

Dec. 29, 1936.

F. H. SHEPARD, JR

2,065,758

LIGHT RESPONSIVE DEVICE

Filed March 8, 1935

2 Sheets-Sheet 1

Fig. 1

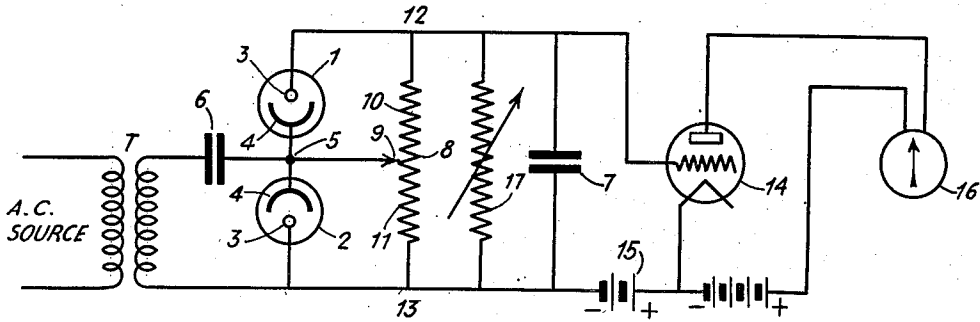


Fig. 2

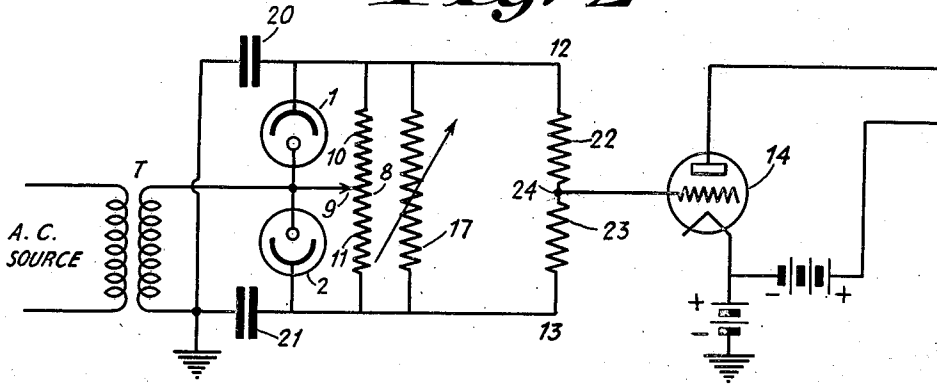
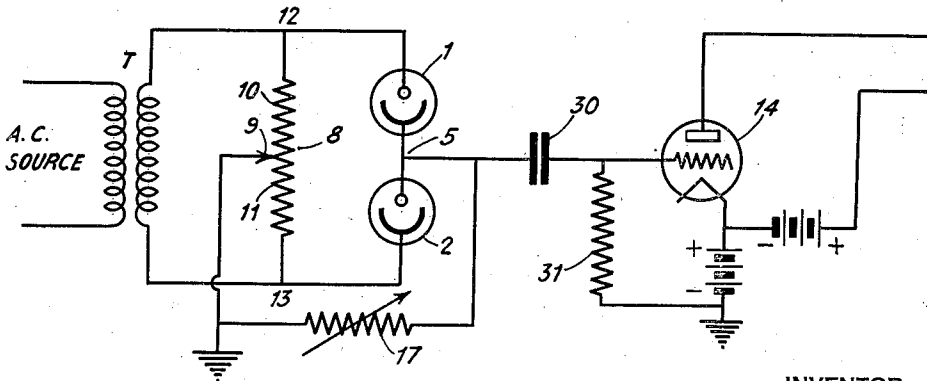


Fig. 3



INVENTOR
FRANCIS H. SHEPARD JR.

BY
Charles McClart
ATTORNEY

Dec. 29, 1936.

F. H. SHEPARD, JR

2,065,758

LIGHT RESPONSIVE DEVICE

Filed March 8, 1935

2 Sheets-Sheet 2

Fig. 4

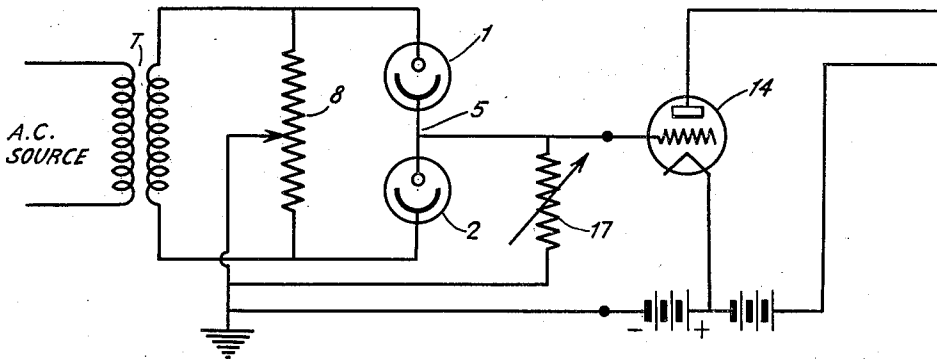


Fig. 5

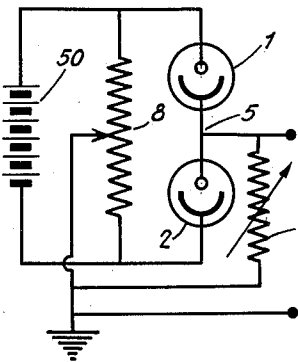


Fig. 6

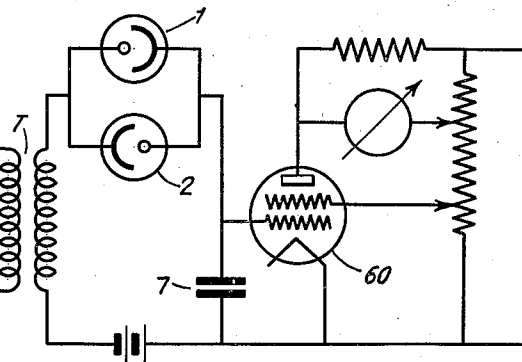


Fig. 7

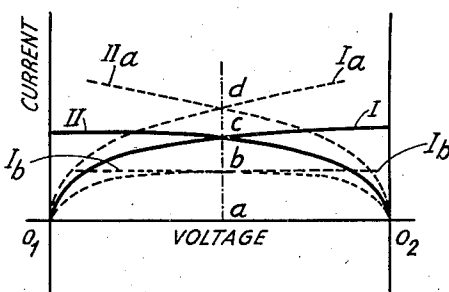
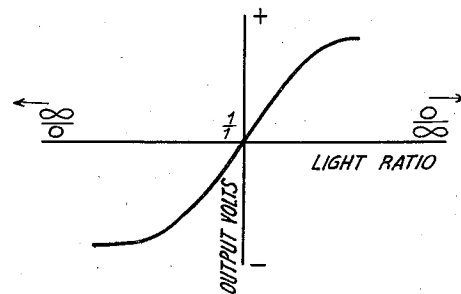


Fig. 8



INVENTOR
FRANCIS H. SHEPARD JR

BY
Charles M. Cain
ATTORNEY

UNITED STATES PATENT OFFICE

2,065,758

LIGHT RESPONSIVE DEVICE

Francis H. Shepard, Jr., Rutherford, N. J., assignor, by mesne assignments, to Radio Corporation of America, New York, N. Y., a corporation of Delaware

Application March 8, 1935, Serial No. 9,931

4 Claims. (Cl. 250—41.5)

My invention relates to light responsive devices and is particularly directed to phototube actuated photometers and light relays.

Light responsive devices, such as phototubes, usually consist of an evacuated or gas filled envelope containing an anode and an electron emitting cathode. The cathode is formed of a highly volatile solid, such as caesium or barium or oxides of these, which, in the presence of light, are capable of emitting considerable quantities of electrons. These cathodes have been found to emit electrons, the quantity of which is proportional to the intensity of light on the cathode. With an external circuit, including a potential source connected between the anode and the cathode, the flow of electrons between the electrodes, and accordingly the current in said circuit, is determined by the intensity of the illumination upon the cathode. That is, the space current thru the phototube is controlled by and is a function of the light intensity exposed to the cathode of the tube. One application of this device is found in sound reproducing, where a film with varying degrees of translucence throughout its length, representing sound waves, is passed between the phototube and a lamp or light source. The variations in light upon the tube caused by the traveling film produce variations in space current, this space current in the external circuit being utilized to operate a loud speaker thru suitable relays. Assuming a steady source of light from the lamp of the sound reproducing device, the space current and consequently the loud speaker articulations faithfully follow the light variations caused by the film. It is found in practice, however, that the light from the lamp, which may be either of the incandescent or the arc type, is subject to 120 cycle flickering when lighted by the usual alternating current of commercial power lines. Slow or gradual variations also in the supply voltage cause corresponding gradual variations in the light source which is reproduced in the signal output of the loud speaker or reproducer.

Likewise in light comparison photometers, where phototube space current is calibrated in terms of light intensity by a current meter, the maintenance and accuracy of calibration depends upon the constancy of the standard or reference source of light.

Further, it has been found that photometer circuits energized by the usual batteries are subject to instability because of poor voltage regulation in the batteries.

It is accordingly an object of my invention to

provide a light responsive device which is insensitive to undesired variations in light intensity in the light source.

A further and more specific object of my invention is to construct a light relay device in which variations in the light source are neutralized or balanced out in the circuits of the device.

A still further object of my invention is to devise a light responsive circuit energized entirely by alternating current, thus eliminating the instability and other inconveniences of batteries.

I accomplish the objects desired by connecting two phototubes in a balanced bridge circuit in such a manner that variations in light upon the two phototubes result in equal or opposite current variations which in the output neutralize each other. Said bridge is so arranged that alternating current is particularly applicable in its energization.

For a more complete understanding of my invention, reference may be had to the accompanying drawings in which Figures 1, 2, 3, 4 and 6 show several circuits embodying my invention in which alternating current energization is provided for the phototubes; Figure 5 shows a battery operated light responsive circuit; and Figures 7 and 8 are curves illustrative of the operation of my device. Like reference characters throughout the several figures represent similar parts.

Referring to Figure 1, two light responsive phototubes which may be of the conventional photoelectric type are shown at 1 and 2 with the usual anodes 3 and light responsive cathodes 4. The two phototubes are connected at their common cathode terminal 5 to the secondary of a supply transformer T, thru condenser 6. If desired the two tubes may be reversed so that their anodes are connected together, which would facilitate the incorporation of the phototubes in one envelope. The alternating current supply which may be from the conventional 60 cycle power circuit or from a high frequency oscillator circuit is impressed across phototubes 1 and 2, thru condenser 6, the anode of phototube 1 being practically shorted for alternating current to the anode of phototube 2 thru high capacity condenser 7. Bridged across the two phototubes is a resistor 8 with a sliding contact 9, the resistance 8 thus being divided into two resistor portions 10 and 11, which form, respectively, load impedances for phototubes 1 and 2. It will be noted that since the phototubes as rectifiers are conductive in opposite directions with respect to point 5, the current flow in the load re-

sistors 10 and 11 will be in opposite directions with respect to contact point 9. Hence, the voltage drops thru resistors 10 and 11 will cause points 12 and 13 at all times to be of the same polarity with respect to that of point 9. Accordingly, there will be no potential difference between the points 12 and 13 when the voltage drops across resistors 10 and 11 are equal. Thermionic relay 14, the input circuit of which is connected across the outer ends of resistors 10 and 11, will under such a condition of balance show no response; that is, with equal illumination of 1 and 2, and with sliding contact 9 adjusted to give equal voltage drops across resistors 10 and 11, no potential from the phototubes will be impressed upon the grid of the relay 14. Equal variations in light intensities upon phototubes 1 and 2 will produce corresponding voltage drop variations thru resistors 10 and 11, but as seen, these variations balance out and produce no change in the grid potential of relay 14. If, however, the light upon phototube 1 is increased or decreased with respect to the light upon phototube 2, the space currents therein will change and thereby cause unequal voltage drops across the two portions 10 and 11 of the resistor 8. A potential difference then results between point 12 and point 13, which potential is impressed upon the input electrodes of relay 14. Relay tube 14 may be statically biased by battery 15 so that its normal plate current is of some value intermediate saturation and cut-off. If then a zero-center marked milliammeter, as shown at 16, is connected in the plate circuit, current values may be read above or below the normal or static anode current. With such an arrangement the potential difference between points 12 and 13, as well as their relative polarities may be registered. Adjustable resistor 17 is bridged across the phototubes so that the load and consequently the sensitivity of the phototubes may be varied at will.

In operation the contact 9 of Figure 1 is adjusted to provide no voltage between the ends of resistor 8 when the two phototubes are exposed to the same light source, and resistor 17 is manipulated to adjust the phototubes to any desired sensitivity. Let it be assumed the system is to be used as a comparison photometer. One of the phototubes, say 1, is exposed to a standard source of light while phototube 2 is exposed to the unknown source of light. The direction of deflection of the milliammeter needle will indicate which source of light is the brighter and the magnitude of deflection indicates the difference in intensities of the two sources. Or, if the reflecting properties of a substance is to be measured, one phototube is exposed directly to a source of light of any value, the other cell being positioned to receive only reflected light of the substance from said source. Meter 16 will then give a direct measure of the per cent of reflected light.

In each of the above mentioned applications of my invention, when the phototube bridge is balanced the output of relay 14 is undisturbed by any variations of light which affect equally the two phototubes.

A further and important characteristic of my invention, as illustrated in Figure 1, is its adaptability to alternating current energization as distinguished from the usual direct current or battery actuation. Because of the rectifying or unidirectional properties of the phototubes 1 and 2, direct current potentials appear across

resistor portions 10 and 11, and by virtue of the balanced bridge arrangement, the pulsations in said direct current potentials are balanced out. My system, further, is insensitive to voltage instability of the current source.

Figure 2 illustrates a circuit arrangement similar in most respects to that shown in Figure 1 with the phototubes 1 and 2 connected in series and so poled as to be conductive in opposite directions in said series circuit. One side of the secondary of the alternating current supply transformer T is connected to the common terminal of the phototubes as shown, and the other terminal is connected to the opposite electrodes of the phototubes thru coupling condensers 20 and 21. Condensers 20 and 21, like condenser 7, Figure 1, are of such size as to offer negligible impedance to the impressed alternating current. Load resistor 17 is paralleled across the two cells as in the first modification, while center tapped resistor 8 is connected thru its sliding contact to the common terminal of the phototubes. Balancing resistor 8 is connected across the phototubes as in Figure 1. In addition the phototubes are paralleled by impedances 22 and 23, which are of equal value and are connected in series. The grid of relay 14 is connected centrally of the two impedances. With phototubes 1 and 2 equally illuminated so that the potential drops thereacross are equal, point 24 is at the electrical center of resistance 22-23; that is, point 24 is at zero potential.

Now, if phototube 1 is exposed to more light than phototube 2, phototube 1 becomes more conductive; point 12 becomes more positive; the electrical center moves upward on resistor 22; and the contact point 24 becomes negative with respect to ground. The resulting change in conductivity of relay tube 14 may be recorded in terms of light ratio as in the case of Figure 1. An opposite unbalancing of light upon the cells causes contact 24 to swing positive.

In Figure 3 the two phototubes 1 and 2 are connected in series and are so poled as to be conductive in the same direction. The alternating current supply is connected directly across the outer terminals of the phototubes with the balancing resistor 8 connected thereacross. As a modification, resistor 8 may be omitted and tap 9 adjusted to the windings of the secondary of transformer T. Here the load resistor 17 is connected from the common terminal of the phototubes to the sliding contact of the balancing resistor as shown. 31 is a grid resistor, the function of which is well-known. In this embodiment of my invention, relay 14 is energized by alternating current impulses only thru coupling condenser 30. With tubes 1 and 2 equally conductive, and with contact 9 adjusted to the electrical center of resistance 8, no potential differences will appear between the ends of load resistor 17. Since resistor 17 in this case functions as a coupling impedance to the following stage, relay 14 will remain in its static condition. An unbalance of the light upon the phototubes, however, causes a pulsating direct current to flow thru resistor 17 which, thru the reactive coupling means 30, produces a pulsating current in the output of the relay, the amplitude of which is a measure of the light or unbalance on the phototubes.

Figure 4 shows a circuit similar to that shown in Figure 3 with the provision of a galvanic coupling between the phototube circuits and the amplifying relay. Here, the pulsating direct cur-

rent impulses across resistor 17 may be amplified in the coupled amplifier stage 14 either as an intermittently pulsating or direct current voltage.

The circuit of Figure 4 may be modified by substituting a constant current source for the alternating current supply, as shown at 50 in Figure 5. In this form of energization of the phototubes, pure direct currents flow thru load impedance 17 during unbalanced illumination of the phototubes.

A more complete understanding of the operation of the circuits of Figures 3, 4 and 5 may be had by referring to the curves in Figure 7.

In Figure 7 is plotted a family of curves for phototubes 1 and 2, each curve of one group representing the voltage-current characteristic for one tube for a given intensity of illumination. Curve 1 is taken from experimental data to show that the current thru phototube 1 rises abruptly from zero 0, as the voltage across it is increased and gradually flattens out to a substantially constant current above a certain limited value of applied voltage. Curves 1_a and 1_b were similarly determined for different intensities of illumination upon phototube 1. The characteristics of phototube 2 have been plotted upon the same graph with those of phototube 1 but with the abscissa values plotted in the reverse direction and with the initial or zero voltage 0₂ set over and to the right of the first zero point by an amount equal to the maximum potential applied to the cells. It will be noted that the voltage-current characteristics of phototubes 1 and 2 for a common intensity of illumination are symmetrically conjugate one with the other, and that the value of current thru the phototubes are equal. If the illumination upon tube 1 is decreased to a value indicated by curve 1_b and if the illumination of tube 2 is correspondingly increased to a value indicated by 1_a, the mean value of current thru phototube 1 decreases to $a-b$ while the mean current thru phototube 2 increases to $a-d$. The shift in potential of point 5, Figure 3, 4, or 5, is directly proportional to the difference between current values $a-b$ and $a-d$.

In Figure 6 the two phototubes 1 and 2 are connected in parallel and are so polarized as to be conductive in opposite directions, one terminal of each phototube being connected to the control grid of relay 60 and the other terminals of which are connected to one side of the alternating current supply source. By-pass condenser 7, as before, is of relatively high capacity so as to readily pass the alternating current supply. In this modification one phototube acts to charge condenser 7 in one direction while the other acts to charge condenser 7 in the opposite direction. In operation, when the positive loop of the alternating current is impressed on the upper end of the transformer secondary, tube 1 is conducting and tube 2 is blocked, and conversely, when the voltage reverses tube 2 is conducting and tube 1 is blocked. The internal impedance of either phototube places a high impedance load on the other, each acting as a high impedance coupling to relay 60 for the other. The space current flowing in one tube directly determines the voltage drop thereacross, which is applied without loss to the control grid of relay 60. When the two tubes are irradiated with the same light source, the positive and negative loops of voltage appearing upon the grid of the relay are equal, giving a

continuous and symmetrical sign wave in the output of the relay 60. If, however, the light ratio upon the two phototubes is unequal, the voltage loop of one polarity will cause an increase in magnitude and duration of the current thru one tube with respect to the magnitude and duration of current thru the other tube for the voltage loop of opposite polarity. A condition of unbalance of illumination accordingly causes current to flow into condenser 7 in greater quantities from one side than from the other, thus causing condenser 7 to assume a charge. Whether the upper plate of the condenser, which is connected to the grid of relay 60, swings positive or negative is determined by the relative conductivities of phototubes 1 and 2.

Figure 8 has been drawn to illustrate the functional relationship between the voltage across condenser 7, Figure 6, and the ratio of light intensities upon phototubes 1 and 2. With a light ratio of 1 to 1 or equality of illumination upon the phototubes the mean condenser voltage is zero. From this zero point the voltage describes a sloping straight line on either side of the zero point. As the light ratio approaches infinity in either direction it is found that the corresponding output volts flatten off, indicating a saturated condition of one tube. The limiting values in either direction of course indicate complete darkness on one phototube with a light intensity of infinite value upon the other.

Other modifications will be readily suggested to those skilled in the art.

I claim:

1. In a photometer; two phototubes, each with an anode electrode and a light responsive cathode electrode; a connection common to one electrode in each phototube; a source of alternating current coupled on the one hand to the common connection and on the other to the remaining electrodes of said phototubes, an impedance connected between said remaining electrodes with a point intermediate the ends of the impedance connected to said common connection; a thermionic relay, and means for coupling the input circuit of said relay across at least a portion of said impedance.

2. In a light comparison device, two phototubes, each with an anode and a light responsive cathode, an alternating current source, a connection between said anodes and one terminal of said current source, two condensers, the cathodes of said phototubes being coupled to the other terminal of said current source through said condensers, a resistor connected between said cathodes with an adjustable tap connected to said anodes, an electron amplifier tube, a second resistance connected between said cathodes and connected intermediate its end to the grid of said amplifier tube, the last mentioned terminal of said alternating current source and the cathode of said amplifier tube being grounded.

3. In a photometer two phototubes with their cathodes connected together and coupled to one terminal of an alternating current source, a condenser and a resistance connected in parallel between the anodes of said phototube and coupled at one end to the other terminal of said source, said resistance having an adjustable tap connected to said cathodes, an electron amplifier tube with input electrodes connected

to said resistance and a translating device in the output circuit of said amplifier tube.

4. In a light responsive device; two phototubes, each comprising an electron emitting
5 cathode and an anode hermetically sealed in an envelope; a source of alternating current comprising a transformer winding; coupling means between one terminal of said winding and like
10 electrodes of said phototubes the other winding terminal being coupled to the other electrodes of the phototubes for impressing an alternating

current potential between the cathode and anode of each of said phototubes; a resistor connected between said other electrodes with a midpoint connected to said like electrodes; and a
5 relay responsive to changes in potential across said resistor comprising a thermionic amplifier with a cathode, grid and anode, and means to connect the resistor in the grid-cathode circuit
of said amplifier.

FRANCIS H. SHEPARD, Jr.