

Aug. 25, 1942.

R. E. GRAHAM

2,294,116

ELECTROSTATIC SCANNING

Filed June 4, 1941

4 Sheets-Sheet 1

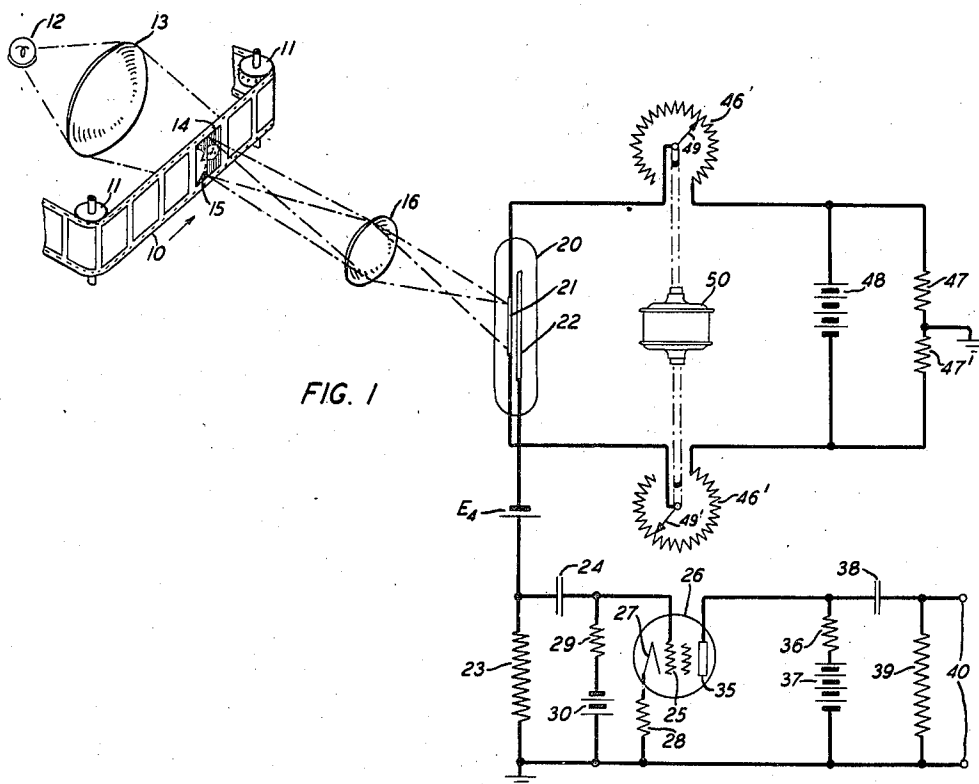


FIG. 1

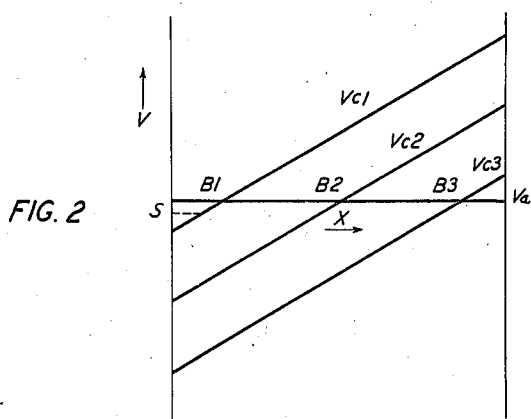


FIG. 2

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4 Sheets-Sheet 2

FIG. 3

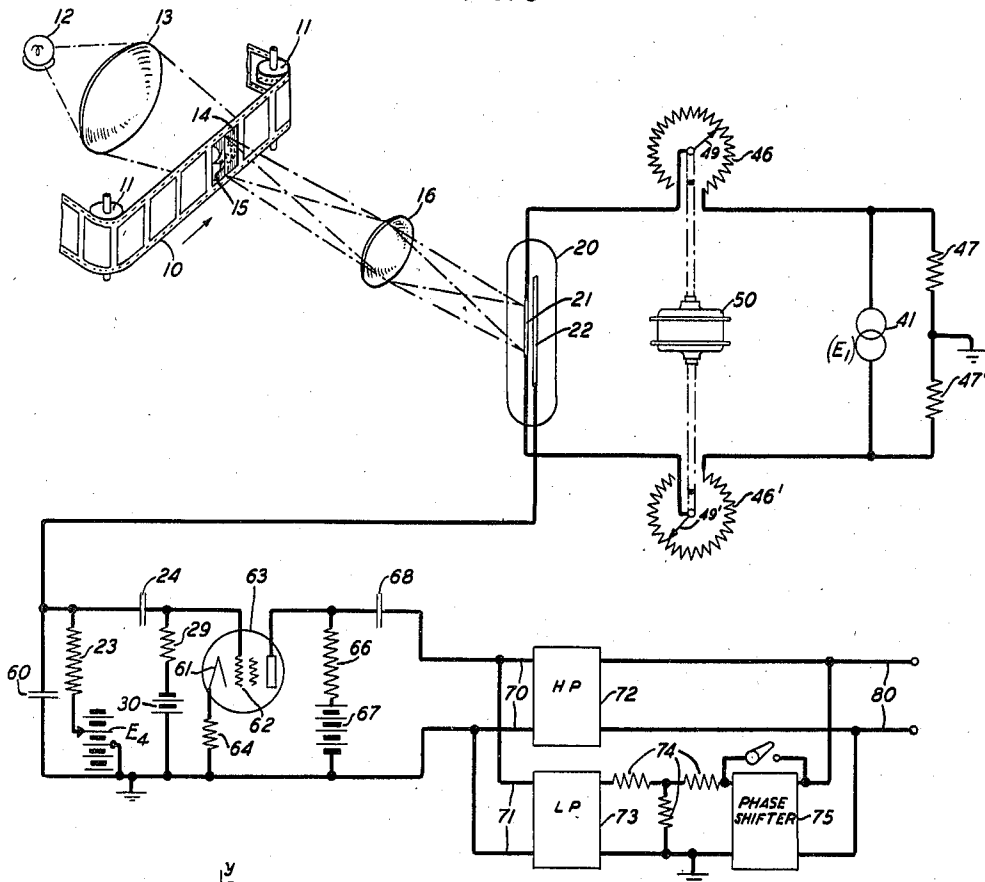
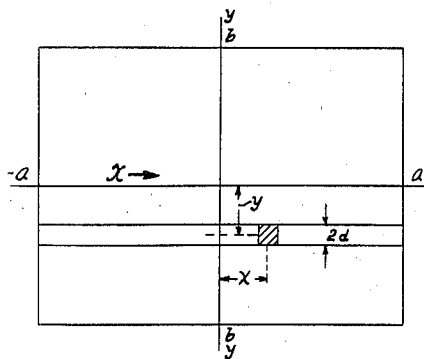


FIG. 4



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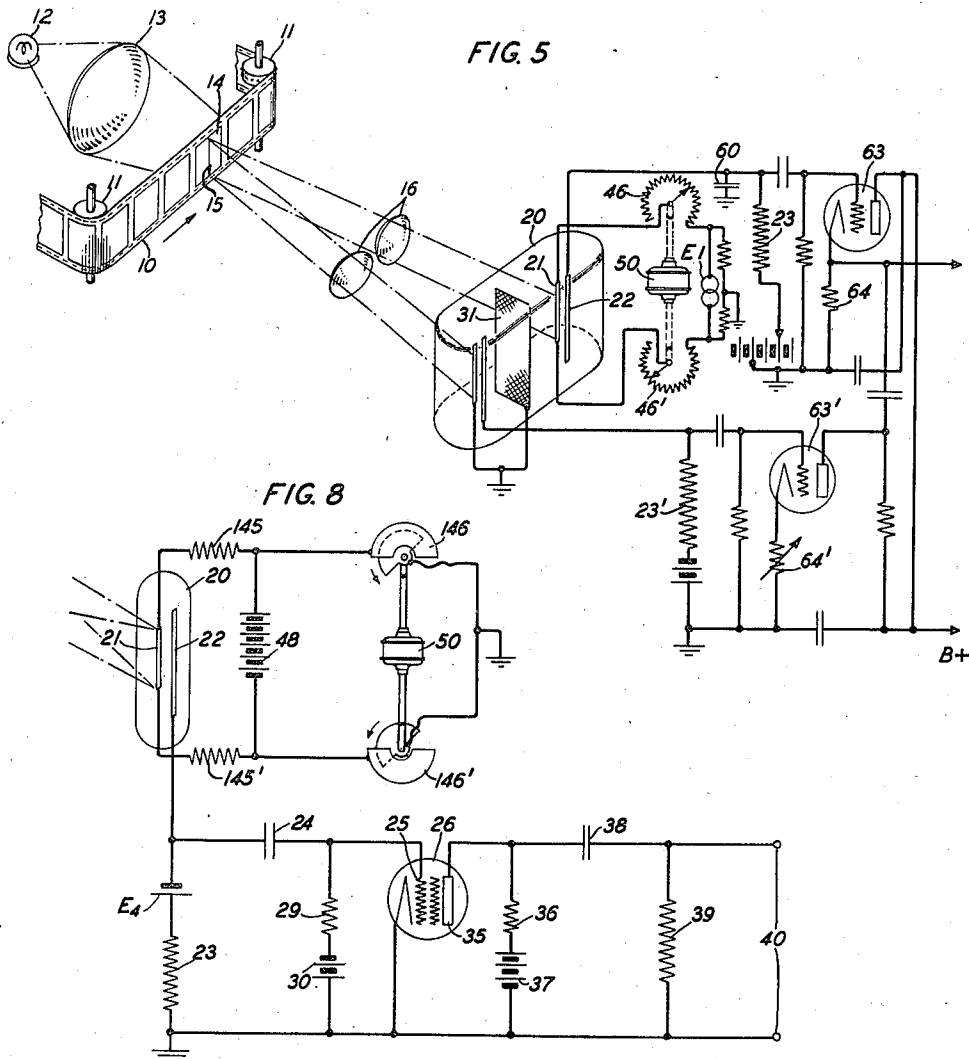
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4 Sheets-Sheet 3



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4 Sheets-Sheet 4

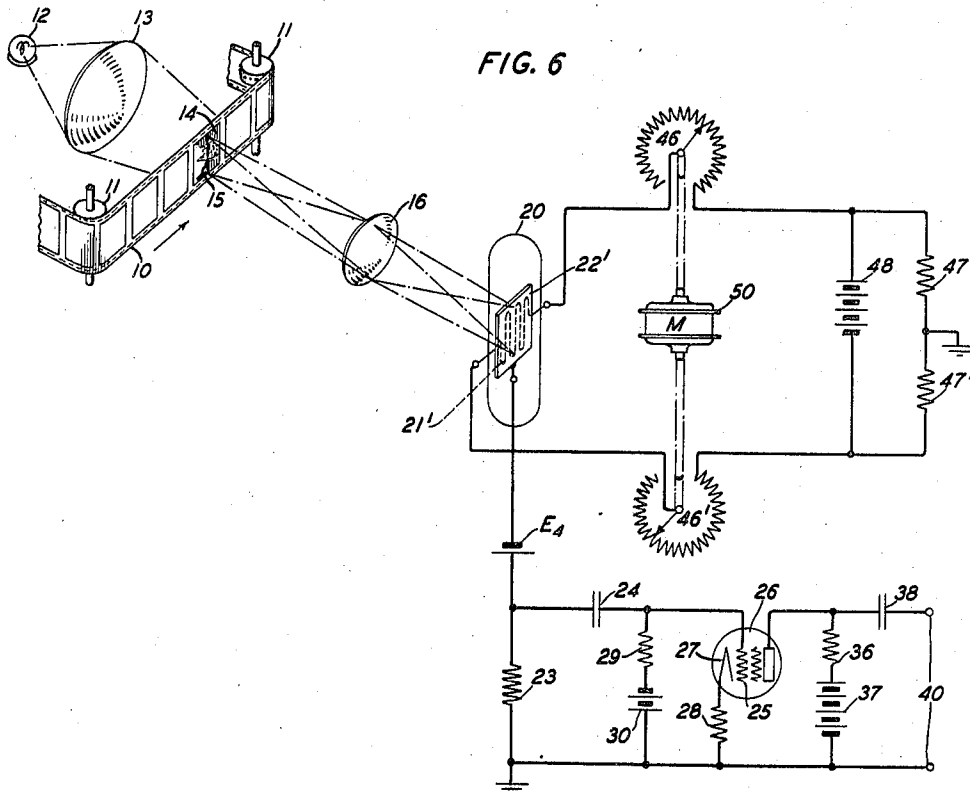
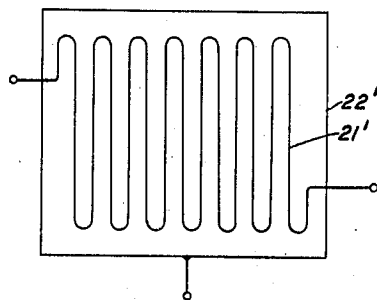


FIG. 7



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2,294,116

ELECTROSTATIC SCANNING

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Application June 4, 1941, Serial No. 396,522

16 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 this 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 copending 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 photo-

cathode 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 support 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.

In my copending application, Serial No. 396,521, filed June 4, 1941, there are described and claimed certain modifications of that system of application, Ser. No. 396,006, characterized, in particular, by the employment of high frequency carrier voltages, modulated and unmodulated, in various combinations to produce movement of the scanning point lengthwise of the photocathode and at the same time rapid reversals of the electron collection conditions which offer certain distinct advantages.

In some of the systems described in the aforementioned applications, Serial No. 396,006 and Serial No. 396,521, the scanning voltage is unavoidably impressed as an electromotive force on the input circuit of a translating device such as a coupling tube. It is necessary in such case that this electromotive force be balanced out or otherwise disposed of, else it will appear as a distorting component in the output signal.

It is an object of this invention to provide other and further means for effecting the scanning movement of the neutral point or region lengthwise of the photocathode, and in particular to effect this scanning movement without the application of any unbalanced electromotive force of a scanning frequency to or between the scanning electrodes, i. e., the photocathode and the collector anode. To this end one of the electrodes which is constructed to support a longi-

tudinal voltage drop is connected as an element of a bridge network, into which are also connected one or more variable impedance elements. These variable impedance elements are then varied in such fashion that the balance point of the bridge is swept lengthwise of the extended electrode. The other scanning electrode, for example, the collector anode is maintained at the potential of the bridge terminal which is conjugate to the balance point or removed therefrom by a suitable constant bias. Thus the bridge balance point is the point or region which is inactive or neutral from the standpoint of the collection of photoelectrons and its movement along the extended photocathode effects a scanning of the image focused thereon.

It is a feature of the invention that constant speed movement of the neutral point is secured by linear variation of the variable impedance elements of the bridge, and this is the case whether two variable elements be employed with complementary variations or whether only one be employed. The former arrangement offers the further advantage that the bridge current may be maintained constant throughout the course of the scanning cycle by proper selection of the mode of variation, with the result that the "aperture effect" remains constant.

The bridge may be energized with a steady voltage, in which case the derived signal is a vision integral like the signal of the first application above referred to, i. e., Serial No. 396,006 and may be converted into a true vision signal by means of a differentiating network, as described in that application. Or the bridge may be energized with a high frequency carrier voltage, in which case the derived signal may contain an undesired component like that of the signal of the second application above referred to, i. e., application Serial No. 396,521 which may be removed by the use of an auxiliary balancing photocathode which is illuminated but not scanned and an associated auxiliary collector, or by means of a suitable arrangement of filter elements as described in that application, or in any other desired manner.

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 film scanning. It will be concluded by a brief description of an embodiment suitable for frame scanning.

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

Fig. 1 shows electrostatic scanning apparatus in which the extended photocathode element forms one arm of a balanced direct current bridge network and movement of the scanning point is obtained by the use of a pair of auxiliary impedance elements which are varied in complementary fashion;

Fig. 2 is a diagram illustrating the mode of operation of Fig. 1;

Fig. 3 shows an alternative arrangement to Fig. 1 in which the bridge is energized from a high frequency carrier source;

Fig. 4 is a diagram illustrating the mode of operation of the apparatus of Fig. 3;

Fig. 5 shows a modification of the high frequency bridge arrangement of Fig. 3 employing auxiliary electrodes for removing an undesired signal component;

Fig. 6 shows an arrangement suitable for scanning a surface as distinguished from a line, the associated circuit arrangement being, for the sake of illustration, the same as that of Fig. 1;

Fig. 7 shows a portion of the apparatus of Fig. 6 to an enlarged scale; and

Fig. 8 shows a bridge network of modified form which may be employed in lieu of the bridge forms of the other figures.

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 the film in a direction parallel with its length, for example with an intermittent line-by-line motion.

Light from any suitable source, for example, an incandescent filament lamp 12, may be directed upon a film frame 14 intermediate the guide rollers 11, 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 of the invention.

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 21 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 voltage drop even with the passage of a comparatively small current. For example, this element may be a wire of about five mils diameter and one inch in length and made of material such that with these dimensions the total resistance as measured between its end terminals is of the order of one 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 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 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 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 the various points of the photocathode is proportional to the translucency of the corresponding points 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 well-known manner.

Operating potentials may be applied to the electrodes and movement of the scanning point along them may be secured in various ways. In accordance with the invention and as shown in Fig. 1 the potentials may be applied to the electrodes by connecting them in suitable manner to the proper terminals of a bridge network while movement of the scanning point along the length of the photocathode may be secured by the use of certain variable impedance elements which are likewise suitably connected in circuit with the bridge network. Thus, as shown in Fig. 1, the respective end terminals of the photocathode 21 are connected through variable impedance elements 46, 46' and impedance elements 47, 47' to ground. A source of direct current, such as a battery 48, is connected across the impedance elements 47, 47' to supply a bridge voltage E_1 . The collector anode 22 may be connected through a bias battery E_4 and a resistor 23 to ground, and also through a condenser 24 to the control element 25 of a discharge device, for example, to the control grid of a four-electrode vacuum tube 26 whose cathode 27 is connected through another resistor 28 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 may be supplied with potentials through a load resistor 36 from a suitable source, for example a battery 37, the negative terminal of which is grounded. The signal output from this tube may be delivered through a condenser 38 and across an output resistor 39 to output terminals 40.

When the extended electrode which is connected as an element of the bridge network shown displays the characteristic of a resistor, the elements 46, 46', 47, 47' may likewise be resistors. Similarly when the bridge-connected extended electrode displays a reactance characteristic, either inductive or capacitive, these elements should display corresponding characteris-

tics, in order that the bridge may be balanced throughout a desired frequency range. In the particular case selected by way of illustration in Fig. 1, wherein the photocathode is the bridge-connected electrode, and the bridge is energized with a steady voltage, the photocathode is assumed to be a pure resistor, and accordingly the elements 46, 46', 47, 47' are likewise shown as resistors in order that the bridge may be balanced with direct currents flowing through its arms.

In the direct current bridge of Fig. 1 the variable elements 46, 46', which are connected in the opposite arms of the bridge network may be of any desired type and are represented in the figure as having a circular arrangement and wiping contacts 49, 49' pivoted at the center of each of the circles. These moving contacts may be arranged to be driven in synchronism and in phase by any suitable means such as a motor 50. The variable resistors 46, 46' and the manner in which they are connected in the circuit should preferably be such that as one, 46, is increased by movement of its wiper contact 49, the other, 46', is decreased in the same amount by movement of its wiper contact 49', so that the sum of the resistance values of these two elements and, therefore, the sum of the total resistance in the bridge circuit remain constant.

The speed of the motor 50 is preferably adjusted to a value such that the frequency of the resistance variation of the elements 46, 46' is the line scanning frequency, that is, a frequency at which the period for each cycle of resistance variation is equal to the time elapsing between movements of the film 10 parallel to its own length through a distance equal to the width of a single scanning line.

The operation of the arrangement depicted in Fig. 1 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 which are at negative potentials with respect to the collector anode 22 are drawn to it and caught by it and 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 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 in the 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 over which the photocathode potential is substantially equal to the collector potential or differs from it by a small amount, for example, by the voltage of the bias battery E_4 . This neutral region or point is the balance point or null point of the bridge network. As the wiping contacts 49, 49' of the variable resistors 46, 46' are rotated in synchronism the total resistance of one arm of the bridge between one terminal of battery 48 and the balance point, that is to say, the resistance of element 46 and a part of the photocathode 21 increases, while the resistance of the correspondingly varied arm of the bridge including element 46' and the other portion of the photocathode 21 decreases in such a way that the total resistance of these two arms remains

constant. This operation is, in effect, a movement of the neutral balance point lengthwise of the photocathode element 21 from one end to the other. When the resistances 46 and 46' are varied in a manner which is linear with time the neutral balance point travels lengthwise of the photocathode element 21 at constant speed to scan the line image focused thereon. The magnitudes of the resistors 46 and 46' are preferably such that as the neutral point comes close to either end of the photocathode 21, the wipers 49 and 49' reach the end of their travel and begin another cycle whereupon the neutral point flies back rapidly to its starting point close to the other end of the photocathode 21 to commence its constant speed scanning travel once more.

The magnitude of the steady bridge voltage E_1 is preferably set at a comparatively high value so that the voltage drop between the collector and the photocathode rises steeply on each side of the neutral balance point to a value which ensures saturated collection of photoelectrons from all points of the photocathode which lie to the low potential side of this neutral point, except for a very narrow region surrounding the neutral point over which collection increases progressively toward the low potential end of the photocathode. Thus the effective photocathode-collector potential difference is substantially uniform at a collecting value along one part of the photocathode and substantially uniform at a non-collecting value along the other part, dipping sharply from the one value to the other at the neutral point.

The electrostatic conditions which obtain in the course of the operation of the apparatus of Fig. 1 as above described are illustrated graphically in Fig. 2 in which the potentials of the electrodes are plotted against distance along the photocathode. The horizontal line V_a represents the uniform potential of the collector anode 22. The potential of the photocathode 21 varies uniformly over its length at each instant while the potential of the photocathode as a whole varies uniformly with time, occupying in succession the values indicated on the diagram by the sloping lines V_{c1} , V_{c2} , V_{c3} . As the photocathode occupies successively different positions on the potential diagram, the bridge balance point at which the photocathode potential is equal to the collector potential (or differs from it by a small constant amount, i. e., the bias voltage E_4) occupies the positions indicated on the diagram by the points B_1 , B_2 and B_3 in succession. The active portion of the photocathode, represented by the dotted line S in Fig. 2 thus extends from one end of the photocathode to the point B_1 at the instant T_1 and increases progressively in length until it occupies the full length of the photocathode at the termination of the scanning cycle.

The resulting collector current at a given instant and, therefore, the voltage across the external resistor 23 may then be expressed as

$$e_c = \int_0^x k_1 L(x) dx \quad (1)$$

where $L(x)$ represents the illumination of the neutral balance point of the photocathode which lies at a distance x from one end of the photocathode, and the factor K_1 which, disregarding the finite width of the mutual region, is a constant, includes both the emission properties of the photocathode and the collecting properties

of the system due to the electrode configurations. If this neutral point moves along the photocathode at a constant speed v , as it will when the variation of resistors 46 and 46' is linear with time, then

$$x = vt$$

and

$$e_c = \int_0^x k_1 L(x) dx = \int_0^t k_1 v L(vt) dt \quad (2)$$

In accordance with the invention this signal may be applied to a differentiating circuit, for example, the cathode 27 and control grid 25 of a high impedance tube such as a tetrode 26 in whose output circuit are connected a condenser 38 of comparatively small capacitance and a resistor 39 of comparatively high resistance in series. As is well known, if the reactance of the condenser is high as compared with the internal and external plate resistances of the tube, taken both separately and together, the voltage appearing across the external resistor 39 will be proportional to the time derivative of the input voltage e_c . Thus

$$e = k_2 \frac{de_c}{dt} = k_2 \frac{d}{dt} \int_0^t k_1 v L(vt) dt \quad (3)$$

$$= k_1 k_2 v L(vt) \quad (4)$$

which is evidently in the form of a conventional vision signal.

After the neutral point has progressed over the full length of the photocathode 21 or that part of it on which the film line 15 is imaged, the resistance of the resistor 46 drops suddenly from its greatest value to its least value while at the same moment the resistance of the element 46' rises suddenly from its lowest value to its highest and the neutral scanning point jumps rapidly back to its starting point to commence a new scanning cycle. Meantime, the film 10 has advanced by the width of a single scanning line so that as the neutral point starts its progress along the photocathode a slightly different part of the film 10 will be imaged upon it. Successive repetitions of this process result in complete scanning of the film image.

It is to be noted that with the arrangement of Fig. 1 the scanning movement of the neutral balance point is obtained without the use of any saw-tooth electromotive force applied exclusively between the photocathode and the collector anode, since the bridge circuit arrangement with its variable resistors 46 and 46' accomplishes the same purpose. Therefore, there is not in this arrangement any unbalanced electromotive force impressed on the input terminals of the tube 26 which requires to be balanced out. This feature distinguishes the arrangement of Fig. 1, as well as other arrangements of this application, from arrangements shown in the aforementioned copending applications, Serial Nos. 396,006 and 396,521 and constitutes one of the principal advantages of the bridge circuit arrangement.

It is to be understood that paired linearly variable resistors 46 and 46' are not essential. It is entirely possible to replace one of them with a constant resistor and secure the movement of the neutral balance point along the photocathode solely through changes in the resistance value of the other. In such case, since the total resistance of the bridge circuit does not remain constant, the total current through the photocathode likewise changes with time. These conditions would be representable in a

diagram similar to that of Fig. 7 but differing therefrom in that successive values of the photocathode potential line would not lie parallel to each other but would have successively different slopes. The result of such an arrangement is that the "aperture effect" would change progressively in the course of the travel of the neutral point from one end of the photocathode to the other. In some applications the consequent variation of resolution across the image may be advantageous.

Fig. 3 shows a modification in which the bridge network of the invention is energized not by a battery as in the case of Fig. 1 but by a high frequency carrier source 41 which supplies the bridge voltage E_1 . In this high frequency bridge arrangement the bridge elements, including the extended scanning electrode may be constructed to display reactive characteristics to balance the bridge at the carrier frequency. However, it is believed simpler to employ resistance elements as before, and accordingly a resistance bridge will be described on the understanding that a reactance bridge or an impedance bridge may be employed instead if desired.

The pick-up device 20 with its cathode 21 and collector 22, as well as the resistors 47, 47' and the variable resistance elements 46 and 46', the load resistor 23 and the bias battery E_4 may be similar to those shown in Fig. 1 and above described. The frequency of the generator E_1 should be of such value that its period is small in comparison with the time required to scan a single elemental area of the line image focused upon the photocathode 21 so that during each single cycle of the output of this generator the neutral balance point shall have moved only a minute amount lengthwise of the photocathode. Thus the potential conditions which obtain among the electrodes as depicted in the diagram, Fig. 2, are reversed during the immediately following half-cycle of the carrier voltage generator E_1 , the part of the photocathode which was active becoming inactive and vice versa. Thus, collection of photoelectrons having taken place during one carrier half-cycle from the left-hand portion of the photocathode, it will take place during the immediately following carrier half-cycle from the right-hand portion of the photocathode. Diagrammatically, any one of the photocathode potential lines V_c of Fig. 2 oscillates rapidly about the intersection point B_1, B_2, B_3 , as the case may be. During the minute interval of time represented by one half-cycle of the carrier voltage, the neutral balance point B has, of course, moved; but the amount of its movement in one carrier half-cycle is inappreciable, 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 variation of the photocathode due to the linear variation of the resistors 46 and 46' causes this neutral point B to progress along the length of the photocathode at a constant speed until it approaches the end of the photocathode 21, whereupon, the resistors 46 and 46' having reached their maximum and minimum resistance values respectively, a new scanning cycle is commenced as the neutral balance point flies rapidly back to its starting point near the other end of the photocathode to commence its scanning travel anew. Meantime the

film 10 is advanced, either with continuous movement or with an intermittent line-by-line movement as preferred, by the width of a single line so that as the neutral balance point starts its progress along the photocathode, a slightly different part of the film 10 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 which is necessary to ensure 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 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. This signal is therefore of a different character from the signal derived from the direct current bridge of Fig. 1 and there termed a vision integral signal. It cannot therefore be translated into a conventional vision signal by any differentiating circuit. However, it is possible by various means to make this translation of the signal derived from the high frequency carrier bridge into a true vision signal.

As more fully explained in the aforementioned copending application Serial No. 396,521 filed, the bias battery E_4 may if preferred be adjusted to a point such that collection takes place from the neutral region throughout both carrier half-cycles. This results in a desired signal which differs in sign only from the desired signal produced when the neutral region operates as a barrier.

The two signal components mentioned above 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 filtered out by any appropriate means, either ahead of the utilization circuit or following it, for example a by-pass condenser 60. The two signal components above described may be applied together through a condenser 24 across the cathode 61 and control grid 62 of a discharge device, for example a tetrode 63. The control

grid of this tube is returned to ground through a resistor 29 and a bias battery 30. The output electrode or plate 65 is supplied with operating potential through a loading resistor 66 from a suitable source such as battery 67. The signal output of this tube thus appears across the resistor 66 and is fed through a condenser 68 to a network to be described below.

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 but of opposite phase. 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. 4, 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 on alternate carrier half-cycles 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:

$$I(x,y) = \int_{-d}^d \int_{-a}^a L(\epsilon, y+\eta) d\epsilon d\eta - \int_{-d}^d \int_{-d}^d L(x+\epsilon, y+\eta) d\epsilon d\eta \quad (5)$$

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 the Bell System Technical Journal for July, 1934, at pages 464 to 515, (vol. 13) it is shown that the light distribution of the projected picture may be represented by the complex double Fourier

$$L(x,y) = \sum_{-\infty}^{\infty} m \sum_{-\infty}^{\infty} n A_{mn} \exp i\pi \left(\frac{mx}{a} + \frac{ny}{b} \right) \quad (6)$$

where the A 's are complex constants.

Substituting this value of L into Equation 5 and integrating, there is obtained

$$I(x,y) = 4d^2 \left[\sum_{-\infty}^{\infty} n A_{0,n} Y(0,n) \exp \left(\frac{i\pi ny}{b} \right) - \sum_{-\infty}^{\infty} m \sum_{-\infty}^{\infty} n A_{mn} Y(m,n) \exp i\pi \left(\frac{mx}{a} + \frac{ny}{b} \right) \right] \quad (7)$$

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 7 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 common occurrence of these components in both terms of the Equation 7 makes it apparent that the undesired signal cannot be separated from the desired signal on a conventional frequency separation basis alone, and that more involved means must be employed to effect the separation.

To this end a circuit arrangement of Fig. 3 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 63 into two separate paths, the one path 70 including a high frequency pass filter 72 and the other path 71 including in tandem order a low frequency pass filter 73, an attenuator pad 74 and a phase shift-

ing device 75. These two paths 70 and 71 are then brought together at common terminals 80.

The low frequency cut-off of the high-pass filter 72 and the high frequency cut-off of the low-pass filter 73 are preferably adjusted to the same value which may advantageously be set at or just above one-half the line scanning frequency, that is, the frequency of variation of the resistors 46 and 46'. The attenuation ratio of the pad 74 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 of the active portion $2a-2d$ of the photocathode to the length of the neutral region $2d$ (Fig. 4). In accordance with present day practice this ratio may be about 400:1. The phase shifting device 75 should be designed to alter the phase of components of half line frequency and below by an amount which will place these components in the path 71 in phase opposition to the same components in the path 70. For example, if phase rotation in the filters 72 and 73 and in the pad 74 be disregarded, the phase shifter 75 may turn the phase angle of these 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 7, the latter may be written shortly

$$I(x,y) = 4d^2U - V \quad (8)$$

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

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

and U , the undesired component, is evidently related to G by the equation

$$V = \frac{a}{d}G \quad (10)$$

Therefore, the Equation 8 may again be rewritten

$$\begin{aligned} I(x,y) &= 4d^2 \left(\frac{a}{d}G - H - G \right) \\ &= 4d^2 \left(\left(\frac{a}{d} - 1 \right) G - H \right) \end{aligned} \quad (11)$$

in which the components have been regrouped, the first term of the parenthesis containing all components of half-line frequency or below while the second term contains all components of line frequency or above. Therefore, when the signal as a whole is fed to the paths 70 and 71 in parallel, the components represented by the first term of (11) are excluded by the filter 72 while passing the filter 73 and the components represented by the second term are excluded by the filter 73 while passing the filter 72.

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

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

by the attenuation 69 and reversed in phase by the device 70; thus

$$\left(\left(\frac{a}{d} - 1 \right) G \right) \left(-\frac{1}{\left(\frac{a}{d} - 1 \right)} \right) G = -G \quad (12)$$

The resulting signal, $-G$ is then mixed with the signal $-H$ in the path 65 to give

$$-H - G = -V \quad (13)$$

and therefore the signal appearing at the terminals 80 is

$$I'(x,y) = 4d^2V =$$

$$-4d^2 \left[\sum_{m=-\infty}^{\infty} m \sum_{n=-\infty}^{\infty} n A_{mn} Y(m,n) \exp i\pi \left(\frac{mx}{a} + \frac{ny}{b} \right) \right] \quad (14)$$

which, except for a reversal in phase of all components alike which is of no importance, is the desired conventional vision signal.

If the bias battery E_4 is adjusted to give a positive desired component the same treatment of the whole signal may be employed to remove the undesired component, with the exception that the phase shifter 70 may be omitted or short-circuited.

The undesired signal which appears when the bridge is energized with carrier frequency voltage, and which is eliminated in the arrangement of Fig. 3 by the apparatus 65-70 may also be eliminated by other means. Fig. 5 shows such other means in combination with a circuit arrangement similar to that of Fig. 3. In this figure an auxiliary photocathode 21' and an auxiliary collector anode 22' are included in the same envelope 20 as the main photocathode 21 and collector anode 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 paired optical means 26, for example as indicated in the figure, the line to be scanned may be 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. 3. The auxiliary photocathode, though illuminated like the principal photocathode, is not scanned. Therefore, while the signal represented by Equation 7 is derived from the principal electrodes, another signal represented by the first term of Equation 7 is derived from the auxiliary collector anode 22' and is impressed on an auxiliary tube 63'. The impedance element 23 should present a substantial impedance value at vision frequencies but may have a very low value at carrier frequencies. This filters out most of the carrier voltage from the signal before it reaches the tube 26. The impedance element 23', on the other hand, should maintain its value only up to the line frequency. The output may be taken from the cathode of tube 63 and the anode of tube 63', so that corresponding components will be in phase opposition. An adjustable element, for example, the cathode resistor 64' of the tube 63' permits control of the magnitude of the output of the tube 63' to the value necessary to permit it to cancel the undesired components in the output of the tube 63, and so leave only the desired components at the output terminals.

Fig. 6 shows an arrangement by which the bridge balance 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 net on which the image as a whole may be focused, as shown in greater detail in Fig. 7. The collector anode 22' is a plate mounted behind the photocathode net. The scanning action, which may be secured in accord-

ance 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. Such an arrangement may also be employed with an alternating current bridge as shown in Fig. 3, in which case it offers a further important advantage in 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 as a source of average illumination or direct current correction signal, thus eliminating the necessity of making separate provision therefore and at the same time eliminating the necessity of removing the undesired signal which arises with the extended line photocathode and to remove which special apparatus must be provided as above described in connection with Figs. 3 and 4.

The particular arrangement of bridge circuit connections heretofore described is by no means the only one possible. Various modified bridge circuits will occur to those skilled in the art. Another suitable bridge circuit is shown in Fig. 8, where instead of the constant resistance ratio arms 47 and 47' and the variable elements 46 and 46', two variable impedance elements, for example variable condensers 146 and 146' are connected as the ratio arms of the bridge, their common terminal being grounded. These variable condensers may be arranged to be driven by a motor, the capacitance of one increasing linearly with time and that of the other decreasing in complementary fashion so that their sum remains constant. Marginal resistors 145 and 145' are connected in series with the photocathode to permit complete scanning of the latter without the necessity of driving the capacitance of either of the condensers 146, 146' to zero. Such a bridge is suitable either for direct current or carrier frequency excitation, and causes the electrode which is in circuit with the bridge to undergo the same potential variations and the apparatus to deliver the same signals as obtain with the bridges having constant ratio arms and variable intermediate elements. It will be understood, however, that with this arrangement the scanning spot was forward and backward, alternately.

Still other modifications of the variable impedance bridge circuit may occur to those skilled in the art as embodying the principles of the invention.

Movement of the neutral point in the scanning operation may also be accomplished without the variable impedance bridge of the invention by the use of electromotive forces impressed on and between the scanning electrodes. Such arrangements are shown in the aforementioned copending application Serial No. 396,006 which is directed to systems employing steady voltages and voltages of modified or unmodified saw-tooth wave form; and also in the aforementioned copending application Serial No. 396,521 which is directed to systems employing carrier frequency voltages in various combinations, both unmodulated and modulated with saw-tooth envelopes of linear or modified form.

The fact that the invention has been illustrated and described in terms of an embodiment wherein the scanning field originates in part in a lon-

gitudinal voltage gradient supported by one of the electrodes is not to be taken as restrictive. The bridge network 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 a bridge network of which some field-producing electrode, as well as an appropriate variable impedance, form the elements. When in such an arrangement an undesired signal arises of the type dealt with above, it may be removed by any of the above-described arrangements adapted to effecting such removal, independently of the particular nature of the apparatus in which the undesired signal originates. Likewise, when in any such modified arrangement the derived signal is a vision integral signal, it may be converted into a conventional vision signal by the use of a differentiating circuit of the type above described in connection with Fig. 1.

What is claimed is:

1. 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, a bridge network including said photocathode as a circuit element, means including said bridge network for creating on said photocathode a region defining a scanning aperture over which collection of photoelectrons differs in amount from said collection elsewhere on said photocathode, said bridge network being balanced at a point of said region, and means for varying the balance point of said bridge network to sweep said aperture-defining region lengthwise of said photocathode and scan said line image.

2. 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, a network including as circuit elements a variable impedance element and said photocathode, means including said network for creating on said photocathode a region defining a scanning aperture over which collection of photoelectrons differs in amount from said collection elsewhere on said photocathode, and means for varying the impedance of said variable impedance element to sweep said aperture-defining region lengthwise of said photocathode to scan said line image.

3. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, a network including as circuit elements one of said electrodes, a variable impedance element and a source of electromotive force, means including said network for causing collection by an anode of photoelectrons from an area of said photocathode extending from one end thereof to a boundary region, and means for varying said variable impedance element to sweep said boundary region

lengthwise of the element containing it, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

4. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, a bridge network including as circuit elements one of said electrodes, a variable impedance element and a source of electromotive force, means including said network for causing collection by an anode of photoelectrons from an area of said photocathode extending from one end thereof to a boundary region, and means for varying said variable impedance element to sweep said boundary region lengthwise of the element containing it, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

5. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, means for producing an electrostatic field between said two electrodes, said field having one polarity over a part of one of said electrodes extending from one end of said last-named electrode to a boundary region and an opposite polarity over a part extending from the other end of said last-named electrode to said boundary region, a network including one of said electrodes as a circuit element and a variable impedance element as another circuit element, means for applying an electromotive force to a pair of terminals of said network, and means for varying said variable impedance element to sweep said boundary region lengthwise of the electrode containing it, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

6. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, means for producing an electrostatic field between said two electrodes, said field having one polarity over a part of one of said electrodes extending from one end of said last-named electrode to a boundary region and an opposite polarity over a part extending from the other end of said last-named electrode to said boundary region, a bridge network including one of said electrodes as a circuit element and a variable impedance element as another circuit element, means for applying an electromotive force to a pair of terminals of said bridge network, and means for varying said variable impedance element to sweep said boundary region lengthwise of the electrode containing it, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

7. Image signal translating apparatus which comprises an extended photocathode disposed to be illuminated in a manner such as to cause elec-

tron emission from each elemental area thereof in accordance with the illumination of said elemental area, an extended anode disposed to intercept electrons emitted by said photocathode, one of said electrodes being constructed to support a uniform longitudinal voltage gradient, means for causing a steady current to flow lengthwise of said electrode to produce a uniform longitudinal voltage gradient thereon, a network including as elements said gradient-supporting electrode, a variable impedance element and a source of electromotive force, means including said network for causing collection by said anode of photoelectrons emitted from a part of said photocathode extending from one end thereof to a boundary region, and means for varying said variable impedance element to sweep said boundary region lengthwise of said photocathode, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

8. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, one of said electrodes being constructed to support a uniform longitudinal voltage gradient, means for causing a steady current to flow lengthwise of said electrode to produce a uniform longitudinal voltage gradient thereon, a bridge network including as elements said gradient-supporting electrode, a variable impedance element and a source of electromotive force, means including said network for causing collection by said anode of photoelectrons emitted from a part of said photocathode extending from one end thereof to a boundary region, said bridge network being balanced at said boundary region, and means for varying said variable impedance element to sweep said bridge balance point and said boundary region lengthwise of said photocathode, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

9. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, a network including as circuit elements one of said electrodes, a variable impedance element and a source of high frequency electromotive force, means including said network for causing alternate collection by an anode of photoelectrons from areas located in opposite parts of said photocathode, which parts are separated by a boundary region, means for varying said variable impedance element to sweep said boundary region lengthwise of the element containing it, whereby currents drawn from said anode contain components related to the illumination of the elemental areas of said photocathode.

10. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, a network including as circuit elements one of said

electrodes, a variable impedance element and a source of high frequency electromotive force, means including said network for causing alternate collection by an anode of photoelectrons from areas located in opposite parts of said photocathode, which oppositely located areas have a boundary region in common, means for varying said variable impedance element to sweep said boundary region lengthwise of the element containing it, whereby currents drawn from said anode contain components related to the illumination of the elemental areas of said photocathode.

11. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, a bridge network including as circuit elements one of said electrodes, a variable impedance element and a source of high frequency electromotive force, means including said network for causing alternate collection by an anode of photoelectrons from areas located in opposite parts of said photocathode, which parts are separated by a boundary region, said bridge network being balanced at a point of said boundary region, means for varying said variable impedance element to sweep said bridge balance point lengthwise of the element containing it, whereby currents drawn from said anode contain components related to the illumination of the elemental areas of said photocathode, and means for removing undesired components from said anode currents.

12. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, a bridge network including as circuit elements one of said electrodes, a variable impedance element and a source of high frequency electromotive force, means including said network for causing alternate collection by an anode of photoelectrons from areas located in opposite parts of said photocathode, which oppositely located areas have a boundary region in common, said bridge network being balanced at a point of said boundary region, means for varying said variable impedance element to sweep said bridge balance point lengthwise of the element containing it, whereby currents drawn from said anode contain components related to the illumination of the elemental areas of said photocathode, and means for removing undesired components from said anode currents.

13. 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, at least one extended anode element disposed to intercept electrons emitted by said photocathode, means for producing a substantial uniform longitudinal voltage gradient on one of said electrodes, a network including as circuit elements said last-named electrode, a variable impedance element and a source of electromotive force, and means for varying said variable impedance element to sweep the potential of another of said electrodes through

a range of potentials occupied by successive portions of said gradient-supporting electrode, which potentials are intermediate the potentials of the extremities of said gradient-supporting electrode.

14. Image signal translating apparatus which comprises an extended photocathode element, means for illuminating said photocathode element 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 producing a substantial uniform longitudinal voltage gradient on one of said electrodes, a bridge network including as circuit elements said last-named electrode, a variable impedance element and a source of electromotive force, and means for varying said variable impedance element to sweep the potential of another of said electrodes through a range of potentials occupied by successive portions of said gradient supporting electrode, which potentials are intermediate the potentials of the extremities of said gradient-supporting electrode.

15. Image signal translating apparatus which comprises an extended photocathode 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 by said photocathode, one of said electrodes being arranged as a net extended in two dimensions, the other of said electrodes being plate-like in form, a network including as circuit elements said net-like electrode, a variable impedance element and a source of electromotive force, means including said network for causing collection by said anode of photoelectrons from areas of said photocathode located between one end thereof and a boundary region, and means for varying said variable impedance element to sweep said boundary region lengthwise of the element containing it, whereby currents drawn from said anode are related to the illumination of the elemental areas of said photocathode.

16. Image signal translating apparatus which comprises an extended photocathode 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 parallel with and close to said photocathode in position to intercept electrons emitted by said photocathode, said photocathode being constructed to support a uniform longitudinal voltage gradient, a bridge network comprising at least a variable impedance element and said photocathode, a source of steady potential connected to two terminals of said bridge network to establish a constant potential difference between the ends of said photocathode and a steady potential gradient longitudinally thereof, means for maintaining a certain point of said bridge network at a steady potential with respect to said anode, which certain point and a point of said photocathode intermediate its extremities are conjugate to said first-named terminals, means for varying said variable impedance element to sweep said photocathode point lengthwise of said photocathode from end to end thereof at a line scanning frequency, and means for utilizing currents drawn from said anode.

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