April 28, 1942. R. M. KALB 2,281,040

THERMIONIC RELAY CIRCUIT

Filed April 26, 1941 2 Sheets-Sheet 1

FIG. 1

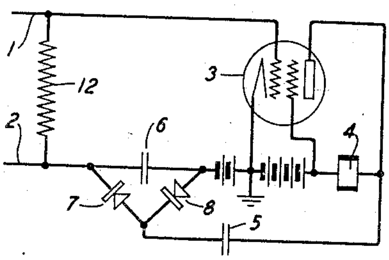


FIG. 3

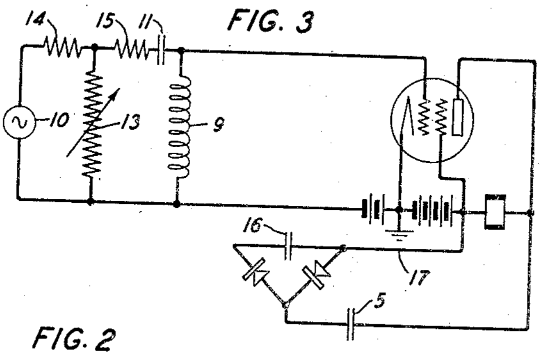


FIG. 2

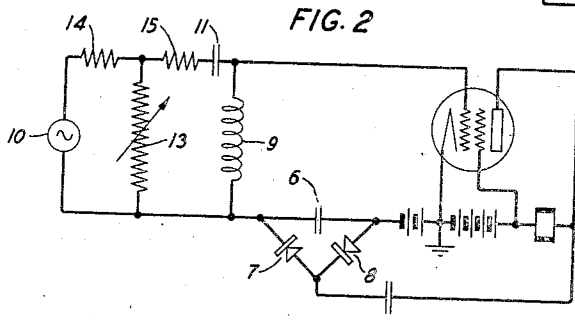
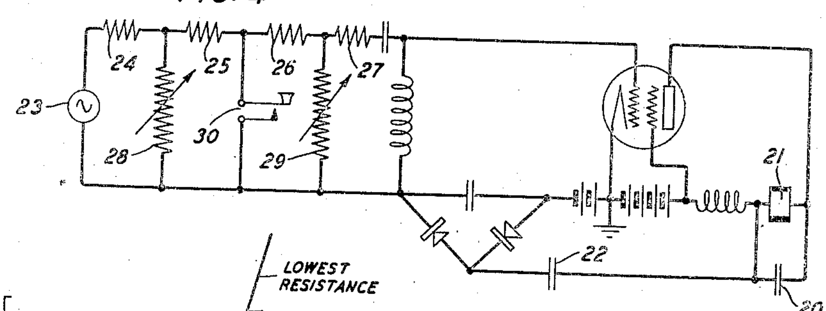


FIG. 4



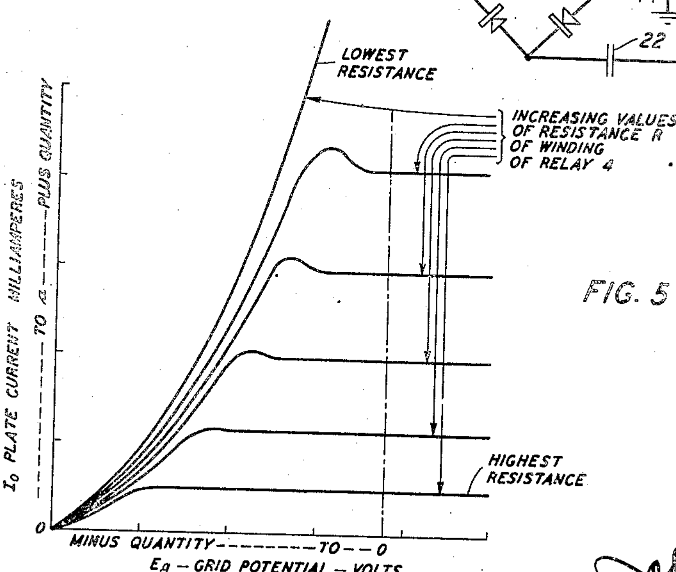


FIG. 5

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April 28, 1942. R. M. KALB 2,281,040

THERMIONIC RELAY CIRCUIT

Filed April 26, 1941 2 Sheets-Sheet 2

FIG. 6

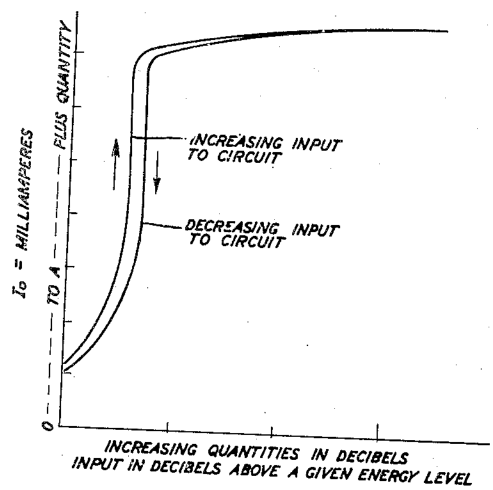


FIG. 7

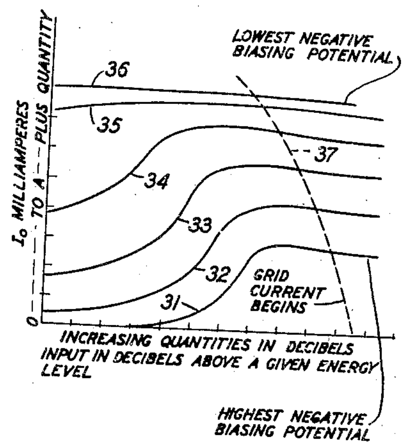


FIG. 8

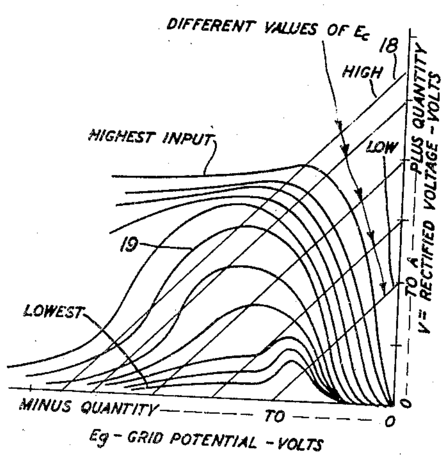
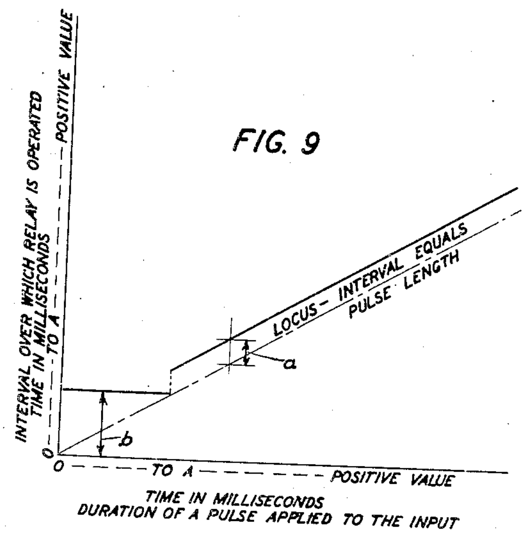


FIG. 9



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Patented Apr. 28, 1942

2,281,040

UNITED STATES PATENT OFFICE

2,281,040

THERMIONIC RELAY CIRCUIT

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Application April 26, 1941, Serial No. 390,464

10 Claims. (Cl. 175—320)

This invention relates to thermionic relay circuits and has for its object the production of certain useful relay effects.

One object of the invention is to provide means whereby a relay will both operate and release on the same value of input current whereby an accurate signal may be given whenever the current passes a given point in either direction. Such a signal may be particularly useful in certain relay voice controlled circuits where echo suppressors and like apparatus are employed.

Another object of the invention is to provide means whereby a relay will operate and remain operated over a definite time period in response to an input signal of shorter duration, which may vary over a wide range.

Still another object of the invention is to provide means whereby a relay will operate and remain operated thereafter over an indefinite time interval in response to short and weak disturbances.

In accordance with these objects a thermionic tube is operated in a unilateral feedback circuit and a relay in the output circuit thereof is controlled in various manners by the signals applied to the input. The invention is an improvement of the thermionic relay circuit disclosed in Patent 2,070,900, granted to Lionel Herbert Harris on February 16, 1937.

A feature of the invention is the use of a multigrid tube operating in a feedback circuit having a comparatively high impedance to current in one direction and comparatively low impedance to current in the other direction whereby economical operation and enhanced effects may be secured even where the tube is operated under those conditions where unstable behavior might be expected.

Generally speaking, two kinds of instability are manifest in a feedback rectifier circuit. One kind is the ambiguity of the plate current which depends in its value upon the direction of its change; the other kind consists of oscillations in the circuit. Heretofore instability has been avoided and removed by means which has removed the sensitiveness of the device while the present invention aims rather to control and use to advantage the means and the conditions which lead to unstable behavior. Accordingly, a feature of the invention is a means for securing the benefit of the phenomena exhibited during unstable behavior while holding the circuit firmly under control.

Another feature of the invention is a feedback circuit where the plate current when raised by an input signal is limited by grid bias potential and load resistance rather than by the flow of grid current. Heretofore the phenomenon of feedback enhancement of the plate current in a triode was wasteful and uneconomic in that the life of the tube was shortened by the use of grid current as a limiting factor or a limiting means. The present invention employs other factors for limiting purposes and thereby achieves more acceptable operating practices and economical results.

Another feature of the invention is the use of a multigrid tube whereby operation of the tube may be achieved in regions where automatic compensation for changes is achieved. The characteristics of the circuit employing such a tube are such that values of the various factors in the circuit may be chosen so as to work in a very stable region. By way of example, the resistance of the load may be so chosen that the characteristic relation between plate current and grid potential exhibits a limiting function. The rectified value of the alternating current components of the plate current show a maximum at an average value of grid potential where there can be no harmful flow of grid current and a deviation from such maximum on either side thereof is inhibited by the circuit reaction. Again the grid biasing potential may be so chosen that the characteristic relation between plate current and input to the circuit exhibits a similar limiting function. Here again the rectified value of the alternating components of the plate current show a maximum at a point where there can be no harmful flow of grid current and where a deviation from such maximum is inhibited by the circuit reaction.

Another feature of the invention is a rectified reaction thermionic tube circuit comprising a multigrid tube and a condenser in the feedback circuit thereof which exercises a critical control over the characteristic relation between the anode current and the input. In some cases the characteristic curve for increasing inputs lies above the corresponding curve for decreasing inputs and in other cases this relation is reversed. In still other instances, the curve for decreasing inputs becomes a straight line since after the plate current has attained a given value on an increasing input it remains at that value thereafter regardless of any further change of input in either direction. In this latter case the circuit may be employed in the manner of a gas tube which when fired maintains a steady flow of current even after the activating impulse has ceased. In this manner an ordinary relay may be employed to give the same type of operation as a so-called trigger tube.

The term rectified reaction thermionic tube circuit used herein and in the appended claims will be understood to define a thermionic tube circuit having a feedback connection between the grid and plate circuits thereof including alternating current rectifying means for producing a controlling grid potential by rectifying alternating current in the plate circuit produced by an original alternating current potential on the grid thereof.

The drawings consist of two sheets containing nine figures.

Figs. 1 to 4, inclusive, are circuit diagrams illustrating the invention. Fig. 1 shows the essential elements of the rectified reaction thermionic tube circuit; Fig. 2 shows this same circuit connected to a means for varying the input for operating the circuit; Fig. 3 shows how the feedback circuit may be temporarily disconnected in order to gather data for plotting the curves of Fig. 8 for the purpose of arriving at an understanding of the unstable behavior of the circuit; and Fig. 4 shows an alternative arrangement of the circuit of Fig. 1 connected to a means for stimulating the circuit by impulses;

Fig. 5 is a family of curves showing the relation between plate current and grid biasing potential for different load resistances;

Fig. 6 is a characteristic curve showing the difference in the relation of plate current to input under increasing and decreasing values of input;

Fig. 7 is a family of curves showing the relation of plate current to input under varying negative grid biasing potentials;

Fig. 8 is a family of curves showing the relation between the rectified voltage and the grid potential for various values of input and explaining the phenomenon of separation of the characteristic curves of Fig. 6 on increasing and decreasing inputs; and

Fig. 9 is a graph showing the hang-over operation of the relay and indicating the peculiar operation thereof when the stimulating impulse is of very short duration.

The action of the feedback rectifier can be understood in its fundamental aspects by reference to the circuit diagram of Fig. 1. An alternating voltage applied to the input terminals **1** and **2**, appears, amplified, on the anode of tube **3**. Blocked by the inductance L of the winding of relay **4**, an alternating current flows through condenser **5** and thence to ground, through condenser **6** while in one direction and directly in the other, as determined by the two rectifier units **7** and **8**. The rectified voltage established across the condenser **6** as a result biases the control grid of tube **3** more positive by its average value.

The anode current through the inductance L and resistance R of the winding of relay **4** is thereby increased and results in the operation of relay **4**. The anode voltage decreases by the drop across the resistance of the relay winding until the diminished gain effects equilibrium at the ultimate anode current. The screen electrode tends to keep the potential of the space between the control grid and the anode more nearly constant and hence this process is more satisfactory than limiting by the flow of grid current, such as is depended upon in triodes. In the triode circuits the load in the anode circuit reduces the potential on the plate and this in turn affects the point at which grid current begins to flow.

The choice of tube is governed by the relay current and the sensitivity. Since the relay current permits some leeway and may be adjusted some by the tube potentials, the sensitivity becomes the chief factor for consideration. Sensitivity is the rate of change of the direct current plate current with respect to the alternating current input voltage.

$$\frac{dI_0}{dE}=\frac{\partial I_0}{\partial V}\frac{dV}{dE} \qquad (1)$$

where I_0 represents the plate current; E is the peak value of the alternating current input voltage and V is the direct current voltage across condenser **6**.

If the rectification is linear, this voltage is proportional to the alternating component of the plate current:

$$V=\frac{X}{R_0+X+X_1}\mu E \qquad (2)$$

where μ is the amplification factor of the tube, R_0 is the plate to filament resistance,

$$X_1=\frac{1}{\omega C_1} \text{ and } X=\frac{1}{2\omega C}$$

C_1 is the capacity of condenser **5** and C is the capacity of condenser **6**. The reactances X_1 and X are evaluated at the fundamental frequency. The factor 2 in X results from the half-wave rectification. Equation 2 may be differentiated and substituted in Equation 1. In terms of the mutual conductance of the tube, which is defined as

$$g_m=\frac{\partial I_0}{\partial V}=\frac{\mu}{R_0}$$

the sensitivity is thus expressed as follows:

$$\frac{dI_0}{dE}=\frac{R_0Xg_m^2}{R_0+X+X_1} \qquad (3)$$

This relation is rigorous to the extent that the linear amplification implied by Equation 2 is realized. A rectification that is other than linear or the flow of grid current or a variable mutual conductance will alter the quantitative results somewhat, but not the conclusions.

With the reactances fixed by the exigencies of speedy operation and effectual separation of the alternating and direct components of the plate current, a high mutual conductance yields the best sensitivity. This is greatest and equals Xg_m^2, when the plate resistance well exceeds the series reactance $X+X_1$; it is smallest, reduced by the factor

$$\frac{R_0}{X+X_1}$$

when this factor is much less than unity. Then the criterion for the best sensitivity the circumstances allow is a high figure of merit, defined as $g_m^2R_0$. The multigrid tube **3** diagrammatically illustrated represents any one of a number of commercially available tubes having such a high figure of merit.

The present invention will best be understood by an explanation of the characteristics of the circuit. Therefore, Fig. 2 may be used for this purpose. Here an inductance **9** tuned to the frequency of the source of alternating current **10** by the condenser **11** is used as a direct current path for the application of a direct current potential to the grid of the tube 3 in place of the resistance 12 illustrated in Fig. 1.

It is desirable as hereinbefore pointed out to regulate this circuit by means other than the flow of grid current for it is well known that such flow of grid current shortens the life of a tube. This aim is attained in the present invention by taking advantage of certain characteristics of the tube, illustrated in Fig. 5. Here is shown a family of curves showing the relation between the current flow in the plate or anode of the tube and the grid potential. Each graph represents a different value of resistance in the winding of relay 4, and comparison of the various graphs from a low resistance winding to a high resistance winding shows a peculiar characteristic which is used to advantage herein. Thus it shows that with the highest resistance winding a certain plate current is reached which remains at the same level over a wide range of grid potential extending from a minus quantity through zero to a plus quantity. This means that, since if the grid potential is varied periodically about an average value, fixed by a biasing battery for instance, the resulting alternating component in the plate current will have that one of a wide range of amplitudes which is determined by the average grid potential that is maintained, that amplitude will be small when the average grid potential has a large negative value and also when it has a positive or only slightly negative value such that the plate current is in the level region of the graph and cannot change. For moderate negative average grid potentials between these two extreme ones the alternating component of the plate current takes on its largest values. However, on account of the feedback arrangement of the circuit some of this alternating component of the plate current will be fed back through condenser 5 and rectified by rectifiers 7 and 8, thereby altering the average grid potential. Since the rectifiers are so poled that their direct current potential acts to make the grid potential more positive the tube circuit automatically adjusts itself to a stable point where the rectified portion of the plate current is a maximum and the average grid potential is still a minus quantity. As the fundamental frequency component of the plate current reaches its maximum at a net average grid potential where the graph is steepest and the stronger harmonic components (i. e., the even order components) have maxima near the top of the hump but always on the negative side of the top, the stable operating point must lie between the steepest part of the graph and the top of its hump, the exact point depending upon the distorting characteristics of the tube. This is a narrowly defined region with a strong flow of direct current-plate current whereby operation of the relay is effected. Since a deviation in either direction of the net average grid potential from this operating point will cause a lowering of the rectified component of the plate current the result will be a change of a compensating nature so that stability is realized. Thus the resistance of the winding of the relay 4 is of material interest.

By means of the variable resistance 13 connected in a network with resistances 14 and 15 the input of the circuit may be changed over a wide range. By operating this variable resistance 13 and observing the values of the plate current the graph of Fig. 6 may be obtained. This is a characteristics curve depicting the relation between the input to the circuit and the resulting plate current. It should be especially noted that the curve obtained on decreasing values of input lies always somewhat below the curve obtained on increasing values of input. Put in another way, it will be observed that the same value of input produces different plate currents in accordance with the direction of change in input. Thus for a given value of input the plate current reaches a higher value on increasing input than on decreasing input. Since a relay requires more current to operate it than to maintain it operated, this characteristic of the circuit may be employed through suitable adjustment of values to cause the relay to operate and release on exactly the same input.

Fig. 7 shows a family of curves illustrating the effect of the negative biasing potential of the battery between ground and condenser 6 in Fig. 1. Here it is found that in all of the graphs except those for the lowest negative biasing potentials a well-defined rise in plate current being to develop below the input for which grid current begins to flow. The absence of such a rise indicates a bias insufficiently negative to get the maximum rectified plate current, whereupon no reactive effects of the feedback circuit can be realized unless the polarity of the rectifiers is reversed. This procedure would be undesirable because the grid could easily go positive and because there would not be enough change in plate current to make available safe operating margins for the relay. With the circuit as in Fig. 1 it will be seen from Fig. 7 that at some point between the highest and the lowest negative biasing potentials a value may be chosen where the maximum rise in plate current takes place before the point at which grid current begins to flow.

An examination of the graphs of Fig. 7 shows that the difference in plate current between low input and the input where the plate current is at a maximum is small for graph 31, is larger for graph 32, is largest for graph 33 and then progressively becomes smaller for graphs 34, 35 and 36, respectively. Graph 33 shows the maximum change in plate current between low input and the input producing the maximum point of this particular graph. In this figure the graph 37 indicates the point at which grid current begins to flow and since the maximum point in graph 33 is reached before the graph 37 is reached, stability will be produced without drawing grid current. After the discovery of these maximum points in the relation between plate current and grid potential in one instance and between input and the change of plate current in the second instance it becomes an engineering problem to select the proper values of the various circuit factors in order to devise a circuit wherein limitation is achieved by biasing potential and load resistance rather than by the harmful flow of grid current.

In order to further explain the action of this circuit the feedback circuit may be uncoupled and the circuit arrangement of Fig. 3 employed. The reverse biasing voltage V (across condenser 16) and the root-mean-square feedback current I (in conductor 17) may be measured at several values of grid bias over a given range of inputs. The result is shown in the family of curves of Fig. 8 wherein the relation between V and the grid potential is shown, each curve representing a different value of input. This reverse biasing voltage V results from rectification of the alternating component of the plate current fed back through condenser **5**.

Since reconnection of the feedback to the grid circuit requires that

$$E_g = V - E_c$$

where E_g is the grid potential and E_c is the potential of the grid biasing battery, one of the family of diagonal lines drawn to satisfy this relation defines the state in which the retroactive circuit will be. Thus, following the line corresponding to the particular value of the fixed grid bias, its intersection with the curve of rectified voltage for any given input defines the net average grid potential, E_g, from which the plate current can be ascertained by reference to the static characteristics shown in Fig. 8. When a curve is intersected more than once by the same line, for instance where line **18** intersects curve **19**, the several values of E_g specify a multi-valued region in the characteristic of plate current versus input volume and the actual value depends upon the direction of approach and thus explains the phenomenon illustrated by Fig. 6. In finding these values it is necessary to bear in mind the ultimate extension of all the curves of rectified voltage asymptotically toward zero at sufficiently large negative grid potentials, to avoid overlooking an intersection beyond the plotted data. The number of intersections between a line and curve on this graph must always be odd, and when plural the two extreme ones specify the stable positions for the two directions of approach.

While it is apparent that these regions of instability may be avoided by reducing the fixed grid bias, it is more the object of this invention to control and employ the unstable behavior of this circuit and to turn such unstable behavior to a useful purpose. Hence by exploring the separation between the two curves of Fig. 6 and then employing a relay whose difference between operating and releasing current is equal to the difference in anode currents on rising and falling inputs, a signal device may be produced which will operate and release on exactly the same value of input when changing in either direction.

To prolong the interval during which the relay remains operated, the arrangement of Fig. 4 may be employed. A condenser **20**, bridged across the winding of relay **21**, charges during the fore part of an actuating pulse, and upon cessation of the pulse discharges through the relay to keep it operated longer. Successive pulses separated by less than the hold-over time will keep the relay operated continuously. The feedback condenser **22** may equally well be tapped off the other junction of the relay **21** and its condenser **20** to provide a feedback path direct from the plate, in which case the condenser **20** then does not form part of the feedback circuit.

The graph shown in Fig. 9 indicates the action of the relay **21** and has been drawn from data gathered under controlled experimental conditions. A circuit such as that shown in the left-hand portion of Fig. 4 may be used. A source of alternating current **23** is used to stimulate the feedback thermionic tube circuit. The resistances **24** to **27** form parts of attenuators whereby by means of the variable resistances **28** and **29** adjustments of volume and potential at the input may be regulated. By means of key **30** pulses of any length may be produced.

The graph of Fig. 9 shows that with an incoming pulse of any duration longer than the time b the relay will remain operated for a time a longer than the incoming pulse. For incoming pulses of shorter duration the relay will remain operated for a time b which in practice is substantially constant. The graph does not extend completely from the zero point as it has been found that there is a minimum length of incoming pulse below which the circuit will not respond but there is a great range over which the relay will remain operated a definite length of time in response to stimulating pulses of shorter duration. Since the location of the graph of Fig. 9 may be variously changed with respect to the locus shown in dot and dash lines it is possible to produce any given result. By way of example such a circuit may be employed as a pulse regenerator in a signaling circuit where equal length signals are used as in some permutation code signaling circuits. In such a case the circuit may be adjusted so that the time interval b will exactly equal the standard length of a pulse employed in such a circuit.

It has hereinbefore been mentioned that an object of the invention is to make use of the factors leading to unstable behavior in this type of circuit. Two kinds of instability are manifest in all the arrangements of the device described. One kind is the ambiguity of the plate current which depends in its value upon the direction of its change and the other kind consists of oscillations in the circuit, and although these appear at first to be unrelated there is a recognizable connection between the two. As mentioned hereinbefore and particularly in connection with Fig. 6 the decreasing plate current in the circuit of Fig. 1 or Fig. 2 lies below the increasing values. This is controlled by the value of the feedback condenser **5**. When this condenser has a low value of capacity the values of plate current are as above stated. However, when the capacity of this condenser is raised the relation between the curves for increasing and decreasing values is reversed so that now the values of plate current for decreasing input lie above the values of plate current for increasing input. This relationship may be carried so far that sustained oscillations are set up and the plate current having attained a given value will remain thereafter at that value regardless of any further change in input. With a circuit so adjusted by a proper value of capacity of the feedback condenser the relay may be made to operate in the manner of a trigger tube, that is, it may be energized by a short and weak impulse and thereafter remain energized until some other switching function is performed to release it.

What is claimed is:

1. A rectified reaction thermionic tube circuit comprising a multigrid tube, a feedback circuit therefor and a condenser in said feedback circuit for controlling the relation between the characteristic curve of anode current with respect to input to said circuit on increasing input and the said characteristic curve for decreasing input.

2. A rectified reaction thermionic tube circuit comprising a multigrid tube, a feedback circuit therefor and a condenser in said feedback circuit, said feedback condenser being critical whereby within one range of values of said condenser, the characteristic relation between anode current and input will be higher on increasing input than on decreasing input, and within another range of values of said condenser the said characteristic relation will be reversed, and at

still other values between said ranges the said characteristic relation on decreasing input will assume a steady and unchanging value.

3. A rectified reaction thermionic tube circuit comprising a multigrid tube having a high figure of merit, a relay in the anode circuit thereof and a negative grid biasing battery, the resistance of said relay and the potential of said battery being chosen within ranges where a maximum in anode current is produced before the grid bias reaches a point where grid current begins to flow, said relay having a difference in its operating and releasing current characteristics equal to the difference in anode current characteristics on rising and falling input to said circuit.

4. A rectified reaction thermionic tube circuit comprising a multigrid tube, a feedback circuit therefor, a condenser in said feedback circuit, a negative grid biasing battery for controlling the potential, the grid of said tube and a relay in the anode circuit of said tube, the resistance of said relay being chosen to control the characteristic relation between plate current and grid potential whereby a maximum in plate current is produced before grid current begins to flow and the value of said negative grid biasing battery being chosen to control the characteristic relation between plate current and input whereby a maximum change in plate current is produced before grid current begins to flow.

5. A rectified reaction thermionic tube circuit having a relay in the output thereof, said relay having a difference between its operating and releasing current characteristics equal to the difference between output current characteristics of said circuit on rising and falling input thereto.

6. A rectified reaction thermionic tube circuit comprising a multigrid tube, a feedback circuit therefor and a condenser in said feedback circuit having a capacity adjusted to cause the graph of the relation between anode current and input to said circuit on decreasing input to lie below the graph of the same relation on increasing input.

7. A rectified reaction thermionic tube circuit comprising a multigrid tube, a feedback circuit therefor and a condenser in said feedback circuit having a capacity adjusted to cause the graph of the relation between anode current and input to said circuit on decreasing input to lie above the graph of the same relation on increasing input.

8. A rectified reaction thermionic tube circuit comprising a multigrid tube, a feedback circuit therefor and a condenser in said feedback circuit having a capacity adjusted to cause the anode current to rise to a given value in response to an input stimulus and to thereafter automatically maintain such value regardless of the presence or absence of input stimulus.

9. A rectified reaction thermionic tube circuit comprising a multigrid tube, a relay in the anode circuit thereof and a condenser bridged about said relay for rendering said relay slow to release, said relay controlled by said condenser acting to remain operated for a definite and uniform time interval when stimulated by an input impulse of any finite duration shorter than said interval.

10. A rectified reaction thermionic tube circuit having a relay in the output thereof, said relay having a difference between its operating and releasing current characteristics and means in said tube circuit for adjusting the difference between the output current characteristics of said circuit on rising and falling input thereto to substantially the said difference between the operating and releasing current characteristics of said relay.

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