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APPARATUS FOR CORRECTING SENSITIVITY VARIATIONS IN PHOTOMULTIPLIER TUBES

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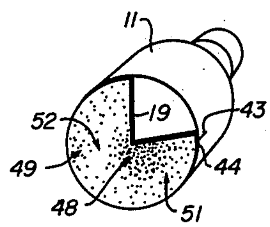

Fig. 3.

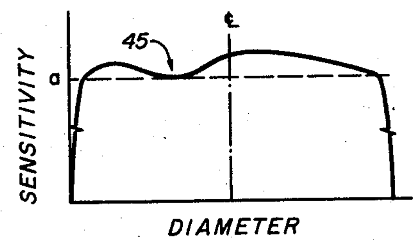

Fig. 2.

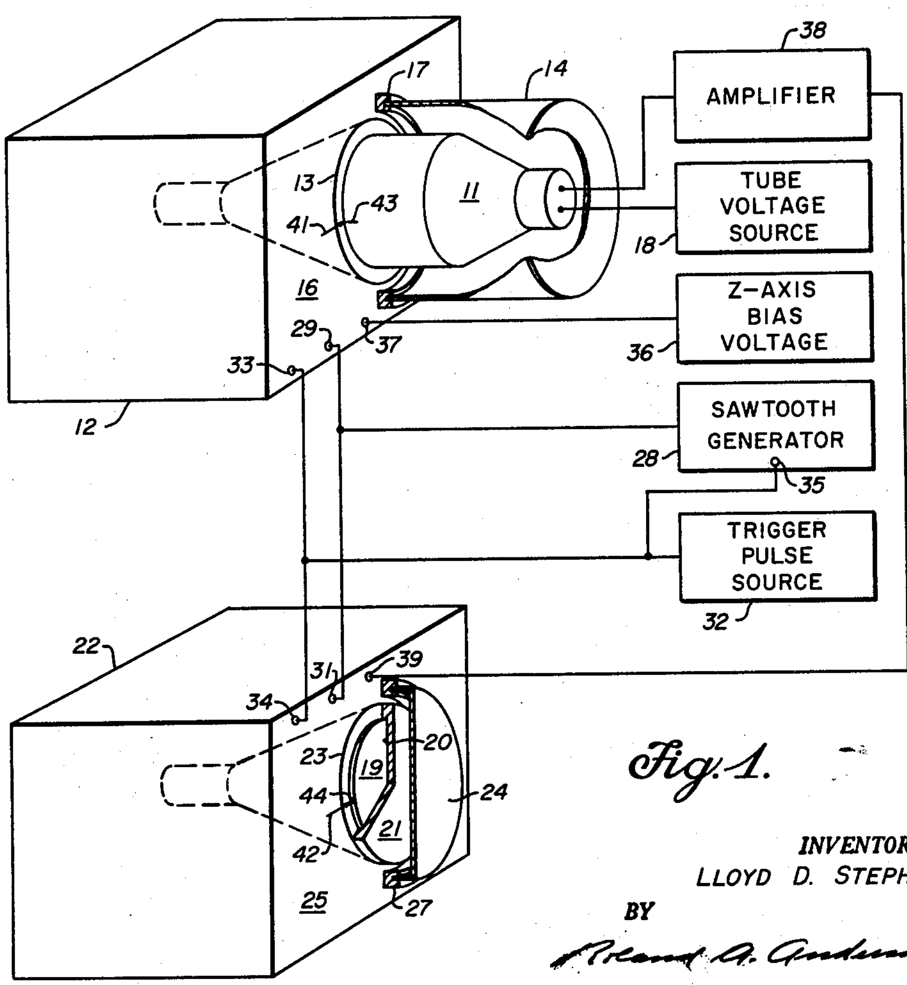

Fig. 1.

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APPARATUS FOR CORRECTING SENSITIVITY VARIATIONS IN PHOTOMULTIPLIER TUBES

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The present invention relates to photoelectric devices and more particularly to a method and apparatus for eliminating differences in the response to a given quantity of light at differing points on the face of a phototube or photomultiplier tube. It is an inherent characteristic of such tubes that the sensitivity to light will vary from point to point on the detecting surface of the tube. Recent development of phototubes has made better known the causes of these variations in sensitivity and has brought about much refinement in the accuracy and operation thereof. However, provisions for total correction within the tube itself are restricted by physical limitations in the tube design.

The essential elements of any photomultiplier tube are a cathode for releasing photoelectrons, a series of dynodes for producing electron multiplication, and an anode for collecting the electron pulse. In a typical photomultiplier tube these elements are contained in an evacuated glass envelope having a flat circular end to form the face or window of the tube. A semi-transparent coating of photoemissive material is applied to the interior surface of the window to form the cathode. This cathode surface is generally composed of one of the alkali metals which are the most effective electron emitters when exposed to visible light. An apertured focusing electrode in the tube directs electrons from the cathode surface through the aperture and on to a first dynode located behind the aperture. A series of similar dynodes are provided in the tube to sequentially multiply the electron emission before striking the final anode from which anode the output signal is taken.

One cause of the variation in sensitivity over the detecting face of photomultiplier tubes is a minute variation in the coating of the photoemissive substance on the cathode surface. Following the detection of an incident photon, the possibility of additional electron emission through scattering is related to the availability of neighboring atoms of the cathode substance for escaped elecrons to strike. Any variation in the thickness of the coating thus causes a change in the possible number of electrons resulting from an incident photon at this point.

In addition to the above mentioned random variation in the cathode coating over the entire face of the tube, the sensitivity near the outer edges of the face is consistently reduced due to the absorption of scattered electrons by the peripheral elements of the tube structure. By extending the photoemissive cathode coating further beyond the boundary of the exposed detecting face in an attempt to overcome this an increase in the error arising from backscattering is introduced.

While these non-uniformities in electron emission are a real source of error in the operation of phototubes, the greatest source of irregularities in the tube response arise from unreliable electron collection from all locations on the cathode surface. The electrons which are emitted from the cathode must be drawn toward the focusing electrode and directed through the central aperture thereof which aperture is a small opening relative to the area of the cathode surface. The physical shape and location of the dynodes, the first of which receives the electrons emerging from the aperture, must be such as to intercept the paths of the incoming electrons from all points on the cathode surface at an angle whereby the

reflected paths lead directly to the following dynode of the series. The dynode arrangement is an electron optical system for drawing secondary electrons away from one dynode and causing them to strike the succeeding dynode with a minimum loss of electrons. Each dynode stage is maintained at a particular voltage level which level is higher than that of the preceeding stage to enhance the electron collecting efficiency of the system. These electrical fields associated with the dynodes must be arranged so as not to attract the secondary electrons out of succession in the dynode series.

In view of the foregoing critical requirements of the dynode system with regard to the spatial arrangement and the disposition of the separate potential levels, in addition to the demands upon the focusing electrode, it is found that there is little possibility of the apparatus providing an equally advantageous arrangement for all the electron originating positions on the cathode surface.

In the applications of photomultiplier tubes in such activities as nuclear research it is often desired to view very minute light events and to distinguish between events of differing energy. The aforementioned non-uniform sensitivity of the tubes becomes a critical problem in these applications. It can be seen that a photon of light incident at one discrete point on the face of the tube can produce an output signal different in amplitude from that of a photon incident at another point on the tube face. Thus these applications generally require a detecting device having an over-all uniform response to a given quantity of light. A typical specific instance of this nature is in the energy measurement of nuclear particles using scintillation detectors. In this apparatus, a scintillation crystal is placed between the photomultiplier tube and the source of radiation. Upon striking the crystal, the particles produce scintillations therein proportional in light intensity to the energy of the particle. The viewing photomuliplier tube, in response to the scintillation, in turn produces an output signal proportional in amplitude to the energy of the particle. It can be seen that a particle impinging on one portion of the crystal and viewed by that area of the photomultiplier tube may produce an output signal different in amplitude from that of a signal produced by a particle of the same energy impinging on another portion of the scintillation crystal, whereby erroneous energy measurements of the events will be made.

The present invention provides a means of compensating for the sensitivity variation in a photomultiplier tube by a light-transmissive filter to be used in conjunction with the detecting surface of the particular photomultiplier tube. The filter is best prepared from a sheet of photographic film which is exposed to have a light transmission distribution pattern which is inversely related to the sensitivity distribution pattern of the photomultiplier tube. By the properly oriented disposition of the film on the face of the tube, the intensiy of the incident light transmitted to the different locations over the photocathode surface is proporionately reduced according to the degree of sensitivity of the particular location. In the more sensitive areas of the cathode the intensity is reduced in greater amounts so as to produce output signals from these areas which signals are equal in amplitude to signals resulting from an equivalent amount of light incident to the less sensitive areas of the cathode. In this way the response over the entire detecting surface is normalized to a degree which is lower than the maximum sensitivity available from the tube but which provides more than adequate signal strength, through amplification, for uniformly reliable detection.

Since the sensitivity variation distribution of any photomultiplier tube is unique to that particular tube, it is obvious that a special filter must be prepared for each tube, the non-uniformity of which it is desired to correct. To prepare the filter, a raster is established on a cathode ray oscilloscope and the photomultiplier tube is disposed against the oscilloscope screen. The cathode ray beam of the oscilloscope serves as an essentially point source of light having continuously uniform intensity and the raster pattern which the beam traces provides a means of systematically scanning the face of the photomultiplier tube to separately excite each incremental area of the cathode surface. The output of the photomultiplier tube is coupled to the Z-axis input of a second oscilloscope whereby the amplitude of the output signals from the photomultiplier tube modulates the intensity of the second cathode ray beam as it traces a similar raster pattern. The unexposed photographic film sheet is disposed at the screen of the second oscilloscope and receives an incremental light exposure pattern according to the incremental intensity variations of the modulated cathode ray beam. As the raster patterns simultaneously develop, the degree of light exposure received at any point on the photographic film from the second raster is being determined by the degree of light sensitivity of a corresponding point on the face of the photomultiplier tube as it views the first raster. Upon the photographic development of the film sheet the areas most strongly exposed will become the most darkened and thus the least light transmissive. The developed film sheet is then disposed in proper orientation on the face of the photomultiplier tube. Thus it can be seen that any incident light transmitted to the most sensitive portions of the tube photocathode will be reduced in the relatively greatest degree by the superposition of the darkest portions of the film thereon, whereby the output signals resulting from a unit of incident light on this area will agree in a amplitude with the signal from a similar degree of incident light on the less sensitive areas of the detecting face.

It is accordingly an object of this invention to improve and extend the use of photosensitive devices by providing for a uniform response from all portions of the photosensitive surfaces thereof.

It is another object of this invention to provide a method and means for obtaining uniform sensitivity to light at all points on the face of a photomultiplier tube.

It is an object of this invention to provide a corrective filter for disposition on the face of a phototube which filter evens the response of said tube to a given quantity of light at any point on the face of the tube.

It is a further object of the invention to provide a method of making a filter for correcting sensitivity variations over the detecting face of a photomultiplier tube.

It is another object of the invention to provide apparatus for exposing a photographic film sheet to have a light transmission distribution inversely related to the light sensitivity distribution of a photomultiplier tube whereby the film may be used as a corrective filter in conjunction with the photomultiplier tube.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the accompanying drawing of which:

FIGURE 1 is a schematic perspective view showing a photomultiplier tube and means for preparing a photographic film for use as a corrective filter thereon,

FIGURE 2 is a diagram showing the variation in sensitivity along a diameter of the face of a typical photomultiplier tube, and

FIGURE 3 is a cut-away view showing the photomultiplier tube with the corrective filter secured against the face thereof.

Referring now to the drawing and more particularly to FIGURE 1 thereof there is shown a photomultiplier tube **11** of the end window type, the variations in sensitivity of which tube it is desired to correct. To provide a point source of light excitation to the detecting surface of the photomultiplier tube **11** which source may sequentially excite each incremental area of the surface, the tube is disposed at the screen of a first cathode ray tube oscilloscope **12** to view the beam thereof. The photomultiplier tube **11** is positioned with the flat end window of the tube abutting the frontal glass envelope of the oscilloscope **12** and is centered thereon whereby the oscilloscope beam will be directed most normal to the detecting surface of the photomultiplier tube **11**. The peripheral portion of the screen of the oscilloscope **12** which is not covered by the face of the photomultiplier tube **11** is covered by a light-absorbing ring-like mask **13**. The mask **13** serves to minimize unwanted excitation of the outer regions of the photomultiplier tube face by interreflections within this peripheral portion of the oscilloscope glass envelope. To further shield the oscilloscope screen and photomultiplier tube face from stray light, the tube **11** is enclosed in an opaque cylindrical housing **14**. An open end of the housing **14** abuts the front panel **16** of the oscilloscope **12** and fits into an annular grooved support **17** mounted against the panel **16**. The electrode voltages to the photomultiplier tube **11** are supplied from a conventional tube voltage source **18**.

A sheet of photographic film **19**, which film is to become the sensitivity correcting filter for the photomultiplier tube **11**, is cut to a circular form with a diameter equal to that of the face of the photomultiplier tube **11**. The film **19** is retained in a circular film pack **21** which pack is opaque and which has a disk-shaped cavity **20** in one face to receive the film. The pack **21** is disposed at the screen of a second cathode ray oscilloscope **22** with the film sheet **19** centered on the frontal glass envelope thereof and adjacent thereto. Each incremental area of the film **19** may then be separately exposed to a point source of light as provided by the beam of oscilloscope **22** in a pattern corresponding to the excitation of photomultiplier tube **11** by the beam of oscilloscope **12**. A second annular light-absorbing mask **23** covers the peripheral portion of the screen of oscilloscope **22** to reduce unwanted exposure of the outer regions of the film by interreflections within the oscilloscope glass envelope. A circular opaque encasement **24** is provided with a circular cavity in one face to house the film pack **21** and is disposed against the front panel **25** of the oscilloscope **22** to shield the film **19** and oscilloscope screen from stray light. The encasement **24** is held in light-tight abutment to the oscilloscope panel **25** by a grooved annular support **27** mounted thereon.

In order that the entire surface of both the film **19** and the face of tube **11** will be evenly scanned by the point light sources provided by the beams of the oscilloscope **12** and **22**, the beams are caused to trace similar raster patterns on the respective oscilloscope screens. For this pattern the internal horizontal sweep circuit and internal blanking signal circuit of the oscilloscopes **12** and **22** are used in the conventional way whereby the beam is repeatedly swept across the screen in a visible trace in one direction and an invisible trace in the return direction. The traces are successively repositioned in the vertical direction by a constant gradual change of deflecting voltage acting on the beam in the vertical direction. The signal for this vertical deflection is provided by a sawtooth voltage generator **28** having an output coupled to the Y-axis input terminal **29** of oscilloscope **12** and to the Y-axis input terminal **31** of oscilloscope **22** whereby the deflection of each of the beams in this direction will be identical. The slope of the sawtooth signal from generator **28**, relative to the sweep time of the oscilloscope beam, is preferably set at a low value to cause each succeeding horizontal trace to be closely adjacent to the previous trace and thereby effect a complete incrementalized scanning.

It is necessary for the beams of the oscilloscopes **12** and **22** to be actuated only during the period required for a single complete raster pattern, otherwise a second exposure to some areas of the tube photosensitive surface and the film would occur. To effect this accurate timing, a pulse source **32** is provided for producing a square wave pulse having a pulse length equal to one complete raster time of the oscilloscopes. The output from pulse source **32** is coupled to the trigger input terminal **33** of oscilloscope **12** and to the trigger input terminal **34** of oscilloscope **22**. With these connections, upon the occurrence of the square wave pulse from pulse source **32** the respective beams of oscilloscopes **12** and **22** are simultaneously unblanked and the aforementioned internal sweep circuits are simultaneously triggered. The output from pulse generator **32** is also connected to the input **35** of sawtooth generator **28** whereby the vertical deflection voltage for the raster patterns is established at the proper time. On the cessation of the square wave signal from generator **32**, after the oscilloscope beams have scanned the entire surfaces of the respective screens, the beams are immediately blanked and the beam deflecting voltages are inactivated. Thus it can be seen that the entire face of the photomultiplier tube **11** and the entire surface of the photographic film **19** are scanned only once by the point source of light of the respective oscilloscope beams and are exposed at identical locations at substantially the same instant of time.

In order that all locations on the photomultiplier tube face receive equal incident energy, the intensity of the beam of oscilloscope **12** is maintained at a constant level and is supplied by a bias voltage source **36** connected to the beam intensity, or Z-axis, input terminal **37** of oscilloscope **12**. The output from the photomultiplier tube **11** is connected through a variable gain amplifier **38** to the beam intensity terminal **39** of oscilloscope **22**. In this way the amplitude of the output signal from the photomultiplier tube **11** at each raster position on the screen of oscilloscope **12** modulates the intensity of the beam of oscilloscope **22** at each corresponding raster position on the screen thereof. Thus the relative degree of exposure of the film **19** at each location is determined by the degree of response of the photomultiplier tube at the corresponding location. Due to the negative character of photographic film whereby the degree of light exposure to the film is inversely related to the resulting degree of light transmissibility produced in the film, it can be seen that the film **19** will acquire a light transmission distribution pattern which is the inverse of the light sensitivity distribution pattern of the photomultiplier tube **11**.

To insure accurate and clearly defined point by point excitation of the photomultiplier tube **11** and the photographic film **19**, the oscilloscopes **12** and **22** should be of the type having a very short persistence phosphor. A short duration of luminescence at the individual raster positions enables the output signals from photomultiplier tube **11** and the exposure of the photographic film **19** to be a more discrete product of single point excitation rather than including the lingering luminescence of the most previously excited points on the respective screens.

In further regard to the fluorescent coating of the oscilloscopes **12** and **22** it is desirable that the phosphor have a high brightness characteristic and that it radiate in the spectral range similar to that which the particular photomultiplier tube **11** is to view in normal operation. The absorptivity characteristic of the film **19** should be spectrally non-selective, therefore neutral gray type film is preferably used.

Oscilloscopes **12** and **22** are provided with index markings **41** and **42**, respectively, located at the side of the oscilloscope screens which markings indicate identical azimuths on the circumferences thereof. An index mark **43** on the side of the photomultiplier tube **11** is aligned with index **41** of oscilloscope **12** and, similarly, an index mark **44** on the edge of the photographic film **19** is aligned with index **42** of oscilloscope **22**. Upon the disposal of the developed film **19** on the photomultiplier tube face for use as a filter, the alignment of index marks **43** and **44** with each other will thus insure the proper orientation whereby corresponding locations on the film and photomultiplier tube face will be superimposed upon each other.

In the preparation of the filter it is necessary to know the range of response sensitivity possessed by the particular photomultiplier tube **11** in order to select the optimal sensitivity level to which the tube is to be corrected and to control the density level of the film in accordance therewith. Generally, it would be disadvantageous to correct the tube **11** to an overall sensitivity level which is lower than that of the least responsive area in the detecting surface of the tube. There is a variety of ways in which this range can be found and which are common knowledge within the art. From any of these methods a curve or family of curves indicating the response at the various surface areas can be plotted. Such a curve is shown in FIGURE 2 of the drawing which curve represents the variation in response in a line segment across the diameter of the tube detecting surface. A family of curves representing the responses across parallel line segments would yield the range of responses over the entire surface. Upon comparative examination of the curves the optimum level of response for the corrected tube is chosen from the lowest sensitivity present over the central area of the detecting surface. In all such curves the response near the periphery of the tube will drop off abruptly, as in the curve shown, and for obvious reasons, these areas are not included in the determination. With respect to the curve shown, the level at the lowest point **45** would dictate the sensitivity level to which the tube should be corrected.

Thus the tube surface areas having a sensitivity above the ordinate value "*a*" will be superimposed by a filter area of appropriate densities to reduce the sensitivity of the value "*a*." The tube surface area represented by the dip **45** in the curve, however, is superimposed by a filter area having had substantially no exposure and thus is substantially fully transmissive. The gain setting on variable amplifier **38** is established such that input signal levels below the signal amplitude from the low sensitivity area corresponding to response "*a*" on the curve will not be transmitted in the amplifier output. Thus the film **19** will receive no exposure in that area but will receive degrees of exposure in all other areas in proportion to the amplitudes of the signals transmitted.

After the photomultiplier tube and the photographic film have been exposed to the raster patterns of oscilloscopes **12** and **22** the film **19** is removed from the film pack **21** for development. In such photographic processes the final density acquired by a film is essentially a function of the degree of light exposure to the film and the degree of development of the film. In order to have the differences in density in the exposed portions of the film **19** equal the differences in light intensity which caused them, and thus be equal in a one to one relationship to the corresponding differences in sensitivity which are to be corrected in the photomultiplier tube **11**, the film must be developed to a gamma of 1.0. Development to a gamma less than 1.0 will shrink the range of density, or contrast, attained in the film and result in insufficient opacity of the filter for adequate tube correction. Conversely, development to a gamma greater than 1.0 will expand the range of final density in the film and result in superfluous opacity of the filter and overly reduce the light transmitted to the tube for accurate correction.

Referring now to FIGURE 3 there is shown the developed film sheet **19** used as a corrective filter in conjunction with the photomultiplier tube **11**. The film **19** is applied to the frontal glass envelope of the photomultiplier tube **11** by a suitable optical adhesive and is oriented with index mark **44** aligned with index mark

43 of the tube. As an alternate method the emulsion may be stripped from the film **19** and coated directly on to the frontal glass of the tube **11** in the correct orientation therewith. Thus, with the filter in place and corresponding raster locations of the film **19** and the tube face superimposed, the most sensitive portions of the tube face are confronted with the highest density portions of the filter as indicated in the drawing by the darkly shaped area **48**. The progressively less sensitive areas of the tube face are confronted with the progressively less dense portions of the filter, indicated by the lesser shaded areas **49** and **51**, respectively, while the unshaded area **52** confronts the least sensitive portion of the tube face represented by the dip **45** in the curve of FIGURE 2. It should be understood that the pictorial shading in the figure is a schematic representation and that in practice the transmission of the film will vary in finer degree and in various patterns for various tubes and is not limited to the pattern shown.

In operation, with the corrective film **19** affixed to the face of the photomultiplier tube **11**, the incident light admitted to each increment of the photocathode is regulated by the transmissibility of the filter at each corresponding increment thereof. The incident light transmitted by the film **19** to the cathode at the most sensitive points on the tube face will be reduced by the greatest amount and, conversely, the incident light transmitted to the cathode at the less sensitive points will be reduced by the least amount. Thus, by reducing the incident light transmitted at each point of the tube face in direct proportion to the relative sensitivity of the tube face at that point, output signals of equal amplitude are obtained from equal amounts of incident light in all regions of theh photomultiplier tube face.

Although the invention has been described as pertaining to photomultiplier tubes it will be understood that the concept is equally applicable to other devices having a photosensitive surface as an element thereof. The invention is applicable, for example, to electron camera tubes such as the image orthicon, iconoscope, or vidicon tube. The image section of each of those devices utilizes a photosensitive surface to convert light impulses to electron impulses, comparable to the cathode of the photomultiplier tube, and as such, are subject to much of the same non-uniform sensitivity. The use of such a filter to control the intensity of the incident light in accordance with the sensitivity variation of the receiving surface effects more accurate image reproduction from the electron camera tubes.

Thus while the invention has been described with respect to a particular embodiment thereof, it will be apparent to those skilled in the art that numerous variations and modification are possible within the spirit and scope of the invention and thus it is not intended to limit the invention except as defined in the following claims.

What is claimed is:

1. In a method of preparing a corrective filter of photographic film for use on the detecting surface of a photosensitive device which displays a non-uniform sensitivity, the steps comprising scanning the photocathode surface of said device with a first essentially point source of light of constant intensity to produce output signals therefrom indicative of the characteristic variations in sensitivity of said device, scanning the surface of said photographic film with a second essentially point source of light, regulating the intensity of said second source of light by said output signals during said scanning of said film, and developing said film whereby a varying degree of opacity is obtained at each point on said film which degree of opacity is proportional to the response of said device at a corresponding point on said photocathode surface.

2. In a method of making a sensitivity correcting filter from photographic film to be mounted on the face of a photomultiplier tube, the steps comprising mounting said photomultiplier tube at the screen of a first oscilloscope in light-tight relationship therewith, mounting said photographic film at the screen of a second oscilloscope in light-tight relationship therewith, simultaneously scanning the screens of said first and second oscilloscopes with the respective beams thereof, controlling the light intensity of the beam of said second oscilloscope by the output of said photomultiplier tube in response to the beam of said first oscilloscope, and developing said photographic film.

3. In a method of providing uniform sensitivity at differing points on the face of a photomultiplier tube by a filter of photographic film to be used in conjunction therewith, the steps comprising mounting said photomultiplier tube at the screen of a first oscilloscope in light-tight relationship therewith, mounting said photographic film at the screen of a second oscilloscope in light-tight relationship therewith, applying a voltage of constant gradual change to the respective vertical deflection means of said first and second oscilloscopes to deflect the sweep of the beams thereof to track corresponding raster patterns, applying a pulse to the respective triggering means of said first and second oscilloscopes to simultaneously actuate the beams thereof for the tracking of a single raster pattern, controlling the intensity of the beam of said second oscilloscope at each raster location thereof by the response of said photomultiplier tube at each corresponding raster location on said first oscilloscope, developing said film, and mounting said film on the face of said photomultiplier tube with corresponding locations superimposed.

4. In apparatus for making a response equalizing filter from a photographic film for use in front of the face of a photomultiplier tube, the combination comprising means for energizing said tube, a first light source having means for mounting said photomultiplier tube thereat and having provision for sweeping a point of light of constant intensity through successive portions of said face of said photomultiplier tube, a second light source having means for mounting said photographic film thereat and having provision for sweeping a second point of light through successive portions of said photographic film in a pattern which is identical to the pattern followed by said first source of light on said tube and which is simultaneous therewith, and means modulating the intensity of said second light source in proportion to the amplitude of output signals of said photomultiplier tube whereby said film obtains a degree of light exposure at each point which is inversely proportional to the relative light sensitivity of each corresponding point on said face of said photomultiplier tube.

5. Apparatus for exposing a photographic film to produce a varied light transmission pattern thereon which is the inverse of the pattern of variation in sensitivity on the photocathode surface of a photoelectric device said apparatus comprising, in combination, a first light source of constant intensity having means for supporting said photoelectric device thereat and having provision for sequentially exciting successive areas of said photocathode surface, a second light source having means for supporting said photographic film thereat and having provision for sequentially exposing corresponding successive areas of said film, and means coupling the output of said photoelectric device to said second light source to control said exposure of said film in proportion to said output.

6. In apparatus for making a corrective filter from photographic film for use on the face of a phototube which phototube displays non-uniform sensitivity over the detecting face thereof, the combination comprising a first oscilloscope having a screen and having an X-axis trigger input and a Y-axis deflection input, a second oscilloscope having a screen and having an X-axis trigger input and a Y-axis deflection input and a Z-axis intensity input, a sawtooth voltage generator having a first output coupled to said Y-axis input of said first oscilloscope and a second output coupled to said Y-axis input of said second oscil-

loscope for deflecting the respective beams of said first and second oscilloscopes to trace a raster pattern on the respective screens thereof, a pulse generator having a first output coupled to said trigger input of said first oscilloscope and a second output coupled to the trigger input of said second oscilloscope to simultaneously activate said beams for the tracking of a single raster pattern, means for mounting said phototube to face the screen of said first oscilloscope, means for mounting said photographic film at the screen of said second oscilloscope, and means coupling the output of said phototube to said Z-axis input of said second oscilloscope to control the exposure of said film in proportion to said phototube output.

7. Apparatus for preparing a photographic film to provide a sensitivity correcting filter for use on the face of a photomultiplier tube, comprising a first cathode ray oscilloscope having a fluorescent screen and having a Y-axis deflection voltage input and an X-axis trigger voltage input, means for mounting said photomultiplier tube against the screen of said first oscilloscope, a second cathode ray oscilloscope having a fluorescent screen and having a Y-axis deflection voltage input and an X-axis trigger voltage input and a Z-axis bias voltage input, amplifier means for coupling the output of said photomultiplier tube to the Z-axis bias input of said second

cathode ray oscilloscope, a sawtooth voltage generator having a first output coupled to the Y-axis input of said first oscilloscope and a second output coupled to the Y-axis input of said second oscilloscope, a pulse source having a first output coupled to the X-axis input of said first oscilloscope and a second output coupled to the X-axis input of said second oscilloscope whereby occurrence of a pulse therefrom establishes identical raster patterns on the respective screens of said first and second oscilloscopes, and means for mounting said photographic film at the screen of said second oscilloscope whereby an exposure pattern is produced thereon which is the inverse of the sensitivity distribution pattern of said photomultiplier tube.

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