Oct. 25, 1949. J. A. SARGROVE 2,485,925

CIRCUIT ARRANGEMENT FOR ELECTRONIC TUBES OPERATING ON DYNAMIC GRID CURRENT PRINCIPLES

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2 Sheets-Sheet 1

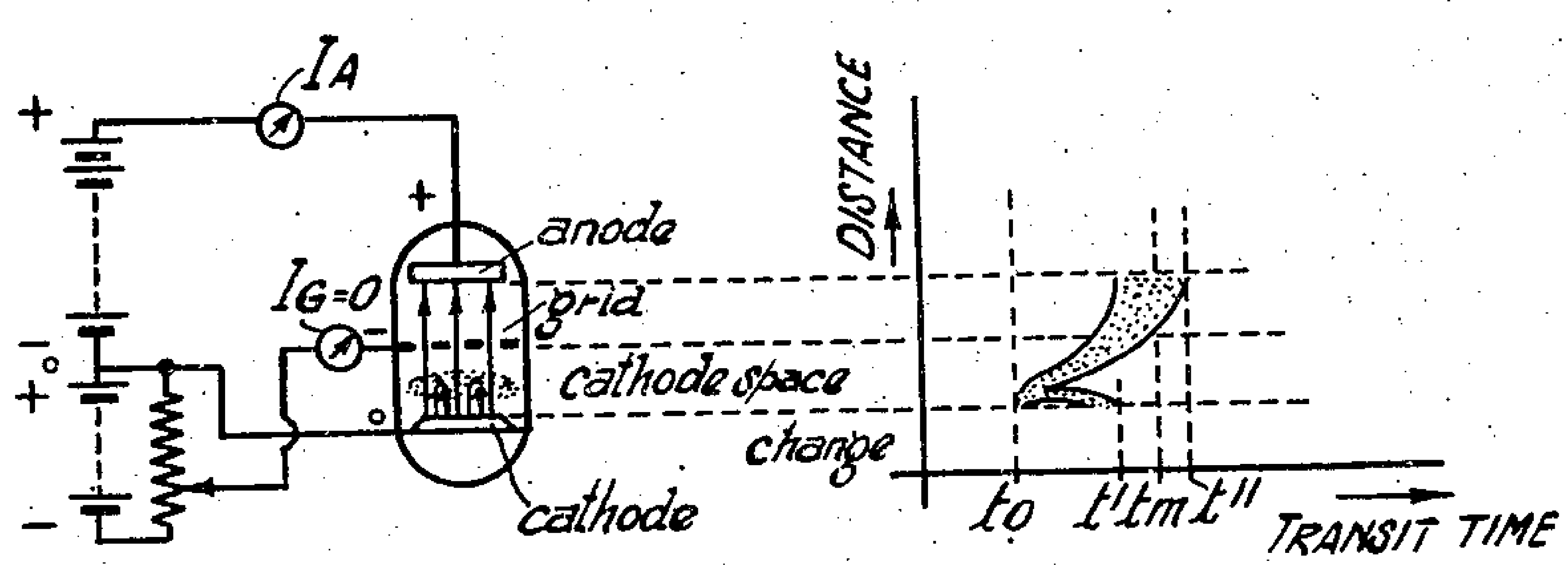

FIG. 1.

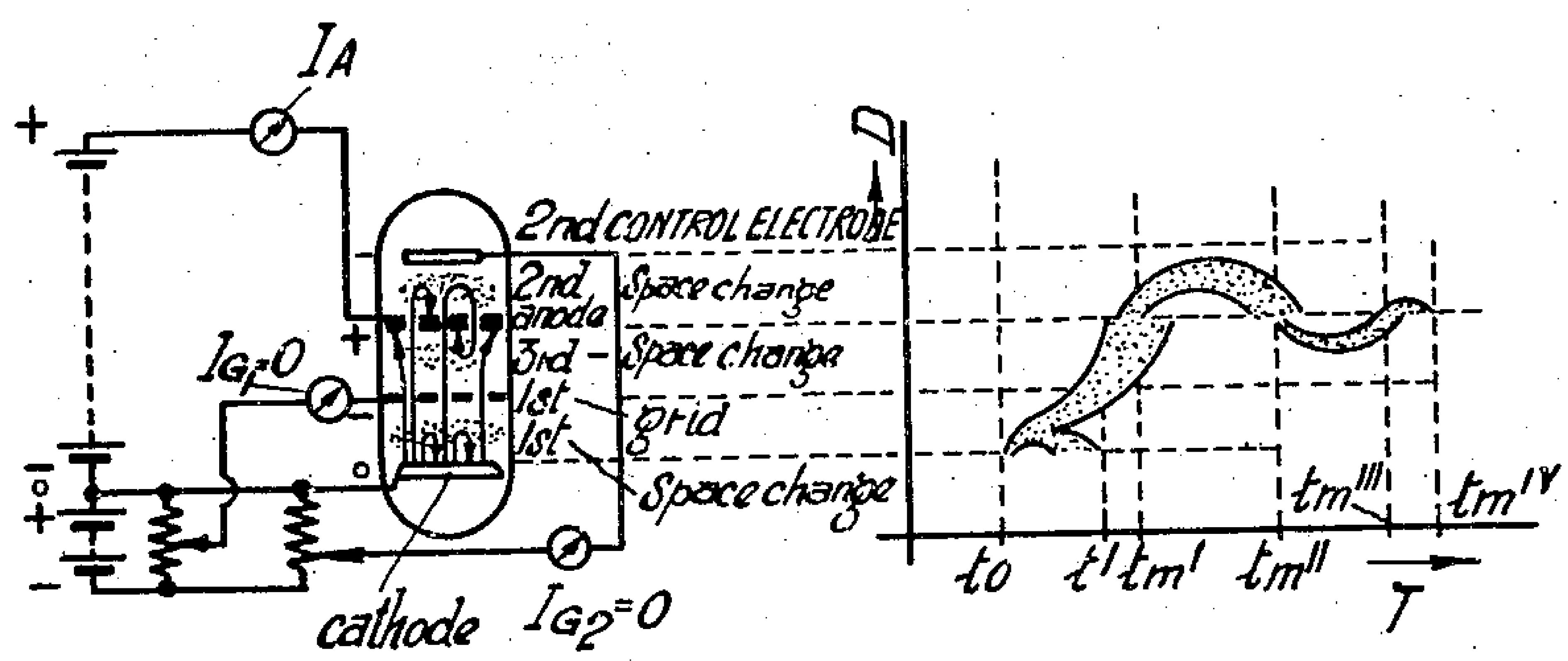

FIG. 2.

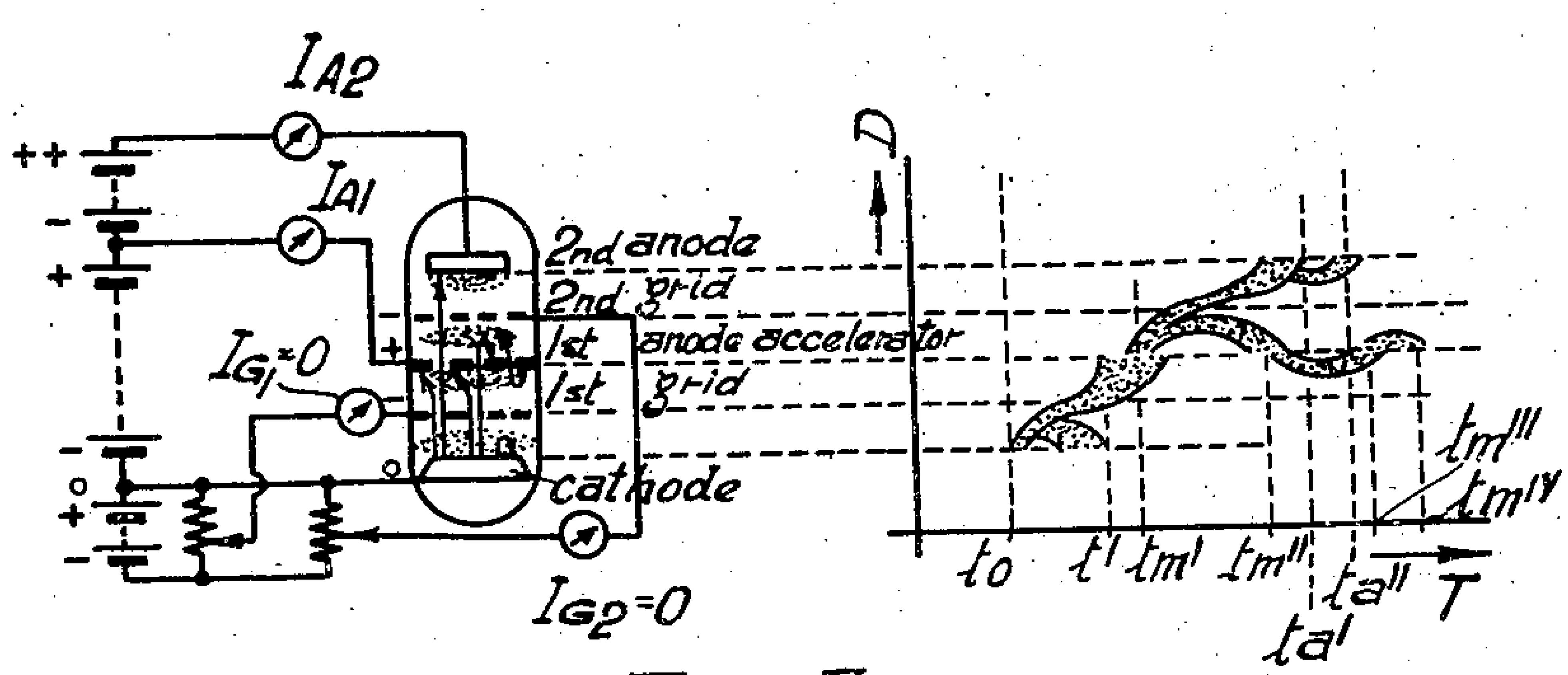

FIG. 3.

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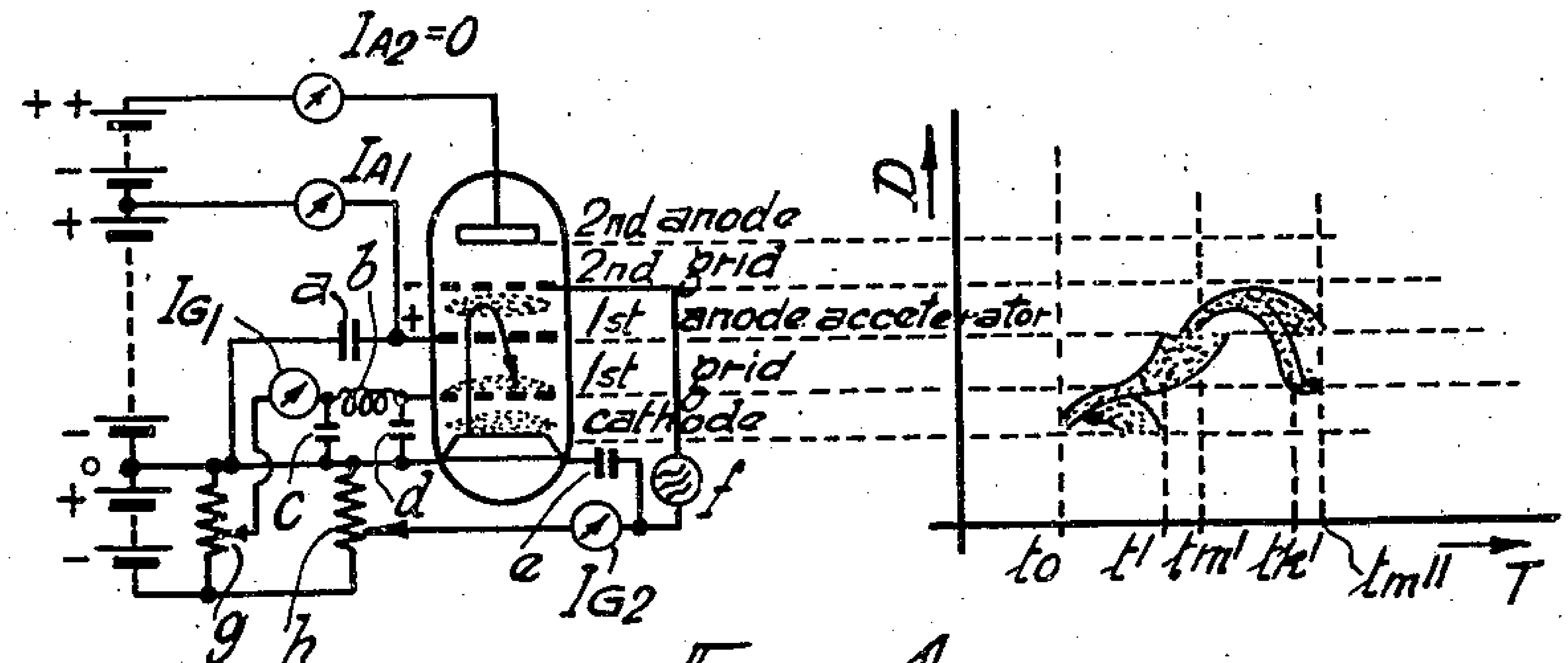

Fig. 4.

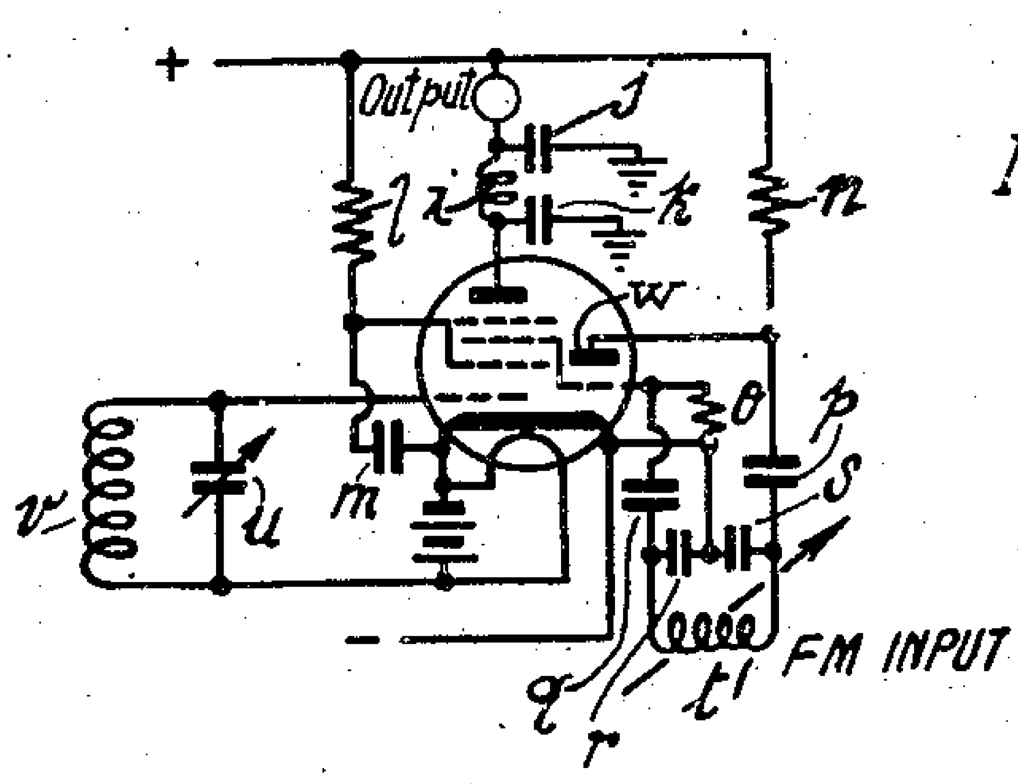

Fig. 5.

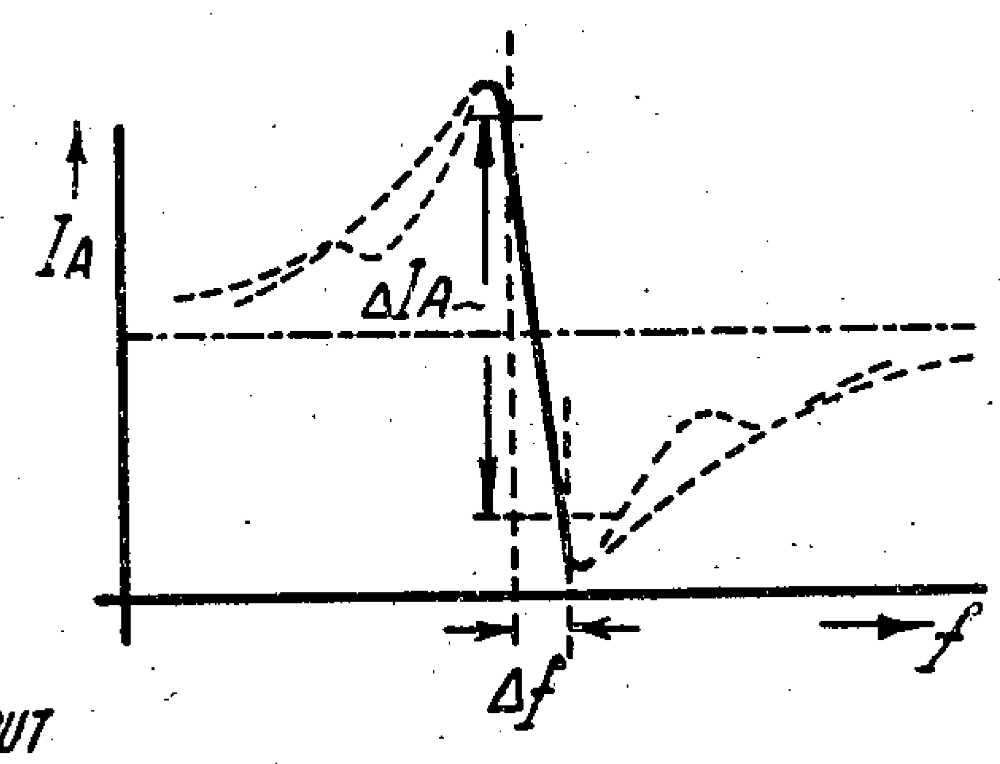

Fig. 6.

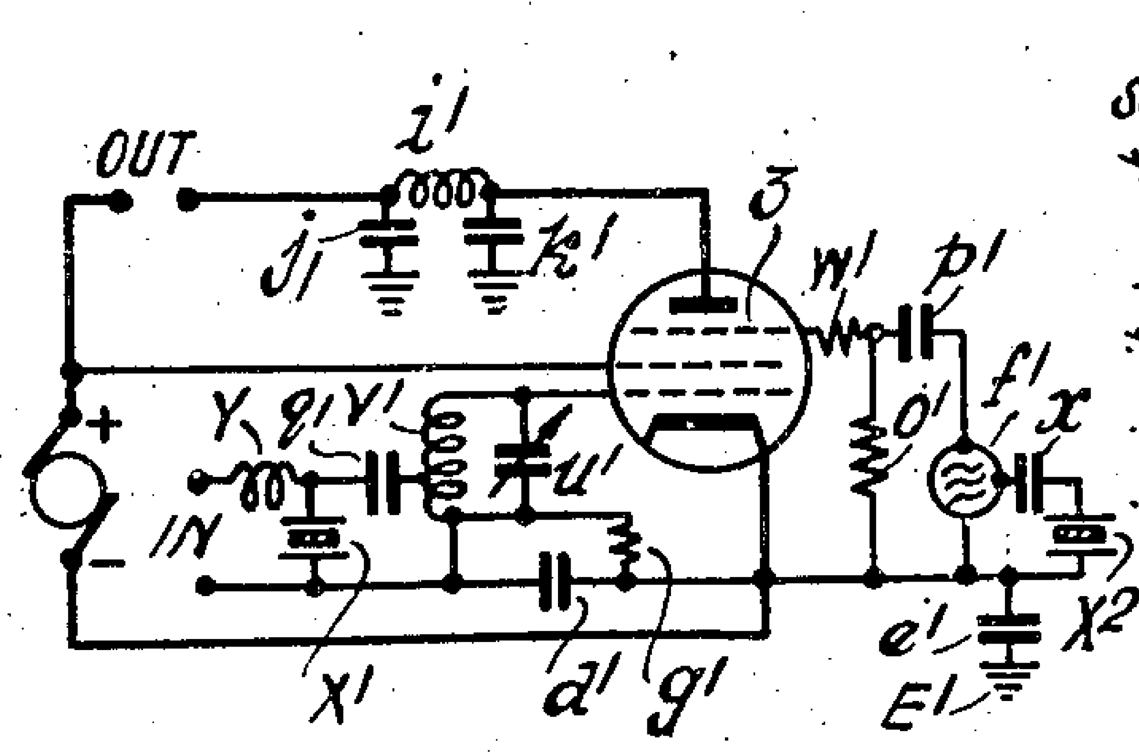

Fig. 7.

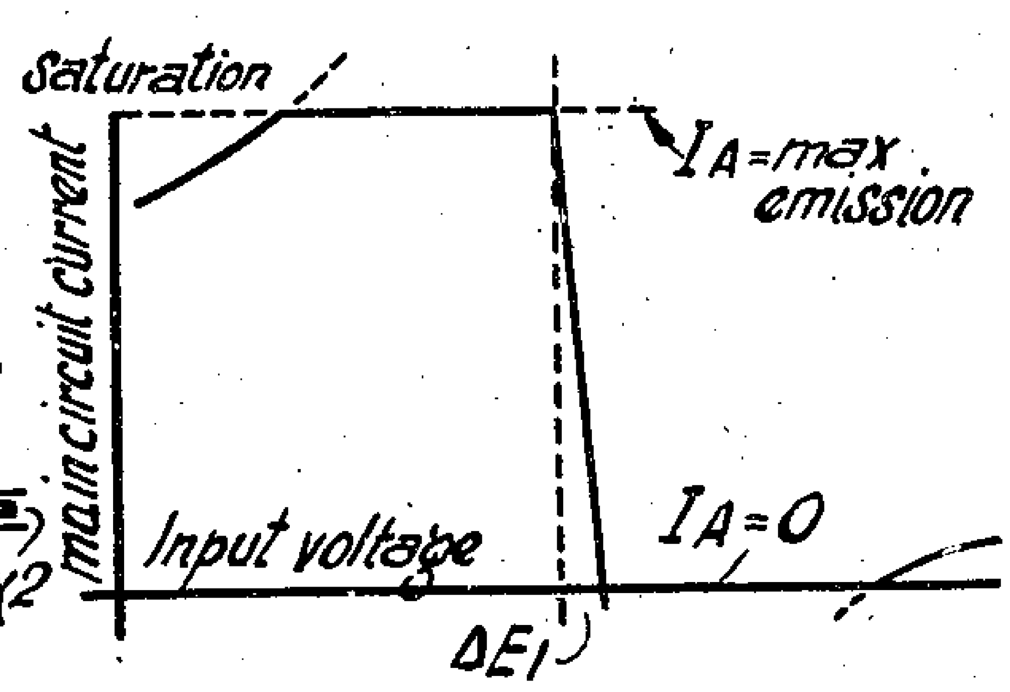

Fig. 8.

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CIRCUIT ARRANGEMENT FOR ELECTRONIC TUBES OPERATING ON DYNAMIC GRID CURRENT PRINCIPLES

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Patent expires March 28, 1962

9 Claims. (Cl. 332—58)

This invention relates to the operation of electronic vacuum tubes or valves.

In vacuum tubes or "hard" valves having an emissive cathode, an anode and an interposed grid, it is generally known that if the grid has a negative bias in excess of the so-called contact potential with reference to the cathode, no grid current will flow provided that the vacuum is hard enough. In fact this property of the valve is used to determine the degree of the vacuum of the valve in manufacture, namely if the vacuum is insufficiently high the normal electron stream flowing from cathode to anode will cause ionisation of the residual gas molecules, the negative ions joining the electron stream flowing to the anode which is the most positive electrode augmenting the anode current, whilst the positive ions will flow independently to the grid which in the condition under review is the most negative electrode. On touching the grid the positive ions will extract electrons from the grid and form neutral gas molecules again. These electrons leaving the grid constitute a grid current which can be measured in the D. C. grid circuit and has the same direction of flow as if the grid itself were emissive.

It is clear that this current, besides being proportional to the anode current, is also proportional to the gas content of the evacuated vessel. Hence if the vacuum is very high this current is so very small that it can be considered non-existent from all practical, technical points of view.

If in a valve in which the vacuum is high enough so that this type of grid current will not flow, we move the grid bias gradually from negative in a positive direction, a point will be reached as we approach zero, i. e. the cathode potential, when the grid will begin to attract electrons from the main electron stream flowing to the anode. In fact the grid will act as a subsidiary anode. The direction of current flow in the grid circuit is now opposite to that discussed above. As this direction of current flow, however, is the same as the anode current flow it is called "forward grid current" (or just "grid current") whilst the previously mentioned gas current is called "inverse grid current."

Having now clearly defined those static potential conditions which must prevail so that no grid current will flow, we will lead up to examining a dynamic phenomenon the comprehension of which is essential to a clear understanding of the subject matter of the present invention which consists essentially of an electronic circuit arrangement comprising a discharge device having cathode and anode the discharge between which

is governed by an accelerating field on either side of which there are control fields, an output circuit responsive to the power variations of the discharge due to the action of the control fields, characterised in that oscillations of an amplitude sufficient to cut off the main anode current during part of the operating cycle are applied to the control means furthest from the cathode and are coupled to the control means nearest to the cathode by the electrons cut off from reaching the main anode being reversed in flow with sufficient kinetic energy to cause them to return through the interposed accelerator means to excite the control means nearest to the cathode, whereby the output power is modulated by a change in the phase angle of the oscillations of the control means nearest the cathode.

In the following description, it is to be assumed that the vacuum is hard enough for no gas current of any appreciable magnitude to flow.

Figs. 1 to 4 are schematic diagrams which show, for tubes with different grid arrangements, the changing direction of travel of a pulse or bunch of electrons during a time period of a few microseconds after the electrons leave the cathode;

Fig. 5 is a diagram of a multigrid tube and associated circuit embodying the invention;

Fig. 6 is a curve sheet showing the variation of anode current with frequency shift when the Fig. 5 apparatus is operated as a frequency-shift discriminator or detector;

Fig. 7 is a fragmentary circuit diagram of a multiple grid tube operated as a trigger relay; and

Fig. 8 is a curve sheet showing the sharp variation in anode current with small change in the oscillator voltage input to the dynamic grid current tube.

Considering the case of the normal flow of electrons in a triode valve as described above, and illustrated in Figure 1. On the left-hand side a simple representation is shown of a triode having a cathode which is emissive either by thermionic or other physical phenomena, a grid and an anode each having normal operating potentials. Current meters are inserted into these two electrode leads.

It is known that the electrons leaving the cathode having a slight negative charge with reference to the cathode are repelled by the larger negative potential of the grid and thus form the so-called cathode-space-charge which is a cloud of electrons in a state of instantaneous zero velocity in a forward direction but which may have a sideways velocity without affecting matters at all. This instantaneous condition is due to the fact that the electrons have emerged at varying velocities from the cathode surface, have reached this point in space together with a large number of other electrons all having a negative charge and hence a decelerating influence on each other, and unless attracted by some other influence will reverse their direction and move back to the cathode. Hence the number of electrons in the cathode space is at equilibrium. The point at which these electrons reverse their direction is at a lesser or greater distance from the cathode according to the different initial velocity (according to the law of probability) of the original cathode emission.

Some of the faster moving electrons actually reach so far away from the cathode before entirely losing velocity that they come within the influence of the positive anode field which penetrates through the interstices of the grid, that they are re-accelerated in the direction of the anode, fly through the grid and ultimately reach the anode at varying velocities. The right-hand side diagram of Figure 1 shows a transit-time versus distance diagram, the time axis representing an arbitrary time interval of the order of 10^{-7} to 10^{-8} seconds but naturaly this depends on the operating conditions, distances etc. of the actual valve structure. In this diagram it is imagined that the cathode is only emissive for an infinitely small instant and this pulse of emission is examined.

It will be seen that at point t_o at the commencement of the phenomenon electrons of varying speed are emitted, the slope of the curve representing speed (distance traversed over time). The slower moving ones all return to the cathode by the time t^1 is reached, some of the slower ones arriving back at the cathode even earlier. The faster ones, however, approach the grid and still continue to rise and arrive ultimately at the anode at a varying speed, every electron arriving there by t^{11}, the mean transit time, however, for the entire anode current pulse being t_m.

Having explained this method of notation and illustration in the simple case, let us examine Figure 2, when we assume the anode to be perforated or to be of a grid-like structure and has beyond it a further electrode which for the moment we will consider to be at a potential at which it will neither attract nor repel electrons. In this case any electron flying towards a gap in the anode will fly through this having reached its maximum velocity in the moment of transit, shown on the right-hand diagram of Figure 2 at tm_1, the anode having acted as an accelerator to the electron while it was approaching from the cathode but as soon at it passes through the gap in the anode the latter will act as a brake or decelerator, reducing the forward velocity of the electron to zero. Then the electron will be re-accelerated in the opposite direction until it reaches the anode again at tm^{11}.

If by chance it falls towards a gap in the anode from this opposite direction and provided its path is not barred by an overwhelming mass of electrons coming direct from the cathode (which in this case of the examination of an electron emission pulse is not the case), it will again pass through the gap at maximum speed, will then again lose velocity to zero and reverse, repeating the above sequence, passing through the anode at tm^{iii}, going above the anode, reversing again, returning to the anode at tm^{iv} and so on.

Of course, if we consider a larger number of electrons the laws of probability will cause a

gradual decrease in the number of electrons repeating this periodic oscillation due to the absorption of a large proportion of electrons by the solid parts of the anode at each period of this oscillation.

It will be noticed that the electrode beyond the anode has no effect on this phenomenon as we have presupposed it to have a neutral potential. The same also applies to the grid before the anode which is also at such a neutral potential.

Under these circumstances, in addition to the cathode space charge above defined, marked 1st space charge (on Figure 2), two other space charges occur, one beyond the anode, i. e. the accelerator grid, marked 2nd space charge and one before the accelerator grid, marked 3rd space charge which is due to the reversed electrons. The actual position of these subsidiary space charges depends on all sorts of conditions, principally on the voltage conditions prevailing on the accelerator electrode but also on the voltage of the other two negative electrodes. If the potential of the farthest negative electrode is not neutral as above supposed but more negative, the point of zero forward velocity will be nearer to the anode, i. e. the accelerator grid, and conversely. If the first negative control electrode is more negative then the total number of electrons in the two subsidiary space charges will be reduced and the space charges can disappear entirely if the first control electrode has a negative potential large enough to cut off the anode current. This is called the cut-off grid potential.

Let us now add a further second anode outside this structure and consider what happens whilst looking at Figure 3. The time distance diagram on the right shows that up to the time tm^1 the phenomenon has exactly the same sequence as in Figure 2 and Figure 1. Thereafter in addition to the slower moving electrons which emerge through the interstices of the first anode performing a similar phenomenon to that referred to in Figure 2, the faster moving ones which reach further away from the first anode come under the attractive influence of the second anode whose positive field penetrates through the interstices of the negative second control grid and pass through this negative control grid and reach the second anode at time tm^{ii} approximately, all reaching the second anode at time ta^1.

To complete the description of the phenomenon these high velocity electrons reaching the second anode cause the emission of secondary electrons from the anode which have low velocity and hence after leaving the anode in a reverse direction immediately revert to the anode, finishing their excursion ta^{11}. These secondaries form a small secondary space charge which in the left-hand diagram is the fourth one nearest to the second anode represented by the dotted cloud. This final explanatory point has only been introduced for the sake of clarity and none of the subsidiary phenomena has anything to do with these secondary electrons.

We have now sufficient data to describe the subject-matter of the invention as follows: Throughout the above phenomena no grid current flows in grid I circuit and these voltage conditions will be maintained, i. e. we will make the control grids have a voltage sufficiently negative with relation to the cathode for just no grid current to flow, but if it were slightly less negative some grid current (of the normal forward type) would flow.

If we now apply an oscillatory potential to the negative second control grid, and shift its own potential to a point when under no circumstances of its oscillatory voltage excursion does it draw grid current, we can make the space charge between the first anode (accelerator grid) and the second control grid oscillate in position moving nearer to the accelerator when the oscillating voltage on the second control grid is more negative. The quantity of electrons in this space charge is not materially affected, nor is the quantity of electrons in the space charge beneath the second accelerator materially affected though some variation in this is bound to occur.

If the oscillatory voltage on the second control electrode has a relatively low frequency no effect will be introduced on grid 1 in spite of the capacity coupling between control grid 2 and control grid 1. However, if the oscillator frequency is a very high frequency whose period is comparable to the transit time, a grid current will flow in grid 1 circuit in spite of the insertion of a complete de-coupling filter circuit which maintains the grid 1 at a fixed potential with reference to the cathode and eliminates the capacity coupling.

The grid current is due to the following sequence of occurrences: Electrons have finite though exceedingly small mass and hence their emission is not entirely free from inertia when dealing with time intervals smaller than a microsecond (10^{-6} second). Hence it takes certain exceedingly small time for an electron to traverse the space between the electrodes as indicated in the time distance diagrams discussed above. This is called the transit time.

If we imagine the electrons forming the space charge between the accelerator and the second control grid to emerge from the interstices of the accelerator electrode during the second half of the time interval tm^1 to tm^{11} (Figure 4) they are moving "en masse" in the reverse direction towards the first anode electrode just as the weight on a pendulum moving towards the neutral position after its initial excursion in one direction. If at the same time the dynamic voltage on the second control electrode goes from zero to a relatively high negative value at the same speed, i. e. in the same short time interval as the electrons are on their own account moving back towards the first anode; the action that takes place is similar to giving the pendulum weight above illustrated a large impulse in the direction in which it is already moving. Clearly this will impart so much kinetic energy to the weight that it will swing on the other side of the neutral position very much farther than it would have done on its own account. The same thing happens with these electrons under discussion, i. e. if the period of the oscillation is commensurate with the transit time of the electrons emerging from the interstices of the first anode, the kinetic energy imparted in an opposite direction to the normal flow of electrons from cathode to anode will be so great at the moment when the voltage on the second control grid approaches its own cut-off potential that the electrons so reversed will actually reach the first control grid and have sufficient kinetic energy to force themselves into this grid. This causes the "kinetic" grid current to flow as above described and to stop it we must move the grid bias of this first control grid to a greater negative value so that it has increased repulsion to act as a cushion for these high kinetic energy electrons.

It can be experimentally demonstrated, as described in my article of August 10, 1939, in the Wireless World entitled "Parasitic Oscillation in Frequency Changers," that to avoid this kinetic grid current the grid has to become increasingly negative as the frequency is increased, and also as the oscillator amplitude on the second control electrode is increased. The law relating to "kinetic grid current" shows it to be directly proportional to the effective grid volts and approximately proportional to the square of the frequency within the range of frequencies examined (30 to 120 megacycles).

It is more than likely that the law is not strictly square law but is a composite law; though this still requires further investigation at still higher frequencies.

The purpose of the invention is to make use of this kinetic grid current which hitherto has been considered a parasitic phenomenon and a nuisance, as follows: Viewing Figure 5, if a resonance circuit is connected to grid 1 of a multi-grid valve, grid 2 acting as a positive accelerator, grid 3 having a high frequency oscillation of say 10 megacycles or more impressed upon it, the "kinetic electrons" reaching the first grid after grid 3 approached its own cut-off potential, will cause a uni-directional high impedance coupling between the oscillation on grid 3 and resonant circuit connected to grid 1 which will excite the resonant circuit and cause it to oscillate, this causing grid 1 to follow an approximately sinusoidal voltage sequence. This coupling is very much greater than if it were due only to the capacity coupling between these grids which is only of the order of 0.1 $\mu\mu$ F. The smaller the damping on this circuit, i. e. the higher the "Q" of the circuit, the more truly sinusoidal becomes its oscillation though it is caused by periodic pulses as described above. By suitably adjusting the inductance and capacitance of the tuned circuit one can vary the phase of the first control grid A. C. voltage with reference to the second control grid A. C. voltage.

It is known that the second anode current of the valve will have a magnitude proportional to the multiple of the two oscillatory voltages, hence it can be shown that the anode current will have a component twice the frequency of the oscillator frequency and also a D. C. component proportional to the cosine of the phase angle between the two control voltages.

$$Ia = c(E_1 \sin \omega ot)(E_2 \sin \omega ot + \alpha) = \frac{cE_1E_2}{2}[\cos(2\omega ot + a) - \cos \alpha]$$

If we filter out the higher frequencies from the second anode circuit we are left with an anode current only varying due to the variation in phase angle mentioned above.

Under these circumstances, if the tuned circuit on grid 1 has a constant tuning (which can if desired be maintained by a resonant piezo-electric crystal, or the whole circuit can be substituted by a crystal in any known manner) and the frequency on the second control grid is varied or modulated the D. C. anode current of the second anode will vary very rapidly from a maximum value when the phase angle is approximately zero to a minimum value when the phase angle is approximately 180°, as shown by the thick line in Figure 6. Clearly this arrangement forms an ideal frequency modulated carrier de-modulator of extremely high efficiency as shown in Figure 6 in which the slope of the anode current change to change in frequency is proportional to the square of the Q multiplied by the square of the voltage multiplied by the fundamental frequency raised to a power which in the frequencies between 10 and 120 megacycles approximates to the square.

The present invention is based on the realisation of the fact that in this F. M. demodulator circuit, if the negative amplitude of the grid voltage greatly exceeds the cut-off value and by a simple grid-leak-grid-condenser limiter is not allowed to exceed zero voltage in a positive direction to any appreciable degree, i. e. if the second control grid is overloaded, the demodulation slope of the device is very great due to the very high kinetic energy imparted to the electrons moving to grid 1 and thus exciting this too to a very large amplitude oscillation. But due to the control on the second anode current being in the form of what amounts to square waves of fixed amplitude, the demodulation slope is constant and independent of the carrier amplitude. Thus if this device is the demodulator in an F. M. receiver, the device acts as its own amplitude limiter. As this function plus the demodulator function is usually accomplished by three or more valves, the new device consisting of only one valve is clearly of considerable advantage (the valve can be a simple pentode or a hexode etc., the incorporated triode shown in Figure 5 not being required for this demodulating purpose).

Figure 5 shows an example of a device in accordance with the invention for converting frequency shift or frequency modulation input into input circuit power variations with the oscillation generator incorporated in the form of a self-contained triode and associated circuits. The valve is a triode-hexode of the type in which the triode grid is internally connected to the third grid of the hexode whose function is that of second control grid. In the output anode circuit a filter network is included consisting of inductance *i* and two capacitances *k* and *j* followed by an output power dissipating device; this can be a simple current meter or a loading resistance or impedance across which a voltage drop will appear, or the like, in which the power variations of the device can be developed.

The accelerator anodes of the hexode valve are supplied with positive potential (with reference to the cathode) by known means of keeping this potential constant, for instance by a series resistance *l* connecting them to the source of positive potential and a shunt means of stabilisation which can be a condenser *m* (or a gas discharge stabiliser or any other device having a large capacitance e. g. a floating battery or the like). The oscillator anode is fed through a feed impedance *n* and the grid through a grid leak *o*, both having known functions, and tend to make the oscillator less dependent on supply voltage fluctuations than if they were absent.

The function of condensers *p* and *q* is to make the oscillator tuned circuit consisting of condensers *r* and *s*, and inductance *t* (either of which may be variable) independent of the D. C. potentials of the triode anode *w* and grid. The tuned circuit connected to the hexode control grid nearest to the cathode and which is excited by the kinetic grid current effect consisting of inductance *v* and capacitance *u* (either of which may be variable) and which can be tuned to the mean frequency of the oscillator or to any desired part of the frequency sweep of the frequency modulated oscillator.

The particular setting of this tuning with reference to the instantaneous oscillator frequency determines the amount of output circuit current *Ia* (on Figure 6) or power, being developed.

The grid bias of the first control grid of the hexode is shown connected for convenience to the negative end of the heater circuit battery (but can clearly be fed from any suitable source of negative potential).

The frequency-shift discrimination sensitivity of this device is also exceedingly high, and thus it can be used as a capacity change detector having a sensitivity of the order of lmA/10^{-13} farads which increases with frequency. The device can also act as an inductance variation detector capable of use in many ways. As examples of this type of application one can mention the direct radio-frequency conversion of mechanical displacement into voltage or current change, such as the displacement of the diaphragm of a condenser microphone, a condenser pick-up for gramophones or the like detection of irregularities in a surface, or variation of minute dimensions (ultra micrometer) etc., the displacement of the core of the inductance by minute amounts, the detection of frequency or phase shift and the like.

In many such instrument applications it is necessary to enable the exceedingly sensitive device to function without being seriously affected by operating conditions of the valve such as mains voltage variations and the like and hence it may be necessary to balance out fluctuations in applied potentials, also the frequency drift of the basic oscillator by the use of a balanced circuit comprising two similar devices, the difference in output of the two giving the desired indication whilst drift of both in one direction due to operating conditions having negligible effect on the indicator.

The general conception of balancing two devices in this manner is known but particular advantage can be derived by the following arrangement:

If for example circuit shown in Figure 5 is considered and two valves are to be used in a balanced manner the output meter shown can be substituted in both valve anode circuits by a difference indicating instrument of known type or a balanced bridge type output load circuit. In various applications it will be of advantage to leave one device undisturbed by the outside physical phenomenon to be converted and to apply such phase shifting phenomenon to the other device only. In this case the preliminary set up can provide for the synchronisation of the two oscillators either by operating them in parallel or in push-pull the two circuits *v* and *u* connected to the first control grid being independent. One having the external change applied for example to the condenser *u*, or the inductance *v*, or both.

The difference indicator in the anode circuits will show a signal with the same high order of sensitivity as that mentioned above for one valve but with considerably reduced dependence on fluctuating operating conditions.

Further possibilities in connection with the use of two devices which according to the application present various advantages are to make the initial set up before the application of the external signal so that the phase relationship between the control voltages on the two control grids of one valve are in quadrature thereby obtaining an anode current from this valve of the value represented by the horizontal line in Figure 6, i. e. substantially in the middle of the operating region of the demodulation slope of the line, This permits the signal to be detected in an incremental or decremental sense equally well. To balance this condition in one valve the other valve can also be set to have an internal phase-relationship in quadrature.

According to the conditions of the particular application it is possible to arrange that corresponding grids in the two valves have a mutual in phase or out of phase relation or a mutual quadrature relation.

In some applications where the very greatest sensitivity is required a further group of possibilities exist.

Two different types of triode hexode valves exist. A type in which the triode grid is internally linked to the hexode control grid farthest from the cathode (as shown in Figure 5) and a type in which the triode grid is internally linked to the hexode control grid nearest to the cathode.

If one combines two such dissimilar types having otherwise similar characteristics special advantages can be obtained as follows:

The quadrature relation in one can be obtained in a leading sense and in the other in a lagging sense i. e. for instance the grids connected to the oscillator triodes can be in phase opposition whilst the two other grids are in phase hence any change applied from an external signal which alters the reactance of the circuit connected to the two in phase grids, causes, an exceedingly sudden change from the initial quadrature relation with balanced anode currents corresponding to the horizontal line in Figure 6 in both valves, to an entirely out of balance condition when in one valve the maximum current flows whilst in the other the minimum.

The combination of dissimilar valve types can of course be made use of also with other initial phase relationships providing different features. For instance if both valves are set to pass minimum current (per Figure 6) without outside signal one valve can be made to ignore the input signal if it has an incremental sense, whilst the other responds to it and vice versa if the input signal is in a decremental sense. This type of sense discrimination having special advantages for instance in navigational instruments, such as automatic pilots, blind landing apparatus and goniometric applications and the like. As a general rule it can be said that the sensitivity and stability of operation in all these circuits increases as the oscillation amplitude increases beyond the linear limits of the valves i. e. when the oscillations become amplitude limited.

Where the instrument in which the device, according to the invention, is used has for its purpose the detection of radiant energy or the reception of a message or communication transmitted by modulation of such radiant energy it is possible to connect the radiation detector such as a photo-cell and the like in a manner so that it upsets the phase relationship of the quiescent condition in many ways and the detection takes place on the sloped part "S" of curve Figure 6.

It is also possible to use a radiation detector of a non linear type (such as one relying on a barrier-layer phenomenon for its operation) connected into the reactive circuit u, v, above described in a manner that irradiation causes shift in the phase response of this circuit to the frequency produced by the oscillator circuit.

It is also possible to use a radiation detector which alters its capacitance or its inductance (or both) when irradiated and this can be incorporated in part of the reactive circuit, v and u in Figure 5.

However, if the simple detection of a change in radiation is required with a very high sensitivity but without regard to the ability to discriminate the degree to which this occurs (i. e. in picture transmission without regard to half tones but only responding to black or white) a preferred manner of operation is to set the device to operate at one of its extreme points of operation (say at the maximum anode current or the minimum anode current part of the curve in Figure 6) and to arrange the radiation detector shunted across the reactive circuit v, u (Figure 5).

The operation will then become different in so far as, in the unirradiated condition the maximum or minimum anode current will flow in the valve whilst when irradiated the radiation detector (which shall be of a type changing its impedance from a very high value (practically infinity) to a comparatively low value) will damp the low loss reactive circuit to such an extent that the anode current suddenly reverts to substantially the value represented by the horizontal line (Figure 6). The anode current reverting to the above extreme value, when the irradiation ceases, in a very short time interval, the speed of operation being inversely proportional to the "Q" value of the reactive circuit.

In any device where any physical phenomena can be changed into a variation of capacitance or a variation of inductance or, for that matter, a variation of both or a variation of either combined with a variation of resistance etc. such change can be resolved into a current or voltage change with this exceedingly sensitive device.

Figure 6 shows that outside the boundaries of Δf the anode current varies in a complex manner depending on circumstances not yet investigated as they have no bearing on the present invention. These parts of the curve are shown dotted in Figure 6. Figure 7 shows a high vacuum pentode device used as a trigger relay, the individual parts of the circuit are designated with references similar to those in Figure 5 except the generator of high frequency oscillations in this case is assumed to be a separate device shown symbolically as f^1 which is shown to be frequency stabilised by having connected thereto a piezo-electric crystal X_2 through a condenser x.

It is sometimes found necessary to insert resistance w^1 into the second control grid lead to make this grid act as a more effective limiter in known manner.

The resonator circuit, consisting of v^1 and u^1 both of which can be variable is shown to be frequency controlled by the resonant piezo-electric crystal x^1. This can be compressed by the application of a polarizing potential applied as an input at terminals marked "in" via H. F. choke y and isolated from the resonator circuit from the D. C. point of view by condenser q^1. For convenience grid bias is applied to the first control grid by its own action as an amplitude limiter causing a voltage to be built up across the series grid resistor g^1 by the grid current that flows during the periods corresponding to the clipped off peaks of the amplitude limited waves. A condenser d^1 shunts the resistor g^1.

By the action of this polarizing voltage the resonant frequency of crystal x_1 is shifted and hence the phase angle of the oscillating voltage (built up on the resonant circuit v^1 and u^1) with reference to the exciting oscillator voltage. It is obvious that without departing from the spirit of the invention this shift in phase angle can also be produced by the input energy being applied to the crystal X_2 instead of X_1. Furthermore the input energy can be made to influence the inductive or capacitive components of the resonator or oscillator directly for instance by causing the input energy to alter the permeability of the core of the inductance v^1 or by causing it to alter the dielectric constant of condenser u_1 or the like.

In this case both control grids are overloaded, i. e. the A. C. signal on them exceeds the negative grid bias range of the valve, and hence the main anode current which is the main circuit current (shown thick line) can be switched on and off by input voltage control. This control voltage can be applied either to the piezo-electric crystal thereby altering the natural frequency thereof and controlling the frequency discrimination of the circuit network v^1 and u^1 attached to control grid nearest to the cathode or to a crystal controlling the frequency of the oscillator or by any other voltage, or current operated tuning shift converter system.

In this case the anode current of the device follows a law as that shown by the full line in Figure 8 in which the device has either no anode current at all or rapidly reaches a saturation value. The anode current attempts to follow a law similar to that shown in Figure 6 but as this curve is larger than the anode current limits of the valve we get this reversible trigger phenomenon.

Clearly a device of this type is superior to a gas-discharger grid-controlled trigger relay as it has no inertia up to speeds two to three orders of magnitude higher than that of the gas-discharge devices.

Also the anode current can be switched both "on" and "off" by pure grid control.

The size of the main circuit current that can be switched on and off is at present only limited by the size of multi-control grid valves available and could in theory be developed to very large sizes given the necessary demand permitting the manufacture of such large high vacuum devices.

If used as a radiation detector with, for instance, a photo-cell, these devices can and preferably would be so coupled to the circuit that they can cause a shift in first control grid bias from a point where the kinetic grid current phenomenon occurs with, say, a minimum anode current flowing to a point where the absorbed grid current damps the resonant system coupled to it, causing the anode current to revert to a mean value.

It is to be understood that the phenomenon of "space-charge-coupling" is well known and proposals for taking advantage of this phenomenon have previously been made, one example which I am familiar with being disclosed in the specification of British Letters Patent No. 487,913 where it was suggested to use this space-charge-coupling effect to obtain an unidirectional high impedance coupling element between the source of the frequency, either constant or variable, and a tuned circuit.

In this prior case the circuit contained a multigrid mixer valve and an oscillatory circuit connected to one grid of the mixed valve and by the said oscillatory circuit being excited by an unmodulated or frequency modulated control potential applied to another grid of the valve a change of frequency was converted into current variations.

In the arrangements particularly described in the aforesaid specification the source of oscillations was connected to the grid nearest to the cathode of the mixer valve.

It was indicated in this specification that current variations in the output circuit could be produced by changes of frequency by applying the source of oscillations to the control grid furthest from the cathode and exciting the tuned circuit connected to the control grid nearest to the cathode by means of the usual or (tube) valve capacity.

I have, however, discovered that provided the phenomenon which I term "kinetic grid current" is made use of as a coupling an output current variation of greater magnitude is obtained than is possible when employing only the valve or tube capacity. To obtain this greater magnitude of current variation, it is necessary to apply an oscillation amplitude so large that the grid or grids cut off the anode current during part of the operating cycle during which period the electrons are returned through the first accelerator grid in a direction reverse to the normal electron flow with sufficient kinetic energy as to reach and be absorbed by the control grid nearest to the cathode and constituting the kinetic grid current. This will be best understood by a consideration of the phenomenon described with relation to Figure 4 where it will be observed that the electrons having passed through the first anode (or first accelerator) after time reference point tm^1 have been flung back by the time reference point tk is reached.

Thus, so long as the arrangement is such that the control grid furthest from the cathode acts as an amplitude limiter, cutting off the main anode circuit during part of the operating cycle this greater magnitude of output circuit current variation will occur.

It will be seen from the foregoing that I have by my invention, indicated means by which great advantage can be taken of the existence of the kinetic grid current phenomenon hereinbefore discussed.

I claim:

1. An electronic circuit comprising an electronic tube having three electrodes in series arrangement between a cathode electrode and an anode electrode, the inner and outer electrodes as measured from the cathode being control grid electrodes and the intermediate electrode being an accelerator electrode, voltage source means establishing relative static potentials on the control grid electrodes to prevent flow of grid current, means maintaining the static potentials of the anode and accelerating electrode positive with respect to the cathode, whereby space charges between the accelerating electrode and the respective control grid electrodes set up control fields at opposite sides of said accelerator electrode, input circuit connected between the inner control grid electrode and the cathode, and a control circuit connected between the outer control grid electrode and the cathode to impose upon said outer control grid electrode an oscillatory voltage of an amplitude sufficient to block anode current during a part of the oscillatory cycle and to drive electrons in reverse direction through the accelerating electrode to reach the inner control grid, the oscillatory voltage having a period of the order of the electron transit time and said input circuit being resonant at approximately the frequency of said oscillatory voltage, whereby the instantaneous output power devel-

oped at the anode is dependent upon the phase angle between said control fields.

2. An electronic circuit as recited in claim 1, in combination with means to vary the phase angle between said control fields, thereby to modulate the output power developed at the anode.

3. An electronic circuit as recited in claim 2, wherein said means for varying the phase angle comprises means for adjusting the resonant frequency of one of said circuits.

4. An electronic circuit as recited in claim 2, wherein said means for varying the phase angle comprises means for adjusting the static potential fields at opposite sides of said accelerator electrode.

5. An electronic circuit as recited in claim 1, wherein the static potential impressed upon one of the control grid electrodes is such that the negative half-wave of the oscillatory voltage imposed upon that control grid electrode carries the instantaneous voltage thereof substantially beyond cutoff, thereby to limit the effective amplitude of such oscillatory voltage.

6. An electronic circuit as recited in claim 1, wherein said control circuit includes means for modulating the oscillatory voltage impressed upon the outer control grid electrode in frequency or phase.

7. An electronic circuit as recited in claim 1, wherein said control circuit includes an electronic oscillator.

8. An electronic circuit as recited in claim 1, wherein said control circuit includes an electronic oscillator, said oscillator having the elements thereof enclosed within the envelope of said tube.

9. An electronic circuit as recited in claim 1, in combination with a second tube having an accelerator electrode sandwiched between control grid electrodes and located between a cathode and anode, said second tube being connected in balance circuit relation to the said first tube.

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REFERENCES CITED

The following references are of record in the file of this patent:

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