled network impedance: third, that a relatively large amount of power may be drawn from this circuit and supplied to any desired out-put circuit, and, fourth, that the circuit is very readily adaptable to use in common with a low potential coupling line whereby the controlling inductance or capacity may be separated a considerable distance from the point to which the out-put circuit is connected to the controlled network impedance, the coupling itself being relatively insensitive to changes of its impedance or capacity to ground, a feature frequently of great importance when dealing with high frequencies. This circuit is relatively insensitive to resistance variations and the effect of resistance variations can be still further minimized at desired points by a suitable choice of the fixed reactances. Thus the potential variations of the net work are governed substantially entirely by variations of reactance and the current through the network varies between a value approaching that of the supply potential divided by in-put impedance and the value approaching zero, depending on the variations of

the variable controlling impedance. This circuit has a wide variety of applications wherever a change of inductance or capacity is produced by mechanical or other means and it is desired to convert this variation of reactance to a variation of either current or voltage. Particularly where it is desired to control substantial power out-put this type of control is of great advantage.

For a more complete understanding of this invention, reference may be had to the accompanying drawings in which

Figures 1 and 2 are diagrammatic views of two forms of the fundamental series-parallel circuit.

Figure 3 is a diagram showing a circuit of the general type of Figure 1 with a remote controlling reactance.

Figures 4 and 5 are fragmentary diagrams showing certain forms of impedance and reactance, respectively, which may be employed.

Figures 6, 7 and 8 are diagrams showing specific applications of such an amplifying circuit for various power circuits.

Figure 9 is a fragmentary front elevation of a lathe in connection with which the circuit shown in Figure 8 may be employed.

Figure 10 is a detail section on line 10—10 of Figure 9.

Figures 11 to 18 inclusive are diagrams illustrating various out-put circuit voltage characteristics responsive to changes of controlling impedance which may be obtained by variations in the characteristics of capacity, inductance, and resistance and combinations thereof of various parts of the amplifying circuit.

Figures 1 and 2 show the circuit in two of the simplest forms both being series-parallel circuits. In Figure 1 a constant frequency constant potential source 1 of a potential E' has a high impedance 2 in series therewith, and in series with this impedance 2 are the parallel branches, one including a reactance 3 and the other including an inductance 4 and a capacity 5 in series with each other. The impedance 2 may be capacitive, inductive, a resistance, or combinations thereof. The reactance 3 may be either capacitive or inductive. When the impedances of the inductance 4 and the condenser 5 are equal, the impedance of the two in series is quite low compared with the impedance 2. As a result the current flowing through the impedance 2 and the inductance 4 and condenser 5 produces a large voltage drop through the impedance 2 and a relatively small voltage drop through inductance 4 and condenser 5. The voltage across the lines at E_2 is thus small compared with the voltage E', which is the sum of this voltage and the voltage drop across the impedance 2. Since in this condition the reactance 3 is not in resonant condition with any other part of the circuit, its impedance is large compared to the impedance of inductance 4 and condenser 5, so that the current through it is small compared to the current through the inductance 4 and condenser 5. Since this current likewise flows through the impedance 2, its effect is small compared with the current through the inductance 4 and condenser 5 and whatever effect there is will tend to increase the voltage drop through the impedance 2, thus reducing the voltage E_2 still further and decreasing the ratio between E_2 and E_1.

We will first assume that the reactance 3 is capacitive. If now the capacity of the condenser 5 be increased, thereby decreasing its impedance, or if the inductance of inductance 4 be increased, thereby increasing its impedance, or both, then the impedance of the inductance 4 will be greater than the impedance of the condenser 5 and the two together behave like a single inductance whose value will depnd on the difference of impedance between the two. This inductance is in parallel with the reactance 3 which we have assumed to be capacitive. If the impedance of this effective inductance is equal to the capacitive impedance of the reactance 3, a condition of parallel resonance will exist and the impedance of the circuit consisting of the parts 4, 5 and 3 will be quite large—of a value comparable with the value of the impedance 2. If the impedance of the circuit containing the elements 3, 4 and 5 should be exactly the same as the impedance 2 in magnitude and phase angle, then the current flowing in the circuit would produce a voltage drop through the element 2 exactly equal to the voltage drop through the circuit containing the elements 3, 4 and 5. Voltage E_2 would then be one half the applied voltage E', which is large, compared with its value when the impedances of the elements 4 and 5 are equal. Under other conditions of phase and magnitude of these impedances the voltage E_2 may be much greater than the voltage E_1. Thus by varying the value of the impedance of either element 4 or 5 by a relatively small amount, the voltage E_2 can be caused to vary a much greater amount. Since the point of parallel resonance is controlled by the value of the reactance 3, and the point of series resonance is independent of this value but is determined wholly by the relative values of the impedance of elements 4 and 5 a variation of the value of the reactance 3 will produce a corresponding variation in the relative amount of change in the values of the impedance of the elements 4 and 5 to go from series to parallel resonance or vice versa. This produces a facile arrangement for control of the ratio of change of total impedance, or total voltage, to change of controlling inductance or capacity.

In the preceding discussion it has been assumed that the reactance 3 is capacitive, but it may be inductive, in which case, the total reactance of the elements 4 and 5 would be made capacitive by decreasing the capacity of the condenser 5 or decreasing the inductance of the element 4, or both, from a condition of equal impedance for both to effect a change from series to parallel resonance.

Figure 2 shows a varient of the circuit of Figure 1 in which the inductance 4 and the condenser 5 are arranged in parallel with each other and both in series with the reactance 3. With this arrangement when the impedance of the elements 4 and 5 are equal a condition of parallel resonance exists with resultant high impedance and relatively large value of E_2. When the impedance of the inductance 4 becomes less than that of the condenser 5, the two taken together result in an effective inductance of a value depending on the differences of such impedances and if the value of the inductive impedance is equal to the capacitive impedance of the reactance 3, series resonance exists, with a relatively low impedance of the circuit and a low value of the voltage E_2.

If the reactance 3 is inductive instead of capacitive, and the impedance of the inductance 4 is increased above that of the condenser 5, the impedances of the elements 4 and 5 together become capacitive and if this is made equal to the inductive reactance of the element 3, series resonance exists and the value of E_2 is low.

Instead of using a source of alternating current power of relatively constant potential and fre-

quency fed to the series-parallel circuit through the impedance 2, it is possible to omit the impedance 2 provided the source of alternating current power be such that without the impedance it supplies directly to the series parallel circuit alternating current of equally constant frequency and current value, this current value being independent of the impedance of the circuit through which it flows.

A large number of amplifications of the simple circuits of Figures 1 and 2 is possible, but for the sake of simplicity some of these based on the elemental circuit of Figure 1 will be further considered, it being understood, however, that these may be rearranged as in Figure 2 if desired so long as the proper relations in values are observed. Thus the various units instead of being in the forms of simple inductance or capacity or resistance units may be more comprehensive. In Figure 4, for example, the impedance 2' is shown in the form of a loose coupled transformer and in Figure 5 the reactance 3' is shown as an autotransformer, though a full insulating transformer might be substituted, and the connection to the unit 4 may be taken off at a different point from the connections to the impedance 2. It is also possible to take off the out-put circuit across to operate at the voltage E_2, or it may be in series with the reactance 3, and operate on current variations in the amplifier circuit. Further, any of the impedances may be circuits, each having as a whole suitable values of inductance, capacity or resistance and they may be connected in through suitable leads. For example, in Figure 3, the unit or head comprising the somewhat loosely coupled transformer 10 and the variable condenser 11 so related to each other that the whole is capacitive, may take the place of the condenser 5 in Figure 1. In order that it may be capacitive, the capacity of the controlling condenser is sufficiently high so that its impedance is always less than that of the inductance, the impedance of the two in parallel thus being capacitive and varying with the exact difference between these impedances. While this unit or control head might be connected directly into the remainder of the circuit, it is often convenient to have it small, easily movable, and at some distance from the remainder of the circuit. So, as shown, it is connected by a coupling circuit including the leads 12. The condenser 11 may be a variable measuring condenser as shown, for example, in either of the Allen Patents No. 1,708,073 and No. 1,708,074, both granted April 9, 1929. When the ratio of the transformer 10 is low and it is sufficiently loose coupled, though it cannot be very loosely coupled because of the loss of sensitivity of the circuit, variations of internal capacity and of capacity to ground of leads 12 do not act appreciably on the control head, nor on other parts of the circuit. This feed line is then so nearly aperiodic that the leads 12 may comprise an ordinary lamp cord several feet in length and may be moved around with no appreciable effect, while the head circuit is subjected to measuring changes of the condenser 11 of the order of 10^{-13} farads.

In Figures 6, 7 and 8 various types of industrial circuits employing the general arrangements of amplifying circuit of Figure 1 are illustrated by way of example, though it should be understood that these arrangements are applicable to many others. The source of power may be a vacuum tube oscillator circuit.

Figure 6 is a diagram of a condenser microphone set-up. The source of power is any suitable oscillator connected to the lines 15 and 16. It is not necessary that its frequency be particularly constant. The microphone is indicated at 17 and corresponds in so far as its function in the amplifying circuit is concerned to the control head comprising the parts 10 and 11 of Figure 3. The controlling variable condenser 18 is formed by a fixed plate set close to the diaphragm of a microphone. Sound waves striking the diaphragm cause it to vibrate and vary the capacity of this condenser. Since the diaphragm is entirely unloaded, the capacity variation corresponds very closely to sound pressure variation in a properly designed instrument. While this microphone unit contains an inductance 19 as well as the condenser 18, it acts as a whole capacitively and is arranged with reference to the inductance 4 and the reactance 3 shown as capacitive as in Figures 1 and 4. The out-put circuit is taken off in parallel with the reactance 3 and as shown may be a vacuum tube rectifying circuit indicated generally at 20 from which it emerges as audio frequency electrical waves corresponding exactly to the sound waves which produce them. The combination of effective amplification of both impedance and controlled power makes possible the elimination of two stages of vacuum tube amplification, materially reduces oscillator frequency stabilization requirements, reduces the size and materially simplifies the construction of the microphone proper and makes the whole apparatus much more stable and simple to operate than were this amplification produced by vacuum tube stages. Instead of rectifying the power out-put from this impedance amplifier circuit, it could be directly amplified and fed to an antenna system for broadcasting if desired.

Figure 7 shows a complete position responsive circuit patterned after that of Figure 3 but showing the actual oscillator and out-put circuits. This complete circuit may be used to indicate minute variations of physical dimensions, causing these variations of dimensions to vary capacity as by varying the spacing of two plates forming a condenser. This variable capacity is represented by one of the condensers 21, the other being an adjusting condenser. The oscillator enclosed by the dotted outline 22 forms the source of power and is a modified Hartley circuit embodying the self-compensating features of the circuit shown in the Field Patent No. 1,813,488 granted July 7, 1931, operating directly from a 110 volt 60-cycle lighting circuit. This circuit operates with the compound secondary circuit herein shown, as well as with the single resonant secondary shown in the Field patent. The out-put circuit of Figure 7 consists of a high resistance high frequency voltmeter comprising a rectifying tube 23, a high resistance 24, radio and audio frequency chokes 25 and 26, respectively, and a low current ammeter 27. By using a meter with a suppressed zero a uniform scale reading directly in variation of dimension over the entire scale of the indicator is obtainable. The condenser at 28 corresponds to the impedance 2 in Figures 1 and 3.

In Figure 8 is shown a diagram for the control of the feed motor of a machine tool in such a manner that the tool will follow the in and out contour of a pattern as followed by a tracer which is made to traverse the pattern.

Figures 9 and 10 show sufficient of the machine construction to show the relations of the tool

and tracer and the connections of both to the feed motor. The tracer shown at 30 is spring mounted on a feed carriage 31 being urged as by the spring 32 to bear against the pattern P. This tracer has a portion forming a condenser plate movable toward and from a condenser plate 33 fixed to the feed carriage. Small variations in spacing of these two plates which together constitute a measuring device furnishes the controlling variable capacity. The feed carriage 31 also supports the tool T (Figure 10). The motor M acts to move the feed carriage in and out and its motions are controlled by the small changes of capacity of the tracer condenser 30, 33 in a manner to minimize these variations as will later appear.

Traversing motions between the work W and the tool T and between the tracer and the pattern P may be produced by any suitable means as by the motor M' shown in Figure 9 but for the sake of simplicity of description the control of the motor M' has not been included in the diagram of Figure 8. Power for the impedance amplifier circuit is provided by the oscillator circuit enclosed by the dotted line 40 in Figure 8 and the coupling and shunt condensers 41 and 42 correspond in functions to the impedance 2 and the reactance 3, respectively, of Figures 1 and 3. Both are shown as variable and coupled mechanically for simultaneous variation. The controlling reactance consists of the tracer condenser and its inductance 43, which together are capacitive, and the inductance 4 of Figure 8 corresponds to the same numbered inductance of Figure 1. Two separate out-put circuits are used in this arrangement each connected to the impedance amplifier circuit through small fixed condensers as 45 and 46, 47 and 48, which permit a free flow of radio frequency energy but provide complete insulation against flow of direct current. Each of these output circuits includes a rectifier such as the tubes 50 and 51 and suitable filters to provide substantially uniform direct current potentials. On each of these direct current potentials are superposed a direct current voltage of predetermined value as from a biasing battery 54, and an alternating current component from a phasing unit 55 suitably out of phase with the supply from the transformer 56, for controlling the grid potentials of a pair of gas filled power rectifier tubes 57 and 58. These tubes when supplied with alternating current plate cathode potential start to pass current in each positive half cycle whenever the grid voltage reaches a point sufficiently positive and continue to pass current through the remainder of the half cycle quite regardless of the grid voltage, so that by varying the opening time of the tube in each half cycle the power passed by it is regulated. By the use of the combination of direct current and alternating current grid voltages previously described, the control of the power out-put of each power tube is made responsive to the direct current potential derived from its out-put circuit from the impedance amplifier circuit. These controlling direct current potentials are reversely connected to the grids of the power tubes so that as the grid potential of one becomes more positive, the grid potential of the other becomes more negative and they supply power to the reverse field windings 60 and 61 of the direct current motor M. The grid voltages are so regulated that the motor M is stationary when the spacing between the tracer and the plate 33 is exactly a "null" or standard amount, and is rotated in one or the other direction whenever the spacing of the tracer 30 from the plate 33 is more or less than the predetermined null or standard amount, the rotation of the motor in either case being in such a direction as to move the feed carriage in a corrective direction to space the tracer and condenser plate 33 at exactly the null or standard amount. This method of controlling the out-put of a gas filled power rectifier tube is not claimed herein but forms subject matter of my application for patent Serial No. 562,694, filed September 14, 1931, for Method of controlling gas filled thermionic rectifiers and fundamental circuit therefor.

The curves shown in Figures 11 to 18 illustrate a few of the various effects which can be produced in output circuit voltage by variation of a controlling reactance, by the use of various combinations of inductances, resistors and condensers. For example, in the circuit of the type shown in Figure 3, it is possible to select values of E_1, of the resistance and reactance of the out-put circuit, of the resistance, inductance and capacity of the feed line or coupling circuit including the connecting leads 12, and of the resistance and impedance of the elements 2, 3 and 4, as well as of the resistance, self-inductance and mutual inductances of the main and coupling windings of the controlling unit 5, to produce a wide variety of resultant voltages on the out-put circuit as well as ratios and variations of ratio between change of the controlling reactance and the voltage of the out-put circuit. It has heretofore been mentioned how in the circuit of Figure 1 a variation of the reactance 3 varies the ratio of change of capacity of the condenser 5 to change of E_2. The same effect is produced in the circuit of Figure 4 for the same reason, except that the effect is extended so that the ratio may not be only increased or decreased, but also may be reversed by variations of the reactance 3. Many other effects can be produced in most cases by the simultaneous variations of two or more of the constants of the circuit.

Figure 11 shows a typical curve. As the controlling variable reactance approaches and passes through the point of series of resonance, the out-put voltage decreases, passes through a minimum marked *a* and then increases. Similarly as the control reactance approaches and passes through the point of parallel resonance the voltage rises and passes through a maximum at the point *b* and then decreases. For most practical purposes only a part of the curve lying between the points of resonance is used, the actual resonance points and the spaces beyond being set outside the range of use. It may be noted that the ratio of change of voltage to reactance is always less beyond the points of resonance and that as the controlling reactance approaches zero or infinity the out-put voltage approaches a fixed value, this value being the same for zero and infinity and it may be set either for a value mid-way between maximum or minimum or for any desired value through a wide range above or below this point.

In Figures 12 to 18 the typical curve of Figure 11 has been shown in dotted lines in order to show some of the variations which may be produced by modifying the circuit constants. For example, in Figure 12 the curve is shown as reversed, the parallel resonance point being shown at *b* and the series resonance point at *a*.

In Figure 13 the curve between the resonance points *a* and *b* has been considerably flattened and lowered.

In Figure 14 it has been shown as less steep

between the two resonant points which, however, are maintained at substantially the same out-put voltage.

In Figure 15 the curves beyond the resonance points have been varied without change between them. In Figure 16 the curve between the resonance points, departs substantially from straight line.

Figure 17 is somewhat similar to Figure 15, except that the curve beyond the resonance points is still further modified.

In Figure 18 the major portion of the curve between the resonance points is unchanged but the maximum and minimum out-put voltages are less widely separated.

From the foregoing description of this invention and certain circuits in which the invention has been shown as embodied, it will be evident to those skilled in the art that various other changes and modifications might be made without departing from the spirit or scope of this invention as defined by the appended claims.

I claim:

1. In combination, three reactances at least one of which is inductive, at least one of which is capacitive, and at least one of which is variable, said reactances being in series parallel arrangement in a circuit and of relative values such that small variations in said one variable reactance cause impedance of the circuit as a whole to pass between conditions of parallel and series resonance, thereby producing a large variation in impedance of the circuit as a whole as the result of such small variations in said variable reactance.

2. In combination, an alternating current circuit comprising an impedance, three reactances in series with said impedance, two of said reactances being arranged in series with each other and one of said two in parallel with the third, at least one of said two reactances being variable, said reactances being of such relative values that variation of said one variable reactance causes variations in said circuit between series and parallel resonance, and an output circuit connected to said first mentioned circuit.

3. In combination, an alternating current circuit comprising an impedance, a reactance in series with said impedance, a pair of reactances in said circuit one of which is capacitive and the other of which is inductive and at least one of which is variable, said reactances being in series-parallel arrangement and of relative values to cause variation of said one variable reactance to cause variations between series and parallel resonance in said circuit, and an out-put circuit connected to said first mentioned circuit.

4. In combination, a series-parallel circuit consisting of three reactive impedances, at least one of which is capacitive and at least one of which is inductive and one of which is variable, the values and arrangements of said impedances being such that small variations in said one variable impedance produce much larger changes in the impedances of said circuit as a whole, a source of substantially constant frequency and current value alternating current power connected to said circuit, and an out-put circuit deriving power from said series-parallel circuit.

5. In combination, a series-parallel circuit consisting of three reactive impedances, at least one of which is capacitive and at least one of which is inductive and one of which is variable, the values and arrangements of said impedances being such that small variations in said one variable impedance produces much larger changes in the impedances of said circuit as a whole, a source of substantially constant frequency and potential alternating current power, means including a coupling impedance for connecting said source to said circuit, and an out-put circuit deriving power from said series-parallel circuit.

6. In combination, an alternating current circuit comprising an impedance, a series-parallel circuit comprising a reactance in series with said impedance, an inductance and a capacity, at least one being variable, in series with each other and both together in parallel with said reactance, the relative values and characteristics of said reactances and the relative values of said capacity and inductance being such that variation of said one variable causes change between series and parallel resonance between said reactance, capacity and inductance, and an output circuit deriving power from said series-parallel circuit.

7. In combination, an alternating current circuit comprising an impedance, a series-parallel circuit comprising a reactance in series with said impedance, an inductance and a capacity at least one being variable, in parallel with each other and both together in series with said reactance, the relative values and characteristics of said reactances and the relative values of said capacity and inductance being such that variation of said one variable causes change between series and parallel resonance between said reactance, capacity and inductance, and an out-put circuit deriving power from said series-parallel circuit.

8. In combination, an alternating current circuit comprising an impedance, a series-parallel circuit comprising a capacity in series with said impedance, an inductance and a variable capacity in series with each other and both in parallel with said first mentioned capacity, said capacities and inductance being of such relative values that variations of said variable capacity causes change in said series-parallel circuit between series resonance between said variable capacity and inductance and parallel resonance between said variable capacity and inductance together and said first mentioned capacity, and an out-put circuit deriving power from said series-parallel circuit.

9. In combination, a series-parallel circuit consisting of three reactive impedances, at least one of which is capacitive, at least one of which is inductive and at least one of which is variable, said one variable impedance being responsive in its variations to a controlling variable to which an amplified response is desired, and having a low voltage connection with the other of said impedances, a source of substantially constant frequency and potential alternating current power, means including a coupling impedance connecting said source to said circuit, and an out-put circuit deriving power from said series-parallel circuit.

10. In combination, a series-parallel circuit consisting of three reactive impedances, at least one of which is capacitive, at least one of which is inductive, and at least one of which is variable, a measuring device of which said one variable impedance forms a part and the value of which is responsive to that of the variable being measured, a source of substantially constant frequency and potential alternating current power, means including a coupling impedance connecting said source to said circuit, and an indicator responsive to electrical conditions of said circuit.

11. In combination in a machine for controlling the feed of a cutting tool to reproduce on a

work blank the contour of a pattern surface, a support for said blank and the pattern, a measuring device comprising an element for tracing the pattern surface, a support for said tool, a reactive impedance variable automatically in response to relative movement between said pattern surface and a portion of said device and between said tool and blank, a direct current motor having reverse field windings for producing relative feed and retracting movements between said portion of said device and said pattern and between said tool and said blank, a series-parallel circuit including said reactive impedance and two other reactive impedances, one at least of said three impedances being capacitive and one at least being inductive, a source of substantially constant frequency and potential alternating current power, means including a coupling impedance connecting said source to said circuit, a rectifier tube for feeding power to each of said field windings and to the armature of said motor, a pair of grid control circuits for said tubes derived from said series-parallel circuit, a rectifier in each control circuit between said series-parallel circuit and its grid to produce a direct current bias on each grid, said rectifiers being reversely connected to said grids whereby as one grid becomes more positive the other grid becomes more negative, and other grid potential components for said tube including alternating current potential of suitable magnitude and phase relation to the plate-cathode potential of said tubes to cause said motor to be operated in a corrective direction to minimize variations between said pattern surface and said measuring device portion.

12. The method of amplifying variations of a reactance, which comprises causing such variations of said one reactance to vary circuit reactances of an alternating current series-parallel circuit between series and parallel resonance, said reactances being in series with an impedance of substantial value, and taking off amplified response across said series-parallel circuit.

13. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, an in-put impedance, a net work comprising three reactances in series with said impedances, two of such reactances being arranged in series with each other and one of said two in parallel with the third, at least one of said two reactances being variable, said reactances being of such relative values that variation of said one variable reactance causes variations in said net work between series and parallel resonance, and an output circuit connected to said net work.

14. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, an in-put impedance, and a net work comprising a reactance in series with said impedance, a pair of reactances in said net work one of which is capacitive and the other of which is inductive and at least one of which is variable, said three reactances being in series parallel arrangement and of relative values to cause variation of said one variable reactance to cause variations between series and parallel resonance in said net work, and an output circuit connected to said system.

15. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, an in-put impedance, and a network comprising three reactive impedances, at least one of which is capacitive and at least one of which is inductive and one of which is variable, the values and arrangements of said impedances being such that small variations in said one variable impedance produce much larger changes in the impedance of the network as a whole, and an output circuit deriving power from said network.

16. In combination, three reactances at least one of which is inductive, at least one of which is capacitive, and at least one of which is variable, said reactances being in series parallel arrangement in a circuit and of relative values such that small variations in said one variable reactance cause the circuit as a whole to pass between parallel and series resonance, and so arranged that the ratio of change of total circuit impedance to change of variable reactance is determined by choice of values of the others of said reactances, thereby producing a large variation in impedance of the circuit as a whole as a result of much smaller variations in said variable reactance.

17. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, a network, a substantially constant impedance through which energy from said source is supplied to said network, at least three reactances in said network at least one of which is inductive and at least one of which is capacitive and at least one of which is variable, the network being so arranged that a small proportionate change of reactance of said one variable reactance will cause the impedance of the network as a whole to vary between values large and small in proportion of the in-put impedance, thereby causing the potential across the net work to vary between a value approaching the potential of said supply source and a value approaching zero, and means responsive to said potential variation.

18. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, a network, a substantially constant impedance through which energy from said source is supplied to said net work, at least three reactances in said net work at least one of which is inductive and at least one of which is capacitive and at least one of which is variable, the network being so arranged that a small proportionate change of reactance of said one variable reactance will cause the impedance of the network as a whole to vary between values large and small in proportion to the in-put impedance thereby causing the current through said network to vary between a value approaching that of the supply potential divided by the in-put impedance and a value approaching zero, and means responsive to said current variations.

19. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, a network, a substantially constant impedance through which energy from said source is supplied to said network, at least three reactances in said network at least one of which is inductive and at least one of which is capacitive and at least one of which is variable, the network being so arranged that a small proportionate change of re-

actance of said one variable reactance will cause the impedance of the net work as a whole to vary between values large and small in proportion to the in-put impedance, thereby causing the potential across the network to vary between a value approaching the potential of said supply source and a value approaching zero, said variations of impedance and potential being governed substantially entirely by variations of reactance and being substantially entirely independent of variations of resistance of said variable reactance.

20. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, a network, a substantially constant impedance through which energy from said source is supplied to said network, at least three reactances in said network at least one of which is inductive and at least one of which is capacitive and at least one of which is variable, the network being so arranged that a small proportionate change of reactance of said one variable reactance will cause the impedance of the network as a whole to vary between values large and small in proportion to the input impedance, thereby causing the current through said network to vary between a value approaching that of the supply potential divided by the in-put impedance and a value approaching zero, said variations of impedance and current being governed substantially entirely by variations of reactance and substantially entirely independent of variations of resistance of said variable reactance.

21. An electrical circuit supplied with alternating current power of substantially constant frequency comprising at least three impedances at least one of which is variable, said impedances having such relative values that variation in said variable impedance causes the impedance of the circuit as a whole to vary between the conditions of parallel and series resonance, thereby producing a variation in the impedance of the circuit as a whole.

22. An electrical circuit supplied with alternating current power of substantially constant frequency comprising at least three impedances, at least one of which has an effective inductive reactance, at least one of which has effective capacitive reactance, at least one of which is variable, said impedances connected in series-parallel and having such relative values that variation in said one variable impedance causes the impedance of the circuit as a whole to vary between the conditions of parallel and series resonance, thereby producing a variation in the impedance of the circuit as a whole.

WILFRED H. HOWE.

CERTIFICATE OF CORRECTION.

Patent No. 2,074,396. March 23, 1937.

WILFRED H. HOWE.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, second column, line 46, strike out the word "of" after "series"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of April, A. D. 1937.

Leslie Frazer
Acting Commissioner of Patents.

(Seal)

actance of said one variable reactance will cause the impedance of the net work as a whole to vary between values large and small in proportion to the in-put impedance, thereby causing the potential across the network to vary between a value approaching the potential of said supply source and a value approaching zero, said variations of impedance and potential being governed substantially entirely by variations of reactance and being substantially entirely independent of variations of resistance of said variable reactance.

20. An electrical system responsive to small changes of electrical reactance, comprising a source of alternating current energy of substantially constant potential and frequency, a network, a substantially constant impedance through which energy from said source is supplied to said network, at least three reactances in said network at least one of which is inductive and at least one of which is capacitive and at least one of which is variable, the network being so arranged that a small proportionate change of reactance of said one variable reactance will cause the impedance of the network as a whole to vary between values large and small in proportion to the input impedance, thereby causing the current through said network to vary between a value approaching that of the supply potential divided by the in-put impedance and a value approaching zero, said variations of impedance and current being governed substantially entirely by variations of reactance and substantially entirely independent of variations of resistance of said variable reactance.

21. An electrical circuit supplied with alternating current power of substantially constant frequency comprising at least three impedances at least one of which is variable, said impedances having such relative values that variation in said variable impedance causes the impedance of the circuit as a whole to vary between the conditions of parallel and series resonance, thereby producing a variation in the impedance of the circuit as a whole.

22. An electrical circuit supplied with alternating current power of substantially constant frequency comprising at least three impedances, at least one of which has an effective inductive reactance, at least one of which has effective capacitive reactance, at least one of which is variable, said impedances connected in series-parallel and having such relative values that variation in said one variable impedance causes the impedance of the circuit as a whole to vary between the conditions of parallel and series resonance, thereby producing a variation in the impedance of the circuit as a whole.

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