Nov. 9, 1937. F. B. AUBERT ET AL 2,098,217

ELECTRONIC APPARATUS

Filed Aug. 22, 1935 2 Sheets-Sheet 1

Fig. 1.

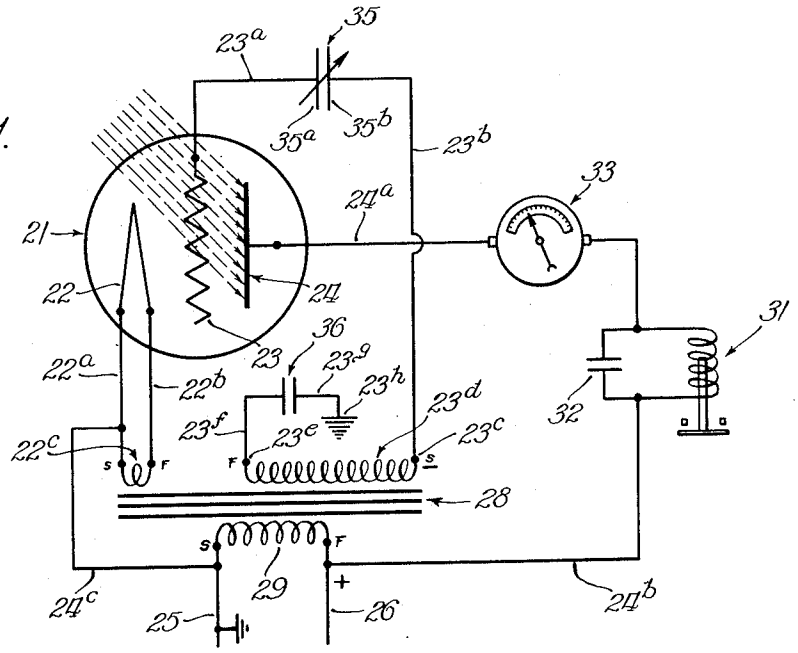


Fig. 2.

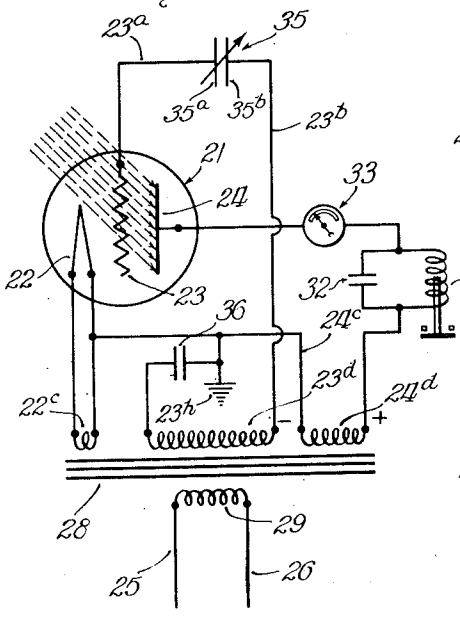
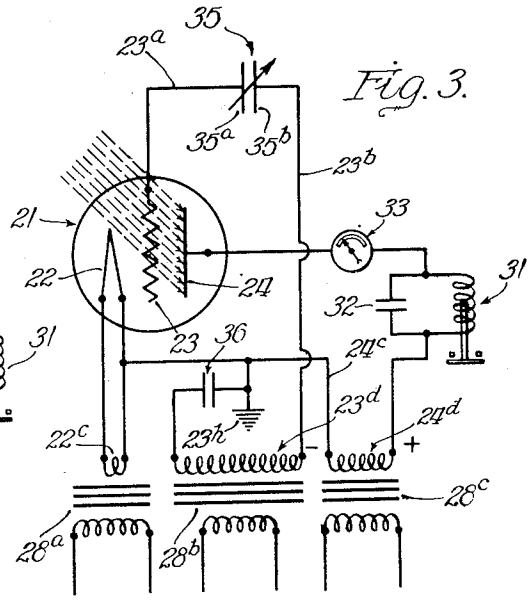


Fig. 3.



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Fig. 4.

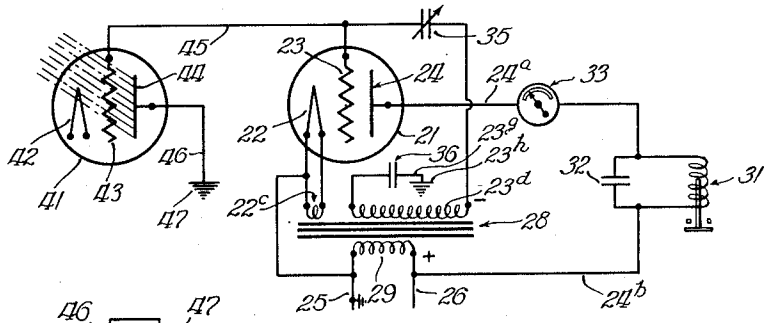


Fig. 5.

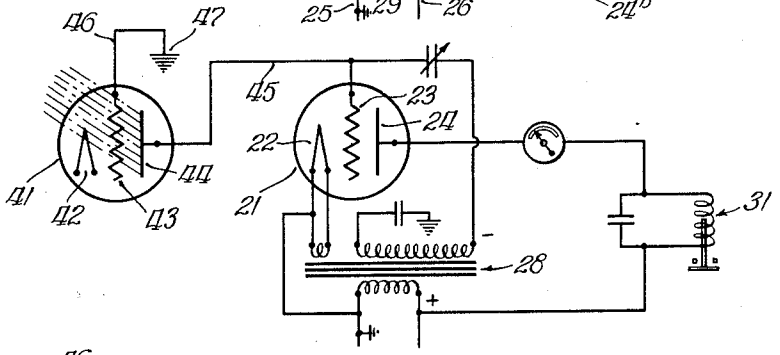


Fig. 6.

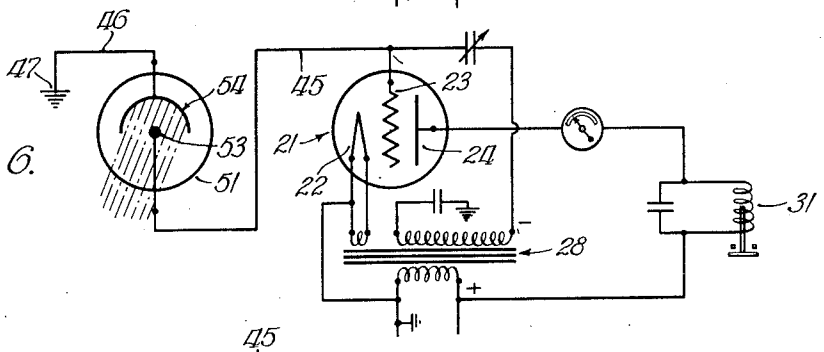


Fig. 7.

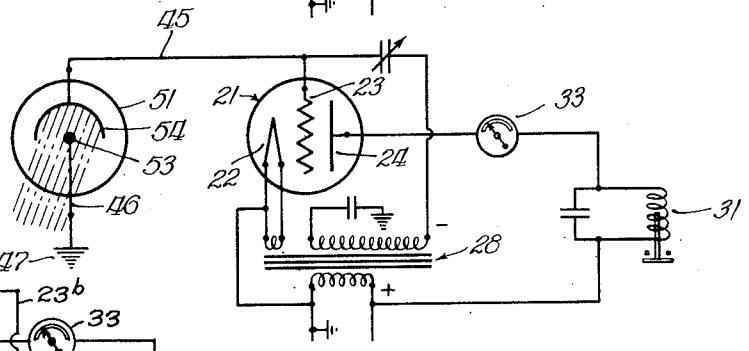
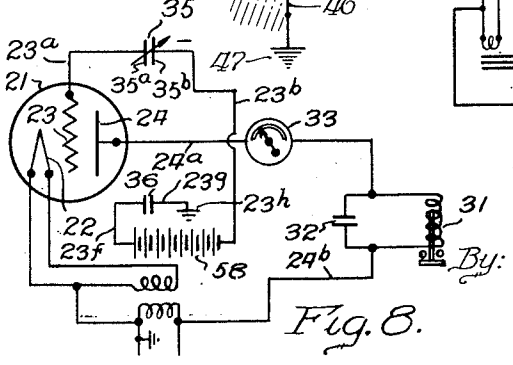


Fig. 8.



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UNITED STATES PATENT OFFICE

2,098,217

ELECTRONIC APPARATUS

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Application August 22, 1935, Serial No. 37,396

17 Claims. (Cl. 250—41.5)

The present invention relates to electronic apparatus.

The principal object of the invention is to provide improved electronic apparatus which is responsive to light.

Another object of the invention is to provide improved electronic apparatus wherein a single electron tube serves both as a light-sensitive device and as an amplifying device.

Another object of the invention is to provide improved electronic apparatus serving as an amplifier.

Our invention is based on an improved relation of circuits and the establishment of certain approximate conditions in association with an electron tube, whereby the tube is caused to operate in a manner, and with attendant phenomena, which, so far as we know, have not heretofore been known. As one illustration of this phenomena, by the practice of our invention we are enabled to make a typical three-element amplifying tube responsive to light. Such a tube, of the high vacuum type, constructed primarily for amplifying purposes, has no photosensitive coating of caesium, sodium, or the like on the plate (anode) in the original manufacture of the tube. Nevertheless, such a tube, operated according to our invention, is made highly sensitive to light, exhibiting many of the properties of the conventional phototube or photo-electric cell, and, in addition, affording a greater stability of operation, greater reliability, and a longer life, than are attainable with the conventional phototube. Furthermore, the use of such a three-element tube appears to cause the control grid to function in an amplifying capacity so that the range of current variation in response to light variation is in a much larger ratio than is obtainable from a conventional phototube.

Other objects, features and advantages of our invention will appear from the following detailed description of certain preferred embodiments thereof.

In the accompanying drawings, illustrating these embodiments and illustrating a hypothesis of operation:

Figures 1, 2, and 3 are diagrammatic illustrations of different embodiments of our invention functioning as light-sensitive apparatus, and employing a single tube;

Figures 4 5, 6, and 7 are diagrammatic illustrations of other embodiments utilizing the fundamental circuit arrangements of our invention for amplifying purposes; and

Figure 8 is a diagrammatic illustration of another embodiment using direct current in the grid circuit.

We shall first describe the invention in an alternating current adaptation, wherein the plate circuit is energized by an alternating current. Referring first to Figure 1, the tube **21** is a standard three-element tube of the high vacuum type, commercially referred to as an R. C. A. Radiotron or Cunningham "Type 71A". Such tube comprises a filament or cathode **22**, a control grid **23**, and a plate or anode **24**. In the alternating current adaptation of the invention the source of power supply is any 110-volt, 60-cycle lighting circuit represented by the conductors **25, 26** connecting with the primary winding **29** of the power transformer **28**. In this embodiment the plate circuit or work circuit of the tube is supplied directly from the lighting circuit **25, 26**, this plate circuit comprising the conductor **24*a*** leading from the plate **24** and connecting with the responsive device **31**, the conductor **24*b*** leading from the responsive device to one side **26** of the supply circuit, and the conductor **24*c*** leading from the other side **25** of the supply circuit to the filament circuit **22*a*, 22*b*** connecting with the filament winding **22*c***. The actuated device **31** is shown as a relay adapted to open and close one or more secondary circuits, the winding of this relay being shunted by a condenser **32**. For maximum sensitivity when using a 71–A tube, the relay is preferably between 3000 and 5000 ohms and the condenser is preferably between 2 and 4 microfarads, the sensitivity being materially influenced by proper choice of values in this part of the circuit. Other values may be desirable for other tubes. Reference will hereinafter be made to the plate current flow as given by a milliammeter **33** interposed in the plate circuit at any appropriate point.

The circuit for the filament **22** is represented by the conductors **22*a*** and **22*b*** connecting with the secondary winding **22*c*** of the transformer **28**. The conductor **24*c*** of the plate circuit can be connected to either end or to a mid-point of the secondary winding **22*c***. The filament is energized with its standard rated voltage and current, which is approximately 5 volts and .25 ampere.

The control exercised over the grid **23** is influenced in part by certain connections which, for brevity, we shall refer to as a grid circuit, although these connections may not establish a complete electrical circuit in the common conception of that term. This so-called grid circuit comprises a conductor **23*a*** leading from the grid

to one side 35a of an adjustable condenser 35. From the other side 35b of this adjustable condenser, a conductor 23b extends to one terminal 23c of a secondary winding 23d of transformer 28. From the other terminal 23e of said secondary winding, a conductor 23f extends to one side of a condenser 36. The other side of said condenser is preferably connected through conductor 23g with ground at 23h, although connection with a true "ground" is not essential, as will hereinafter appear.

The apparatus is most sensitive to light when the potential set up in the secondary winding 23d of the grid circuit is relatively high, and preferably higher than the plate voltage. For example, with a potential of 110 volts impressed on the plate, the best results have been secured when a potential of approximately 550 volts is established in the grid circuit. Using the type of tube referred to, and the above ratio of approximately 5 to 1 between the grid and plate potentials, best results have been obtained when the upper condenser 35 is adjustable in capacity between .002 and .000006 microfarad. In this same relation, the lower condenser 36 may be either a fixed condenser or a variable condenser, best results being secured when the capacity is in the neigborhood of .002 and .00025 microfarad.

For placing the apparatus in condition to respond to light, the system is first adjusted to a stand-by condition in the absence of light, or with minimum light incident upon the tube, this adjustment preferably being performed by adjusting the upper condenser 35. Increasing the capacity of this adjustable condenser reduces the plate current flow in effecting this stand-by adjustment, and, conversely, reducing the capacity of this condenser increases plate current flow. A typical stand-by condition is with a plate current flow of approximately 5 milliamperes, as read on the milliammeter 33 included directly in the plate circuit.

Light is now caused to fall upon the tube. This may be daylight, or it may be artificial light, such as that from any ordinary electric light bulb. The experiments conducted by us to date and our present hypothesis of the operation lead us to believe that it is desirable, if not essential, that the light fall upon the inner surface of the plate 24, i. e., upon that surface of the plate which is subjected to the bombardment of the electrons from the filament. In the above type of tube, the plate completely surrounds the filament and the grid on all sides but is open at top and bottom. When using this tube, the light is caused to enter the top of the tube so as to pass down through the filament and the grid and to fall upon an inner surface or surfaces of the plate, approximately as indicated by the dash-and-dot lines in Figure 1. Immediately that light is thus incident upon the tube, the plate current varies. When the apparatus is operated in the relation described above of Figure 1, the presence of light reduces the flow of plate current. By subjecting the tube to a sufficient intensity of light the plate current can be reduced from its stand-by value of 5 milliamperes completely down to a zero reading on the milliammeter 33, such indicating either a complete cessation of plate current flow or the reduction thereof to a value not capable of being read upon such an instrument.

Exploring operations conducted with an ordinary 60 watt light bulb, either with or without an appropriate lens for concentrating the rays, give results which indicate that the responsiveness of the device to light is dependant upon light striking the inner surfaces of the plate. The above type of tube has the upper ends of the filament and grid supported by a thin supporting plate or cap of insulating material, which is provided with an oblong opening therein. When the light is caused to pass straight down through this opening so that practically no light, or a minimum amount of light, falls directly upon the inner surfaces of the plate, the variation of plate current flow is barely perceptible on a milliammeter, except when the light is of relatively high intensity, as for example, when the bulb and lens are held just a few inches from the top of the tube. Under the latter circumstances, it is possible that there is some appreciable amount of light reflected off the surfaces of the filament and grid wires laterally on to the plate. The rays which are being caused to pass axially into the tube fall directly on the filament and grid and intersect the paths of the electrons flowing from the filament to the plate, but the lack of any substantial response to the light rays at this time indicates that it is not the action of the light striking the filament and/or grid that gives rise to the photo-sensitive action of the apparatus. As the rays are caused to take more of a lateral angle through the oblong opening they fall upon the inner surfaces of the plate, and thereupon there is an immediate diminution in the plate current flow. When the inclined beam of light is in a plane parallel to the greater dimension of the oblong opening there is a greater diminution of plate current than when it is in a plane parallel to the shorter dimension of said opening. This is apparently merely a quantitative variation resulting from the rays being incident upon a greater area of the plate when projected through the long dimension of the opening. Daylight and sunlight result in the same response when caused to fall upon the inner surfaces of the plate, and, as above stated, when the light is of sufficient intensity the plate current flow can be reduced from as much as 5 milliamperes down to approximately zero flow.

The apparatus appears to respond instantly to the application of light, at least human eye observations of the milliammeter deflections and of cathode ray oscillograph deflections do not reveal any sensible lag. A sensible lag seems to prevail, however, when light is removed or interrupted, this lag being of the approximate order of a fraction of a second to possibly a second or so from a no-flow condition in the plate circuit to a stand-by flow of say 5 milliamperes.

The potential established in the grid circuit is an important factor in the operation of the apparatus. As above stated, the greatest range of plate current change is obtained when the grid-plate potentials are substantially in the ratio of 5 to 1, i. e., 550 volts in the grid circuit and 110 volts in the plate circuit. Increasing the potential in the grid circuit to 600 volts and 700 volts, etc., while retaining the plate potential at its original value of 110 volts does not increase the responsiveness of the apparatus in proportion. Conversely, decreasing the grid potential while retaining the plate potential at its 110 volts value decreases the responsiveness of the apparatus, until a grid potential is reached in the neighborhood of 150 or 200 volts when the apparatus shows no sensible response to light. It will be understood that we have given the above ratios and potentials for illustrating the

practical applications of our invention to those skilled in the art, but we do not mean to limit our invention thereto, since other tubes now in existence or to be hereafter produced will probably have different constants and different structural characteristics calling for different ratios and different potentials for producing the same general results.

The apparatus is most responsive when the conductor **24***b* of the plate circuit is connected to the ungrounded side of the lighting circuit **25**, **26**. The secondary winding **23***d* is so connected in the grid circuit that the end **23***c* of said winding will impress negative polarity on the conductor **23***b* of the grid circuit during the same alternation that the supply circuit **25**, **26** is impressing positive polarity on the plate **24**. The notations "S" and "F" are conventional transformer designations indicating the start and finish of the windings **23***d* and **29**, and Figure 1 shows their proper connection for the above described relation. A reversal of the connections to the secondary winding **23***d* results in a plate current flow which is a maximum in relation to the impressed plate voltage; for example, approximately 10 milliamperes at 110 volts plate potential. Adjustment of the condenser 35 manifests no controlling influence at this time, and the tube is not responsive to light.

Figure 2 illustrates a modified arrangement in which the plate circuit receives its potential from a secondary winding **24***d* on the transformer **28**, instead of directly from the supply circuit **25**, **26**. The connection of the secondary windings **23***d* and **24***d* in the grid and plate circuits is such that the winding **23***d* impresses negative polarity on the conductor **23***b* substantially at the same instant that the winding **24***d* impresses positive polarity on the plate **24**, i. e., there is substantially 180 degrees difference in phase between the potentials impressed by these secondary windings on the side **35***b* of the adjustable condenser **35** and on the plate **24**. The conductor **24***c* of the plate circuit is connected to ground at **23***h*. In this embodiment, the potential developed in the grid circuit secondary **23***d* is preferably from three to six times the potential developed in the plate circuit secondary **24***d*, the aforementioned ratio of approximately 5 to 1 causing the apparatus to exhibit substantially the same degree of light sensitivity referred to above in connection with Figure 1. That is to say, assuming an arbitrary stand-by condition with a flow of approximately 5 milliamperes through the plate circuit, the subjection of the tube to a sufficient intensity of light, incident upon the inner surfaces of the plate, causes the plate current flow to diminish to approximately zero value.

Figure 3 illustrates a further modified arrangement, in which three separate transformers **28***a*, **28***b*, and **28***c* are employed for energizing each of the three tube circuits. Here again, for best performance, the ratio of grid voltage to plate voltage is preferably substantially 5 to 1. The secondaries of the transformers **28***b* and **28***c* are so connected in the grid and plate circuits that the potentials impressed on the side **35***b* of the adjustable condenser **35** and on the plate **24** are substantially 180 degrees out of phase. The conductor **24***c* of the plate circuit is connected to ground **23***h*. This embodiment is also operable to cause a stand-by plate current flow of approximately 5 milliamperes to be reduced to zero value when sufficient light is caused to fall on the plate of the tube. The employment of three separate transformers for assuring complete absence of inductive coupling between the tube circuits in such embodiment, demonstrates that the phenomena of the apparatus in being responsive to light is not predicated on any mutual coupling between the tube circuits.

As previously stated, it is also an object of our invention to provide improved electronic apparatus serving as an amplifier. Figures 1, 2, and 3 exemplify three fundamental circuit arrangements, either one of which can also be used in an amplifying capacity. Figures 4, 5, 6, and 7 show the fundamental circuit of Figure 1 connected in amplifying relation to another tube designated **41** in Figures 4 and 5. For clarity of description, we shall refer to the tube **41** as a "pilot" tube. The results attained in the operation of either of these amplifying embodiments of our invention afford helpful data in arriving at a theory of operation, and accordingly these amplifying embodiments will be described before proceeding to advance our theory of operation.

In Figure 4, the pilot tube **41** is also a typical three-element amplifying tube, such as a "71—A". The grid **43** of such tube is connected through conductor **45** with the grid **23** of the tube **21**. The plate **44** of the pilot tube is connected through conductor **46** with ground at **47**. In this amplifying situation, the pilot tube **41** is made the light sensitive element, the tube **21** remaining permanently shielded from light. In this arrangement, the pilot tube can be operated in a cold state, i. e., its filament **42** need not be heated. Assuming that the fundamental circuit arrangement of the tube **21** has been adjusted to a stand-by condition where a plate current of approximately 5 milliamperes is passing through this tube with little or no light incident upon the pilot tube **41**, this plate current flow will diminish as light is caused to fall on the inner surfaces of the plate **44** of the pilot tube. Increasing the intensity of the light falling upon the pilot tube is effective to reduce the plate current flow of the tube **21** substantially to zero. Particular attention is directed to the fact that when the grid of the pilot tube is connected to the grid of the amplifying tube, the plate current is caused to diminish with increasing light on the pilot tube, this direction of plate current change corresponding to that occurring in the embodiments above described.

Figure 5 illustrates a reversed arrangement in which a reverse operation occurs. In this instance, it is the plate **44** of the pilot tube that is connected through conductor **45** with the grid **23** of the amplifying tube, and it is the grid **43** of the pilot tube that is connected through conductor **46** with ground at **47**, the filament **42** remaining cold as in Figure 4. The operating characteristics of this embodiment are substantially the direct reverse of the operating characteristics of the embodiment of Figure 4. With substantially the same stand-by conditions established in the fundamental circuit arrangement of the amplifying tube, light falling upon the plate **44** of the pilot tube causes the plate current flow through the amplifying tube to increase instead of decrease. The degree of change is substantially the same in both cases, except that it is in opposite directions.

Figures 6 and 7 illustrate two other embodiments of our invention using photoelectric cells **51** as the pilot tubes. These photoelectric cells or phototubes may be of any conventional con-

struction, either of the vacuum type or of the gas filled type. These tubes usually consist of two electrodes, namely, the anode 53 and the photo-sensitive cathode 54. The light-receiving surface of the cathode 54 is usually coated with a layer of alkaline metal, such as caesium or potassium.

Referring to Figure 6, the anode 53 of the phototube is shown connected through the conductor 45 with the grid 23 of the tube 21, and the cathode of the phototube is connected through the conductor 46 with ground at 47. The tube 21, now functioning as an amplifying tube, is connected in the same fundamental circuit arrangement illustrated in Figure 1. Assuming that a stand-by condition with a desired current flowing through the plate circuit of the amplifying tube is established, the subjection of the phototube 51 to light, (amplifying tube 21 meanwhile remaining shielded from light), first causes the plate current flow to diminish a slight amount and thereafter to increase. That is to say, assuming light of gradually increasing intensity to be projected into the phototube, the first reaction in the plate circuit of the amplifying tube is a reduction of current flow in the neighborhood of approximately 1 milliampere, followed thereafter by a rise of plate current flow of approximately 3 to 8 milliamperes. When a vacuum type of photoelectric cell is employed as the pilot tube 51 there is a greater subsequent rise of plate current flow than when a gas filled type of phototube is used. Both types of phototubes cause the initial drop in plate current flow described above when first subjected to relatively feeble light intensity.

Referring now to Figure 7, in this embodiment the phototube is connected in reversed relation, i. e., the photo-sensitive cathode 54 is connected through conductor 45 with the grid of the tube 21 and the anode 53 is connected through conductor 46 with ground at 47. In this embodiment, when the phototube is subjected to light a continuous rise of current flow results in the plate circuit of the amplifying tube. This action is somewhat comparable to the action occurring in the embodiment of Figure 5.

In each of the amplifying embodiments illustrated in Figures 4, 5, 6, and 7, the fundamental circuit arrangements of Figures 2 and 3 can be used in conjunction with the tube 21, in lieu of the fundamental circuit arrangement of Figure 1, with substantially the same results in each case. In each of the embodiments of Figures 1 to 7, inclusive, alternating current is used in the plate circuit and the grid circuit, such being the preferred manner of operating our apparatus. The apparatus is also operable when using direct current, particularly in the grid circuit. Referring to Figure 8, this embodiment is the same as Figure 1, except that a battery or other source of direct current 58 is connected in the grid circuit in lieu of the secondary winding 23*d*. To obtain the desired light sensitivity of the tube 21, the voltage of this battery must be relatively high. Approximately the same aforementioned ratio of 5 to 1 between grid circuit voltage and plate circuit voltage gives satisfactory results, altho a lower ratio can be used where a relatively high degree of sensitivity is not desired. It is significant that for satisfactory results the negative terminal of said battery 58 should be connected to conductor 23*b* for making the plate 35*b* of the variable condenser 35 negative. This would indicate that in the alternating current embodiments of Figures 1 to 7, inclusive, it is the establishment of a negative condition on the condenser plate 35*b* by those alternations which impress negative polarity on this condenser terminal that places the grid in proper condition or state of balance for rendering the tube sensitive to light. A battery or other source of direct current can also be interposed in the grid circuits of Figures 2 and 3 to take the place of the transformer windings 23*d* with satisfactory results in each instance; and, correspondingly, these embodiments of the apparatus can be utilized in the amplifying arrangements of Figures 4 to 7, inclusive. The filament or cathode 23 can be energized by direct current if desired, and irrespective of the current used the cathode can be of the directly or indirectly heated type, as desired.

In the preceding description we have referred to the tubes 21 and 41 as being of the type commonly designated as "71—A". Our specific reference to this tube is solely for the purpose of giving definite values in changes of light current flow under certain operating conditions. Experimental tests show that the present invention is not limited to the use of this specific tube functioning in the capacity of the tubes 21 or 41 of our disclosure, since numerous other tubes of this same general class give corresponding results in the same fundamental circuit arrangements of Figures 1 to 7, inclusive, although possibly different values in change of plate current flow, etc.

Our proposed theory of operation, which appears to be completely supported by experimental results obtained from the embodiment of Figures 1 to 8, inclusive, is: (1) that a coating of light-sensitive material is transferred from the cathode and is deposited on the plate 24 during the use of the tube; (2) that when this light sensitive coating on the plate is subjected to light it results in an electronic emission from the plate, particularly when the plate is negative. The first hypothesis that a coating of light-sensitive material is deposited on the inner surfaces of the plate 24 with continued use of the tube appears to be definitely substantiated by experimental proofs. As originally constructed, the plate of a 71—A tube has no coating of light-sensitive material thereon. The cathode of such a tube is of the directly heated type wherein the electrons passing to the plate are emitted directly from the filamentary wire, and this filament is coated with an alkaline-earth, such as an alkaline-earth oxide, which material is photo-sensitive to a marked degree, i. e., it emits electrons in the presence of light. Upon the assembly of these tubes in the factory, they are all subjected to a relatively brief testing operation before shipment. Experimental results indicate that this brief testing operation results in a limited amount of the filamentary coating being carried over from the filament to the plate along with or as a part of the flow of electrons and being deposited on the plate; and that continued operation of the tube over a longer period of time increases the amount of photosensitive material which is carried over to the plate and deposited thereon. The difference in results obtained when first using a brand new tube secured directly from stock, and when using this same tube after a certain conditioning operation, would support this theory. A new tube gives the same character of response when used either as the tube 21

in Figures 1, 2, 3, and 8, or the tube 21 or 41 in Figures 4, 5, 6, and 7, except that such new tube does not have as much sensitivity or responsiveness as has been pointed out above. However, by subjecting the tube to a certain conditioning operation which we have developed for the purpose, the sensitivity or response of the tube can be greatly increased. This conditioning operation is that of producing an electronic flow from the filament to the plate for a substantial time interval, say for one or two hours or more. The filament is heated with its rated current flow, and the rated positive potential is impressed on the plate, the grid meanwhile being retained neutral or preferably positive for securing a maximum electronic discharge from the filament to the plate. The plate potential at this time is preferably direct current, although alternating current can be used, the latter merely necessitating a longer conditioning period. The conditioning interval can be shortened by utilizing a higher plate potential, or a higher filament current, or both, but this introduces the possibility of injuring the tube. It would appear that this conditioning operation results in a greater amount of the light-sensitive filamentary coating being carried over to the plate and deposited thereon, because after such conditioning operation the sensitivity of the tube is increased to a marked degree.

The other hypotheses that this coating of light sensitive material on the plate emits electrons in the presence of light, and that these electrons enable positive charges to be dissipated from the grid, appear to be supported by the results obtained in the embodiments of Figures 4 and 5. Referring to Figure 4, the fact that when light is projected on the plate 44 of tube 41 (a conventional three-element tube with the filament in a cold state) there is an immediate diminution of plate current flow through tube 21 would indicate that grid 23 of tube 21 has been placed in a less positive or more negative condition. Positive charges have apparently been dissipated from this grid over conductor 45 to grid 43, and thence over the stream of electrons to the plate 44 and through conductor 46 to ground. These positive charges apparently flow in a direction opposite to the direction of flow of the electrons, similarly to the commonly accepted sense of a current flow in a direction opposite to the flow of the electrons. Referring to Figure 5, the fact that the plate current flow through tube 21 increases as light is projected on tube 41 would indicate that the grid 23 of tube 21 is caused to acquire a more positive or less negative condition. This would indicate that positive charges are conducted from ground 47 through conductor 46 to grid 43, and thence over the stream of electrons to plate 44, in a direction counter to the flow of electrons, and through conductor 45 to grid 23. Both of these embodiments demonstrate a photosensitive property in the tube 41, and the opposite results obtained by reversing the connection of this tube in the circuit would indicate that there is an electronic emission from the plate 44 of said tube in the presence of light.

In Figure 6, the fact that the plate current flow through tube 21 first diminishes when relatively feeble light is projected on the photo-tube 51 indicates that positive charges are being conducted from grid 23 through the photo-tube 51 to ground at 47. The fact that the plate current flow rises when a greater intensity of light falls upon the photo-tube 51 indicates that there is a plate-grid current flow from plate 24 to grid 23 and thence through photo-tube 51, which plate-grid current flow renders the grid 23 more positive or less negative.

Referring to Figure 7, the fact that the plate current flow through tube 21 rises from the time minimum light falls on the photo-tube 51 until maximum light falls thereon indicates that there is a conduction of positive charges from ground 47 through the photo-tube to the grid 23.

The following theory is advanced as a basis for explaining the novel functioning of the tube 21 in controlling the current flow in the load circuit in response to change in intensity of light either on the plate 24 itself or on the "pilot" tubes 41 and 51. It will be understood that this description is not to be considered as limiting our invention in any way but rather it is to be considered merely as a means for more clearly understanding it.

Considering first the circuit arrangements illustrated in Figures 1, 2, and 3 of the drawings, it will be recalled that the potentials of the grid 23 and the plate 24 are opposed to each other. That is, at the instant when a positive potential is applied to the plate 24, a negative potential is applied to the grid 23, both of these potentials being relative to the filament or cathode 22. Since the windings 23*d* and 24*d*, Figure 2, are connected in additative circuit relation they may be considered as being a single winding of a transformer one terminal of which is connected through the load circuit including the relay 31 to the plate 24 while the other terminal is connected through the condenser 35 to the grid 23. A tap is taken off of this winding at an appropriate position intermediate the terminals and is connected to ground or at least it is connected to the cathode 22. Thus, during the half-cycle of the alternating current when a positive potential under these conditions is applied to the plate 24, a negative potential is applied to the grid 23. During this half-cycle the tube 21 is conducting to an extent which is determined by the potential of the grid 23 with respect to the cathode 22. That is, the more negative that the grid is with respect to the cathode 22 during this half-cycle the less current will be conducted through the tube since a smaller number of electrons will be permitted to leave the heated cathode 22 for bombarding the plate 24. It will then be observed that by changing in an appropriate manner the negative potential of the grid 23 with respect to the cathode 22, a control of the amount of current conducted by the tube 21 may be effected.

During the next half-cycle of the alternating current the grid 23 becomes positive with respect to the cathode 22 while the plate 24 becomes negative. Since current is conducted only during the time when the plate 24 is positive, no current will be conducted by the tube 21 at this time. However, electrons will bombard the grid 23 during this half-cycle since it is positive relative to the cathode 22. As a result a negative charge will be acquired thereby, which to a certain extent, will leak off through the grid circuit and through the various parts of the tube 21. It will be understood that these other paths are formed by the electrostatic capacity between the grid 23, the plate 24, the cathode 22, and the structure of the tube 21 itself.

A portion of the negative charge acquired by the grid 23 will remain during the next half-cycle at which time the plate 24 becomes positive and

the grid 23 becomes negative. Finally an average negative potential of the grid 23 will result when a balance is finally reached between the number of electrons bombarding the grid 23 during the half-cycle when it is positive and the number of electrons which it loses due to leakage. If now the voltage which is applied between the cathode 22 and the grid 23 is increased there will be an increased thermionic flow to the grid from the cathode 22 during the half-cycle when the plate 24 is negative, more electrons will remain on the grid 23 during the next half-cycle and as a result the average negative grid voltage is increased with a consequent result of a decrease in the flow of current through the valve 21 during the half-cycle when the plate 24 is positive.

After a very few cycles of the alternating current the balanced condition will be reached and a constant current will flow through the tube 21 and through the load circuit including the relay 31. Assuming now that light rays are directed onto the plate 24 as indicated in the drawings, there will be an emission from the plate 24 during the half-cycle when it is negative and the grid 23 is positive relative thereto. Additional electrons will, therefore, be received by the grid 23 in addition to those which it is receiving during this half-cycle from the cathode 22. As a result the grid 23 will become still more negative than before. In other words the average negative voltage of the grid 23 will be increased relative to the cathode 22. During the next half-cycle when the plate 24 is positive, there will be a reduction in the number of electrons emitted by the cathode 22 and arriving on the plate 24 because of the control exerted by the grid 23. This control will be a function of the number of electrons reaching the grid 23 from the plate 24 which, in turn, is a function of the intensity of the light rays. When the grid 23 is made sufficiently negative relative to the cathode 22 no electrons from the cathode 22 will reach the plate 24 during the half-cycle when the plate 24 is positive and, therefore, no current will flow through the tube 21.

A similar result occurs when the circuit connections shown in Figure 4 of the drawings are used. During the half-cycle when the grid 23 is positive, the grid 43 of the "pilot" tube 41 is also positive and as a result the grid 43 will receive a negative charge which will be conducted through conductor 45 to the grid 23. The average negative potential of the grid 23 relative to the cathode 22 will then be increased with a corresponding decrease in the conductivity of the tube 21.

When the connections for the "pilot" tube 41 are reversed, as shown in Figure 5 of the drawings, there will be an increase in the number of electrons which reach the plate 24 during the half-cycle when it is positive since the average negative potential of the grid 23 will be decreased. This decrease in the average negative potential of the grid 23 is due to the increased leakage from the plate 44 to the grid 43 during the half-cycle when the plate 24 is positive.

The functioning of the circuit shown in Figure 6 of the drawings may be explained on this same basis. For low illumination of the photo electric cell 51 electrons will arrive on the anode 53 which is connected to the grid 23 during the half-cycle of the alternating current when the plate 24 is negative and the grid 23 and the anode 53 are positive. For this range of operation the average negative potential of the grid 23 will be increased with the result that the tube 21 is less conducting. However, with an increase in illumination on the photo electric cell 51 the leakage through it predominates with the result that the negative potential on the grid 23 is drained off, thereby decreasing the average negative potential of the grid 23 and consequently increasing the conductivity of the tube 21 and a corresponding increase in current flow in the load circuit results.

In the circuit shown in Figure 7 of the drawings the leakage effect of the photo electric cell 51 alone controls the potential of the grid 23. Since the cathode 54 is connected to the grid 23, any illumination received thereby will cause an increase in the photo electric current between the cathode 54 and the anode 53 thereby forming a conducting path through which the negative potential on the grid 23 will be drained off with a consequent continued increase in the conductivity of the tube 21 as a function of the degree of illumination applied to the cathode 54.

The so-called grid "circuit" seems to exert its influence on the operation of the tube solely through an electrostatic or capacity effect. A complete circuit is not necessary, in that the conductor 23*g* can be completely disconnected from any actual ground, and the same characteristic operation will follow. The ground, however, enables the apparatus to be operated with a lesser degree of capacity at the variable condenser 35. With conductor 23*g* disconnected from ground 23*h*, the condenser 35 must be adjusted close to its maximum capacity, whereas with the conductor 23*g* connected to ground, the condenser 35 may be adjusted for a lesser amount of capacity. Assuming the apparatus to have been adjusted so that the tube 21 is sensitive to light, the establishment of a shunt across the condenser 35 results in the plate current flow falling to zero. With this condenser still shunted, a reversal of the terminals of secondary winding 23*d* or a reversal of the terminals of the battery 58 (Figure 8) in the grid circuit results in a plate current flow of approximately 10 or 12 milliamperes, and at this time the tube is not sensitive to light. As previously stated, a reversal of the connections of the secondary winding 23*d* or of the battery 58 in the grid circuit, with no shunt established across the condenser 35, results in an increased plate current flow from its stand-by value to approximately 10 or 12 milliamperes.

The length of the conductor 23*a* exerts an appreciable influence on the performance of the apparatus. Increasing the length of this conductor apparently increases the positive condition of the grid 23 because it results in increased plate current flow. With this longer length of conductor, the plate current flow can be brought down to its normal stand-by value by increasing the capacity of the variable condenser 35. When the length of this conductor 23*a* is increased, the sensitivity or response of the tube 21 to light is reduced. The shorter the length of this conductor from the grid 23 to the adjustable condenser 35, the more sensitive the tube is to light changes.

In the above described embodiment of Figures 1, 2, 3, and 8, the tube 21 is functioning both in the capacity of a light sensitive device and as an amplifier. This follows from the fact that within this single tube two actions are taking place, namely, the light responsiveness of the tube is controlling the charged condition of the grid, and

the charged condition of the grid is controlling the plate current flow.

In accordance with the teaching of our invention, we contemplate an improved construction of grid controlled electron tube in which a photosensitive material is incorporated in the plate or is coated thereon during the manufacture of the tube. Such material may be caesium, rubidium or any of the well known photosensitive materials. Such a tube would preferably embody a cathode and a grid arranged more or less similarly to the arrangement of these elements in tubes 21 and 41, so that the grid would be in position to influence the electrons emitted from the cathode and in position to influence the electrons emitted from the photosensitive material of the plate. Such a tube would preferably have a larger opening in the top insulating cap, or would have the cap eliminated entirely, in order to permit a greater volume of light to fall upon the effective surfaces of the plate. The operation of such a tube would be generally the same as the operation of the tubes above described, except that the greater concentration of photosensitive material on the plate would result in a greater density of electron emission from the plate in the presence of light.

We believe our invention to be of a fundamental nature and broadly new. Accordingly, while we have illustrated certain preferred embodiments thereof and certain preferred methods of carrying the invention into effect, nevertheless it will be understood that these are merely exemplary and that numerous variations and modifications may be made therein without departing from the broad scope of the invention.

We claim:—

1. Light sensitive apparatus including a tube comprising a filament, grid and plate, a transformer comprising a primary and two secondary windings, said primary winding being adapted to be connected to an alternating current supply circuit, a plate circuit connecting directly with said supply circuit, a filament circuit connecting one of said secondary windings with said filament, a grid circuit including the other secondary winding having one end connected to said filament, and a variable condenser connected between the other end of said latter secondary winding and the grid, said latter secondary winding impressing on said variable condenser a potential which is out of phase with said latter potential, said apparatus functioning to reduce the flow of current in said plate circuit when said plate is subjected to light.

2. Light sensitive apparatus including a tube comprising a cathode, grid and plate, the surface of said plate which is subjected to bombardment by the electrons from said cathode being coated with a light-sensitive material, means for heating said cathode, a transformer comprising primary and secondary windings, said primary winding being adapted to be connected to an alternating current supply circuit, a plate circuit connected to said supply circuit, and a grid circuit connected with said secondary winding, one end of said secondary winding being connected to said filament, and a variable condenser connected between the other end of said secondary winding and said grid, said secondary winding impressing on said variable condenser a potential which is out of phase with said latter potential, said apparatus functioning to reduce the flow of current in said plate circuit when the light sensitive coating on said plate is subjected to light.

3. Light sensitive apparatus including a tube comprising a cathode, grid and plate, the surface of said plate which is subjected to bombardment by the electrons from said cathode being coated with a light-sensitive material, means for heating said cathode, a transformer comprising two secondary windings, a plate circuit connected to one of said secondary windings, and a grid circuit connected to the other of said secondary windings, one end of said secondary winding being connected to said cathode, and a variable condenser connected between the other end of said latter winding and the grid, said latter winding impressing on said variable condenser a potential which is out of phase with said latter potential, said apparatus functioning to reduce the flow of current in said plate circuit when the light sensitive coating on said plate is subjected to light.

4. Light sensitive apparatus including a tube comprising a cathode, grid and plate, the surface of said plate which is subjected to bombardment by the electrons from said cathode being coated with a light-sensitive material, means for heating said cathode, a grid circuit and a plate circuit, separate transformers for energizing said circuits, said grid circuit including the secondary winding of the transformer individual thereto having one end connected to said cathode, and a variable condenser connected between the other end of said secondary winding and the grid, the transformer supplying said grid circuit impressing on said variable condenser a potential which is out of phase with said latter potential, said apparatus functioning to reduce the flow of current in said plate circuit when the light sensitive coating on said plate is subjected to light.

5. Light sensitive apparatus including a tube comprising a cathode, grid and plate, means for heating said cathode, a plate circuit including a source of alternating current, a grid circuit including a source of potential, said grid circuit comprising a first condenser connected between one terminal of said source of potential and the grid, the other terminal of said source of potential being connected to said cathode, said source of potential impressing on said first condenser a potential which is out of phase with the potential impressed on said plate, said apparatus responding to the presence of light on said plate by a reduction of current flow in said plate circuit.

6. Light sensitive apparatus including a tube comprising a cathode, grid and plate having a light sensitive coating, means for heating said cathode, a plate circuit including a source of alternating current, a grid circuit including a source of potential, said grid circuit comprising a condenser interposed between said source of potential and the grid, and means for changing the conductivity of said tube, in response to the presence of light on said plate by a reduction of current flow in said plate circuit.

7. Light sensitive apparatus including a tube comprising a cathode, grid and plate having a light sensitive coating, means for heating said cathode, means for impressing an alternating current potential on said plate, a condenser having one terminal connected to said grid, means for impressing on the other terminal of said condenser an alternating current potential opposite in phase from that impressed on said plate, and means for changing the conductivity of said tube in response to light incident on said plate by a reduction of current flow in said plate circuit.

8. In apparatus of the class described, the combination of an enclosure, a heated member with-

in said enclosure for emitting electrons, a second member within said enclosure emitting electrons in the presence of light, a common control element within said enclosure influencing the flow of the electrons emitted from both of said members, and circuit means for connecting a source of alternating potential between said second member and said common control element in such manner as to cause said control element to receive electrons from said heated member and said second member during the half cycle of the alternating potential when said second member is negative relative to said heated member and said control element.

9. In apparatus of the class described, the combination of an enclosure, a heated cathode member within said enclosure for emitting electrons, an anode member within said enclosure towards which said electrons are adapted to be projected, said anode member also emitting electrons in the presence of light, a common control element disposed between said members for influencing the flow of the electrons emitted from both of said members, and circuit means for connecting a source of alternating potential between said anode member and said common control element in such manner as to cause said control element to receive electrons from said cathode and said anode during the half cycle of the alternating potential when said anode is negative relative to said cathode and said control element.

10. A translating system comprising, in combination; an electric valve having an anode, a cathode and a control electrode, said anode being disposed to emit electrons on application of light thereto; means for applying an alternating potential between said anode and cathode, means for biasing said control electrode to a potential negative with respect to said cathode, and means connected to be responsive to the change in current flow through said valve on application of light to said anode.

11. A translating system comprising, in combination; an electric valve having an anode, a cathode and a control electrode, said anode being disposed to emit electrons on application of light thereto; means for applying an alternating potential between said anode and cathode, means for applying an alternating potential between said cathode and control electrode opposite in phase to the potential applied between said anode and cathode, and means connected to be responsive to the change in current flow through said valve on application of light to said anode.

12. A translating system comprising, in combination; an electric valve having an anode, a cathode and a control electrode, said anode being disposed to emit electrons on application of light thereto; means for applying an alternating potential between said anode and cathode, means for biasing said control electrode to a potential negative with respect to said cathode, impedance means interconnected between said biasing means and said control electrode for decreasing the leakage of negative charges therefrom, and means connected to be responsive to the change in current flow through said valve on application of light to said anode.

13. A translating system comprising, in combination; an electric valve having an anode, a cathode and a control electrode, said anode being disposed to emit electrons on application of light thereto; means for applying an alternating potential between said anode and cathode, means for applying an alternating potential between said cathode and control electrode opposite in phase to the potential applied between said anode and cathode, impedance means interconnected between said last named means and said control electrode for decreasing the leakage of negative charges therefrom, and means connected to be responsive to the change in current flow through said valve on application of light to said anode.

14. A translating system comprising, in combination, an electric valve having an anode, a cathode and a control electrode; means for applying an alternating potential between said anode and cathode, means for biasing said control electrode to a potential negative with respect to said cathode, means for increasing the negative potential of said control electrode as a function of light intensity, and means connected to be responsive to the change in current flow through said valve in response to change in said light intensity.

15. A translating system comprising, in combination, an electric valve having an anode, a cathode and a control electrode; means for applying an alternating potential between said anode and cathode, means for applying an alternating potential between said cathode and control electrode opposite in phase to the potential applied between said anode and cathode, means for increasing the negative potential of said control electrode as a function of light intensity, and means connected to be responsive to the change in current flow through said valve in response to change in said light intensity.

16. A translating system comprising, in combination, an electric valve having an anode, a cathode and a control electrode; means for applying an alternating potential between said anode and cathode, means for applying an alternating potential between said cathode and control electrode opposite in phase to the potential applied between said anode and cathode, impedance means interconnected between said biasing means and said control electrode for decreasing the leakage of negative charges therefrom, means for increasing the negative potential of said control electrode as a function of light intensity, and means connected to be responsive to the change in current flow through said valve in response to change in said light intensity.

17. A translating system comprising, in combination, an electric valve having an anode, a cathode and a control electrode; means for applying an alternating potential between said anode and cathode, means for applying an alternating potential between said cathode and control electrode opposite in phase to the potential applied between said anode and cathode, impedance means interconnected between said last named means and said control electrode for decreasing the leakage of negative charges therefrom, means for increasing the negative potential of said control electrode as a function of light intensity, and means connected to be responsive to the change in current flow through said valve in response to change in said light intensity.

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