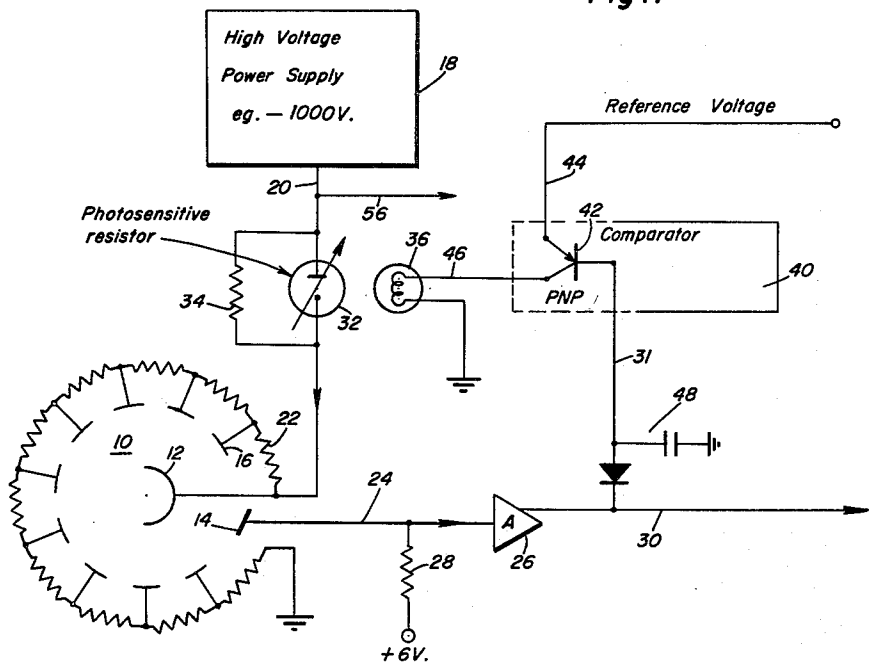
Feb. 23, 1965 A. W. HOLT 3,171,032

PHOTOMULTIPLIER WITH STABILIZED GAIN

Filed March 8, 1962

Fig. 1



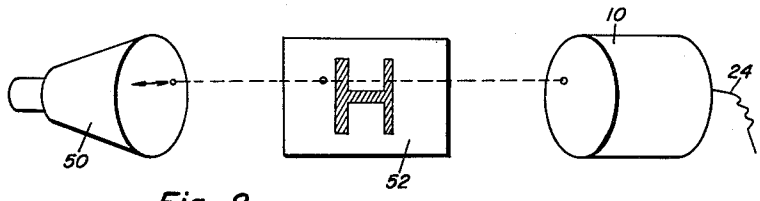


Fig. 2

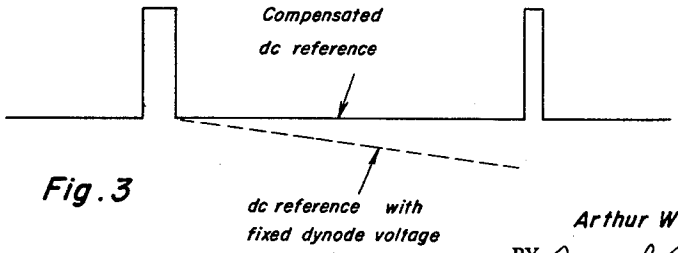


Fig. 3

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PHOTOMULTIPLIER WITH STABILIZED GAIN

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This invention relates to electron multiplier phototubes, and particularly to circuits for these tubes to stabilize the total amplification or gain notwithstanding one or more variations of the tube characteristic and operating conditions which are generally encountered in using this type of phototube.

Electron multiplier phototubes (henceforth called photomultipliere) are often used where there is a requirement for amplification which is higher than can conveniently be obtained through conventional vacuum tube or transistor amplifiers. Although several types of photomultipliers are available, each relies on secondary emission to amplify electron streams. For example, the electrostatic tube has a photosensitive cathode, a series of intermediate dynodes, and a collector or anode. The dynodes are maintained at consecutively increasing potentials to form a plurality of stages of amplification. Electrons emitted from the cathode in response to incident light are accelerated to the first dynode where they impinge on the dynode's surface and cause it to emit many other electrons. The secondary electrons are then directed by an electrostatic field along curved paths to the second dynode where they cause new additional electrons to be emitted. This multiplying procedure is repeated in each stage with an ever-increasing stream of electrons, until those emitted from the last dynode are collected by the anode and constitute the current which is henceforth called the output signal.

The potentials for the various dynodes are usually obtained from a voltage divider connected across the power supply, and it is ordinarily made of a number of series-connected fixed resistors. This uusal circuit is subject to variations arising from several causes. If the output voltage of the power supply varies, the voltage drops across the resistances of the voltage divider will vary. This will cause a resulting variation in the potentials on the electrodes of the photomultiplier. Since the gain of a photomultiplier is directly related to the voltage difference between adjacent dynodes, the output signal will change in accordance with power supply drift. Furthermore, very small changes in output voltage of the power supply, causing only a small change in the amplification of each stage of the photomultiplier, will cause in the gain of the photomultiplier to vary between wide limits. This problem could be overcome by using a precision, expensive power supply; but often, the expense is prohibitive. Furthermore, a precision power supply will overcome only this single problem and not others which are generally encountered in using photomultiplier tubes. For instance, the tube characteristic often changes with age. This may be considered as long term drift of the tube itself and is independent of all precision which can be built into the power supply.

It is unnecessary to point out the numerous applications of photomultipliers since these are well known. However, photomultipliers are light sensitive devices, and the usual application of a photomultiplier is accompanied by only moderate control over the primary or secondary

light source for the object being examined by the photomultiplier. An excellent example of this is found in reading machines, often used for character recognition, e.g. as in U.S. Patent No. 3,104,369. Character recognition machines examine documents of numerous types and provide output signals identifying the characters so that they may be fed to a computer either directly or through a buffer.

In the reading machine application of my invention, where a character on a document is examined by having the photomultiplier detect the difference in light reflectivity between the character itself and its background, there is a very wide variation of possible background reflectivity to say nothing of any drift in the light source for illuminating the character and its background. This particular drift is caused by the source of illumination itself. As to the variations in background, this is a more difficult problem to cope with. The documents on which the characters are printed can vary not only from document to document but also between areas of the same document through a very wide range. Sometimes a document (the character background) may be very white i.e., almost 100% reflective, and the background of other documents may reflect only 50 or 60% of the incident light. Furthermore, smudges, documents aging, and other noise causes the background to reflect light very erratically. Yet, the output signal of the photomultiplier must be stable under these adverse conditions which have nothing to do with tube characteristics nor drift of the power supply.

Therefore, an object of this invention is to provide a circuit for a photomultiplier which permits the output signal of the circuit to be stabilized at a predetermined level (called D.C. reference herein) nothwithstanding the existence of one or more of the above-described variables i.e., long term drift due to changes of tube characteristic, power supply variations, changes in reflectivity of the article being examined by the tube, and changes in light source.

Another object of the invention is to achieve the above by an exceedingly simple circuit arrangement which is far more economical and versatile than previous proposals to stabilize photomultipliers.

There are many prior patented circuits for stabilizing the gain of photomultipliers. However, most of the prior disclosures of which I am aware deal with correction of only one or two of the variables which affect the output of a photomultiplier, usually power supply drift. Typical examples are found in U.S. Patent Nos. 2,854,583; 2,982,860; 2,994,782; and 2,605,430.

Of the above group, only Patent No. 2,982,860 emphasizes one of the practical considerations confronting a circuit designer. The circuit disclosed in this patent provides a compensating system to control the voltage supply of the photomultiplier by means of a feed-back loop which does not respond to the normal detection of signal pulses having a given duration resulting from defects or flaws in the article being examined by the photomultiplier tube. In contrast to variations of that type, the variations in tube sensitivity are said to have a comparatively long duration and therefore, the variations which are to be compensated are susceptible of selection by a filter network having a long time constant which will pass the compensating signal but reject the normal operating pulse having the relatively shorter time. This will not overcome the problem of a shift in the D.C. reference of the output signal, in those cases where the

background reflectivity of successive articles (or different areas of same article) being examined varies.

In the example which I have discussed, pertaining to reading machines, it is pointed out that I have used a light background and dark character to present the problem. The problem is exactly the same if the background is dark and the character is light, for instance, when examining the negative of a character image instead of its positive.

Another object of the invention is to provide a photomultiplier compensation circuit which is particularly, although not exclusively, useful to solve ordinarily encountered problems in the examination of patterns, characters, and the like which are generally hand or machine printed. Although it is about equally common in the reading machine art at this time to use a single photomultiplier tube for the examination of a character or to use a plurality of these tubes for the same purpose, I have shown only one photomultiplier tube and circuit since the others would be identical.

In achieving the above objectives I use a conventional high voltage power supply which feeds the voltage divider and cathode. The anode is connected with a line which conducts the output signals from the photomultiplier. A photosensitive resistor, for instance, a cadmium sulfide cell is connected in series between the voltage divider and the high voltage power supply. By changing the amount of light falling onto the photosensitive resistor, the voltage input to the photomultiplier is correspondingly varied. Thus, in my system I examine the output signal for the desired D.C. level and provide a new output which energizes a light source for the photosensitive resistor whereby the shifts in D.C. reference, exclusive of the information modulation on the output signal line, are transduced to corresponding light-level changes. These, in turn, regulate the voltage which is impressed on the cathode and voltage divider of the photomultiplier. Thus, the D.C. level of the photomultiplier output signal is continually monitored and held at the desired level. In the reading machine example, the dark characters on a white paper document will have the same effect on the D.C. level, due to the integration of the "dark" with the "white" by using a simple filter. Since the characters on a document cover only a small fraction of the area of a document the effect is small. But even this effect can be very greatly reduced by selecting a peak detector as the filter configuration.

An important feature of my invention is that the voltage regulation stimulus i.e., the illumination of the light source for the photoresistor (not the photomultiplier itself, for instance as in Patent No. 2,982,860) is electrically isolated from the power supply circuit and voltage divider. The previously mentioned prior patents show that it is quite common to use voltage regulators in the dynode supply line or in the voltage divider for the dynodes. However, my system has the advantage of isolation between ground and the high voltage section of the circuit. I have no electrical feed back coupling to any part of the high voltage segment of my circuit. Instead, the only coupling between the output signal of the photomultiplier and the high voltage section is by means of a light path between a light source and a photoresistor.

I use the term "photomultiplier" to describe the electron multiplier phototube. Although the term "photomultiplier" may have a resricted meaning in some fields, I use this term as a matter of convenience, rather than a more general expression such as "an electron multiplier phototube which relies on secondary emission for its gain." Thus, the term "photomultiplier" as used herein is defined as a general term consistent with the above.

Other objects and features of importance will become apparent in following the descriptions of the illustrated form of the invention.

FIGURE 1 is a diagrammatic view showing a photomultiplier and my circuit for stabilizing its amplification.

FIGURE 2 is a diagrammatic view showing only one of the many possible applications of a photomultiplier used with my circuit.

FIGURE 3 is a curve showing a typical compensated D.C. reference as obtained by using my invention and also showing one of the possible erratic D.C. references which may be encountered with ordinary fixed dynode voltage circuits for photomultipliers.

In the accompanying drawings FIGURE 1 shows a photomultiplier **10** having a photosensitive cathode **12**, an anode **14**, and a plurality of dynodes **16**. A conventional high voltage power supply **18** has an output line **20** which is connected to cathode **12** and to one end of voltage divider **22**. The other end of voltage divider **22** is connected to ground. The voltage divider is conventional and connected in the usual way at successive stations with successive dynode terminals. The output signal line **24** is connected to the anode **14** of the photomultiplier and to a conventional amplifier **26**. A voltage source, for instance +6 volts, is connected through resistor **28** to the signal line **24**, and the output signal line **30** from the amplifier is adapted to be connected with a utilization device (not shown). The above circuit arrangement is considered to be conventional.

I have interposed a photosensitive resistor **32** in the high voltage line **20**. The resistor can be selected from numerous commercially available photosensitive resistors, for instance a cadmium sulfide photocell. A load limiting resistor **34** is connected across the cell **32**. Thus, by interposing the photosensitive resistor **32** in line **20**, it becomes serially connected between the high voltage power supply **18**, voltage divider **22**, and cathode **12**. Regulation of tube **10** is obtained by varying the amount of light falling on the sensitive surface of resistor **32**, which, in turn, varies the voltage which is impressed on the voltage divider **22**. As pointed out previously, the light falling on photoresistor **32** is a function of the luminosity of a light source **36** which is completely isolated from the high voltage section of my circuit. In practical use, the source **36** which is preferably a filament lamp, can be mounted in a holder adjacent to the photosensitive resistor **32**.

I obtain operating voltage for lamp **36** by examining the amplified output signal on line **30**, although the signal on line **24** (prior to amplification at **26**) could be used with a corresponding requirement of complexity of the signal examination device (due to the low signal level prior to amplification at **26**). Examination of the signal conducted on line **30** is made by a simple comparator **40** consisting of a PNP transistor **42** whose emitter is connected with a reference voltage by line **44** and whose base is connected by line **31** with the photomultiplier output signal line **30**. The collector of the transistor **42** is connected by line **46** with the filament of light source **36**, and the light source is connected to ground. Assuming a six-volt system, when the signals on lines **31** and **44** are each six volts (neglecting the voltage drop across the transistor **42**) transistor **42** is cut off and the source of illumination **36** will be extinguished. But, as the voltage on line **31** becomes lower, transistor **42** will conduct a signal proportional to the voltage differences between lines **31** and **44** thereby correspondingly illuminating light source **36**.

Since my invention is concerned with compensating the D.C. reference of the output signal on line **30** for the reasons discussed previously, the voltage on line **31** should be made to represent the D.C. reference and not the information modulations (see FIGURE 3). Accordingly, I have a filter **48** (e.g., a peak detector capacitor-diode) for the signal conducted on line **31**, and the time constant of the filter is sufficient to filter the information modulations but allow the comparatively steady state signals to pass i.e., a signal representing the D.C. refer-

ence of FIGURE 3. The curve shown in FIGURE 3 is a typical wave-form of a signal that would appear on line 30 when the character H (FIGURE 2) is scanned by a spot of light from a source, for example the cathode ray tube scanner 50, and the incident light is reflected from surface 52 onto the face of tube 10. The dotted line (FIGURE 3) shows how the D.C. reference of the output signal on line 30 might shift (when using conventional photomultiplier circuits) for various reasons such as changes in the power supply, light reflectivity changes of the background of the character formed by surface 52, and for many other reasons or combinations thereof. Instead of the shifts in the D.C. reference ("down" as shown in FIGURE 3 in dotted lines), my circuit filters the information content modulations (pulses in FIGURE 3) and detects incipient changes in the D.C. reference by comparator 40. This results in a change in illumination of source 36 and the resulting change in the resistance value of the photosensitive resistor 32. This in turn, will cause a corresponding change in the voltage divider input voltage. The above example is principally based on a change in the light level of the background 52. Precisely the same advantageous results are obtained if the high voltage power supply 18 should drift, the tube characteristic change, the ambient illumination for the background area 52 be varied, or the primary illumination for the article being examined (character H and its background 52) in those rather common applications where an optical system projects an image of the article being examined, and that image is examined in other ways using a photomultiplier, e.g., as in the J. Rabinow Patent No. 2,933,246, and many others.

It is understood that the illustrated embodiment of the invention is given by way of example only and that certain variations may be made without departing from the protection of the following claims. In addition, since my system is so simple including a filter, a comparator which can be made of a single transistor, a light bulb and a photoresistor (primarily) my system is economically well suited to be used in those cases where it would otherwise be uneconomical to use plural photomultipliers. Thus, line 56 attached to the high voltage power supply line 20 diagrammatically represents a connection to one or more additional photomultipliers which would be serviced by power supply 18 and equipped with compensation circuits just as shown in FIGURE 1.

I claim:

1. In a circuit for stabilizing the operation of a photomultiplier tube to compensate for variations in background area reflectivity when the tube is used to optically examine an object on the background, and wherein the tube has a cathode, an anode and a plurality of dynodes, a voltage divider, a high voltage power supply connected to said cathode and to the voltage divider, and means connecting successive dynodes to successive stations of said voltage divider; photosensitive resistive means in series with and arranged between said power supply and voltage divider to change the voltage input to said voltage divider and hence to said dynodes without adjusting said power supply, an output signal conductive means connected to said anode, means including a peak detector and a comparator connected with said output conductive means to examine the photomultiplier output signal and provide a new signal corresponding to the drift of the D.C. level of said output signal from a predetermined level, and means responsive to said new signal for changing the value of said photosensitive resistive means thereby correspondingly changing the voltage inputs to said dynodes.

2. The circuit of claim 1 wherein said means responsive to said new signal are electrically isolated from said resistive means.

3. The circuit of claim 2 wherein said means responsive to said new signal include a light source, and said resistive means include a photoresistor.

4. In a photomultiplier circuit where the photomultiplier has an anode, a cathode, a plurality of dynodes, and the circuit includes a power supply, a conductor connected between the power supply and the photomultiplier cathode and voltage divider, the improvement comprising a stabilizing circuit to stabilize the D.C. reference of the output signal conducted from the anode of the photomultiplier, said stabilizing circuit including a line conducting a reference signal, comparison means to examine the output signal of the photomultiplier and provide a new signal as a result of a comparison with said reference signal, to provide said new signal which corresponds to changes in D.C. level of said output signal, and means electrically separate from but adjustable in response to said new signal for varying the high voltage from said power supply which is impressed on said voltage divider.

5. In a photomultiplier circuit where the photomultiplier has an anode, a cathode, a plurality of dynodes, and the circuit includes a fixed power supply, a conductor connected between the power supply and the photomultiplier cathode and voltage divider, the improvement comprising a gain stabilizing circuit to stabilize the D.C. reference of the electrical output electrical signal conducted from the anode of the photomultiplier when the photomultiplier is exposed to rapidly changing light intensities, said gain stabilizing circuit including means to examine the output signal and provide a new signal which corresponds to changes in D.C. level of said output signal, means electrically separate from said new electrical signal for varying the value of the signal from said fixed power supply which is impressed on said voltage divider, the last-mentioned means including a photosensitive resistor responsive to said new electrical signal and connected in series between said voltage divider and said power supply, and a light source energized by said new signal and coupled by an illumination link with said photosensitive resistor.

6. The subject matter of claim 5 wherein said means to examine said photomultiplier output signal include an electrical comparator to compare a reference voltage with said photomultiplier output signal, means to filter the information modulations of said output signal ahead of said comparator, and said filter having a time constant sufficient to pass the D.C. reference of said photomultiplier output signal.

7. In a photomultiplier circuit including a photomultiplier to provide an output signal as a result of the examination of a surface having an object on a contrasting background area so that the photomultiplier is exposed to rapid changes in light intensities, means to stabilize said circuit to prevent shifts in the D.C. level of said output signal caused at least by variations of reflectivity of said background area, said means including means to examine said output signal of the photomultiplier and provide a new signal in response to initial early changes in said D.C. level of said photomultiplier output signal, said photomultiplier circuit including power input means, and photosensitive means electrically isolated and separate from said new signal but responding to said new signal for varying said power input means to maintain the D.C. level of said output signal stable.

8. The photomultiplier circuit of claim 7 wherein said photosensitive means include a photo resistor operatively connected with said power input means, and a light source for said photoresistor energized by said new signal.

9. In a photomultiplier circuit having a photomultiplier provided with an anode, a plurality of dynodes and a cathode, a high voltage power supply remaining substantially fixed while said circuit is operative, conductive means connecting said power supply to said dynodes and to said cathode, and a photomultiplier output signal conductor connected to said anode, the improvement to stabilize the photomultiplier including a reference voltage signal providing means, an electrical comparator, said reference voltage signal forming one input to said comparator, means

including an electrical filter for providing the filtered photomultiplier output signal to said comparator as another input thereof so that said comparator provides a new signal as a result of the comparison of the filtered photomultiplier output signal and said reference signal, whereby said new signal corresponds to a shift in the D.C. level of the electrical output of the photomultiplier, a source of illumination isolated from the photomultiplier and responsive to said new signal, photoresistive means interposed in said conductive means between said photomultiplier dynodes and said power supply, and said photoresistive means responding to the light of said isolated source of illumination to alter the signal of the power supply reaching said photomultiplier from said power supply.

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