

May 22, 1956

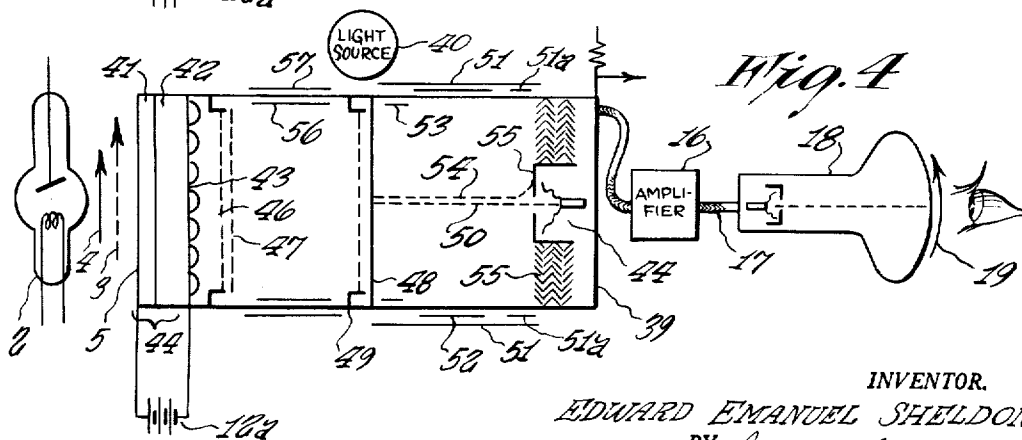
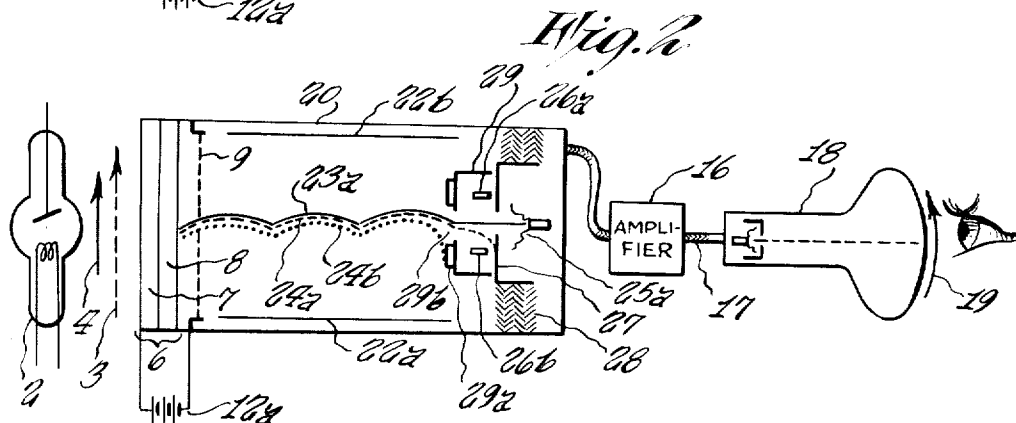
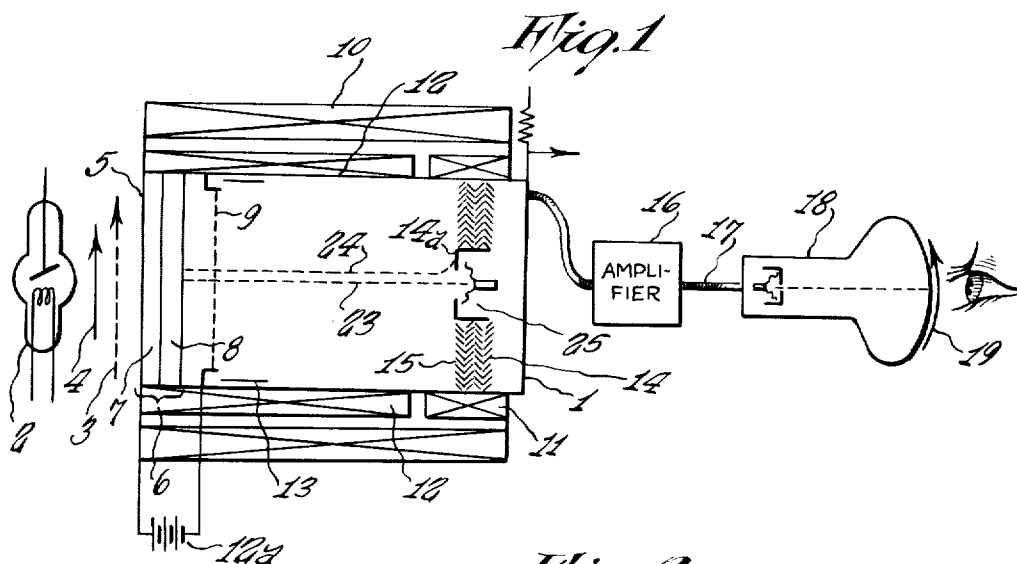
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2,747,131

ELECTRONIC SYSTEM SENSITIVE TO INVISIBLE IMAGES

Filed Oct. 12, 1951

3 Sheets-Sheet 1



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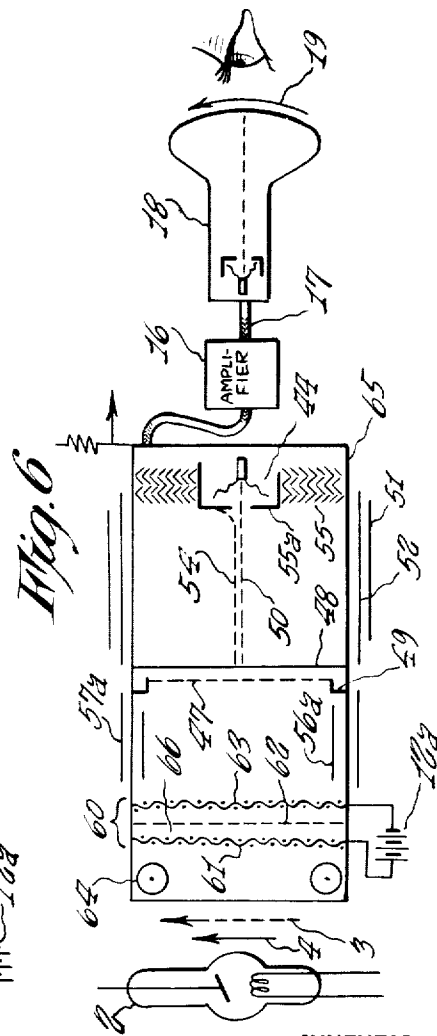
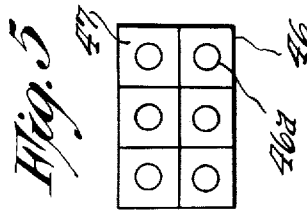
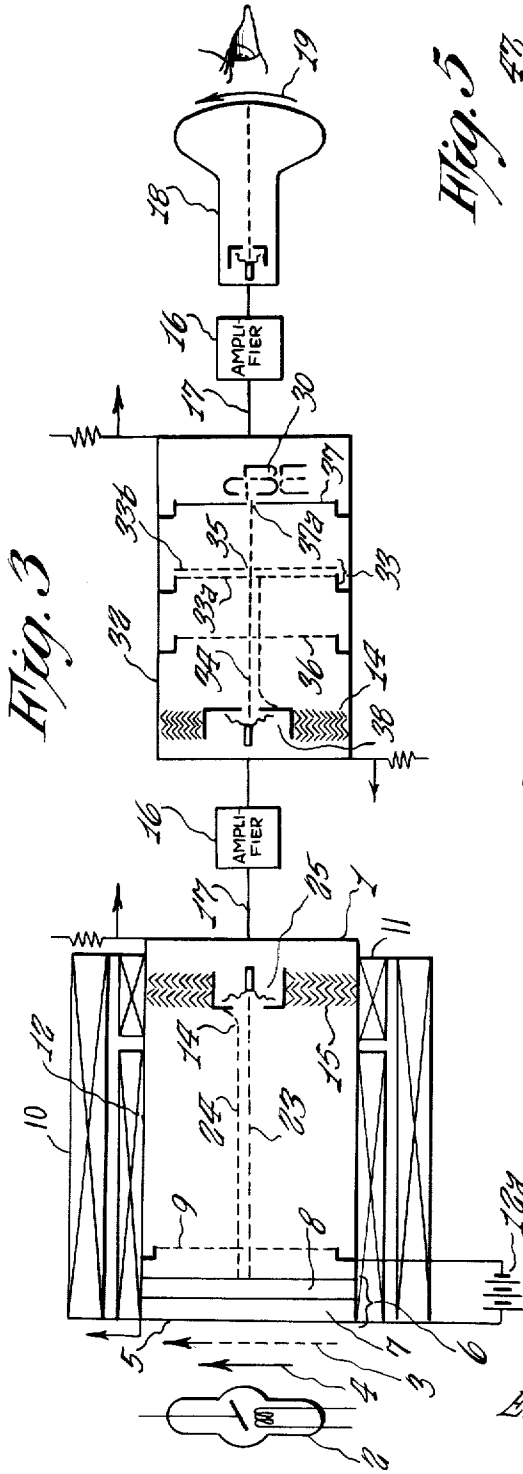
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ELECTRONIC SYSTEM SENSITIVE TO INVISIBLE IMAGES

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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

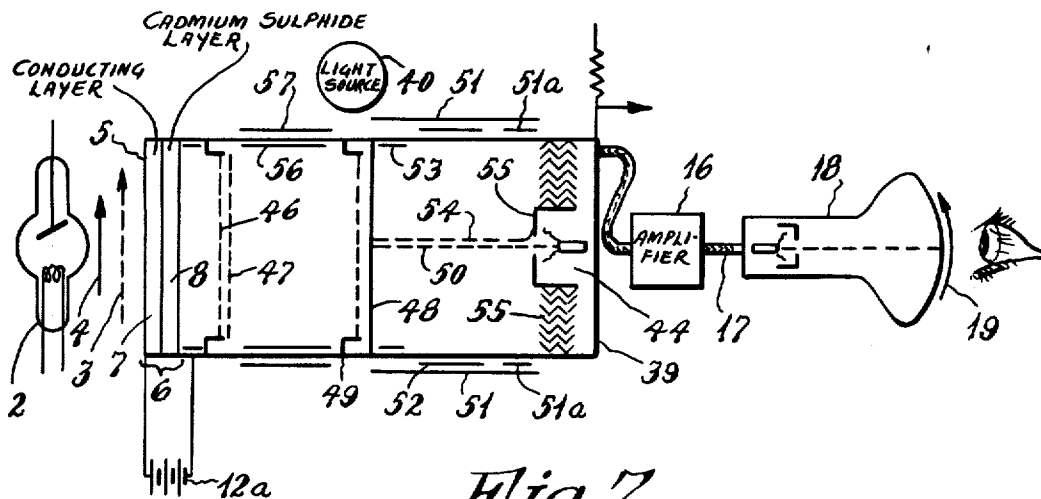


Fig. 7

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2,747,131

ELECTRONIC SYSTEM SENSITIVE TO INVISIBLE IMAGES

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17 Claims. (Cl. 315—11)

This invention relates to an improved device for intensifying images and refers more particularly to an improved device for intensifying images formed by the X-ray radiation, which term is meant to include other invisible radiations, such as gamma rays and the like. My invention can be also used for images formed by irradiation by beams of atom particles, such as e. g. neutrons, and is for the same subject matter as my U. S. Patent No. 2,555,424.

The main problem in using X-rays or neutrons for medical diagnosis is the danger of causing damage to the patient by radiation. The danger of over-exposure necessitates the use of a very weak X-ray or neutron beam, which means that the X-ray intensity must be very low and, therefore, we do not have enough of X-ray quanta in the invisible X-ray image of the human body. If we do not use all X-ray quanta, we will not be able to reproduce an image having all the necessary intelligence, no matter how much we will subsequently intensify this image by electronic means. The present X-ray receivers of photoemissive type have a very low quantum efficiency, such as the order of a fraction of 1% and, therefore, suffer from this basic limitation. The solution of this problem and primary objective of my invention is to provide an invisible radiation receptor, which will utilize all incoming photons of radiation, which means it will have a quantum efficiency close to unity.

Another object of this invention is to provide a device to produce intensified images. This intensification will enable the overcoming of the inefficiency of the present X-ray fluoroscopic examination. At the present level of illumination of the fluoroscopic image, the human eye has to rely exclusively on scotopic (dark adaptation) vision, which is characterized by a tremendous loss of normal visual acuity in reference both to detail and to the contrast.

Without intensification of luminosity of at least of the order of 1000, the eye is confined to so-called scotopic vision, at which it is not able to perceive definition and contrast of the fluoroscopic image. It is well known that intensification of the brightness of the X-ray fluoroscopic image cannot be achieved by increase of energy of the X-ray radiation, as it will result in damage to the patient's tissues. Therefore, to obtain the objects of this invention, a special X-ray sensitive pick-up tube and system had to be designed.

Another object of this invention is to make it possible to prolong the fluoroscopic examination since it will reduce markedly the total strength of radiation affecting the patient's body. Conversely, the exposure time or energy necessary for the radiography may be reduced.

Another object is to provide a device to produce sharper X-ray fluoroscopic and radiographic images than was possible until now.

Another important objective of this invention is to provide a device to amplify the contrast of the X-ray image.

The objectives of this invention were obtained by a novel invisible radiation sensitive pick-up tube. This

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tube has X-ray or neutron image receiving surface of a dielectric material, which exhibits property of becoming conductive and producing a current of electrical charges therein in response to X-ray neutron beam.

The theory and explanation of this phenomenon is given by the article of S. G. Zizzo and J. B. Platt "Detection of X-ray quanta by a cadmium-sulphide crystal counter," Physical Review, volume 75, September 1, 1949, page 704. It is believed that energetic X-ray photons striking X-ray sensitive dielectric materials are able to remove an electron from its place in the matter. The deficiency of an electron can be considered as a positive particle, which is also called a positive hole. Electrons and positive holes move across said insulator under the influence of electrical field applied by means of conducting electrodes, which are deposited on either side of insulator. The electrons and positive holes form, therefore, a current of electrical charges produced by X-rays, and produce in the invisible radiation sensitive screen a pattern of electrical charges with a high quantum efficiency, such as approaching unity. The electrical charges have the pattern of the X-ray or neutron image. They cannot, however, be used directly for reproduction of a visible image with the necessary intensification. In my invention they are used to modulate an electron beam which scans this electrical pattern on said screen in television-like raster. The modulated scanning electron beam will have, therefore, the pattern of the original X-ray or neutron image. This electron beam is converted into video signals. Video signals are sent to amplifiers. By the use of variable mu amplifiers in one or two stages, intensification of video signals can be produced in non-linear manner, so that small differences in intensity of succeeding video signals can be increased one to ten times, producing thereby a corresponding gain of the contrast of the final visible image in receivers, which was one of the objectives of this invention. Amplified video signals are transmitted to kinescopes to reproduce a visible image with necessary intensification, as was explained in my U. S. Patent No. 2,555,424.

In some cases, it may be necessary to include a special storage tube in the X-ray image intensifying system, in order to overcome the flicker resulting from too long a frame time. In such case, video signals are sent to the storage tube having a special storage target and are deposited there by means of modulating electron scanning beam of said storage tube. The stored electrical charges, having the pattern of X-ray image, are released from said electrode, after predetermined time, by scanning it with another electron beam or, in a modification of the storage target having photoemissive elements, by irradiating it with light. The released electron image is converted again into video signals and sent to final receivers to produce visible image with desired intensification and gain in contrast and sharpness.

In this way, all purposes of the invention were accomplished. The invisible X-ray image is converted into video signals without any loss of information because of quantum efficiency of the X-ray sensitive layer and the resulting video signals are intensified to give the necessary brightness of reproduced X-ray image.

The invention will appear more clearly from the following detailed description when taken in connection with the accompanying drawings by way of example only preferred embodiments of the inventive idea.

In the drawings:

Figure 1 is a cross-sectional view of the X-ray image intensifying system showing the novel X-ray sensitive pick-up tube.

Figure 2 is a cross-sectional view of the X-ray intensifying system showing a modification of the X-ray sensitive pick-up tube.

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Figure 3 is a cross-sectional view of the X-ray image intensifying system showing, in addition, X-ray image storage tube.

Figure 4 is a cross-sectional view of the X-ray intensifying system showing a modification of the X-ray sensitive pick-up tube.

Figure 5 is a front view of the photoemissive screen in the pick-up tube shown in Fig. 4.

Fig. 6 is a cross-sectional view of a modification of the X-ray pick-up tube having a perforated X-ray sensitive screen.

Fig. 7 shows a preferred embodiment of invention.

Reference now will be made to Fig. 1, which illustrates new X-ray sensitive pick-up tube 1 to accomplish the purposes of the invention as outlined above. The X-rays or neutrons 2 produce invisible image 3 of the examined body 4. The invisible X-ray image 3 penetrates through the face 5 of the X-ray sensitive pick-up tube and strikes the composite screen 6 acting as a photocathode. Screen 6 consists of a very thin X-ray transparent conducting layer 7, such as of aluminum, gold, silver or platinum, and of layer 8 of a dielectric material, which becomes conductive and produces a current of electrical charges therein when irradiated by X-rays or neutrons. Such materials sensitive to X-rays or neutrons are CdS, diamond, quartz, MgO, ZnS or antimony compounds. It is to be understood, however, that my invention is not limited to any particular material, as there are many substances, which have such properties and which are known in the art. The impingement of X-ray beam modulated by the examined body on said screen produces, therefore, a flow of electrical charges (electrons and positive holes) across it, as was explained above. The positive electrical charges have the pattern of X-ray image and migrate to one side of said screen under the influence of polarizing electrical field provided by a source of electrical power, such as battery 12a. The negative charges migrate to the opposite side of said screen. In the preferred embodiment of my invention, the positive charges are directed to the uncovered side of layer 8, which is facing electron gun 25. The uncovered side of layer 8 has a continuous surface, as shown in Fig. 1 or Fig. 7.

In some cases, in order to improve the action of the polarizing field across the layer 8, an additional mesh screen 9 is mounted in close spacing, such as a few microns, from the layer 9, between said layer 8 and electron gun 25 and is connected to one of the terminals of battery 12a.

The response of X-ray sensitive layer 8 to X-rays may be increased by irradiating said layer with green light simultaneously with X-ray or neutron exposure. In some cases, the use of red or infra-red will be preferable for intensification of the current of charges produced by X-ray beam. The scanning electron beam 23 produced by electron gun 25 is decelerated in front of the layer 8 by a ring electrode 13. Also, a mesh screen may be used for this purpose. A high velocity scanning electron beam used can be used in a modification of my invention as well. The electron beam 23 is focused by focusing electrostatic or electro-magnetic coil 10 and by the alignment coil 11, which are well known in the art and, therefore, are not described in detail, in order not to complicate drawings. The electron beam 23 is deflected by deflecting coils 12 and scans the layer 8 of the target 6 in the usual television manner. The scanning electron beam neutralizes the positive charges in layer 8 produced by X-ray beam. Therefore, the scanning beam 24, which returns to the electron gun 25, is modulated by the pattern of said charges and carries video information. This novel arrangement makes it possible to obtain much better results than the previously known systems, because the quantum efficiency of the novel screen 8 approaches unity, whereas the best quantum efficiency of fluorescent materials in combination with photoemissive materials is only a frac-

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tion of 1%. The returning electron beam 24 strikes the first stage of the electron multiplier 14a. The secondary electrons from the first stage of the multiplier strike the succeeding stage 15 around and in the back of the first stage. This process is repeated in a few stages, resulting in a marked multiplication of the original electron signals. The signal currents from the last stage of the multiplier are converted over a suitable resistor into video signals and are fed into television amplifiers 16. The current of charges produced in the insulator 8 by X-ray or neutron beam consists in reality of two different currents; one of them is A. C. current and another one is D. C. current. These two currents have different characteristics and clear understanding of their differences is very important. D. C. component of the current requires certain period of time to reach its equilibrium. A. C. component, on the other hand, reaches its equilibrium very fast and would be, therefore, more suitable for reproduction of X-ray images than D. C. component, if not for the fact that A. C. current is much weaker than D. C. current. In some applications, A. C. component is preferable in spite of its low intensity. The separation of A. C. and D. C. components can be accomplished in many ways, such as the use of A. C. amplifier, which has a low frequency cut-off at thirty cycles per second. Video signals, after amplification, are sent by coaxial cable 17 or by high frequency waves to the receivers of kinescope type 18, facsimile or skiatron type, in which they are reconverted into a visible image 19 for inspection or for recording. In order to obtain amplification of contrast of the X-ray image, the amplifiers 16 are provided with variable mu tubes in one or two stages. Small differences in intensity of the succeeding video signals are increased by variable mu tubes in non-linear manner, resulting in a gain of the contrast of the visible image in receivers. The synchronizing and deflecting circuits 12 are not shown in detail, as they are well known in the art and would complicate drawings.

The impingement of X-ray or neutron beam on dielectric layer 8 produces also changes in its electrical conductivity which have the pattern of said X-ray beam. The phenomenon of X-ray or neutron induced conductivity in dielectrics and of the X-ray induced current of charges in dielectrics, which was described above, are closely related to each other. The impingement of X-ray or neutron image on dielectric layer 8 makes it electrically conductive according to the pattern of said image. The electron beam 23 which scans layer 8 cannot pass through it when it has its normal dielectric properties. As a result a negative charge is left on the scanned surface of layer 8. When layer 8 becomes by X-ray irradiation electrically conductive, the remaining charge, as well as electrons of beam 23 arriving at the new scan, can leak through layer 8 to layer 7. This current is modulated therefore by the X-ray or neutron image stored as a conductivity pattern and may be converted into video signals over a suitable resistor, as it is well known in television art.

The duration of X-ray or neutron induced conductivity in dielectric layer 8 may vary considerably according to the type of material used and the manner of its preparation. In the system described above the duration of induced conductivity was $\frac{1}{30}$ – $\frac{1}{50}$ second, so that the X-ray exposure had to be maintained throughout the examination. The lag in this system would be very detrimental because without a fast succession of pictures such as 15–30 per second, flicker or trailing of images would result. On the contrary in medical X-ray examinations I discovered that a long duration of induced conductivity may be of a great benefit. If the conductivity changes which have the pattern of the invisible image will persist for a long time we will be able to reproduce X-ray images during all this time without necessity of maintaining X-ray radiation. Once the conductivity pattern in layer 8 was formed, the X-ray beam may be shut off and the

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scanning beam 23 will produce video signals as long as this conductivity pattern lasts. In this system of operation the tube 1 acts as a storage tube. It is preferable in this system to use video signals produced by electrons of beam 23 which pass through layer 8 and appear at the conducting layer 7, where they can be converted over a suitable resistor into video signals for reproducing visible images.

In modification of my invention shown in Fig. 2, the invisible radiation image 3 is projected onto the pick-up tube 20. The invisible radiation sensitive tube 20 has photocathode 6, which has the same construction as photocathode 6 used in the tube 1. The X-ray image produces in the dielectric layer 8 a current of electrons and "positive holes," as was explained above, and which has the pattern of said X-ray image. The positive charges migrate to the side of the layer 8 facing the electron gun 25a. The photocathode 6 is scanned by electron beam 23a from the electron gun 25a, as was explained above. The scanning electron beam 23a is given helical motion, which means an additional transverse velocity. This is accomplished by the use of two electrodes 26a and 26b disposed on both sides of the scanning beam 23a. The electrodes 26a and 26b are provided with a positive potential from an extraneous source of electrical energy. The helical motion may also be produced in other ways, such as, for example, by misalignment of the electron gun 25a in relation to the axial focusing field. The scanning electron beam is decelerated in front of the X-ray sensitive screen 6 by means of ring electrode or preferably by using a mesh screen. The scanning electron beam 23a neutralizes the positive charges in screen 6, and is, therefore, modulated by said pattern of the electrical charges. The returning electron beam consists of two different groups of electrons. One of them, 24b, is made of electrons reflected by the photocathode 6, whereas the other group, 24a, is formed by scattered electrons. The reflected electrons correspond to dark areas of the picture. The scattered electrons correspond to the light areas of the picture, because the light areas produce stronger charges on the target, as was explained above. The returning electron beam, consisting of these two different groups of electrons, is deflected from the original path of the scanning beam 23 by electrodes 22a and 22b. These electrodes may be planar or curved and do not have to be described in detail, as they are well known in the art. In front of the electron gun 23, there is disposed cylindrical electrode 29, which pulls the secondary electrons from the first multiplying dynode 27 into the multiplier 28. A disc 29a is connected with the electrode 29 or forms a part of it. The disc 29a has an opening 29b, which may be of a circular or rectangular shape. The electrodes 22a and 22b cause displacement of the returning electron beam downwards. As was explained above, the scattered electrons 24a, having larger transverse velocity than the reflected electrons, are outside of the beam of the reflected electrons 24b. Therefore, by depressing the returning electron beam by electrodes 22a and 22b, the reflected electrons may be directed against the disc 29a below its aperture 29b and will be eliminated, whereas the scattered electrons will be admitted into aperture 29b. In this way, both groups of electrons may be separated from each other. The scattered electrons, after passing through the aperture 29b, strike the first dynode 27 of the multiplier 28. The secondary electrons are drawn by the action of the electrode 29 to the next stage of the multiplier, which is around and in the back of the first stage. This process is repeated in a few stages, resulting in a marked multiplication of the original electron signals. The signal currents from the last stage of the multiplier are converted over a suitable resistor into video signals. The strongest video signals will correspond to the highlights of the picture, because the strongest scattering of electrons takes place at the most positively charged areas of the X-ray sensitive screen 6. In front of

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the X-ray sensitive screen 6, there is disposed a mesh screen 9, which provides a uniform electrical field necessary for good resolution of the picture. Video signals are fed into the television amplifiers 16 and then are sent by coaxial cable 17 or by high frequency waves to the receivers of kinescope type 18 or facsimile, in which they are reconverted into visible images 19 for inspection or recording.

In another modification of my invention shown in Fig. 3, an additional feature of the storage of invisible radiation image is added. By the use of a special storage tube 32 for video signals, a great improvement in the operation of the X-ray image intensifying system was obtained. By the use of storage tube, the scanning time in the X-ray pick-up tube can be prolonged, as well as the frame time, resulting in a proportionally greater electron output of the composite photocathode and better signal to noise ratio. Also, the flicker caused by prolongation of frame time can be in this way successfully eliminated.

Another advantage of the use of the storage tube in the X-ray intensifying system is the reduction of total X-ray exposure, which is given to the patient, because X-ray radiation does not have to be maintained any more while studying the X-ray image. This saving of the X-ray exposure will make it possible to use strong but short bursts of X-rays or neutrons without endangering the patient. The possibility of using a strong X-ray or neutron beam will markedly improve signal to noise ratio of the whole system and will, therefore, make it possible to obtain pictures of good detail and contrast even of the thickest part of the body.

The X-ray image in the form of the video signals is sent from the X-ray pick-up tube 1 or 20 to the storage tube 32 and is deposited there in the form of electric charges, by means of modulating the scanning electron beam 34 of said storage tube, in a special target 33, in which it can be stored for a predetermined time.

The storage target 33 consists of a thin perforated sheet of metal or other conducting material, or of a woven conducting wire mesh 33a. On the side of the target opposite to the electron gun, there is deposited by evaporation storage material 33b in such a manner that openings 35 in the target should not be occluded. In some cases, on the side of the target facing the electron gun, there is deposited by evaporation, a thin metal coating to prevent leakage of charges. The scanning electron beam 34 is produced in the storage tube 32 by the electron gun 38 and is modulated by incoming video signals from the X-ray pick-up tube 1. The scanning electron beam is focused and deflected to produce television-like raster by electromagnetic or electrostatic means, which are well known in the art. This scanning electron beam should have the finest spot compatible with the required intensity of beam. Between the electron gun and the storage target 33, in close spacing to the target, there is mounted a fine mesh conducting screen 36. On the opposite side of the storage target, there is disposed a metal electrode 37, which acts as an electron mirror during the writing phase of operation and as a collector of the electrons during the reading phase.

The scanning beam is decelerated between the screen 36 and the target 33. Then it passes through the openings 35 in the target 33. The reflector electrode 37 during writing is kept at the potential negative in relation to the electron gun cathode 38. Therefore, the electrons of the scanning beam are repelled by it, fall back on the storage target 33 and deposit thereon varying charges at successive points according to the amplitude of modulating input signals from the X-ray pick-up tube 1. The best way of operating my system is to have the storage surface at zero potential or at cathode potential and then to write on it "positive," which means to deposit positive charges. This can be accomplished by adjusting the potential of the surface of the storage target so that its secondary emission is greater than unity. The secondary electrons will

be collected by the conducting mesh 33a of the storage target and positive charges will be left on the storage surface. These positive charges deposited on the storing surface of the target may be stored thereon for many hours depending on the type of the storage material 33b which was used. Whereas BaF₂ has a time constant of 0.1 second, CaF₂ has the time constant of 50 hours.

The video signals corresponding to X-ray image may be stored in the form of a charge image also on the side of the storage target facing the electron gun. In such a case, the storage surface of the target should face the electron gun and reflector 37 is not operating during the writing phase. When the stored image is to be read, the potential of the electron reflector 37 is made more positive than the potential of the storage screen mesh 33 so that it will act now as a collector of electrons. Therefore, the scanning electron beam 34 after passing through the perforations 35 in the target 33 will land on the collector 37. The passage of the scanning electron beam is modulated by the pattern of deposited charges on the storage target. The greater the positive charge, the more electrons will pass through the openings 35 in the target. The less positive the stored charge, the fewer electrons will be transmitted through these openings. In this way, the electron beam 34 scanning the storage target in the usual television-like raster will be modulated by the stored image. The transmitted electrons will be collected by the collector 37 and will be converted over suitable resistor into video signals. The transmitted electrons may also be multiplied by using as a collector 37 an apertured electrode and deflecting fields to make said electrons pass through said aperture 37a in succession and to be fed into multiplier 30 before converting them into video signals. This multiplication system is well known in the art as evidenced by image dissector of Farnsworth and, therefore, it does not have to be described in detail. Video signals, having the pattern of the original X-ray image, are amplified and transmitted by coaxial cable 17 or by high frequency waves to receivers. Receivers of various types, such as kinescopes 17, skiatrons, facsimile receivers, electrographic cameras, may be used to reproduce images for inspection or of recording.

After the stored image has been read and no further storage is desired, it may be erased by the use of the scanning electron beam 34 and by adjusting the potential of the storage target to the value at which the secondary electron emission of its storing surface is below unity. In such a case, the target will charge negatively to the potential of the electron gun cathode. The potential of the reflector in the erasing phase of operation must be more negative than of the storage target so that the scanning electron beam will be repelled to the storage target and will neutralize the stored positive charges.

Another modification of my novel invisible radiation image intensifying system is shown in Fig. 4. The face 5 of the X-ray pick-up tube 39 is of a material transparent to radiation to be used. Inside of the tube there is a composite screen 44 sensitive to X-rays or neutrons. The screen 44 comprises a radiation transparent conducting layer 41, such as of aluminum, gold, silver or platinum, and X-ray or neutron sensitive layer 42 of dielectric material, which has property of becoming conductive and producing a current of electrical charges thereon in response to said irradiation. Such materials are CdS, diamond, MgO, ZnS or antimony compounds. On the side of the layer 42 remote from the X-ray source, there is deposited another thin conducting layer 43. This layer may be formed by a plurality of small conducting islands of platinum, gold or silver, which are insulated from each other. Such layer may be produced by covering layer 42 with a fine mesh screen and evaporating a conducting material over said mesh. After evaporation, the mesh screen is removed leaving a mosaic of conducting islands. The conducting layers 41 and 43 are connected to the terminals of battery 12a to supply electrical

field across layer 42. In some instances, the layer 43 may be formed by a continuous conducting layer of any of the materials mentioned above. In other cases, layer 43 may be omitted and instead of it, a mesh screen is disposed in close spacing, such as a few microns, from the uncovered side of the layer 42. Mesh screen is then connected to one terminal of the battery 12a, whereas the second terminal is connected to the layer 41. In this way, electrical field is provided across layer 42. The use of a mesh screen improves the storage of electrical charges in the layer 42. If this storage time should be excessive, the stored charge pattern may be removed by changing the polarity of battery 12a.

In close spacing, such as a few microns, from the composite screen 44, there is mounted a fine mesh screen 46 of conducting material. On said mesh, there is deposited a photoemissive layer 47 in such a manner as not to obstruct the openings 46a in the mesh screen 46. A front view of this screen is shown in Fig. 5. The pattern of the electrical charges in the layer 42 can be considered as a pattern of various potentials or electrical fields. I discovered that these potentials will modulate the emission of photoelectrons from the photoemissive layer 47, although they are behind said layer. In some cases, the mesh screen 46 can be used both for providing the necessary potential for photoemissive layer 47 and for providing electrical field across the layer 42. The layer 47 is irradiated by a source of light 40 and produces a strong beam of photoelectrons. The emission of photoelectrons from layer 47 depends on electrical fields in its proximity. The more positive are the charges in the layer 42, the more suppressed will be the emission of photoelectrons from layer 47. In this way the photoelectron beam is modulated by the charges in the screen 44 which have the pattern of the original X-ray or neutron image.

The photoelectron beam emitted from the layer 47 is focused by fields 57 and can be further intensified by acceleration by electrostatic or by electromagnetic fields 56, as well as by electron-optical demagnification. Acceleration of electrons and electron-optical demagnification of electron image are well known in the art and therefore, it is believed, they do not have to be described in detail. The intensified photoelectron image is projected on the storage target 48, which is of a semiconductor, such as glass. The photoelectron beam strikes target 48 with velocity, at which the secondary emission of the target is greater than unity. The emitted secondary electrons are drawn away by the adjacent mesh screen 49. As a result, a positive charge pattern remains stored in target 48. As target 48 is very thin and has semi-conductive properties, the charge can pass through it and appears on the opposite side of the target, which is facing electron gun 44. Electron gun 44 produces a fine beam 50 of electrons. The electron beam 50 is focused by electrostatic or electromagnetic focusing coil 51 and by an alignment coil 51a and is deflected into two directions perpendicular to each other by deflection coils 52, so that it scans target 48 in a television-like raster. The electron beam 50 is decelerated in front of the target 48 by a ring electrode 53. Also, a mesh screen may be used for this purpose. Target 48 has stored on its surface a pattern of electrical charges having the pattern of the original X-ray or neutron image. The scanning beam 50 neutralizes these stored positive charges. The returning electron beam 54 is, therefore, modulated by said charges and carries video information. The returning electron beam strikes the first stage of the electron multiplier 55. The secondary electrons from the first stage of the multiplier strike the succeeding stage 56 around and in the back of the first stage. This process is repeated in a few stages resulting in a marked multiplication of the original electron signals. The signal currents from the last stage of the multiplier are converted over a suitable resistor into video signals and are fed into television

amplifiers 16. After amplification, they are sent by coaxial cable 17 or by high frequency waves to the receivers of kinescope type 18, skiatron type or facsimile type in which they are reconverted into visible image 19 for inspection or for recording.

The synchronizing and deflecting circuits are not shown in detail as they are well known in the art and would only complicate drawings.

The pick-up tube 39 may also serve for storage of X-ray or neutron images if the energy of the scanning electron beam 50 is selected so that it is not sufficiently strong to neutralize the electrical charges on the target 48 in one scan. With proper selection of intensity of the scanning beam 50 and of the capacity and resistance of target 48, the charge image can be stored in said target for many seconds. It is also obvious that the fraction of scattered electrons of returning scanning beam may be used for producing video signals, as was explained above and illustrated in Fig. 2.

Another modification of my invention is shown in Fig. 6. The invisible radiation sensitive pick-up tube 65 has an X-ray or neutron sensitive composite screen 60, which is similar to the screen 6, which was described above, except that the composite screen 60 is of perforated type. The layer 61 is of a conducting mesh screen, such as of aluminum, gold, silver or platinum. The layer 62 is deposited on the mesh screen 61 in such a manner as not to obstruct openings 66 therein. The layer 62 is of a dielectric material which has the property of becoming conductive and producing current of electrical charges (electrons and positive holes) in response to X-ray or neutron radiation. Such materials are CdS, diamond, quartz, ZnS and others. The layer 63 is a conducting mesh screen, such as of aluminum, gold, silver or platinum and is deposited on the layer 62 in proper alignment with the mesh screen 61, so that the openings in both screens will be aligned with each other. The mesh screen 63 may also be mounted in close spacing to the layer 62, such as a few microns, instead of being deposited thereon. A source of electrical power, such as battery 12a is connected to the conducting layers 61 and 63 to provide a polarizing electrical field across the layer 62, as was explained above. A source of photoelectrons 64, such as photoemissive surface irradiated by light, or an electron gun producing a broad beam of electrons, is disposed within the pick-up tube 65 to provide a strong uncontrolled beam of electrons. This beam photoelectrons is projected on the X-ray and neutron sensitive composite screen 60. The screen 60 has a pattern of charges or potentials thereon, which corresponds to the original X-ray image. The passage of electrons from the source 64 through said perforated screen 60 depends on potentials present around the openings therein. Therefore, the transmitted electron beam is modulated by the pattern of said potentials and will also have the pattern of the original invisible radiation image. The transmitted electron beam is now accelerated, is electron-optically diminished and is focused on the storage target 48 described above and illustrated in Fig. 4 and is stored there. The rest of the operation of this pick-up tube is the same as described above and illustrated in Fig. 4. The electron image stored in the target 48 is scanned by electron beam and is converted into video signals. Video signals are, after amplification, transmitted to receivers for reproducing of the visible images.

The accelerating fields 56a may be electrostatic or electro-magnetic. The focusing fields 57a may also be of electro-static or electro-magnetic type and are well known in the art. It is evident that the tube 39 will operate as a storage tube if we substitute photocathode 44 by photocathode 6. Also the tube 65 may be used for storage. In such a case the layer 63 preferably should be omitted.

It is obvious that my system of intensification of X-ray or neutron images may be used not only for medical ex-

aminations, but for industrial testing or X-ray diffraction studies as well.

It will thus be seen that there is provided a device in which the several objects of this invention are achieved and which is well adapted to meet the conditions of practical use.

As various possible embodiments might be made of the above invention and as various changes might be made in the embodiment above set forth, it is to be understood that all matter herein set forth or shown in the accompanying drawings, is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. A vacuum tube comprising in combination a cathode disposed within said tube and comprising a layer of material which converts an invisible radiation image into electrical conductivity changes corresponding to said invisible image, and means for producing a beam of electrons modulated with said electrical conductivity changes on said cathode, said means being separated from said cathode, said layer furthermore having an uncovered surface presented to said means.

2. A vacuum tube comprising in combination a cathode disposed within said tube for receiving an image produced by an invisible and ionizing radiation, said cathode comprising a layer of material which converts said ionizing radiation image into electrical conductivity changes corresponding to said ionizing radiation image, and means for producing a beam of electrons modulated with said electrical conductivity changes in said cathode, said means being separated from said cathode, furthermore said layer having an uncovered and imperforated surface presented to said means.

3. A device as defined in claim 2, in which said layer producing electrical conductivity changes has a continuous surface on the side presented to said electron beam.

4. A device as defined in claim 2, in which said cathode consists only of said layer which converts said image into said electrical conductivity changes and of a conducting layer on the side opposite to said uncovered surface, and in which device said electron beam is a decelerated beam.

5. A device as defined in claim 4, which comprises in addition means for receiving said modulated electron beam.

6. A device as defined in claim 4, which comprises in addition means for converting said electron beam into electrical signals.

7. A device as defined in claim 2, in which said layer is of material reactive to X-rays.

8. A device as defined in claim 2, in which said electron beam is a broad beam.

9. A device as defined in claim 8, which comprises in addition means for receiving said broad modulated electron beam.

10. A device as defined in claim 8, which comprises in addition means for converting said broad electron beam into electrical signals.

11. A device as defined in claim 1, which comprises in addition a source of light for irradiation of said cathode when said cathode is impinged by said invisible radiation.

12. A device as defined in claim 1 in which said means for producing said beam of electrons comprise a photoemissive layer.

13. A device as defined in claim 12, which comprises in addition means for receiving said electron beam.

14. A device as defined in claim 12, which comprises in addition means for converting said electron beam into electrical signals.

15. A device as defined in claim 1 in which said means for producing said beam of electrons are a screen comprising a perforated conducting layer and a photoemissive layer.

16. A device as defined in claim 1, in which said electron beam is a broad beam, and which in addition

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comprises means for converting said broad beam into electrical signals.

17. A device as defined in claim 1, in which said cathode comprises cadmium sulphide, said electron beam is a decelerated beam and which in addition comprises means for converting said electron beam into video signals.

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