

UNITED STATES PATENT OFFICE

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AMPLIFYING SYSTEM

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The present invention relates to amplifying systems containing light sensitive devices and more particularly to circuits that employ, in combination, thermionic amplifiers and photo-electric tubes.

In view of the fact that the magnitude of the photographic current derived from the commercial forms of light sensitive apparatus when activated by sources of light of ordinary luminosity is somewhat meagre, usually of the order of micro-amperes, it is necessary to employ one or more stages of amplification in order to obtain an output current of practical amount, i. e., sufficient to actuate relays or other circuit control devices. This amplification conveniently may be provided by one or more three-electrode thermionic devices connected in cascade with the photo-electric cell or tube.

An object of my invention is to provide circuit arrangements of this character which will offer a high degree of sensitivity to changes of the current produced in the photo-electric tube in response to variations of a light source. Another object is to provide circuits which will be simple in both construction and operation, also which may be energized effectively from a source of alternating, and under some conditions, of direct current. A still further object is to provide a light sensitive circuit arrangement in which under certain adjustments the output current varies linearly with respect to the photo-currents.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawings.

Figure 1 shows a bridge circuit organization embodying some of the features of my invention including an amplifier exemplified in the form of a gas-filled thermionic device having an arc-like characteristic and a photo-electric tube; Figure 2 shows the relation between the anode, grid and critical grid voltages under conditions of a balanced bridge; Figure 3 illustrates a typical group

of three curves useful in explaining a convenient method of controlling the gaseous type of amplifier; Figure 4 depicts the relation between the amplifier current and the illumination of the photo-electric cell of Fig. 1 during changes in the degree of illumination and certain conditions of circuit adjustment while Figure 5 graphically typifies the electrical effects introduced into the circuit of Fig. 1 by various adjustments of the condenser.

Referring to Fig. 1, numeral 1 indicates a thermionic amplifier of the grid-controlled arc discharge type. A device of this character is described in articles entitled "Hot cathode thyratrons" by A. W. Hull in the General Electric Review, Vol. 32, No. 2, April 1929, pages 213-223, and Vol. 32, No. 7, July 1929, pages 390-399. A Thyatron tube is characterized by large power output which is controllable by an exceedingly small amount of grid energy of the order of a fraction of a micro-watt. A device of this character usually contains a three-electrode arrangement immersed in an ionizable medium, e. g. mercury vapor or argon at a pressure between 1-50 microns of mercury sufficiently high to support an arc-like discharge at the impressed voltages. The electrodes may comprise a thermionic cathode 2, an anode or plate member 4 and a grid or electrostatic control member 3 interposed therebetween, all of the electrodes being energized preferably by alternating current from a multi-tap secondary coil of a transformer 5. The primary of the transformer may be supplied with alternating current from a source 6 preferably of commercial frequency and voltage. As stated in the articles referred to, the current in an arc discharge device passes through the tube as an arc whose starting only may be controlled by the grid but after starting, the current flow can be stopped only by removing the anode voltage. The operation of such a device consists in periodically removing the anode voltage to stop the discharge and in controlling the restarting of the discharge by the grid; the latter thus determines the average current of the arc. The grid effectively is connected to one

terminal of the transformer secondary through a variable condenser 7 and the anode is connected to the other terminal through the load, the filament current being taken
 5 from the transformer by means of intermediate taps 8, 9 exemplified as being in a symmetrical position. There is a light-sensitive member 10 shown in the form of an ordinary photo-electric cell connected between the
 10 grid and the terminal of the transformer secondary to which the load is connected. As shown, the cathode of the photo-electric cell is connected to the grid while the anode is connected to the transformer. A source
 15 of light 11 which may be of a variable character such as receding or approaching daylight is provided to activate the light-sensitive member. The load which may constitute a relay for controlling external circuits
 20 or an additional amplifier is connected between the plate and the secondary terminal common to the anode of the photo-electric tube.

While the final adjustment of the system
 25 for operation will depend on the type of response desired in the load circuit, i. e. whether sensitivity is required or whether a linear proportionality between the amount of light impinging on the photo-electric tube and the
 30 output current is desideratum, it is generally desirable first to effect a balance of the electrical bridge. This step is most conveniently accomplished by varying the condenser 7 while the photo-electric tube is maintained
 35 in the dark state and noting the response of the arc discharge tube as will be explained hereinafter.

It is apparent that the system constitutes an electrical bridge in which two arms comprise the condenser and coil portion 12, while
 40 the other pair of arms is made up of the capacitative path between the control member 3 and anode 4 in parallel with the path through the photo-electric tube 10, also the coil portion 13. The path through the photo-electric tube in the darkened state is also capacitative since the ohmic resistance is infinite or substantially so. For convenience in
 45 discussing the matter of bridge balance or departures therefrom, the inter-electro capacitances have been shown on the diagram in Fig. 1 as dotted condensers C_2 , C_a effectively in shunt to the anode-cathode path of the photo-electric tube and to the grid-plate path
 50 of the amplifier. The filament-grid capacitance is not shown inasmuch as its magnitude is relatively small. The filament taps may be positioned on the secondary coil so that when the capacities in the opposite arms are
 55 properly adjusted by varying the condenser the bridge may be balanced, in which case the capacitance C_1 of the condenser 7 exactly neutralizes or balances the combined effect of capacitances C_2 , C_3 . Hence, no alternating
 60 current charge is applied to the grid during

the positive portion of the alternating current cycle for well understood reasons. However, even though the grid is substantially not charged under these conditions, the arc
 discharge device will normally start for the
 70 reason that a definite negative grid potential at all times greater than the critical voltage is necessary to prevent initiation of the arc. This is clearly shown in Fig. 2 wherein
 75 curve a represents the voltage applied to the anode by the transformer secondary and the broken line b indicates the critical negative voltage necessary to restrain the tube from operating. An arc is prevented only in the
 80 event that the grid voltage line c does not intersect the critical voltage curve b . The curve c is drawn for an exact balance between the capacitance C_1 and $(C_2 + C_3)$ hence, it is a straight line parallel to the horizontal axis
 85 whose position depends only on the leakage currents between the grid and other elements of the tube and upon electrons received from the cathode. Under these conditions the grid assumes a floating potential of about half a
 90 volt negative with respect to the cathode. It will be observed in Fig. 2 that the grid voltage line c intersects the grid voltage curve b hence the arc will start and current will flow for practically the entire positive portion of
 95 the cycle as indicated by the cross-hatched area. In case a high vacuum tube were substituted for the arc discharge device, it is evident that the voltage assumed by the grid when the bridge is balanced may be sufficiently negative to prevent flow of substantial plate current throughout the entire positive portion
 100 of the cycle. During the negative portion of the alternating current cycle, no current can flow either through the arc discharge device or the high vacuum device for well understood reasons.

When the photo-electric tube is activated by light from the source 11 so that the resistance of tube 10 is materially decreased, the
 system no longer remains in a balanced condition as will be explained hereinafter and an alternating potential is impressed on the grid. In the event that this potential is
 110 more positive than the critical amount necessary to operate the thermionic device or less negative than the amount necessary to restrain the tube from operating, an arc is initiated or triggered which thereafter and
 115 until the end of the positive half-cycle is no longer controllable by the grid. This condition is readily noted in the diagrams of Fig. 3. An arc is started only when the grid voltage c intercepts the critical voltage curve b during the interval the anode is positive. It is evident that the constants of the circuit,
 120 also the position of the filament taps may be adjusted to give the desired type of response by way of current through the tube to operate relays or any other type of load circuit. The phase of that portion of the current
 125 130

which under dark conditions had flowed through capacitive path C_2 , C_3 in order to off-set or balance the current flowing to the grid through capacitance C_1 is now changed when the photo-electric tube is activated due to the introduction of resistance into the branch containing capacitance C_2 , giving a grid voltage curve of the form shown in diagrams A, B and C, Fig. 3. Hence, the grid is subjected to phase control having two aspects of current and no current respectively when considered with respect to the action of the photo-electric tube under conditions of light and no light. However, if the light is progressively changed, the phase relation is likewise progressively varied as will be pointed out hereinafter and the average current flowing through the tube may be controlled in this manner. It is also apparent that the change in phase of voltage applied to the grid may also be controlled by the condenser 7 assuming a light of constant brilliancy. Under conditions of a variable light source or variations of the capacitance of condenser 7, the output current can be changed continuously from zero to full value. This is clearly shown in Fig. 3 wherein diagrams A, B and C represent three typical stages in the phase control method of determining the point in the alternating current cycle at which the arc shall start. In diagram A, the grid voltage is nearly 180° out of phase with the anode voltage and the current starts near the end of the cycle; in diagram B, the grid voltage is advanced in phase so that the current starts at the middle of the cycle, while in diagram C the grid voltage is nearly in phase with the anode voltage and current starts nearly at the beginning and flows for practically the whole of the half cycle. The amount of current per cycle is represented by the shaded area and the average current is the integrated amount per unit of time. It is obvious that the average current is determined by the point of intersection between the grid voltage curve c and the critical voltage curve b which in turn is determined by the phase relation between the grid voltage c and anode voltage a . It will be understood that while the system lends itself readily to a continuous change in output current for a correspondingly continuous change in the reactive constants of the bridge, the system is equally applicable to abrupt changes in the constants as when the photo-electric tube is subjected first to a darkened state and then suddenly to an illuminated condition or vice versa.

According to another feature of my invention, I have discovered that in addition to serving as a means for neutralizing the capacitances C_2 , C_3 existing between the electrodes of a discharge tube and photo-electric tube thereby to obtain maximum sensitivity of operation, the condenser 7 under various adjustments may also serve to produce a linear relation between the output current and the illumination of the photo-electric tube. These condenser adjustments consist in producing an over-neutralization of the inter-electrode capacitances C_2 , C_3 and it has been found that with a certain degree of neutralization, depending upon the characteristics of the discharge tube, photo-electric tube and associated circuits, the relation between output current and the illumination becomes nearly linear or directly proportional. When adjusted in this manner, it is apparent the circuit has utility in many applications where a uniform proportionality is required. For example, it may be necessary to cut out resistance in a lamp load circuit by a device responsive to the tube output current wherein the device is to be actuated in a progressive manner precisely in accordance with changes of the intensity of light impinging on the photo-electric tube. Fig. 4 shows three curves plotted against output current and photo-electric tube illumination under conditions of over neutralization of the inter-electrode capacity. It will be noted that curve d which was taken under conditions of having the capacitance C_1 adjusted in a given circuit to give ten times the amount of inter-electrode capacitance (C_2 , C_3) is substantially a straight line, indicating an approximate linear relation between output current and photo-electric tube illumination. On the other hand, curve e shows the relation between these factors when C_1 is twice (C_2 , C_3) in the same circuit as before while curve f is predicated on an adjustment in which C_1 only slightly over-neutralizes the inter-electrode capacity. It will be evident that curves e and f represent a much more sensitive adjustment than curve d but lack the strict proportionality feature. Moreover, the curves also show that as the value of C_1 approaches that of ($C_2 + C_3$) the degree of sensitivity in the system is increased assuming the operation to take place on the steep portion of the characteristic. The best value for the capacitance C_1 depends upon the type of response desired in the load circuit. This capacitance in all cases must be at least as large as ($C_2 + C_3$) otherwise the maximum current will flow in the discharge tube at all times even with no light. The necessity for over-neutralization, however slight, is clearly shown by the voltage curves typified in Fig. 5. Diagrams G, H, and I show the effects introduced into the system of Figure 1 under different degrees of photo-electric tube illumination when the condenser 7 is set to (a) under-neutralize; (b) exactly neutralize; and (c) over-neutralize respectively, the capacitances ($C_2 + C_3$). In these diagrams, the lines marked 1, 2, 3 and 4 represent the voltage applied to the grid under different degrees of

illumination, line 1 being typical of the weakest light. It will be observed that in the case of under-neutralization and balanced conditions (Diagrams G and H), the grid voltage is more positive than the critical starting voltage under all conditions of illumination and hence, current will flow in the discharge tube throughout the entire positive half-cycle or substantially so, as indicated by the area in cross-hatch. On the other hand, when the condenser 7 is sufficiently large to over-neutralize the inter-electrode capacitances ($C_2 + C_3$) a condition depicted by the curves in Diagram I results. It will be noted that the effect of different degrees of illumination when the system is over-neutralized is to move the position of intersection between the grid voltage curves 1, 2, 3 and 4 and the critical voltage curve b so that the starting of the arc occurs earlier in the cycle, as the light intensity is increased.

The total current per cycle for the weak light represented by curve 2 is shown by the cross hatched area. Similar areas may be drawn for other values of light corresponding to curves 3 and 4 and it is evident that the total current per cycle will increase progressively with increased illumination.

While I have explained my invention with particular reference to the combination of an arc discharge device and a photo-electric tube, it will be understood that modifications of the apparatus may be readily made within the principles of the invention. As examples of such changes, it will be evident that a selenium cell may be substituted for the photo-electric tube and that many of the advantages of the invention would be present in case a high vacuum tube were substituted for the arc discharge device. Furthermore, the use of the neutralizing condenser 7 is not limited to systems employing arc discharge devices but also has application in photo-electric-tube-amplifier combinations employing high vacuum tubes when energized by alternating voltage.

In the case of high vacuum tubes with a direct current voltage supply, the neutralizing condenser 7 is not needed. With arc discharge devices on the other hand, employed in conjunction with a direct current supply voltage, the arc will frequently start when the anode switch is closed even though the grid is biased at a sufficiently negative potential to prevent starting under constant voltage conditions. This is due to the capacity coupling between the grid and plate which makes the grid instantaneously positive when the plate suddenly becomes positive. This impulsive starting might be minimized by closing the anode circuit first through a very high resistance so that it attains its positive voltage slowly, and then short-circuiting this resistance. It may be entirely avoided however, by the use of the neutralizing condenser

7 connected between the grid and a point of opposite surge polarity to that of the anode. One method of obtaining this result is to use the circuit of Fig. 1, replacing the transformer 5 by a resistance energized by direct current. The difference between the two types of tubes with a direct current supply as regards the use of a neutralizing condenser, is that in the case of a high vacuum device the plate current flows only while the grid is positive, which is of the order of a micro-second so that the amount of such current is negligible. In the case of the arc discharge device however, a positive grid potential lasting only a micro-second is sufficient to start the current which will continue thereafter until the anode circuit is opened.

With alternating current power, in the event it is desired to turn off the current in response to the illumination of the light sensitive member, the condenser 7 and the light sensitive member would occupy a position reverse to that shown in Fig. 1, i. e. the condenser 7 in the figure would be replaced by the said member and the photo-electric tube by the condenser. In this case, current does not decrease continuously with increasing illumination but falls discontinuously from full value to zero when the illumination reaches a critical intensity. The light-sensitive member in this case should be a "two-way" resistance, for example, a selenium cell or a photo-electric tube having two plates coated with a light-sensitive material. If a "one-way" resistance be employed for this purpose, e. g. a photo-electric tube of ordinary construction which conducts current during only one-half of the cycle, the current will be turned off in response to the light but will not start again when the illumination is removed.

It will also occur to those skilled in the art that other sources of controlling impulses may be utilized in place of the photo-electric tube. For example, a signal which it is desired to amplify may be impressed between the grid 3 and the anode 4, and if of sufficient magnitude to unbalance the bridge, conduction of current will take place between the cathode 2 and anode 4 through the load circuit. In all of these cases, the condenser 7 is necessary to off-set the grid-anode capacitance of the arc discharge device for otherwise the latter will start and continue to operate even with no signal, exactly as explained hereinbefore in connection with the photo-electric tube in the case of no illumination.

While I have described and illustrated several preferred embodiments of my invention, I do not wish to be restricted thereto, but I desire that only such restrictions shall be placed upon my invention as are set forth in the appended claims.

What I claim as new and desire to secure

by Letters Patent of the United States is:

1. In combination, a thermionic device containing a cathode, an electrostatic control member and an anode, a source of alternating current connected between the cathode and anode and serving as the source of current supply for the cathode-anode circuit, and means connected to said source for neutralizing the grid-plate capacity effect of said device.

2. In combination, a thermionic device containing a cathode, an electrostatic control member and an anode, a source of alternating current connected between the cathode and anode and serving as the source of current supply for the cathode-anode circuit, and means connected to said source for neutralizing the grid-plate capacity effect of said device, said means comprising a condenser.

3. In combination, a thermionic device containing a cathode, an electrostatic control member and an anode, a source of alternating current connected between the cathode and anode and serving as the source of current supply for the cathode-anode circuit, and means connected to said source for neutralizing the grid-plate capacity effect of said device, and means for impressing upon said control member a signal to be amplified.

4. In combination, a thermionic device containing a cathode, an electrostatic control member and an anode, a source of alternating current connected between the cathode and anode and serving as the source of current supply for the cathode-anode circuit, a condenser connected between the grid and a point on said source whose voltage phase with respect to the cathode is opposite to that of the point to which the anode is connected.

5. In combination, a thermionic device containing a cathode, an electrostatic control member and an anode, a source of alternating current connected between the cathode and anode and serving as the source of current supply for the cathode-anode circuit, and a condenser connection between the control member and a point on said source of opposite phase to the anode, the electromotive force at said point being such that the capacity action between the grid and plate is neutralized.

6. In combination, a thermionic device containing a cathode, an electrostatic control member and an anode, a source of alternating current connected between the cathode and anode, a condenser connected between the grid and a point on said source whose voltage phase with respect to the cathode is opposite to that of the point to which the anode is connected and a photo-electric tube connected between the control member and said source.

7. In combination, a discharge tube comprising an evacuated envelope containing a thermionic cathode, an electrostatic control member, an anode and an inert gas at a pres-

sure sufficient to support an arc-like discharge at the impressed voltages, a source of alternating current connected between the cathode and anode, a condenser connected between the grid and a point on said source whose voltage phase with respect to the cathode is opposite to that of the point to which the anode is connected.

8. In combination, a discharge tube comprising an evacuated envelope containing a thermionic cathode, an electrostatic control member, an anode and a small amount of inert gas, a source of alternating current connected between the cathode and anode, a condenser connected between the grid and a point on said source whose voltage phase with respect to the cathode is opposite to that of the point to which the anode is connected, the electromotive force at said point being such as to over-neutralize the capacity action between the grid and plate.

9. In combination, a discharge tube comprising an evacuated envelope containing a thermionic cathode, an electrostatic control member, an anode and a small amount of inert gas, a source of alternating current connected between the cathode and anode, a condenser connected between the grid and a point on said source whose voltage phase with respect to the cathode is opposite to that of the point to which the anode is connected, the electromotive force at said point being such as to over-neutralize the capacity action between the grid and plate, and a photo-electric tube having a cathode connected to said control member and an anode connected to a point on said source of the same phase as the anode of said discharge tube.

10. In combination, a discharge tube comprising an evacuated envelope containing a thermionic cathode, an electrostatic control member, an anode and an inert gas at a pressure sufficient to support an arc-like discharge at the impressed voltages, a source of alternating current associated therewith, and means for neutralizing the effect of the capacitance between the control member and the anode.

11. In combination, a discharge tube comprising an evacuated envelope containing a thermionic cathode, an electrostatic control member, an anode and a small amount of inert gas, a source of alternating current associated therewith, and means for neutralizing the effect of the capacitance between the control member and the anode, and a photo-electric tube connected between said control member and said source.

12. In combination, a thermionic device comprising an evacuated envelope containing a cathode, an electrostatic control member, an anode and an inert gas at a pressure sufficient to support an arc-like discharge at the impressed voltages, a source of alternating current for energizing said device, a photo-

electric tube connected between the control member and source, a load circuit connected between the cathode and anode.

13. A system for amplifying photo-electric currents comprising an electric bridge arrangement having a plurality of inter-connected arms, and amplifier connected to the bridge, said amplifier including a cathode, an anode and an electrostatic control member, one of the arms of the bridge comprising a capacitance, said arm being joined to another arm which includes a photo-electric tube, the bridge being closed by a source of energy, electrical connections between the control member and the junction of the arms containing the capacitance and photo-electric tube, also between the cathode and an intermediate tap on said source of energy, and also between the anode and the junction of the arms containing the photo-electric tube and a portion of the source of energy.

14. In combination, a photo-electric tube, means for amplifying the photo-currents, said means comprising an envelope containing a cathode, a grid, an anode and an inert gas at a pressure sufficient to support an arc-like discharge at the impressed voltages, a source of alternating current for energizing the photo-electric tube and the amplifier, said photo-electric tube being connected between the grid and a terminal of said source, and a condenser connected between said grid and a terminal of said source, which is of opposite polarity to said first mentioned terminal whereby a variable activation of the photo-electric tube serves to shift the phase of the grid voltage with respect to voltage applied to the anode thereby to initiate an arc discharge between the said anode and cathode in response to changes in activation of the photo-electric tube.

15. The method of operating a light-responsive apparatus which consists in subjecting the electrostatic control member of a three-electrode device substantially to equal and opposite potential impulses whereby substantially no space current flows between the anode and cathode of said device, and then shifting the voltage phase of one impulse with respect to that of the other in accordance with variations of light whereby current is initiated in the anode-cathode circuit which varies in response to the variations in light.

In witness whereof, I have hereunto set my hand this 22nd day of June, 1929.

ALBERT W. HULL.