

Aug. 25, 1942.

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2,294,115

ELECTROSTATIC SCANNING

Filed June 4, 1941

4 Sheets-Sheet 1

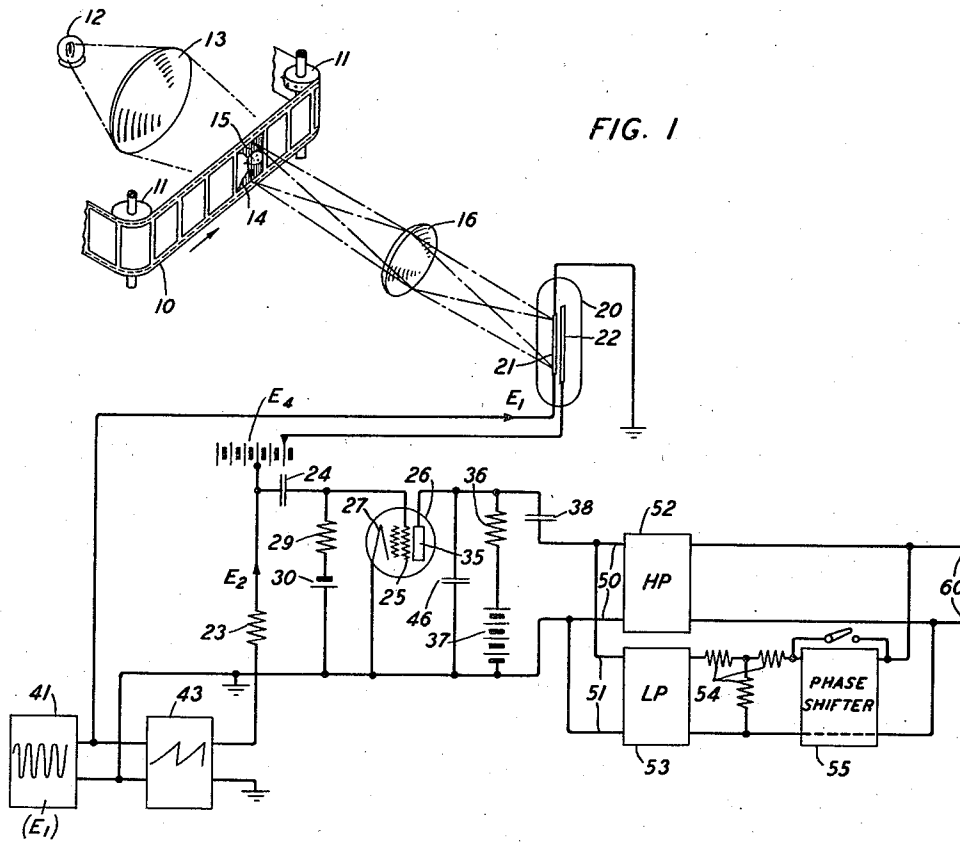


FIG. 1

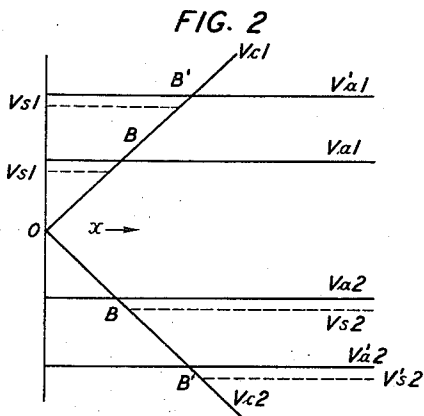


FIG. 2

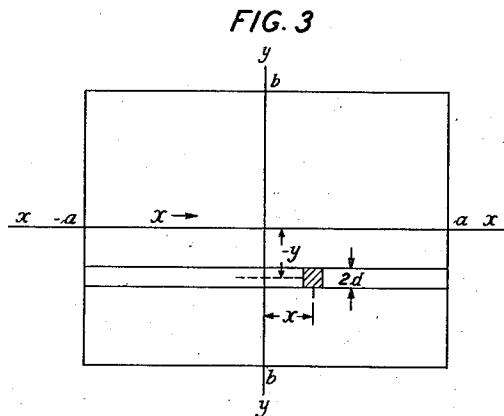


FIG. 3

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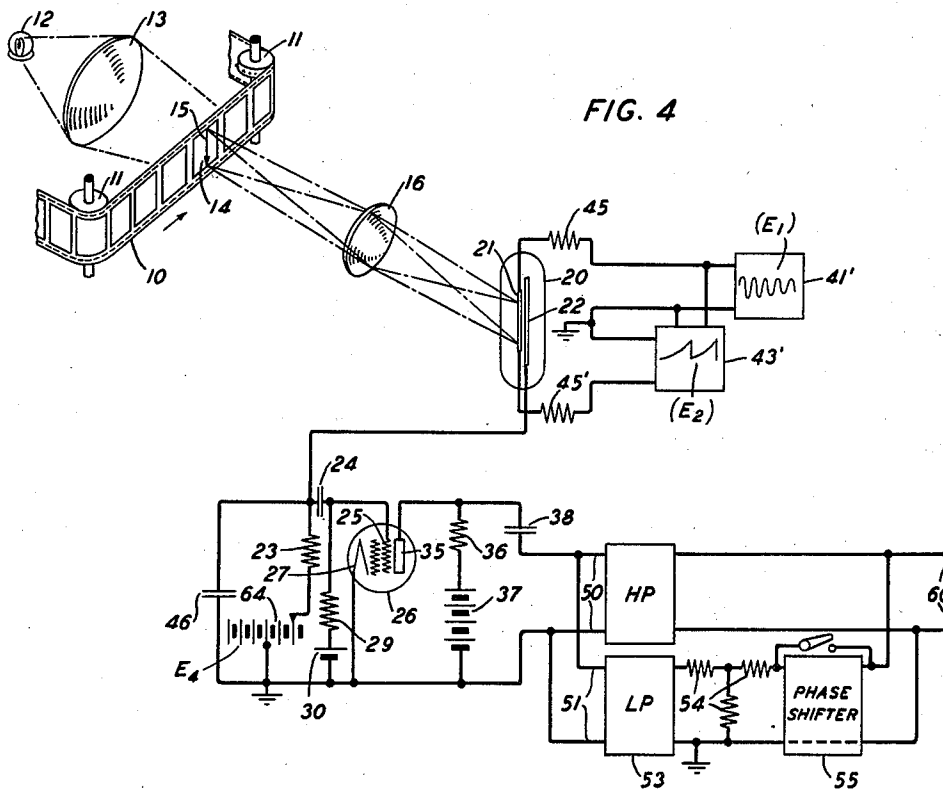
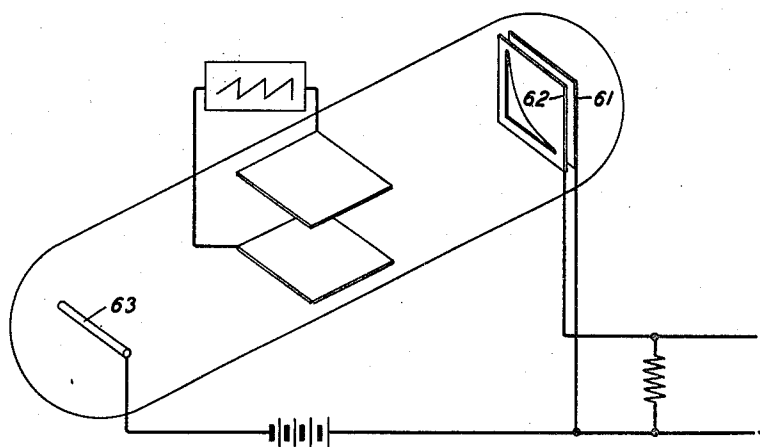


FIG. 5



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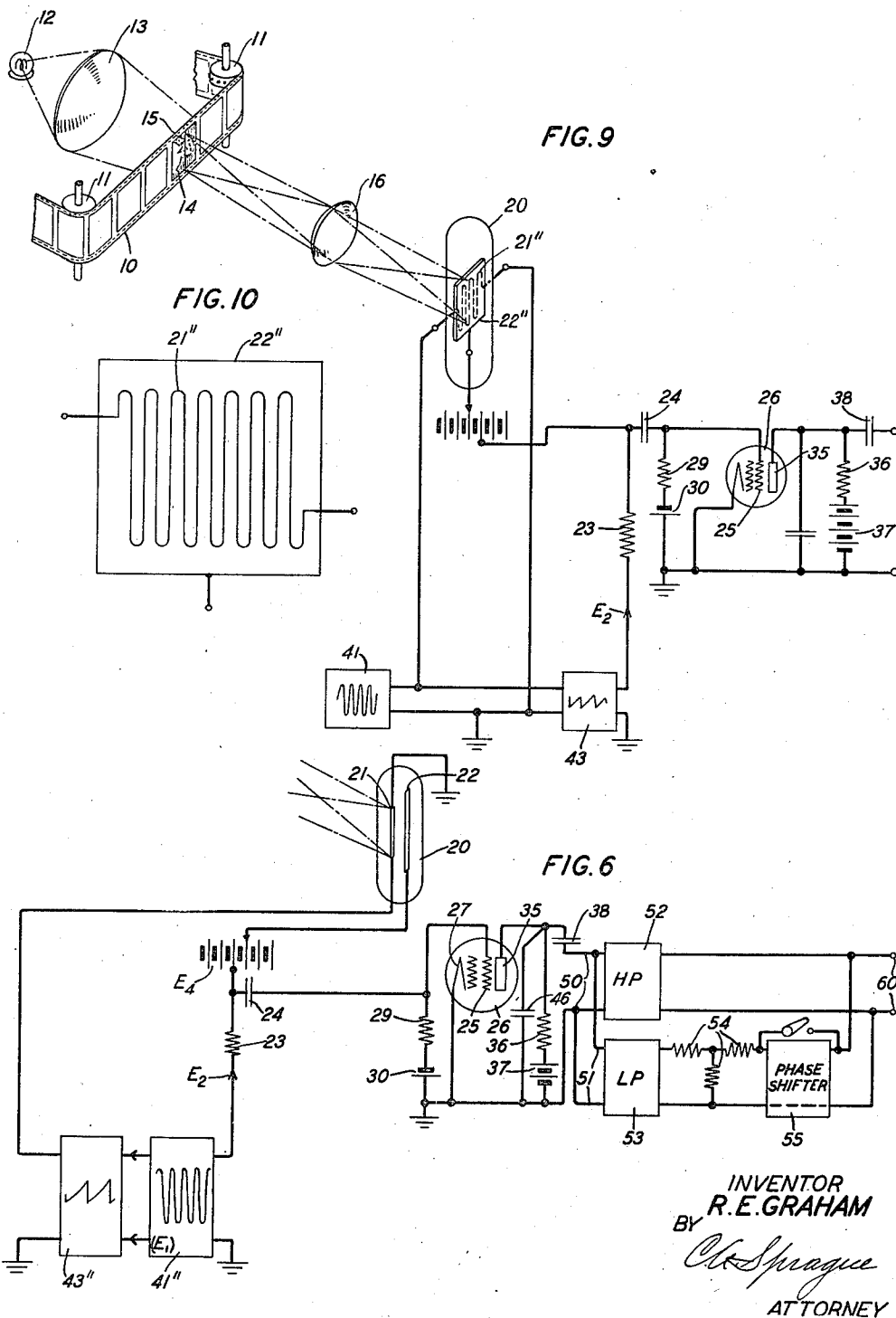
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4 Sheets-Sheet 3



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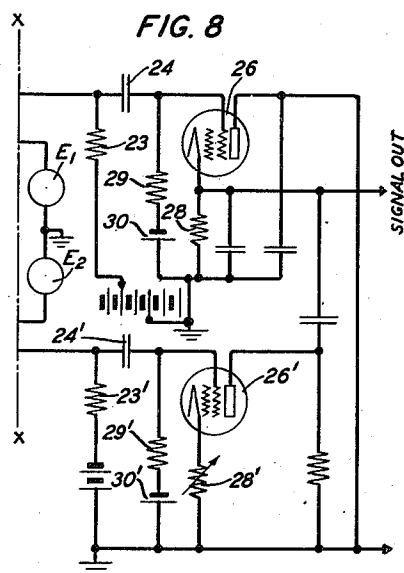
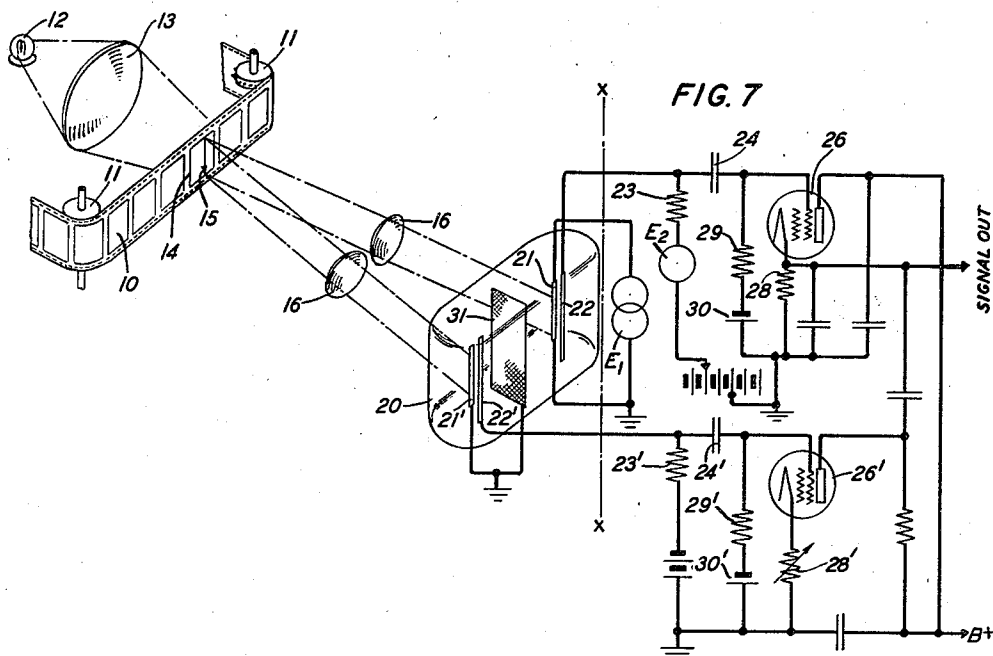
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2,294,115

ELECTROSTATIC SCANNING

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Application June 4, 1941, Serial No. 396,521

22 Claims. (Cl. 178—7.2)

This invention relates to television transmitters and more particularly to a television camera in which the scanning operation is accomplished without the use of any moving material agent such as a focused electron beam.

The now common electronic scanning systems, while they constitute a marked improvement, especially for "instantaneous" image transmission, over the earlier systems employing moving optical elements are nevertheless limited from the practical standpoint by the necessity for the provision of electron-optical systems for sharply focusing a beam or beams of electrons onto a beam receiving target.

In order to escape from the restrictions imposed by the electron-optical system, it has already been suggested to dispense entirely with the electron beam and carry out the scanning operation by the movement along a prescribed path, not of any material agent, but of a point or region which is distinguished electrostatically from neighboring points. For example, it has been proposed to provide two plate-like conductors spaced apart and supply them with different potentials to produce an electrostatic field between them; to provide in this field a third conductor of elongated form and serving as a photocathode on which an image is focused; and by changing the potential of the photocathode to cause a point or line separating parts of it from which photoelectrons are withdrawn from other parts from which they are not withdrawn to progress lengthwise of the photocathode in such fashion that the resulting current flowing from the photocathode to one of the plate-like conductors bears a relation to the brightness of successive image points.

A system of the character described is disclosed as to its broadest outlines in British Patent 476,714, complete accepted December 14, 1937. That system, however, is open to the objections that in some forms no less than three electrodes are required, at least one and preferably two of which must be large as compared with the dimensions of the image line scanned, while in other forms certain relations must obtain between the disposition of and coupling between the electrodes, which relations may be difficult to secure in practice.

In my application Serial No. 396,006, filed May 31, 1941, there are described and claimed improved electrostatic scanning apparatus of compact construction employing a minimum number of electrodes. The apparatus comprises two extended electrodes, i. e., a photocathode on

which an image of a part of a field to be transmitted is focused and an anode collector of photoelectrons which may be disposed parallel to and closely adjacent to the photocathode. One of these electrodes, for example, the anode, may be at a uniform potential, while the other, for example the photocathode may be arranged to sustain a substantial voltage drop along its length so that successive points thereof are at successively different potentials with respect to the collector anode, one point or narrow region being at the same or substantially the same potential as the collector anode. This point or region divides the first electrode into two parts over one of which collection of photoelectrons takes place, while over the other it does not take place. This dividing point is caused to progress along the length of the photocathode to scan the image focused upon it by the provision of scanning voltages of suitable wave form on and between these electrodes. This results in the flow of a current in an external circuit connected to the collector which is or may readily be converted into a vision signal for amplification and transmission.

It is an object of this invention to provide improvements in electrostatic scanning apparatus, both of the type described in the aforementioned application Serial No. 396,006 and of other types. Specifically it is an object to provide other and further means for effecting the scanning movement of a neutral point or region along the length of an extended photocathode, and in particular to effect this scanning movement through the medium of suitably modulated high frequency or carrier generators. It is a feature of the invention that the signal obtained in the form of a current from the collector is not a vision integral signal as in the arrangements shown in the aforementioned application Serial No. 396,006 with the result that it becomes unnecessary to provide a differentiating circuit to convert it into a conventional vision signal. On the other hand, the signal obtained from the collector does include a certain undesired component which it is impossible to remove on a straightforward frequency separation basis without degrading the desired component. Accordingly, it is a subsidiary object of the invention to provide means for eliminating this undesired component.

It is another feature of the invention that by a simple adjustment the effective aperture of the system may be altered at will and the signal delivered by the apparatus may be made positive or negative, as desired.

While in a broad sense the invention may be useful in the scanning of object fields generally, it is especially applicable to the scanning of images borne by a moving film wherein scanning of successive image lines is carried out in accordance with the novel principles of the invention while frame scanning, that is, scanning in a direction perpendicular to the length of the image line, is accomplished by movement of the film. Accordingly, the following illustrative description is directed in the main to preferred embodiments designed especially for line scanning. It will be concluded by a brief description of an embodiment suitable for field scanning.

The description will be more readily understood by reference to the accompanying drawings in which:

Fig. 1 shows electrostatic scanning apparatus in which a voltage drop along an extended photocathode is provided by a high frequency source of carrier voltage;

Figs. 2 and 3 are diagrams illustrating the mode of operation of the apparatus of Fig. 1;

Fig. 4 shows an alternative arrangement to Fig. 1 in which the movement of the scanning point is obtained by application to the photocathode of a novel combination of modulated and unmodulated high frequency carrier voltages;

Fig. 5 shows auxiliary apparatus which may be employed to obtain wave forms suitable for use with the apparatus of Figs. 4 and 6;

Fig. 6 shows a modification of Fig. 4;

Figs. 7 and 8 show arrangements alternative to Figs. 1, 4 and 6, respectively, employing a discharge device containing auxiliary electrodes;

Fig. 9 shows an arrangement designed for scanning a surface as distinguished from a line, the associated circuit being, for the sake of illustration, the same as that of Fig. 1; and

Fig. 10 shows a portion of the apparatus of Fig. 9 to an enlarged scale.

Referring now to Fig. 1 an elongated flexible member 10 is provided on which are recorded successive images of a field of view to be transmitted. For the sake of definiteness of illustration this member 10 is shown as a transparent film, for example a motion picture film. It may be passed around sprocket or guide rollers 11 and any suitable means of a type well known in the art may be employed to maintain a part of it intermediate the guide rollers in a definite focal plane. Likewise, any suitable means may be employed to advance this portion of the film in a direction parallel with its length, for example, with a continuous uniform motion. Light from any suitable source, for example an incandescent lamp filament 12 may be directed upon a film frame 14, for example by a lens 13. The film frame 14 is thus evenly flooded with light. A line 15 of the film frame 14 extending transversely of the film length may be imaged, for example by a lens 16, on the extended photocathode element of the novel pick-up device.

The pick-up device may be disposed in a position to be impinged by light from the source passing through the transparent film 10. This device may comprise an evacuated envelope 20 containing two principal electrodes. The first electrode 21 is the photocathode and the second is a collector anode 22. The photocathode may be an elongated narrow element, for example, a wire or thin strip of electrically conductive material and, by reason of an appropriate surface treatment or otherwise, having pronounced photoelectric properties. The base material should be one

whose unit impedance or resistivity is of an intermediate value, that is to say, it should be neither an insulator nor a good conductor, but should offer an impedance or resistance to the passage of electric current such that it can sustain a comparatively large longitudinal voltage drop even with the passage of a comparatively small current. For example, this element may be a wire of about 5 mils diameter and 1 inch in length and made of material such that with these dimensions its total resistance as measured between its end terminals is of the order of 1 megohm. If desired this element may be constructed in the form of a tight spiral of small diameter in the manner well known in the incandescent filament art. It is important that the material of which the photocathode element is constructed be uniform both as to its unit impedance or resistivity and its photoelectric properties so that the voltage drop per unit length and the electron emission per unit of illumination shall be the same throughout.

The collector anode 22 may be an elongated wire or strip of ordinary conducting material such as a metal and may be disposed close to and parallel with the photocathode within the envelope. The photocathode element and the collector anode may be supported and maintained in correct parallel alignment by any suitable supporting means in a manner well known in the art.

Although the construction and arrangement as above described offer certain distinct advantages, an opposite arrangement may be employed, i. e., one in which the photocathode is a highly conductive element which tends to remain at a uniform potential throughout its length while the collector anode offers a comparatively high impedance or resistance to electric current and supports a longitudinal voltage drop. The description in this specification will be directed principally to the preferred arrangement though it is to be borne in mind that the invention applies equally to the converse arrangement above briefly alluded to.

The pick-up device 20 may be disposed with the photocathode element 21 extending in a direction perpendicular to the length of the film 10 and the line 15 of the film extending transversely of the film length and illuminated by the source 12 may be imaged upon the photocathode 21 so that the amount of light falling upon each point of the photocathode is proportional to the translucency of the corresponding point of the illuminated film line 15. Emission of photoelectrons will then take place from each point of the photocathode 21 in proportion to the illumination of the corresponding points of the illuminated film line 15 in a well-known manner.

Operating potentials may be applied to the electrodes of the pick-up device in various ways and may be of various forms. In the modification of Fig. 1 a high frequency carrier voltage E_1 derived from a generator 41 is applied at constant amplitude to the end terminals of the photocathode 21, one of which is grounded. The output of this generator is also fed to a modulator 43 which modulates the carrier envelope with a saw-tooth wave form at line scanning frequency. The resulting saw-tooth modulated carrier voltage, designated E_2 , is applied to the collector anode element 22. The collector anode 22 may be connected through a bias battery E_4 , a resistor 23 through which the voltage E_2 is applied, to ground. At the same time it may be impressed

by way of a condenser 24 on the control element 25 of a discharge device, for example to the control grid of a vacuum tube 26 whose cathode 27 is connected to ground, the control grid 25 being returned to ground through a resistor 29 and a biasing battery 30. The output electrode or plate 35 of this tube is supplied with potential through a loading resistor 36 from a suitable source, for example, a battery 37, the negative terminal of which is grounded. The signal output from this tube appears across the loading resistor 36 and is delivered through a condenser 38 to a network of two separate branches each containing certain elements for modifying the signal in a particular manner as hereinafter fully described. A small condenser 46 may be connected from the plate 35 to ground to by-pass undesired carrier frequency components of the tube output.

The internal connections and arrangement of the elements of the high frequency carrier voltage generator 41 and of the device 43 which modulates the wave form of the carrier voltage with a saw-tooth line frequency envelope may be of any desired type since they form no part of the invention. It is preferred that the carrier component of the output of the modulator 43 which is applied to the collector anode 22 be in phase with the unmodulated carrier E_1 applied to the photocathode 21. This may likewise be provided for in any desired manner.

The frequency of the carrier voltages E_1 and E_2 applied to the photocathode 21 and collector anode 22, respectively, should be high in comparison with the vision frequencies to be produced. They may, therefore, properly be termed "carrier frequency" voltage. The bias battery E_4 is included between collector anode and photocathode for a reason later explained. Its magnitude is preferably adjusted so that, in the absence of the carrier voltages, the potential of the photocathode 21 is just below the collection threshold for a negative signal and just above for a positive signal.

The operation of the arrangement depicted in Fig. 1 for a negative signal is as follows. The photocathode 21 being illuminated as above described, emission of photoelectrons takes place from the various points thereof in proportion to the light incident thereon. Of these photoelectrons those emitted from points of the photocathode 21 which are, at any particular instant of the carrier cycle, at negative potentials with respect to the collector anode 22, are drawn to the collector anode and caught by it, whereupon they return to the photocathode through the external resistor 23 to produce a voltage drop across the latter. On the other hand photoelectrons emitted from parts of the photocathode 21 which are at positive potentials with respect to the collector anode 22 are repelled by it and fail to reach it and therefore make no contribution to the voltage drop across the external resistor 23.

Those parts of the photocathode from which collection takes place are separated from those parts from which it does not take place by a point at which, or a narrow region throughout which, the photocathode potential is substantially equal to the collector potential or differs from it by a small amount equal to the voltage of the bias battery E_4 .

The operation of the system of Fig. 1 will be better understood by reference to the diagram Fig. 2 in which the potentials of the electrodes are plotted as functions of distance measured along the photocathode element at two different

instants of time within a single cycle of the carrier voltage. Thus at one instant, t_1 , the line V_{c1} represents the potential of the photocathode which increases progressively along its length, the left-hand end being taken as at zero or ground potential. The collector anode, a conductor, is at a uniform potential which, at the instant t_1 , may be represented by the line V_{a1} . It will be observed that under these conditions parts of the photocathode to the left of the point of intersection B are at lower potentials than the collector anode and therefore active, whereas parts of the photocathode to the right of the intersection point B are at higher potentials than the collector and therefore inactive. Thus, at the instant t_1 collection of photoelectrons is taking place from all parts of the photocathode between its left-hand end and the point B. This condition represented by the dotted line V_{s1} persists throughout one half cycle of the high frequency carrier voltage E_1 . During the immediately ensuing half cycle of the carrier voltage the potential conditions of the photocathode with respect to the collector are reversed, the part which was at a low potential and active during the first half cycle becoming inactive and vice versa. The new photocathode potential is represented by the line V_{c2} over which the potential gradient is reversed and the new uniform potential of the collector anode is represented by the horizontal line V_{a2} . Collection of photoelectrons now takes place from parts of the photocathode to the right of the intersection point B as indicated in the figure by the dotted line V_{s2} and not from parts to the left. During the minute interval of time represented by one half cycle of the carrier voltage the neutral point B has, of course, moved, but the amount of its movement in one carrier half cycle is imperceptible, or at least it is small in comparison with the length of an elemental area of the line image focused on the photocathode. Thus over a full carrier cycle or a plurality of such cycles, emission takes place from all points of the photocathode to the collector except from the neutral point B.

The potential variations of the collector in the course of the modulation cycle cause this neutral point B to progress along the length of the photocathode at a constant speed under control of the saw-tooth modulation due to the modulator 43. Conditions at a later part of the saw-tooth scanning cycle of the modulation envelope E_2 are schematically represented on the diagram of Fig. 2 by the lines $V_{a1'}$ and $V_{a2'}$, respectively. It will be observed that, due to the increase of the collector potential in the course of the scanning cycle the point B has moved along the photocathode element to a point B', where but for an insubstantial movement, it remains over the ensuing carrier half cycle. In accordance with the invention, this process continues until the neutral point B has reached or slightly passed the end of the line image focused on the photocathode element 21.

After the neutral point has progressed over the full length of the photocathode or that part of it on which the film line 15 is imaged, the saw-tooth voltage envelope drops rapidly to its initial value to commence a new cycle, and the neutral region B flies back to its starting point to commence the scanning of a new line. Meantime the film 10 has advanced by the width of a single line so that as the neutral point starts its progress along the photocathode a slightly different part

of the film will be imaged upon it. Successive repetitions of this process result in complete scanning of the film image.

The amplitude of the carrier voltage is preferably set at a comparatively high value so that the carrier frequency voltage drop between collector and photocathode rises very rapidly on either side of the neutral point B to the value, indicated in Fig. 2 by the dotted lines V_s , which is necessary to insure saturated photoelectron collection from all points of the photocathode except a very narrow neutral region. Thus the effective cathode-collector potential difference is approximately uniform along the photocathode except for a sharp dip in the vicinity of the neutral point. This sharp dip in the cathode-collector effective potential then corresponds to a rejection of the signal due to the light falling on or near the neutral point. As the collector potential changes in the course of the saw-tooth scanning cycle the rejection point or barrier travels along the photocathode at the prescribed sweep velocity, thus producing in the external collector circuit a signal of two components, first a signal representing the aggregate photoemission from the entire photocathode, and second, a signal of opposite sign, corresponding to rejection due to the barrier and proportional to the light distribution along the length of the photocathode.

In the preceding explanation it has been assumed that the critical potential difference at which collection of photoelectrons commences is zero; that is to say no collection takes place when the collector is at a lower potential than the photocathode. This assumption is sometimes not borne out by the facts. For example, collection may continue until the collector potential is one or two volts negative with respect to the photocathode. In this event, were it not for the bias E_4 , the collection region would extend beyond the nominal neutral point on one carrier half cycle in one direction and would extend beyond it in the other direction on the next carrier half cycle. The result would be a reduction of the desired signal as compared with the undesired signal, and a consequent reduction in efficiency. The bias voltage E_4 may therefore be employed to reduce the collector potential to the critical collection potential so that the collection regions for successive half cycles just meet. Too great a negative bias would produce a large gap between the collection regions which would result in a loss of definition due to the increased size of the neutral region which is in effect the aperture of the system. Thus adjustment of the magnitude of this bias offers a convenient means for adjusting the aperture of the system.

These two signal components appear in the form of modulation envelopes of half cycle carrier frequency pulses, or, more precisely, since the neutral point differs slightly from the collector potential, partial-cycle pulses. Since these pulses as so modulated have a net direct current contribution over each carrier cycle instead of being sine waves, the aggregate collector current will contain the two signal components above mentioned both in terms of the usual vision frequencies and also as modulation side-bands of the carrier frequency, so that either the vision frequency signal itself or the carrier frequency signal modulated with the vision signal may be utilized as desired. Assuming that the vision signal itself is to be utilized, the carrier frequency with its side-bands and harmonics may be fil-

tered out by any appropriate means, for example, a small by-pass condenser 46, which may indeed be merely parasitic capacity between the plate 35 and ground. The two signal components above described are impressed together between the cathode 27 and control grid 25 of the tube 26.

If the same line image were to be continuously focused on the photocathode and repeatedly scanned, the first signal component above mentioned, namely the component representing the aggregate emission from the entire photocathode, would be harmless. However, in the usual case successive line images are to be scanned in which the aggregate light is not constant from one line image to the next. In such case it is desirable to dispose of this first component, leaving as the final output signal of the apparatus only the second component above mentioned, namely, the one which represents the light distribution over the whole image, from the beginning of the first scanning line to the end of the last.

The removal of the undesired component cannot be effected by an ordinary separation on the basis of frequency discrimination because the desired vision signal itself contains certain essential components of frequencies equal to the frequencies of the undesired component, that is to say the desired and undesired components overlap in frequency spread. This fact, as well as an appreciation of a means and method by which the undesired component may be removed will be understood from the following analysis which is based on the complete scanning of a single image frame or still picture, for example, a single image frame 14 of the film 10. As is well known, the movement to be expected in ordinary fields of view or the differences in aspect of successive film frames are of such a low order that the analysis on the basis of a still picture may be extended with no modifications of practical importance to the scanning of moving object fields or of successive film frames.

Referring then to Fig. 3, the picture or image frame to be scanned may be assumed to be set up on coordinate axes as indicated. The picture, of width $2a$ and of height $2b$, is to be swept parallel to the Y axis across a strip photocathode of length $2a$ (equal to the picture width) in the X direction and of height $2d$ (equal to the height of a single scanning line or strip) in the Y direction. At the same time the neutral point or region which serves as a scanning spot is to be swept from the position $-a$ to the position $+a$, that is, from end to end of the photocathode strip. As explained above, collection of photoelectrons takes place over a complete carrier cycle from the whole strip except the neutral region. The latter may, therefore, be conceived of as a barrier equal in area to the neutral region. For the sake of simplicity of analysis the barrier may be taken as a square of length and height both $2d$, i. e., of the size and shape of an idealized elemental area of the picture. Furthermore it may be taken to be of complete opacity to photoelectrons and the carrier frequency collector currents will be assumed to be adequately by-passed or otherwise disposed of so that the carrier frequency variations in the collection of photoelectrons may be disregarded and the collection taken as zero at the barrier and complete elsewhere.

These simplifying assumptions correspond to those generally made in scanning analysis and acknowledged to be justified by the results. Without them the analysis would be so complex as to obscure its own conclusions.

For any given position of the strip photocathode relative to the picture and of the barrier relative to the strip, the coordinates of the center point of the barrier may be designated as x and y . Then the total collection of photoelectrons from the whole strip photocathode is given (neglecting constant factors) by:

$$I(x, y) = \int_{-d}^d \int_{-a}^a L(\epsilon, y + \eta) d\epsilon d\eta - \int_{-d}^d \int_{-d}^d L(x + \epsilon, y + \eta) d\epsilon d\eta \quad (1)$$

where

$L(x, y)$ = light distribution of projected picture,
 ϵ, η = integration variables.

In this equation the first term represents the aggregate collection from the whole strip. It would be the same if the barrier were not present. The second term represents the diminution of total collection due to the presence of the barrier.

In a comprehensive analysis of the scanning function by P. Mertz and F. Gray published in volume 13 of the Bell System Technical Journal for July, 1934, at pages 464 to 515 it is shown that the light distribution of the projected picture may be represented by the complex double Fourier series:

$$L(x, y) = \sum_m \sum_n A_{mn} (\exp) i\pi \left(\frac{mx}{a} + \frac{ny}{b} \right) \quad (2)$$

where the A's are complex constants.

Substituting this value of L into Equation 1 and integrating, there is obtained

$$I(x, y) = 4d^2 \left[\sum_n A_{0,n} Y(0, n) (\exp) \frac{i\pi ny}{b} - \sum_m \sum_n A_{mn} Y(m, n) (\exp) i\pi \left(\frac{mx}{a} + \frac{ny}{b} \right) \right] \quad (3)$$

where $Y(m, n)$ is an aperture distortion factor.

By reference to the aforementioned treatment in the Bell System Technical Journal it may be seen that in this Equation 3 the second term is of the form of an ordinary vision signal obtained with conventional scanning systems. It is therefore the desired signal. The first term, which is the undesired signal, is of the form obtained by putting $m=0$ in the second term. In other words, signal components representable by putting $m=0$ are common to the desired and undesired signals. These components are of importance since they are representative of images or scenes whose light values do not vary across the picture in the X direction but do vary in the Y direction or from top to bottom of the picture. The occurrence of these components in both terms of the Equation 3 makes it apparent that the undesired signal cannot be separated from the desired signal on the basis of a conventional frequency separation alone, and that more elaborate means must be employed to effect the separation.

To this end the circuit arrangement of Fig. 1 is provided which permits the characteristics which are common to the desired and undesired signals to be taken advantage of. The whole signal, including the desired and the undesired portions, is fed from the triode 26 into two separate paths, the one path 50 including a high-pass filter 52 and the other path 51 including in tandem order a low frequency pass filter 53, an attenuator pad 54 and a phase shifting device 55. These two paths 50 and 51 are then brought together at common terminals 60.

The low frequency cut-off of the high-pass filter 52 and the high frequency cut-off of the low-pass filter 53 are preferably set at the same value which may advantageously be at or about one half the line scanning frequency of the sawtooth modulator 43. The attenuation ratio of the pad 54 may be set at a value equal to the ratio of the length of a scanning line to the length, measured along the line, of a single elemental picture area, that is, the ratio of the length $2a-2d$ of the active portion of the photocathode to the length $2d$ of the neutral region. (Fig. 3.) In accordance with present-day practice this ratio may be about 400:1. The phase shifting device 55 should be designed to alter the phase of the components passed by the filter 53 by an amount which will place these components in the path 51 in phase opposition to the same components in the path 50. For example, if the phase rotation in the filters 52 and 53 and in the pad 54 be disregarded, the phase shifter 55 may rotate the phase angle of the low frequency components through 180 degrees. A phase shifting device of any desired type may be employed, for example, a single resistance-coupled triode stage.

The operation of this circuit arrangement is as follows. Referring again to Equation 3, the latter may be written shortly

$$I(x, y) = 4d^2 [U - V] \quad (4)$$

where V , the desired vision signal, is in turn composed of a group of high frequency components H and a group of low frequency components G ; that is

$$V = H + G \quad (5)$$

and U , the undesired component, is (from (3)) related to G by the equation

$$U = \frac{a}{d} G \quad (6)$$

Therefore the Equation 4 may again be written

$$I(x, y) = 4d^2 \left[\frac{a}{d} G - H - G \right] = 4d^2 \left[\left(\frac{a}{d} - 1 \right) G - H \right] \quad (7)$$

in which the components have been regrouped, the first term of the parenthesis containing essentially components below half line frequency while the second term contains essentially components above half line frequency. Therefore when the signal as a whole is fed to paths 50 and 51 in parallel, the components represented by the first term of (7) are excluded by the filter 52 while passing the filter 53 and the components represented by the second term are excluded by the filter 53 while passing the filter 52.

The first term components are then reduced in magnitude in the ratio

$$\left(\frac{a}{d} - 1 \right)$$

by the attenuator 54 and reversed in phase by the device 55, thus

$$\left[\left(\frac{a}{d} - 1 \right) G \right] \left[-\frac{1}{\left(\frac{a}{d} - 1 \right)} \right] = -G \quad (8)$$

The resulting signal, $-G$, is then mixed with the signal $-H$ at the terminals 60 to give (see Equation 4)

$$-H - G = -V \quad (9)$$

and therefore the net signal at these terminals may be represented by

$$I'(x,y) = -4d^2V = -4d^2 \left[\sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} n A_{mn} Y(m,n) \exp i\pi \left(\frac{mx}{a} + \frac{ny}{b} \right) \right] \quad (10)$$

Except for a reversal in phase of all components alike which is of no importance this is the desired vision signal.

The vision signals derived as above described may be amplified and transmitted by wire or radio, by carrier modulation or otherwise as desired, to a receiver station where they may be reconstituted by suitable apparatus as an image. If desired, the whole anode current signal including the undesired part may be transmitted to the receiver and the removal of the undesired component may be carried out at the receiver end instead of the transmitter end. It is preferred, however, to effect the removal at the transmitter end.

Fig. 4 shows a further modification in which the scanning electromotive forces are applied exclusively to the photocathode 21, the potential of the collector anode remaining steady. In this case an unmodulated carrier voltage E_1 and another carrier voltage E_2 of like phase and frequency but modulated with a modified saw-tooth scanning voltage are applied in series to the photocathode E_1 . The voltage E_2 may be derived from a modulator 43' supplied with voltage from the carrier frequency generator 41' which also supplies the voltage E_1 to the photocathode directly.

It will be understood that with modifications of a minor character the unmodulated carrier voltage E_1 and the modulated carrier E_2 may be interchanged with reference to the photocathode and the collector anode, respectively.

The form of the modulating envelope may be calculated from Fig. 4 as follows:

If

E_1 =unmodulated carrier

E_2 =modulated carrier

Z_c =photocathode impedance

Z_1, Z_2 =dummy load impedances 45 and 45'

then, measuring from the terminal connected to the impedance 45 along the photocathode, the neutral point will appear at KZ_c , where

$$0 < K < 1$$

Then K is determined by

$$E_1 \frac{(1-K)Z_c + Z_2}{Z_1 + Z_2 + Z_c} = E_2 \frac{KZ_c + Z_1}{Z_1 + Z_2 + Z_c} \quad (11)$$

or

$$\frac{E_2}{E_1} = \frac{(1-K)Z_c + Z_2}{KZ_c + Z_1} \quad (12)$$

In this expression the factor K is to be obtained by modification of a saw-tooth voltage and is to increase linearly with time over each saw-tooth voltage cycle. Putting $K = K_1 t$, where K_1 is a constant factor,

$$\frac{E_2}{E_1} = \frac{(1-K_1 t)Z_c + Z_2}{K_1 t Z_c + Z_1} \quad (13)$$

In particular, taking $Z_c = 10Z_1 = 10Z_2$,

$$\frac{E_2}{E_1} = \frac{11 - 10K_1 t}{1 + 10K_1 t} \quad (14)$$

Any desired means may be employed to secure a voltage which varies inversely with time in the required manner. For example, an arrange-

ment such as that disclosed in copending application Serial No. 342,601 filed June 27, 1940, or in United States Patent 1,757,345, May 6, 1930, may be adapted to the present purpose. In these disclosures it is pointed out that currents having various desired wave forms may be generated by the use of a cathode beam tube in which a broad electron beam is projected on a suitably shaped target or on a target disposed behind a suitably shaped aperture and swept over the target or aperture in accordance with a signal whose wave form it is desired to modify. For the present purposes, if the aperture has the form of a plot given by Equation 13, a current varying inversely with the time in the required manner will flow in the target circuit when the beam is deflected past the aperture at a uniform speed. This inverse current may be translated into a voltage of like wave form in any desired manner, for example by allowing it to flow through a resistor across which are connected the input terminals of a high impedance tube. The voltage appearing in the output circuit of this tube may be employed to modulate the carrier and the latter, as modulated, may be applied to the photocathode to produce progressive movement of the neutral point as above described.

Fig. 5 is a diagram showing the essentials of such a translating device and including a target 61 disposed behind an aperture in a plate 62 one of whose sides is cut to follow the curve given by Equation 13 on the basis of unity amplitude for E_1 . Deflection of an electron sheet originating at an extended cathode 63 past this aperture at uniform speed will give a target current of the required wave form.

It will be apparent that with this arrangement the rate of change of the potential difference between photocathode and collector is greater when the neutral point is near one end of the photocathode than when it is near the other end. As a result, the region of saturated collection of photoelectrons is closer to the neutral point at one end of the photocathode than at the other. In other words, the "aperture effect" varies along the length of the photocathode and the received image will have higher definition at one side than at the other. In some applications this may be of advantage.

The signal current in the external circuit of the collector 22 and therefore the voltage impressed on the input circuit of the triode 26 contains the same two components as are derived in the apparatus of Fig. 1. These two components may be separated by a circuit identical with that above described, to deliver the desired vision signal at the output terminals 60. Furthermore, the high frequency carrier component of the collector current may be by-passed to ground, for example, by the use of a condenser 46, or may be disposed of in any other desired manner.

Fig. 6 shows a modification of Fig. 1 in which the modulated carrier is applied to the photocathode and the unmodulated carrier is applied to the collector anode. In such case the carrier voltage E_2 may be derived from a carrier generator 41'', while the latter feeds a modulator 43'' which supplies a modified wave form envelope for application to the photocathode. The modulator may be of the type described above as being suitable for use with the apparatus of Fig. 4, and shown in Fig. 5. However, for motion of the neutral point at constant speed, the necessary wave form is no longer a conventional

saw-tooth but rather an inverse function of time, either of the form

$$E(t) = \frac{a}{t} \text{ or } E(t) = \frac{a}{b-t}$$

where a and b are constants.

In the practical application the modulating voltage need not become infinite as these equations indicate that it must, when t is equal to zero or b respectively. This difficulty is most simply avoided by merely providing a photocathode of somewhat greater length than the line image focused on it so that the "tag end" furnishes a marginal resistance. If preferred, separate marginal resistors may be connected to the ends of the photocathode, either inside or outside of the envelope 20. It may easily be shown that inclusion of a marginal resistor or tag end of the photocathode as a part of the circuit gives rise to a modified inverse time function, i. e., to the equation

$$E(t) = \frac{Z_1 + Z_c}{Z_1 + KZ_c} E_0$$

where

Z_c = total photocathode impedance;

Z_1 = impedance of marginal resistor or tag end;

E_0 = minimum value of the saw-tooth voltage; and

K is a constant.

It is to be noted both in Fig. 4 and Fig. 6 that since the saw-tooth scanning generator is not applied directly to the triode 26, no auxiliary balancing generator such as shown in Fig. 1 and designated "E₃" is required.

The undesired signal which accompanies the desired signal and which is eliminated in the arrangements of Figs. 1, 4 and 6 by the apparatus 50-60 may also be eliminated by other means. Fig. 7 shows such other means in combination with a circuit arrangement similar to that of Fig. 1. In this figure an auxiliary photocathode 21' and an auxiliary collector 22' are included in the same envelope 20' as the main photocathode 21 and collector 22. The two pairs of electrodes are preferably separated by an electrostatic shield 31 which may be grounded to prevent interaction between them. By suitable optical means, for example by the use of two lenses 16 and 16' as indicated, the line to be scanned is imaged in like manner on both photocathodes. The excitation of the principal photocathode and the scanning operation proceed as described above in connection with Fig. 1, but the auxiliary photocathode 21' is not scanned longitudinally. At the same time another signal similar to the undesired signal represented by the first term of Equation 3 is derived from the auxiliary collector anode 22' and is impressed on the auxiliary tube 26'. The impedance element 23 should present a substantial impedance value at vision frequencies but may have a very low value at carrier frequencies. This serves to filter out the carrier voltage from the signal before it reaches the tube 26. The impedance element 23', on the other hand, need maintain its value only up to about line frequency. The output is taken from the cathode of tube 26 and the anode of tube 26', so that corresponding components will be in phase opposition. An adjustable element, for example, the cathode resistor 28' of the tube 26' permits control of the magnitude of the output of the tube 26' to the value necessary to permit it to cancel the undesired component in the tube 26 to leave only the desired component at the output terminals. In

order to simplify the drawings, the voltages E_1 and E_2 are shown as derived from separate generators, which should of course be synchronized. It is to be understood that they may likewise be derived from a generator and modulator as in Fig. 1.

A tube with auxiliary electrodes as above described may also be employed to eliminate the undesired signal component in the circuit arrangement of Figs. 4 and 6. One such arrangement is shown in Fig. 8.

Although for the sake of particularity the desired signal has been described throughout the preceding discussion as being of opposite sign to the undesired signal, since it had its origin in a rejection of photoemission over the neutral region, it will be apparent that merely by changing the bias potential E_4 of the collector with respect to the photocathode the collection regions for successive carrier half cycles can be caused to overlap so that collection takes place over the neutral region for both carrier polarities. In this event the desired signal will be of the same sign as the undesired signal and in other respects will be as described above. This change of sign will be manifested as a change from a negative rejection signal to a positive double collection signal. It can be separated from the undesired signal by arrangements similar to those described above with modifications appropriate with respect to the change of sign. For example, in the separating circuit of Figs. 1, 4 and 6, the chief modification would consist in the omission of the phase shifter, secured by closing the short-circuiting switch, whereas in Figs. 7 and 8 no circuit change is necessary, since these circuits operate by balancing out the undesired component whose sign remains unchanged.

Fig. 9 shows an arrangement by which the neutral point scanning of the invention may be applied to the scanning of a whole surface image as distinguished from a line image. In this figure the photocathode strip 21'' is bent back and forth to form a field net on which the image as a whole may be focused, as shown in greater detail in Fig. 10. The collector 22'' is a plate mounted behind the photocathode net. The scanning action, which may be secured in accordance with any of the circuit arrangements hereinabove described, the arrangement of Fig. 1 being shown merely by way of example, moves the neutral point along the continuous photocathode strip, effecting both horizontal and vertical scanning together without the necessity for separate means for effecting line-by-line movement of the image across the photocathode strip. A further important advantage of this system is to be found in the fact that it delivers a true vision signal combined with a signal representing the aggregate illumination of the whole image frame instead of the aggregate illumination of a single line. This aggregate illumination signal may be utilized at the receiver as a direct current background signal, thus eliminating the necessity of making separate provision therefor.

Movement of the neutral point or region in the scanning operation may also be accomplished by the use of a variable impedance element caused to vary according to a proper law, and suitably connected in circuit with the photocathode or other electrode along whose length the neutral point or region is to move. Such an arrangement may be of various types, some of which form the subject-matter of copending application Serial No. 396,522, filed June 4, 1941.

The fact that the invention has been illustrated and described in terms of an embodiment wherein one of the electrodes supports a longitudinal voltage gradient is not to be taken as restrictive. The carrier excitation of the invention may also be applied with advantage to other apparatus in which, for example, the electrodes are all at uniform potentials and the boundary or barrier region is caused to move longitudinally of one of them by means of suitably modulated carrier frequency potential differences between them. When in such an arrangement an undesired signal arises of the type dealt with above, it likewise may be removed by any of the above-described arrangements adapted to effect such removal, independently of the particular nature of the apparatus in which the undesired signal may originate.

What is claimed is:

1. Image signal translating apparatus which comprises an extended photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, at least one extended anode element disposed to intercept electrons emitted by said photocathode, means for causing alternate collection and rejection by an anode of photoelectrons from areas of said photocathode extending from one end thereof to a boundary region, said collections and rejections alternating at a high carrier frequency means for causing said boundary region to progress longitudinally of said photocathode cyclically at a line-scanning frequency, and means for drawing signal currents from said anode.

2. Image signal translating apparatus which comprises an extended photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, at least one extended anode element disposed to intercept electrons emitted by said photocathode, means for causing collection by an anode of electrons from areas located in opposite parts of said photocathode in alternation, which parts are separated from each other by a boundary region, means for causing said boundary region to progress longitudinally of said photocathode, and means for drawing signal currents from said anode.

3. Image signal translating apparatus which comprises an extended photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, at least one extended anode element disposed to intercept electrons emitted by said photocathode, means for causing collection by an anode of electrons from areas located in opposite parts of said photocathode in alternation, which oppositely located areas have a boundary region in common, said collections alternating at a high carrier frequency, means for causing said boundary region to progress longitudinally of said photocathode, and means for drawing signal currents from said anode.

4. Image signal translating apparatus which comprises an extended photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, an extended

anode element disposed to intercept electrons emitted by said photocathode, means for producing an electrostatic field between said two elements, said field having one polarity over a part of one of said elements extending from one end of said last-named element to a boundary region and an opposite polarity over a part extending from the other end of said last-named element to said boundary region, means for reversing said electrostatic field at a high frequency, means for causing said boundary region to progress longitudinally of said last-named element, and means for drawing signal currents from said anode.

5. Image signal translating apparatus which comprises an extended photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, an anode disposed to intercept electrons emitted by said photocathode, means for producing an electrostatic field between said anode and said photocathode, said field having one polarity over a part of said photocathode extending from one end thereof to a boundary region and an opposite polarity over parts extending from the other end of said photocathode to said boundary region, means for reversing said electrostatic field at a high frequency, means for causing said boundary region to progress longitudinally of said photocathode, and means for drawing signal currents from said anode.

6. Image signal translating apparatus which comprises an extended photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, at least one extended anode element disposed to intercept electrons emitted by said photocathode, means for causing collection by an anode of electrons from areas located in opposite parts of said photocathode in alternation, which areas meet in a boundary region, said collections alternating at a high carrier frequency, means for causing said boundary region to progress longitudinally of said photocathode, means for drawing signal currents from said anode, said signal currents containing a desired vision component and an undesired component, said two components having at least one frequency in common, and means for removing said undesired component.

7. Apparatus as defined in claim 6 wherein said means for removing an undesired component comprises an auxiliary photocathode similar to said principal photocathode and similarly disposed to be similarly illuminated, an auxiliary anode similar to said principal anode and similarly disposed to intercept electrons emitted from said auxiliary photocathode, means for drawing auxiliary signal currents from said auxiliary anode, and means for balancing said auxiliary signal currents against said principal signal currents.

8. Apparatus as defined in claim 6 wherein said means for removing an undesired component comprises a network of two parallel branches into both of which said entire signal currents are fed, one of said branches containing means for passing only oscillations of all frequencies above said common frequency and blocking said common frequency, the other of said branches containing means for passing said common frequency and frequencies below said common frequency and blocking all other frequencies, means in one of said branches for ad-

justing the amplitudes of the signals in said branch, means in one of said branches for adjusting the phase of signals in said branch, and means for mixing the signals of said two branches as modified to provide a desired signal.

9. Image signal translating apparatus which comprises an extended photocathode element disposed to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, an extended anode disposed to intercept electrons emitted from said photocathode, means for applying a carrier frequency voltage of constant high frequency to the end terminals of one of said elements to produce a voltage gradient along its length, means for applying another voltage between said two elements, means for varying one of said voltages to sweep a region at which the potentials of said elements are substantially alike along the length of said gradient-supporting element, means for drawing current from said collector element, and means for removing undesired components from said current.

10. Apparatus as defined in claim 9 wherein the voltage applied between the two elements is a carrier voltage of frequency equal to that of said first-named carrier voltage and of related phase, amplitude-modulated with a saw-tooth voltage of line-scanning frequency.

11. Apparatus as defined in claim 9 wherein the first-named voltage is compounded of two synchronized high frequency carrier voltages, the one being unmodulated and the other being modulated by a voltage of a wave form such as to cause said equipotential region to be swept at constant speed, and the second-named voltage is a steady bias.

12. Image signal translating apparatus which comprises an extended photocathode element disposed to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, an extended anode disposed to intercept electrons emitted from said photocathode, means for applying a carrier frequency voltage of constant high frequency to the end terminals of one of said elements to produce a voltage gradient along its length, which gradient is spatially uniform but alternates at a high frequency, means for varying the amplitude of said voltage to sweep a region at which the potentials of said elements are substantially alike along the length of said gradient-supporting element, means for drawing current from said collector element, and means for removing undesired components from said current.

13. Image signal translating apparatus which comprises an extended photocathode element disposed to be illuminated in a manner such as to cause emission of photo-electrons from various points of said element in accordance with the illumination of said points, an anode element disposed to intercept electrons emitted from said photocathode, means for causing said anode to collect electrons emitted from all points of said photocathode except a barrier region, means for causing movement of said barrier region along said photocathode, and means for utilizing current drawn from said anode.

14. Image signal translating apparatus which comprises an extended photocathode element disposed to be illuminated in a manner such as to cause emission of photo-electrons from various points thereof in accordance with the illumina-

tion of said points, an anode element disposed to intercept electrons emitted from said photocathode, means for causing said anode to collect electrons from all points of said photocathode except a barrier region, means for causing repeated movement of said barrier region along said photocathode at a line-scanning frequency, means for drawing from said anode a signal current containing a desired vision component and an undesired component containing frequencies present in said desired component, and means for eliminating said undesired component.

15. In combination with image signal translating apparatus characterized by an effectively composite scanning aperture, one component aperture being of the length of a scanning line and moving in a frame scanning direction, the other component aperture being comparable in size with an elemental area and moving along said first component aperture in a line scanning direction, said apparatus being adapted to deliver a desired signal derived from said second component aperture and an undesired signal derived from said first component aperture, said two signals having at least one frequency component in common, means for separating said undesired component from said desired component which comprises means for excluding said common component from said desired signal, means for adjusting the amplitude of undesired signal to bring the common component thereof to the level of the common component in said desired signal, and means for reinserting said common component as modified into said desired signal as modified, to produce said desired signal unmodified.

16. In image signaling apparatus, in combination with a circuit arrangement carrying a desired vision signal having a plurality of frequency components and an undesired signal having at least one frequency component in common with said desired signal, apparatus for separating said undesired signal from said desired signal which comprises a network of two parallel branches, one of said branches including a high-pass filter constructed to pass all components of said desired signal except said common component, the other of said branches including a low-pass filter arranged to include all components of said undesired signal and no components of said desired signal other than said common components, one of said branches including means for adjusting the amplitude of said common component of said undesired signal in a stipulated amount, and means for mixing the signals of one of said branches as modified by the circuit elements of said branch with the signals of said other branch as modified by the circuit elements of said other branch.

17. Image signal translating apparatus which comprises two extended photocathode elements each of which is disposed to be illuminated in a manner such as to cause emission of photoelectrons from various points thereof in accordance with the illumination of said points, an anode element disposed to intercept electrons emitted from one of said photocathodes, another anode element disposed to intercept electrons emitted from the other of said photocathodes, means for causing one of said anodes to collect electrons from all points of its associated photocathode except a barrier region, means for causing the other of said anodes to collect electrons from all points of its associated photocathode, means for causing movement of said barrier region along said photo-

cathode, means for drawing current from each of said anodes, and means for balancing said anode currents against each other to provide a signal related to the movement and illumination of said barrier.

18. Image signal translating apparatus which comprises a photocathode, means for imaging a part of a field of view on said photocathode to cause electron emission from various points thereof in accordance with the light-tone values of corresponding points of said image, an anode disposed to intercept electrons emitted from said photocathode, a generator of carrier frequency oscillations, means including said generator for causing collection of photoelectrons emitted from all points of said cathode located on one side of a neutral point during carrier oscillation half cycles of one polarity and for causing collection of photoelectrons emitted from all points of said cathode located on the other side of said neutral point during carrier oscillation half cycles of the other polarity, means for causing movement of said neutral point along said photocathode at a line scanning frequency, and means for utilizing current drawn from said anode.

19. Image signal translating apparatus which comprises an extended photocathode element disposed to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, an extended anode disposed to intercept electrons emitted from said photocathode, means including a constant carrier frequency generator for producing a uniform voltage gradient along the length of one of said elements, which gradient oscillates in polarity at the carrier frequency, means for sweeping a region at which the potentials of said elements are alike along the length of said gradient-supporting element, means for drawing current from said collector element, and means for removing undesired components from said current.

20. Image signal translating apparatus which comprises an extended photocathode element, an extended anode element disposed to intercept electrons emitted from said photocathode, one of said elements being arranged in the form of a net extended in two dimensions, the other of said elements being plate-like in form, means for imaging a field of view on said photocathode to cause electron emission from various points thereof in accordance with the brightness of corresponding

points of said image, means for causing said anode to collect electrons emitted from all points of said photocathode except a barrier region, means for causing movement of said barrier region along said net-like element from end to end thereof, and means for utilizing current drawn from said anode.

21. Electrostatic scanning apparatus which comprises an extended photocathode disposed in position to have an image of a line of a field of view projected upon it in a manner such as to cause electron emission from each point of said photocathode in dependence upon the light-tone value of a corresponding point of said image, an anode disposed to intercept electrons emitted from said photocathode, means for creating on said photocathode a region over which collection of photoelectrons differs in amount from said collection elsewhere on said photocathode, the length of said region defining an effective scanning aperture, means for causing said region to progress along said photocathode to scan said image, means for translating currents drawn from said anode into vision signals, and means for adjusting the length of said region to provide an effective aperture of desired size.

22. In electrostatic image translation apparatus, an extended lineal resistance photocathode element disposed in position to be illuminated in a manner such as to cause electron emission from each elemental area thereof in accordance with the illumination of said elemental area, an extended lineal conductive anode element disposed parallel with and close to said photocathode element, means for causing a current to flow through said photocathode element from end to end thereof to establish a uniform voltage gradient therealong, means for reversing said current at a constant high frequency to cause reversal of the direction of said gradient at said high frequency, means for maintaining the potential of said anode at the potential of a point of said photocathode which point is intermediate the ends of said photocathode, said potential being intermediate the peak values of the potentials of the ends of said photocathode, means for sweeping said equipotential points lengthwise of said elements at a line-scanning frequency, and means for utilizing currents drawn from said anode.

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