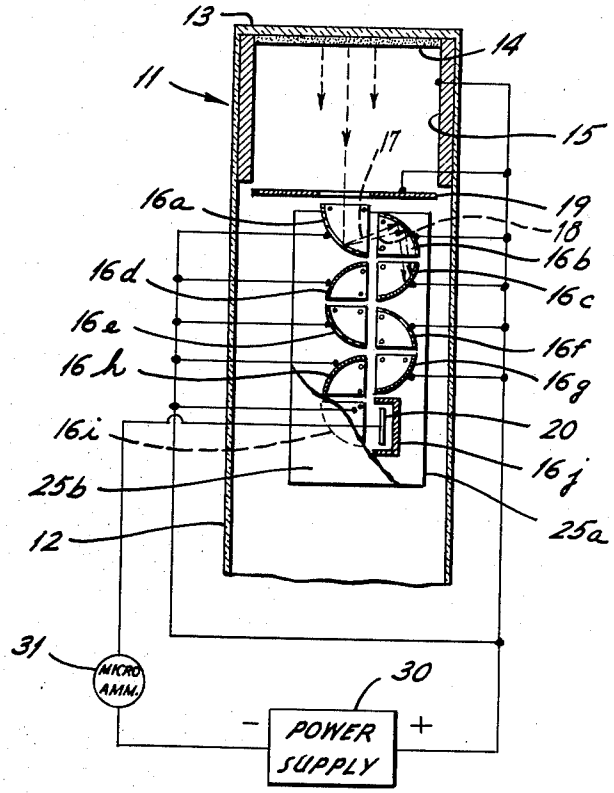
Sept. 13, 1960 G. L. CARSON 2,952,499

PROCESSING SYSTEM

Filed Nov. 18, 1957

FIG. 1.



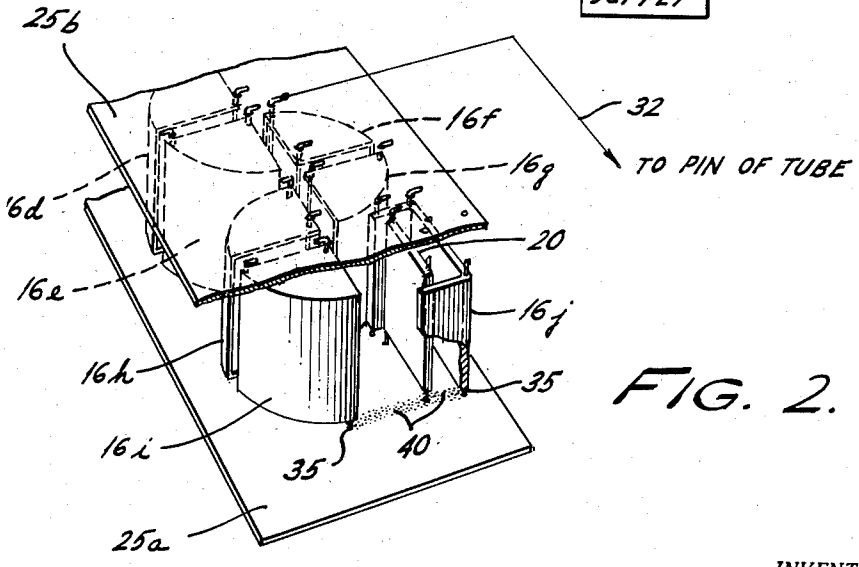


FIG. 2.

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PROCESSING SYSTEM

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11 Claims. (Cl. 316—1)

This invention relates to improvements in photosensitive devices and especially to a method for improving the performance of photomultiplier tubes.

Photomultiplier tubes have become widely used in various diverse applications and apparatus, such as devices for the detection of nuclear radiation, flying spot scanners for deriving signals from still or motion picture transparencies for television transmission, colorimetry, and certain types of color television reproducing systems employing the so-called "photo-indexing" principle. Typical of the latter is the system disclosed in the W. E. Bradley, et al., Patent No. 2,749,449 issued June 5, 1956. In these and other applications photomultiplier tubes are very useful because they are extremely sensitive, because they cost less than many other competitive types of radiation-sensitive devices, and because they have a relatively long useful life.

In essence, a photomultiplier tube is a device having a radiation-sensitive photocathode constructed of a material which emits free electrons in response to a particular form of incident radiation, such as visible, infrared or ultraviolet light. These emitted electrons are attracted from the photocathode by an electrode known as a "dynode" to which a potential is applied which is more positive than that applied to the cathode. The "dynode" has a secondary emission ratio greater than 1, so that for every primary electron incident thereupon several secondary electrons are liberated therefrom. These secondary electrons are attracted, in turn, to a series of even more positive dynodes which respectively release progressively greater numbers of secondary electrons in response thereto. The secondary electrons emitted from the last dynode are collected by an anode and the resulting total current is passed to external circuitry for utilization. Although the structure of commercially available photomultiplier tubes may take several forms, it usually comprises one or more insulating supporting members on, or between which, the dynodes and other electrodes are mounted by means of supporting rods, lugs, or similar structures.

The performance of photomultiplier tubes is somewhat impaired by certain types of "noise" which is defined herein as comprising unwanted variable amplitude signals. This "noise" may be divided into two main types, i.e., so-called "noise-in-signal" and "dark current noise." "Noise-in-signal," which arises out of the inherent statistical nature of the photoelectric emission phenomenon, occurs only when radiation is incident on the photocathode and is similar to "shot" noise in thermionic vacuum tubes.

"Dark current noise," on the other hand, refers to noise which occurs in the absence of any incident radiation because of the generation of electrical currents within the tube which reach the anode. It is essentially random in nature and arises from a variety of causes, i.e., thermionic emission by the photocathode and dynodes at room temperature, bombardment of dynode surfaces by particles of residual gases which have been ionized by

electrons flowing through the tube, scintillations caused by electron bombardment of the secondarily emissive material of the dynodes, charging of the glass envelope of the device by an associated metallic shield, and ohmic leakage currents which reach the anode via a path across the insulators on which the various electrodes of the tube are mounted. I have discovered that by far the largest constituent of dark current noise in most types of commercially available photomultiplier tubes is ohmic leakage current which, at room temperature, may constitute from about 50%–95% of the total dark current.

Dark current is a factor which limits the operation of the tube in many of its applications, especially in cases where the incident radiation is of low intensity and the ratio of dark current to the total noise accordingly is high. For example, in scintillation counters the level of incident radiation which causes scintillations is extremely low and the total light emitted from the scintillating material is therefore extremely small, so that dark current is the chief source of the total tube noise. Unless the photomultiplier tube of the scintillation counter has good sensitivity it will be difficult for the user to distinguish between the information-significant component of the indication which is due to the incident radiation and the component of the indication which is due to dark current.

In other applications, also, the reduction of the dark current component of the total noise is also highly desirable. For example, in single beam color television reproducing tubes of the previously mentioned photo-index type, when the scanning beam has low intensity and scans the elements which serve to index the position of the beam, the amplitude of the radiation produced is very small, and under certain conditions of receiver adjustment could be overriden by the dark current component of the total noise of the photomultiplier tube. The resulting loss of indexing signals would then cause the indexing system to misfunction with a consequent degradation of the color fidelity of the reproduced image.

Previous methods of reducing the leakage factor in dark current noise involved attempts to improve the nonconductivity of the insulating material of the electrode-supporting members, or spacing the high voltage electrodes as far away from the low voltage electrodes as possible so that there would be a longer and consequently higher resistance path between them. These attacks on the problem have been only partly successful since, even if the insulating material is of very high quality, a film of cesium may nevertheless become deposited upon the insulator by vaporization of the photocathode material thereupon during manufacture or thereafter. This film, though microscopically thin, acts to provide a resistive path connecting high and low voltage electrodes which is far more conductive than the material of the supporting member itself. Moreover, these thin films of cesium are unstable and cause fluctuations in the leakage currents.

It is therefore an object of the present invention to provide a method for improving the performance of photomultiplier tubes.

Another object of the invention is to provide a method of reducing noise in the operation of photomultiplier tubes.

Still another object of the invention is to improve the useful sensitivity of photomultiplier tubes.

Another object of the invention is to provide a method for reducing dark current in photomultiplier tubes.

These objects, as well as others which will appear are achieved according to my invention by applying, in the absence of radiation to which the photocathode is sensitive, an abnormally high voltage between the anode of the photomultiplier device and selected other electrodes thereof for a predetermined period, usually of the order of

several minutes. At the end of this period this voltage is removed from the device which is then preferably not put into operation for at least a period which may extend from several minutes to several days.

In one form of the invention the voltage is applied between the anode, on the one hand, and all the other electrodes on the other, beginning with a low value of voltage and gradually increasing to a maximum value which is somewhat lower than the value of voltage at which the device will arc-over. In this form, if a D.-C. voltage is used, the anode is connected to the negative terminal of the source, and the other electrodes are connected to the positive terminal thereof since, for a given processing time, the maximum voltage required is lower than if the anode and the other electrodes were connected oppositely.

Figure 1 is a schematic and sectional longitudinal view of a typical photomultiplier tube; and

Figure 2 is a cut-away perspective view of the anode region of such a tube.

Referring to Figures 1 and 2 a photomultiplier tube **11** of the so-called "box" type is shown. There are several other types of photomultiplier tubes and the invention will prove efficacious with all of them, the box type being chosen merely for illustration. The structure and conventional operation of the tube will first be explained before considering its operation in the actual circuit of the processing system depicted. The tube **11** comprises an evacuated envelope **12** having a generally cylindrical form, one of whose ends **13** is transparent and coated on the interior surface with a photo-emissive material to form a photocathode **14**. The photocathode **14** may be composed of a cesium-antimony material which possesses high efficiency and a long useful life. Radiant energy of the type which causes the cesium-antimony cathode to respond, such as visible light, passes through the transparent end **13** and falls upon the photocathode **14**. An aluminum coating **15** may be deposited on the inner surface of the envelope **12** near the photocathode **14**. This coating helps to prevent light from undesired sources from exciting the layer **14**, helps to focus electrons, and also serves as a connection between a lead from a pin on the base of the tube (not shown) and the photocathode so that the latter may be connected to a source of potential. The photocathode **14**, in response to the incident light, emits electrons which are attracted toward a first oversized dynode **16***a* to which a positive potential is applied in actual operation. The first dynode **16***a* and the subsequent dynodes **16***b*—**16***i*, are shaped somewhat like longitudinal quarter-sections of a drum as shown in perspective in Fig. 2 and are mounted on supports **35** between two planar insulating supporting members **25***a* and **25***b*. Leads such as the lead **32** shown in Fig. 2, are connected between each dynode and a corresponding pin (not shown) on the base of the tube. The first dynode **16***a* may be made somewhat larger than the others in order to enhance the collection of photoelectrons emitted in various directions from the photocathode **14**. A shield **19** may be placed intermediate dynode **16***a* and the photocathode **14** and may be connected, in actual operation, to a positive potential in order to obtain optimum collection and focus of the photoelectrons. This shield has the further function of preventing positive ions produced by the electrons passing between the various dynodes, from bombarding the cathode thereby causing emission of secondary electrons which would then be added to the total dynode current.

Assuming for purposes of illustration that the secondary emission ratio is 2:1, the incidence of each photoelectron upon the emissive material of the dynode **16***a* causes the emission of two secondarily-emitted electrons whose paths are represented by the broken lines **17** and **18** respectively. After the secondary electrons are emitted from the first dynode **16***a* they are caused to impinge upon dynode **16***b* by a positive potential applied thereto which is higher than that on dynode **16***a*. On striking dynode **16***b* they each, in turn, liberate two other secondary electrons which are attracted in similar fashion by a more positive potential applied to the dynode **16***c*, from whence the electron-multiplication process continues in the same manner in the succeeding dynodes **16***d*—**16***j* until a greatly augmented current is collected by the anode **20** and supplied to a particular external utilization circuit (not shown). The last dynode **16***j* is shaped somewhat differently than the others and partially surrounds the anode **20** so as to insure that practically all of the secondary electrons from dynode **16***i* are collected.

Having explained the structure of tube **11** and its conventional operation, the processing of the tube for reduction of dark current in accordance with my invention will now be considered with special reference to Fig. 2.

Although the insulators **25***a* and **25***b* are themselves substantially non-conductive, there is deposited thereupon some of the cesium-antimony of which the photocathode **14** is composed thereby providing a high resistance path between electrodes at different potentials. The cesium-antimony deposits may develop on the planar insulators **25***a* and **25***b* as shown at numeral **40** in Fig. 2 in either of two ways, i.e., (1) by thermionic emission of the photocathode material at room temperature or, more often, (2) by the process employed in the deposition of the photocathode on the internal surface of the end of the tube **11**. Because cesium-antimony is extremely oxidizable, it is not deposited on the interior surface of the end of the tube until all the air has been evacuated therefrom. Then the cesium-antimony, which has been deposited on a tungsten wire in the vacuum, is evaporated by heating the wire by an electric current. In the evaporation process some of this photocathode material is inevitably deposited on the insulating supports **25***a* and **25***b* as shown at numeral **40**.

In the normal operation of such tubes a relatively high potential difference is applied between various elements thereof causing minute currents to flow along the surface of the insulating supports **25***a* and **25***b* to the anode proper, to the members which attach it to the insulating supports **25***a* and **25***b*, or to the lead connecting it to a pin on the tube base. These currents give rise to the "dark current noise" hereinbefore mentioned.

In accordance with one form of my invention the anode **20** is connected to the negative terminal of a power supply **30** which is preferably of the unregulated type and of high internal impedance. All the other electrodes, including the dynodes **16***a*—**16***j*, the photocathode **14**, and the shield **19**, are connected to the positive terminal of the power supply **30**. A voltage nominally on the order of 2000 v. is then applied to the tube **11** in the absence of radiation to which its photocathode responds so that secondary emission current through the tube is negligible. At first, a very large leakage current will flow along the surface of the insulators **25***a* and **25***b* to the anode **20** and through the microammeter **31**. Because of the poor regulation of the power supply **30** the applied voltage drops considerably below its nominal value and this has the advantage of limiting the initial surge of current to a safe value. Since this leakage current rapidly diminishes to a very small value, the voltage actually supplied by the power supply **30** increases until, at the end of about 4 to 6 minutes, it is at its nominal (or maximum) value of about 2000 v., a value which is considerably below the "arc-over voltage," a term which shall be considered herein to apply to that value of applied voltage at which one can first notice a rather abrupt increase in current accompanied by a visible discharge (if the tube is viewed in the dark) between adjacent electrodes at different potentials or along the surface of the planar insulators **25***a* and **25***b* in the region between adjacent electrodes. From investigation of many different types of photomultiplier tubes I have found that the "arc-over voltage" is generally in the vicinity of 4500–5500 v. depending on the particular tube structure involved.

The value of the voltage applied during the processing of the tube in accordance with my invention may be at least ten times the voltage customarily applied between the last dynode and the anode. In general, normal operating voltages are in the range 50–100 v., although maximum voltages of about 150 v. are sometimes used when maximum amplification and sensitivity are desired.

Immediately after the end of the approximately 4–6 minute high voltage processing period the dark current as measured by the microammeter during normal operation will be relatively high and possibly may exceed the dark current which characterized the tube in normal operation before processing.

However, in accordance with another feature of my invention, I have found that if the tube is permitted to rest without the application of any voltage thereto for several minutes, the dark current in normal operation will be found to have decreased to a value somewhat lower than its value before the tube was processed. Furthermore, if the tube is permitted to rest for from about 24 to 72 hours it will be found that the normal dark current will be substantially lower than it was before the tube was processed. The period of time during which the tube is rested after processing is, of course, optional and depends to a certain extent on the desired degree of reduction of the dark current.

Although in the system shown in Fig. 1 the anode is connected to the negative terminal and the other electrodes are connected to the positive terminal of the power supply **30**, it should be understood that the opposite connection will also produce satisfactory results but higher voltages may be required. In many tests, tubes with the anode connected to the positive power supply terminal and the other electrodes to the negative terminal thereof were processed for 4 to 6 minutes at voltages of 3000 to 3500 volts and produced the desired reduction in the leakage component of the dark current. With the anode negative, tubes could be processed during the same interval at voltages from 1800 to 2200 volts.

Instead of using a power supply with poor regulation it is, of course, possible to use a power supply having good regulation provided the supply first is adjusted so as initially to furnish a low voltage and then is adjusted to provide a higher voltage, as the dark current decreases, until the desired maximum voltage is attained. Alternatively, a power supply with an external series voltage-dropping resistor may be utilized.

Repeated checks on tubes before and after processing have revealed no evidence of damage due to the application of a higher than normal voltage between the anode and the other electrodes. In fact, there is often an increase in the sensitivity of the dynodes ranging from possibly a few percent to fifty percent in some cases. This increase in sensitivity is probably due to the fact that the the material which has been vaporized from the supporting elements **25***a* and **25***b* by the processing, and which settles on the dynodes is fresher than the material previously deposited. Also, in some tubes, this material may have a higher secondary emission ratio than the original dynode material.

If desired, the process may be repeated several times on the same tube with a rest period being given to the tube after each processing. It will be noted that most of the reduction in the dark current will be evident after the first processing and that smaller reductions will be obtained in successive treatments. Tubes treated according to my invention have shown improvements in total dark current ranging from 15% to 94% without any concomitant harm to the tube and, in fact, often with an increase in overall sensitivity as noted previously.

Since the last dynode-anode region is usually the shortest resistance path in tubes such as the "box" type herein illustrated, it is often the path through which most of the leakage current flows. It therefore follows that a large part of the leakage current may be diminished if the high voltage is applied only between the last dynode (or last few dynodes) and the anodes. One can, of course, reduce leakage currents flowing between selected ones of the more distant dynodes (or other electrodes) and the anode if desired.

It will be understood that still other applications of the processes according to the diverse forms of my invention described herein will occur to those skilled in the art. Consequently, I desire the scope of this invention to be limited only by the following claims.

What I claim is:

1. In the processing of photomultiplier tubes, which tubes comprise at least a photocathode electrode, a plurality of dynode electrodes, a final electron collecting electrode, and insulating support structures therefor, a method of substantially decreasing the tube's "dark current" effect, said method comprising the steps of shielding said tube from incident radiation of wavelengths to which said photocathode electrode is principally responsive, and applying an abnormally high voltage between said final electron collecting electrode and at least selected ones of said other electrodes, said voltage being applied for a time sufficient to effect a substantial decrease in the conductivity of deposits fortuitously precipitated on the surface of said insulating support structures during an earlier stage in the production of said tubes.

2. The method according to claim 1 wherein said applied voltage has a maximum value somewhat below the "arc-over voltage" of the tube.

3. The method of improving a photomultiplier tube having a final electron-collecting electrode and at least one secondarily-emissive electrode mounted on a common insulating member, comprising the steps of applying, in the absence of substantially all radiation to which the photocathode thereof principally responds, an abnormally high voltage between the final electron-collecting electrode and at least one selected other electrode thereof for a period of several minutes, and then removing all voltages from said tube for at least a predetermined interval.

4. The method according to claim 3 further characterized in that said final electron-collecting electrode is at a negative potential and said selected electrode is at a positive potential.

5. The method according to claim 3 wherein said voltage is initially applied at a first level and then is gradually raised to its maximum value.

6. The method according to claim 3 wherein said predetermined interval during which all voltages are removed from said tube is at least several minutes in duration.

7. The method according to claim 3 wherein said predetermined interval is at least twenty-four hours in duration.

8. The method of improving the performance of a photomultiplier tube comprising the step of applying an abnormally high voltage between the final electron-collecting electrode and selected ones of the other electrodes therein for a relatively short time in the absence of substantially all radiant energy to which the photocathode thereof is substantially responsive.

9. The method of improving the performance of a photomultiplier tube comprising the step of applying an abnormally high voltage having a value somewhat below the "arc-over voltage" of the tube between the final electron-collecting electrode and selected ones of the other electrodes therein for a relatively short time.

10. The method of improving the performance of a photomultiplier tube comprising the step of applying an abnormally high voltage between the final electron-collecting electrode and selected ones of the other electrodes therein for a relatively short time, said applied voltage having a value of at least ten times the potential nor-

mally applied between the final dynode and the final electron-collecting electrode in conventional operation of said tube.

11. The method of improving the performance of a photomultiplier tube comprising the step of applying an abnormally high voltage between the final electron-collecting electrode and selected ones of the other electrodes therein for about 5±1 minutes.

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