

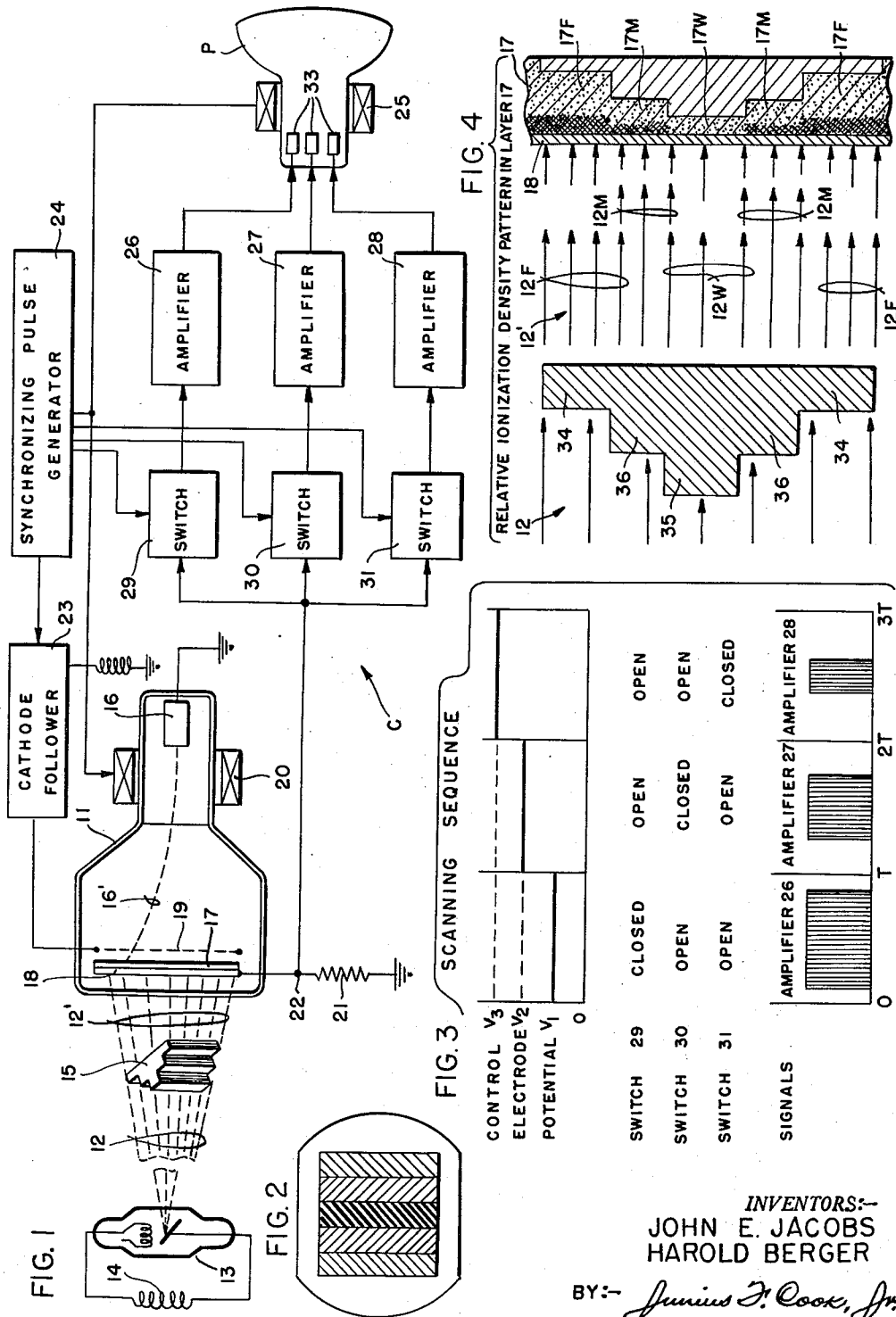
Oct. 10, 1961

J. E. JACOBS ET AL

3,004,101

COLOR RADIOGRAPHY

Filed April 9, 1956



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1

3,004,101

COLOR RADIOGRAPHY

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Filed Apr. 9, 1956, Ser. No. 577,098

8 Claims. (Cl. 178-6.8)

The present invention relates in general to electronics and has more particular reference to the conversion of latent images carried by penetrating rays, such as X-rays, into optically visible form, the invention pertaining more especially to a method of and means for producing electrical signals corresponding with latent images, borne by X-rays of unlike hardness or penetrating power, and applying such signals for the production of a composite visual image in contrasting color values varying in accordance with the hardness of the image carrying rays.

Invisible picture images may be formed in and carried by penetrating rays, such as X-rays, and other invisible ray-like emanations of penetrating character, by applying the rays through an object to be pictured. The image carrying rays may then be impinged upon a penetrating ray transducer of the sort disclosed in an application for U.S. Letters Patent, Serial No. 357,222, filed May 25, 1953, now Patent No. 2,951,898, on the invention of John E. Jacobs, in Iconoscope; and in applications for U.S. Letters Patents on the joint inventions of John E. Jacobs and Harold Berger, in Penetrating Ray Transducer, Serial No. 418,414, filed March 24, 1954, now Patent No. 2,809,323; in Image Intensification, Serial No. 518,884, filed June 29, 1955, now Patent No. 2,890,360; and in Method of Making Transducer Tubes, Serial No. 538,846, filed October 6, 1955, now Patent No. 2,839,188.

The transducer described in each of the aforesaid applications for U.S. Letters Patent, comprises a cathode ray tube which operates, in response to the impingement thereon of image carrying rays, to generate electrical signals corresponding with any latent image carried by the impinging rays. The signal thus generated may be applied upon conventional television apparatus to cause the same to produce a visual picture corresponding with the latent ray carrying image.

Image carrying rays, such as X-rays, define the latent image in terms of varying degrees of penetrating power or hardness of the image carrying rays. When passed through objects to be pictured, embodying portions of unlike ray translucence, such as body tissues, bones and cartilage, for example, the more highly translucent portions of the object to be pictured may freely transmit hard rays of relatively high penetrating power, as well as soft rays, while absorbing only relatively small amounts of the hard and soft ray components. The less translucent portions of the object will absorb relatively higher amounts of both hard and soft ray energy from rays passing therethrough, and will absorb a relatively higher proportion of the soft rays of relatively low penetrating character. As a consequence, the most opaque portions of the object to be pictured may absorb substantially all of the soft ray components of the impinging ray beam while passing appreciable amounts of the hard ray component thereof.

An important object of the present invention is to provide means for and a method of producing a plurality of visual pictures corresponding with images latently carried by penetrating rays, such as X-rays, having varying degrees of penetrating power, the several pictures thus produced being optically combined to form a composite picture incorporating the several images borne by ray components of unlike penetrating power; a further object being to apply contrasting color in the composite

2

picture corresponding with the penetrating character of the picture producing ray components.

Another important object is to provide means for and method of producing a plurality of electrical signals in a cathode ray transducer disposed in the path of image carrying X-rays, including the application of such signals through separate translation channels to a color television picture producing device, whereby images carried by rays having different penetrating powers may be reproduced in unlike colors.

Another important object of the invention is to produce several ray carried images respectively showing the same object as seen by ray components of unlike degrees of penetrating ability or hardness, and then to electrically and optically combine the several images to produce a single composite visual picture in colors corresponding with the ray translucence of the various portions of an object disposed in the path of a beam of picturing rays.

Briefly stated, in accordance with a preferred aspect of the invention, a cathode ray image pickup tube embodying a relatively thick layer of semi-conducting material, such as lead oxide, having one side thereof in electrical contact with a backing plate of electrical conducting material, may be disposed in position to receive the impingement of an image carrying beam of X-rays emitted from a suitable ray source and applied upon the semi-conducting layer after traversing an object to be pictured. The layer may be subjected to an electrical field by applying an electrical potential difference between the backing plate and a mesh electrode overlying and spaced closely adjacent the plate remote surface of the layer of semi-conducting material. Image carrying rays applied upon the semi-conducting layer will penetrate the same to various depths therein, and will ionize the semi-conducting material of the layer, at such various depths, in accordance with the hardness or penetrating power of the impinging rays, thereby applying in the layer, in terms of the intensity of ionization in the various portions thereof, an image of the object to be pictured. Means may be provided for continuously scanning the plate remote surface of the ionized layer with an electron beam, in order to read out the layer carried image by producing a transmissible signal corresponding with the degree of ionization of the semi-conducting layer, said signal being made to correspond with ionization intensities at any desired depth in the layer by maintaining a corresponding or appropriate potential difference between the mesh electrode and the backing plate.

A gating circuit may be employed to regulate the potential applied upon the mesh electrode, in order to determine the depth in the layer at which the scanning beam may read out the image to be reproduced, the gating circuit serving also to control the operation of electronic switches which serve to control the delivery of the electrical signals, generated by the operation of the pickup tube, successively to a picture reproducing tube, through each of a plurality of signal delivery circuits or channels. Accordingly, signals corresponding with images carried by rays of unlike penetrating power may be delivered through corresponding channels or circuits for application upon a conventional color picture reproducing tube, in order to operate the same for the production of a composite color picture having color values corresponding with the hardness of the picturing rays applied upon the pickup tube.

The foregoing and numerous other important objects, advantages and inherent functions of the invention will become apparent as the same is more fully understood from the following description, which, taken in connection with the accompanying drawings, discloses preferred embodiments of the invention.

3

Referring to the drawings:

FIG. 1 is a schematic diagram of apparatus for producing visible picture images, in accordance with the teachings of the present invention, including a pickup tube embodying a semi-conducting layer in position to receive latent image carrying X-rays delivered thereto, from a suitable ray source, through an object to be pictured, and a color picture reproducing tube controlled by signals emitted by the pickup tube when excited by picture carrying rays;

FIG. 2 is a representation of an image which would be produced in the color picture tube if a body of material, comprising portions having various ray transluence, were to be interposed, in the path of the picturing X-ray beam, between the ray source and the pickup tube, as shown in FIG. 1;

FIG. 3 is a graphical representation of gating and signal voltages which may be produced in the circuit shown in FIG. 1; and

FIG. 4 is a diagram illustrating the ionization pattern produced in the semi-conducting layer of the pickup tube in response to the application thereon of X-rays bearing the image of an object to be pictured.

To illustrate the invention, the drawings show picture reproducing apparatus comprising a transducer or image pickup tube 11 adapted to receive an image carrying beam of penetrating rays 12, such as X-rays, from a suitable ray source 13 which may conveniently comprise a conventional X-ray generating tube operably connected with a suitable source of energizing power, such as the transformer winding 14. The pickup tube 11 is adapted to produce signal impulses in response to excitation thereof by an image carrying ray beam 12', such as may be produced by disposing a body 15 to be pictured in the path of the penetrating ray beam 12, between the source 13 and the pickup tube 11, said body, for purposes of illustrating the invention, having stepped configuration providing adjacent zones of unlike thickness, and hence of unlike ray transluence; and the present invention includes suitable translation circuitry C for applying such impulses upon a picture reproducing tube P which may be of conventional character.

The pickup tube 11 may conveniently comprise a device of the sort disclosed in the above named applications for U.S. Letters Patents on the inventions of John E. Jacobs and Harold Berger, the same comprising a sealed envelope formed with a neck, at one end, enclosing an electron gun 16 adapted to emit an electron beam 16'. The sealed envelope of the pickup tube may also enclose a target embodying a layer of semi-conducting material 17 supported upon a backing panel 18 of electrical conducting material, such as aluminum, and a target mesh electrode 19, said target and mesh electrode being enclosed in the neck remote end of the envelope, in line with the electron gun, with the mesh electrode overlying the gun facing surface of the layer 17. A conventional deflection yoke 20 may be mounted around the neck of the tube envelope and energized to deflect the gun emitted beam 16', in fashion causing the same to scan the target layer 17 through the mesh electrode 19, in accordance with any desired or conventional raster or scanning pattern.

Impingement of an image carrying ray beam 12' upon the layer 17 will ionize the material of the layer, thereby releasing electrically negative electrons from bound condition in the lattice structure of the material and creating electrically positive holes or centers in the material at the places of electron release. Electrons thus ionized or released from bound condition in the layer 17 are subject to an urge to reenter a vacant hole and thus recombine in bound condition in the lattice structure. They may also be subjected to the influence of an electrical force field that may be established across the layer 17 by the application of a potential difference between the panel 13 and electrode 19. A cathode follower amplifier 23

4

of the sort shown on page 343 of "Vacuum Tube Circuits," by Lawrence B. Arguimbau, as published by John Wiley & Sons, Inc., New York, may be provided for maintaining a potential difference of selected magnitude between the panel 13 and electrode 19, the panel being preferably held electrically positive as compared with the electrode, to thus determine the magnitude and direction of the electrical force field across the layer 17.

The potential difference between the mesh electrode 19 and the plate remote surface of the layer is dependent upon the spacement therebetween and is preferably of the order of one volt. The electrical force field thus established across the layer 17 will operate to drive electrons toward the panel contacting side of the layer and away from its panel remote surface, thereby making each integral portion of said surface electrically more positive than is normally the case, such more positive condition being proportional to the degree of ionization of the layer material beneath said surface. By scanning the panel remote surface of the layer 17, through the mesh electrode, the beam 16' will successively and momentarily restore the surface potential of the scanned areas to normal potential, thereby producing a signal corresponding with the potential pattern of the image as applied at the panel remote surface of the layer. Image carrying rays applied upon the semi-conducting layer will penetrate the same to various depths therein, and will ionize the semi-conducting material of the layer, at such various depths, in accordance with the hardness or penetrating power of the impinging rays, thereby applying, in the layer, at various depths therein, and in terms of ionization intensity in the various portions of the layer, images of the object to be pictured, as carried by beam components of unlike hardness. The scanning beam may be caused to read out the layer carried image as a signal corresponding with the degree of ionization of the semi-conducting layer, at any desired depth in the layer, by maintaining a corresponding potential difference between the mesh electrode and the backing plate 18, thereby subjecting electrons, released in the semi-conducting layer, to the action of an electrical field of desired intensity.

If a strong electrical field be maintained across the layer, relatively few electrons, released as the result of ray induced ionization of the layer 17, will become entrapped in electrically positive holes and thus be recombined in the lattice structure of the layer material. Conversely, when the field is relative weak, a correspondingly large number of electrons will be trapped in holes and recombined in the material of the layer 17. The probability of recombination depends upon the mean free path of the electrons, which in turn is directly related to the potential between panel 13 and electrode 19. It is consequently possible to read out a scanning beam signal corresponding with the degree of ionization accomplished at desired depth, within the layer, by applying a corresponding potential upon the mesh electrode.

A sequential field type of electron beam scanning of the target layer is employed, the electron velocity controlling potential on the mesh electrode 19 being maintained at unlike levels during successive scanning cycles, in order to allow the beam 16' to produce signals corresponding with ionization patterns at various depths in the layer 17. Accordingly, a selected potential is applied on the mesh electrode 19 during one complete scanning cycle. Thereafter, the potential on the electrode 19 is changed to other values during succeeding scanning cycles. In the illustrated embodiment, three successive scanning cycles are performed with unlike potentials applied to the mesh electrode, after which the electrode potential sequence is repeated. The scanning of the target by the electron beam is thus accomplished at a different electrical field strength across the layer 17 for each of three successive scanning cycles. Since sequential field scanning is utilized, a master syn-

5

chronizing pulse generator 24 may be employed to control the cathode follower amplifier 23, as well as the energy supply to the deflection yoke 20 of the pickup tube 11, and to the deflection yoke 25 of the color picture reproduction tube P.

The signal which appears at the terminal 22 may be applied for the control of the picture tube P alternately through separate amplifiers 26, 27 and 28 under the control of corresponding electronic switches 29, 30 and 31 which operate, under the control of the master synchronizing pulse generator 24, to pass the signals in accordance with the required sequential field timing pattern successively through the appropriate amplifiers 26, 27 and 28. Accordingly, tube actuating signals delivered through the amplifiers 26, 27 and 28 respectively, comprise signals delivered by the pickup tube during successive scanning cycles of the beam 16' on the target layer 17, at unlike field potentials, as determined by the potential applied between the panel 18 and the mesh electrode 19. Each of the electronic switches 29, 30 and 31 may comprise a conventional electron flow device, such as a pentode tube, the signal delivered at the electrode 22 being continuously impressed upon the control grids of each of the pentodes, the switching action of which may be caused by applying a variable bias upon the screen grid of the pentode as the result of the operation of the master synchronizing pulse generator. The signal thus produced at the terminal 22 may either be relayed through the pentode or blocked by selectively controlling the bias of the screen grid of the tube.

Picture tube actuating signals may thus be delivered through the amplifiers 26, 27 and 28 sequentially, in a desired field controlling pattern, and may be applied upon the picture reproducing tube P, which may be a conventional three color picturing tube having three electron guns 33 for three color reproducing purposes, said guns being respectively connected each with a corresponding one of the amplifiers 26, 27 and 28. As a consequence, the color images reproduced in the tube P, by operation of the three guns thereof, will each respectively correspond with images, impressed upon the layer 17, in response to the impingement of the image carrying ray beam thereon. In that connection, the three separate color images will respectively correspond with images applied in the layer 17 in terms of ray induced ionization of said layer, as measured at the various depths therein corresponding with the sequential field potentials applied between the panel 18 and the mesh electrode 19. Accordingly, each of the color images produced in the tube P will correspond with images produced in the layer 17 by X-rays of selected unlike hardness corresponding to the various penetration depths thereof in the layer 17.

Reproduction of a color picture may also be accomplished by delivering signals produced by the operation of the pickup tube 11, through the amplifiers 26, 27 and 28, to corresponding monochrome picturing tubes, each capable of producing an image that may be passed through an appropriate color filter and then optically combined with color filtered images emitted by the other tubes, in order to produce a composite picture incorporating the combined images. Any other suitable known method of combining signals to produce a three color image may, of course, be employed.

Where a body, of the sort shown at 15 in FIGS. 1 and 4, is interposed in the penetrating ray beam 12, the thickness of the several stepped portions of the body produces an image having a pattern of the sort shown in FIG. 2. The relatively thin, highly translucent outer portions 34 of the body may pass relatively soft, as well as hard or highly penetrating rays, whereas the medial or thickest body portion 35 of minimum translucence may absorb substantially all of the soft components of the beam, permitting only the harder beam components to pass there-through. The body portions 36 of intermediate thickness may pass soft as well as hard ray components, but will

6

absorb substantially more of the softer beam components than the highly translucent body portions 34. The body portions 36, however, will allow a substantially larger quantity of X-rays to pass therethrough than are able to penetrate the medial body portions 35 of minimum translucence.

Upon reaching and impinging upon the layer 17, the soft components may all be absorbed in the outer portions of the layer 17 at and inwardly of the surface thereof which faces the source 14. The hard components, however, may penetrate entirely through the layer 17. As indicated in FIG. 4, the beam portions 12F, 12W and 12M, which respectively traverse the body portions 34, 35 and 36, will ionize the material of the layer in accordance with an ionization density pattern corresponding with the translucence of the body portions traversed by the beam portions prior to impingement upon the layer. The beam portion 12W which impinges the layer after traversing body portions 35 of minimum translucence will ionize the layer portions 17W impinged thereby to a substantially lesser density than is accomplished in the layer portions 17F upon which the beam portions 12F, delivered through the highly translucent body portions 34, are applied. Likewise, the beam portions 12M, delivered upon the layer 17 through body portions 36 of intermediate translucence, will ionize the layer portions 17M impinged thereby to a density intermediate that caused by ray impingement thereon after traversing the highly translucent and relatively opaque body portions 34 and 35.

When ionized by application of image carrying X-rays, the portions of the layer 17 which absorb the soft ray components have a large number of free electrons in the portions thereof adjacent the panel 18 and nearest to the exciting ray source. The panel remote layer portions containing the fewest number of free electrons are those that have received the hardest radiation. The output signal delivered at the electrode 22 is produced as the result of restoration of the electron beam scanned side of the target layer 17 to full charge by the action of the scanning beam, the greatest amount of restoration energy being required in those zones of the layer which are least heavily ionized as the result of image carrying X-ray impingement thereon.

The sequential operation of the master synchronizing pulse generator, in triggering the switches 29, 30 and 31 and establishing desired potential levels upon the mesh electrode 19, is revealed in FIG. 3 of the drawings, which illustrates three successive field scanning cycles, the first of which is accomplished during the time interval from zero to T. During such interval, the scanning of a complete frame pattern is accomplished in both the pickup tube 11 and the picture tube P. During such scanning interval, the switch 29, or first field gate, may be placed in a conductive state to pass the signal from the terminal 22 through the first field amplifier 26, the other switches 30 and 31 being non-conductive during such interval to prevent any signal from being delivered through the second and third field amplifiers 27 and 28.

During this initial scanning interval from time zero to time T, a relatively low potential may be applied to the mesh electrode 19, as indicated at V₁. The majority of free carriers reaching the backing plate 18 will be derived from the zone 17F adjacent said backing plate, which zone contains a large number of carriers, due to the impingement of soft radiation in said zones. The gating pulse will cause the signal produced during the initial scanning interval to be delivered through the switch 29 to the first video amplifier 26, the switches 30 and 31 being then inactive.

During the period of elapsed time between the instant T and the instant 2T, the potential of the mesh electrode 19 may be adjusted to a higher value, as indicated at V₂ in FIG. 3, than that maintained on the electrode during the time interval from zero to the instant T, in order to

permit the read-out of an intermediate charge potential corresponding with the ionization produced in the zone 17M of the layer by the impingement thereon of the beam portions 12M, the resulting signal being passed to the picture tube through the amplifier 27 by way of the switch 30, which is in conductive condition during the second scanning time interval, the switches 29 and 31 being then in non-conducting condition. In like fashion, during the scanning time interval between the instants 2T and 3T, the potential on the mesh electrode 19 is maintained at a relatively high value, as shown at V_3 in FIG. 3, at which potential value only the most penetrating ray effects may be read out of the layer 17 by the scanning beam, the resulting signal produced in such scanning interval being passed to the picturing tube through the amplifier 23 under the control of the then conductive switch 31, the switches 29 and 30 being in non-conducting condition during such interval.

The signals thus successively passed to the picturing tube are illustrated in the lowermost portions of FIG. 3; and it will be seen that the strongest and weakest signals respectively correspond with the portions of the image carrying ray which traverses the parts of maximum and minimum translucence of the object being pictured.

Although sequential field operation may be employed in the manner herein described, it will be apparent that alternate modes of operation may be utilized to attain the desired result. For example, sequential line operation may be utilized wherein the impingement velocity of the electrons of the scanning beam of the pickup tube is varied by changing mesh electrode potential during each scanned line of a raster, rather than during each complete frame. Where sequential line scanning is employed, the electronic switches 29, 30 and 31 should be operated to switch the color channel amplifiers during each scanned line, in accordance with the change in potential of the mesh electrode. Obviously, any other mode of operation may be employed in order to apply desired read-out voltages upon the mesh electrode 19 during successive time intervals of any convenient duration, and to deliver the picturing tube control signal through appropriate color control circuits during such intervals.

It is thought that the invention and its numerous attendant advantages will be fully understood from the foregoing description, and it is obvious that numerous changes may be made in the form, construction and arrangement of the several parts without departing from the spirit and scope of the invention, or sacrificing any of its attendant advantages, the forms herein disclosed being preferred embodiments for the purpose of illustrating the invention.

The invention is hereby claimed as follows:

1. Apparatus for visually reproducing images latently carried by penetrating rays, comprising an image pickup device embodying a layer of ray sensitive semi-conductor material supported on a backing plate of electrical conducting material and positioned to intercept an image carrying ray beam to thereby excite the same at various depths therein, in accordance with the picture image as carried by ray beams components of varying penetrating ability, means for scanning the layer successively with an electron beam, means for applying an electrical field of different selected intensity across said layer for any two of said successive scans, whereby to develop a signal on said backing plate corresponding with the excitation of said layer at a depth therein determined by the selected intensity level of said field, a picturing tube, and means for applying said signal for the control of said tube.

2. Apparatus as set forth in claim 1, wherein the layer of semi-conducting material comprises lead oxide.

3. Apparatus as set forth in claim 1, wherein the means for applying the electrical field across the layer comprises a mesh electrode overlying a surface of the layer of semi-conductor material in the path of the scanning

beam, and a panel of electrical conducting material in electrical contact with the other surface of the layer.

4. Apparatus as set forth in claim 1, wherein the means for applying the electrical field across the layer comprises a mesh electrode overlying a surface of the layer of semi-conductor material in the path of the scanning beam, a panel of electrical conducting material in electrical contact with the other surface of the layer, and means for maintaining a selected potential between said electrode and panel.

5. Apparatus as set forth in claim 1, wherein the means for applying the electrical field across the layer comprises a mesh electrode overlying a surface of the layer of semi-conductor material in the path of the scanning beam, a panel of electrical conducting material in electrical contact with the other surface of the layer, and means for maintaining a selected potential between said electrode and panel, during a scanning interval, and for maintaining different potential between the panel and electrode during a succeeding scanning interval.

6. Apparatus as set forth in claim 1, wherein the means for applying the electrical field across the layer comprises a mesh electrode overlying a surface of the layer of semi-conductor material in the path of the scanning beam, and means for maintaining a selected potential between said electrode and panel, during periodically recurring scanning cycles, for maintaining a different potential between said electrode, and panel during scanning intervals immediately preceding each of said recurring intervals, and for maintaining still another potential between said electrode and panel during scanning intervals immediately following each of said recurring intervals.

7. Apparatus for visually reproducing images latently carried by penetrating rays, comprising an image pickup device embodying a layer of ray sensitive semi-conductor material positioned to intercept an image carrying ray beam to thereby excite the same at various depths therein, in accordance with the picture image as carried by ray beam components of varying penetrating ability, means to apply an electrical field across the layer, means for scanning the layer successively with an electron beam, means to adjust the field at different intensity values during successive scanning intervals, whereby to develop signals successively corresponding with the excitation of said layer at unlike depths therein as determined by the adjusted field intensity values, a picturing tube, and means for applying said signals successively for the control of said tube.

8. Apparatus for visually reproducing images latently carried by penetrating rays, comprising an image pickup device embodying a layer of lead oxide (PbO) as a ray sensitive semi-conductor material and positioned to intercept an image carrying ray beam to thereby excite the same at various depths therein, in accordance with the picture image as carried by ray beam components of varying penetrating ability, said layer being supported on and having a surface in electrical contact with a backing panel of electrical conducting material, means for scanning the layer successively with an electron beam, a mesh electrode overlying the panel remote surface of the layer in the path of the electron beam, means to apply electrical potential between said electrode and panel at different intensity levels during successive scanning intervals, to thereby establish electrical fields of unlike intensity values across the layer and thus develop voltage signals successively on said backing plate corresponding with the excitation of said layer at unlike depths therein corresponding with the several intensity values of said electrical fields, a picturing tube, and means for applying said signals successively for control of said tube.

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