

Feb. 23, 1937.

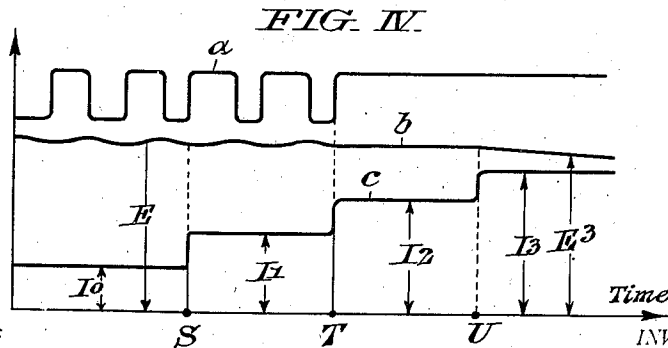
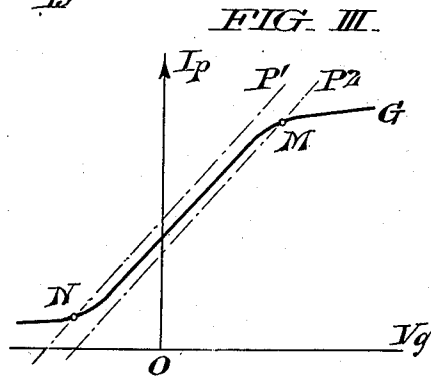
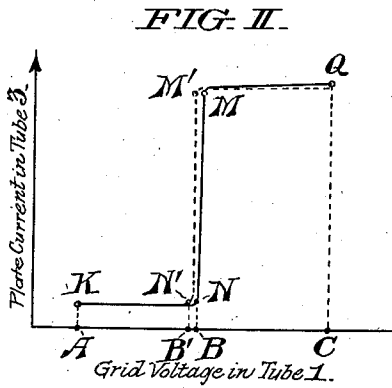
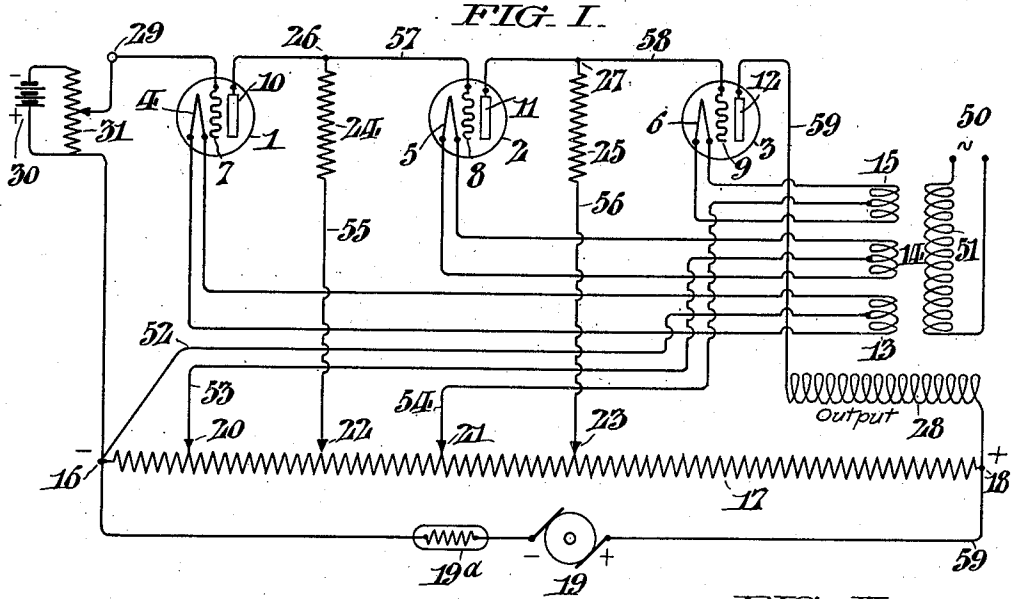
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2,071,759

ELECTRON DISCHARGE TUBE SYSTEM

Filed June 25, 1926

5 Sheets-Sheet 1



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FIG. V.

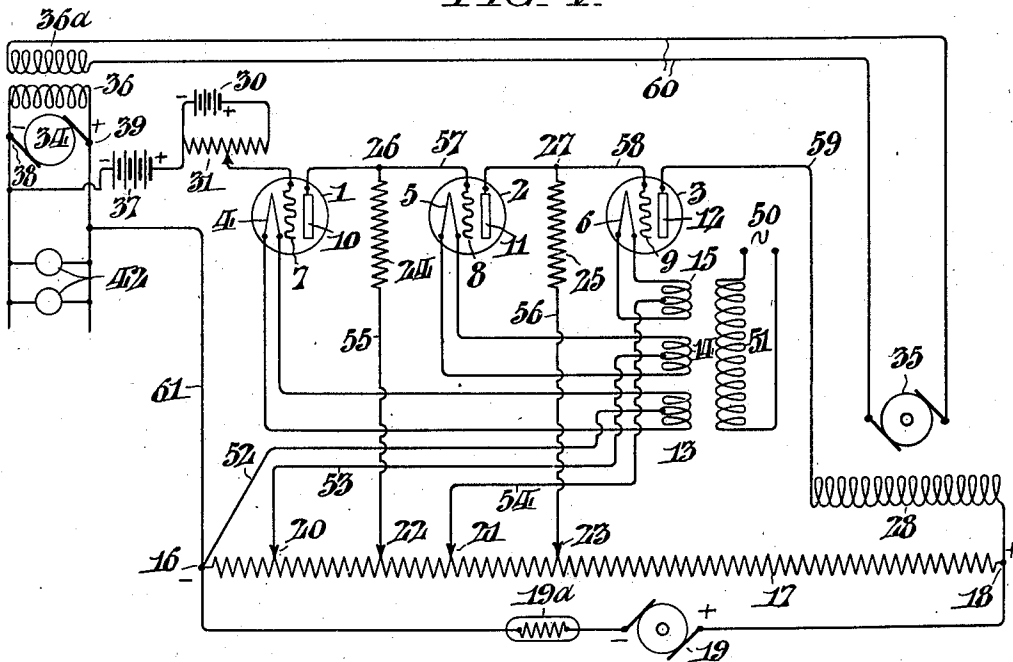
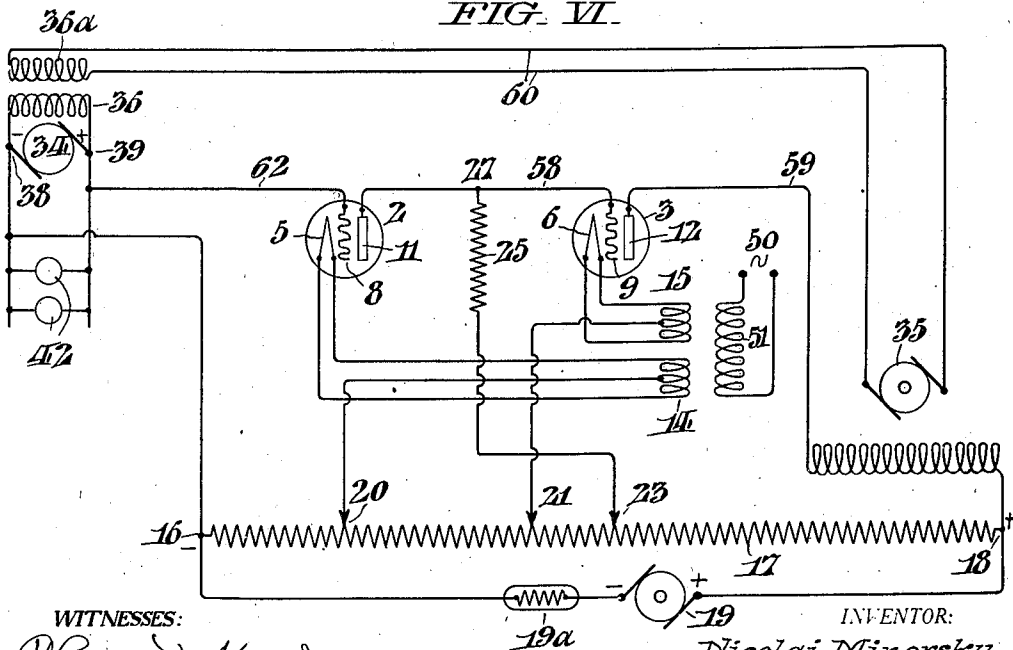


FIG. VI.



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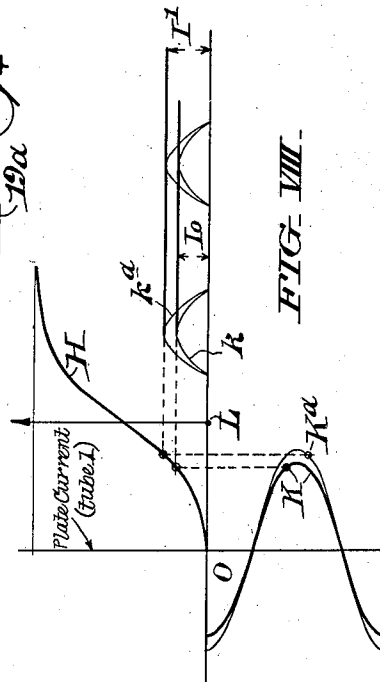
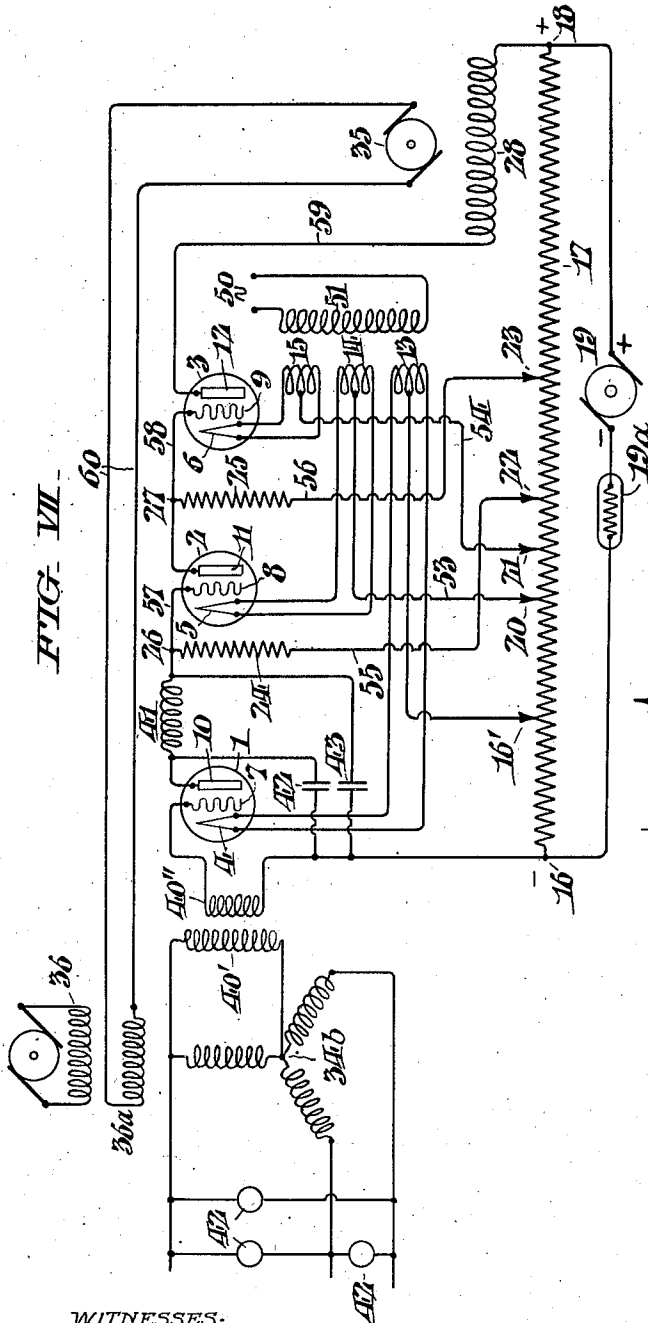
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ELECTRON DISCHARGE TUBE SYSTEM

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5 Sheets-Sheet 3



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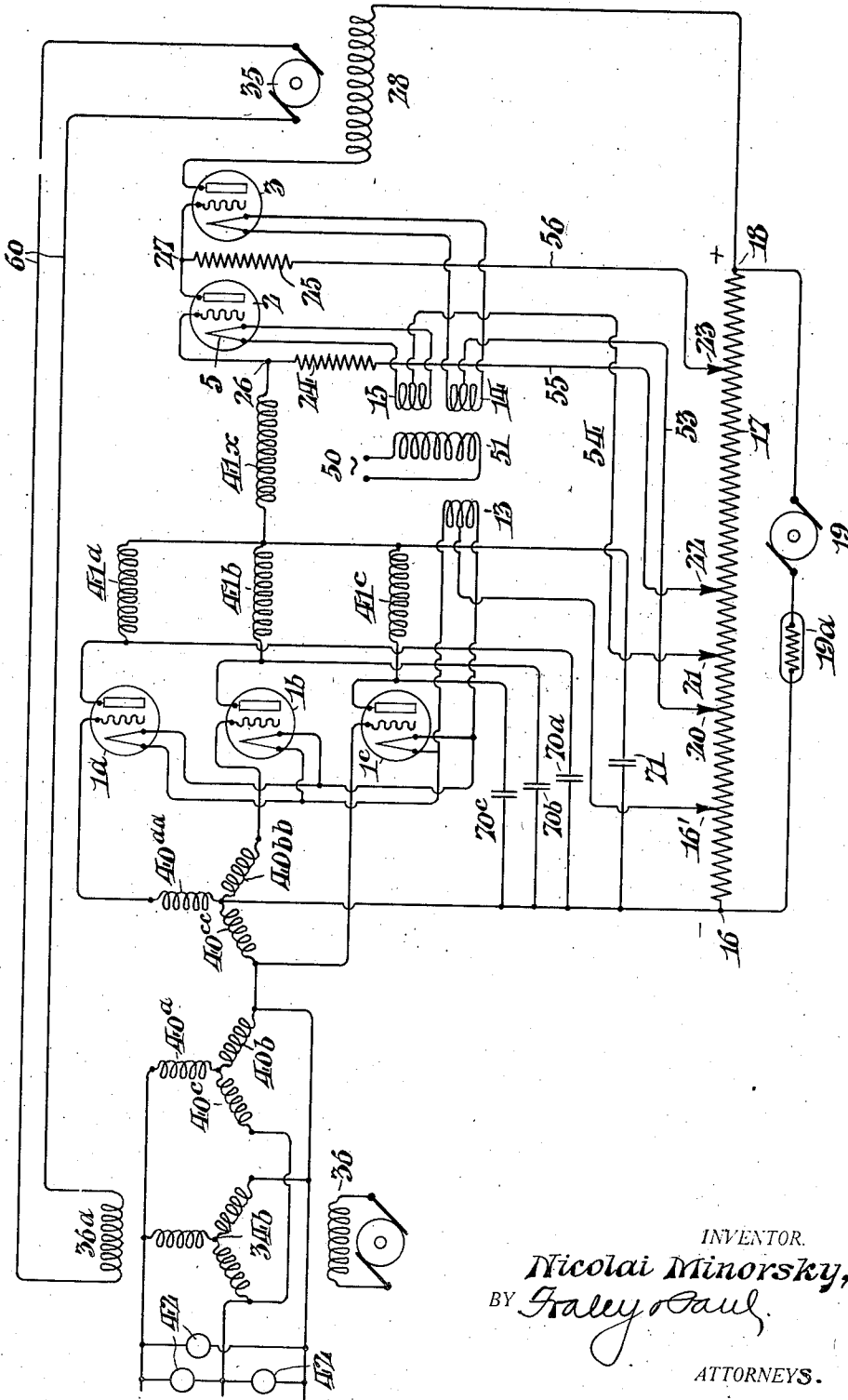
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ELECTRON DISCHARGE TUBE SYSTEM

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FIG. 11.



Feb. 23, 1937.

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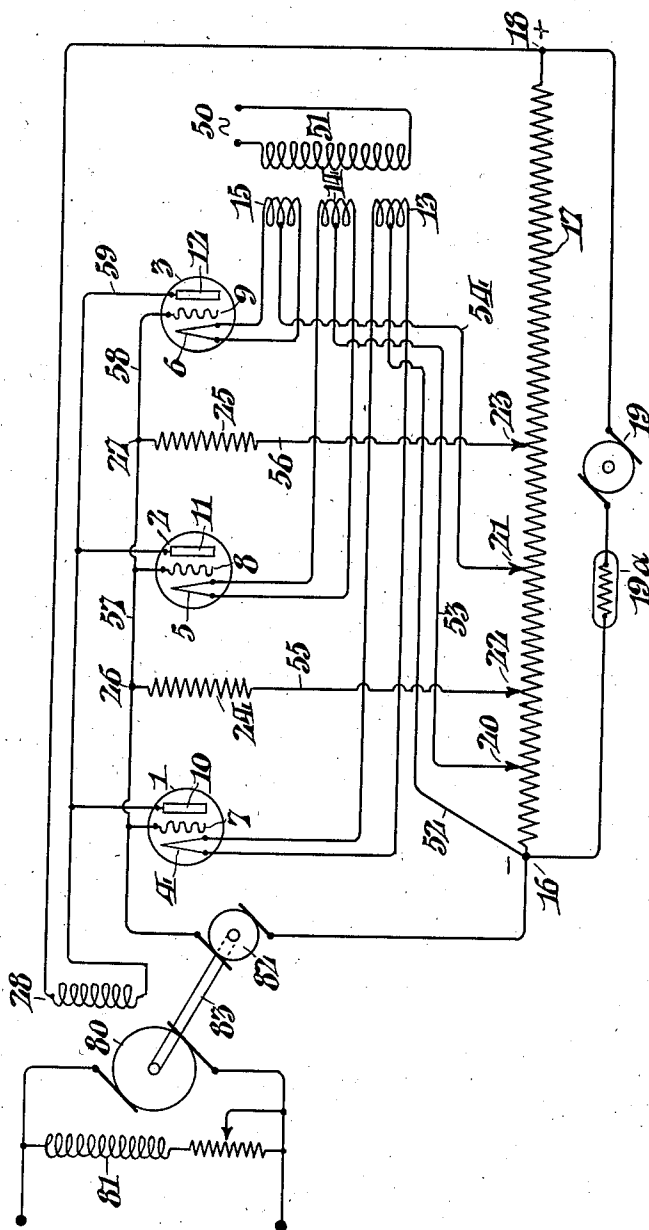
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ELECTRON DISCHARGE TUBE SYSTEM

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FIG. X.



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2,071,759

ELECTRON DISCHARGE TUBE SYSTEM

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Application June 25, 1926, Serial No. 118,508

12 Claims. (Cl. 179—171)

This invention relates to circuits employing electron discharge tubes, and more particularly to such systems for use with direct currents.

It has heretofore been proposed to employ the remarkable properties of such tubes in various ways, but very little progress has been made in their use in direct-current circuits, although theoretically, the applications of such tubes in this connection are very attractive, as the tubes would form inertialess relays with very high ohmic resistance particularly adapting them for series operation in highly inductive circuits, with a low time constant and hence rapid control.

An especial difficulty encountered with such systems was the necessity for many and very large grid batteries, which are difficult to adjust when several stages of amplification are used.

The present invention resulted from work designed toward eliminating difficulties inherent in former systems, and incidentally provides a tube system with entirely new properties differing from those of an ordinary amplifier. Under certain conditions, the system behaves abruptly, similar to the action of an electric contact switch.

It is further found that by its use, an electron discharge tube is associated with circuits in such a way that both the grid and the filament may change potentials; and in particular the grid is caused to change its potential from an input, and the filament to change its potential from the output of the tube, so that a regenerative effect may be obtained, either directly or reversely as the direction of change of potential at the grid may be established.

A resistance coupled amplifier circuit is provided having a plurality of electron discharge tubes, in which the tubes receive their space current and grid biasing potentials from a common direct current source, in such manner that the regulation of the tube circuits produces reactions from this common source and its associated elements upon the tube circuits themselves, whereby the cumulative or regenerative effect is obtained.

A peculiar feature of this invention is the fact, as set forth above, that the tube system has the characteristic of acting, under certain circumstances, as an electric contact switch rather than in the usual continuous or gradual manner of electron discharge tube circuits: this is herein-after termed the "contact effect", as by it a discontinuous and instantaneous circuit-making and circuit-breaking performance may be produced, similar to the action of an electric contact

switch. This phenomenon may be employed in controlling and regulating apparatus associated with such a circuit, whereby an instantaneous and decisive action may be obtained at a predetermined and adjustable point, and substantial quiescence or continuity of action at other points. To this purpose, the circuits are provided to establish a single point of stability in the output of the system at each of a plurality of applied grid potentials, and these individual values for stability are separated by graph distances corresponding to a large space current variation in the tube as it passes from one grid potential differing very little from the first.

This invention may be employed in conjunction with various electrical controlling systems, in which a supervising instrument such as a bolometer, a thermostat or thermometer, a pressure gage, a Pitot or Venturi tube, a photoelectric cell, or other hydraulic, centrifugal electrical, mechanical or optical device is employed to govern an electric circuit including a regulator such as a trip-out relay, voltage or current regulator for a direct or alternating current generator, speed controlling device, etc., whereby the regulation is accomplished.

The invention is illustrated by way of example in the accompanying drawings, which demonstrate the circuits employable and several applications of the phenomena produced thereby, to the regulation of electrical machinery: but it will be understood that these illustrations are not limitations.

In the drawings:

Fig. I is a circuit diagram of the arrangement of a system according to the invention, having three three-electrode electron discharge tubes.

Fig. II is a graphic diagram of a phenomenon which may be produced in the circuit of Fig. I.

Fig. III is another graphic diagram illustrating the principle of the phenomenon.

Fig. IV is a further graphic diagram illustrating the result of the phenomenon when the circuit is associated with a regulator for an electric generator.

Fig. V is a circuit diagram similar to Fig. I, with the tube system employed to regulate a direct current generator.

Fig. VI is a modification of the circuit shown in Fig. V.

Fig. VII is a circuit diagram of the application of the invention to the regulation of an alternating current generator.

Fig. VIII is a graphic diagram illustrating the

rectifying and regulating effect of the apparatus shown in the diagram of Fig. VII.

Fig. IX is another circuit diagram of an arrangement similar to that of Fig. VII.

Fig. X is a circuit diagram resembling Fig. I, in which the speed of an electric motor is supervised and controlled.

Referring to Fig. I, the electron discharge tubes 1, 2, 3 have the filamentary cathodes 4, 5, 6; the grids 7, 8, 9; and the anodes 10, 11, 12. The tubes 1 and 2 are preferably high amplification tubes, while the tube 3 is a power tube. The filaments 4, 5, 6 are heated by individual sources of electricity, such as the separate secondaries 13, 14, 15 of the transformer whose single primary winding 51 is connected to an alternating current supply main 50.

The potentiometer 17 has the end terminals 16 and 18 across which is applied a direct current from a source of such energy, e. g., the generator 19. The cathodes or filaments 4, 5, 6 are connected respectively to the points 16, 20, 21 on this potentiometer by the respective conductors 52, 53, 54 which, with the illustrated employment of an alternating heating current, are connected to the middle points of the secondary windings 13, 14, 15. The filaments 4, 5, 6 are thereby maintained at negative potentials; filament 4 being at the negative potential of generator 19, while filaments 5 and 6 may have their potentials varied by sliding the contacts 20, 21 along the potentiometer 17.

The anode circuits of the tubes 1, 2 are connected by wires 55, 56 through the respective fixed resistors 24, 25 to the points 22, 23, which represent sliding contacts on the potentiometer 17. The points 26, 27 intermediate the anodes 10, 11 and the resistors 24, 25 are connected by wires 57, 58 to the grids 8, 9 of the succeeding tubes 2, 3, in their respective relations. The anode 12 of the tube 3 is connected by wire 59 through a coil 28 to the end point 18 of the potentiometer 17 which is at the positive potential of the generator 19. The coil 28 constitutes the output of the system, and may be the field coil of an exciter, the trip coil of a relay, etc.

The staggering of points 16, 20, 22, 21 with regard to each other eliminates the necessity of having biasing batteries, but requires the use of separate sources of heating current.

The grid 7 of the tube 1 is connected to a terminal 29; and the input potential for the system is applied between points 16 and 29. In order to explain the operation of the system for the "contact effect", these points are shown with the electromotive force of a battery 30 applied across them, as regulated by the potentiometer 31, since generally the grid 7 must be biased at a certain negative potential with respect to the point 16 or the filament 4. The potential applied across points 29 and 16, by slight variation at the critical condition of the system, produces the phenomenon of the "contact effect", and this potential will therefore be hereinafter called the "trigger voltage".

The tube 1 is normally at the potential difference between points 22 and 16 on the potentiometer 17; the tube 2 at the potential difference between points 23 and 20; and the tube 3 at the potential difference between points 18 and 21. These potential differences 22-16, 23-20, 18-21 are staggered with respect to each other by the amounts corresponding to the potential drops across the overlaps 20-16, 21-20, respectively. By moving the sliding contacts, it is possible to so control these differences as to eliminate the

necessity for grid biasing batteries between point 26 and the grid 8 on the one hand, and between point 27 and the grid 9 on the other.

If desired, the current from the generator or source 19 may be kept constant by a ballast device 19^a of well known type.

The system shown in Fig. I may be operated in any one of three ways: (1) as a resistance-coupled amplifier; (2) as a regenerative amplifier; (3) as a "contact effect" device, with self-excitation: which will now be individually described.

1. In this case, the elements of the system are so adjusted that the current through the potentiometer 17 is much greater than the space currents in the tubes themselves. The tubes 1, 2 are voltage amplifier tubes and their internal resistance is very high, so that the plate currents therein are generally negligible as compared to the plate current of the power tube 3, which itself must be negligible as compared to the current flowing through the potentiometer 17: in such event, changes in the several plate currents, or in any of them, will not cause any appreciable change in the distribution of current along the potentiometer.

In an actual test, the potentiometer 17 had a total resistance of about 350 ohms; the generator 19 delivered a steady potential difference of about 350 volts. The tubes 1 and 2 were Western Electric type 102-D tubes, and tube 3 was a Western Electric 101-D power tube. The plate resistors 24 and 25 were each of about 200,000 ohms. The tube 1 worked under the potential difference between 16 and 22, and tube 2 under that between 20 and 23, which were staggered so that the controlling point 26 of tube 1 was about 1½ volts below the potential of the filament (point 20) of the second tube, which corresponds approximately to the middle point of the rectilinear part of its characteristic. The alternating current mains 50 were fed by 110 volt, 60 cycle current. Thus the plate currents in tubes 1 and 2 may be of the order of 1 milliamperes or less; the plate current in tube 3 of the order of 20-30 milliamperes; and the potentiometer current 1 ampere.

Assuming that the potential of the grid 7 of tube 1 is increased by a small amount in any way, e. g., by moving the sliding contact of the potentiometer 31; the increased potential of the grid 7 will cause an increased space current to flow between filament 4 and anode 10 of the tube 1, with a resultant decrease of the potential of the point 26 and at the grid 8 of the tube 2. The space current in the tube 2 will decrease, so that a correspondingly increased potential will be applied at point 27 and the grid 9 of the tube 3. The space current in the tube 3 will accordingly increase, and hence the plate current flowing through the output coil 28. In the instance above, the plate or output current variations in tube 3 will be of the order of 25 or 30 milliamperes.

The amplification obtained is linear, i. e., a small variation of the input voltage on tube 1 will produce a proportional variation of the plate current of tube 3, provided the sliding contacts 20, 21, 22, 23 have been located at such positions that the initial point of performance is approximately at the middle of the rectilinear portion of the characteristic curve of the respective tube. When the points 20, 22, 2, are once adjusted, their potentials remain constant and no further adjustment is needed: the system works as a very stable and reliable amplifier whose amplification may readily be calculated in the known way.

2. If the plate current variations of the power tube 3 are approximately of the same order of magnitude as the current flowing through the potentiometer, for example the current through the potentiometer being about one hundred milliamperes and the plate current variations of the tube 3 around 20-50 milliamperes, the tube 3 constitutes a variable resistance connected in parallel with the section 21-18 of the potentiometer 17. Then, by Kirchhoff's laws, for the parallel resistances (tube 3 and section 21-18) in series with the section 21-16 of the potentiometer, a decreased resistance of the tube 3 will cause an increase of the current flowing between points 16 and 21, so that the potential at point 21 increases in proportion. Likewise, the potentials of points 20 and 22 increase and the potential difference between points 21 and 18 decreases, in proportion. This redistribution along the potentiometer causes important reactions upon the tubes in the system.

Firstly, the effect of variation in the plate current in tubes 1 and 2 upon the potential and current distribution along the potentiometer 17 may be neglected, as in a practical case these variations were of the order of 0.5 milliamperes or less, whereas the potentiometer current was 100 milliamperes, and the fluctuation of the power tube 3 was about 50 milliamperes, and hence the redistribution of currents and voltages is due solely to the variable conductance of the tube 3.

Secondly, the potential of the grid 7 is made slightly more positive than before. The space current in the tubes 1 and 3 increases, and in the tube 2 decreases. The increased conductance of the tube 3 causes the redistribution of potentials indicated above, and the potentials of the points 20, 21, 22, become more positive. The filament 5 is connected to point 20, and its potential is accordingly increased. The space current in tube 2 therefore decreases because (1) the grid potential becomes more negative, and (2) the filament potential becomes more positive. This constitutes a distinctive feature of the invention and contributes to produce a greater increase by amplification than is the case when the potential of the filament remains constant, and gives the regenerative effect, since the filament potential of tube 2 depends on the current flowing in the succeeding tube. The opposite effect is obtained in the tube 3, so that when the potential of the grid 9 increases, the potential of the filament 6 also increases, so that the amplification in the tube 3 is slightly decreased. The final effect when three tubes are employed, as shown in Fig. 1, is a gain of amplification because the gain in the tube 2 considerably outweighs the loss in the tube 3. The first tube is not in such case affected by the regeneration, as its filament 4 is maintained at the fixed potential of the point 16. In case more than three tubes be connected in a similar manner, there will always be a gain of amplification, since the regenerative effect in each subsequent tube will be less than that in the preceding tube, and there is always a gain in the second tube where the regenerative effect first appears: and the same gain of amplification is obtained if only two tubes be employed, the second being a power tube, although the result is not then so apparent as with three tubes.

3. The third method of operation is the most important, and constitutes an entirely new method of employing electron discharge tubes with associated circuits. This method is a fur-

ther development of the second, in which the amount of regeneration is increased above a certain critical value, whereby the performance of the system becomes abrupt and discontinuous; there is a substantially instantaneous passage from a condition at which a certain amount of plate current flows through the output coil to a condition at which a widely different amount flows, and this passage is provoked by a very small change of the applied potential. These amounts of current remain fairly constant when the applied potential departs in the respective direction from this critical value. The abrupt effect greatly resembles that of a contact switch in making or breaking a circuit; and hence is called the "contact effect". It usually occurs at substantially the same critical value whether the input potential is increasing or decreasing in value.

This is represented by the graphic diagram of Fig. II in which the plate current in tube 3 and the applied grid potential on tube 1 are plotted as coordinates. If the grid potential on tube 1 be originally negative, and be steadily increased from a value A to a critical value B, the plate current in the tube 3 changes but very little in passing from the value K to the value N. A discontinuity however occurs at the critical value B, so that a further increase of grid potential in the tube causes the plate current in tube 3 to jump abruptly from the value N to the value M, which generally is that of the saturation current in the tube 3. A further increase of applied grid potential on tube 1 to the value C produces substantially no further change of the plate current in passing from the point M to the point Q.

When the applied grid potential on tube 1 is decreased from an initial value C, an inverse action occurs. As the potential approaches a critical value B' which is very close to the critical value B with an increasing grid potential, the plate current abruptly drops from the value M' which is substantially equal to the value Q, to a value N'. A further decrease of grid potential from the value B' to the value A produces substantially no further change of the current. The points M, M' and N, N' are very close together, and respectively represent substantially the same current values. In practice, it has been found possible to make the zone B-B' very narrow, and its position within the range A-C may be varied at will.

In an actual instance, this potential difference was varied from 5 to 20-30 millivolts, and in one particular instance was reduced to 0.1 millivolt; with a plate current variation in the last stage of about 35-40 milliamperes in each case. The potentiometer 17 had a resistance of about 3500 ohms, resistors 24, 25 about 200,000 ohms each, and the grid bias potentials were about 1½ volts as before. The phenomenon is very erratic when the grid potential lies between B' and B: There is no actual grid control and the plate current moves from high to low value upon the occurrence of extremely slight changes.

The slightest increase at B' or decrease at B acts as a trigger to release the "contact effect".

The position of this range B'-B may be shifted to another place by changing the staggering of the filament potentials, by changing the plate resistors 24, 25, etc.; but for given parameters, it is constant to a remarkable degree of precision, and the discontinuity always occurs at a strictly identical point of the grid voltage of the first tube.

This "contact effect" appears to require no spontaneous alternating current self-excitation, though of the same nature as the self-excitation of a shunt-wound direct current generator.

- 5 When a generating and a receiving circuit exchange energy, the equilibrium may be defined as stable when a small departure of the system from this equilibrium position disappears spontaneously in the course of time if the system is left
10 to itself. The Kaufman criterion (Ann. d. Phys. (4) 2, 158, 1900) may be phrased: The equilibrium of an electric system is stable when the slope of the tangent to the characteristic of the receiver at the point of equilibrium is greater than
15 the corresponding slope for the generator: and is unstable in the opposite case.

In Fig. III, the curve G is plotted from the plate current I_p and the grid voltage V_g of the tube 3 of Fig. I; and the straight line P^1 represents the effect of the reaction to the potentiometer due to the variation of the plate current in the tube 3. This variation appears as explained above as a variation of the filament potential of tube 3, i. e. as an equivalent opposite variation of the grid potential of this tube, and can therefore be represented on the same diagram as the characteristic curve G of this tube. In this case G is the generator curve, and P^1 and P^2 the receiver curves: At N, the slope of G is less than the slope of P^1 , and the system is stable, and the same is true at M with respect to P^2 .

The theory shows that for a variation of the grid potential of tube 1 there is a displacement of the straight line substantially parallel to itself from P^1 to P^2 . Line P^1 intersects the curve G only at the point N, while line P^2 intersects it only at the point M: these points N and M in Fig. III correspond to those in Fig. II. Although generally lines P^1 and P^2 are curved instead of straight, the same remarks hold: and the maximum sharpness occurs when the shapes of the curves P^1 , P^2 are substantially identical with the shape of the curve G, in which case it is sufficient to give the slightest change at B or B' in Fig. II to the grid potential of tube 1 to release the phenomenon through the whole range from N to M in Fig. III, or vice versa.

The tubes 2 and 3 therefore have a mutual controlling action upon each other; when one is at a maximum, the other is at a minimum, and vice versa. In practice, it is preferable to have one or the other at a saturation value at all times. When tube 2 is at saturation, the tube 3, with its opposite characteristic in the circuit system of the present invention, is delivering a constant current of minimum value (i. e. the graph from K to N in Fig. II); and when tube 3 is at saturation, (graph from M to Q in Fig. II) its reaction upon tube 2 reduces the current in this latter tube to a minimum. Hence the values of current output from tube 3 are dependent upon the saturation currents in tubes 2 and 3, and are substantially constant at a maximum or a minimum.

The "contact effect" therefore occurs where the electron discharge tube is associated with circuits which afford at two widely separated positions stable current equilibrium separated by a zone of instability, and whereby the passage from one position to the other is accomplished by means of a very small variation of applied potential which displaces the receiver curve from its position P^1 determining current stability at the value N to the position P^2 determining such stability at value M.

It may be stated that oscillograms show that the time for passage from N to M or from M' to N' is of the order of one two-thousandth of a second.

The above description of the circuit arrangements of the electron discharge tubes demonstrate the method of obtaining the "contact effect", and hereinafter a number of applications of this "contact effect" to the regulation and control of mechanisms will be described.

Fig. V represents the application of this contact effect to the voltage regulation of a direct current generator 34. The electron discharge tube system and its circuits have the same reference characters in Fig. I, and the output of the last tube 3 passes through the coil 28 which in this instance is the field coil of a direct current exciter 35 which is connected by the conductors 60 with the auxiliary field 36a of the generator 34. It will be understood that the generator 34 may have the customary main fields 36. The control winding 36a has a sufficient value in ampere-turns to counteract the effect of the armature reaction in the generator 34 during the regulation. Connected in parallel across the generator terminals 38, 39 is a source of reference voltage 37 such as a battery whose voltage may be maintained very nearly constant, and the purpose of which is to determine the magnitude of the voltage to be maintained by the generator 34 at all loads. The negative terminal of the source 37 is connected to the negative terminal 38 of the generator 34; and the positive terminal of the source 37 is connected to the grid 7 of the tube 1, while the end terminal 16 of the potentiometer 17 is connected by a conductor 61 with the positive terminal 39 of the generator 34. It is preferred to connect a small regulating battery 30 in shunt of a potentiometer 31 in the circuit between the reference battery 37 and the grid 7 of the tube, so that the exact potential of the batteries 37 and 30 may be closely regulated. The load on the generator 34 is conventionally represented by the lamps 42.

The operation of this voltage regulating system is as follows:

Assuming that initially the generator is at a condition of no load and that its terminal voltage is exactly equal to the electromotive force of the source 37. The potentiometer 31 for this particular position must be adjusted so as to impress upon the grid 7 of the tube 1 a potential slightly more negative than that corresponding to the point B in Fig. II. The voltages of the generator 34 and of the reference source 37 annul each other under this condition of operation. The current flowing in the coil 28 is therefore either zero or very small, and is represented by the value N in Fig. II. Therefore the exciter 35 under such condition delivers substantially no current through the auxiliary winding 36a, and the voltage of the generator 34 is determined by the main winding 36.

If a load 42 is placed upon the generator, its terminal voltage decreases and no longer annuls the effect of the reference battery 37; the grid voltage of the tube 1 increases accordingly and goes beyond the critical value B' in Fig. II. In passing the value B the plate current abruptly jumps from the value N to the value M, releasing the transient: in this way, the plate current of the tube 3 flowing through the output coil 28 is suddenly increased in value, whereby the exciter 35 will deliver current through the conductor 60 and the auxiliary winding 36a of the

generator 34, with a resultant increase in the voltage from the generator. As this generator voltage increases, it will restore the mains to the initial condition of predetermined constant voltage. On the other hand, when the voltage of the generator increases in proportion to the reference voltage until they are equal to each other again, which is equivalent to the decrease of the applied grid voltage on tube 1 from C to beyond B' in Fig. II, the reverse phenomenon occurs and the current flowing through coil 28 now drops from the value M' to the value N', so that the auxiliary winding 36a no longer receives current from the exciter 35, and the generator again is excited by its main winding 36 alone.

This action resembles that of a Tirril regulator of the well known type employing vibrating switch contacts: oscillation will usually occur in the same manner as with this device. Such oscillation is represented in Fig. IV, in which the upper graph a represents the fluctuation of the current through the coil 28 and the middle graph b represents the corresponding fluctuation of the voltage across the generator terminals while the lower graph c represents the load on the generator. If at a certain instant S the generator's output increases from I_0 to I_1 , the plate current through the coil 28 will remain at its maximum value for a slightly longer time than at its minimum value, but the voltage E of the generator will maintain substantially the same value as before, with but a slight minimum fluctuation. If at a time T, the load is increased to a greater value I_2 , at which the current through the coil 28 continues, this particular value I_2 of generator current corresponds to the maximum range of the regulator, beyond which it cannot maintain a constant voltage E across the generator terminals. If at a certain time U, the load on the generator is further increased to the value I_3 , the regulator cannot deliver a greater excitation than for the current value I_2 , and a drop of voltage across the generator begins at this point. The regulator thus has a well defined range which varies according to the constructional dimensions given the parts, and may be made adequate for any particular purpose.

It is apparent that the connections shown on Fig. V between the positive terminal of the generator 34 and the filament 4 on the one hand, and between the positive terminal of the source of reference voltage 37 and the grid 7 on the other hand may be reversed with regard to each other if the connections of the auxiliary field winding 36a be reversed with regard to the terminals of the exciter 35. In a similar manner, the condition represented on Fig. IV may be modified in various ways, and for example, its performance shown at the left from the point S may be made to correspond to the full load condition, and its performance represented between the points T and U will correspond to the position of no load; in which case the action of the coil 36a must be differential with respect to that of the main field winding 36 of the generator 34.

Many other connections and combinations of the above described elements are of course possible without departing from the general method of regulation shown in Fig. IV. Instead of obtaining the reference voltage from a separate source as the battery 37, it is possible to obtain it from the potentiometer 17 as shown in the diagram of Fig. VI. In this only two tubes are employed, representing the second and third tubes in the circuit of Fig. I. The filament 5

of tube 2 is shown in Fig. VI as being connected to a point 20, which is separated from the negative terminal 16 of the potentiometer 17 to obtain a potential difference equal to the ohmic drop between these two points. The negative terminal 38 of the generator 34 is connected to the point 16, and the positive terminal 39 to the grid 8 of the tube 2 by a conductor 62. The potential difference between the points 16 and 20, will maintain the grid potential of tube 2 normally while the terminal voltage to the generator 34 supplies the small voltage necessary to counteract this, and to produce the potential at which the "contact effect" is released. In this case, the potential difference between the points 16 and 20 will act as the reference voltage, and an adjustment thereof may be made by sliding contact 20 along the potentiometer. The method of operation of the circuit in Fig. VI is therefore as follows:

Assume that initially the generator voltage 38-39 is slightly below the critical voltage B at which the "contact effect" is released in the system formed by the devices 2 and 3. If the voltage of the generator 34 increases, the potential of the grid 8 of the tube 2 will be increased and the "contact effect" will be released, the current jumps to the full saturation value in tube 2, and for reasons previously explained, the current in the tube 3 will drop abruptly to a low value and cut down the field of the exciter 35 as in Fig. V, and thus diminish the excitation of the auxiliary field 36a of the generator 34. As soon as the voltage of the generator 34 decreases by a very small amount, the effect is produced in the opposite direction. The equilibrium at the point of given voltage will thus be dynamical as in the above case, although an arrangement according to the diagram of Fig. VI will be less sensitive than that of Fig. V, since not only is a lesser number of stages employed but also the potential of the filament of tube 2 (point 20, on the potentiometer 17) increases at the same time that the plate potential is increasing, and vice versa; it is, however, sufficient for practical industrial purposes.

It is possible to obtain the utmost precision of voltage regulation with the employment of an additional tube 1 in front of tube 2, according to the general diagram shown in Fig. VI. For this purpose, the arrangement is made specifically the same as in Fig. I, except that the staggering of the potentials between the points 16 and 20 will occur as in Fig. VI.

Fig. VII shows another example for the voltage regulation by an alternator 34^b utilizing the same principle of the "contact effect". The load 42 is supposed to be balanced between the phases, as is usually the case, so that it is sufficient to regulate the voltage of only one phase. A small potential transformer, with a primary winding 40' connected across one phase of the alternator, has a secondary 40'' connected at one terminal to the point 16 of the potentiometer 17, the other end of this transformer secondary being connected to the grid 7 of the vacuum tube 1 which in this instance operates as a rectifier since suitable negative bias is obtained on the grid of this tube by the potential difference between the points 16 and 16' of the potentiometer 17; in order to obtain the direct current control required for the release of the transient or "contact effect", the plate circuit of the tube 1 may contain any suitable filter system comprising the inductance 41 in series with the coupling resistor 24, which is

connected at each end by the condensers 42, 43 with the terminal 16. The remaining elements are connected exactly as before, and the performance and operation may be explained in connection with Fig. VIII, in which H represents the dynamic curve of tube 1 corresponding to the given impedance, and the sinusoidal curve K represents the normal electromotive force induced in the secondary 40' of the transformer.

The point L from the zero point O of the graph represents the potential drop between points 16 and 16' of the potentiometer 17. The wave K produces a rectified wave k which is smoothed out by the filter system so as to obtain a practically steady direct current of amplitude I_0 which passes to the resistor 24 and the potential of the point 26 differs from that of point 22 by the ohmic drop of this current along the resistor 24. The potential of the point 26 is therefore substantially constant, and varies only with corresponding variations in the potential wave K. If the potential at the generator rises to the new value K^a on Fig. VIII, a new rectified wave k^a is produced which in turn is smoothed out by the filter system so as to obtain the direct current of amplitude I' through the resistor 24. If the constants of the circuits of the several tubes are properly proportioned, as set forth above, this rise of potential will release the "contact effect" or transient as before; and again a very small change in the amplitude of the potential wave at the generator will produce a very great change in the current output of the system, and this occurs at a very fixed and constant point of the operation when once established. A steady voltage is therefore maintained across the alternator terminals in spite of any fluctuations of the load.

In Fig. IX, such a system is employed to control the excitation of a three-phase alternator in accordance with the condition of the loads upon all three phases. In this case the voltage regulating transformer has the primary phase windings 40^a, 40^b, 40^c associated with the respective secondary phase windings 40^{aa}, 40^{bb}, 40^{cc} which are each coupled to the grid of a respective tube 1^a, 1^b, 1^c. The filaments of these tubes are supplied in multiple with current from the secondary winding 13 of a transformer with its primary 51 connected to a source 50. The middle point of winding 13 is connected as before to a point 16' on the potentiometer 17, so that the control potential is determined by the drop along the potentiometer 17 from point 16 to point 16'. The tubes 1^a, 1^b, 1^c act as rectifiers, and the current passing through each of them is smoothed out by the choke coils 41^a, 41^b, 41^c and the bypass condensers 70^a, 70^b, 70^c for the respective tubes, and the condenser 71 for the common output. It is preferred to connect this common output through a further choke coil 41^x to the grid of the tube 2 in a manner similar to that described heretofore. The neutral point of the secondary windings 40^{aa}, 40^{bb}, 40^{cc} is connected to the negative terminal 16 of the potentiometer. The operation is substantially the same as before, and the potential at the common output point 26 of the tubes 1^a, 1^b, 1^c controls the rest of the system. The other connections are the same as before.

While the foregoing illustrations have shown the employment of such a system for regulating output potentials in generators, it must be understood that many other uses are possible. For example, in Fig. X is shown a system employed for the speed regulation of an electric motor 80.

The field coil 81 of this motor is its normal shunt

coil, while coil 28 is the output coil of the tube 3 of the system, and is an auxiliary field winding for the motor. A small tachometer generator 82, preferably of the magneto type to assure a constant magnetic field intensity is positively driven from the motor 80 as shown by the mechanical connection 83. The voltage produced by the generator 82 is a function of its speed, and is applied to the tube 1 in the manner set forth above. The "contact effect" will be released each time the motor departs in speed in one direction or another from its predetermined value, even if by only a small amount.

It is clear that any other device may be employed to impress varying potentials upon the grid of tube 1, and that the system may be so regulated that at a predetermined value of potential, a very small change will cause a very great change in the output current of the tube 3, i. e. the "contact effect".

Although specific examples of the arrangement and connection of the various parts, and dimensions thereof, are given by way of examples which have been found operative in practice, yet it will be recognized that the invention is not limited to these illustrations, but may be modified within the scope of the appended claims.

Having thus described my invention, I claim:

1. In a system employing a plurality of electron discharge tubes each having a cathode, a grid and an anode, independent means for exciting said cathodes, a potentiometer, a source of current connected to the ends of said potentiometer, a ballast device in series with said source and potentiometer arranged to maintain the direct current therethrough substantially constant, intermediate taps on said potentiometer, and conductors from said taps to the cathodes, grids and plates of the respective tubes, the conductor from the cathode of the first tube being spaced from the adjacent end of said potentiometer whereby a bias potential is applied between the grid and cathode of such tube, the resistance of said potentiometer being so designed that the direct current therethrough is considerably greater than the total space current of said discharge tubes.

2. An electrical amplifier system including a plurality of three electrode vacuum tubes connected in cascade, means for applying a biasing potential to the grid electrode of the first tube of the series, means linking said tubes and cooperating therewith to transfer the effect of said biasing potential to the grid of the last tube of the series to produce a plate current flow in said last tube responsive to said biasing potential, and means responsive to said plate current flow for determining the degree of said biasing potential.

3. An electrical amplifier system including a plurality of three electrode vacuum tubes connected in cascade, means linking said tubes whereby a potential bias on the grid electrode of the first tube of the series controls the degree of plate current flow in the last tube of the series, and means responsive to said plate current flow for determining the degree of said biasing potential.

4. An electrical amplifier system including a plurality of three electrode vacuum tubes connected in cascade, means for impressing a fixed biasing potential on the grid electrode of the first tube of the series, means linking said tubes whereby a potential bias on said grid electrode controls the degree of plate current flow in the last tube of the series, and means responsive to

said plate current flow for altering the degree of said biasing potential.

5 An electrical amplifier system including a plurality of three electrode vacuum tubes connected in cascade including conductive connections between the plates of preceding tubes and the grids of succeeding tubes, one or more of said tubes requiring for normal operation as amplifiers grid biasing potentials different from one or more of the other of said tubes, means for supplying negatively to the grids of succeeding tubes a direct current potential of the order required for biasing the grids of said succeeding tubes for said normal operation as amplifiers by way of the filament-to-plate impedance of and the conductive connection to the plates of succeeding tubes, and high resistances connecting the grids of said tubes to their respective cathodes.

20 6. The method of energizing an amplifier system including an output tube and an amplifier tube, which consists in controlling the average intensity of the space current of the output tube by the intensity of the space current of the amplifier tube, and controlling the average intensity of the space current of the amplifier tube by the average intensity of the space current of the output tube.

30 7. The method of energizing an amplifier system including an odd number of tubes including an output tube and a plurality of amplifier tubes arranged in cascade, which consists in producing a rise in the average space current of the output tube by a rise in the space current of any odd numbered tube of said cascade, and producing a decrease in the average space current of said odd numbered tube by the rise in the space current of said output tube.

40 8. The method of energizing an amplifier system including an odd number of tubes including an output tube and a plurality of amplifier tubes arranged in cascade, which consists in producing a rise in the average space current of the output tube by a rise in the space current of any odd numbered tube of said cascade, and producing a

rise in the average space current of any even numbered tube of said cascade by the rise in the space current of said output tube.

5 9. The method of energizing an amplifier system including an odd number of tubes including an output tube and a plurality of amplifier tubes arranged in cascade, which consists in producing a decrease in the average space current of the output tube by a decrease in the average space current of any odd numbered tube of said cascade, and producing a rise in the space current of said odd numbered tube by the decrease in the space current of said output tube.

10 10. The method of energizing an amplifier system including an output tube and an amplifier tube arranged in cascade, which consists in producing a decrease in the average space current of the output tube by a rise in the average space current of said amplifier tube, and producing a decrease in the average space current of said amplifier tube by said decrease in the average space current of said output tube.

15 11. An amplifying circuit comprising a potentiometer having its terminals connected to the opposite leads of a potential supply source; 25 vacuum tubes connected in cascade, each having an anode, cathode, and control electrode, the anode of one tube being directly connected to the control electrode of the succeeding tube; connections between the electrodes of said tubes and said potentiometer at such points that the voltage of said last mentioned control electrode due to anode current is compensated; and means for separately and independently heating the cathodes of said tubes to emitting temperature.

30 12. In a vacuum tube system comprising a plurality of cooperating thermionic vacuum tubes; means for coupling said tubes to form an amplifying circuit; means whereby the cathodes of said tubes are operated at substantially the same potentials but at different portions of the voltage gradient and separate independent and insulated heating sources for maintaining said cathodes at emitting temperature.

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