Sept. 2, 1958 C. E. ATKINS 2,850,674

LIGHT RESPONSIVE CIRCUIT AND ELECTRONIC TUBE THEREFOR

Filed Nov. 17, 1955 2 Sheets-Sheet 1

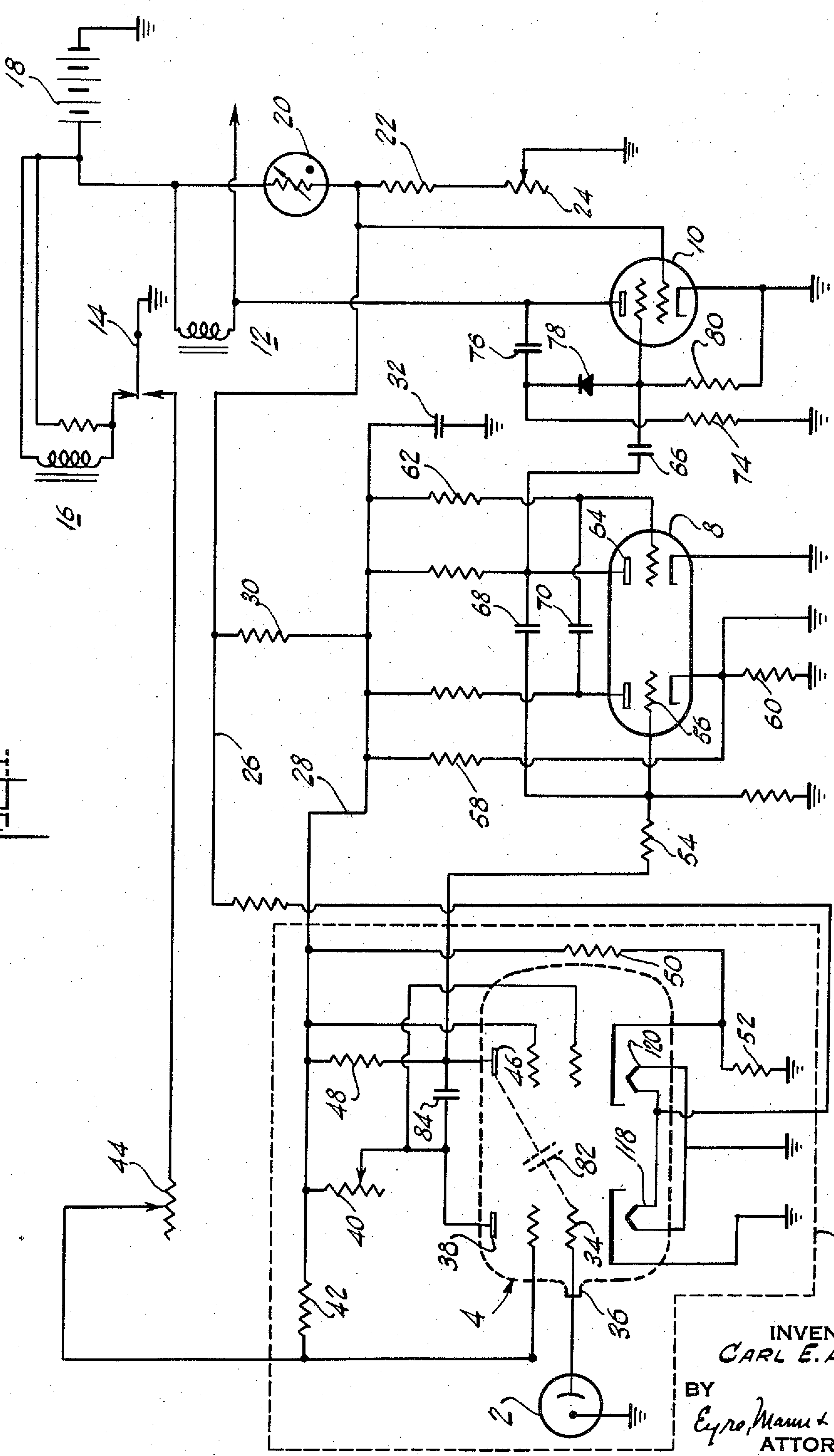

Fig. 1

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Fig. 2.

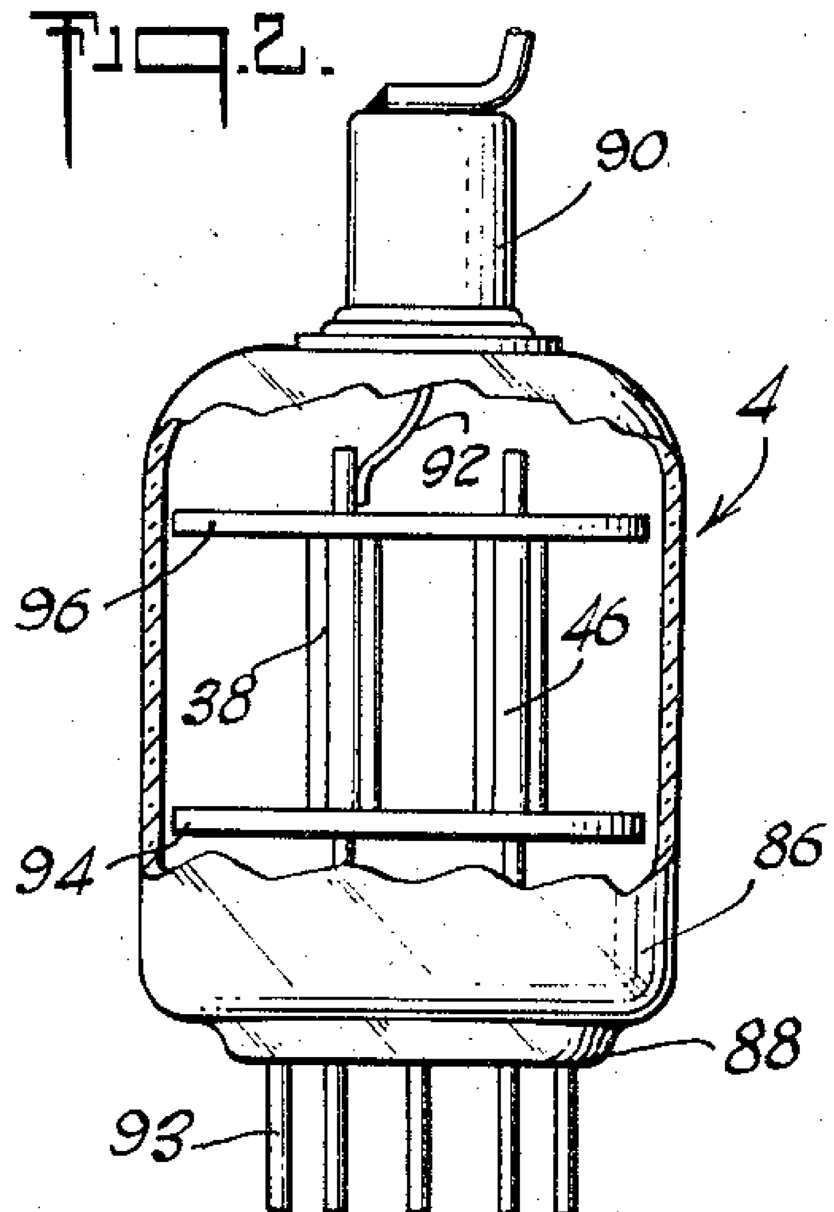


Fig. 3.

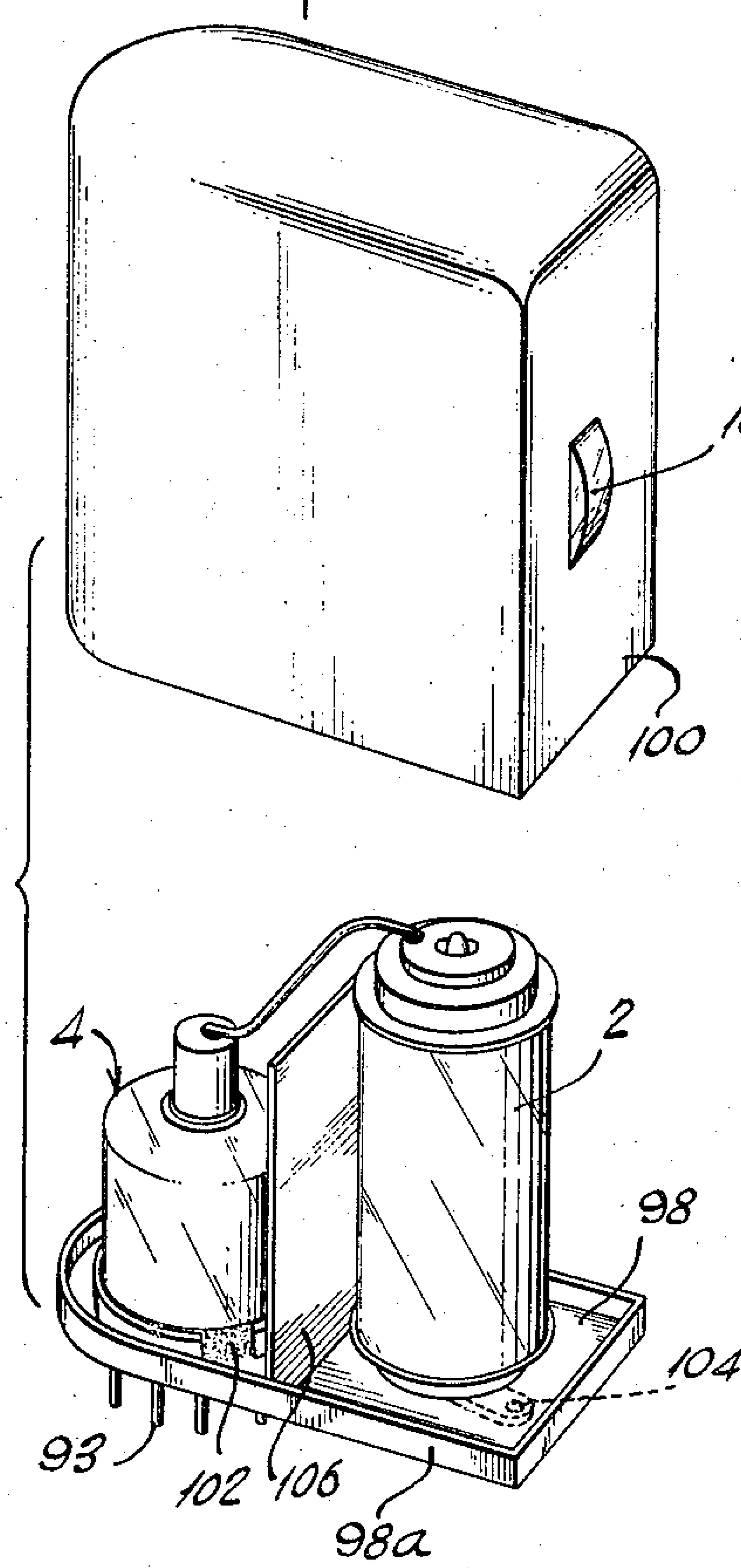


Fig. 4.

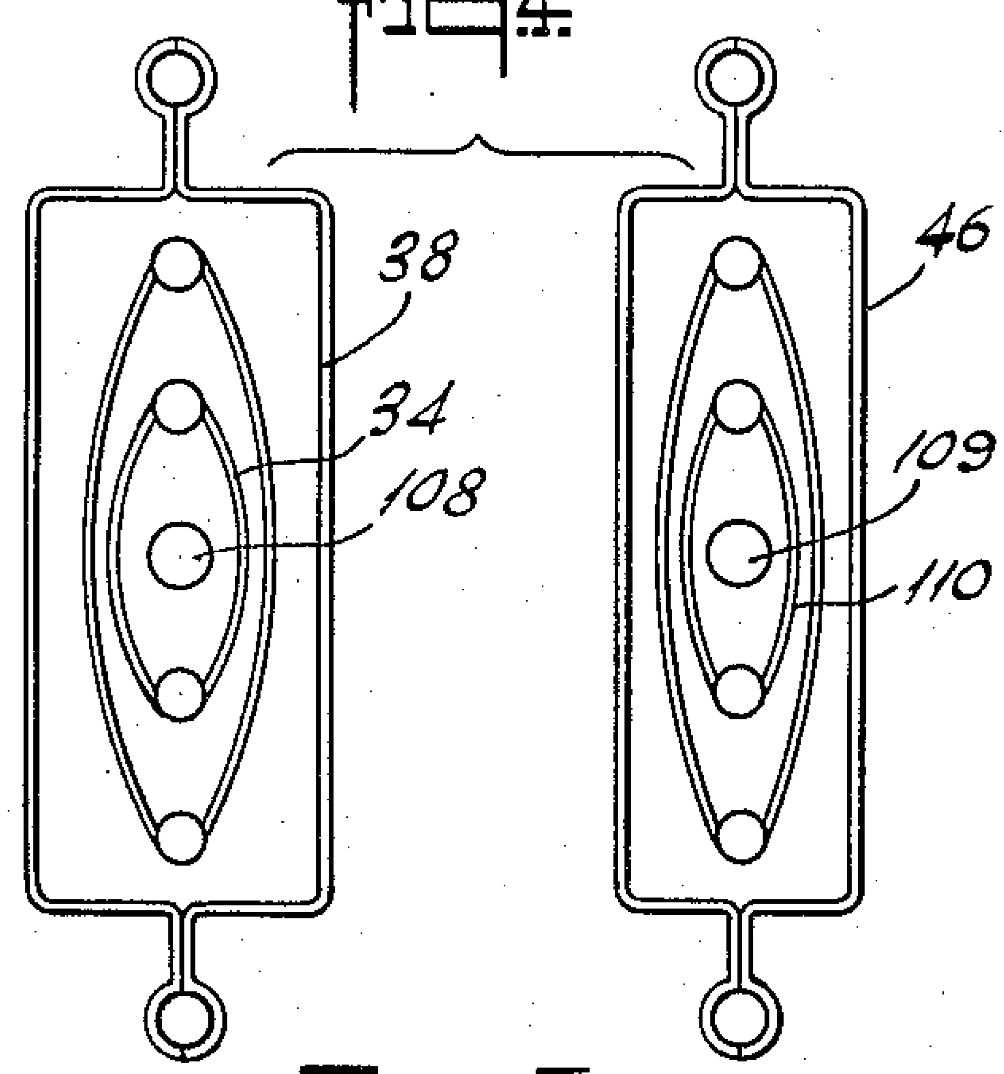


Fig. 5.

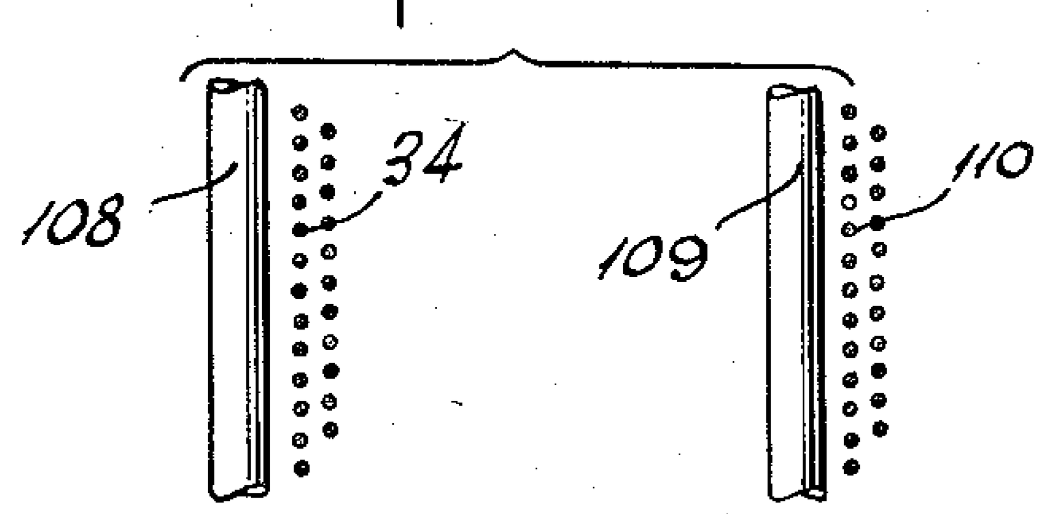
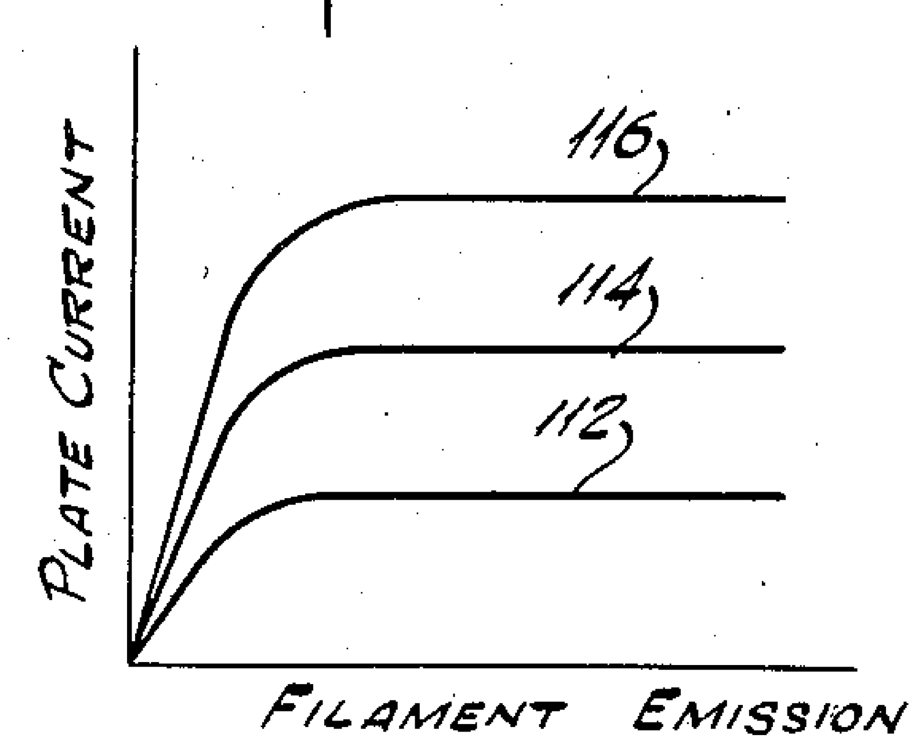


Fig. 7.



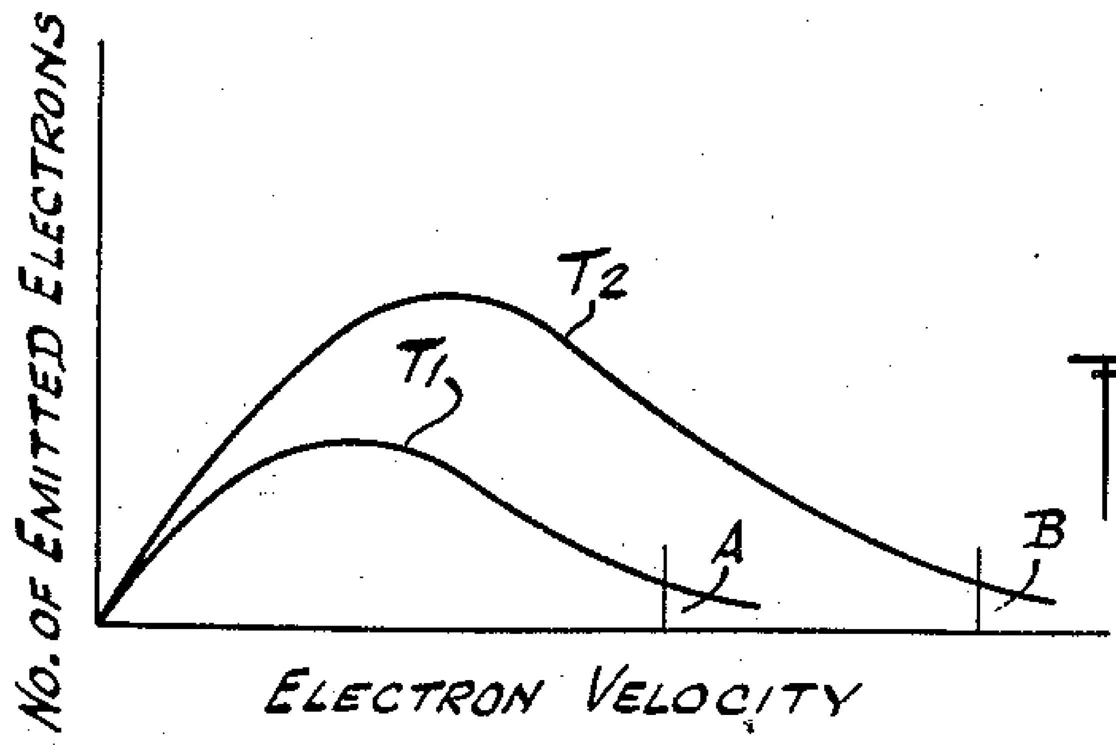


Fig. 6.

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LIGHT RESPONSIVE CIRCUIT AND ELECTRONIC TUBE THEREFOR

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Application November 17, 1955, Serial No. 547,508

12 Claims. (Cl. 315—83)

The present invention relates to light responsive control circuits and more particularly to circuits for control of the dimming switch of automobile headlamps. The circuit of the present invention while similar in many respects to those disclosed and claimed in my copending applications, Serial No. 411,208, filed February 18, 1954, and Serial No. 433,959, filed June 2, 1954, comprises an improvement over such circuits in a number of important respects. The present invention includes also a novel electron tube construction particularly designed for use in the improved circuit.

The present circuit, like those of my said copending applications, comprises in general a photoelectric tube, preferably a diode, which when subjected to light causes increase in current through an electronic multi-element tube, in the present circuit through the first half of a double tetrode embodying features of the new tube construction, an oscillatory circuit coupled to the electronic tube and so connected in the circuit as to be quiescent except when light is incident on the photocathode of the photoelectric tube and a relay control tube connected to the oscillatory circuit to receive controlling pulses therefrom when the photoelectric tube is subjected to light. The relay control tube is normally conductive to hold energized in its plate circuit a sensitive relay which, upon release of its armature, closes contacts controlling the circuit of a power relay. Positive pulses delivered by the oscillatory circuit when light of given intensity is incident on the photocathode of the photoelectric tube drive negative the grid of the relay control tube by virtue of the self-rectifying properties of the cathode-grid circuit of the relay control tube to cause release of the sensitive relay and consequent operation of the dimming switch by the power relay. To prevent return to the high beam conditions when an approaching car dims its headlights the circuit includes means for increasing the sensitivity to incident light after release of the sensitive relay.

A feature of the present invention comprises the electrode mounting within the double tetrode which yields an inherent capacity between the control grid of the first half of the tube and the anode of the second half of the tube of a value such as to insure rapid response to change in intensity of incident light.

Another feature of the invention, also resulting from the construction of the novel double tetrode, is the provision of means to insure that the initial position of the relay contact will be that corresponding to low beam conditions. This result is obtained by so constructing the cathode heaters of the new tube that the first half of the tube warms up before the second half of the tube when the circuit is first energized.

Another feature of the invention also involving the construction of the new double tetrode is the arrangement whereby compensation is obtained for change in cathode emission, the change in grid bias with change in cathode emission being just sufficient to compensate for change in plate current with change in cathode emission.

This result is obtained by a cathode-grid spacing large enough to avoid "island formation" on the cathode, as will be explained in more detail hereinafter.

Still another feature of the invention is the means for preventing "motor boating" should too rapid action result from the utilization of the inherent capacity between the control grid of the first half of the double tetrode and the anode of the second half thereof. These means, which comprise a relatively large capacitor connected between the anodes of the double tube, also serve to filter out from the circuit any A. C. hum or ripple which might be present in the circuit.

Other features of the invention, including novel means for mounting the photoelectric and double tetrode tubes as a unit, will become apparent as the description proceeds.

For a better understanding of the invention and of the novel features thereof reference may be had to the accompanying drawings of which:

Fig. 1 is a schematic diagram of the new circuit;

Fig. 2 is a side view of the new double tetrode of the invention;

Fig. 3 is an exploded isometric view of the unit comprising the photoelectric tube, double tetrode and housing therefor;

Figs. 4 and 5 are diagrammatic views explanatory of the electrode spacing of the double tube; and

Figs. 6 and 7 are graphs for use in explanation of the operation of the circuit.

The general circuit will first be described with reference to Fig. 1. The overall operation of the circuit except for the variations introduced by the new double tetrode and the connections thereto is substantially like the circuit of my said copending application Serial No. 433,959 and therefore such parts of the present circuit as correspond to like parts of the circuit of the said application will be but briefly described. For a more complete description reference may be had to the said copending application.

In general the system comprises a photoelectric tube 2 positioned together with the new double tetrode 4 within a housing or head indicated by the dotted lines 6 of Fig. 1 and shown in more detail in Fig. 3, and a double triode 8 connected as a multivibrator and serving to impress control pulses upon the control grid of a relay control tube 10 when light is incident upon the photocathode of the tube 2. The relay control tube 10, in the absence of light, is conducting to maintain energized the winding of a relay 12 which relay over its armature 14 controls the circuit of a power relay 16. A car carried battery 18 of nominally twelve volts has its negative terminal grounded and its positive terminal connected to one end of the winding of power relay 16. The positive terminal of the battery 18 is also connected through the winding of relay 12 to the anode of the relay control tube 10. A voltage regulator tube 20, connected in series with resistors 22 and 24 across the battery 18, provides a regulated voltage, approximately eight volts, in a line 26 connected to the junction of regulator tube 20 and resistor 22. A line 28 is connected to line 26 through a low resistor 30, which, with a by-pass capacitor 32, serves as a filter. The line 28 of regulated and filtered voltage provides operating energy for the tubes 4, 8 and 10.

The photocathode of tube 2 is connected to the control grid 34 of the first half of the double tube 4. To avoid leakage current between electrodes of different potentials the connection to the control grid 34 is through a top cap of the tube, as indicated in Fig. 1 by the bracket 36. The cathode of the first half of the tube 4 is grounded and the anode 38 thereof connected through an adjustable resistor 40, serving as the "hold control," to line 28. The No. 2 or screen grid of the first half of the tube is connected through a resistor **42** to line **28** for reception of positive potential therefrom, and through an adjustable resistor **44**, serving as the "dim control," to the front contact associated with the armature of relay **12**. Thus when relay **12** releases to cause operation of the dimming switch the potential of the screen grid of the first half of the tube **4** is raised to increase the sensitivity of the circuit and prevent return to high beam conditions when the lights of an approaching car are dimmed.

When the photoelectric tube is not conducting, due to absence of light, electrons from the heated cathode of the first half of the tube **4** charge the control grid **34** negatively and thereby maintain low the current through that half of the tube. The second half of tube **4** operates as a phase inverter and amplifier. The control grid thereof is connected to the anode **38**, the screen grid is connected to line **28** and the anode **46** thereof is connected through a dropping resistor **48** to line **28**. The cathode of the second half of the tube **4** is operated at above ground potential by virtue of connection to the junction of a pair of resistors **50** and **52** connected in series between the eight volt line **28** and ground. Thus when the current through the first half of the tube **4** is a minimum because of insufficient light on the photocathode of tube **2**, the potential at the control grid of the second half of the tube will be high enough to permit that tube to conduct.

The anode **46** of tube **4** is connected through a resistor **54** to the control grid **56** of the first half of the oscillator tube **8**, which half is normally non-conducting because the cathode thereof is at above ground potential by virtue of a connection to the junction of resistors **58** and **60** connected in series between the eight volt line **28** and ground. The second half of tube **8**, of which the cathode is grounded and the control grid connected through a resistor **62** to line **28** will thus pass a steady current under conditions of low incident light. No pulses will be transmitted from the anode **64** of the second half of the tube either to the control grid of relay control tube **10** through a capacitor **66** or to the control grid **56** through a capacitor **68**.

When light is incident on the photocathode of tube **2** the negative charge accumulated by control grid **34** will leak off through the tube **2** increasing the current through first half of tube **4**. Consequently the potential of the control grid of the second half of the tube falls, reducing the current through that half of the tube and causing a positive potential to be impressed upon the control grid **56** of the first half of the oscillator tube **8**. Consequently the first half of tube **8** will conduct and a negative pulse will be transmitted from the anode thereof through a capacitor **70** to the control grid of the second half of that tube. The potential at anode **64** thereupon rises and a positive pulse is transmitted through capacitor **66** to the No. 2 or control grid of the relay control tube **10** and through capacitor **68** to control grid **56**. When the charge on capacitor **70** is dissipated through resistor **62** conduction by the second half of tube **8** is resumed and the potential of control grid **56** is driven below cut-off. If, however, light is stil incident on the photocathode of tube **2**, the potential of grid **56** will rise again and the cycle will repeat with a continued creation of positive pulses at anode **64**. The positive pulses thus appearing at the anode of the second half of tube **8** during the presence of a light signal result in depressing the potential of the control grid of the relay control tube **10** by virtue of the self-rectifying properties of the cathode grid circuit of that tube. Consequently as the pulses continue the relay **12** releases to cause energization of the power relay **16** and opening of the circuit through the dim control resistor **44**.

In order to increase the bias of the control grid of the relay control tube **10** during the presence of a light signal a circuit comprising a resistor **74** and capacitor **76** is connected between the anode of the relay control tube and ground and the junction of the resistor and capacitor is connected to the cathode of a diode **78**, the anode of which is connected to the junction of the control grid and its bias resistor **80**. When signals are impressed upon the control grid of tube **10** negative voltage pulses will appear at the anode of the tube. These negative pulses are applied through capacitor **76** to the cathode of the diode **78**. The potential at the anode of this diode will thus be driven to the lowest potential occurring during each such pulse and the negative charge on capacitor **66** will thereby be enhanced. Thus during the presence of signals additional negative potential is automatically applied to the control grid of the output tube **10**. When the signals cease discharge of capacitor **66** through resistor **80** restores normal grid bias.

The circuit so far described differs in no substantial respect from that of the aforesaid copending application. The circuit of the present invention includes means, not heretofore disclosed, for increasing the rapidity of response to change in light intensity. These means are symbolized in Fig. 1 by the capacitor indicated in dotted lines at **82** as connected between the control grid **34** of the first half of tube **4** and the anode **46** of the second half of the tube. With a small capacitor, connected as symbolized at **82**, when conduction through the second half of the tube begins to decrease as a result of incidence of light the rise in potential at the anode **46** will be immediately reflected as an increase in potential at control grid **34**. Consequently the potential of grid **34** rises more rapidly than if dependent only upon the photoelectric current and more rapid response of the circuit is assured. If, as in the circuit of application Serial No. 433,959, the two sections of tube **4** were separate tubes it would be entirely impracticable to include in the circuit a capacitor between the control grid of the first tube and the anode of the second tube of a capacity sufficiently small to serve the purpose of capacitor **82**. It would involve shielding of leads and it would unduly increase the inherent capacity to ground of the control grid of the first tube. In accordance with the present invention, by consolidating the first two tubes of the earlier circuit into a single double tetrode and by accurate positioning of the electrodes and their leads I have been able to make the inherent capacity between the control grid of the first half and the anode of the second half of the double tube of the correct magnitude for increasing the rapidity of the response of the circuit as above described. The capacitor symbolized at **82** should be very small, of the order of 0.1 micromicrofarad and such small value can be readily achieved by the tube construction hereinafter described.

Although rapidity of response to change in light intensity is desired and is provided for in the new circuit as above described it is also important that the system be stable and not "motor boat." Accordingly a capacitor **84** is provided in the new circuit interconnecting the anodes **38** and **46**. Capacitor **84** is of relatively large magnitude, say .05 microfarad, and serves to dampen any possible oscillations which might otherwise be introduced by the capacitive coupling between grid **34** and anode **46** when the incident light is at threshold value. Capacitor **84** also serves to suppress any hum or A. C. ripple which might appear in line **28** due to engine noise or proximity of a vibrator power supply or the like on a car equipped with the headlamp dimming circuit of the invention.

In Fig. 2 the tube **4** is shown as comprising a glass envelope **86**, glass button base **88** and a top cap **90** which, within the envelope, the control grid **34** of the first section is connected by a lead **92**. The other electrodes are connected to pin terminals **93** embedded in the base. The electrode assembly of each section is mounted between a lower mica wafer **94** and an upper mica wafer **96**.

As will be apparent from the view of tube **4** in Fig. 2, the lead **92** to the control grid **34** is close to the anode **46** so that there will be a small amount of capacitative coupling thereto. The lead 92 is made relatively heavy and stiff to prevent shift thereof during handling of the tube. As the grid 34 is conductively connected with the cap 90 and with the photocathode of tube 2, the capacity symbolized in Fig. 1 by the reference numeral 82 will depend not only upon the position of the lead 92 but also upon the positioning of these elements with respect to the anode 46 and upon the areas thereof which are not electrostatically shielded from that anode. As the tubes 2 and 4, in the preferred embodiment of the invention illustrated in Fig. 3, are mounted in fixed relation within a hermetically sealed enclosure ample means are provided for insuring during manufacture and assembly that the capacitative coupling between the anode 46 and the grid 34—top cap 36—photocathode will be of the proper magnitude for optimum operation and that such capacity will remain constant.

As shown in Fig. 3, the enclosure for the tubes 2 and 4 is formed of two parts, a metal tray or base member 98 and a metal cover member 100, which, after the tubes are fixed in the tray member, are sealed together about the periphery of the flange 98*a* of the tray by soldering, or the like. A suitable lens 101 is sealed in an aperture in the end wall of cover member 100. The base 88 of tube 4 is mounted in an aperture in the tray 98 by means of a ring 102 of a thermoset resin, preferably an epoxy resin of the type sold under the trade name Araldite by Ciba Co. Inc. of New York, N. Y. The base comprising the anode terminal of the photoelectric tube 2 is mounted in a close fitting aperture in the tray 98 and soldered or otherwise conductively fixed therein, the tube 2 being oriented for reception by the photocathode of light passing through the lens 101. Preferably a terminal connector 104 is soldered to the anode terminal for connection of a ground lead thereto. Mounted on the tray 98 between the tubes 2 and 4 is a shield 106 to protect the photocathode from heat given off by tube 4 during operation of the circuit. The shield 106 is preferably of metal to prevent or reduce capacitative coupling between anode 46 and the photocathode and thereby maintain the capacity symbolized in Fig. 1 by the reference numeral 82 at the desired low value. Should the tube structure be such that the capacity between the anode 46 and the parts conductively connected to grid 34 be too low, the shield 106 could be of suitable insulating material, and the orientation of tube 4 in the tray 98 altered to increase the spacing between the photocathode and anode 46. Alternatively, a heat shield partly of metal and partly of dielectric material could be employed.

With the tubes 2 and 4 fixedly mounted as above described within the grounded hermetically sealed enclosure, the sensitive components of the system are amply protected from the effects of humidity changes, vibration and the like. The enclosure, while preferably of metal so as to serve as an electrostatic shield, need not necessarily be of metal. Satisfactory operation has been had with the tubes 2 and 4 mounted within a sealed enclosure of glass.

As heretofore indicated the electrometer portion of tube 4 is of a construction particularly designed for operation in a circuit wherein the control grid draws current and is connected only to a constant low current device such as the photoelectric tube 2 and wherein relatively low voltages are applied to the anode of the tube. In such type of circuit, with tubes heretofore in use, as for example a 6K6, change in cathode emission during operation due to aging or to change in heater voltage, causes a change in plate current which, because of the low plate voltage, corresponds to an appreciable change in amplification factor. In the new tube compensation for change in cathode emission is obtained by reducing the ratio of grid pitch to grid-cathode spacing to a value such that "island formation" on the cathode is avoided. In conventional tubes this ratio is unity or higher. In the electrometer tube of the present invention this ratio is less than unity, say about one-half. The terms "island" and "island formation" are well understood in the art as referring to the shielding effect of the grid wires upon the cathode which, in a tube having a grid pitch-grid cathode spacing ratio of unity or more causes non-uniform electron emission over the area of the cathode. (See J. Deketh, Fundamentals of Radio Valve Technique, a publication of Philips Technical Library.)

Figs. 4 and 5 illustrate diagrammatically the electrode spacing of tube 4. Fig. 4 corresponds to a horizontal section and Fig. 5 to a fragmentary vertical section through the tube. From these figures it will be apparent that the spacing between the cathode 108 of the electrometer section of tube 2 and grid 34 is considerably larger than the spacing between adjacent turns of grid 34. Thus the grid pitch-grid cathode spacing ratio of the first half of the tube is substantially less than unity. In the second half of the tube, where the electrode spacing is conventional, the spacing between the cathode 109 and control grid 110 is slightly less than the space between adjacent turns of the grid. Hence the grid pitch-grid cathode ratio is greater than unity.

The photoelectric tube 2, when light of given intensity floods the photocathode, can pass only a fixed amount of current and therefore is a constant current device, the current being of a very small order of magnitude. Electrons given off by the heated cathode 108 follow a Maxwellian distribution such as indicated by the curves of Fig. 6. In Fig. 6 the ordinates represent the number of emitted electrons and the abscissae represent electron velocity at emission from the cathode. The curve T–1 represents the velocity or energy distribution for a temperature T_1 of the cathode. The second curve T–2 represents the velocity distribution of the emitted electrons at a higher temperature, T_2 of the cathode. With the grid 34 connected only to the constant current device (assuming constant low light intensity on the photocathode), and the cathode temperature T_1, the operating point will be at a point such as point A. Tube 2 will be saturated and the potential of the grid 34 will be negative as compared to the cathode 108. If now the temperature of the cathode increases to T_2, the distribution of electron velocities will shift to curve T–2 and as the tube 2 can not pass any additional number of electrons the operating point will shift to the right along the curve T–2 of Fig. 6 to say, point B. In other words the grid will be driven more negative because of the inability of tube 2 to pass a higher current without change in light intensity. This automatic increase in negative potential on the control grid with change in cathode temperature tends to reduce the plate current to compensate for the increase in plate current which would otherwise result because of the increased electron emission from the cathode. Thus, because the photoelectric tube 2 is a constant current device and takes but small current, compensation for change in plate current with heater voltage can be effected. Similarly, so long as there is no "island formation" on the cathode an increase or decrease in the area over which emission is effected due to aging or the like will cause an increase or decrease respectively in the negative potential of the grid 34 sufficient to compensate for the change in plate current which would otherwise occur.

In the graph of Fig. 7, wherein plate current is plotted against filament emission for different light intensities falling on the photocathode of tube 2, this substantial constancy of plate current with change in filament emission is shown by the substantially horizontal portions of the curves. When the intensity of light on the photocathode increases the plate current will increase say from curve 112 of Fig. 7 to curve 114 of Fig. 7 or curve 116 of Fig. 7 depending upon the amount of increase in light intensity, but change in filament emission resulting from variations in heater voltage or aging of the tube, provided the operating point is above the knees of the curves, will have substantially no effect.

The importance of this construction which insures independence of plate current with change in filament emission will be apparent when it is appreciated that the plate voltage, when the electrometer tube is conducting, will drop to roughly 2 volts due to the magnitude of resistor **40**. Obviously but a slight change in plate current with change in cathode emission corresponds to a large fraction of the operating current of the tube under such conditions and therefore, for optimum operation of the circuit, the compensation effected by the new tube construction is of substantial importance.

It is advantageous in the operation of circuits for automatic dimming of headlamps that when such a circuit is first energized the dimming switch be promptly operated irrespective of whether or not light is incident on the light sensitive element of the circuit. In the circuit of Fig. 1, initial deenergization of the control relay and consequent operation of the dimming switch results when the first half of tube 4 heats up more promptly than the second half. Accordingly, in the construction of tube 4 the cathode heaters **118** and **120** (see Fig. 1) of the first and second halves of the tube, respectively, are provided with unequal thickness of insulated coating, a relatively heavier coating being provided on heater **120**. Thus the cathode of the second half of the tube will not begin to emit electrons as soon as the cathode of the first half of the tube. The potential at the control grid **56** of the oscillator tube 8 will therefore be above cut-off, and oscillations of that tube will be initiated to cause operation of the dimming switch. Assuming no light is incident on the photoelectric tube, as soon as the control grid 34 of the first half of tube 4 becomes negatively charged from the heated cathode of that half of the tube, and the cathode of the second half becomes heated, normal operation under control of the photoelectric tube takes place.

The preferred embodiment of the invention has now been described with specific reference to the control of the dimming switch of automobile headlamps. Obviously the new tube construction of the invention could be advantageously employed to compensate for change in cathode emission in any amplifier where grid impedance is high and grid current essentially constant and the improved light responsive circuit of the invention could be used for control of devices other than dimming switches.

The following is claimed:

1. A condition responsive circuit comprising in combination a device the current through which is determined by the condition, an electronic tube having a grounded cathode, a control grid connected to said device and comprising equally spaced grid wires, and an anode, a low voltage source of energizing potential connected to said anode through a dropping resistor, and output means adapted to be actuated in response to a predetermined decrease in anode potential consequent to increase in current through said device, the spacing between said grid and said cathode of said tube being greater than the spacing between adjacent grid wires whereby change in anode current with change in cathode emission is minimized.

2. The circuit according to claim 1 wherein said electron tube is a double tube the second half of which operates as a phase inverter, said second half of the tube comprising a cathode connected for operation at above ground potential, a control grid connected to the anode of the first half of the tube and an anode connected to said source through a dropping resistor, said last mentioned anode and the first mentioned control grid being coupled together capacitatively to increase the rapidity of response of the circuit to change in condition.

3. The circuit according to claim 2 wherein said tube has a top cap internally connected by a lead to said first mentioned control grid and externally connected to said device, said internal lead and said top cap being so positioned relative to said second anode as to provide said capacitative coupling.

4. The circuit according to claim 3 including a capacitor connected between said anodes of a value large compared to that of the capacitative coupling between the control grid of the first half of the tube and the anode of the second half of the tube.

5. The circuit according to claim 1 wherein said device is a photoelectric tube having a photocathode and wherein said electron tube is a double tube the second half of which operates as a phase inverter, said second half including a cathode, a control grid connected to the first mentioned anode and an anode connected to said source through a dropping resistor, a cathode heater for each of said cathodes, and means comprising insulating coatings of unequal thickness on said heaters for insuring that the first half of the tube will warm up faster than the second half of the tube and thereby cause initial actuation of said output means irrespective of the intensity of light incident on said photocathode.

6. The circuit according to claim 1 wherein said device is a photoelectric tube having a single anode and a photocathode and wherein said electronic tube is a double tube the second half of which operates as a phase inverter, an enclosure for said tubes comprising a base portion and a cover portion hermetically sealed together, means insulatedly sealing said double tube into an aperture in said base portion, a lens sealed in an aperture in said cover portion, means for mounting said photoelectric tube in another aperture in said base portion with the photocathode orientated for reception of light through said lens, and a top cap on said electronic tube internally connected to said control grid and connected within said enclosure and externally of said electronic tube to the photocathode of said photoelectric tube.

7. The circuit according to claim 6 including means within said enclosure and positioned between said tubes for shielding said photoelectric tube from heat given off by said electronic tube.

8. The circuit according to claim 7 wherein said shielding means is of metal to reduce capacitative coupling between said photocathode and electrodes of said electronic tube.

9. The circuit according to claim 6 wherein said base and cover parts of said enclosure are of metal and are grounded to provide a ground connection for the anode of said photoelectric tube and electrostatic shielding for both tubes.

10. A light sensitive circuit adapted for control of the dimming switch of the headlamps of an automobile and adapted for operation directly from a car carried battery, comprising in combination a photoelectric tube having an anode connected to the negative terminal of the battery and a photocathode, an electronic tube having a control grid connected through a top cap to said photo-cathode, a cathode connected to the negative terminal of the battery and an anode connected through a dropping resistor to the positive terminal of the battery, and output means adapted to actuate the dimming switch upon predetermined decrease in anode potential consequent to increase in intensity of light incident on said photocathode, the construction of said grid and the spacing thereof from the cathode being such as to avoid "island formation" and thereby render the anode current substantially independent of change in cathode emission.

11. A low voltage electronic tube for use in condition responsive circuits of the type including a device the current through which is determined by the condition, comprising an envelope, a control grid of equally spaced grid wires, a cathode and an anode in said envelope, the spacing between said cathode and said grid being greater than that between adjacent grid wires whereby when said grid

is connected to such device change in anode current with change in cathode emission is minimized.

12. The low voltage electronic tube according to claim 11 including a second cathode, a second control grid and a second anode within said envelope, a top cap on said envelope and a connection within said envelope between said top cap and said first mentioned control grid positioned with respect to said second anode to provide a capacitative coupling between said first mentioned control grid and said second anode and thereby to increase the rapidity of response to change in condition when the second cathod, second control grid and second anode are connected to serve as a phase inverter and amplifier of current passed by said first anode.

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