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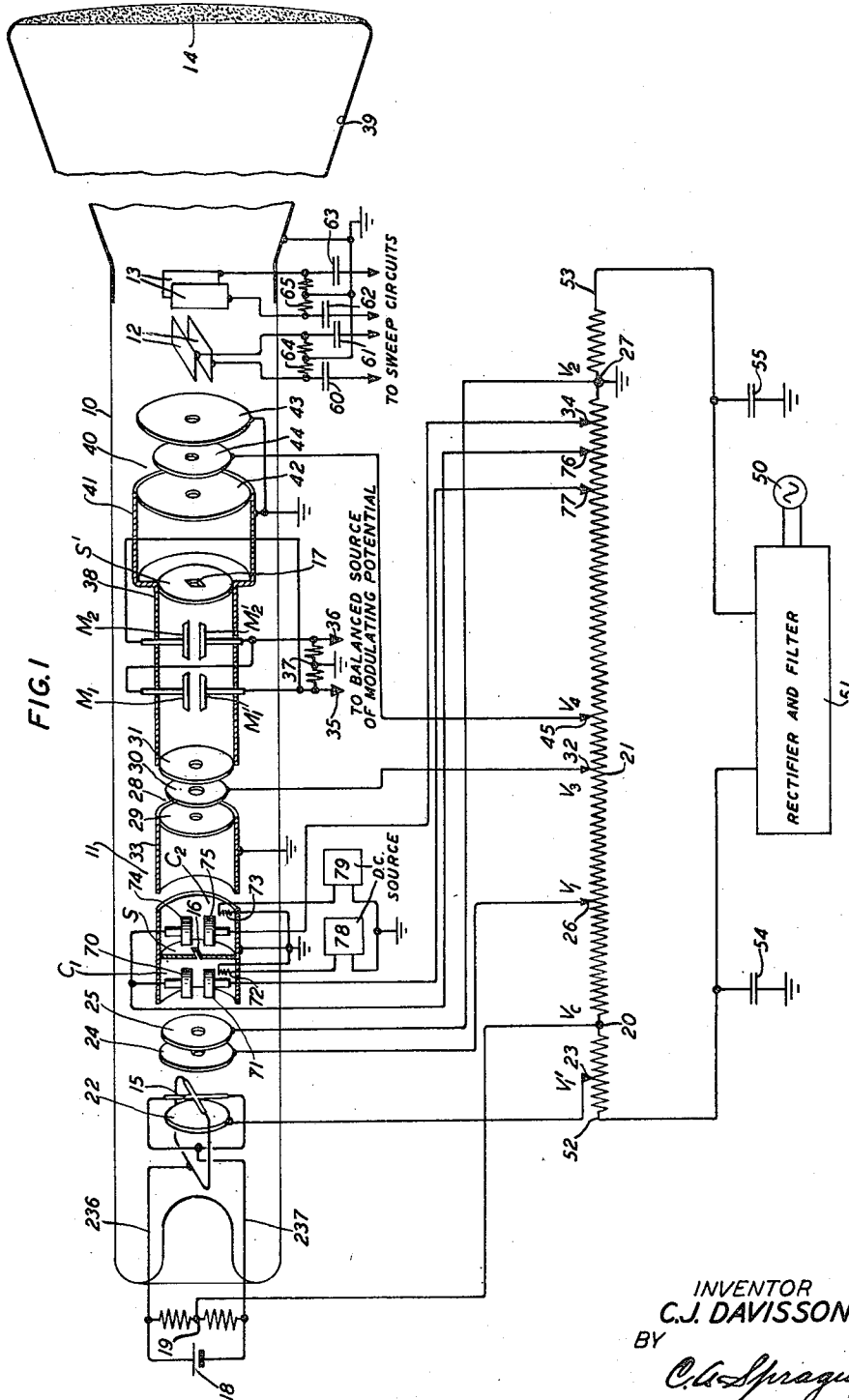
C. J. DAVISSON

2,217,198

CATHODE RAY DEVICE

Filed Oct. 16, 1937

4 Sheets-Sheet 1



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Oct. 8, 1940.

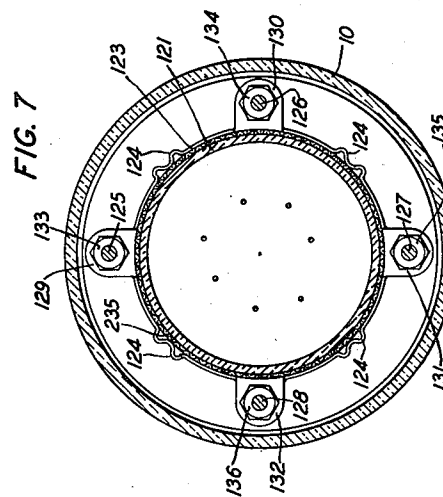
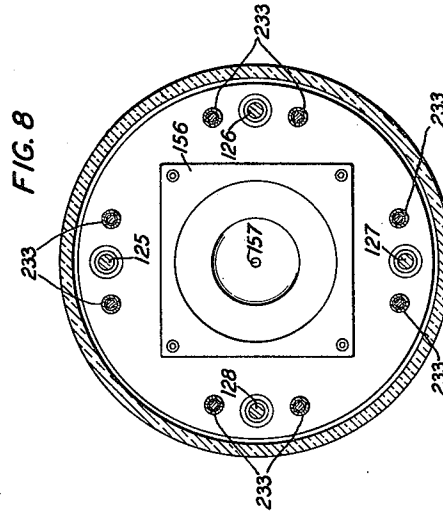
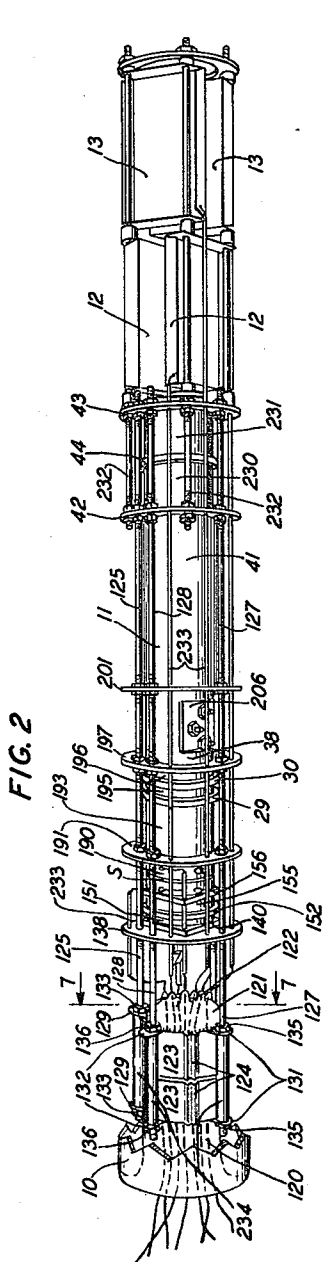
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CATHODE RAY DEVICE

Filed Oct. 16, 1937

4 Sheets-Sheet 2



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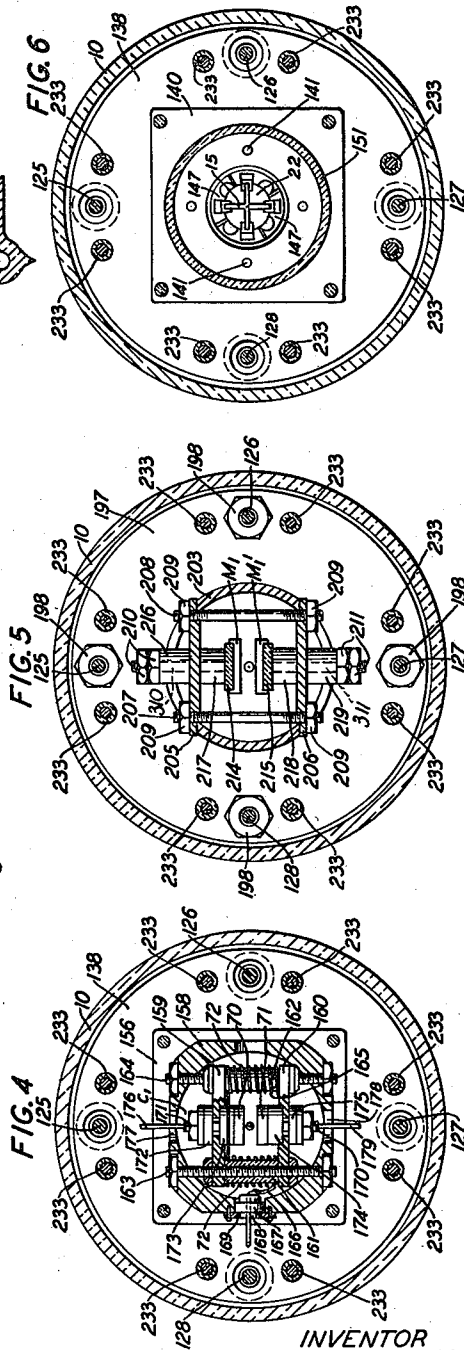
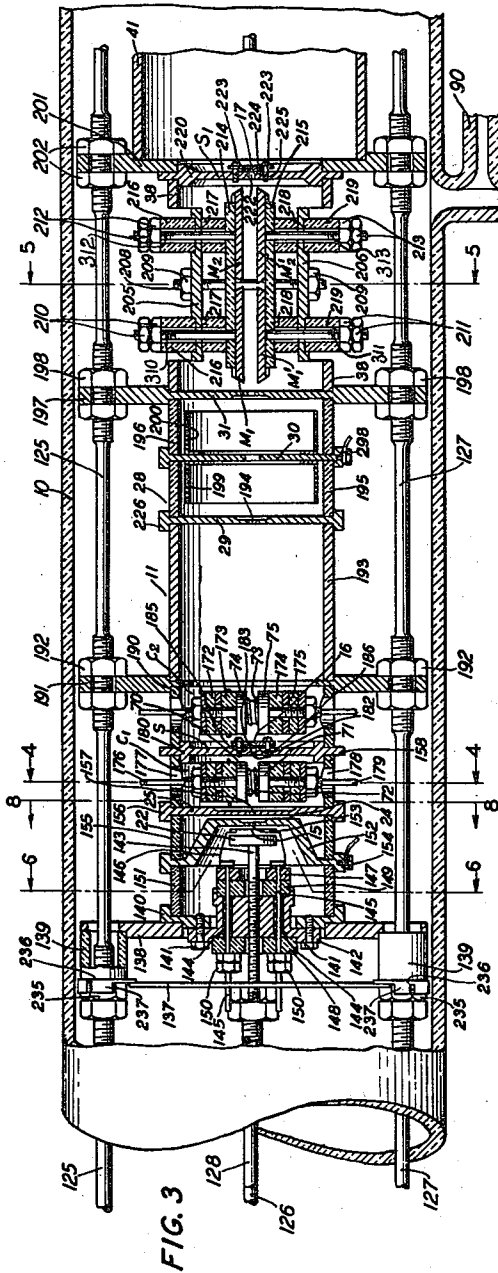
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CATHODE RAY DEVICE

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4 Sheets-Sheet 3



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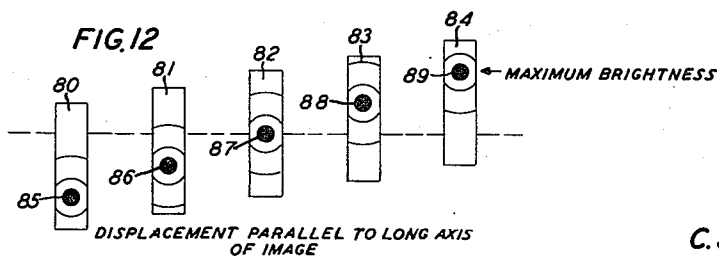
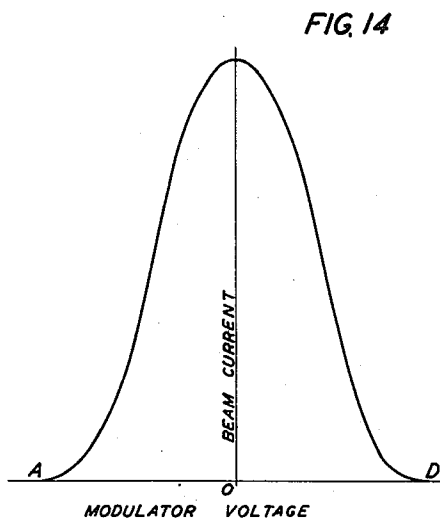
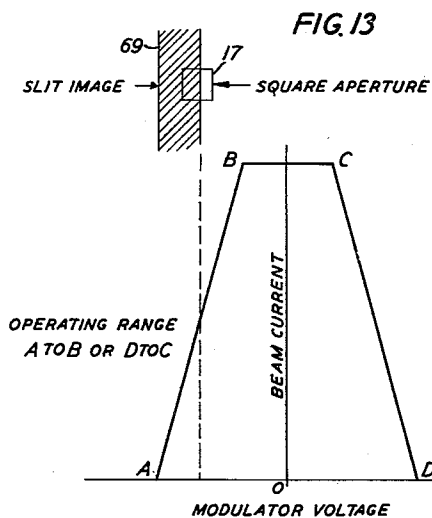
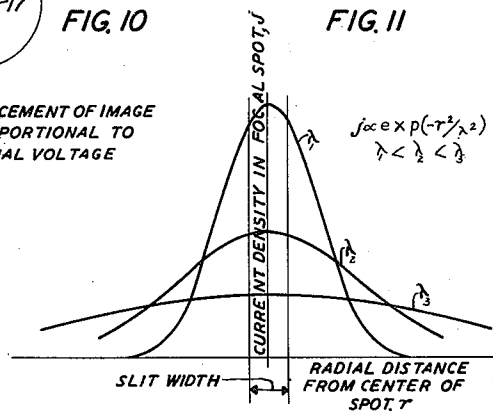
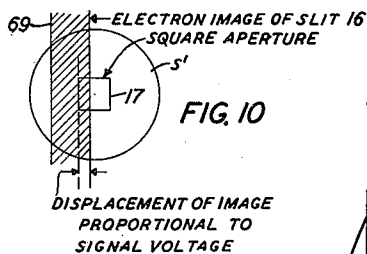
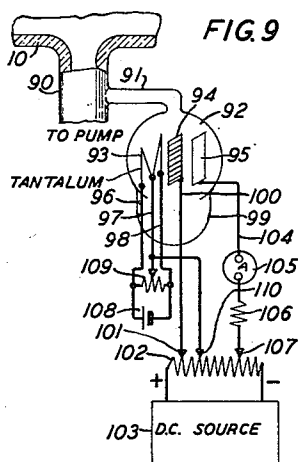
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2,217,198

CATHODE RAY DEVICE

Filed Oct. 16, 1937

4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,217,198

CATHODE RAY DEVICE

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Application October 16, 1937, Serial No. 169,423

23 Claims. (Cl. 250—27)

This invention relates to cathode ray devices and more specifically to methods of and apparatus for generating, focussing, accelerating and modulating the intensity of an electron beam in a cathode ray device.

An object of this invention is to provide improved cathode ray generating and controlling means for cathode ray tubes.

Another object of this invention is to provide a novel electron optical system for a cathode ray device.

In a copending application of C. J. Davisson, Serial No. 118,277, filed December 30, 1936, there is described an electrode system for a cathode ray television receiver tube in which modulation is achieved by deflecting a beam of electrons with respect to an aperture by means of a signal applied between a pair of modulating plates arranged on opposite sides of the axis of the tube. The modulating plates are located in a field free space within a metallic cylinder having three apertured diaphragms, the middle diaphragm containing the aperture through which the electrons pass after having been deflected by the modulating plates which are between the middle diaphragm and that one of the other diaphragms nearest the cathode. By insulating both the modulating plates from the other elements in the tube, balanced modulation can be achieved. The fact that the modulation curve (that showing the relationship between the modulating voltage and the beam current) for a tube of this type is substantially a probability curve, that is, one based on the distribution of electrons in the beam transversely of its axis calculated from the theory of probabilities, makes it possible for this system to have certain advantages over systems in which the beam current always increases with voltage increase, such as (1) the prevention of large changes in the beam current which might otherwise result from surges due to noise in the modulating signal and (2) it makes possible an easy reversal of the blacks and whites of the image by changing the sign of the biasing potential; but there is the disadvantage that due to the curvature in the region of low intensity the signals of low intensity are "compressed," that is, the rate of change of variation in this signal region is too small and there results a great loss of shadow detail in the television image.

It is an object of this invention to prevent this "compression" of the low intensity signal in electron beam modulating systems of the general type described above.

It has been discovered that if the electrons pass through a slit, which will be hereinafter designated the aperture in the S-plane, before entering the modulator field, and an image of this slit is formed on an aperture in another plane, S', by an electron lens system, linear modulation with sharp cut-off can be obtained by moving the electron image of the slit with respect to the second aperture.

It is a further object of this invention to provide a cathode ray tube in which modulation is achieved by moving an electron image of an aperture with respect to a second aperture in accordance with signals.

Other and ancillary objects will be apparent from the following description and the appended claims.

In the previously filed Davisson application, two lens systems are employed: (1) a condenser lens system for condensing the electrons from the cathode to such an extent that they reach a sharp focus in the aperture in the S-plane, and (2) a projecting lens system for projecting an electron image of the aperture upon a fluorescent screen. In the tube of this invention, however, three electron lens systems are employed which will be designated (1) a condenser lens system for concentrating the electrons into a beam in the plane of a slit in a diaphragm in the S-plane, (2) a modulator lens system for forming an electron image of the slit in the S-plane upon an aperture, which is preferably square, in a diaphragm in the S'-plane, and (3) a projector lens system for projecting an electron image of the aperture in the S'-plane upon the fluorescent screen.

Briefly stated, the electrode structure of the television receiving tube of this invention is as follows:

A cross-shaped filament serving as a cathode is located between and parallel to a back electrode and an accelerating electrode in the form of an apertured diaphragm constituting the first member of the condenser lens system. A positive potential with respect to that of the cathode is applied to the first member of the condenser lens system and a negative potential with respect to the cathode is applied to the back electrode and so adjusted that a uniform field is produced between the back electrode and the first condenser lens member, the effect of which is to cause the electrons emitted from the four arms of the cross-shaped filament to traverse paths which are substantially parallel to the axis of the tube. An apertured diaphragm adjacent the first condenser

lens member constitutes the second member of the condenser lens system and a potential is applied to this second condenser lens member which is positive with respect to that of the first condenser lens member. This second condenser lens member is also placed at ground potential which is also the potential of many of the other electron lens members to be described below. The cathode is thus highly negative with respect to the potential of the second condenser lens member and hence with respect to the earth or frame potential. (In the description below, however, potentials will often be considered with respect to the filamentary cathode as a reference potential since these potentials give directly the electron energy and are of more significance in electron optical calculations than potentials with respect to ground.) Proceeding along the axis of the tube, a first collimator unit is provided to produce electric and magnetic fields normal to the tube axis and parallel to each other. The function of the first collimator unit is to deflect the electrons after they pass through the aperture in the second condenser lens member in such a manner as to place the maximum electron intensity at any desired point in the S-plane. The slit in the S-plane in the preferred embodiment is .006 inch wide and is parallel to the pair of plates constituting the first collimator unit. A second collimator unit, similar to the first collimator unit, is placed on the side of the S-plane remote from the cathode. The function of this second collimator unit is to change the direction of motion of the electrons so that they are once more proceeding approximately parallel to the tube axis, thus compensating for any angular deviation which the first collimating unit may have given them when it displaced the maximum intensity point of the beam to the correct place on the slit in the S-plane. Proceeding along the axis after the electrons have passed through the second collimating unit, an electron image of the slit in the S-plane is formed in the S'-plane (which has a rectangular or square aperture therein) by the modulator lens system which comprises three apertured diaphragms, the two outside diaphragms being placed at earth potential and the inside diaphragm being connected to a potential which is negative with respect to earth. Between the modulator lens system and the S'-plane is the modulating system consisting of four plates which are cross-connected in order to produce a displacement of the image without angular deviation of the electrons. Variation of the modulating voltage will vary the number of electrons incident upon the aperture in the S'-plane which aperture is preferably .005 or .006 inch square. Since this aperture is uniformly "illuminated" only in a direction parallel to the modulating plates, it is advisable that this direction should be perpendicular to the lines of the television image. To produce modulation of the beam, the image of the slit is moved across the square aperture in accordance with the signal voltages applied between the modulating plates. Between the S'-plane and the fluorescent screen is the projector lens system preferably comprising three apertured diaphragms, the two outside diaphragms being placed at frame potential and the inner diaphragm being connected to a potential which is negative with respect to earth. The purpose of the projector lens system is to project an electron image of the square aperture in the S'-plane upon the fluorescent screen. Between the projector lens system and the fluorescent

screen are located two pairs of electrostatic deflecting plates to which are applied deflecting voltages, the purpose of which is to so deflect the beam that it scans every elemental area of the field of view on the screen in turn within the period of persistence of vision. To each pair of deflecting plates is applied a voltage of saw-toothed wave form of the proper frequency to produce this result.

A feature of the present invention as distinguished from the electron optical arrangement of the preceding Davison application is that each of the modulator and projector lens systems of the present arrangement consists of three lens members instead of two, the two outer lens members of each system being connected to ground. The advantage of this arrangement is that the average potentials of the modulating and deflecting plates may be made substantially the same as that of the final beam, and thus both modulating and deflecting plates operate at approximately earth potential.

A further feature of the present invention is the provision of an ionization manometer, comprising a filament of tantalum, a grid and a plate, connected onto a side tube which is attached to the television cathode ray tube. This manometer serves to measure the pressure of the residual gas in the tube and at the same time to reduce the amount of this gas. This "clean-up" of the gas results from chemical actions between constituents of the gas and the glowing tantalum filament the products of which are solids, from adsorption of gases by deposits of tantalum freshly vaporized on the manometer parts, and to some extent from absorption of gases by the hot tantalum filament.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a schematic top view of the television receiving tube and its associated circuits which embodies the invention;

Fig. 2 is a perspective view of the electron optical system of the tube shown in Fig. 1;

Fig. 3 is a longitudinal cross-sectional view of a portion of the electron optical system shown in Fig. 2;

Figs. 4 to 8, inclusive, are cross-sectional views taken at different portions of the electron optical system shown in Figs. 2 and 3;

Fig. 9 is a schematic view of a "clean-up" manometer used in connection with the tube shown in Fig. 1; and

Figs. 10 to 14, inclusive, are graphical and schematic representations used to explain the operation of the invention.

Referring more specifically to the drawings, Fig. 1 shows schematically in top view a cathode ray tube and its associated circuits for use in television receiving. Briefly, this tube comprises a gas-tight envelope 10 containing an electron optical assembly 11 (shown in perspective in Fig. 2 and by various sectional views in Figs. 3 to 8, inclusive), for generating, focussing and accelerating a beam of electrons, means for modulating this beam in accordance with signals, and means comprising the deflecting plates 12, 12 and 13, 13 for deflecting the beam so that it traverses every elemental area of the field of view on a fluorescent screen 14, of a material such as willemite, and which is located at the end of the tube remote from the electron optical structure.

Broadly speaking, the electron optical ar-

rangement comprises three electron focussing or lens systems of the electrostatic type. These are (1) a condenser lens system for condensing the electrons emitted from a cathode 15 into a beam which is focussed upon an aperture 16 in the metallic diaphragm S, (2) a modulator lens system for forming an electron image of this electron "illuminated" aperture in the S-plane upon an aperture 17 in a metallic diaphragm S', and (3) a projector lens system for projecting an image of this electron "illuminated" aperture 17 in the S'-plane upon the viewing screen 14. Preferably the shape of the aperture in the diaphragm S is made in the form of a slit and the shape of the aperture in the diaphragm S' is made square or rectangular.

The cathode 15 is preferably formed in the shape of a cross from a single sheet of tungsten of the order of .001 inch thick. The opposite ends of this cross are fastened together and the terminals 236 and 237 are connected to a suitable source of heating current 18. A resistor 19 is also connected across the terminals 236 and 237, the mid-point of which is connected to a tap 20 of a potentiometer resistor 21. By this method of cross-connection the electrostatic and electromagnetic fields due to filament current and potential are reduced to substantially zero. For a more complete description of a cross-shaped cathode element similar to the one described above, reference may be made to Patent 2,117,709, issued May 17, 1938 to C. J. Davisson.

Back of the filament 15 (with respect to the fluorescent screen 14) is placed a back electrode 22 which preferably comprises a circular plate spaced a short distance from the cathode 15 and parallel thereto. The function of this back electrode 22 is to so terminate the enclosure which contains the filamentary cathode 15 that the fields about the filament 15 at its center may be made free from distortion by proper adjustment of the back electrode potential. The plate 22 is connected to a point 23 on the potentiometer resistance 21 which is at a negative potential with respect to V_c , the voltage of the tap 20 and of the mid-point of the resistance 19 connected across the cathode 15.

The electric fields about the apertures in the plates 24 and 25 serve as a condenser lens system to concentrate the emission from the filament 15 onto the slit 16 in the apertured diaphragm S. The parts defining this slit 16 will be referred to more fully below. The converging power of this lens system depends upon the ratio of the potential differences between the filament 15 and the plate 24 and between the filament 15 and the plate 25. Measuring potentials from the filament, it depends upon the ratio V_1/V_2 where V_1 and V_2 represent the potentials applied to the plates 24 and 25 by means of the taps 26 and 27 on the potentiometer resistance 21. The converging power of the condenser lens system is adjusted to produce the greatest possible current density in the plane of the slit 16.

The potential V_1' (the potential applied to the back electrode 22) is so adjusted with respect to the potential V_1 that the potential increases uniformly with distance from the back electrode 22 to the first condenser lens member 24. In other words, the back electrode potential is adjusted so that the volts per centimeter from the back electrode to the filament is the same as the volts per centimeter from the filament to the first condenser lens member. The zero potential surface (the plane of the cathode) is then flat in its cen-

tral portion; the filament 15 is merely a certain part of this flat surface which emits electrons. Thus, there is, in effect, a flat cathode. The requirement for this condition is that the potential differences $(0-V_1)$ and (V_1-0) be proportional to the distances 22 to 15 and 15 to 24 respectively. Representing these by d_1' and d_1 , the proportionality requires that

$$V_1' = -V_1 \left(\frac{d_1'}{d_1} \right)$$

V_1' is negative with respect to the cathode and its absolute value is a fixed fraction of V_1 . This fixed ratio of $-V_1'$ to V_1 is maintained in all adjustments of the condenser lens system. For a more complete description of the relation between a cathode, a back electrode and an accelerating anode together with the reason therefor, reference should be made to the above-mentioned Davisson application Serial No. 118,277.

Another lens system known as the modulator lens system 28 is placed substantially half-way between the slit 16 and the square aperture 17. This lens system preferably comprises three plates 29, 30 and 31 containing circular holes therein. The center plate or diaphragm 30 is electrically connected to a tap 32 on the potentiometer resistance 21 thus placing the plate 30 at a potential which will be designated V_3 . The two outer plates or diaphragms 29 and 31 are electrically connected to cylindrical members 33 and 33 which are connected to ground. The tap 27 of the potentiometer resistance 21 is also connected to ground, this potential being designated V_2 . The distances between the diaphragms 29 and 30 and between the diaphragms 30 and 31 are made equal to each other for symmetry. The purpose of the modulator lens system is to form an electron image of the slit 16 in the diaphragm S upon the plane of the square aperture 17 in the diaphragm S'. The strength or converging power of the modulator lens system 28 is varied by changing the potential V_3 with respect to the potential V_c of the filament. When correctly adjusted a real electron image of the slit 16 is formed in the S'-plane. From the symmetry of the system it is evident that the image of the slit is the same size as the slit itself, or, in other words, the magnification is unity.

Proceeding along the tube axis, the position of the electron image in the S'-plane can be displaced laterally by applying signal potentials between the modulating plates M_1 and M_1' and between the plates M_2 and M_2' . The modulating plates M_1 and M_2 are connected together and the modulating plates M_1' and M_2 are also connected together so that a displacement of the image is produced without an angular deviation of the electron beam. Image signals are applied to the terminals 35 and 36 from a balanced source of modulating signals (not shown) which signals are representative of the light-tone values of the successively scanned elemental areas of the object at the television transmitting station. A high resistance 37 is connected between terminals 35 and 36 and the mid-point of this resistance is connected to ground in order to place the average of the potentials applied to each of the sets of deflecting plates M_1 and M_1' and M_2 and M_2' substantially at ground potential which is also the potential of many of the other elements of the tube. This resistance 37 may be, if desired, the output resistances of a balanced modulator circuit. The modulating plates are within a metal-

lic cylindrical member 38 which is connected to ground.

To form an electron image of the aperture 17 in the S'-plane on the fluorescent screen 14 there is provided a projector lens system 40 comprising a cylindrical member 41, apertured diaphragms 42 and 43 at the same potential as the cylinder 40 and a third circular plate 44 between the plates 42 and 43 which is placed at a potential V_4 by means of a tap 45 on the potentiometer resistance 21. The projector lens system 40 is similar to the modulator lens system 28 in that each comprises three lens members. The outside lens members in each case are placed at the frame potential V_2 while the inside lens members are placed at potentials which are negative with respect to the frame potential. The system is operative if the inner lens members are made positive with respect to the frame potential but for practical purposes it is better that the frame potential be the highest potential as otherwise a greater range of voltages would have to be supplied by the power supply system. A conducting coating 39, of, for example, aquadag, on the inside walls of the tube 10 extends from the region of the deflecting plates 13, 13 to the region of the fluorescent screen 14. This coating 39 is placed at the frame potential V_2 .

The direct current potentials for biasing the various elements of the electron optical system are preferably derived from an alternating current oscillator 50, the output of which is rectified by any suitable device represented schematically in Fig. 1 of the drawings by the block 51 which has in its output circuit the potentiometer resistance 21 having a plurality of taps as described above from which the various voltages for the electron lens elements are taken. An alternating current ground is provided for two spaced apart terminals, 52 and 53, by means of condensers 54 and 55, of about one microfarad capacity each, which are connected between these terminals and ground. It should be understood that while a power supply system comprising a single rectifier, filter and potentiometer has been shown to supply the various elements of the electron lens system, it is possible to provide two or more power supply systems for this purpose, if desired. For example, one rectifier and filter may supply potentials up to 1,800 volts direct current and another supply up to 6,000 volts. In such an arrangement the two power supply systems may have different current capacities if desired. As an example of the voltage applied to the various elements of the electron optical system, the following potentials are given, these voltages being with respect to the cathode 15 as a reference or zero point inasmuch as the potential of a particular element of the lens system with respect to this reference point determines the energy of the electron at the element. (In practice, V_2 is at zero or ground potential.) Thus with the cathode 15 considered as a zero or reference potential, V_1 is about 1,000 to 1,200 volts positive, V_2 around 5,000 volts positive, V_3 around 2,100 volts positive and V_4 around 2,500 volts positive. V_1' is made about 300 volts negative with respect to the cathode 15. It is to be understood that these voltages are merely given by way of example and the invention is not limited thereto.

The tube will operate equally well with each of the potentials mentioned above increased (or decreased) by a given factor. The ratios of the operating voltages are critical; not the voltages

themselves. The magnitude of V_2 with respect to the cathode is important in that it determines the energy of the electrons incident on the screen, and also in that it sets a limit to the magnitude of the beam current, the limit being greater the greater the value of V_2 . Apart from these considerations, the designer is concerned only with the ratios of voltages. But even with respect to these, there is a certain latitude. In the example given above the tube operates with $V_4=2,500$ volts and $V_2=5,000$ volts, that is, with V_4 and V_2 in the ratio of 1 to 2. The tube would also be operative for one other ratio of V_4 to V_2 . This other critical ratio might, for example, be 5 to 2. The tube would be operative then with $V_2=5,000$ volts and $V_4=2.5 \times 5,000=12,500$ volts. The same is true of the other voltage ratios with the exception of the ratio of V_1' to V_1 which has but one critical value. It is to be understood that while the voltage ratios are critical, they are not absolutely so; the tube is still operative with the voltage ratios displaced slightly from their best or critical values.

In order to cause the electron beam generated by the electron optical apparatus described above to scan every elemental area of the field of view on the fluorescent screen 14 in turn, suitable deflecting plates such as, for example, two pairs of electrostatic deflecting plates 12, 12 and 13, 13, the normals to whose surfaces are located at right angles to each other, are provided. To the deflecting plates 12, 12 are applied deflecting voltages of line scanning frequency (5,760 cycles per second, for example) and of saw-toothed wave form to produce the horizontal deflection, while deflecting voltages of framing frequency (24 cycles per second, for example) and of saw-toothed wave form are applied to the deflecting plates 13, 13 to produce vertical deflection of the beam. Any appropriate sweep circuits (not shown) may be used to generate the horizontal and vertical deflection voltages. For example, reference may be made to Patent No. 2,178,464, dated October 31, 1939 to M. W. Baldwin, Jr., which discloses suitable balanced sweep circuits for this purpose. Connections may be made from the balanced sweep circuits to the pairs of plates 12, 12 and 13, 13 by means of coupling condensers 60 and 61 and 62 and 63, respectively, of about one microfarad capacity each. Coupling resistances 64 and 65 of the order of twenty megohms each are respectively connected across the pairs of plates 12, 12 and 13, 13. The mid-points of the resistances 64 and 65 are connected to ground (V_2) so that the average of the potentials of the deflecting plates does not deviate more than slightly from the potential of the frame. This relationship is maintained to avoid changes in the sensitivity of the deflecting system, and a consequent distortion of the image, which would otherwise result. For a more full description of the advantages of balanced sweep circuits for use with cathode ray television tubes, reference may be made to the above-mentioned Baldwin patent and also to Patent 2,209,199, issued July 23, 1940 to Frank Gray.

In order to more fully understand the principles of modulation employed in the tube shown in Fig. 1, several factors must be thoroughly considered and understood. Television transmitters and circuits are designed to supply at the receiving tube a signal voltage proportional to object element brightness. To utilize this signal directly, the receiving tube should yield screen element brightness proportional to signal voltage

so that brightness or tone values in the picture will be the same as in the object. If screen brightness is proportional to beam current, as for most screens it is, then beam current in the receiving tube should be proportional to signal voltage; in other words, the modulation of beam currents by signal voltage should be linear. Failure to meet this requirement results in the falsification of tone values in reproduction, and when departures from linearity are marked, unsatisfactory pictures result. A common fault of television receivers is that beam current rises more rapidly than signal voltages; the low tones of the picture are lower relatively to the high lights than they should be; the picture appears "muddy" and has generally the faults of an under-exposed photograph. In the design of the television receiver of this invention, a decided attempt has been made to establish direct proportionality between beam current and signal voltage.

To better understand the arrangement for achieving this objective, reference should be made to Fig. 10. A real electron image 69 of the uniformly electron "illuminated" slit 16 is formed on the metal diaphragm S' containing the square aperture 17. If the image 69 overlaps the aperture a current of electrons proportional to the extent of the overlapping flows through the aperture, and this constitutes the beam current. By means of the signal potentials applied between the modulating plates M₁ and M₁' and M₂ and M₂' the slit image 69 may be displaced laterally by amounts proportional to the signal voltage. If the image 69 is just off the aperture 17 (to the left in Fig. 10) when the signal voltage is zero and completely covers the aperture when the signal voltage is at its maximum, then direct proportionality between beam current and signal voltage results and the beam currents are as large as possible. That this be strictly so requires the fulfillment of several conditions which it will be well to have in mind in order to completely understand the desired features of a "perfect" tube (at least "perfect" in so far as modulation is concerned); (1) all or a fixed fraction of the electrons which pass through the aperture 17 must appear in the beam incident on the screen 14; (2) the brightness of the part of the slit image 69 which moves on to the aperture 17 must be uniform; (3) the edge of the image 69 must be perfectly defined and strictly parallel to the contact edge of the aperture 17; (4) the image and aperture contact edges must coincide when the signal voltage is zero; and (5) the displacement of the image must be strictly proportional to the signal voltage. The last two of these conditions are strictly fulfilled in the tube of this invention and the other three are nearly enough fulfilled to result in essential linearity between beam current and signal voltage.

The strength of the condenser lens system comprising the plates 24 and 25 may be altered by changing the ratio of the potentials V₁ and V₂, ordinarily by varying V₁ (and V₁') with V₂ fixed. For a particular value of this ratio the strength of the condenser lens system is such that a real image of the filamentary cathode 15 is formed on the plate or diaphragm S which contains the slit 16. There would be a certain advantage in adjusting the condenser lens system to this condition. The central part of the image would be uniformly bright, and assuming this to fall squarely on the slit 16, a portion at least of the slit would be uniformly illuminated, and this, it will be noted, is one of the requirements men-

tioned above. The condenser lens system is not, however, operated in this adjustment. Another adjustment can be made which provides almost uniform illumination of a sufficient length of the slit, and which has the advantage of putting through the slit many more electrons, that is, of producing much greater beam current. The difficulty of obtaining sufficiently large beam current, even with fluorescent screens of high efficiency, is such that it is almost necessary to choose the latter of these adjustments, that is, the one which yields the greater current.

This latter adjustment is primarily the one which yields the greatest attainable beam current. Optically, it is the adjustment which brings the principal focus of the condenser lens system on to the plate S. In this adjustment a focal spot is formed in which current density falls off from its center in a manner described by the expression

$$e^{-r^2/\lambda^2}$$

where r represents radial distance and λ is a parameter which depends for its value on the geometry of the system, the temperature of the filament 15, and the voltage V₂. The form of this distribution is shown in Fig. 11 where $\lambda_1 < \lambda_2 < \lambda_3$. These are so-called probability curves. The ordinates represent current densities along any straight line through the center of the focal spot. This is the distribution which would be expected if the cathode were a uniformly emitting flat surface of considerable extent. Actually the width of the arms of the cross-shaped filament is less than the diameter of the condenser lenses and as a consequence the focal spot is not quite circular. However, this departure from circular form can be neglected in most tubes.

It will be clear from a consideration of the curves of Fig. 11 that with the condenser lens system adjusted to form a focal spot, the illumination of the slit 16 cannot be strictly uniform. There is, however, a region about the center of the spot within which the illumination is nearly uniform. The area of this region is greater for larger values of λ . If the diameter of this region is greater than the width of the slit it is evident that a length of the slit, sufficient for the purpose, can be "nearly uniformly" illuminated. If the area of nearly uniform illumination is too small it can be enlarged by moving away slightly from the exact focal spot adjustment. The first effect of this departure is to "fuzz out" the spot and increase the "nearly uniform" area. This involves a loss of beam current and is only resorted to when necessary. In tubes built in accordance with the description above, the "nearly uniform" area is sufficiently large with the condenser lens adjusted for maximum beam current.

If the apparatus were perfect geometrically, the center of the focal spot would fall on the center of the slit 16, and the brightest part of the image 69 of the slit would fall squarely on the center of the square aperture 17. Actually, the errors of alignment are such that perfect registration cannot be expected. The chief difficulty is with the filament which should be flat, accurately centered and in a plane normal to the axis of symmetry. The filament is usually warped a bit one way or another, and for this reason, if for no other, the registration is never perfect.

In order to correct errors due to misalignment, two collimator units C₁ and C₂ (each of which comprises means for forming an electrostatic and

an electromagnetic field) are provided, one on each side of the slit 16 in the S-plane. Each of these has a symmetrical yoke electromagnet as shown in greater detail in the cross-section of C₁ shown in Fig. 4. The pole-pieces 70 and 71 of C₁ are insulated from the yoke and serve also as the plates of an electrostatic deflector. The focal spot is moved laterally (in Figs. 1 and 3) by the electric field between the deflector plates 70 and 71 and at right angles to the drawing by the magnetic field produced by the coils 72 (shown schematically only in Fig. 1). Details of the mountings of the elements of the collimator unit C₁ will be considered more fully below.

The collimator unit C₂, placed just beyond the slit 16, is used to direct the beam of electrons, which enters this region through the slit 16, into the modulator lens system 28. The diameter of the beam at the modulator lens 28 is the same, approximately, as the diameter of the aperture in the lens plate 30 so that the beam and the lens must be accurately registered if loss of beam current at this point is to be avoided. Failure of the beam to register with the aperture may result from misalignment of the structure or from deflection of the beam in collimator unit C₁ or from both. The collimator C₂ is used to correct these errors.

The coils 73 of the collimator C₂ are similar to the coils 72 of the collimator unit C₁ while the electrostatic deflector plates 74 and 75 are similar to the plates 70 and 71 of C₁ shown in Fig. 4.

With the condenser lens system and the two collimator units C₁ and C₂ in proper adjustment, the focal spot falls squarely on the slit 16 and the beam from the slit falls squarely on the aperture in the modulator lens diaphragm or plate 30. Further, if the modulator lens is properly adjusted, an inverted image of the slit of magnification unity is formed in the plane of the square aperture 17 on the S'-plane. It is hardly to be expected that the brightest part of the image will fall squarely on the square aperture 17 as it would if the system were perfect. It will ordinarily fall to right or left of the aperture and above or below it.

In order to bring the image into the desired relationship with the square aperture 17, the electric field of the modulating plates and the magnetic field of the collimator units C₁ and C₂ may be used. The lateral (in the plane of Fig. 1) displacement of the image can be varied by applying direct current potentials across the modulator plates M₁, M₁', M₂, and M₂', by any appropriate means (not shown), and the displacement at right angles to the plane of Fig. 1 can be varied by simultaneous adjustment of the magnetic fields produced by the coils 72, 72 and 73, 73 of the collimator units C₁ and C₂ by varying the currents flowing through the coils 72, 72 and 73, 73 from the direct current sources 78 and 79. It will be clear that when the magnetic field of the collimator unit C₁ is varied, the center of the focal spot is moved up or down the slit, also that the beam from the slit is deflected and displaced upward or downward from the modulator lens. This latter displacement may, however, be compensated by readjustment of the magnetic field of the collimator unit C₂. It is thus possible to move the focal spot along the slit 16 and at the same time keep the beam on the modulator lens 30. This has two distinct effects upon the slit image: (1) the brightest part of the image (corresponding to the center of the focal spot) occupies a different position in the image

(the image is inverted so that if the focal spot has been moved upward the brightest part of the image will move downward (see Fig. 12)); and (2) the image itself is displaced in the same direction as the brightest part of the image due to the deflections given the electrons by the magnetic field of the collimator unit C₂.

If both the electric and magnetic fields of the unit C₂ are zero, electrons from an element of the slit 16 approach the modulator lens member 28 along straight lines. If the fields are not zero, the electrons approach the lens, not as if they had come directly from the actual element but as if they had come directly from a virtual element displaced somewhat from the actual one. The fields affect the electrons from all elements equally, or nearly so, so that the over-all effect is a replacement of the actual source by a displaced virtual source. The virtual source is displaced laterally by the electric field and normally to the plane of Figs. 1 and 3 by the magnetic field of the collimator unit C₂. Equal displacements in opposite directions occur in the image of the slit 16, as is clear from simple optical considerations. The effect of varying the magnetic fields of the collimator units C₁ and C₂ simultaneously in such a way that the beam from the slit is kept centered on the modulator lens 28 is to cause the image of the slit to move normally to the plane of Figs. 1 and 3 in which the tube is shown in top view, and for the brightest part of the image to move along the image in the same direction. This is illustrated in Fig. 12 which shows how the slit image and the brightest point in the image are displaced by the magnetic fields produced by the coils of the collimator units, the rectangles 80, 81, 82, 83 and 84 representing various vertical positions of the slit image and the members 85, 86, 87, 88 and 89 representing the points of maximum brightness in the slit image. In viewing Fig. 12 the lateral displacements of the images are to be disregarded. The images are displaced laterally from one another in Fig. 12 only to avoid confusion. To represent the situation accurately, the rectangles representing the images should be brought together by lateral displacements, so that only their longitudinal or vertical displacements remain.

With these adjustments, that is, the double magnetic adjustment of the coils of the units C₁ and C₂ for moving the image 69 and its brightest part in a direction parallel to the slit edges and the electrical adjustment of the modulating plates for moving the image laterally, it is possible to place the image in the desired relationship with respect to the square aperture. The brightest part of the image may be placed squarely on the aperture or the image may be so displaced that one of its edges is just in contact with an edge of the aperture.

With the image 69 in this latter relation to the aperture, the condenser lens, the modulator lens and the collimator adjustments are complete; signal voltages applied in the proper direction to the modulator plates M₁, M₁' and M₂, M₂', will move the image 69 of the slit 16 with respect to the aperture 17. This might be done with a single pair of modulator plates and if moving the image with respect to the aperture by an amount proportional to the signal voltage were the only requirement, only one pair of plates would be used. It is important, however, that the beam which passes through the square aperture into the region beyond shall not be deflected by the modulating field. From the square

aperture 17 the beam passes to the projector lens system 40. It is important that the fraction of the beam which enters the lens system shall not change with modulating voltage. Any change in this fraction represents additional modulation of the beam reaching the viewing screen 14 and a modulation which is not linear. It is important, therefore, that the beam from the square aperture 17 does not change in direction with modulator voltage as such a change would affect the fraction of the beam entering the projector lens 40. To avoid this the beam from the modulator lens system 28 is displaced rather than deflected.

This result is accomplished by cross connecting the plates of the modulator (M_2' is connected to M_1 , and M_1' to M_2) so that signal voltage applied across the plates M_1 and M_2 appears simultaneously across the plates M_1' and M_2' , but in the opposite direction. The beam is deflected through a certain angle in one direction as it passes between the plates M_1 and M_2 , and then through an equal angle in the opposite direction as it passes between the plates M_1' and M_2' . The deflections cancel but a displacement remains; the image 69 is thus moved across the aperture 17 without deflecting the beam beyond.

If the requirements for strictly linear modulation enumerated above were met, the graph of beam current against voltage applied across the modulator terminals 35 and 36 would have the form shown in Fig. 13. For zero voltage the median line of the image 69 would fall on the center of the square aperture 17 and the beam current would have its maximum value. If aperture 17 and image 69 are not the same width, the voltage can be increased a certain amount (or decreased an equal amount) without decreasing the beam current. This ends when an edge of the image comes into contact with an edge of the aperture. From this point onward the beam current decreases linearly to zero at the voltage at which the image passes completely off the aperture. This occurs at a certain positive voltage and also, of course, for a negative voltage of equal magnitude.

An example of the actual beam current-modulator voltage relationship for a particular tube is shown in Fig. 14. This is an oscillograph record of beam current against modulator voltage, the applied voltage being 60-cycle alternating current. The departures of the observed characteristic of Fig. 14 from the ideal characteristic of Fig. 13 are quite considerable and yet from the lower values of beam current to near the maximum, the curve is essentially a straight line on each side of the median line. The width of the modulation curve on the X-axis from zero current to zero current is about 20 volts with the tube operating at 5,000 volts. The straight portions are about 7 or 8 volts in width. In operation the modulator plates are biased by appropriate means (not shown) to make zero signal voltage correspond to one or the other of the cut-off voltages, that is, equal to AO or OD in Fig. 14, and the signal voltage is appropriately poled. A suitable arrangement for applying bias to the modulator plates is shown in Patent 2,168,760, issued August 8, 1939, to C. J. Calbick. The maximum signal voltage must not exceed the 7 or 8 volts which correspond to the straight portion of the characteristic and for most efficient operation it must not be less. If it is less, the picture is not so bright as it can be made and the current-voltage relationship over the operat-

ing range is not so nearly linear as it is possible to make it. If, for example, the maximum signal voltage were only half a volt, the operating characteristic would be dominated by the rounded section at the bottom of the modulation curve and the modulation would not be essentially linear.

When the image 69 of the slit 16 completely covers the square aperture 17 the whole aperture is uniformly illuminated and the image on the screen is a square of uniform brightness. As the magnifying power of the projector lens as used is about 5, the linear dimensions of the image are about five times those of the aperture 17. When the image 69 of the slit covers only half the square aperture 17, the image is only half as wide as when the whole aperture is illuminated. In general, what appears on the screen is an image of the part of the square aperture which is "illuminated," that is, the part which is covered by the slit image 69. These images have all the same height (the width of an elemental line of the screen 14 which is scanned horizontally) and the same brightness but differ in width. Modulation consists in varying the width of a uniformly bright rectangular image. The average or effective or subjective brightness of an element of the screen 14 is proportional to the fraction of the total time the scanning spot or image of the aperture 17 remains upon it, and this with the scanning image moving horizontally at a uniform speed is proportional to the width of the image. The intrinsic brightness of the image remains constant; it is the subjective brightness of the screen elements which varies with the image width, and which alone the observer is capable of appreciating or sensing.

The type of modulation described above is quite different as regards the behavior of the scanning spot from that ordinarily employed. In most types of television receiving tubes known to the art, modulation consists in changing both the diameter and the intrinsic brightness of a spot which is circular in form. Full subjective brightness is obtained by making the spot large and bright; low subjective brightness by making the spot small and dim. There are obvious undesirable features in this type of modulation; for example, the path of the spot is narrow in the dim parts of the picture and wide in the bright parts, and adjacent paths do not join up in the dim parts of the picture so that "line structure" appears or, if they do join up in the dim parts, they overlap in the bright parts causing loss of detail resolution.

The uniform path-width of the present arrangement is one of its important advantages. Another important advantage of the arrangement of this invention is that the path is uniformly bright across its width. These features make it possible to match paths, edges to edges, at all parts of a picture on the screen 14 without overlapping, the "line structure" of the picture being suppressed practically completely.

It is very desirable that the gas in the cathode ray tube of this invention be almost entirely removed so that a high vacuum prevails. It has been discovered that the presence of gas in the tube above a certain level produces the following among several undesirable results: (1) a modulation distortion of the television image field, (2) a position modulation of the cathode ray beam, and (3) a white "cross" on the image field caused by accumulations of positive ions, a well-known phenomenon in cathode ray tubes. Due to the

large number of parts in this tube and also to the size of these parts, it is impossible to bake all of them sufficiently to reduce the pressure to a point low enough to produce an efficient tube by the use of ordinary pumping methods. To assist the ordinary vacuum pump and also to measure the gas pressure in the cathode ray tube an auxiliary tantalum filament manometer "pump" is provided.

Referring to Fig. 9, a side tube 90 is connected to the envelope 10 at any desired point, as, for example, opposite the modulating plates M_1 , M_1' , M_2 and M_2' . This side tube 90 leads to an ordinary vacuum pump (not shown) for removing the gas from the envelope 10. Connected to this side tube 90 is a smaller tube 91 leading to an electron discharge device 92 comprising an M-shaped filament 93, a grid 94 and a plate 95. The filament 93 has three leads 96, 97 and 98 which pierce the press 99 and extend out from the tube 92. The grid 94 has a connection 100 which extends through the press 99 to a tap 101 on a potentiometer resistor 102 which is connected across a direct current source 103. The plate 95 is connected by means of a terminal 104 through an ammeter 105 and a resistor 106 to a tap 107 on the potentiometer resistor 102. A source of potential 108 supplies heating current for the filament 93, this source being connected to the terminals of a potentiometer resistor 109. The two external terminals of the resistor 109 are connected to the connections 96 and 98 and the mid-tap of the resistor 109 is connected to the terminal 97. The terminal 97 is also connected to a tap 110 on the potentiometer resistor 102. It will be noted from a study of this arrangement that the grid 94 is polarized positively with respect to the filament 93 while the plate 95 is made negative with respect thereto. The electrons emitted by the tantalum filament 93 are drawn to the grid 94; some of them miss the grid on the first passage and finally reach the grid only after one or more excursions in and out of the region between grid and plate. On these excursions some of them strike molecules of the residual gas remaining in the cathode ray tube envelope 10, ionizing them. The positively charged gas ions so produced are drawn to the plate 95 due to the negative bias thereof and the positive ion current measured by the ammeter 105 is a measure of the gas pressure in the tube.

An advantage of the tantalum filament 93 is that it evaporates the deposited tantalum on the walls and plates of the manometer tube and this deposited tantalum adsorbs gas very efficiently. In other words, an evaporated film of the tantalum acts as a very good "getter." It is thought that there are two additional actions taking place which assist in the "cleaning up" of the gas in the cathode ray tube. One of these is the chemical actions between constituents of the gas and the glowing tantalum filament, the products of which are solid, and the other of which is the absorption of gases by the hot tantalum filament. Thus, the tantalum filament manometer, in addition to measuring the pressure, acts as if it were a pump sealed on to the television tube 10. Experience with these tubes has confirmed this pumping action of a tantalum filament and experiments have also been conducted to determine the life and the consequent efficiency of pumping of a .008 inch tantalum filament. With a heating current of about 3 amperes, the life is about 7,500 hours. At this current the filament, which is about five inches long, is hot enough to emit

an electron current of about .05 ampere. In the manometer circuit used for measuring pressure, this is about the emission current required. It was found that the gas pressure in a television tube which has a volume of about 75 liters, decreased at a rate of about 10^{-6} millimeters per hour of manometer operation when the pressure was 10^{-5} millimeters of mercury or thereabouts, and at about 1 per cent of the instantaneous pressure per minute when the pressure was 10^{-6} millimeters of mercury or lower.

The tantalum filament "pump" has a limited total capacity. It is indicated that it can "clean up" a total gas pressure of the order of 10^{-2} millimeters of mercury in a volume of 75 liters. This capacity is ample for the purpose. The television tube 10 is sealed off the pump after the usual baking treatment at a pressure of about 2×10^{-6} millimeters of mercury. Operation of the tube subsequently may evolve gas due to a heating of parts around the filament 15 of the television tube, which may amount to a total pressure of perhaps 1×10^{-4} millimeters of mercury. Operation of the manometer pump for a few days reduces this pressure to less than 1×10^{-7} millimeters of mercury and even as low as 5×10^{-8} millimeters of mercury. Thus the tantalum filament electron discharge device operates both as a very efficient "pump" and also in combination with the ammeter 105 and the associated circuit acts as a manometer to indicate accurately the gas pressure in the television tube 10 which has been sealed off from the pump.

The operation of the tube shown in Fig. 1 will now be described. Electrons emitted by the cross-shaped filament 15 are caused to travel toward the condenser lens member 24 by means of the uniform electrostatic field existing between the back electrode 22 and the first lens 24 of the condenser lens system. The electrons would move in this region along straight lines parallel to the axis of the system were it not for the fact that they are emitted from the filament with relatively small initial velocities which have, in general, lateral components, that is, components at right angles to the axis of the system. The effect of an initial lateral component of velocity is to cause an electron to describe a parabola, in the uniform field being considered, instead of a straight line. Under the conditions of operation the velocity acquired by the electrons in the field between the filament 15 and the condenser lens plate 24 is some hundreds of times greater than the average value of the lateral components of the initial velocities. It is in comparison with this velocity that the initial velocities are "relatively small." A consequence of this relative smallness of the initial velocities is that the parabolic trajectories which the electrons actually describe lie close to the straight line trajectories which they would describe were their initial velocities zero. The electrons which flow from an infinitesimal element of the filament 15 form a beam which coincides in cross-section with the boundaries of the element at the filament but which broadens and becomes less sharply defined at increasing distances from the filament. The loss of definition in the boundary of the beam is due to the fact that there is no definite upper limit to the magnitudes of the lateral components. The average value of the component is fixed by the temperature of the filament but the actual components range in magnitude from zero to values considerably greater than the average. The diameter of the elementary beam considered

above becomes definite at some distance from the filament if it is defined as the diameter of the circle about the axis of the beam through which some arbitrarily chosen fraction—say 0.9—of the electrons pass. Nine-tenths of the electrons pass through the circle and one-tenth outside it. Enough is known about the initial velocities to make the calculation of the diameter of this circle possible. In the case under consideration, the diameter (as defined above) of the elementary beam at the condenser lens plate 24 is, under operating conditions, a few tenths of a millimeter. By means of the electrostatic fields about the circular apertures in the condenser lens members 24 and 25 an intense beam is focussed upon the plane of the diaphragm S which contains the slit 16. This amounts to superposing elementary beams from elements of the filament opposite the lens. The first collimator unit C₁ is adjusted, by means of the potentials taken from taps 76 and 77 of the potentiometer resistance 21 and by means of the direct current source 78, to deflect electrons after they pass through the aperture in plate 25 in such a manner as to place the maximum electron intensity at the desired point in the S-plane. The second collimator unit C₂ located on the opposite side of the slit 16 from the first collimator unit C₁ is similar in function to C₁ in that it changes the direction of the motion of the electrons so that they are once more proceeding approximately parallel to the tube axis, thus compensating for any deflection which the first collimator unit C₁ has given them when it has placed the maximum intensity point at the correct place on the slit 16 in the S-plane. Potentials for the second collimator unit C₂ are obtained by means of the taps 34 and 76 on the potentiometer resistor 21 and by means of the source of direct current 79 (for the coils 73). The taps 34, 76 and 77 are usually located very close to the tap 27 which is connected to ground (V₂), being generally of the order of 25 to 50 volts negative with respect to ground or, in some cases, even slightly positive with respect to ground. All of the taps 34, 76 and 77 are variable and they may or may not be at the relative positions shown, depending on local conditions. In other words, one or more may be positive and the others negative with respect to V₂ and vice versa or all be positive or all negative. The modulator lens system 28 comprising, the outside lens members 29 and 31 connected to the frame and the inner lens member 30 placed at the potential V₃, forms an image of the slit 16 upon the S'-plane containing the square aperture 17. The image 69 of the slit 16 is displaced laterally without deflection with respect to the aperture 17 by means of modulating signals applied to the terminals 35 and 36 as described above. An electron image of the electron illuminated aperture 17 is then focussed upon the fluorescent screen 14 by means of the projector lens system 40 comprising the two outside lens members 42 and 43 connected to the frame and the inside member 44 placed at a potential V₄. The conducting coating 39 covers the inner surface of the walls of the tube 10 from near the fluorescent screen 14 to near the projector lens system 40. This coating is connected to the frame so that the coating 39, like the frame, is at earth potential. The fluorescent screen 14 is insulating, or nearly so. It is not possible for this reason to adjust the potential of the fluorescent screen 14 to a desired value as it would be if it were conducting. When the tube is in operation, that is, when the fluorescent screen 14 is

being scanned by the electron beam, it assumes a fairly definite potential which differs only slightly (ordinarily by only a few volts) from the potential of the coating 39, and this in spite of the fact that a negative charge is being delivered to it steadily by the electron beam. The nearly steady condition is maintained by a compensating flow of secondary electrons from the fluorescent screen 14 to the conditioning coating 39. The balance is maintained by automatic adjustment of the small potential difference between screen 14 and coating 39.

The region inside the tube 10 extending from the deflector plates 13, 13 to the fluorescent screen 14 is thus almost completely enclosed by 15 walls at earth potential or at nearly earth potential. This region therefore is essentially free from electric fields. In fact the whole of the region from the projecting lens member 43 to the screen 14 is field free except for the transverse fields between the plates 12, 12 and 13, 13 which deflect the beam in two directions at right angles to each other by means of the sweep potentials applied between the plates 12, 12 and 13, 13 in order to scan every elemental area of the field of view on the screen 14 in turn within the period of persistence of vision. For example, the screen is scanned 24 times per second to reproduce the object so that it presents a moving image to the eye.

There have been described up to this point the electrical elements of the tube of this invention, the circuits therefor and the method of operation of the tube and circuits. Reference will now be made to Figs. 2 to 8, inclusive, in order to describe how the various electrode elements are supported in the tube. The envelope 10 has a reentrant stem 120 terminating in a press 121 through which a number of leads 122 extend. Tightly engaging the press 121 are two nickel clamps 123 which have several corrugated portions 124 (see Fig. 7) to allow for a tight fit around the press 121, this tight engagement being assisted by a mesh member 235 to prevent slippage. Four rods 125, 126, 127 and 128 are held in position around the stem 120 by means of upturned lugs 129, 130, 131 and 132 of the clamps 123 and suitable nuts 133, 134, 135 and 136 engaging the threaded portions of these four rods. The cylinders 234 are used as spacers for the clamps 123. The various elements of the electron optical system are supported from these rods 125, 126, 127 and 128.

The stiff wires 137 are used to lock the four nuts 235 which they join. The wires 137 are welded to thin washers 236 which have fins 237 extending beyond the sides of the nuts 235. After the nuts are tightened these fins are folded against the side faces of the nuts. These folded-over fins can be observed in Fig. 3. The nuts 235 (and not others) are locked because these are heated rather severely during the sealing-in process and one or more of them might otherwise become loosened.

An aluminum disc 138 is supported from these rods by means of bushings 139 of glass or lavite in order to insulate the aluminum disc from the potential of the rods (which is, of course, frame potential). Fitting into the disc 138 is a square plate 140 of aluminum which is fastened to the disc 138 by any suitable means. Fastened to the square plate 140 by means of bolts 141 is an aluminum holder 142 for the filament 15. The member 142 is threaded so as to support a rod 143 on one end of which is mounted the back electrode 22. The holder 142 is also pierced by four

insulated holes 144 through which extend rods 145 which make contact with contact members 146 which are electrically connected to the four portions of the cross-shaped filament 15. The four portions of the cross-shaped filament 15 make contact with a member 147 (see Fig. 6) which is in four segments, each segment of which is connected to a rod 145 which leads to the external circuit. The glass discs 148 and 149 act as spacers between the aluminum holder 142 and the nuts 150 on the rods 145 and between the holder 142 and the segmented contact member 147, respectively.

Fitting into a recess in the square plate 140 is a glass cylinder 151 which holds in position a member 152 having an aperture 153 therein, this member 152 serving as the first lens member of the condenser lens system (shown schematically as plate 24 in Fig. 1). The member 152 may be tapped at 154 to provide a contact.

The member 152 has a shoulder into which fits a glass cylinder 155 which acts as a spacer and support member for a square plate 156 having an aperture 157 therein, this member 156 serving as the second lens member of the condenser lens system (shown schematically as plate 25 in Fig. 1).

Fitting into a recess in the rectangular plate 156 is a support ring 158 having an octagonal outer surface (see Fig. 4). In this support ring are yokes 159 and 160 of permivar which are spaced apart by glass cylinders 161 and 162 held in position by bolts 163 and 164. Around the glass cylinders 161 and 162 are wound the coils 72, 72 for the first collimator unit. (It is to be understood that the second collimator unit C_2 is of exactly the same construction as that of the first collimator unit shown in detail in Fig. 4.) The present practice (although the invention is not limited thereto) is to bring out one coil lead from each collimator and one plate lead from each collimator on single common leads. The other two coil leads and the other two plate leads are brought out separately. The common lead from one of the coils is connected to the frame at 165, the other lead of this coil being connected to the other coil 72, the external lead 166 of which extends through a glass cylindrical bead 167 through a hole 168 in a clamping plate 169 to make contact with an appropriate source of potential. Electrostatic plate elements 70 and 71 are held in position by means of the rods 171 and 170 and insulating spacers 172, 173, 174 and 175. Connections to the electrostatic deflector plates 70 and 71 are made by means of wires 176 and 179 which pass through apertures 177 and 178 in the ring 158. One of these leads (as, for example, the wire 176) is connected to the corresponding lead from a deflector plate of the collimator unit C_2 , as shown in Fig. 1.

Separating the collimator units C_1 and C_2 and tending to support them is the plate S having a shoulder 180. The plate S has a circular hole 182 about .025 inch in diameter therein. Fastened to the plate S by means of small screws is a disc 183 having an aperture about .040 inch in diameter. Held in position between the plate S and the disc 183 are two small tungsten ribbons 185 and 186 which may have their positions regulated so that the distance between them determines the width of the slit 16, the electron image of which is to be projected upon the aperture 17. The slit 16 is preferably .006 by .025 inch. The cylindrical member 190 enclosing the collimator unit C_2 is held in position by a recess 75 in the aluminum disc 191 which disc is held in

position from the rods 125, 126, 127 and 128 by means of the nuts 192.

Also fitting into a recess in the supporting plate 191 is the aluminum cylinder 193 of the modulator lens system 11. A circular plate 29 having a circular aperture 194 therein has raised portions 226 which support and space a glass cylinder 195 located between the circular plate 29 and the circular plate 30, another insulating cylinder 196 being used as a spacer between the plate 30 and the diaphragm 31 which is part of a larger plate 197. The plate 197 of aluminum is supported by means of the nuts 198 from the rods 125, 126, 127 and 128. The glass cylinders 195 and 196 in addition to supporting and spacing the plates 29 and 30 from the supporting plates 191 and 197 also serve to insulate plate 30 from the potentials of plates 29 and 31. A contact 298 is made to the plate 30. Located inside the glass cylinders 195 and 196 are aluminum shields 199 and 200 which are electrically connected to the plate 30.

Supported between the supporting discs 197 and 201 (which latter disc is supported from the rods 125, 126, 127 and 128 by means of nuts 202) is a metallic cylinder 38, a portion of which is cut out to form a support for the plates 205 and 206 which are held tightly in position by means of the bolts 207 and 208 and the nuts 209 (see Fig. 5). Piercing the plates 205 and 206 are rods 310, 311, 312 and 313, fastened to which are the modulating plates M_1 , M_1' , M_2 and M_2' , respectively. These modulating plates are held in position by means of rectangular glass plates 214 and 215 and glass cylindrical spacers 216, 217, 218 and 219. Contacts are made to the modulating plates M_1 , M_1' , M_2 and M_2' , by means of connections inserted respectively between the pairs of nuts 210, 211, 212 and 213.

Supported within an aperture in the disc member 201 is the plate S' which has shoulders 220 to engage the plate 201 and to lend support to the cylinder 38. The plate S' has a circular aperture 222 therein. Supported by screws 223 from the plate S' is a perforated plate 224. Between the plate S' and the plate 224 is clamped a small tungsten plate 225 about .001 inch thick in which is punched an aperture 17 which is .005 or .006 inch square.

Also supported from the disc 201 and the disc 42 (see Fig. 2) is a cylinder 41, these discs being clamped to and supported by the rods 125, 126, 127 and 128. The disc 43 is also clamped to these rods. The disc 44 is supported from discs 42 and 43 by glass cylinders 230 and 231 fitting into recesses in discs 42 and 43.

Supported from the disc 43 and also by means of rods 232 from the disc 42 are the deflecting plates 12, 12 and 13, 13, the planes of the plates 12, 12 being at right angles to the plane of the plates 13, 13 in order that the beam may be deflected in two directions at right angles to each other.

Due to the complexity of the structure, all of the connections have not been shown for the sake of clarity in the drawings but connections to the different elements are made by means of metallic wires inside of glass insulating cylinders 233 which are usually located adjacent to and in pairs on opposite sides of each of the rods 125, 126, 127 and 128.

The following aperture sizes were used in an operative form of this invention. It is to be understood that these sizes are merely given by way of example and the invention is not necessarily 75

limited thereto. These circular apertures have the following diameters:

In the plate 24, .040 inch; in the plate 25, .040 inch; in the plate 29, .100 inch; in the plate 30, .200 inch; in the plate 31, .100 inch; in the plate 42, .250 inch; in the plate 44, .500 inch, in the plate 43, .250 inch.

In the above-mentioned operative form of the invention the distances between various elements of the electron optical system were as follows:

Between the back electrode 22 and the cathode 15, .020 inch; between the cathode 15 and the plate 24, .080 inch; between the plate 24 and the plate 25, .080 inch; between the plate 25 and the diaphragm S, .65 inch; between the diaphragm S and the plate 29, 2.2 inches; between the plate 29 and the plate 30, .6 inch; between the plate 30 and the plate 31, .6 inch; between the plate 31 and the diaphragm S', 2.2 inches; between the diaphragm S' and the plate 42, 5.5 inches; between the plate 42 and the plate 44, 1.5 inches; between the plate 44 and the plate 43, 1.5 inches; between the plate 43 and the fluorescent screen 14, 33.5 inches. Plates M₁ and M₁' are separated by a distance of .100 inch and plates M₂ and M₂' are separated by the same distance. The deflecting plates 12, 12 and also the deflecting plates 13, 13 are separated by distances of 1.0 inch. Plates M₁, M₁', M₂ and M₂' each are .95 inch long. Plates 12, 12 and 13, 13 are each 4.5 inches long.

The effect of the earth's magnetic field on the tube is compensated by the use of coils (not shown) in order to avoid magnetic deflection of the beam. The vertical component of the earth's field within the tube is compensated by the field of a pair of rectangular coils which lie in horizontal planes above and below the tube. These coils are 5 or 6 feet long and about 2 feet wide and are about 2 feet apart. The current through these coils in series is adjusted to bring the electrically undeflected beam onto the vertical median line of the fluorescent screen 14. Another similar pair of coils, one on each side of the tube with their planes vertical, is used to compensate the component of the earth's field which is horizontal and at right angles to the tube axis. The current in this pair of coils is adjusted to bring the electrically undeflected beam into the horizontal median line of the screen 14. When both adjustments have been made the electrically undeflected beam falls on the center of the screen. These adjustments can be made when the screen is being swept by the beam. In this case the currents in the coils are adjusted to center the scanned rectangle on the screen. This compensation is important not only for centering the picture on the screen, but also to avoid magnetic deflections of the electrons through the electron optical system from the filament on.

The modulator section of the tube is surrounded with a magnetic shield to avoid modulation of the electron beam by small sporadic variations in the vertical component of the earth's field and in the field which is local to the positions of the tube. The shield comprises a cylinder of laminated magnetic alloy suitable for the purpose. The reasons this shield is used even though the field has already been compensated are that the field within a building is also subject to slight variations, and that the vertical component of these variations was found to move the image 69 on and off the aperture 17 and so to modulate the beam. The vertical magnetic field necessary to displace the image

a distance equal to the width of the square aperture is surprisingly small and the variations in the vertical component are large enough to do it. The magnetic shield reduces these fluctuations within the modulator to .01 or .001 of what they would be without the shield.

The above-described tube made in accordance with this invention produces a well-defined high intensity square spot on the screen when the beam is stationary. Television images produced by this tube are free from distortion and accurate in tone values. The detail resolution of the pictures produced is as great in the center of the field as the number of scanning lines permits and is only slightly less in the corners.

While certain of the features of this invention are applicable to television receiver tubes, it will be appreciated that in certain of its aspects, the invention is of broader application and relates equally well to other types of cathode ray devices.

Various modifications may obviously be made without departing from the spirit of the invention, the scope of this invention being defined in the appended claims.

What is claimed is:

1. In a cathode ray device having a screen or target, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for fixing the position of said stream with respect to the aperture in said first diaphragm so that a smaller stream of more uniform cross-sectional intensity than the original stream passes through said aperture, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, means for moving said electron image with respect to said aperture in said second diaphragm in a direction transverse to the axis of the stream generating means, and means for focusing an electron image of said second diaphragm upon said screen or target.

2. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for fixing the position of said stream with respect to the aperture in said first diaphragm so that a smaller stream of more uniform cross-sectional intensity than the original stream passes through said aperture, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, and means for moving the electron image of the aperture in said first diaphragm with respect to the aperture in said second diaphragm in accordance with signals, said movement being in a direction which is transverse to the axis of said stream generating means.

3. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for forming an electron image of the aperture of said first diaphragm in the plane of said second apertured diaphragm, means for moving the electron image of the aperture in said first diaphragm with respect to the aperture in said second diaphragm in accordance with signals, and means for moving the region of maximum brightness in said electron image independently of the movement of said image.

4. In a cathode ray device having a screen or target, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for fixing the position of said stream with respect to the aperture in said first diaphragm so that a smaller stream of more uniform cross-sectional intensity than the original stream passes through said aperture, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, means for moving the electron image of the aperture in said first diaphragm with respect to the aperture in said second diaphragm in accordance with signals, said means comprising two pairs of electrostatic modulating plates, the four plates being arranged in two parallel planes, means for connecting a plate of one pair to the plate of the other pair which is in the opposite plane, means for connecting the other two plates together, and means for applying across each set of plates signal potentials, and means for focussing an electron image of said second diaphragm upon said screen or target.

5. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for fixing the position of said stream with respect to the aperture in said first diaphragm so that a smaller stream of more uniform cross-sectional intensity than the original stream passes through said aperture, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, and means for displacing in accordance with signals the electron image of the aperture in said first diaphragm with respect to the aperture in said second diaphragm in a direction transverse to the axis of the stream generating means without angular deflection of the electron trajectories.

6. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, means for concentrating said stream upon the plane of said apertured diaphragm; and deflecting means between said concentrating means and said apertured diaphragm for displacing said stream in two component directions at right angles to each other so that the center of said stream is adjusted with respect to said aperture, said deflecting means comprising means for forming both electric and magnetic fields.

7. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, a first collimator unit located between said concentrating means and said first apertured diaphragm to deflect the electrons of the stream with respect to the aperture in the first diaphragm, and a second collimator unit located between said first apertured diaphragm and said image-forming means for compensating for the angular deviation which was given the stream when it was displaced by the first collimator unit.

8. In a cathode ray device, means for gener-

ating a stream of electrons, an apertured diaphragm, means for concentrating said stream upon the plane of said apertured diaphragm, means for deflecting said beam with respect to said aperture to change the distribution of the electrons in the stream which passes through said aperture from that of the original stream, and means for compensating for the deflection produced by said deflecting means, said deflecting means and said concentrating means each comprising a pair of electrostatic deflecting plates and a pair of magnetic coils.

9. A cathode ray tube comprising a screen or target, means for generating a stream of electrons, a first diaphragm having an aperture therein, a second diaphragm having an aperture therein, means for concentrating said stream of electrons upon the plane of said first apertured diaphragm, means for fixing the position of said stream with respect to the aperture in said first diaphragm so that a smaller stream of more uniform cross-sectional intensity than the original stream passes through said aperture, means for forming an electron image of the aperture of said first diaphragm in the plane of the second diaphragm, means for moving said electron image with respect to said aperture in said second diaphragm in a direction transverse to the axis of the stream generating means, and means for projecting an image of the aperture of said second diaphragm upon said screen or target, said means for forming an electron image of the aperture in the first diaphragm in the plane of the second diaphragm and the means for projecting the image of the aperture in the second diaphragm upon the screen or target each comprising a lens system including two apertured diaphragms placed at the same potential on opposite sides of a third apertured diaphragm at a different potential.

10. A cathode ray device comprising a screen or target, a cathode, a first apertured diaphragm, a condenser lens system including two apertured diaphragms for concentrating a beam of electrons from said cathode upon the aperture in said first diaphragm, a second apertured diaphragm, a modulator lens system comprising three apertured diaphragms for forming an image of said first aperture in the plane of said second apertured diaphragm, a projector lens system comprising three apertured diaphragms for projecting an image of said second apertured diaphragm upon said screen or target, and means for connecting the second diaphragm of said condenser lens system, the two outside diaphragms of said modulator lens system and the two outside diaphragms of said projector lens system at a common potential.

11. A cathode ray tube comprising a cathode, a back electrode located behind said cathode and the following elements in order in front of said cathode: a condenser lens system comprising two apertured diaphragms, a first collimating unit, a diaphragm having a slit therein, a second collimating unit, a modulator lens system comprising three apertured diaphragms, two pairs of oppositely connected modulating plates, a diaphragm having a rectangular aperture therein, a projector lens system comprising three apertured diaphragms, two pairs of electrostatic deflecting plates, a conducting coating on the walls of the tube, and means for placing the second diaphragm of said condenser lens system, the diaphragm containing the slit, the first and third diaphragms of said modulator

lens system, the diaphragm containing the rectangular aperture, the first and third diaphragms of the projector lens system and the conducting coating all at the same potential, which potential is substantially the average of the potentials applied to the modulating plates and substantially the average of the potentials applied to the electrostatic deflecting plates.

12. In a cathode ray device, the method of operation which comprises forming a stream of electrons, concentrating said stream on an aperture in a diaphragm, fixing the position of said stream with respect to said aperture so as to fill the aperture with a beam of electrons of more uniform intensity throughout its cross-section than that of the electron stream, focusing an electron image of said aperture upon an aperture in a second diaphragm, and moving in accordance with signals the image of the first aperture with respect to the aperture in the second diaphragm.

13. In a cathode ray device, the method of operation which comprises forming a stream of electrons, concentrating said stream on an aperture in a diaphragm, fixing the position of said stream with respect to said aperture so as to fill the aperture with a beam of electrons of more uniform intensity throughout its cross-section than that of the electron stream, focusing said electron image of an aperture upon an aperture in a second diaphragm, and displacing in accordance with signals the image of the aperture in the first diaphragm with respect to the aperture in the second diaphragm without angular deflection of the electron trajectories.

14. In a cathode ray device having a screen or target, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for fixing the position of said stream with respect to the aperture in said first diaphragm so that a smaller stream of more uniform cross-sectional intensity than the original stream passes through said aperture, means for forming an electron image of the aperture in said first diaphragm in the plane of said second diaphragm, means for focussing an electron image of said second diaphragm upon said screen or target, and means for moving the electron image of the aperture in said first diaphragm with respect to the aperture in said second diaphragm in accordance with signals.

15. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, electrically responsive means for centering the beam with respect to said aperture in said first diaphragm, said centering means comprising a pair of electrostatic deflecting plates and a pair of magnetic coils, means for focussing an electron image of said first apertured diaphragm on said second apertured diaphragm, and means for causing movement of said electron image with respect to the aperture in said second diaphragm in a direction transverse to the axis of the stream generating means.

16. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, electrically

responsive means for moving the region of maximum brightness of said beam with respect to the center of said aperture in said first diaphragm, means for focussing an electron image of said first apertured diaphragm on said second apertured diaphragm, and means for causing movement of said electron image with respect to the aperture in said second diaphragm in a direction transverse to the axis of the stream generating means.

17. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, electrically responsive means for moving the region of maximum brightness of said beam with respect to the center of the aperture in said first diaphragm, means for compensating for the deflection produced by said moving means, means for focussing an electron image of said first apertured diaphragm on said second apertured diaphragm, and means for causing movement of said electron image with respect to the aperture in said second diaphragm in a direction transverse to the axis of the stream generating means.

18. A cathode ray device comprising means for generating a beam of electrons, a first apertured diaphragm, means for concentrating a beam of electrons from said cathode upon the aperture in said first diaphragm, means for centering said beam with respect to the aperture in said first apertured diaphragm so that the intensity of the beam after passing through said aperture is made more uniform throughout its cross-section, a second apertured diaphragm, a modulator lens system for forming an image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, means for deflecting the electron image of the aperture in the first apertured diaphragm with respect to the aperture in said second diaphragm in accordance with signals, a screen or target, means for projecting an electron image of the aperture in said second apertured diaphragm upon said screen or target, and means for deflecting said electron image with respect to said screen or target in accordance with scanning signals.

19. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, means located between said concentrating means and said first apertured diaphragm to deflect the electrons of the stream with respect to the aperture in the first diaphragm, and means located between said first apertured diaphragm and said image forming means for compensating for the angular deviation which was given the stream when it was displaced by the first deflecting means.

20. In a cathode ray device, means for generating in a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, and means for deflecting the electrons of the stream with respect to the aperture in the first diaphragm, said means com-

prising apparatus for deflecting the beam in two component directions at right angles to each other.

21. In a cathode ray device having a screen or target, means for generating a stream of electrons, an apertured diaphragm, a second apertured diaphragm, means for concentrating said stream upon the plane of said first apertured diaphragm in such a way that said aperture allows the passage of only the central portion of said beam so that the portion of the beam which passes through the aperture is of more uniform cross-sectional intensity than the original stream, means for forming an electron image of the aperture in said first diaphragm in the plane of said second apertured diaphragm, means for moving said electron image with respect to said aperture in said second diaphragm in a direction transverse to the axis of the stream generating means, and means for focussing an electron image of said second diaphragm upon said screen or target.

22. In a cathode beam device, means for producing a beam of electrons, an apertured element, means for concentrating said beam of electrons in the plane of said aperture, said

beam at said plane being larger than said aperture, means for producing a small lateral displacement of said beam in any desired direction at said plane to permit a selection of a portion of the beam for passage through said aperture which will result in an emergent beam of maximum uniformity of cross-sectional intensity distribution, and control means for the emergent beam the proper functioning of which is dependent upon the cross-sectional intensity distribution of the beam.

23. In a cathode beam device, means for producing a cathode beam, an apertured element, means for concentrating said beam in the plane of the aperture of said element, said beam being larger at said plane than said aperture, a second apertured element, adjustable means cooperating with said first apertured element for producing any desired lateral displacement of said beam at said plane to permit the selection of a portion thereof for passage through said aperture which will have maximum uniformity of cross-sectional intensity distribution and for directing said emergent beam to the aperture of said second apertured element.

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