June 4, 1940. J. C. BATCHELOR 2,203,347

ELECTRO-OPTICAL METHOD AND APPARATUS

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Fig. 1.

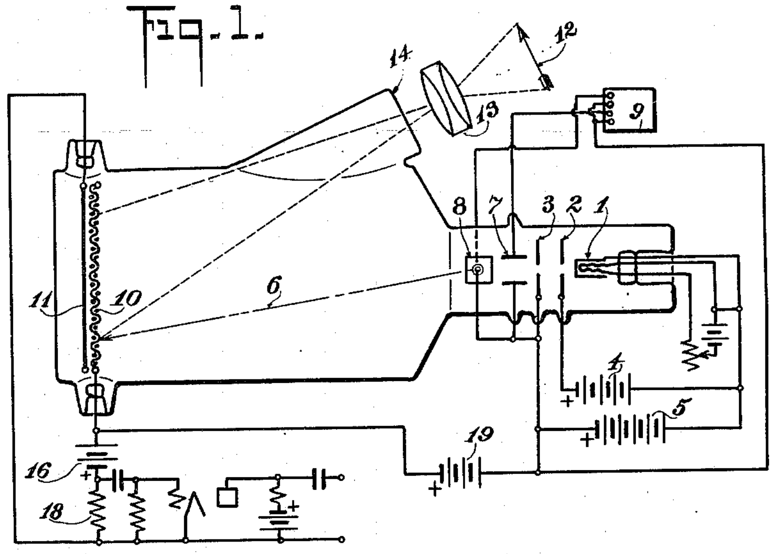


Fig. 2.

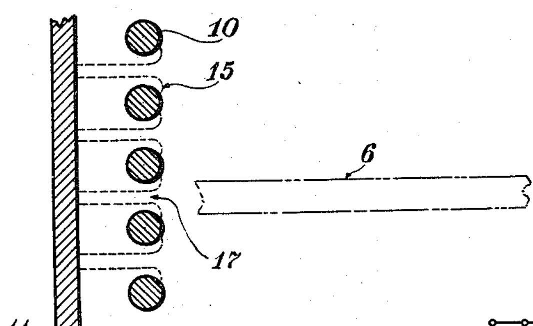
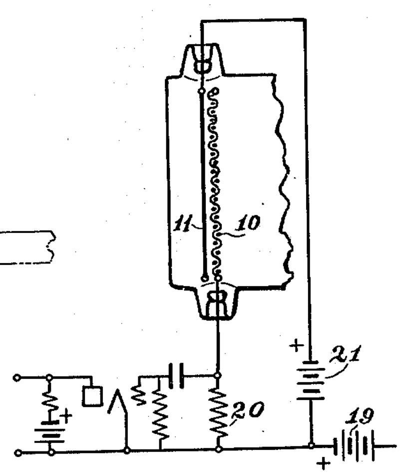


Fig. 3.



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ELECTRO-OPTICAL METHOD AND APPARATUS

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13 Claims. (Cl. 178—7.2)

My invention relates to electro-optical systems, and more particularly to a photoelectric cathode ray tube to be used in such systems.

An object of my invention is to provide suitable apparatus for producing a rapid electro-optical analysis of stationary or moving objects or pictures and for producing an electrical wave train corresponding to that analysis, said train being capable of being transmitted to a distant point where it may be synthesized into a picture or image of the object or picture originally analyzed. A further object of my invention is to provide such a device having no moving parts.

In accordance with my invention, I have provided a perforated, electrically conductive, photoelectrically sensitive member disposed between an electron gun and a flat metallic anode. Further, in accordance with my invention, I have provided means for projecting onto said perforated plate, an image of an object whose image is to be analyzed and transmitted, and causing a beam of electrons from the electron gun to scan the perforated plate rhythmically, and means for taking from the electrical circuit associated with the tube a signal proportional to the image brilliancy at the point being scanned at any instant.

In order to understand the explanation of my invention it is convenient to refer to the accompanying drawing, of which Figure 1 is a diagrammatic representation of one form of my invention; Figure 2 shows an enlarged sectional view of the perforated plate and anode; Figure 3 represents an alternate circuit connection which has been found to give good results.

In Figure 1, an indirectly heated cathode 1 emits electrons which are attracted, collimated and projected by the anodes 2 and 3 under the influence of the batteries 4 and 5 to produce the electron beam 6. The electron beam 6 is deflected by the plates 7 and 8 under the influence of the voltages generated by the generator 9 which causes a systematic rhythmical exploration of the perforated, photoelectrically sensitive plate 10. The electron beam may during and after deflection be subjected to a further acceleration under the influence of the battery 19. Whether the battery 19 is used or the entire acceleration is given to the beam by the battery 5 is in no way a part of this invention, and the procedure followed will be determined by the particular design of electron gun and beam focusing method used. Upon arrival at the plate 10, a part of the electron beam will penetrate the interstices of the plate 10 and impinge upon the anode plate 11.

An image of the object 12 to be transmitted is projected on the plate 10 by the lens 13 through the window 14, and causes photoelectrons to be emitted from the plate 10. Under the influence of the electrostatic field 15, Figure 2, set up by the battery 16, the photoelectrons will be attracted through the interstices 17 of the perforated plate 10 to the anode 11. The photoelectric current flowing in the resistor 18 will be the product of the total number of perforations in the plate 10 and the average of all of the photoelectric currents flowing through the individual perforations 17, and this value will be a steady direct current for any fixed value of average illumination of the object 12.

As a result of the passage of the photoelectrons through the interstices 17, the electrostatic field set up by the battery 16 will not be the resultant field, but will be altered by the space charge effects of the electrons passing through the interstices, and as a result of those transient electrons, the resultant potential gradient through any interstice will be a function of the number of photoelectrons being emitted from the plate 10 in the area adjacent the interstice under consideration, and consequently will be proportional to the amount of illumination incident upon that area.

When the electron beam, in its scanning process, reaches that interstice under consideration, the amount of current from the beam which will flow through the interstice will be a function of the potential gradient in that interstice, and as a result, the amount of current from the beam which reaches the plate 11 will be proportional to the amount of light falling on the portion of the plate 10 adjacent the interstice or group of interstices through which the beam is attempting to pass.

Thus, in addition to the steady direct current in the resistance circuit 18 embracing the plate 11 resulting from the photoelectrons from the plate 10, there is superimposed a controlled component of current resulting from the portion of the electron beam which succeeds in penetrating the space charge barrier caused by that first component of the current. The variable component of the resultant signal will then yield, upon suitable amplification and synthesis by rhythmical scanning synchronous with the scanning of the beam 6, an image of the object 12. This synthesis, can, of course, be accomplished by any one of a number of methods familiar to those skilled in the art, and since the synthesis comprises no part of this invention, it will not be described here.

The foregoing explanation of the operation of my invention presumes the use of an electron beam 6 of relatively low velocity, so that the electrons of the beam may easily be impeded by the space charges present in the interstices of the plate 10. It is possible, however, to operate the tube with an electron beam of relatively high velocity, in which case, the operation is as follows: the velocity of the electrons in the beam is so high that they find virtually no impedance in the space charge in the interstices, and they therefore penetrate quite readily to the plate 11 causing a substantially constant current to that element. To this current will be added the substantially constant current of the photoelectrons, but at the point being penetrated by the electron beam, the photoelectrons will encounter a high impedance caused by the space charge resulting from the electron beam, and will as a result be largely prevented from going to plate 11. As a result, the total current in the circuit associated with the plate 11 will be diminished by the photoelectric current from the region upon which the scanning beam is incident, and the current in the resistor 18 will have a variable component proportional to the number of photoelectrons which do not succeed in penetrating the perforated member.

Referring to Figure 3, it may be seen that the tube may also be operated by taking the signal from the resistance 20 in the return circuit of the member 10 instead of the plate 11 as previously described. In fact, a number of possible circuit connections will immediately occur to those skilled in the art, by means of which a signal may be produced as a result of the interaction of a cathode ray of substantially constant intensity and a space charge of intensity variable in accordance with the view being analyzed, and such modifications in the method of operation and use of my tube should not be construed as departing from the spirit of my invention.

In order to maintain the ulmost utilization of the light incident upon the photoelectrically sensitive surface, I have found it desirable to maintain the ratio between the total solid area and the total aperture area of that surface as large as is consistent with free passage of electrons and yet favorable space charge conditions; I have found that a ratio in excess of 50 percent is satisfactory. The perforated plate may to advantage consist of woven wire mesh.

In arriving at a satisfactory embodiment of my invention, I have had knowledge of the existence of certain other proposed apparatus which claims to produce a result similar to that of my apparatus; for example, apparatus has been proposed wherein a space charge is caused to exist within the openings in a bank of tubular units mutually insulated and photoelectrically sensitized on their interior surfaces. In that proposed apparatus an electron beam is caused to penetrate the tubular elements, and the portion of the beam which succeeds in emerging from the ends of the tubes opposite the ends entered is asserted to create a signal proportional to an image projected upon the bank of tubes in a manner such that light of the image falls upon the interior surfaces of the tubes. My invention differs from that proposed apparatus in a number of important respects which lead to successful operation in my invention.

In the case of that proposed apparatus it is clear that the multiple unit photoelectric element has a plurality of mutually insulated photoelectrically sensitive elements, and consequently the electric potential of each of those units is determined entirely by the difference between the number of electrons arriving at and the number departing from each of those elements. For this reason it may be seen that, except in the case of very intense illumination of the element, a preponderantly negative charge will accumulate on the photoelectric elements and will not be neutralized by the photoelectrically emitted electrons. Thus, in an attempt to operate that apparatus, charges will accumulate upon the photoelectric elements which will operate to prevent access to the tubes by an electron beam. In contrast with this, it is clear that in my device I have provided mutual electrical conductivity between the photoelectrically sensitive elements whereby charges from the electron beam incident upon the photoelectrically sensitive member will be dissipated immediately upon impact, and consequently will cause no impedance to subsequently arriving electrons. Moreover, in the case of previously proposed apparatus, it is carefully shown that the tubes which constitute the multiple unit photoelectric element must be relatively fine and long, and of electrically insulating material insulatedly cemented together to form a mechanically rigid electrically insulating member, following which, with great difficulty, photoelectrically sensitive material is deposited upon the inner walls of the tubular units. In contrast with this, my device is wholly operative when photoelectrically sensitive material is deposited only upon the portion of the peripheral surface of the member 10 adjacent the window 14 through which an image is projected upon the member 10, and consequently the difficulty encountered in introducing photoelectric material on the inner surfaces of the interstices in my member 10 is avoided.

Thus, for proper performance of my tube, it is essential that the photoelectrically sensitive member be of electrically conductive material, and thus, it may be considered to be a plurality of discrete photoelectric cells having all anodes and all cathodes electrically interconnected. In the absence of such electrical interconnection between the cathode elements, the charges which would accumulate on the elements would be of such values that the photoelectrons would be drawn through the interstices with great velocity, with the result that the space charges in said interstices would be very small. Moreover, these charges on the elements would be sufficiently great to seriously impede the progress of the cathode beam in its attempt to penetrate the elements. With electrical conductivity existing between the photoelectrically sensitive elements, the potential difference between the member 10 and the plate 11 may be definitely fixed by a battery 16 at a value sufficiently low that the transit velocity of the electrons in the interstices is sufficiently low to assure the existence of a substantial space charge in said interstices. Thus, with such electrical interconnection, I am enabled to produce a tube of great sensitivity and electrical stability.

The number of openings in the surface per unit length or area will be determined by the cross sectional area of the electron beam and the degree of fineness of the detail into which the image is to be analyzed. For example, if the plate is four inches in height and the image is to be analyzed into 400 lines, the smallest number of openings which will give the desired fineness is 100 per lineal inch. If exactly this number is used, however, the cathode ray in scanning the surface will in passing the openings, generate a signal of a frequency corresponding to the number of openings passed per unit of time. If, however, twice the number of openings is used, allowing the cross sectional area of the scanning cathode ray to remain unchanged, the frequency of the signal generated by scanning the openings will be twice that generated by the smaller number of openings, and the amplitude of the signal generated by the beam in passing the openings will be reduced substantially. Following this reasoning, it is apparent that it is desirable to increase the number of openings per picture element to the greatest value consistent with ease and economy. It is possible to obtain commercially, woven wire cloth having as many as 400 openings per lineal inch, so that in the above case of a four inch plate and a 400 line picture, there would be four openings per picture element in each direction. Such a plate would produce an opening frequency signal of four times the greatest frequency present from the picture analysis, and consequently, a high frequency elimination filter could be used to eliminate the undesirable opening frequency signal.

It is apparent that the application of my system is not limited to images lying in the visible portions of the spectrum. The tube is equally applicable to such fields as ultra-violet electro-microscopy, infra-red electro-telescopy, and electro-optical amplification of X-ray images. By providing suitable photoelectric materials on the photosensitive plate and an appropriate radiation-transmitting window in the bulb, my device may be rendered serviceable in any application where it is required to transform an invisible image to one which is visible.

Still further, my device is applicable to electrooptical systems designed to reproduce images in their natural colors. By the use of three of my devices with suitable color filters and photoelectric materials, it is possible to analyze the three primary colors of the original image and transmit signals corresponding to the intensities of these colors, so that an image corresponding to those components may be reproduced at the receiving terminal.

The design of the electron gun can be widely varied, and the principal requirement is that it give a beam of sufficiently small cross sectional area at an appropriate velocity.

The deflection of the electron beam may be accomplished either by means of the electrostatic deflecting plates shown or electro-magnetically by means of deflecting coils.

It is further, apparent, that the routine of scanning used in connection with my tube is in no way limited, and any convenient procedure may be followed. The scanning may be accomplished by following a spiral pattern; so-called saw-tooth waves may be used to cause linear scanning in a rectangular pattern. These and other methods are all adaptable for use in conjunction with my analyzer tube.

The tube should preferably be exhausted to a high vacuum in order to minimize the neutralization of the space charge by ions.

It should be understood that the described embodiment of my invention is by no means the only one, and modifications will occur immediately to those skilled in the art; such modifications should in no way be construed as limiting my invention.

I claim:

1. In the art of electrical view analysis by pure space electron interaction, the method which comprises producing a plurality of discrete space currents of photoelectrons corresponding respectively to the elementary areas of an image of the view being analyzed, causing said space currents to coexist at a fixed space plane, generating an electron beam of relatively high velocity, traversing directly said space currents at said fixed space plane by said electron beam, and causing said high velocity electron beam to restrain the passage of said space currents through said space plane at the successive points of transit of said electron beam during the instant of transit of said beam.

2. In the art of electrical view analysis by pure space electron interaction, the method which comprises producing a plurality of discrete space currents of photoelectrons corresponding respectively to the elementary areas of an image of the view being analyzed, causing said space currents to coexist at a fixed space plane, generating an electron beam, traversing directly said space currents at said fixed space plane by said electron beam, causing said electron beam to restrain the passage of said space currents through said space plane at the successive points of transit of said electron beam during the instant of transit of said beam, and collecting such electrons as are restrained from passing said space plane.

3. In the art of electrical view analysis by pure space electron interaction, the method which comprises producing a plurality of discrete space currents of photoelectrons corresponding respectively to the elementary areas of an image of the view being analyzed, causing said space currents to coexist at a fixed space plane, generating an electron beam of relatively high velocity, traversing directly said space currents at said fixed space plane by said high velocity electron beam, and causing said space currents to restrain the passage of said electron beam through said space plane.

4. In the art of electrical view analysis by pure space electron interaction, the method which comprises producing a plurality of discrete space currents of photoelectrons corresponding respectively to the elementary areas of an image of the view being analyzed, causing said space currents to coexist at a fixed space plane, generating an electron beam, traversing directly said space currents at said fixed space plane by said electron beam, causing said space currents to restrain the passage of said electron beam through said space plane, and collecting such electrons as are restrained from passing said space plane.

5. A photoelectric device comprising a perforated, electrically continuous, photoelectrically sensitive member, means adjacent said photoelectrically sensitive member adapted to cause photoelectrons from said member to traverse the perforations in said member, means for generating a relatively high velocity electron beam and means for projecting said electron beam through the perforations in said photoelectrically sensitive member in such a manner as to restrain the passage of said photoelectrons through said perforations during the period of transit of said electron beam.

6. In the art of electrical view analysis, the method which comprises producing photoelectrons in space relation substantially corresponding to a view to be analyzed, causing said photoelectrons to traverse a fixed space plane, generating a relatively high velocity electron beam and causing said electron beam to restrain the passage of said photoelectrons through said space plane.

7. Television transmitting apparatus comprising a tube provided with an electrode in the form of a plate and with means for developing a beam

of electrons of substantially constant intensity and directing the beam at the adjacent surface of said plate, means for deflecting said beam to cause the electrons thereof to impinge directly and scan successively the respective elemental areas of said surface, a grid disposed in close proximity to said surface of said plate and between the latter and said beam developing means and spaced and insulated from said plate, said grid being photoelectrically sensitive on the surface thereof facing said beam developing means and being electrically conductive between any two points of the photoelectrically sensitive surface, and image producing means disposed on the same side of said grid as said beam developing means and operating to project on said photoelectrically sensitive surface an image of the view for transmission, said grid being provided with relatively small openings closely spaced with respect to each other and through which electrons of said beam can pass in straight lines from said beam developing means to said surface of said plate and through which photoelectrons emitted from said photoelectrically sensitive surface can pass to said surface of said plate.

8. Electronic apparatus comprising a tube provided with an anode, means for bombarding said anode with electrons of substantially constant intensity, a grid electrode disposed between said anode and said bombarding means and having a continuously electrically conductive electron-emissive surface, means for causing the emission of electrons from said grid electrode in space relation corresponding to an image to be analyzed, and means for causing said emitted electrons to migrate from said grid electrode to said anode, said bombarding means being so disposed that electrons therefrom in migrating to said anode follow paths at least in part coincident with the paths followed by the electrons from said grid electrode in migrating to said anode.

9. Electronic apparatus comprising a tube provided with an anode, means for bombarding said anode with electrons of substantially constant intensity, a grid electrode disposed between said anode and said bombarding means and having an electron-emissive surface conductively associated therewith so that all points of the electron-emissive surface remain at substantially the same potential, means for causing the emission of electrons from said grid electrode in space relation corresponding to an image to be analyzed, whereby the number of electrons from said bombarding means which reach said anode is modulated in accordance with the number of electrons emitted from said grid electrode.

10. Electronic apparatus comprising a tube provided with an anode, means for bombarding said anode with electrons of substantially constant intensity, a grid electrode disposed between said anode and said bombarding means and having an electron-emissive surface, said surface being continuously electrically conductive, means for causing the emission of electrons from said grid electrode in space relation corresponding to an image to be analyzed, a source of substantially constant direct current voltage connected between said grid electrode and said anode to maintain said anode positive with respect to said grid electrode so that said emitted electrons are caused to migrate from said grid electrode to said anode, whereby the number of electrons from said bombarding means which reach said anode is modulated in accordance with the number of electrons emitted from said grid electrode.

11. Electronic apparatus comprising a tube provided with an anode, means for bombarding said anode with electrons of substantially constant intensity, a grid electrode having an electron-emissive surface disposed between said anode and said bombarding means and being electrically conductive between all points on its electron-emissive surface, means for causing the emission of the electrons from the surface of said grid electrode in space relation corresponding to an image to be analyzed, a source of substantially constant direct current voltage connected between said grid electrode and said anode to maintain said anode positive with respect to said grid electrode so that said emitted electrons are caused to migrate from said grid electrode to said anode, and said bombarding means being so disposed that electrons therefrom in migrating to said anode follow paths at least in part coincident with the paths followed by the electrons from said grid electrode in migrating to said anode.

12. Electronic apparatus comprising a tube provided with an anode, means for developing a scanning beam of electrons of substantially constant intensity and directing the beam onto said anode, an electron-emissive grid electrode disposed between said anode and said beam developing means and being electrically conductive between all points on its surface, means for causing the emission of electrons from said grid electrode in space relation corresponding to an image to be analyzed, a source of substantially constant direct current voltage connected between said grid electrode and said anode to maintain said anode positive with respect to said grid electrode so that said emitted electrons are caused to migrate from said grid electrode to said anode, whereby the number of electrons from said beam developing means which reach said anode is modulated in accordance with the number of electrons emitted from said grid electrode.

13. Electronic apparatus comprising a tube provided with an anode, means for developing a scanning beam of electrons of substantially constant intensity and directing the beam onto said anode, a grid electrode having a photoelectric surface disposed between said anode and said beam developing means and being electrically conductive between all points of said surface, means for causing the emission of photoelectrons from the surface of said grid electrode which is toward said beam developing means in space relation corresponding to an optical image to be analyzed, a source of substantially constant direct current voltage connected between said grid electrode and said anode to maintain said anode positive with respect to said grid electrode so that said emitted electrons are caused to migrate from said grid electrode to said anode, whereby the number of electrons from said beam developing means which reach said anode is modulated in accordance with the number of photoelectrons emitted from said grid electrode.

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