

June 15, 1937.

R. A. BRADEN
PHOTOCELL AMPLIFIER

2,084,186

Filed Feb. 1, 1934

3 Sheets-Sheet 1

Fig. 1.

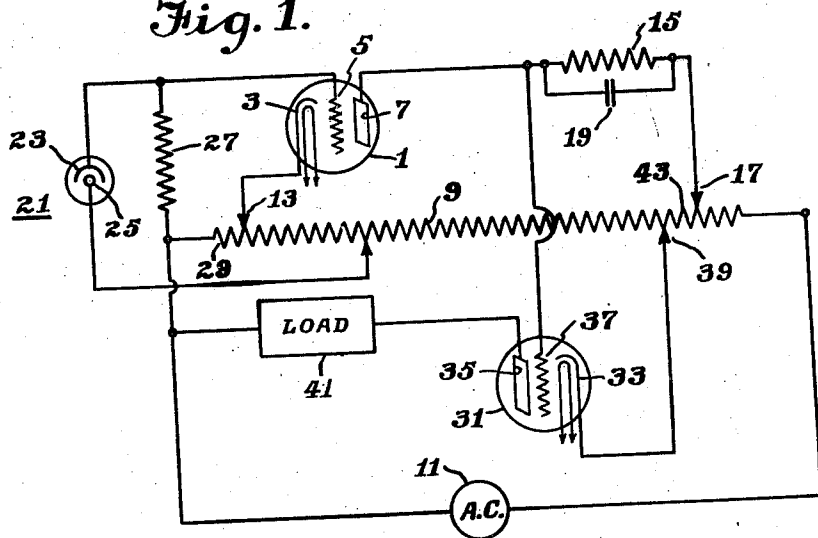
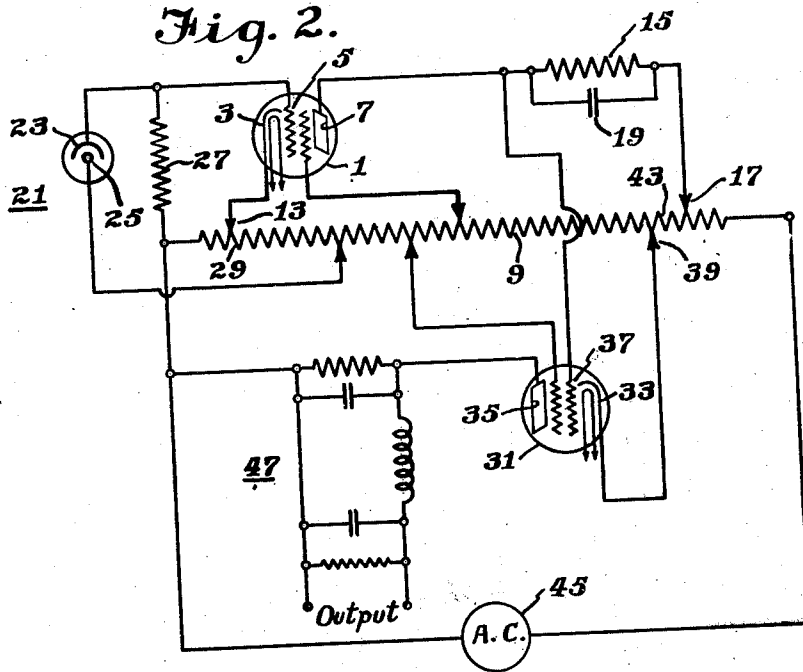


Fig. 2.



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Fig. 3.

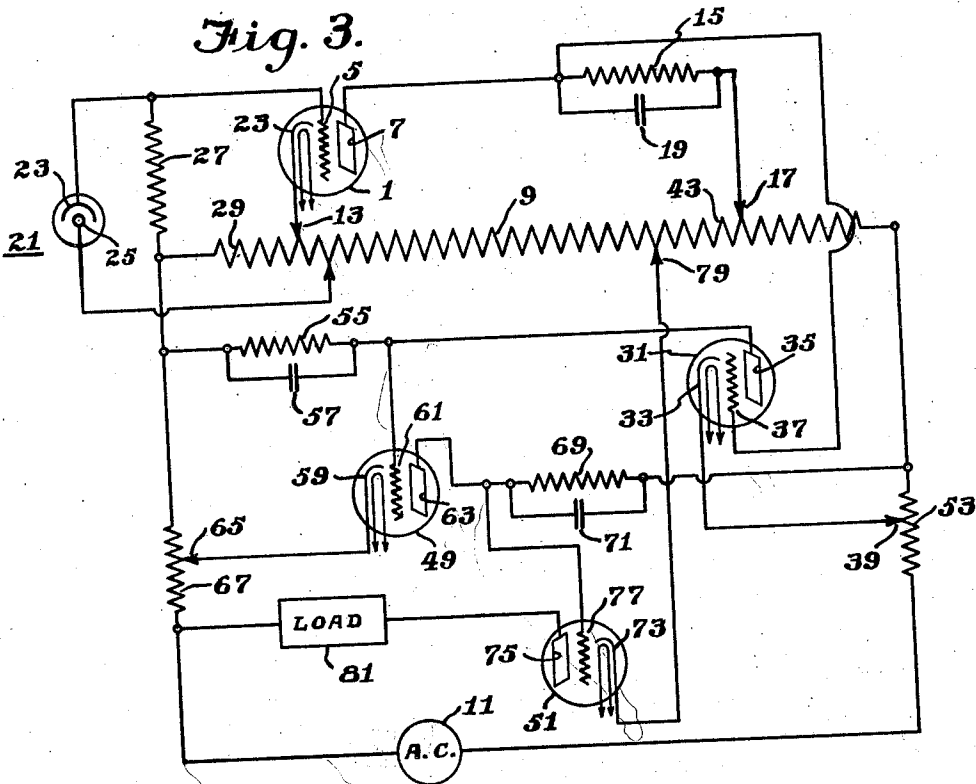
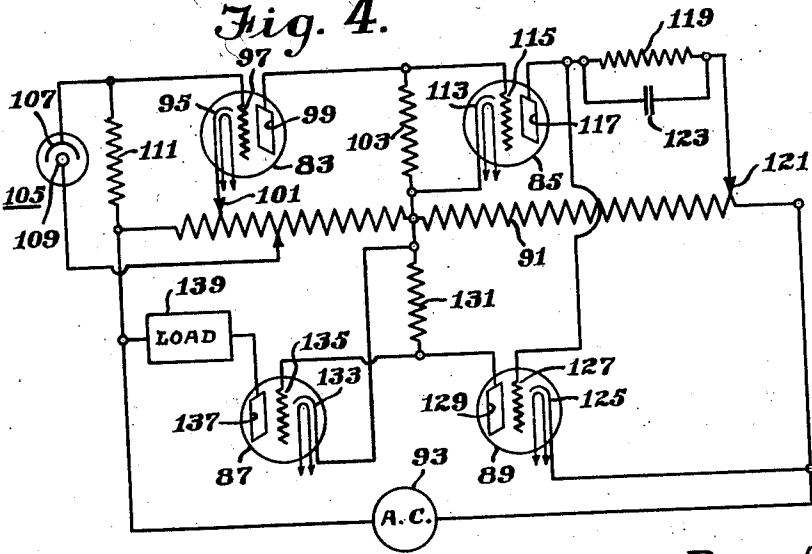


Fig. 4.



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Fig. 5.

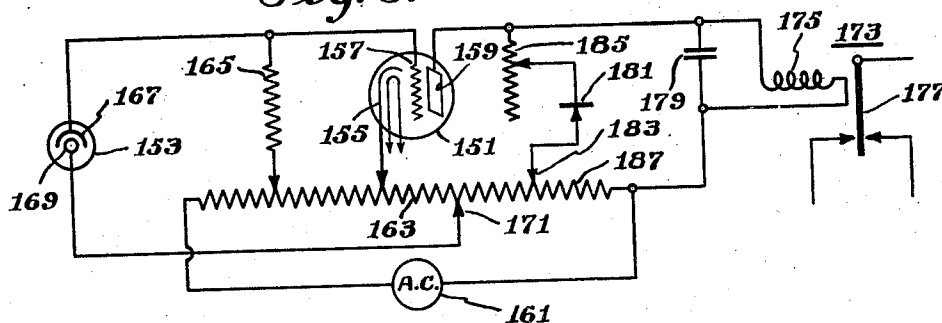


Fig. 6.

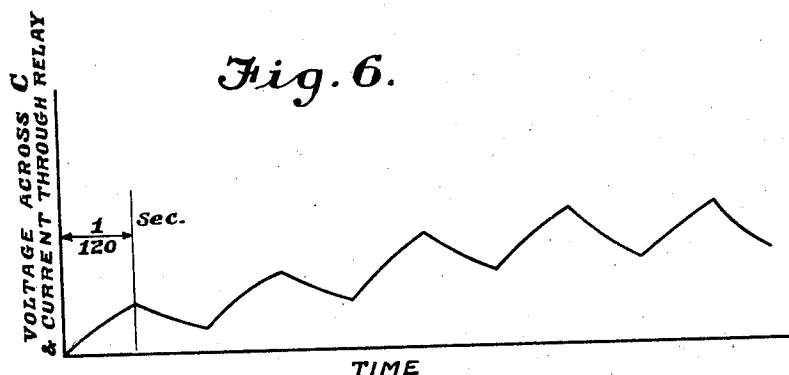


Fig. 7.

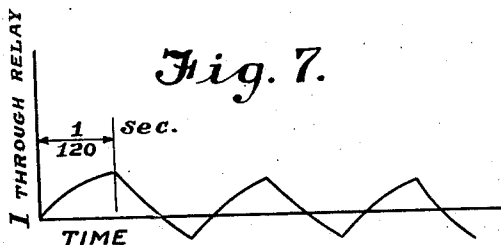
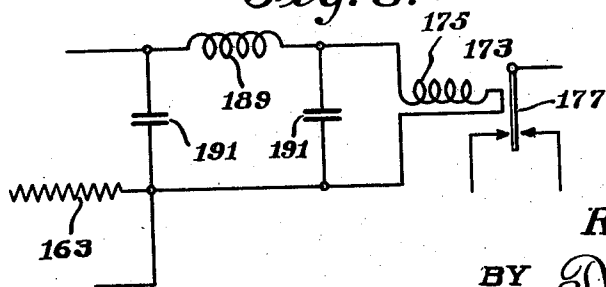


Fig. 8.



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PHOTOCELL AMPLIFIER

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Application February 1, 1934, Serial No. 709,292

7 Claims. (Cl. 179-171)

My invention relates to amplifiers and particularly to amplifiers adapted for use with light-sensitive cells or the like.

One of the objects of my invention is to provide an improved amplifier which may be operated by unrectified alternating current.

A further object of my invention is to provide an improved direct-coupled amplifier.

A further object of my invention is to provide an improved amplifier for use in connection with light-sensitive devices or the like.

A still further object of my invention is to provide an improved amplifier for operating a direct-current relay.

In one embodiment of my invention, I utilize a plurality of electric discharge devices, such as vacuum tubes, so connected to a source of alternating current that one of said devices operates on one half cycle and alternate succeeding half cycles, while another of said devices operates on the intervening half cycles to the opposite polarity. The input circuit of the second of said devices is supplied with amplified energy from the output circuit of the first device by means of a condenser and resistance in said output circuit, this condenser being charged during the first one half cycle of operation, and remaining charged a certain amount during the second half cycle.

In another embodiment of my invention, I operate a direct current relay by means of an electric discharge device connected to an alternating current source. In a circuit of this type the usual mode of operation is to provide a grid bias voltage of such magnitude that the plate current is practically zero. This is done because a relay operates most efficiently when there is no direct current flowing through it except during the period when it is actuated. On the other hand, the tube operates most efficiently (i. e., produces the greatest change in plate current with a certain signal on the grid) when its grid bias is such that the plate current has a fairly large direct current component, because with such a bias the tube has greater mutual conductance than with a bias which reduces the plate current to zero. Therefore, I adjust the electric discharge device for most efficient operation and provide a rectifier circuit for balancing out the direct current component of the plate current which, otherwise, would flow through the relay.

Other objects, features and advantages of my invention will appear from the following de-

scription taken in connection with the accompanying drawings, in which

Fig. 1 is a circuit diagram of one embodiment of my invention,

Figs. 2, 3 and 4 are circuit diagrams of other embodiments of my invention,

Fig. 5 is a circuit diagram of an embodiment of my invention adapted to operate a direct current relay,

Figs. 6 and 7 are curves which are referred to in explaining the operation of the circuit shown in Fig. 5, and

Fig. 8 shows a modification of the form of my invention shown in Fig. 5.

Referring to the embodiment of my invention shown in Fig. 1, the amplifier comprises an electric discharge device 1 such as a three-electrode vacuum tube having a cathode 3, a control grid 5 and an anode 7. Suitable voltages for the operation of the tube 1 are supplied from a voltage divider resistor 9 which is connected across any suitable source 11 of alternating current, such as an ordinary 60 cycle supply.

The cathode 3 is connected to the voltage divider 9 near one end through a variable tap 13, while the anode 7 is connected to the voltage divider at the other end through a resistor 15 and a variable tap 17, whereby substantially the entire voltage of the source 11 is applied across the electrodes 3 and 7. A condenser 19 is connected across the plate resistor 15 for storing energy during one-half cycle of operation, as will be explained hereinafter.

The input circuit of the discharge device 1 includes a light sensitive device such as a photoelectric cell 21 having a cathode 23 and an anode 25, the cathode 23 being connected to the control electrode 5 and the anode 25 being connected to a point on the voltage divider 9. The control grid 5 is connected to one end of the voltage divider 9 through a grid leak resistor 27 whereby the end section 29 of the voltage divider maintains the control electrode at a suitable negative potential during the half cycle of operation that the anode 7 is positive.

When the phase of the voltage from the source 11 is such as to make the right-hand end of the voltage divider 9 positive, a positive voltage is applied to the anode 7 of the discharge device 1, a negative biasing voltage is applied to the control electrode 5, and, at the same time, a positive voltage is applied to the anode 25 of the photoelectric cell 21. Under these conditions, if light strikes the photoelectric cell 21, current will flow through it which is proportional to the

intensity of the light and there will be a corresponding voltage drop across the grid leak resistor 27. The potential drop is such as to make the cathode of the discharge device 1 more negative than normal with respect to its grid which is the equivalent of applying a more positive potential to the said grid, proportional to the light intensity. Accordingly, since the anode 7 is at a positive potential, there will be a flow of plate current having a value proportional to the light intensity. This flow of plate current will charge up the condenser 19 by an amount depending upon the value of the plate current, the right-hand terminal of the condenser 19 acquiring a positive polarity. During the next half of the cycle, the voltage across the condenser 19 is utilized to control a second electric discharge device indicated at 31. The resistance 15 shunting condenser 19 is large enough so that the condenser will not be completely discharged during this one half cycle.

The device 31 may be a vacuum tube similar to the first device and, as illustrated, includes a cathode 33, an anode 35 and a control electrode 37. The cathode 33 is connected through a variable tap 39 to the same end of the voltage divider 9 that the anode 7 of the electric discharge device 1 is connected to. The anode 35 is connected through the load 41 to the opposite end of the voltage divider 9. Thus it will be seen that when the phase of the voltage from the source 11 is such as to make the first tube 1 operative, the second tube 31 is inoperative since its anode 35 is at a negative potential. Likewise, when the phase of the voltage is such that the first tube 1 is inoperative, the second tube 31 is operative.

The control grid 37 of the tube 31 is connected to the plate end of the resistor 15 so that the output of the tube 31 is controlled by the voltage drop across the resistor 15. By connecting the cathode 33 to the voltage divider 9 at a point on one side of the variable tap 17, a suitable biasing voltage may be applied to the control grid 37. In the diagram, the relation of the variable taps 17 and 39 is such that when the second tube 31 is operative, a slight negative bias is applied to its control grid 37 by a section 43 of the voltage divider 9.

Referring now to the operation of the circuit for the second half of the cycle, it will be apparent that during this half cycle the anode 35 of tube 31 is positive whereby a current may flow through the load 41, the value of the current depending upon the voltage applied to the control electrode 37. We have seen that during the first half of the cycle the condenser 19 was charged to some value depending upon the intensity of the light striking the photoelectric cell 21. The charge on the condenser 19, shunted by the resistor 15, is such that, during the second half cycle, a negative potential is impressed upon the control electrode 37. Therefore, if the light striking the photoelectric cell 21 increases in intensity, the value of current through the load 41 decreases.

When light striking the photoelectric cell 21 decreases, the charge on condenser 19 leaks off through the resistor 15 until equilibrium is reached at a new level. The plate current of tube 31 also readjusts itself to a higher value. Thus the output of tube 31 may be either increased or decreased by varying the intensity of the light striking the photoelectric cell.

In Fig. 2, the circuit of Fig. 1 is shown modified

to permit the amplification of signals, particularly those having an audio frequency. In the two figures, like parts are indicated by the same reference numerals. In this circuit, the electric discharge devices 1 and 31 are preferably vacuum tubes of the screen grid type in order that efficient amplification of a comparatively high frequency alternating current may be obtained. Instead of a 60 cycle supply, such as would be used ordinarily in the circuit shown in Fig. 1, an alternating current source 45 preferably supplies current having a frequency which is above audibility, such as a frequency of 25,000 cycles.

The output circuit of the discharge device 31 includes a low-pass filter 47 which has a cut-off frequency above the signal frequencies and below the frequency of the alternating current supplied by the source 45. Thus, the signals will appear in the output, while the high frequency current supplied from source 45 will be filtered out.

While a photoelectric cell has been illustrated in the input circuit of the amplifier, it should be understood that a signal voltage may be impressed upon the amplifier input circuit in any well known manner.

Referring to Fig. 3, the circuit of Fig. 1 is shown modified by the addition of two more electric discharge devices 49 and 51. While only two additional discharge devices have been illustrated, it will be understood from the following description that any desired number may be added. In the two figures, like parts are indicated by the same reference numerals.

It will be seen that the circuit for the first discharge device 1 is the same as shown in Fig. 1. The circuit for the second discharge device 31 is also substantially the same as in Fig. 1, the only difference in the input circuit of said device being that the cathode 33 is connected through the variable tap 39 to an additional voltage divider section 53 for applying a positive bias to the control grid 37 during the half cycle the second device is in operation. This distinction, however, is not of any great importance as the character of the bias which is applied to the control grid 37 depends upon the particular type of tube used. The other distinguishing feature is that the output circuit of the tube 31 includes a resistor 55 shunted by a condenser 57 which will charge up during the half cycle the tube 31 is operating whereby the third electric discharge device 49 may be controlled by the voltage across the resistor 55 produced by the charged condenser 57.

The third electric discharge device 49, as illustrated, is a vacuum tube having a cathode 59, a control grid 61 and an anode 63. The cathode 59 is connected through a variable tap 65 to an additional voltage divider section 67 provided for biasing purposes. The anode is connected to the opposite end of the voltage divider 9 through a resistor 69 which is shunted by a condenser 71. The control grid 61 of the tube 49 is connected to the plate end of the resistor 55 whereby the condenser 57, if charged by tube 31, will apply a negative potential to the control grid.

The fourth electric discharge device 51, as illustrated, is a vacuum tube having a cathode 73, an anode 75 and a control grid 77. The cathode 73 is connected through a variable tap 79 to a point near the same end of the voltage divider 9 to which the plate 63 of the preceding tube is connected. The anode 75 is connected through

a load 81 to the opposite end of the voltage divider 9. The control grid 77 is connected to the plate end of the resistor 69 whereby its potential may be controlled by the voltage to which the condenser 71 has been charged. It may be noted that the position of the variable tap 79 connecting the cathode 73 to the voltage divider 9 is such that a negative bias is applied to the control electrode 77 instead of a positive bias as in the case of the other tubes. The reason for this is that, in the particular circuit illustrated, the tube 51 is a power tube which requires a high negative bias.

In each plate circuit, the resistor which shunts the condenser has a value such that the charge on the condenser will decrease rather rapidly but not so rapidly as to completely discharge the condenser in one half cycle. It will be apparent that the use of the resistors causes the circuit to operate in response to either an increase or a decrease in the amount of light on the photoelectric cell.

The operation of the circuit shown in Fig. 3 will be understood from the foregoing description given in connection with Fig. 1. It may be noted, however, that the signal is delayed a certain amount in passing through the amplifier, the amount of the delay depending upon the number of tubes and the frequency of the alternating current supply. That such a delay exists will be made apparent by considering the fact that a change in the charge on the first condenser can have no effect upon the charge of the second condenser until the second half cycle, and that the change in the charge of the second condenser in turn can have no effect upon the charge of the third condenser until the third half cycle.

Referring to the embodiment of my invention illustrated in Fig. 4, it comprises two electric discharge devices 83 and 85 connected in cascade for operating on one-half cycle of an alternating current and two other electric discharge devices 87 and 89 connected in cascade for operating on the succeeding half cycle of the alternating current. In the circuit illustrated, these devices are three-element vacuum tubes. They are provided with suitable operating voltages by means of a voltage divider 91 which is connected across an alternating current source 93.

The first discharge device 83 includes a cathode 95, a control grid 97 and an anode 99, the cathode 95 being connected through a variable tap 101 to the voltage divider 91 near the left-hand end and the anode 99 being connected through a coupling resistor 103 to the voltage divider 91 at a point near the middle.

A signal or control potential may be applied to the input circuit of the first tube 83 in any suitable manner, as by means of a light sensitive device 105 which may be a photoelectric cell having a cathode 107 and an anode 109. The anode 109 is connected to a point on the voltage divider 91 while the cathode 107 is connected directly to the control electrode 97 and to the left-hand end of the voltage divider 91 through a grid leak resistor 111.

The second tube 85 includes a cathode 113, a control grid 115 and an anode 117, the cathode 113 being connected to the lower end of the coupling resistor 103, and the control electrode 115 being connected to its upper end. The anode 117 is connected to the right-hand end of the voltage divider 91 through a resistor 119 and a variable tap 121, the resistor 119 being shunted by a con-

denser 123 provided for the purpose described in connection with the preceding figures.

It will be apparent that during the half cycle the anodes 99 and 117 are positive the two discharge devices will operate in cascade to charge up the condenser 123 in accordance with the intensity of the light striking the photoelectric cell 105. During the succeeding half cycle, the charge on the condenser 123 will bias the grid of the tube 89 negatively and control the output of tube 87.

The vacuum tube 89 includes a cathode 125, a control grid 127 and an anode 129, the cathode 125 being connected to the same end of the voltage divider 91 as that to which the anode 117 of the second discharge device 85 is connected. The anode 129 is connected through a coupling resistor 131 to the voltage divider at a point near the middle. The control electrode 127 is connected to the plate end of the resistor 119, whereby its potential is controlled in accordance with the discharge of the condenser 123.

The vacuum tube 87 includes a cathode 133, a control grid 135 and an anode 137, the cathode 133 being connected to that end of the coupling resistor 131 which is connected to the voltage divider, and the anode 137 being connected through a load 139 to the left-hand end of the voltage divider 91. The control electrode 135 is connected to the plate end of the coupling resistor 131 whereby the vacuum tube 87 is connected in cascade with the preceding tube 89.

It will be noted that the circuit shown in Fig. 4 differs from that shown in Fig. 1 in that only about half the voltage from the alternating current source 93 is impressed across the cathode and anode of each discharge device and in that a plurality of discharge devices operate as a cascade amplifier during each half cycle.

Referring to Figure 5, there is shown the circuit diagram of a photoelectric cell amplifier designed for operating a direct current relay. This circuit is designed to overcome two apparently conflicting requirements for efficient operation of the amplifier, one requirement being that the amplifier tube be so biased that it has high mutual conductance and the other requirement being that there shall be no flow of direct current through the relay until the relay is to operate. These requirements are conflicting because a bias which will give the amplifier tube a high mutual conductance will cause a flow of direct current in its plate circuit. I have found that by employing a condenser and rectifier combination it is possible to prevent a flow of direct current through the relay, excepting during the period it is to operate, and at the same time to bias the amplifier tube for high mutual conductance.

Referring to the circuit diagram, the apparatus comprises an amplifier tube 151 which may be any suitable form of electric discharge device, such as either a three element or a screen grid vacuum tube having a photoelectric cell 153 connected to its input circuit. In the drawings, there is illustrated a three element vacuum tube having a cathode 155, a control electrode 157 and a plate electrode 159. An alternating current operating potential is supplied to the vacuum tube 151 from any suitable source 161 which preferably has a voltage divider 163 connected thereacross. The voltage divider may be either a tapped inductance coil or a tapped resistor, as illustrated.

The cathode 155 of the amplifier tube is connected to a point on the voltage divider 163 intermediate its ends, while the control electrode 157 is connected through a resistor 165 to a point near one end of the voltage divider.

The photoelectric cell 153 has a cathode 167 which is connected to the upper end of the resistor 165 and an anode 169 which is connected through a variable tap 171 to a point on the voltage divider 163.

The direct current relay 173, which is to be operated in response to a change in light of the photoelectric cell 153, consists of a relay winding 175 and an armature 177. The winding 175 is connected in the plate circuit of the amplifier tube 151, one end of the winding being connected to the plate electrode 159 and the other end of the winding being connected to one end of the voltage divider 163.

It will be apparent that, with the circuit as described above, there would be a flow of pulsating current through the relay winding 175. As is well known, such a current has a direct current component.

I prevent such a direct current component from appearing in the relay winding 175 by means of a condenser 179 and a rectifier 181. The condenser 179 is connected across the relay winding 175 whereby it will become charged during the half cycle that plate current flows in the amplifier tube 151.

One terminal of the rectifier 181 is connected through a variable tap 183 to the voltage divider 163 while the other terminal of the rectifier 181 is connected to the upper terminal of the condenser 179 through a variable resistor 185. The rectifier 181 is connected in such a direction that the current flows through it in the direction indicated by the arrow.

With given values of inductance and resistance for the relay coil 175, the condenser 179 is made large enough to maintain a fairly high value of current flow through the winding during the half cycle that the plate electrode 159 is negative and the condenser is discharging. In other words, the time constant of the circuit comprising the condenser 179 and the relay coil 175 is greater than $\frac{1}{200}$ of a second in the case where the alternating current supply has a frequency of 60 cycles per second. It may be noted that, at the frequency of the supply source employed, the inductive reactance of the coil 175 is small compared with its resistance.

Under the above described conditions, if the rectifier 181 were removed from the circuit, the current flow through the relay winding 175 would be as indicated by the curve in Figure 6. An inspection of this curve shows that during the half cycle that the plate electrode is positive the condenser 179 is given a certain charge, plate current at the same time flowing through the relay winding 175. During the next half cycle the condenser 179 discharges a certain amount through the relay coil 175 but it does not have time to discharge completely before the next positive half cycle appears. Thus the charge on the condenser 179 gradually increases and the current flowing through the relay coil 175 has a rather large direct current component, as indicated by the curve.

By adding the rectifier to the circuit, as previously described, the curve of the current flow through the relay winding 175 is changed to have the characteristic shown in Figure 7. With the rectifier in the circuit, the condenser 179 charges

up during the positive half cycle, as described above, and discharges through the relay winding 175 and the rectifier 181 during the negative half cycle. The difference in the circuit operation is that now, during the negative half cycle, the voltage drop across the voltage divider portion 187 causes a flow of current through the rectifier 181 in such a direction as to aid the discharging of the condenser 179 and to charge it a certain amount in the opposite direction, this charge being indicated by that portion of the curve appearing below the horizontal line. Thus, the circuit may be so adjusted that for a given light intensity on the photoelectric cell 153, the condenser 179 will be discharged a sufficient amount to prevent it from acquiring a greater charge with each succeeding cycle. It will be apparent from the curve of Fig. 7 that the current now flowing through the relay winding contains substantially no direct current component.

The alternating current represented by the curve in Fig. 7 either is maintained at a low value compared with the direct current which is to operate the relay, or it is filtered out entirely by means of a filter connected as shown in Figure 8. If such a filter is provided, it is preferably of the low-pass type comprising a series coil 189 and shunt condensers 191 and having a cut-off frequency below the frequency of the supply current.

The amplifier may be adjusted for the above described condition of no direct current component in the relay winding under the condition of light of any given intensity striking the photoelectric cell. In practice, the usual adjustment is to so adjust the circuit that with no light striking the photoelectric cell 153 the direct current component through the relay winding 175 is eliminated. With this adjustment, the instant light strikes the photoelectric cell, the impedance of the amplifier tube 151 is decreased, since control electrode 157 is made less negative, and the condenser 179 acquires a greater charge than formerly, whereby the circuit is unbalanced and a direct current component appears in the relay winding 175 to operate the relay.

It will be understood that if the circuit is balanced for a condition of a given light intensity on the photoelectric cell 153, the relay may be operated by either a decrease or an increase in the light intensity. By utilizing a polarized relay, it may be made to operate in one direction when the light intensity increases and in the opposite direction when the light intensity decreases.

Various other modifications may be made in my invention without departing from the spirit and scope thereof and I desire, therefore, that only such limitations shall be placed thereon as are necessitated by the prior art and set forth in the appended claims.

I claim as my invention:

1. In combination, a plurality of electric discharge devices, each of said devices having an input circuit and an output circuit, a source of power for supplying alternating current thereto, means for so connecting said devices to said source that one of said devices is operative on only one half cycle of said current while another of said devices is operative on only the succeeding half cycle, a condenser in the output circuit of said one device, and a resistor connected across said condenser, the input circuit of said other device being connected across at least a portion of said resistor.

2. In combination, a plurality of electric discharge devices, a source of power for supplying alternating current thereto, means for so connecting said devices to said source that one of said devices is operative on only one half cycle of said current while another of said devices is operative on only the succeeding half cycle, means for storing at least a portion of the output energy of said first device during said one half cycle, and means for controlling said second device in accordance with said stored energy during said succeeding half cycle.

3. In combination, a plurality of electric discharge devices, each of said devices having a cathode, an anode, and a control electrode, a source of alternating current, the cathode and anode of one of said devices being connected across said source, the cathode and anode of another of said devices being oppositely connected across said source whereby said two devices are operative only on alternate half cycles of said current, means connected between the anode of said one device and said source for storing electrical energy during one half cycle of said current, and means for controlling the potential of the control electrode of said other device during the succeeding half cycle in accordance with said stored energy.

4. In combination, a voltage divider, a plurality of electric discharge devices, each of said devices having a cathode, an anode, and a control electrode, the cathode of one of said devices being connected to one end of said voltage

divider, the anode of said one device being connected to the other end of said voltage divider, the cathode of another of said devices being connected to said other end of said voltage divider and its anode being connected to said one end of said voltage divider whereby said two devices are rendered operative on opposite half cycles, a condenser connected in the anode circuit of said first device, and means for controlling the potential of the control electrode of said second device in accordance with the charge on said condenser.

5. In combination, a plurality of electric discharge devices, means for connecting said devices to a power source of alternating potential, means for rendering one of said devices operative during one half-cycle and means in circuit with each of said devices for controlling the operation of another of said devices during a subsequent half-cycle in accordance with the operation of the first mentioned device during the first half-cycle.

6. Apparatus according to claim 5 characterized in that a photo-electric cell is included in the input circuit of said one device.

7. An amplifier according to claim 2 characterized in that said alternating current has a frequency which is high compared with the frequency of the signal to be amplified and further characterized in that means is provided for filtering out said alternating current from the amplifier output.

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