Oct. 29, 1946. R. H. VARIAN 2,410,115

IMAGE INTENSIFIER

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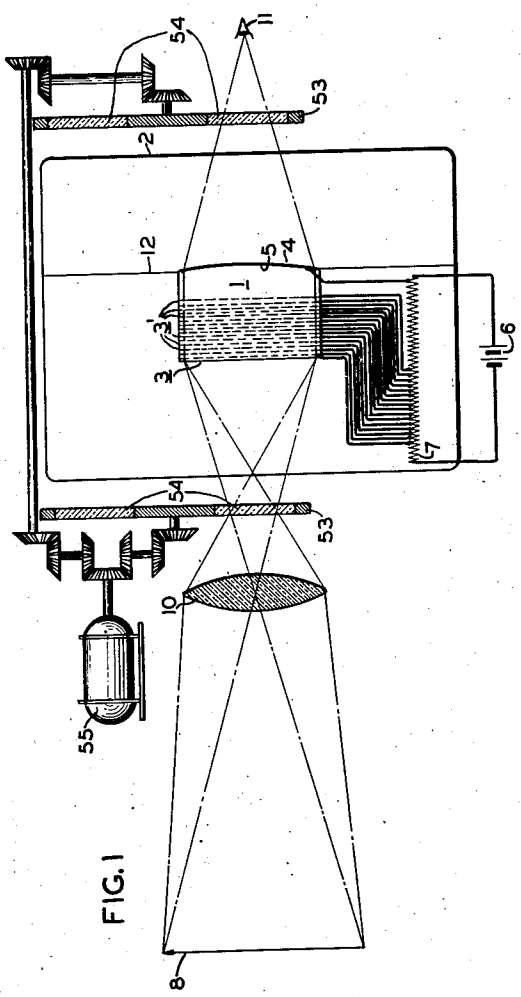


FIG. 1

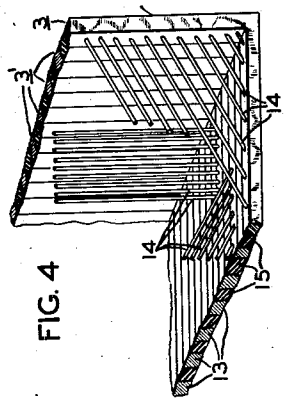


FIG. 4

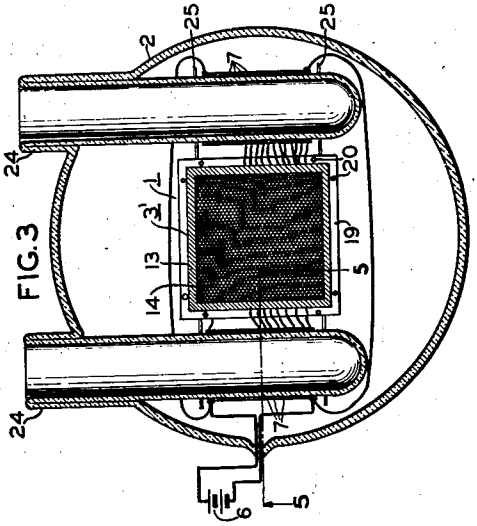


FIG. 3

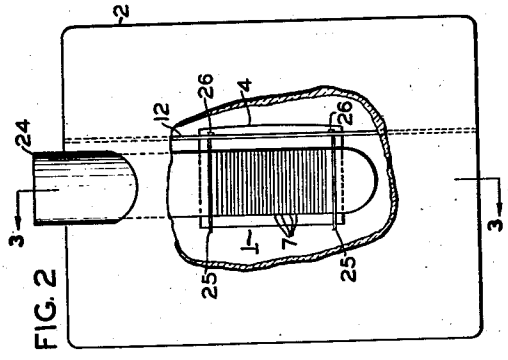


FIG. 2

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IMAGE INTENSIFIER

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FIG. 6

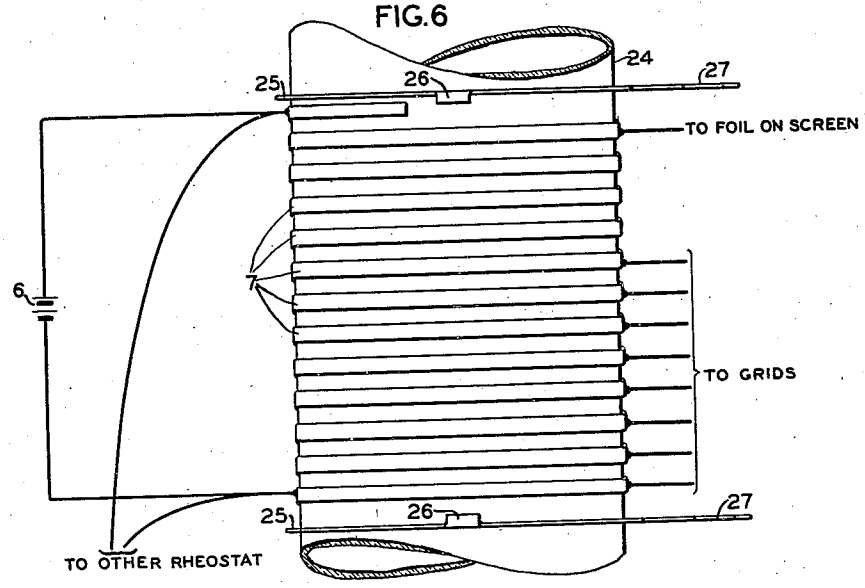
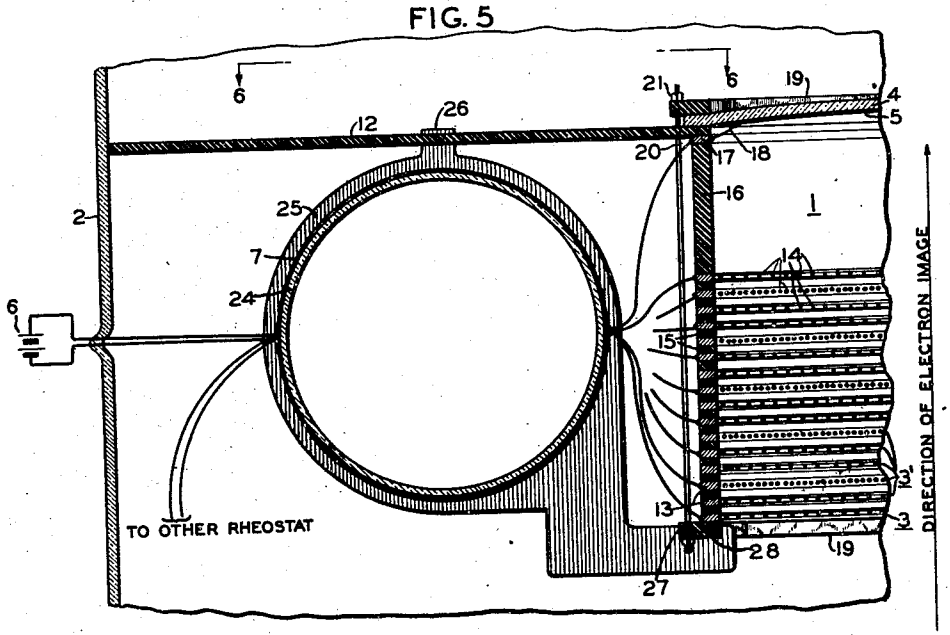


FIG. 5



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IMAGE INTENSIFIER

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FIG. 7

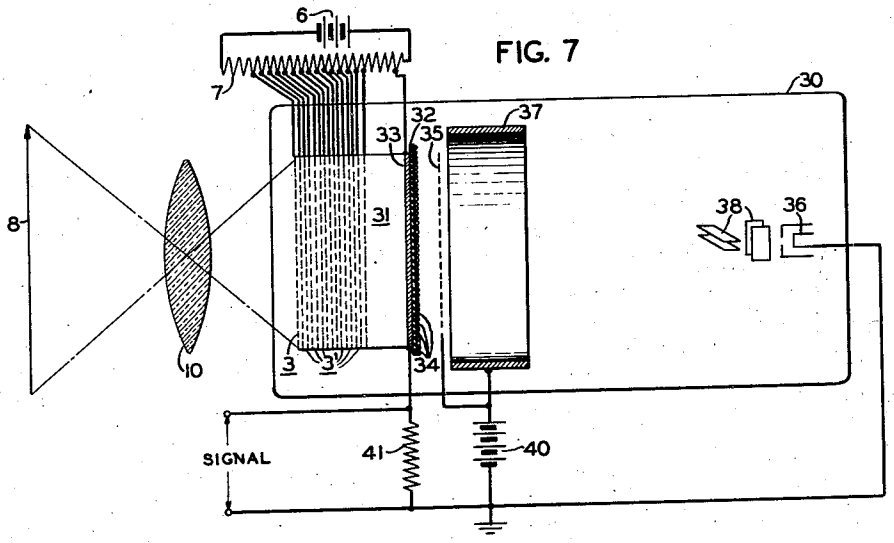
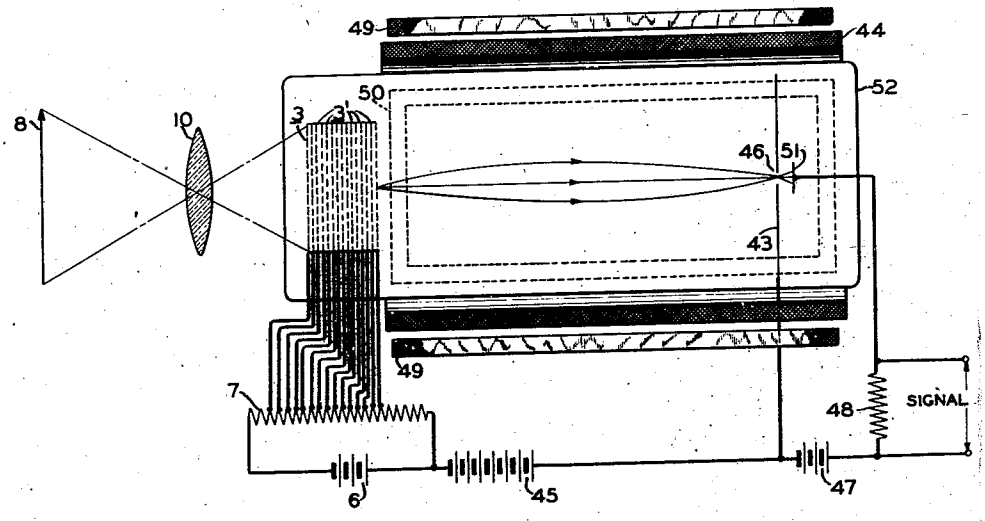


FIG. 8



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Patented Oct. 29, 1946 2,410,115

UNITED STATES PATENT OFFICE

2,410,115

IMAGE INTENSIFIER

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Application September 2, 1942, Serial No. 457,097

10 Claims. (Cl. 250—153)

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This invention relates to a novel type of photoelectric device, which utilizes a novel electron multiplication process in order to amplify the intensity of an electron image, and which may be used in conjunction with a suitable optical system to amplify the intensity of an optical image.

The intensification of an optical image has been a much sought after objective in order to make possible visual detection of the presence of objects which are too dimly illuminated to be seen by the eye. It is a well-known principle of optics that no intensification can ever be realized through the use of a purely optical system. This is because any optical system used with the eye cannot escape the limitations imposed by the actual size and the f value of the human eye, which is necessarily the last stage in the system. It has also been attempted to accomplish image intensification by the use of orthodox television equipment. But, here too, limitations of the known television systems have prevented any appreciable gain in sensitivity.

In the present invention a system of lenses is used to focus an optical image on a photoelectric surface, which converts the optical image to an electron image. The electron image is then intensified as a whole by utilizing the effect of secondary emission to obtain electron multiplication, after which the intensified electron image is converted back to an intensified optical image.

Secondary emission has been used heretofore to obtain electron multiplication, as in the Farnsworth and Zworykin electron multipliers. But, because of the spreading tendency of the electrons as multiplication proceeds, it has only been possible to intensify one element of an electron image at a time. In the novel type of electron multiplier incorporated in the present invention, the spreading of the electrons has been so reduced that it becomes possible to intensify all the elements of the electron image simultaneously, maintaining the electron image as a whole intact, and still obtain a sufficiently high resolving power to produce a satisfactory picture. By using this novel electron multiplier in conjunction with a suitable lens system, a very high gain in light sensitivity over the human eye can be obtained.

The novel electron multiplier may also be used as a basis for a new type of television transmitting tube. There are in present use two principal

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types of tubes for converting an optical image into a television signal. One is the Farnsworth dissector and the other is the Zworykin iconoscope.

The Zworykin iconoscope uses the storage principle to increase its sensitivity, that is, the electrical impulse generated by each element of the photoelectric surface is proportional to all the light falling on that particular element between successive scannings. The disadvantage of this tube is that it is impossible to use any of the previously known types of electron multiplier in conjunction with it.

The Farnsworth dissector, on the other hand, employs the principle of electron multiplication to increase its sensitivity, but cannot take advantage of the storage principle. Hence, neither of these tubes achieves the theoretical limit of sensitivity which can only be obtained by utilizing both the storage principle and the principle of electron multiplication. The reason why it has heretofore been impossible to combine these two principles in one tube is that all previously known electron multipliers were adapted to intensify only one element of an electron image at a time, as previously pointed out.

Since the novel type of electron multiplier of the present invention can intensify an electron image as a whole with the electron image remaining intact, it becomes possible to produce a highly sensitive television transmitting tube which incorporates both the electron multiplication and the storage principles.

The principal object of the present invention is to provide an electron multiplier which will intensify all the elements of an electron image simultaneously, thus maintaining the electron image intact during the intensification process.

Another object of the invention is to provide a device which is capable of receiving a visual image and amplifying its intensity, without altering the characteristics of the image.

A further object is to provide a device which has a high gain in light sensitivity over that of the human eye so that it will render visible objects which are too dimly illuminated to be detected by the human eye alone.

An object of the invention is to provide a device whose intrinsic sensitivity is about equal to that of the eye and whose characteristics may be

made to duplicate those of the eye in dim light.

Another object of the present invention is the provision of a highly sensitive television transmitting tube which incorporates the principles of both electron multiplication and light storage.

A further object of the invention is to provide a device which is capable of reproducing an intensity amplified image of an object, which image appears in the same color as the object.

A still further object of the invention is to provide a device which will produce an intensity amplified color image of an object, in which image invisible radiations from the object, such as infra-red or ultra-violet radiations, are made to appear as any arbitrarily chosen color.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 is a diagrammatic view of a device embodying features of the present invention.

Fig. 2 is an elevation view of the vacuum tube shown diagrammatically in Fig. 1.

Fig. 3 is a cross-sectional elevation view taken along the line 3—3 of Fig. 2.

Fig. 4 is a perspective view of a detail of Fig. 3.

Fig. 5 is an enlarged fragmentary cross-sectional view taken along the line 5—5 of Fig. 3, showing the details of construction and method of support of the grid and screen assembly.

Fig. 6 is a partial view taken along the line 6—6 of Fig. 5, with the grid and screen assembly removed.

Fig. 7 is a diagrammatic view of another embodiment of the present invention.

Fig. 8 is a diagrammatic view of still another embodiment of the present invention.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

Referring now to Fig. 1, there is shown a grid and screen assembly 1 contained in a suitably evacuated glass tube 2. The grid and screen assembly 1 consists essentially of a series of closely spaced grids or electron permeable elements 3, 3', and a fluorescent screen 4 which is coated on its inside with a thin layer of metal foil 5. The first grid 3, at least, must be photoelectric, and the following grids 3' are highly secondary electron emissive. A direct current potential difference which may be of the order of 500 volts or so, is applied between successive grids from a direct current source, represented by the battery 6 and a rheostat 7. A potential difference of some 50,000 volts is maintained between the last secondary emitting grid 3' and the thin metal foil 5 which acts as an anode.

In order to adapt a device to color vision, and for other purposes, as will later be described in more detail, the two identical rotating color discs 53, both driven in synchronism with each other by constant speed motor 55 through suitable gearing, may be associated with the device, one placed in front of the photoelectric grid 3 and the other after the fluorescent screen 4. Each color disc 53 includes the usual series of color filters 54.

In Figs. 2 to 6 there are shown the details of a preferable construction of the vacuum tube shown diagrammatically in Fig. 1. Referring to Fig. 4, it is seen that the grids 3, 3' consist of a square metallic frame 13, the length of each side of which may be about 6 cm., which frame supports a layer of very fine grid wires 14. The grid

wires 14, which all run parallel to each other in any particular grid, may have a diameter of about .010 inch and have a spacing between centers of about .020 inch in the grid. The grids 3, 3' are insulated from each other by thin mica spacers 15 placed between successive grid frames 13. The thickness of the grid frames 13 and the mica spacers 15 are such that the distance between the grid wires of successive grids may be about 1 millimeter. The direction of the wires of successive grids is rotated through an angle of 60°, so that the direction of the wires in any particular grid is parallel to that of the wires in every fourth grid only.

Referring to Fig. 5, it is seen that the grid and screen assembly 1 comprises a complete unit in itself, which may be assembled outside the tube and then inserted as a whole within the tube structure. On top of the first photoelectric grid 3, there are placed about 15 secondary emissive grids 3' which may be also somewhat photosensitive. The last of these grids may be made somewhat less secondary electron emissive in order to prevent cold emission caused by the higher potential difference between it and the layer of metal foil 5. All the grids are separated by mica spacers 15. On top of the last of the secondary emissive grids 3' there are successively stacked a larger insulating spacer block 16, which may be porcelain, a metal conducting block 17, the opaque guard 12, and the fluorescent screen 4. On the top and bottom of the stack are placed the clamping frames 19 which are made of some insulating material, such as porcelain. Tie rods 20, of insulating material threaded at both ends, are inserted through holes in clamping frames 19 and opaque guard 12, and the whole structure is then rigidly clamped together by tightening the nuts 21. Conducting wire 18 makes an electrical connection between the metal block 17 and the layer of metal foil 5.

In Figs. 2 and 3 are shown two cooling tubes 24 extending vertically downward within the tube structure 2 and constructed integrally therewith. These cooling tubes, when filled with liquid air, cool the grids 3, 3' sufficiently so that neither thermionic emission nor cold discharge will take place. Besides cooling the grids, these cooling tubes also serve to support the rheostats 7, and to support the grid and screen assembly 1 within the tube structure 2.

The rheostats 7 may be formed by wrapping a guard strip spirally around a portion of the cooling tubes 24, and then allowing a metal suitable for evaporation in a vacuum, such as silver, to condense upon the unguarded surface of the tube. Thus, when the guard strip is removed, a thin layer of silver 7 in the form of a continuous spiral strip is produced on the surface of the cooling tubes, as shown in Fig. 6 very much exaggerated in thickness. By connecting the opposite ends of the spiralled silver strip 7 to an external source of direct current potential 6, a voltage gradient between turns is produced which may be used to supply the desired voltages to the grids 3, 3' and the thin metal foil 5.

In order to facilitate making the connection to the grids, one cooling tube supplies voltage to the metal foil and every other grid, while the alternate grids are supplied from the other cooling tube. (See Fig. 5.) Connections between the spiralled silver strips 7 of the two tubes are made at such points that the desired voltage difference of 500 volts, or so, is obtained between the successive grids 3, 3'. The conducting wires to the grids

are made large enough to also serve as heat conductors from the grids 3, 3' to the cooling tubes 24.

The method in which the grid and screen assembly 1 is supported within the tube structure 2 is shown in Figs. 5 and 6. Two supporting collars 25 are slid over each of the cooling tubes 24 and fastened rigidly thereto. A slot 27 is provided on an inward extension of the collar 25. The grid and screen assembly 1 may then be inserted as a unit within the tube, the clamping frame 19 sliding into the slot 27 of the collar 25. Another slot 28 in clamping frame 19 similarly engages the inward extension of collar 25, thereby preventing any movement of the grid and screen assembly 1 in any but an axial direction. At the same time a projection 26 on collar 25 projects through a similarly positioned slot in the opaque guard 12. The projection 26 may then be folded over and fastened to the opaque guard 12, thus supporting the grid and screen assembly 1 rigidly within the tube.

For the sake of simplicity, the following discussion of the operation of the device of Figs. 1 to 6 will be confined to the production of an ordinary black-white intensity amplified image. Therefore, it will be assumed for the present that the rotating color discs 53 either are omitted or that ordinary glass has been substituted for the various color filters 54.

In operation, an optical image of the object 8 is focused on the first photoelectric grid 3 by the lens system 10. The lens system 10 might include a pair of erecting lenses so that the image would appear on the photoelectric grid in the same position as the object. The photoelectric grid 3 will emit photoelectrons, the number emitted from any particular point on its surface varying in accordance with the intensity of the optical image at that point, thus producing an electron image of the object 8. The emitted photoelectrons, representing various elements of the electron image, are drawn through the interstices of photoelectric grid 3 to the first of the secondarily emissive grids 3', producing a shower of secondary electrons, which in turn are drawn through that grid and strike against the succeeding grid, producing a new shower of secondary electrons, and so on. Since the various elements of the electron image maintain parallel paths, and consequently the same relative positions in the electron image, it is seen that the electron image is maintained intact as this multiplication process proceeds. Thus an intensified electron image emerges from the last of the emissive grids 3' and passes to the thin metal foil 5 with an energy of 50,000 equivalent volts or so, which is enough to cause the electrons to penetrate the thin metal foil 5 and excite the fluorescent screen 4. Thus an intensity amplified visible image of the object 8 is produced which may be seen by the eye 11.

The thin metal foil 5, besides serving as an anode, also prevents light from the visible image formed on screen 4 from feeding back to the photoelectric grid 3 and producing a self-sustaining discharge. An opaque guard 12 is also placed around the grid and screen assembly 1 and near the fluorescent screen 4 to prevent any light from the outer side of the screen from being reflected around the grid and screen assembly and back to the photoelectric grid 3.

Whenever wire screens are superimposed on top of each other, as the grids are in the present invention, a system of light and dark bands, known as screen patterns, may occur due to non-uniformity of the individual wires. Screen patterns

should, therefore, be considered for light which penetrates beyond the first photoelectric grid, and also for secondary electrons in the multiplication process.

The effect for light has been eliminated in my device, by shifting the direction of the grid wires of successive grids through 60°, so that only every fourth grid has parallel wires. A grid four grids in will receive only about ⅛ as much light as the first grid, and so, even if its photoelectric sensitivity were the same as the first grid, it would emit only ⅛ as many photoelectrons. Also the electrons it does emit will be subject to three fewer stages in the multiplication process, which will give another attenuation factor of at least 8. Therefore, the photoelectric contribution of the fourth grid may be neglected insofar as its effect on the final image is concerned. Hence, there will be no screen patterns due to optical causes.

Considering now the possibility of screen patterns caused by electron shadowing, it will be shown later, when the resolving power of the device is considered, that the total amount of lateral displacement, or spreading, of the elements of the electron image between successive grids is considerably more than the diameter of the grid wires themselves, so that it is impossible for one grid to shadow the electrons produced on the preceding grid. Therefore, there can be no screen patterns caused by the electrons themselves.

The over-all effectiveness of the device as an image amplifier will be determined by two factors: (1) its resolving power, and (2) its relative sensitivity with respect to the human eye.

The resolving power will be dependent on the amount of lateral displacement which the various electrons of the elements of the primary electron image will undergo as they pass from the first photoelectric grid to the fluorescent screen. If we assume that the average secondary electron is ejected from a grid wire with a velocity transverse to the field of five equivalent volts, and that the potential difference applied between grids is 500 volts, the ratio of the transverse velocity to the forward velocity at the succeeding grid is

$$\sqrt{\frac{5}{500}}=\frac{1}{10}$$

since the velocities are proportional to the square root of the voltages. However, the transverse velocity is constant between grids, whereas the forward velocity uniformly increases from approximately zero at the emitting grid to the full forward velocity at the next succeeding grid, so that the ratio of the average velocities is 1/5. Therefore, in traversing the distance of 1 mm. between grids the electrons will undergo a lateral displacement of $\frac{1}{5}\times 1$ mm.=.2 mm., to each side of the center line, or a total displacement between grids of $2\times .2$ mm.=.4 mm. No more spreading will occur between the final grid and the fluorescent screen than occurs between successive grids because, although the forward distance which must be traversed is much greater, nevertheless the forward velocity is proportionately greater due to the increased potential difference. Therefore, if there are 16 grids, the most probable total displacement at the fluorescent screen caused by the random secondary electron emission velocity will be approximately equal to $\sqrt{16}\times .4$ mm.=1.6 mm.=.16 cm.

There is another displacement due to the distortion of the electric field caused by the individual wires of the grid, which should also be

considered. The displacement due to this cause, for the various dimensions chosen, has been found to be approximately equal to the displacement caused by the random secondary electron emission velocity. The most probable total displacement due to both causes will then be of the order of $\sqrt{2}\times.16$ cm.$=.22$ cm.

Thus, if the fluorescent screen is 6 cm. square, the visible image produced thereon will be equivalent in detail to about a 30 line television picture. If a greater degree of detail is desired, it can readily be obtained by altering the proper dimensions. For instance, if detail equivalent to a 300 line picture is desired, it can be obtained by decreasing the distance between grids to 0.1 mm. and decreasing the diameter of the wires to .001 in. With the grids only 0.1 mm. apart, it has been found that, if the grids are cooled by liquid air, a potential difference of 500 volts between grids may still be retained, without cold emission occurring at the grids.

Having shown the resolving power of the device to be satisfactory, the question of its relative sensitivity with respect to the human eye will now be investigated. First, the intrinsic sensitivity of the grid and screen assembly alone, without reference to any lens system, will be considered.

About 100 quanta of light energy is required to stimulate a visual element of the human eye. However, the eye is endowed with the property of being able to change the size of the resolvable elements, thus being able to see in dim light at the expense of definition. It also has the characteristic of persistence of vision.

The number of quanta per photoelectron for Cs—Ag—CsO photocells is about the same as the number required to excite one resolvable element of the eye, i. e., 100. It is clear that the device, through its electron multiplication process, is capable of making a single photoelectron emitted from the photoelectric grid visible as one resolvable element at the fluorescent screen. Therefore, the human eye and the grid and screen assembly alone are very nearly equal in intrinsic sensitivity.

The single photoelectron produced by any group of 100 quanta may be emitted at any point on the grid, but the probability that it will be emitted at any particular point is proportional to the number of quanta striking that particular point. Thus the device is capable of detecting the presence of a very dimly illuminated object, but the detail obtained will depend upon the illumination of the object. The device, then, is also similar to the eye in that it will sacrifice definition for detection in very dim light.

Also, since the effective persistence of vision of the device may be controlled by giving the fluorescent material a time lag, it is possible, when viewing the screen with the eye, to have the effective persistence of vision equal to that of the eye in full light, or have it arbitrarily longer. Hence, the characteristics of the device may be made to duplicate those of the eye in dim light.

In the above discussion it was brought out that the photoelectric part of the device alone has about the same intrinsic sensitivity as the eye. That is, it takes about the same number of light quanta to produce a visual element in both cases. The big advantage of the present invention lies in the fact that there are no inherent limitations placed either upon the actual size of the photoelectric grid surface or diameter and f value of

the auxiliary lens system, whereas the size of the retina, the diameter of the iris and the f value of the eye are all intrinsically limited. Thus by using a photoelectric grid surface larger than the retina of the eye it is possible to use a longer focal length than that of the eye and still retain the same angular field of view. Assuming a lens having an f value equal to that of the eye is to be used, the longer focal length permits the use of a lens of a greater diameter than that of the eye. But by employing a lens of greater f value than that of the eye, still another increase in the diameter of the lens may be obtained. The use of a lens having a much greater diameter than that of the iris of the eye results in the interception of many more light quanta from a particular light source, and accounts for the high over-all gain in sensitivity of the device, with lens system included, over the eye.

Because of the fact that a single photoelectron may be made to produce as bright a spot as desired in this invention, it is the number of quanta arriving through the optical system from a given source which determines its visibility. In other words, the problem of getting enough illumination on the screen to render the object visible has entirely disappeared, and in its place we have only the problem of getting enough quanta to produce sufficient photoelectrons so that the fluctuations in the time and position of their arrival will not obscure the shape and character of the object being viewed. Therefore, it is not the f value of the lens system used with this device which counts in determining the visibility of an object small compared to the field of view, but only the diameter of the objective lens.

It would seem then that the over-all relative sensitivity of the whole device, including the optical system, might be increased to any desired amount by simply increasing the diameter of the objective lens. However, using the highest f value lens obtainable, and retaining a 6 cm. square photoelectric grid surface, it will be seen that, as the diameter of the objective lens is increased the angle of view subtended by the photoelectric grid decreases. Therefore, it becomes necessary to assume some arbitrary angular field of view, which will be large enough so that a particular object can be located and its character interpreted, and to compare sensitivities on that basis.

It can be assumed that 0.75 radian which is about the angular field of view of an ordinary camera will be satisfactory. Since the photoelectric grid is 6 cm. square, the focal length of the lens must be about 8 cm. in order to obtain such a field of view. Using a lens of f/1 and having a focal length of 8 cm., the diameter of the lens that can be used is then fixed at 8 cm. Such high f values are commonly obtained with Schmidt cameras.

In an article of Albert Rose entitled "The relative sensitivities of television pick-up tubes, photographic film, and the human eye," in the Proceedings of the I. R. E., June, 1942, p. 293, a number of constants for the human eye are given. On p. 298, paragraph 4, the f value for the human eye is given as f/2 for threshold vision, f/3.5 for clear vision, and f/8 for bright light. The focal length is given as 1.5 cm. Therefore, using f/3.5 for clear vision, the effective diameter of the lens of the eye is about 0.43 cm.

Since the intrinsic sensitivity of the present device is about the same as that of the human eye, the relative sensitivity of the device, with

the above lens system, compared with the eye, with its lens system, will be determined solely by the amount of light delivered to each from a particular object. Therefore, the over-all gain in light sensitivity of the device over the human eye will be proportional to the square of the ratio of the instrument lens diameter to the effective eye lens diameter, or

$$\left(\frac{8}{.43}\right)^2=430$$

for the particular dimensions chosen.

It is obvious that this over-all gain in sensitivity over the human eye may readily be increased by altering certain dimensions. For instance, if the dimensions of the grid and screen assembly are doubled, the diameter of the objective lens can be doubled, which would then give a gain in sensitivity of $4\times430=1720$. This same result could obviously be obtained, without altering the dimensions of the grid and screen assembly, if it is found possible in any particular application to get along with an angular field of view of half as much as was assumed.

The detailed construction described and the dimensions chosen throughout this description are to be understood as illustrative only, and in no way limit the invention. Arbitrary dimensions were chosen in order to be able to work out results in a particular case so that some idea of the capabilities of the device could be shown.

The above described device can be easily made to see in color by utilizing the two rotating color discs **53**, one placed in front of the first photoelectric grid **3**, and the other placed between the eye **11** and the fluorescent screen **4** (see Fig. 1). Thus, at any particular time, the optical image focused on the first photoelectric grid **3** will include only that much of the object as emits radiation of the same color as the filter **54** which is in front of the first photoelectric grid **3** at that time. This partial image will be converted to a corresponding intensity amplified black-white image at the fluorescent screen **4**, which image will then be seen by the eye in the proper color due to the action of the color filter **54** which is in front of the eye. As the two color discs **53** rotate, the various colors emitted by the object are reproduced at the eye in their proper relative proportions in rapid succession, so that the effect of seeing a color image will be produced at the eye. Some loss of light sensitivity will result in this process, but, since the color vision elements of the eye are very much less sensitive than the black-white elements, the over-all relative sensitivity of the device over the eye will be considerably higher for color work than for black-white work. The fluorescent screen **4** should be given no time lag in this case, since any persistency of the image at the fluorescent screen **4** would interfere with the next succeeding color.

Also, since photocells may be highly sensitive in the near infra-red and the near ultra-violet, the device may be given infra-red and ultra-violet color vision by the insertion of an infra-red or ultra-violet filter screen in place of any one of the color filters **54** in the first color disc **53**. In this way ultra-violet or infra-red light can be made to appear as some arbitrarily chosen visual color. The remaining portion of the picture will appear in its true color except for the omission of the color of the filter which has been replaced.

Referring now to Fig. 7 in which another embodiment of the invention is illustrated, there is shown within a cathode ray tube **30**, a grid and condenser assembly **31** which is identical to the grid and screen assembly **1** of Fig. 1 insofar as the grids **3**, **3'** are concerned. In place of the fluorescent screen **4** and thin metal foil **5** of Fig. 1, however, there is shown an extremely thin dielectric sheet **32**, which may be of mica, and a thin metal sheet **33**, which may be simply a coating of beryllium condensed on one side of the dielectric sheet **32**. Voltages are applied by the battery **6** and rheostat **7** similar to those applied to the grid and plate assembly **1** of Fig. 1, that is, about 500 volts between grids and about 50,000 volts between the last of the secondary emissive grids **3'** and the thin metal sheet **33**.

On the other side of the dielectric sheet **32** there are shown numerous small globules **34** of some heavy metal, such as gold, each of which is separated from and independent of the others. Each of these globules **34** may be considered as forming one plate of a little condenser, the other plate of which is common to all and is formed by the thin metal sheet **33**. Grid **35**, which is maintained at a positive potential with respect to the cathode **36** by the battery **40**, attracts an electron beam from the cathode **36** toward the globuled surface of dielectric sheet **32**. Grid **35** may be replaced by the cylindrical collar **37**, or both may be used. The electron beam may then be caused to scan the globuled surface of the dielectric sheet **32** by means of the deflecting plates **38**. An electrical connection is made from the thin metal sheet **33** through the resistor **41** to the cathode **36**.

The operation of the grid and condenser assembly **31** is identical with that of the grid and screen assembly **1** of Fig. 1 previously described, except that the intensified electron image which emerges from the series of grids in this case penetrates the thin metal sheet **33** and the thin dielectric sheet **32** and is stopped by the globules **34**. In this way a negative charge is stored on each little globule **34** which is proportional to the amount of light falling on the corresponding elementary area of the surface of the photoelectric grid **3**.

As the electron beam from the cathode **36** strikes against any particular charged globule **34**, it knocks out secondary electrons, which are then drawn to the positive grid **35** or cylindrical collar **37**, thus removing the charge accumulated on the globule **34**, and re-establishing the datum potential between it and the grid **35**. Since the charge on globule **34** is removed in a time which is very short compared to the time over which the charge was accumulated, a corresponding charge is induced on the metal plate **33** which in turn causes a voltage drop across the resistor **41**. Since this voltage drop will be proportional to the total charge accumulated on globule **34** between successive scannings, it will also be proportional to the amount of light falling on the corresponding element of the surface of the first photoelectric grid **3** between successive scannings, and may therefore be used as a television signal. Thus it is seen that a television transmitting tube has been produced for converting an optical image into a television signal, which tube takes advantage of both the electron multiplication and the storage principles, and therefore has a much higher sensitivity than any of the presently used tubes.

The above described device will function satisfactorily with the globules **34** removed. In such case, however, the mica strip would have to be made thick enough to stop the electron image.

Each elementary area of the dielectric sheet 32 would then form one plate of a little condenser, and take the place of the corresponding globule 34.

Fig. 8 illustrates a modification of the present invention in which my novel electron multiplier is combined with the essential features of the ordinary Farnsworth image dissector. Within an evacuated glass tube 52, there is shown a series of grids 3, 3', which produce an intensified electron image of the object 3 in the manner previously described. The electron image is drawn from the last of the grids 3, 3' to the anode 43 as a result of the voltage applied by battery 45. The focusing coil 44 produces a uniform axial magnetic field so that electrons emerging from a particular spot on the last of the grids 3, 3' will strike the same spot on anode 43.

Scanning is accomplished by systematically moving the whole electron image across the anode 43 by means of the horizontal deflecting coils 49 and the vertical deflecting coils 50. In this way successive elements of the electron image are allowed to pass through the aperture 46 and strike the collector anode 51, which is maintained at a higher potential than the anode 43 by the battery 47. Hence, the resulting voltage drop across the resistor 48 is proportional to the amount of light falling on the elementary area, which is being scanned at that particular time, and may therefore be used as a television signal.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A light amplifier comprising means for producing an optical image of an object, a photoelectron emissive cathode for producing a primary electron stream forming an electron image from said optical image, electron permeable and secondary electron emissive surfaces for producing an intensified electron image from the primary electron image, said surfaces being separated only sufficiently to maintain electrical insulation therebetween whereby said electron stream is intensified with minimum loss of detail in said electron image caused by secondary electron emission velocities, a fluorescent screen, and means projecting said intensified electron image on said screen for producing an intensified optical image of said object.

2. A light amplifier comprising means for producing an optical image of an object, a photoelectron emissive cathode for producing a primary electron stream forming an electron image from said optical image, plural electron permeable and secondary electron emissive means for producing an intensified electron image from the primary electron image, said secondary electron emissive means being mutually spaced sufficiently close to permit intensification of said electron stream while minimizing deterioration of said electron image by secondary electron emission velocities, a fluorescent screen, and means projecting said intensified electron image on said screen for producing an intensified optical image of said object.

3. An electron image intensifier comprising a plurality of secondary electron emissive and electron permeable surfaces, and means for driving an electron image against and through successive surfaces, said surfaces being mutually spaced sufficiently close to permit intensification of said electron image by secondary electron emission at each of said surfaces while minimizing deterioration of said image caused by secondary electron emission velocities.

4. An electron image intensifier comprising a plurality of secondary electron emissive and electron permeable surfaces, said surfaces being separated only sufficiently to maintain electrical insulation therebetween, and means for driving an electron image against and through successive surfaces whereby said image is intensified at each of said surfaces with minimum loss of detail caused by secondary electron emission velocities.

5. A light amplifier comprising a lens system for producing an optical image of an object, a photoelectrically sensitive cathode for producing a primary electron stream forming an electron image from said optical image, a plurality of electron permeable and secondary electron emissive grids for producing an intensified electron image from said primary electron image, each of said grids comprising substantially parallel wires lying in a direction which is rotated through a predetermined angle for each successive grid, a fluorescent screen, and means projecting said intensified electron image on said screen for producing an intensified optical image of said object free from grid patterns.

6. An electron multiplier comprising a plurality of secondary electron emissive and electron permeable surfaces having a mutual spacing of the order of one millimeter, and means for causing an electron image to impinge upon and to be driven through successive surfaces, whereby said image is intensified by secondary electron emission at each of said surfaces while remaining substantially intact.

7. In an electron multiplier a plurality of electron emissive and electron permeable surfaces each comprising a plurality of closely spaced filamentary means having diameters of the order of one one-hundredth of an inch or less, and means for driving an electron image against and through successive surfaces, whereby said image is intensified by secondary electron emission at each of said surfaces while remaining substantially intact.

8. In an electron multiplier a plurality of electron emissive and electron permeable surfaces having a mutual spacing of the order of one millimeter, each of said surfaces comprising a plurality of closely spaced fine wires having diameters of the order of one one-hundredth of an inch or less and having spacing between centers of the order of two one-hundredths of an inch or less, and means for causing an electron image to impinge upon and to be driven through successive surfaces, whereby said image is intensified by secondary emission at each of said surfaces while remaining substantially intact.

9. A light amplifier comprising means for producing an optical image of an object, a photoelectron emissive cathode for producing a primary electron stream forming an electron image from said optical image, unitary electron permeable and secondary electron emissive surfaces for producing an intensified electron image from the primary electron image, said surfaces being successively adjacent whereby said electron stream is intensified with minimum loss of detail in said electron image caused by secondary electron

emission velocities, a fluorescent screen, and means projecting said intensified electron image on said screen for producing an intensified optical image of said object.

10. A light amplifier comprising means for producing an optical image of an object, a photoelectron emissive cathode for producing a primary electron stream forming an electron image from said optical image, plural electron permeable and secondary electron emissive means for producing an intensified electron image from the primary electron image, said secondary electron emissive means being mutually spaced sufficiently close to permit intensification of said electron stream while minimizing deterioration of said electron image by secondary electron emission velocities, a fluorescent screen, and means comprising a light-opaque anode interposed between said secondary electron emissive means and said screen for projecting said intensified electron image on said screen for producing an intensified optical image of said object.

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