

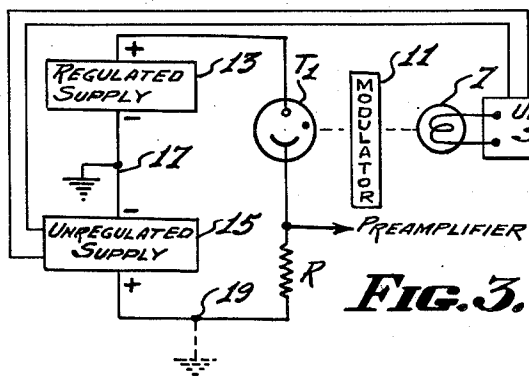
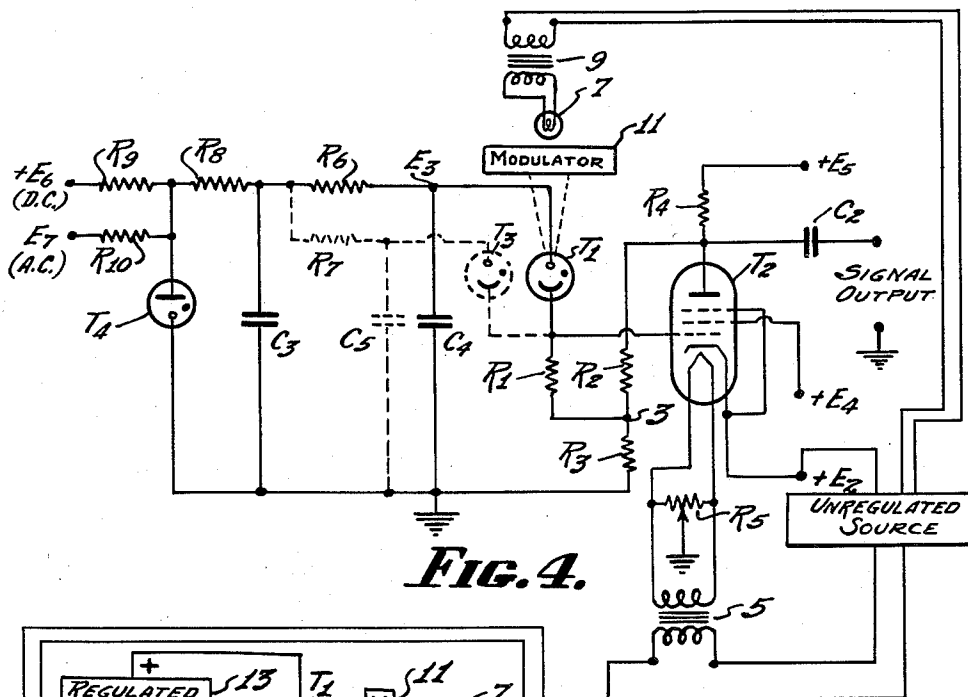
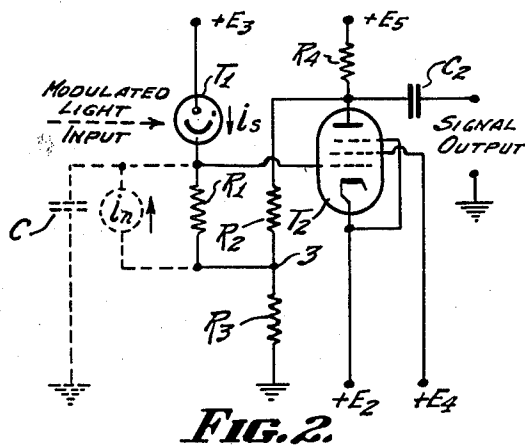
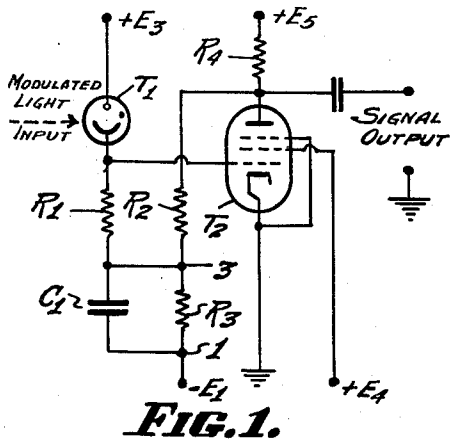
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2,801,342

PREAMPLIFIER FOR PHOTOELECTRIC MUSICAL INSTRUMENTS

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2,801,342

PREAMPLIFIER FOR PHOTOELECTRIC MUSICAL INSTRUMENTS

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7 Claims. (Cl. 250—214)

My invention relates generally to audio frequency electronic amplifiers. In particular, my invention has to do with improvements in preamplifiers suitable for amplifying weak audio signals derived from phototubes, condenser microphones and the like, and for coupling high impedance devices of this type to power amplifiers, such as those employed in public address systems and electronic musical instruments. I shall describe my invention as applied to the type of photoelectric musical instrument disclosed by Jordan in U. S. Patent No. 2,506,599, which may employ one or more generators such as I have set forth in my Patent No. 2,558,653. It will be obvious to one skilled in the art, however, that the utility of my invention will not be limited to the particular embodiments disclosed herein.

In instruments of the type referred to above, light from an incandescent source is converted to parallelism by a parabolic reflector and is projected upon a shutter system comprising a plurality of series of apertures in a shutter plate, each series corresponding to a particular musical voice and each series comprising apertures respectively corresponding to the notes of a musical scale. As apertures are opened by playing-key-controlled shutters, beams of light are permitted to illuminate variable-density, photographically produced, wave form patterns. These patterns are scanned by a rotating "pitch" member comprising an opaque disc having a plurality of concentric series of transparent radial slots. Each such series contains equally spaced, integral numbers of slots, the number of slots in the various series being so related as to approximate the relationship between notes in the equi-tempered scale. Rays of modulated light, produced as the slots of the pitch disc scan exposed wave forms, are focused by a second parabolic reflector upon a phototube. A preamplifier associated with the phototube serves to preamplify the tone signals produced in a phototube load circuit for subsequent amplification and conversion to sound in an electroacoustic system. My invention pertains to such preamplifiers.

The development of a practical preamplifier for use between the one or more phototubes and the main amplifier in photoelectric musical instruments of the above type has presented two primary problems, the solutions to which have, in turn, presented certain secondary problems.

The first basic problem arose from the fact that light from a single source of practical size is so widely dispersed in illuminating the large number of individual wave form patterns corresponding respectively to the notes in the musical scale and to each different tone color for each note, that no one wave form pattern receives enough light to provide in the phototube circuit a very strong tone signal. As a consequence, when a signal is amplified sufficiently to produce the necessary level of loudness (upon conversion to sound), extraneous electrical "noise" resulting from thermal agitation in the phototube load resistor is also amplified and results in noise

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that is especially objectionable when no notes are being played. One skilled in the art is aware that the signal-to-noise ratio in a phototube preamplifier can be increased by increasing the size of the phototube load resistor, and this fact will be discussed in detail hereinafter. However, as will also be explained, increasing the size of the load resistor introduces the following secondary problems, to which my invention affords a solution:

- (1) Instability in the grid circuit of the phototube preamplifier tube due to grid current,
- (2) Intermodulation distortion in the phototube circuit,
- (3) Distortion in the preamplifier tube circuit, and
- (4) Unbalanced frequency response of the preamplifier.

A known solution to these problems lies in a feedback circuit employed in connection with the preamplifier, which I shall describe in detail hereinafter for the sake of clarity. Briefly, a direct current feedback is provided in such a manner as to eliminate the grid instability and an alternating current feedback is employed for reducing both the above types of distortion and for improving the frequency response. Typical circuits of this type are shown in the patents to Gloess 2,202,522 and Weller 2,536,617.

The second basic problem, which is the one to which my invention is specifically directed, has to do with satisfying the requirement that variations in supply voltage to an electric musical instrument must not cause appreciable corresponding variations in loudness of the musical tones. The musician must be able to anticipate a given loudness at a given setting of the loudness control, usually a pedal operated device. To this end, my invention provides in a preamplifier circuit compensating means for automatically varying the sensitivity of the phototube inversely as the intensity of the light source, so that variations in the latter will not result in corresponding variations in tone loudness. Briefly, I accomplish this result by applying to the phototube the difference between a regulated direct current voltage and an unregulated direct current voltage of lesser value than the regulated direct current voltage. Thus, as the supply voltage of the unregulated source decreases, the voltage on the phototube increases, and vice versa. The secondary problem arising from this solution is that if the supply voltage of the unregulated source becomes too low, the voltage on the phototube may exceed recommended limits. My answer to this problem lies in feeding an alternating current, as well as a direct current, to a voltage regulator tube in the power supply for the phototube. The result is an intermittent operation of the regulator tube (off during part of negative half of the A. C. cycle), causing a reduced average D. C. voltage to be applied to the phototube at excessively low values of line voltage.

It is a primary object of my invention to provide an improved system for converting modulated radiant energy into correspondingly modulated electric energy.

It is also an object of my invention to provide improved preamplifiers for phototubes, condenser microphones and the like.

It is also an object to provide in a photoelectric musical instrument a preamplifier having a high signal-to-noise ratio, good frequency response and low distortion.

It is an important object of this invention to provide a phototube modulation system, the output of which will not be affected appreciably by variations from the normal supply voltage fed to the system.

It is a still further object of my invention to provide a preamplifier for a gas phototube wherein intermodulation distortion, arising from excessive alternating components of voltage on the phototube, is eliminated.

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Yet another object is to provide, in phototube preamplifiers of the types set forth in the preceding objects, means for preventing excessive voltage from being applied to the phototube when the supply voltage is substantially below normal.

These and other objects which will be set forth herein after or which will be obvious to one skilled in the art upon reading these specifications, I accomplish by those circuits and arrangements of parts of which I shall now set forth exemplary embodiments, reference being made to the accompanying drawings wherein:

Figure 1 is a basic circuit diagram of my original concept of a preamplifier incorporating certain teachings of my invention;

Figure 2 is a basic circuit diagram of a preferred preamplifier, including certain explanatory symbols;

Figure 3 is a block diagram of a basic light modulation system illustrating certain principles of my invention; and

Figure 4 is a complete circuit diagram of the preferred embodiment of my invention.

The initially developed embodiment of my invention comprised the basic circuit of Figure 1, wherein a phototube T_1 was connected as shown to the control grid of a thermionic pentode T_2 , to a high resistance load resistor R_1 and to a source of positive potential E_s . The anode of tube T_2 was supplied with a positive potential E_s through a load resistor R_4 , while the cathode of tube T_2 was connected to a common return path to all sources of potentials, indicated in the usual manner as ground. The basic novelty in my invention lies in a direct coupled feedback portion of a circuit of Figure 1, comprising the resistors R_2 and R_3 connected as shown between the anode of tube T_2 and a source of negative potential E_1 . A capacitor C_1 was connected in shunt with R_3 . The remainder of the circuit of Figure 1 comprised the usual output circuit, connection between suppressor grid and cathode of tube T_2 and a screen grid connection to a source of positive potential E_4 . It will be understood that the source of D. C. potential herein referred to may be, in fact, a single conventional power supply with portions thereof furnishing the desired potentials.

The operation of the circuit of Figure 1 is as follows: Modulated light falling upon the phototube T_1 causes corresponding modulation in the current through the phototube load resistor R_1 , thus producing a signal voltage across R_1 , which is applied to the grid of the tube T_2 , causing the grid voltage to swing about an average bias voltage determined by the relative values of E_1 , E_s , R_2 and R_3 . When large voltages are developed across R_1 due to grid current or D. C. components of the signal, the grid of T_2 tends to lose its negative bias and cause conditions of low dynamic impedance of the grid and non-linear plate characteristics. However, since the plate current under these circumstances tends to increase, causing the voltage on the anode of T_2 to decrease, the potential drop in R_2 and R_3 also tend to decrease, resulting in a decrease in potential at the point 3. Thus the average voltage on the grid of T_2 is kept at a desired value. In this original circuit of Figure 1, I used the capacitor C_1 to bypass the alternating potential fed back to the point 3, so as not to reduce the gain of the tube T_2 . However, the high frequency response was poor due to the fact that the grid-to-cathode capacitive reactance of the preamplifier tube at the higher frequencies was relatively low compared with the high value of phototube load resistor R_1 . Consequently, in order to avoid having to compensate in later stages of amplification for the poor high frequency response, I omitted the bypass capacitor C_1 , thus allowing A. C. to be fed back also. As a result, not only was the frequency response improved, as would be expected, but also the distortion arising from excessive A. C. voltage (due to strong signals) on the phototube and on the grid of T_2 was eliminated.

Referring now to Figure 2 for a discussion of the rela-

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tionship between the size of the phototube load resistor and the signal-to-noise ratio, the circuit of Figure 2 is similar to that of Figure 1, except that (1) the capacitor C_1 is omitted, (2) the cathode is operated at a positive voltage E_2 above ground, and (3) the resistor R_3 is connected to ground as shown. The dashed line showing of Figure 2 has been added for explanatory purposes.

The thermal noise due to the resistance R_1 may be represented by a voltage source e_n in series with R_1 , where

$$e_n = \sqrt{4R_1KT\Delta F} \text{ volts}$$

In which:

K is Boltzmann constant (1.380×10^{-23} joules/degree Kelvin)

T is absolute temperature in degrees Kelvin

F is band width in cycles per second of the frequencies under consideration.

The thermal noise may also be represented by a current source i_n in parallel with R_1 , where

$$i_n = \sqrt{\frac{4KT\Delta F}{R_1}}$$

The phototube, even if it is of the gas filled type, may at low light levels be considered to have infinite impedance and act as a pure current source, i_s (signal current).

The matter of signal-to-noise ratio can best be appreciated by considering the condition with no feedback, which is obtained by connecting the point 3 of Figure 2 to a fixed potential. In this case, signal and noise current sources, i_s and i_n , respectively, are, for all practical purposes, in parallel and would produce a voltage at the grid of tube T_2 equal to $(i_s + i_n) R_1$, if the stray capacity C could be neglected. The signal-to-noise ratio being i_s/i_n , it can be seen from the above expression for i_n that the ratio can be increased by increasing the value of R_1 . For example, a fourfold increase in R_1 will halve i_n and double the signal-to-noise ratio (assuming that thermal agitation in R_1 is the only source of noise). However, for high values of R_1 , say of the order of 20-25 megohms, the stray capacity C will attenuate high frequency components of a signal voltage quite severely, but since the high frequency components of the noise will be similarly attenuated, it would be possible to put a compensating network in a succeeding stage of amplification to boost the high frequencies to obtain the results which would have been obtained had the stray capacity C been absent. On the other hand, I have found that with the feedback circuit comprising R_2 and R_3 and the connections thereto, as set forth in Figure 2, it is possible to realize the high signal-to-noise ratios obtainable with high values of R_1 , without a compensation network in the succeeding stage. (The current sources i_s and i_n are not exactly in parallel, but if R_2 and R_3 are small compared with R_1 , they have approximately the same effect on the voltage output of the amplifier, and the signal-to-noise ratio is approximately the same as without feedback.)

Assuming the following for certain elements of Figure 2:

R_1 -----	megohms--	22
R_2 -----	do-----	1
R_3 -----	do-----	1.5
T_2 is type 6AU6		

any voltage applied to the grid of tube T_2 is amplified approximately 100 times by the tube and 60% of the voltage is fed back to the point 3 by the resistors R_2 and R_3 , which act together as a voltage divider. At low signal frequencies, where stray capacities can be neglected, there is thus a feedback of about 60 which reduces the effective impedance at the grid of tube T_2 by 60:1 to 22/60 or approximately .4 megohm. Consequently, the input capacity of the tube T_2 , the capacity of one phototube (or even two phototubes in parallel), and the ca-

capacity of the interconnecting leads do not seriously affect the response to higher audio frequencies, and even with a total grid-to-ground capacitance of 40 micromicrofarads, the frequency response is theoretically still good up to 10,000 cycles per second. In order to approach the theoretical response, it is important in the layout of components to avoid capacitance across the resistor R₁ and capacitance from grid to plate of tube T₂.

By virtue of the fact that the effective D. C. impedance at the grid is relatively low (.4 megohm in the above example), instability of the grid voltage due to excessive grid current is avoided. Also, overloading of the tube by large D. C. signals from the phototube is prevented.

The low effective input impedance to the tube T₂ also prevents distortion arising from excessive A. C. voltage on the phototube T₁ when T₁ is of the gas filled type. The critical relation between the sensitivity of a gas phototube and its anode voltage requires that the signals should be kept well below 1 volt to avoid serious intermodulation distortion. In the above case where R₁ is 22 megohms, low frequency notes in a photoelectric musical instrument could, without my feedback circuit, produce signals of 2 volts peak-to-peak on the phototube. Such a signal may cause a 10% peak-to-peak amplitude modulation of the higher frequencies. With my feedback circuit, this type of distortion is negligible. Also, as will be understood by one skilled in the art, distortion due to the use of a pentode amplifier tube will be eliminated.

Thus it can be seen that the basic preamplifier circuit of Figure 2 solves the problems arising out of the use of a relatively high phototube load resistor used to obtain high signal-to-noise ratios.

Reference is now made to Figure 3 wherein is illustrated the basic circuit for meeting those objects of my invention pertaining to compensating for variations in line voltage. A light source 7 is connected to an unregulated source of voltage subject to the usual variations in a supply line. Light from the source 7 is modulated by any suitable means 11 and is directed upon a photocell T₁. Connected in series with a resistor R and T₁ are a source 13 of regulated D. C. voltage and a source 15 of unregulated D. C. voltage, the respective polarities being as shown (Figure 3). The circuit may have a connection to a common return path as desired either at 17 or at 19 (as indicated in dashed lines). As will be described below the circuit shown in Figure 4 includes a specific example of a condition wherein the point 17 (Figure 3) is grounded. Referring again to Figure 3 the regulated D. C. voltage is chosen to exceed the unregulated D. C. voltage by an amount such that a desired voltage is applied to T₁ under normal circumstances. Thus if the supply voltage varies from normal, the voltage across the phototube changes to compensate for the change in intensity of the source 7. For example, if the supply voltage decreases, the voltage across the phototube T₁ will increase. (A specific example is given below in the discussion of Figure 4.) It will be understood that the source 15 of unregulated D. C. voltage and the unregulated supply voltage for the light source 7 will vary proportionately because in a practical system they will be derived from the same supply line. In Figures 3 and 4 the light source 7 may, of course, be considered the light source of a photoelectric musical instrument; and the modulator 11 may be considered the means employed to break up beams of light proceeding from the source to the phototube to provide frequencies and voices in accordance with the requirements of the music. Thus, in the exemplary photoelectric instrument referred to above, the modulator 11 will comprise the pitch disc and the voice disc together with appropriate shutter mechanisms.

Reference is now made to Figure 4 for showing how my invention meets the remaining objects set forth above. Figure 4, the preferred embodiment of my invention, contains the same basic circuits as in Figures 2 and 3, and

the corresponding elements are similarly numbered. In addition, a heater circuit for the cathode of tube T₂ comprises a transformer 5 connected to a source of alternating current and a hum-balancing voltage divider R₅ connected as shown. The anode voltage supply for the phototube T₁, preferably of the gas filled type (because of higher output through a given load resistor), comprises a voltage regulator tube T₄, limiting resistors R₉ and R₁₀, filter resistors R₆ and R₈, filter capacitors C₃ and C₄ connected as illustrated, E₆ and E₇ being D. C. and A. C. voltages, respectively, derived in the usual manner from a power supply, not shown. The light source 7 is connected through a transformer 9 to the same alternating current source as transformer 5. Indicated as a block 11 is a light modulator, which, in the case of a photoelectric musical instrument, may be the combination of a pitch disc, voice disc and an optical system. One such system is disclosed in the aforementioned Patent No. 2,506,599. The modulated light then falls on the phototube T₁. If another light modulation system (not shown) is to operate into the same preamplifier tube T₂ of Figure 4, its phototube T₃ may be connected as indicated in dashed lines with a filter resistor R₇, filter capacitor C₅ and other parts of the circuit as shown.

An exemplary set of values and components for the circuit of Figure 4 is as follows (including in the circuit tube T₃ and associated parts):

R ₁ -----	megohms	22
R ₂ -----	do	1
R ₃ -----	do	1.5
R ₄ -----	kilohms	225
R ₅ -----	ohms	20
R ₆ , R ₇ -----	megohms	2.2
R ₈ -----	kilohms	470
R ₉ -----	do	5
R ₁₀ -----	do	50
C ₂ -----	microfarads	.01
C ₃ , C ₄ , C ₅ -----	do	.1
E ₂ -----	volts (D. C.)	81
E ₄ -----	do	158
E ₅ -----	do	240
E ₆ -----	do	295
E ₇ -----	volts (A. C.)	450

T₂ is type 6AU6

T₁, T₃ are type 918

T₄ is type VR150

The operation of the circuit of Figure 4 is, of course, the same as that of Figure 2 so far as the feedback circuit is concerned. The divider R₅ in the heater circuit is to balance out any hum in the system due to capacitance between the heater leads and the grid of tube T₂. As mentioned above, the circuit of Figure 4 includes a special case of the circuit of Figure 3, the regulated supply indicated by the block 13 of Figure 3 being, in Figure 4, the elements to the left of the phototubes T₁ and T₃. The unregulated supply voltage, E₂, is applied between the ground point and the cathode of tube T₂. By virtue of the fact that the grid of T₂ adjusts itself to a voltage of about -2 volts with respect to the cathode of T₂ (in the example given) the potential of the point 3 in Figure 4 with respect to ground will vary as the cathode voltage E₂ varies. Assuming that the grid-to-cathode voltage of tube T₂ is -2 volts, the cathode of phototube T₁ runs at approximately (81-2)=79 volts. This means that at a normal supply voltage of, say, 115 volts (A. C.), the voltage across phototube T₁ is (150-79)=71 volts. (The tube T₄ being a VR-150, the voltage on the anode of T₁ is maintained at 150 volts.) At a low supply voltage of, say, 90 volts, the voltage across the phototube T₁ is (150-79×⁹⁰/₁₁₅)=88 volts as compared with 71 volts, thus increasing the sensitivity of the phototube by a factor

of about 2. This compensates for the comparable decrease of approximately 50% in light intensity of the source 7.

To prevent the voltage across the phototube T₁ from rising above 90 volts (the recommended maximum for a Type 918) at low supply voltages, the alternating component of the current fed to the voltage regulator tube T₄ by E₇ acts to oppose, during the negative half of each A. C. cycle, the direct component of current fed to T₄ by E₆, resulting in an intermittent cyclic reduction in the voltage across the tube T₄. The effect is a lower average D. C. voltage E₃ at the anode of the phototube. Thus is prevented the danger of exceeding the maximum recommended voltage across the phototube T₂.

So far as I am aware, it is a novel concept to apply to a phototube receiving modulated light the difference between a regulated D. C. voltage and an unregulated D. C. voltage for compensating for intensity variations in the light source caused by line voltage variations. Also, I think it is novel to feed both A. C. and D. C. currents to a regulator tube supplying regulated voltage to a phototube coupled to an amplifier tube having an unregulated bias in a manner such that the voltage across tube phototube is limited to a desired value.

In seeking high signal-to-noise ratios in preamplifier circuits such as I have set forth above, there are limits to the value of resistance which can be used successfully for the photocell load resistor, because other sources of noise, such as "shot" effect due to phototube "dark" current, still remain, in spite of the feedback circuit. Further, it may be necessary to employ metalized types of resistors for R₂, R₃ and R₄ because of electrical noise developed in other types. If these resistors are noisy, the noise can be reduced considerably by bypassing R₂ with a capacitor of appropriate size. This also increases the feedback ratio and improves the frequency response, but the gain of the tube T₂ is reduced to approximately one instead of the 5/3 which is obtained without the bypass for R₂ in the exemplary circuit of Figure 4.

The exemplary sets of values given for the circuit of Figure 4 indicate that the voltage divider resistors R₂ and R₃ are of relatively low value compared to that of the signal input resistor R₁. In the event that relatively high resistance metalized or other types (i. e. types in which additional noise due to the passage of direct current there-through is slight) of "low-noise" resistors become available for general use, it will be within the scope of my invention to employ voltage divider resistors of values of the order of 20 megohms as in the example of R₁ in Figure 4. Should such be the case, R₃ could then serve as the input resistor and R₁ could be zero, the signal being applied directly to the point 3.

In the embodiments disclosed herein, I have shown a light source of nominal intensity determined by the voltage supplied thereto, a separate means being employed to modulate the intensity of the light before it reached a phototube. It will be within the scope of my invention to modulate the intensity of the light at the source, causing the intensity to vary about the aforementioned nominal intensity. Such modulation can be accomplished by any suitable means, such as that described in my copending application Serial No. 135,912, filed December 30, 1949, wherein the intensity of a crater lamp is modulated by an audiofrequency amplifier.

Other modifications may be made in my invention without departing from the spirit of it. Having thus outlined my invention in certain exemplary embodiments, what I claim as new and desire to secure by Letters Patent is:

1. In a phototube modulation system, a light source the intensity of which varies directly with applied voltage coupled to a source of unregulated voltage subject to supply line variations, a phototube having an anode and a cathode, said anode being coupled to a source of regulated D. C. voltage, said cathode being coupled to a source of unregulated D. C. voltage subject to said supply line variations, said unregulated D. C. voltage being of lesser

value than said regulated D. C. voltage, whereby the net voltage between said anode and said cathode varies inversely as the intensity of said light source.

2. The combination claimed in claim 1, wherein said source of regulated D. C. voltage comprises a voltage regulator tube fed through respective limiting resistors by unregulated A. C. and D. C. voltages subject to said supply line variations and including an electric filter between said regulator tube and said phototube anode, whereby at relatively low values of all said unregulated voltages, said regulator tube conducts for only a portion of each cycle of said A. C. voltage thereby reducing said regulated D. C. voltage.

3. In a phototube modulation system, a light source the intensity of which varies directly with applied voltage coupled to a source of unregulated voltage subject to supply line variations, a phototube receiving modulated light from said source, sources of regulated and unregulated D. C. voltages respectively connected in opposition and in series with said phototube, said regulated D. C. voltage being greater than said unregulated D. C. voltage and said unregulated D. C. voltage being subject to said supply line variations, whereby the difference in voltage between said D. C. voltages is applied to said phototube and varies inversely as the intensity of said light source.

4. In a photoelectric system wherein a phototube having an anode and having a cathode illuminated by modulated light, the intensity of which is subject to variations corresponding to variations in an unregulated voltage supplying the source of the light, the combination comprising a preamplifier tube having an anode, a cathode and a signal input grid, a signal input resistor having one end coupled to said phototube cathode and to said signal input grid, a source of unregulated D. C. voltage subject to said supply line variations and biasing said phototube cathode positive with respect to the other end of said resistor, and a source of regulated D. C. voltage coupled to said phototube anode, whereby the net voltage between said phototube anode and cathode varies inversely as said voltage supplying said light source.

5. The combination claimed in claim 4, wherein said source of regulated D. C. voltage comprises a voltage regulator tube fed through respective limiting resistors by unregulated A. C. and D. C. voltages subject to said supply line variations and including an electric filter between said regulator tube and said phototube anode, whereby at relatively low values of all said unregulated voltages, said regulator tube conducts for only a portion of each cycle of said A. C. voltage thereby reducing said regulated D. C. voltage.

6. A preamplifier and power supply system for a phototube illuminated by modulated light from a source the intensity of which varies directly with supply line variations in an unregulated voltage supplied thereto, comprising an electron tube including an anode, a cathode and a signal input grid, a resistive voltage divider having one end coupled to said anode, a source of regulated D. C. voltage, an input resistor of substantially higher resistance than said divider, a phototube including an anode coupled to the positive terminal of said D. C. source and a cathode coupled to said input grid and to one end of said input resistor, the other end of said input resistor being coupled to the dividing point on said divider, a source of unregulated D. C. voltage subject to said supply line variations and biasing said cathode of said electron tube positive with respect to the other end of said divider and to the negative terminal of said regulated D. C. source.

7. The combination claimed in claim 6, wherein said source of regulated D. C. voltage comprises a voltage regulator tube fed through respective limiting resistors by unregulated A. C. and D. C. voltages and including an electric filter between said regulation tube and said phototube anode, whereby at relatively low values of all said unregulated voltages said regulator tube conducts

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for only a portion of each cycle of said A. C. voltage thereby reducing said regulated D. C. voltage, thus preventing the net voltage between said anode and said cathode of said phototube from becoming excessive.

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