Oct. 7, 1941. P. T. FARNSWORTH 2,257,942

IMAGE AMPLIFIER

Filed April 5, 1939

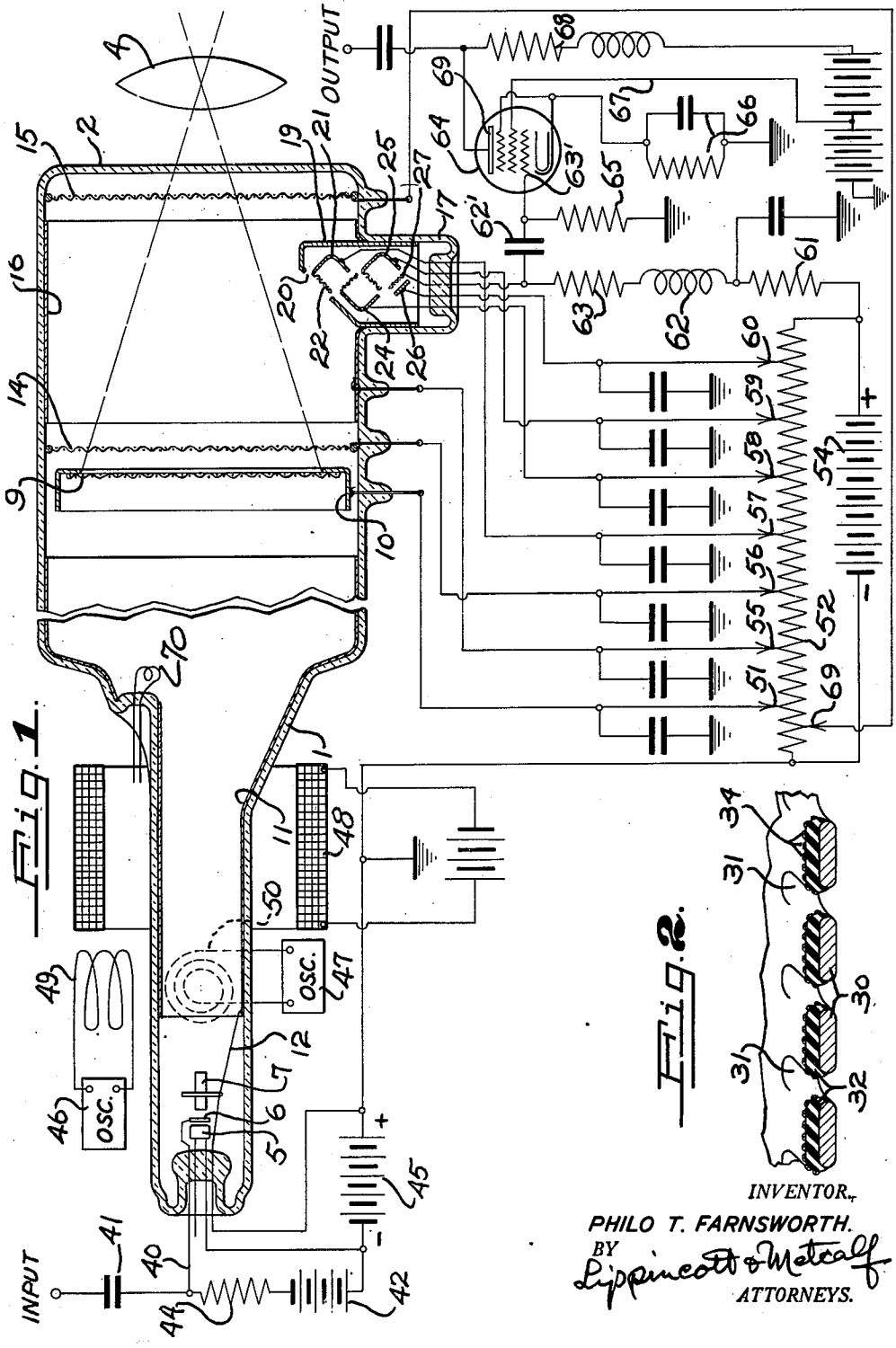


Fig. 1.

Fig. 2.

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IMAGE AMPLIFIER

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Application April 5, 1939, Serial No. 266,138

11 Claims. (Cl. 178—7.2)

My invention relates to image amplifiers, and more particularly to a means and method of obtaining a train of electrical signals representing an optical image. My system is particularly adapted for use in television.

Among the objects of my invention are: To provide an image amplifying tube of high sensitivity and fidelity; to provide an image amplifying tube and system for use in television transmitters; to provide an image amplifying system utilizing grid control of electron emission from elemental cathodes; to provide a means and method of producing a charge storage in an image amplifying tube; to provide a means and method of forming a charge storage electrode; to provide a means and method of controlling the storage time of a charge storage electrode; to provide a charge storage electrode adapted for use in an image amplifying television pickup system; to provide an image amplifying tube having a signal output well above inherent interference values; and to provide a means and method of operating a charge storage image amplifying tube and system.

My invention possesses numerous other objects and features of advantage, some of which, together with the foregoing, will be set forth in the following description of specific apparatus embodying and utilizing my novel method. It is therefore to be understood that my method is applicable to other apparatus, and that I do not limit myself, in any way, to the apparatus of the present application, as I may adopt various other apparatus embodiments, utilizing the method, within the scope of the appended claims.

Referring to the drawing:

Fig. 1 is a longitudinal sectional view, partly diagrammatic, showing one preferred form of my invention, together with a circuit by which the tube may be set into operation.

Fig. 2 is a perspective view, partly in section, showing one preferred form of charge storage electrode.

Referring directly to Fig. 1 for a description of a preferred form of my invention shown therein, an envelope 1 is provided at one end thereof with a planar window 2 through which light from an object may be projected by a lens 4. At the opposite end of the tube is positioned an electron gun which may be of conventional design, utilizing an indirectly heated thermionic cathode 5, a control grid 6 and an accelerating anode 7. Between the electron gun and the planar window 2, and coaxial therewith, is a charge storage electrode 9 mounted in a cup 10, the rim of the cup facing toward the electron gun. Between the cup 10 and the electron gun is a wall film 11 attached by a connection 12 to the anode 7 of the gun. Wall coating 11 approaches but does not connect with cup 10.

Between cup 10 and planar window 2, and immediately in front of charge storage electrode 9, is an accelerating screen 14, and a collecting screen 15 is positioned adjacent planar window 2. Both of these screens 14 and 15 are preferably of extremely fine wire in order that they do not greatly affect an optical image projected by lens 4 on charge storage electrode 9.

Positioned between screens 14 and 15 is a second wall coating 16 electrically separate from either screen, and at one side of the tube, connecting with the space between screens 14 and 15, is a multiplier tubulation 17. This multiplier tubulation 17 supports and positions a multiplier shell 19 having an opening 20 angularly facing screen 14 and charge storage electrode 9, but not extending into the optical path.

I may desire to utilize as an output device an electron multiplier, preferably of the box element type, such as described and claimed in the Richard L. Snyder application for United States Letters Patent entitled "Box element multiplier", Serial No. 149,654, filed June 22, 1937, now United States Patent No. 2,163,966 issued June 27, 1939. The first three stages are cube-shaped silver boxes. One face of each stage is open, and an adjacent face is also open but covered with a fine mesh tungsten wire screen. First stage 21 presents first-stage screen 22 across opening 20. The open side of first stage 21 is presented to the tungsten screen of second stage 24, and in similar fashion the open end of second stage 24 is presented to the screened side of third stage 25. An output screen 27 is positioned across the open end of third stage 25, and is backed by last stage 26 which is in the form of a planar silver electrode. The complete assembly thus described forms an electron multiplier, when sensitized for secondary electron emission, as described and claimed in the Snyder patent cited above.

Before describing the connections of the various elements in the tube shown in Fig. 1, I will describe, by reference to Fig. 2, the structure and formation of charge storage electrode 9. While I have found that various wire-mesh screens may be utilized for the foundation of this charge storage electrode, I have found it preferable to utilize a perforated nickel sheet 30 having approximately 160,000 perforations 31 per square inch, and approximately 0.0005 inch thick. The

nickel sheet may then be attached to cup 10 and placed in an evacuated evaporator in order that a film of refractory insulating material 32 may be evaporated on one side only thereof. This may be accomplished by utilizing the phenomenon that evaporation takes place along straight paths. The film of insulating material should have a low dielectric constant, be highly refractory, and be chemically stable. I have found that barium fluoride is representative of such materials, and this material is evaporated on one side of the nickel screen within an evaporating vessel by placing barium fluoride in a container approximately 6 inches from the screen, and heating the container.

I have found that a film of dielectric between 0.0003 and 0.0005 inch thick may be evaporated onto the nickel sheet in about five minutes. This process provides the dielectric coating 32, with the edges of this coating slightly overlapping the edges of the perforations in the nickel sheet, as shown in the sectional views of Fig. 2. I have also found that it is desirable to apply a tickler coil to the nickel sheet during the evaporation process in order to prevent too great an accumulation of barium fluoride on the sides of the perforations. Bulging sides at these points will greatly reduce the size of the openings in the sheet, which is, of course, undesirable.

The next step is to sputter a film of silver, indicated by globules 34 in Fig. 2, on top of the barium fluoride coating 32, preferably in an atmosphere of rarified oxygen. This silver film should preferably have extremely low conductivity approaching infinite resistance, and it has been found that less conductivity may be obtained by using oxygen than with any other gas.

The nickel screen with its dielectric and silver coatings may then be mounted in envelope 1, with the silvered surface facing the planar window 2 and with the nickel surface facing the electron gun. The other elements are then placed within the envelope 1 and the tube is degassed by baking for several hours at a high temperature. The silver film 34 is then oxidized in a glow discharge in the usual manner, well known in the art.

After cooling, the temperature is reduced to 200° C., and caesium is slowly distilled into the envelope 1 between the gun and the charge storage electrode 9 until the direct current photoelectric peak of the sensitized silver is just passed. The tube is then baked at 200° C. and baked for a short time until the peak value of photoemission is again reached. This procedure results in a mosaic photoelectric surface on the side of the charge storage electrode 9 facing planar window 2 and lens 4.

It will be obvious, however, that I have described just above only one method of obtaining a mosaic photoelectric surface, and I do not wish to be limited in any way to this particular method, as other methods and other materials may also be used to obtain the same result, as is well known in the art.

After the charge storage electrode 9 has been formed as just above described, the electron multiplier stages 21, 24, 25 and 26 may then be treated with suitable materials in order to obtain therefrom secondary electron emission at ratios greater than unity. Caesium treatment similar to that required to produce photoelectric surfaces may be applied to the multiplier stages directly through side tubulation 17 without affecting the sensitization of the charge storage electrode 9.

While there is another step, usually found desirable in the formation of the charge storage electrode 9, namely, the step of controlling the leakage time between the photoelectric mosaic 34 and the nickel screen 30, it is believed that a description of one type of circuit utilized to place the tube in operation will render the discussion of this final step more understandable. Accordingly, cathode 5 may be connected to a heating circuit in a manner well known in the art, in order that this cathode emit electrons. Grid 6 is connected by wire 40 through blocking condenser 41 to a signal input to which blanking impulses may be applied to extinguish the cathode ray beam during retrace intervals, and grid 6 is maintained at the proper biasing potential by bias battery 42 and bias resistor 44. Anode 7 is energized by anode source 45 at ground potential, source 45 placing the cathode 5 more negative than ground potential. Scanning oscillators 46 and 47 through scanning coils 49 and 50 move the electron beam emitted from anode 7 in two directions over a picture area on the nickel side of charge storage electrode 9, and focusing coil 48 is used to define the beam. The nickel screen 30 forming the foundation of this charge storage electrode is made more positive than anode 7 by means of a tap 51 on voltage-dividing resistor 52, this resistor being energized by the source 54. Multiplier housing 19 and connected film 16 are energized at the next higher potential by tap 55; accelerating screen 14 is held at the next higher potential by tap 56; first multiplier stage 21 is held at the next higher potential by tap 57; second multiplier stage 24 is held at the next higher potential by tap 58; third multiplier stage 25 is held at the next higher potential by tap 59; last stage 26 is held at the next higher potential by tap 60.

Output screen 27 of the multiplier is held at the highest potential through a final output circuit comprising a filter resistor 61, a choke coil 62 and an output resistor 63. Output screen 27 is also connected through a blocking condenser 62' to the control grid 63' of an output tube 64, the latter having a bias resistor 65, a screen bias connection 67, and an output resistor 68 connected to the anode 69 of output tube 64, all in the manner well known in the art for the connection of a screen-grid tube. Other output circuits are fully equivalent.

In operation the electron gun may be energized, for example, with a voltage of 500 to 1500 volts, to bombard the nickel side of the charge storage electrode 9. Some of the electrons in the gun beam, as it is scanned over the picture area on the nickel side of charge storage electrode 9, will pass through the perforations of the electrode and are collected on end screen 15 which is only slightly positive relatively to the gun anode 7, as indicated by end screen tap 69 on voltage divider 52. About 80% of the electrons in the gun beam, however, strike the metallic nickel surface of electrode 9 to produce secondary electrons.

I prefer to have a potential difference of from 5 to 50 volts positive on the accelerating screen 14 relatively to the nickel base of the charge storage electrode 9. This potential is insufficient, however, to draw any of the secondary electrons created by beam impact from the nickel side of the storage electrode 9 through the perforations of the storage electrode. However, when an optical image is focused on the mosaic side of the grid through a lens 4, photoelectrons are emitted

and drawn to screen 14, leaving the mosaic elements on the photoelectric side of storage electrode 9 charged positively with a charge that increases proportionally to the product of light intensity and time. This additional positive charge results in secondary electrons from the nickel side being pulled through the perforations in an amount which is proportional to the three-halves power of the voltage between the nickel surface and the photoelectric surface. It should be noted here that the control of each mosaic element is relatively large, since this mosaic element, acting as a grid, is only about one-thousandth of an inch from the source of the secondary electrons. The signal electrons are accelerated through screen 14 into the space between screens 14 and 15 and are drawn into the multiplier for multiplication therein.

We thus have a multiplicity of small amplifiers of which only those very near the area bombarded by the scanning gun beam have an emitting cathode. The current in the gun beam need not be more than a few microamperes, since this is quite adequate to give space charge saturation, for if a beam of elemental size is used and then multiplied by the number of picture elements, the effective cathode emission for the total number of elements may be on the order of an ampere or more.

It will be noted that the elemental grid elements, though effectively free under the conditions described thus far, are operated positively. It might be expected, therefore, that the grid current drawn by it would be excessive, and that the sensitivity would be decreased due to the rapid discharge of a grid element when the scanning beam was operating in its vicinity. Almost the opposite has been found to be true, however, and if a high potential difference is applied between screen 14 and the charge storage electrode 9, the beam discharge action is very low. Thus, the tube may be operated to have a "memory" or storage time of from five to ten minutes, thus rendering the tube practically useless for the transmission of moving objects but useful for other purposes.

Reducing the voltage applied between the screen 14 and the grid improves the speed of response and naturally decreases the sensitivity accordingly. In practice, the voltage difference is adjusted to be as high as possible without blurring of the field when the object moves. It is not necessary, however, that the elemental mosaic grid elements be operated free, as the leakage time may be controlled by evaporating the thin film of metal through the perforations in the grid from the nickel side until the time constants of the grid have the desired value. This effectively results in providing the grid elements around the perforations with a high-resistance leak across the edges of the insulating layer 32 at the edges of the perforations. In this manner the leakage time may be controlled as desired. If desired, a small nickel filament 70 may be positioned within the gun end of the tube and utilized during initial operation of the tube to control the leakage time. Other metals, such as magnesium or the like, may be used.

It should be noted that the potential of screen 14 is higher than the potential of multiplier shield 19 and attached wall film 16, but that the potential of first stage 21, presenting its screen 22 to the space between screens 14 and 15, is the highest positive potential acting on this space. Consequently, signal electrons passing through screen 14 are directed toward the multiplier input, pass through opening 20 and first-stage screen 22, and impact the sensitized surface of the first stage 21. Secondary electrons emitted by impact in first stage 21 are accelerated into second stage 24 to create more secondary electrons. These secondary electrons are accelerated into third stage 25 to create further electrons, and these latter are then accelerated to impact last stage 26. Secondary electrons emitted from the last stage 26 are collected by output screen 27, and the output current, comprising the signal current multiplied by repeated liberation of secondary electrons at a ratio greater than unity, is thereupon utilized in the output circuit in the usual manner for whatever purpose desired.

It has been found, experimentally, that signal electrons from all portions of the charge storage electrode 9 can be uniformly collected in the first stage of the multiplier with an efficiency of approximately 80%.

It should be pointed out also that one of the features of the present invention is the practical elimination of noise or irregularity in output due to the electrons of the scanning beam passing through the charge storage electrode 9. When no means are provided for collecting these primary-beam electrons to keep them from flowing in the output circuit, it is necessary that the component of signal current be at least 10% of the total beam current. Thus, if the beam current were to be 5 microamperes, the signal component would have to be at least 0.5 microampere; in other words, the sensitivity of the tube would be reduced approximately 10 to 1. However, by keeping primary electrons out of the work circuit by the use of the electron multiplier and the collection of scanning-beam electrons on screen 15, this reduction in sensitivity is entirely eliminated. Furthermore, the fluctuation voltage present on the elemental grid elements, that is produced by both thermal agitation and shot irregularities of the photocurrent, has a maximum frequency component in the neighborhood of ten cycles per second, and this frequency component is not passed by the external video-frequency amplifiers. Also, there is little or no shot noise in the multiplied current. The electron multiplier, therefore, may be utilized to increase the sensitivity of the tube by a factor of from twenty to one hundred times, not only without increasing the noise factors, but with actual reduction thereof because of the elimination of the scanning-beam electrons from the output.

The merits of the image amplifying tube and system described and claimed herein may therefore be summed up as follows:

(1) It provides a short optical system with the image plane perpendicular to the axis of the lens;

(2) No excessive power is required in the scanning beam;

(3) The electron beam scans the cathode perpendicularly;

(4) There is no shading compensation required; and

(5) My invention produces a light sensitivity several orders better than previous types of electronic scanning devices without increase in noise level.

I claim:

1. An image amplifier system comprising an envelope containing an electron-permeable charge storage electrode comprising a conducting foun-

dation, a layer of insulating material on one side only of said electrode, the other side of said electrode being capable of producing secondary electrons at a ratio greater than unity, and a mosaic photoemissive surface on said insulating material; means for focusing an optical image on said mosaic; electron producing and directing means for developing an electron beam of elemental cross-section impacting the secondary-emissive side of said electrode at a velocity sufficient to produce secondary electrons therefrom; means for scanning successive elementary areas of the impacted side of said electrode; means spaced from said electrode to collect beam electrons passing through said electrode; and separate means for collecting secondary electrons passing through said permeable electrode.

2. Apparatus in accordance with claim 1, with an accelerating screen positioned in front of said mosaic and energized to a potential insufficient to draw secondary electrons through said permeable electrode in the absence of light on said mosaic.

3. Apparatus in accordance with claim 1, with means positioned on the side of said permeable electrode remote from said electron beam producing means for collecting photoelectrons emitted from said mosaic surface.

4. Apparatus in accordance with claim 1, wherein the separate means for collecting the secondary electrons passing through said permeable electrode is an output electrode positioned between said mosaic and the means for collecting beam electrons, and positioned outside of the path of said beam electrons passing through said permeable electrode.

5. Apparatus in accordance with claim 1, wherein the separate means for collecting the secondary electrons passing through said permeable electrode is the first stage of an electron multiplier, said first stage being positioned outside of the path of beam electrons passing through said permeable electrode.

6. Apparatus in accordance with claim 1, with an accelerating screen positioned in front of said mosaic and energized to a potential insufficient to draw secondary electrons through said permeable electrode in the absence of light on said mosaic but energized to a potential sufficient to collect electrons emitted from said mosaic in the presence of light, said separate means for collecting secondary electrons being positioned between said accelerating screen and said means for collecting beam electrons and out of the path of beam electrons passing through said permeable electrode.

7. An image amplifier system comprising an envelope containing an electron-permeable charge storage electrode comprising a conducting foundation, a layer of insulating material on one side only of said electrode, the other side of said electrode being capable of producing secondary electrons at a ratio greater than unity, and a mosaic photoemissive surface on said insulating material; means for focusing an optical image on said mosaic; electron producing and directing means for developing an electron beam of elemental cross-section impacting the secondary-emissive side of said electrode at a velocity sufficient to produce secondary electrons therefrom; means for scanning successive elementary areas of the impacted side of said electrode; an accelerating screen positioned parallel to and adjacent said mosaic, a beam-electron collecting screen positioned coaxially with and parallel to said permeable electrode and said accelerating screen and spaced from said accelerating screen; and an output electrode positioned between said collecting screen and said accelerating screen and out of the path of beam electrons passing through said permeable screen and said accelerating electrode.

8. Apparatus in accordance with claim 7, wherein said output electrode is the first stage of an electron multiplier energized to a higher potential than either said accelerating screen or said beam-electron collecting screen to attract secondary electrons passing through said permeable electrode and said accelerating screen.

9. In a system utilizing an electron-permeable electrode having one side capable of producing secondary electrons at a ratio greater than unity and an opposite side carrying a photosensitive mosaic spaced from said electrode by an insulating film, the method of producing an electrical signal in response to a light image which comprises generating a primary beam of electrons of elemental cross-section, directing said beam towards a plane to produce secondary electrons thereat, moving said beam across said plane to produce a cloud of secondary electrons delineating a picture area, applying an accelerating potential from the other side of said plane insufficient to draw secondary electrons through said plane in the absence of electrical charges therein, creating a charge image in said plane by projecting an optical image thereon and removing photoelectrons emitted thereat, and collecting secondary electrons passing through said plane under the control of charges therein.

10. In a system utilizing an electron-permeable electrode having one side capable of producing secondary electrons at a ratio greater than unity and an opposite side carrying a photosensitive mosaic spaced from said electrode by an insulating film, the method of producing an electrical signal in response to a light image which comprises generating a primary beam of electrons of elemental cross-section, directing said beam towards a plane to produce secondary electrons thereat, moving said beam across said plane to produce a cloud of secondary electrons delineating a picture area, applying an accelerating potential from the other side of said plane insufficient to draw secondary electrons through said plane in the absence of electrical charges therein, creating a charge image in said plane by projecting an optical image thereon and removing photoelectrons emitted thereat, collecting beam electrons passing through said plane, and separately collecting secondary electrons passing through said plane under the control of charges therein.

11. Method in accordance with claim 10, wherein collected secondary electrons are multiplied by repeated secondary electron producing impacts.

PHILO T. FARNSWORTH.

CERTIFICATE OF CORRECTION.

Patent No. 2,257,942. October 7, 1941.

PHILO T. FARNSWORTH.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, second column, lines 12 and 13, claim 7, for the words "screen and said accelerating electrode" read --electrode and said accelerating screen--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 2nd day of December, A. D. 1941.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)

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