Oct. 8, 1940.

C. J. DAVISSON

2,217,197

CATHODE RAY DEVICE

Filed Dec. 30, 1936

2 Sheets-Sheet 1

FIG. 1

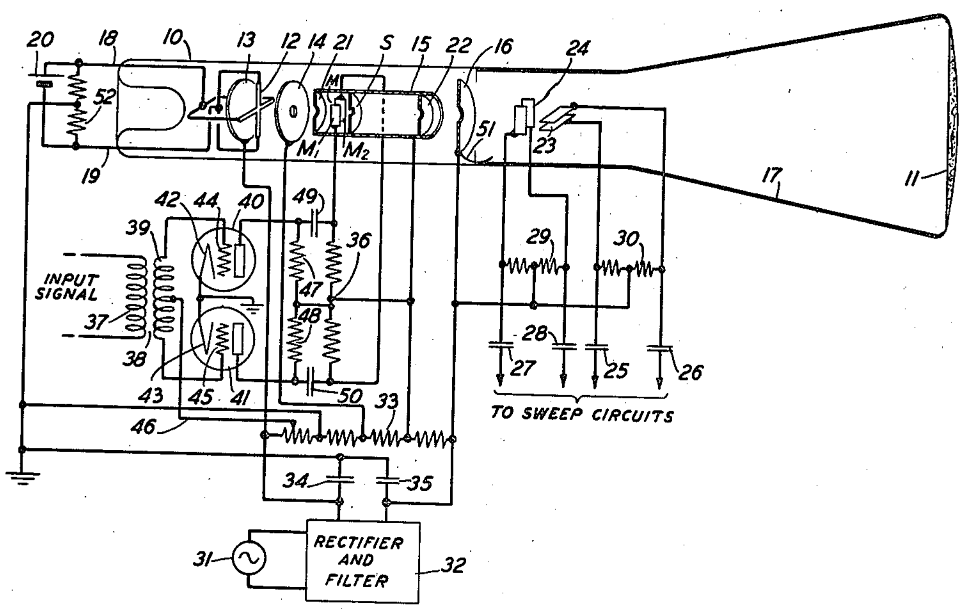
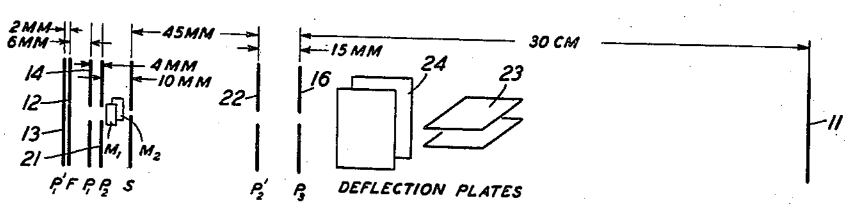


FIG. 2



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2 Sheets-Sheet 2

FIG. 3

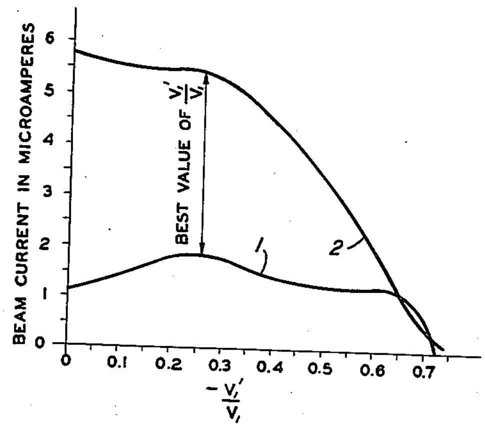


FIG. 4

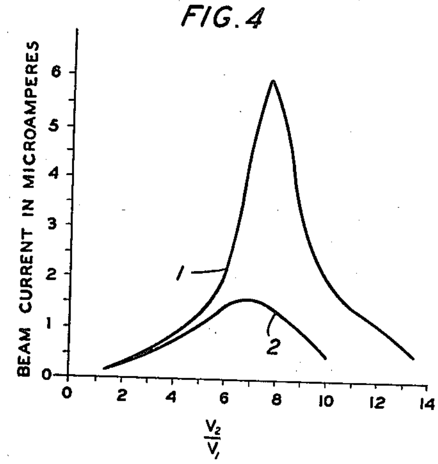


FIG. 5

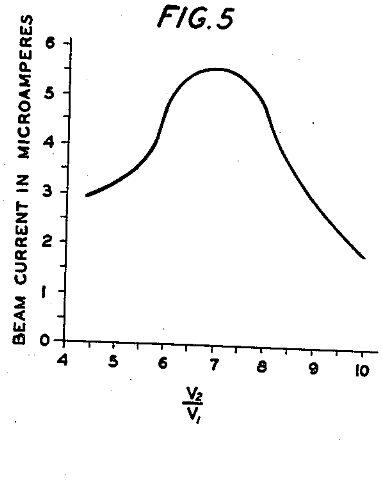
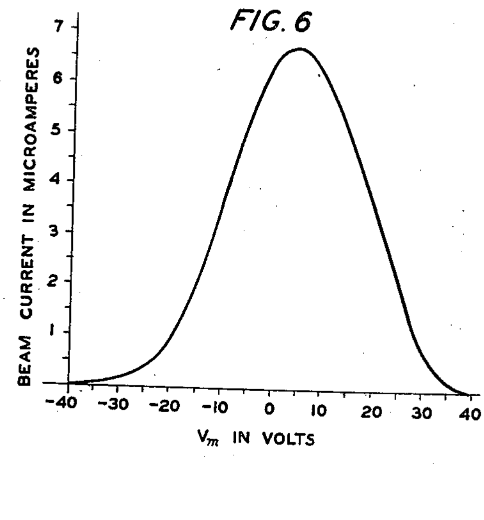


FIG. 6



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UNITED STATES PATENT OFFICE

2,217,197

CATHODE RAY DEVICE

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Application December 30, 1936, Serial No. 118,277

24 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 electron beams in cathode ray devices.

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 gun system for a cathode ray device.

A further object of this invention is to provide an electron lens system in which apertured plates are used throughout for focussing the beam.

A still further object of this invention is to provide a novel modulating system for electron beams in cathode ray devices.

A feature of this invention is that within the electron lens system a field free space is defined, in which region the cathode ray beam is modified.

Another feature of this invention is that a condensing electron lens system is provided for concentrating an intense electron beam upon the plane of a diaphragm having a square aperture therein and a projecting electron lens system is provided for forming an electron image of this aperture upon a screen or target.

For illustrating a practical application of the invention, there is hereinafter described in detail a tube which may be briefly characterized as a high vacuum cathode ray device electron optically designed for use as a receiver for a 72-line television image. It is to be understood that the invention in its various aspects is not limited in its application to any specific type or form of cathode ray device but is of quite general application.

Investigation has disclosed that ideally such a cathode ray receiver as that just mentioned would employ a uniformly bright square spot, modulated in brightness but not in area. It would have a linear brightness versus modulating voltage relationship over a range at least a factor of thirty below maximum brightness, and likewise a linear deflection versus deflecting voltage relationship over the range determined by the field of the image. Further, there would be no distortion of the spot due to deflection nor deflection of the spot by modulation. The size of the image would be n times the size of the spot, n being the number of lines, so that when the image field is illuminated without modulation, a uniform field would be obtained without evidence of line structure. Moreover, the image would be approximately as large as the fluorescent screen permits so that the size of S of the spot is given by the equation:

$$S=\frac{D}{\sqrt{2n}}$$

where D is the effective screen diameter. Finally, provision would be made for adjusting brightness in operation without changing the linear modulation characteristics, maximum brightness being as great as possible. The present invention sufficiently well meets these ideal requirements.

Briefly stated, the electrode structure of the television receiving tube mentioned above is as follows:

A cross-shaped filament serving as a cathode is located between and parallel to a back electrode and an accelerating focussing electrode. A negative potential with respect to that of the cathode is applied to the back electrode and a positive potential is applied to the first accelerating electrode, the effect of which is to produce a uniform field between the two members to cause the electrons emitted from the four arms of the cross-shaped filament to traverse paths which are substantially parallel to the optical axis of the tube. Three diaphragm members are located in a metallic cylinder forming a second accelerating anode. The potential of this second accelerating anode is placed at a value which is positive with respect to that of the first accelerating anode. A third accelerating anode comprising an apertured diaphragm is placed at a potential which is positive with respect to that of the second accelerating anode and is electrically connected to a conducting coating on the inside walls of the tube. The distances of the first accelerating member and the first and second diaphragms of the second accelerating member from the cathode and the relative potentials applied thereto are calculated so as to cause electrons from the cathode to be focussed in the plane of the middle diaphragm of the second accelerating member. The final diaphragm of the second accelerating member (with respect to the position of the filament) cooperates with the third accelerating electrode to form a projection lens system to focus an electron image of the aperture in the middle diaphragm upon a screen or target. The beam is modulated by a pair of modulating plates which vary the number of electrons incident upon the aperture in the middle diaphragm of the second accelerating anode in accordance with the amplitudes of signals received from a transmitting station. The beam is deflected in such a manner that it scans every elemental area of the field of the target or screen in turn by means of two pairs of electrostatic deflection plates to each pair of which is applied a voltage of saw-tooth wave form of the proper frequency to produce this result.

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 diagram of a television receiving tube and its associated circuits which embody this invention;

Fig. 2 is a schematic diagram showing the relative spacing of the various elements of the electrode system in the tube shown in Fig. 1; and

Figs. 3 to 6, inclusive, are graphical representations used to explain the operation of this invention.

Referring more specifically to the drawings, Fig. 1 shows a cathode ray tube and its associated circuits for use as a television receiving device. This tube comprises a gas-tight envelope **10** containing an electron gun assembly for generating, focussing and accelerating a beam of electrons, means for modulating this beam, and means for deflecting the beam so that it traverses every elemental area of a field of view on a fluorescent screen **11** located at one end of the tube.

The electron gun arrangement comprises a cathode **12**, a back plate or electrode **13**, a first accelerating anode **14**, a second accelerating anode **15**, and a third accelerating anode **16** which is electrically connected to a conducting coating **17** located on the inside walls of the tube. Broadly speaking, the electron gun arrangement comprises two electron focussing or lens systems of the electrostatic type, one a condensing lens system for concentrating a beam of electrons generated by the cathode **12** upon the aperture in the metallic diaphragm S which is located in the metallic anode cylinder **15**, and a projection lens system for projecting an image of this electron "illuminated" aperture upon the screen or target **11**. Preferably the shape of the aperture in the diaphragm S is made square or rectangular.

The cathode **12** 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 electrically connected together and terminals **18** and **19** connected to a suitable source of heating current **20**. A resistance **52** is also connected across terminals **18** and **19**, the mid-point of which is connected to ground. By this method of 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 element similar to the one described above, reference may be made to Patent 2,117,-709, issued May 17, 1938 to C. J. Davisson.

The back electrode **13** comprises a circular plate spaced a short distance from the cathode **12** and parallel thereto. The first accelerating electrode **14** comprises an apertured circular plate which is located on the side of the cross-shaped cathode element remote from the back electrode **13**. A positive potential with respect to that of the cathode is applied to the first accelerating anode **14**, while a negative potential with respect to that of the cathode is applied to the back electrode **13**. In order to produce a uniform field between the back electrode **13** and the first accelerating anode **14**, the spacings of these members **13** and **14** from the cathode **12** are so chosen with respect to the respective potentials applied thereto that the ratio of these potentials is equal to the ratio of their respective distances from the cathode. The second accelerating anode **15** comprises a metallic cylinder having (starting at the end nearer the first accelerating anode **14**) three circular apertured diaphragms **21**, S and **22**. The second accelerating anode **15** has applied thereto a positive potential with respect to that of the first accelerating anode **14**. This potential and the spacing and aperture sizes of the diaphragms of the members **15** and **14** are so chosen that the electron beam is brought to a focus in the plane of the apertured diaphragm S. The relative spacings and potentials applied to the various electrode members will be considered more fully below.

The third accelerating anode **16**, which preferably comprises a metallic circular plate having an aperture therein, is placed at a positive potential with respect to that of the second accelerating anode **15**. The potentials applied to the members **15** and **16** and the distance between them is so chosen that an electron image of the aperture in the plate S is formed on the fluorescent screen **11**, which may be of any suitable fluorescent material such as, for example, willemite. The third accelerating anode is electrically connected inside the tube to the conducting coating **17** which serves to make a field free space between the anode **16** and the fluorescent screen **11** and at the same time to serve as a return path for the electrons impinging upon the fluorescent screen **11**.

In order to cause the electron beam generated by the electron gun apparatus described above to scan every elemental area of the field of view on the screen or target **11** in turn, suitable deflecting means, such as, for example, two pairs of deflecting plates **23** and **24**, the axes of which are located at right angles to each other, are provided. To the deflecting plates **23** are applied deflecting voltages of framing frequency (20 cycles) and of saw-tooth wave form to produce the vertical deflection, while deflecting voltages of line scanning frequency (1440 cycles) and of saw-tooth wave form are applied to the deflecting plates **24** to produce horizontal deflection of the beam. Any suitable sweep circuits (not shown) may be used to generate these horizontal and vertical deflection voltages. For example, reference may be made to Patent 2,178,464, issued October 31, 1939 to M. W. Baldwin, Jr., which discloses a suitable balanced sweep circuit for this purpose. Connections may be made from the balanced sweep circuits to the pairs of plates **23** and **24** by means of coupling condensers **25** and **26** and **27** and **28**, respectively, of about 1 microfarad capacity each. Coupling resistances **29** and **30** of the order of 20 megohms each are respectively connected across the pairs of plates. The mid-points of the resistances **29** and **30** are connected to the third accelerating anode **16** in order that the average potentials of the deflecting plates do not deviate from the potential of the third accelerating anode **16** and thus introduce distortion of the beam with the consequent distortion of the image which would be caused by a change in the velocity of the beam. For a full description of the advantages of balanced sweep circuits in cathode ray television devices, reference may be made to the above-mentioned Baldwin patent and also to Patent 2,209,199 issued July 23, 1940 to Frank Gray, Serial No. 65,606.

The direct current potentials for biasing the different elements of the electron gun are preferably derived from an alternating current oscillator **31**, the output of which is rectified and filtered by any suitable device represented schematically on the drawings by the block **32** which has in its output circuit a potentiometer resistance **33** of about 1 megohm having a plurality of taps from which the various voltages may be taken. An alternating current ground is provided for the external terminals of the potentiometer resistance **33** by means of condensers **34** and **35** of about 1 microfarad each which are connected between these terminals and ground.

Modulation of the electron beam generated by the apparatus described above is achieved by applying signals between a pair of modulating plates M_1 and M_2 which are located in a field free space determined by the cylinder **15** and the diaphragms **21** and S, all of these elements being placed at the same potential. The potentials applied to these modulating plates are balanced with respect to the potential of the cylinder **15** by means of a resistance **36** of the order of 200,000 ohms, the mid-point of which is connected to the cylinder **15**, and a balanced modulating circuit is connected to the terminals of the resistance **36**. An input signal is applied (after demodulation by a suitable circuit or circuits) to the primary winding **37** of a transformer **38**, the secondary winding **39** of which is connected to the input circuit of two tubes **40** and **41** which are connected in push-pull manner to produce a balanced output. The cathodes **42** and **43** of the tubes **40** and **41** are connected to ground. A negative bias is applied to the grids **44** and **45** by means of a connection **46** from the mid-point of the transformer secondary winding **39** to a point on the potentiometer resistance **33** which is negative with respect to the tap representing ground potential. The output circuits of the tubes **40** and **41** include resistances **47** and **48** of about 5,000 ohms each, the common terminal of which is connected to the mid-point of the resistance **36**. The output of the tubes **40** and **41** is applied to the modulating plates M_1 and M_2 through coupling condensers **49** and **50** of about 1 microfarad capacity each.

By means of the arrangement described in the preceding paragraph, the average of the potentials applied to the modulating plates M_1 and M_2 is at all times equal to the potential applied to the accelerating anode **15** and hence to that of the diaphragms **21** and S which are connected to the metallic cylinder. Modulation is thus achieved in a field free space except for the variations introduced by the changes in the potentials applied to the modulating plates; that is, if the average of the potentials applied to the plates is always equal to the potential of the diaphragms at both ends of the plates there is no acceleration imparted to the beam while it is being modulated.

Modulation is achieved by deflecting the electron beam more or less upon the square hole in the apertured diaphragm S. Electrons are deflected towards the more positive of the modulating plates M_1. By thus controlling the number of electrons incident upon the square hole in the apertured diaphragm S, modulation of the brightness of the beam can be achieved. The cross section of the beam at the square aperture in the plate S has, of course, an unequal distribution, as explained eleswhere herein, the distribution being a maximum at the center and theoretically falling off to zero at infinity. Strictly speaking, therefore, the beam is never fully deflected off the aperture and the distribution within the aperture is never exactly uniform. This unequal distribution, however, is rarely, if ever, discernible to the observer viewing the image screen.

Specific details of the tube generally described above will now be given in order to fully describe a tube which has been used in practice. A square hole in the plate S was made equal to .006 inch by punching. So far as a square spot on the fluorescent screen in concerned, its source is this .006 inch hole and what happens to the electrons before they reach the hole has no effect upon the size and shape of the image produced on the fluorescent screen by the projector lenses in the diaphragms **22** and **16**. The optical analogue is the projection lantern. The inside wall of the Pyrex glass cylinder is coated with aquadag and this coating **17** is shown connected to member **16** by a spring **51** which is released by burning out a filament during pumping. During the sealing-in process this spring should not be permitted to scrape against the aquadag.

As an aid to visualizing the electrode assembly, it should be mentioned that between the cylinder **15** and the element **16** and between pairs of elements **13** and **14** and **14** and **15** are placed cylindrical glass insulators (not shown) of the same diameter, which diameter is somewhat greater than that of the element **15** and less than that of the other elements. The electrode structure is supported on three metal rods passing through peripheral apertures in elements **13**, **14**, and **16** and a flange or flanges (not shown) on element **15**. These rods are bolted to a metal band which is clamped to the base of the tube. Referring to Fig. 2 it will be seen that the electrically independent parts are the back electrode **13** (designated in Fig. 2 as P_1'), the filament F, the first accelerating anode P_1, the second accelerating anode comprising the apertured diaphragms P_2, S and P_2' (which are all placed at the same potential), M_1 and M_2, the third accelerating anode P_3 (which is electrically connected to the aquadag conducting layer **17**) and each of the four deflecting plates. Thus a total of twelve leads is required. All metal parts are aluminum, except P_1 which is of nickel and the filament F which is of tungsten. Metal flanges protect the cylindrical insulators which prevent or render harmless the accumulation of charges.

The tube is thoroughly pumped. It is impractical to degas the metal parts by high frequency, but the tube is baked for several hours at 460° C.; parts adjacent the filament are heavily bombarded; and the tube is finally sealed off from the pumps at a temperature of about 100° C. and a pressure of 7×10^{-7} millimeters of mercury.

The proper values of the potentials applied to the various electrode members and the distances of these members from each other will now be considered.

The principal physical consideration made use of in arriving at the design of the television receiver tube described above is that in an axially symmetrical electric field the convergence of a paraxial beam of electrons satisfies the differential equation

$$\frac{dc}{dz}=c^2-\frac{cV'}{2V}+\frac{V''}{4V}$$

Before defining the symbols in this equation it will be well to state that "beam" in the foregoing sentence has a special restricted meaning and to explain what this meaning is.

Let it be imagined that electrons are streaming along the axis of an axially symmetrical field—not necessarily all on the axis but near it. If they have all come from the same emitting surface their speeds as they cross any given plane normal to the axis will be sensibly the same. Their trajectories will not, in general, be straight lines. If we draw tangents to their trajectories at the points at which they cut a given plane these will not, in general, meet in a point. If they do meet in a point the stream of electrons constitutes a "beam" in the sense in which the word is here used. The point of meeting may be in front of the plane (in the direction of motion of the electrons) or back of it; it may be on the axis or off it. The only requirement is that the tangents meet in a point on or near the axis. If this condition is satisfied the stream of electrons is a single "beam". It can then be said "once a beam always a beam". It follows from certain theoretical considerations that if the tangents drawn at one cross-section meet in a point then the tangents drawn at all other cross-sections also meet in a point. The convergence of the beam at any given cross-section is defined as the reciprocal of the distance from the cross-section to the point at which the tangents meet, and this is the quantity which is represented by the above equation symbol c.

The convergence of a beam may be either positive or negative. If at a given cross-section the tangents are parallel, the convergence of the beam at this cross-section is zero. If the trajectories are intersecting one another at a given cross-section, the distance from the plane to the point of intersection of the tangents is zero and the convergence of the beam is infinite.

No actual stream of electrons is strictly speaking a single beam. If the stream originates at a themionic cathode the electrons leave the cathode with small initial speeds variously directed. The tangents to their trajectories at the emitting surface do not meet in a point and it follows from theoretical considerations already alluded to that at no cross-section will they meet in a point.

If, however, not all of the electrons in the stream are considered but only those which leave a given very small element of the cathode, it is clear that these constitute a beam at their point of origin, since here the tangents intersect. This being true they constitute a beam at all cross-sections further along their paths. The whole stream of electrons which travels along the axis of the field is an assemblage of such elementary beams originating at the cathode, or may so be regarded.

There are, however, other ways of regarding the stream. The electrons which leave a flat cathode in some particular direction may be thought of as constituting a beam. They form a beam of definite convergence at the cathode—namely, zero—and so have a definite convergence elsewhere along their path. The whole stream may be regarded as an assemblage of beams of this kind if desired.

What the differential equation does is to show how the convergence of a beam—any beam—varies along the axis of an axially symmetrical electric field.

Let c stand for the convergence of the beam at the cross-section through the point z on the axis, z be the distance along the axis measured from any origin, but ordinarily from the cathode, and V be the potential of the field at the point z on the axis relative to the potential of the cathode which is ordinarily assigned the value zero. Then $V'=dV/dz$, (the first derivative of V with respect to z), and $V''=d^2V/dz^2$, (the second derivative of V with respect to z). What the differential equation says is that at every point along the axis the first derivative of the convergence of a beam (dc/dz) is equal to $c^2-cV'/2V+V''/4V$, where the quantities in this expression are those for the particular point or particular cross-section (particular z) under consideration. The equation is derived from the fundamental laws of electrodynamics. It applies to every beam no matter how constituted and whether on the axis or somewhat off.

If the value of V at all points along the axis is known, that is, if V is known as a function of z, $(V=f(z))$, this function can be written into the general equation and thus a particular differential equation in terms of c and z can be obtained. The solution of this equation will be of the form $F(c,z)=$a constant. It will show the convergence of any beam at any value of z in this particular field, provided only its convergence at some one value of z is known. A beam may, of course, have any convergence at any value of z, but once its convergence at one value of z is fixed, its convergence at every other value of z is fixed. Mathematically this amounts to fixing the value of the constant in the equation $F(c,z)=$a constant. If it is known that at z_1 the convergence of the beam is c_1, then the constant is $F(c_1,z_1)$. $F(c,z)=F(c_1,z_1)$ then describes a particular beam in the particular field.

Thus in the cases considered, the beams starting from elements of the cathode are beams in which the convergence is $-\infty$ at $z=0$; thus $c_1=-\infty$, $z_1=0$. The beams made up of electrons leaving along parallel lines are beams of zero convergence at $z=0$.

Axially symmetrical fields are produced by applying potentials to electrodes which are coaxial figures of revolution—such as plates containing circular holes, cylinders, etc., strung along a common axis. When the configuration of the electrodes is fixed and the potentials applied to them are known, the potentials at points along the axis $V=f(z)$ can (in principle) be calculated. Replacing V in the general differential equation by $f(z)$ the appropriate differential equation in c and z is obtained. Solving this and evaluating the constant of integration, a description of the beam is obtained.

Let there now be considered any set of parallel plates containing not too large circular holes. It can be shown that when a beam passes through the field about a hole in an arrangement of this kind, its convergence is increased by an amount $\Delta c=(V_2'-V_1')/4V$, where V is the potential of the plate and V_2' and V_1' are the values of dV/dz on the emergence and incidence sides of the plate respectively—more strictly V_2' and V_1' are the values dV/dz would have on the two sides of the plate if the diameter of the holes were reduced to zero.

When a beam of light passes through a lens of focal length f its convergence is increased by an amount $1/f$. It is natural therefore to regard the field about a hole in a plate as a lens for electrons of focal-length $f=4V/(V_2'-V_1')$.

This fact was pointed out in two notes by applicant in the Physical Review for 1931.

The calculations for a beam traveling along the direction of a uniform field such as occurs between the plates in the arrangement being considered may also be carried through. It is found that in such a field the convergence of a beam varies along its length in such a way that

$$\frac{1}{cV^{1/2}}+\frac{2V^{1/2}}{V'}=\text{a constant}$$

Thus if adjacent plates in the arrangement being considered are at $z=z_2$ and $z=z_1$, and if their potentials are V_2 and V_1, V' between the plates will have the value $(V_2-V_1)/(z_2-z_1)$. If a beam entering the region through a hole in plate P_1 has a convergence c_1, then, by the law just stated, it will have at the second plate convergence c_2, such that

$$\frac{1}{c_2V_2^{1/2}}+\frac{2V_2^{1/2}}{V'}=\frac{1}{c_1V_1^{1/2}}+\frac{2V_1^{1/2}}{V'}$$

These two laws, the lens law and the law just stated are all that are required to calculate the convergence of a beam at any point along its path through any number of plates at any assigned potentials—provided, of course, its convergence at some one value of z is known.

Thus let it be supposed that the cathode is a flat surface normal to the axis of the field. All electrons which leave this surface normally (with zero lateral components of initial velocities) might be considered as a beam. These constitute a beam of convergence zero at $z=0$. In the field to the first plate the convergence will change in such a way as to keep

$$\left(\frac{1}{cV^{1/2}}+\frac{2V^{1/2}}{V'}\right)\text{ constant}$$

The value of this expression at the emitting surface is infinite since at this surface $c=0$, $V=0$ and $V'>0$. The value of the expression is therefore infinite at all points along the beam in this region and the only way this can be is for c to remain zero. The trajectories are straight lines parallel to the axis.

When the beam passes through a hole in the first plate, its convergence is increased by an amount $\Delta c=(V_2'-V_1')/4V_1$ as already explained. The convergence of the beam is increased from $c=0$ to $c=\Delta c$. In the second region the convergence again satisfies the law

$$\frac{1}{cV^{1/2}}+\frac{2V^{1/2}}{V'}=\text{constant}$$

The value of the constant is obtained by using the known value of the convergence of the beam as it enters the region. Applying the law, the convergence of the beam at the second plate is now calculated and then its convergence after passing through the second plate and so on through as many plates as is desired.

The beam being considered is that composed of electrons which leave the flat cathode normally (without initial lateral velocity). The beam composed of all the electrons leaving a small surface element might have been considered instead. In this case the convergence of the beam at $z=0$ is $-\infty$ instead of zero. The calculations are carried through as in the previous case, but the convergences found for the beam are, of course, everywhere different.

It is important to understand how these two kinds of beams are related, the beam of normally emitted electrons on the one hand, and the beams emitted from small surface elements on the other. It is clear that a beam of the latter type shares some electrons with the normally emitted beam; all of the electrons emitted normally from a given small surface element belong naturally to both beams. Not only is this true, but it is also true that of all of the electrons emitted from the small element, those emitted normally are in a way the most important. The reason is that the initial energies of the emitted electrons are small compared to the energy they acquire in the field only a short distance from the cathode. Because the initial energies are comparatively small, the paths or trajectories traversed by the electrons from a small element are none of them so very different from what they would be if the initial velocities were zero. The actual trajectories all lie close to the trajectories of an electron which leaves the element from rest. This is particularly true of the trajectories of electrons which leave the element with normal initial velocity, but no lateral velocity, for these start off from the surface in the same direction as that taken by an electron initially at rest.

It is because of these considerations that the electrons emitted from a surface element, although they leave the element in all possible directions, are, at a short distance from the cathode, formed into a narrow beam. At the center of this elementary beam are the electrons which left the surface normally. The elementary beam is not, however, sharply bounded. The situation is rather this, that the electrons emitted normally from the element follow a certain trajectory through the field, being near the axis of the field in some places, further from it in others, and perhaps at certain points crossing it. The trajectories of the other electrons emitted from the same element cluster about this principal trajectory. The density of these other trajectories is greatest at the center of the cluster, declines and approaches zero asymptotically with distance from the center. It is a probability distribution, like bullet marks about the bull's-eye of a target and for this reason not sharply bounded.

It is important to realize that these trajectories which cluster about the principal trajectory are the trajectories of the beam of electrons which leave the small element. Where the convergence of this beam goes to infinity, the cluster contracts to a point, all trajectories of the cluster pass through a point and this point is, of course, on the principal or central trajectory.

The trajectories of normally emitted electrons are all principal trajectories, each is the principal trajectory of all trajectories starting from some surface element. Thus, one way of describing the whole stream of electrons is to give the convergence of the beam of normally emitted electrons for every value of z and in addition to give the convergence of the elementary beams also for every value of z. All elementary beams have the same convergence at a given value of z but never the same convergence as the beam of normally emitted electrons, the beam of electrons pursuing principal trajectories. It is impossible, for example, to make both convergences infinite at the same value of z. It is impossible, for this reason, to bring all of the electrons from an extended cathode to a point focus. The principal trajectories can be made to pass through a point, but where this happens the convergence of the elementary beams is not infinite. The convergence of the elementary beams can be made infinite, but where this happens the principal trajectories are spread out, and do not come to a focus.

This latter condition is that in which a real image of the emitting surface is formed. The elementary beams are brought to a focus (convergence made infinite) on a fluorescent screen; the electrons which started from a small element of the cathode are brought together on a small element of the screen, but where this happens the beam of principal trajectories is necessarily not focussed. It is spread out, and the effect is to produce on the screen an extended image of the cathode.

In the other condition, that in which the principal trajectories are brought together, the unfocussed elementary beams are superposed. The whole assemblage of elementary beams is reduced to the "cross-section" of a single elementary beam. The whole stream of electrons is as well focussed as possible.

A focus of this kind is produced in the receiver tube described above at the square aperture in the diaphragm S. The arrangement of ribbon filament, backing plate and apertured lens plates is designed to produce an intense focal spot in the plane of the square aperture.

The primary consideration in the design of this part of the tube is to arrange for a crossing of the principal trajectories in this plane. Further back, it was explained how the convergence of a beam at any point or cross-section along the axis of a field determined by any set of arbitrarily disposed plates containing circular holes can be calculated, the plates being at any potentials. While this is possible, it is not actually done. A person really starts with the idea of bringing the principal trajectories to focus somewhere out along the axis, and seeks as general expressions as possible for the positions and potentials of lens plates which will produce this result. It is found that the suitable conditions are not at all unique. It is found that there must be at least two lens plates if the focus is to be produced in a field free space. But it has been discovered that the plates may be anywhere at all between the filament and the point of focussing. No matter where they are placed the principal trajectories will cross at the chosen point when appropriate potentials are applied to the plates, or rather when the potentials applied to the plates have an appropriate ratio.

For best results, certain other factors need to be taken into consideration. One of these is that $(V_1^{3/2}/z_1^2)$ must not have too low a value or trouble will be encountered with space charge (V_1 is the potential of the first plate and z_1 its distance from the filament). Another is the maximum current density in the focal spot. The choice of geometry must be such as to have this as high as possible. Still another is the matter of the solid angle occupied by the electrons which pass through the square aperture. There is no point in getting a great lot of electrons through the square hole if they are going to be spread over a solid angle much greater than that subtended by the lens which is designed to form them into an image on the fluorescent screen. There is also the question of the convergence of the elementary beams. The arrangement should be such, if possible, that the elementary beams enter the field free region with a positive convergence. This is needed to make the focal spot small and also to avoid enlarging the solid angle occupied by the electrons beyond the square hole. There is also the requirement that sufficient room be left between the second lens plate and the square hole to accommodate the modulator plates. The field between these moves the focal spot off and on the square hole. Besides the geometry of the condenser system there is also the question of its scale.

Considering now the beam from the plane of the square hole to the screen, this hole is effectively a new source just as in light optics. An entirely new set of beams is set up. The elementary beam from this point onward is made up of the electrons which stream through a given small element of the aperture. At the aperture it is a certain distance off the axis of the system and has a convergence of $-\infty$.

There is now no principal trajectory. The electrons in these new elementary beams are distributed more or less uniformly in a solid angle only slightly larger than that subtended by the projector lens, toward which they are directed.

The design of the projector lens is based on the same considerations as were previously used in the design of the condenser lens system. Quite a large lens aperture is used in order to gather in all of the electrons which come through the square hole, but if the aperture is too large a poor image of the square hole is produced on the screen because of lens aberration of one sort or another.

The projector lens is really a combination of two lenses, one rather weak lens (P_3) and one strong positive lens (P_2'). The apertures are adjusted to make the F-number of each lens as great at least as 7 or 8. This is about the F-number (ratio of focal length to diameter) of the positive lens. The F-number of the negative lens is greater. From previous experience it is known that a lens of the type here used of F-number 7 or 8 produced sharp images.

Regarding the magnification of the projector system what is wanted on the screen is a spot 30 mils square. This means that the square aperture of which the spot is an image must be 30/M mils square, where M is the magnification of the projector lens system.

The really important quantitatively expressed relationships which have been exactly applied in the making of tubes in accordance with this invention are:

(I) That the field about a circular hole in a plate is, for electrons, a lens of focal length

$$f=4V/(V'_2-V'_1)$$

and

(II) That in a uniform field the convergence of a beam of electrons traveling parallel (or anti-parallel) to the direction of the field, or nearly so, varies in such a way that the expression

$$\left(\frac{1}{cV^{1/2}}+\frac{2V^{1/2}}{}\right)$$

remains constant.

These laws are deduced from the general differential equation

$$\frac{dc}{dz}=c^2-\frac{c}{2V}\frac{dV}{dz}+\frac{1}{4V}\frac{d^2V}{dz^2}$$

which in turn is derived from the fundamental principles of electrodynamics.

It should be mentioned that it has been assumed in the design of the tube that the electrons emitted from the cathode have initially a Maxwellian distribution of velocities and an average energy $\bar{\epsilon}=2kT$, where k is Boltzmann's constant and T the cathode temperature. This is the usual assumption in circumstances of this kind. It is made use of in calculating the "cross-sectiton" of the elementary beams, in particular the "cross-section" of these beams in the plane of the square hole where it becomes the "cross-section" or "size" of the focal spot.

In the tube described above, electrons from the filament pass through circular holes of 1.5 millimeters diameter in plates P_1 and P_2, which constitute the condensing lens system. The potential V_1' of plate P_1' is adjusted so that

$$-V_1':V_1=Z':Z_1$$

where Z refers to the distance from the filament. Then when $V_2:V_1>Z_2:Z_1$, the hole in plate P_1 constitutes a positive electron lens and that in plate P_2 a negative electron lens. As previously discussed, it is possible to calculate the electron distribution on the plane S for any voltage ratio and geometry. More usefully, it is possible to calculate the geometry required to give a maximum intensity-at-peak of the electron distribution on S, subject to the restriction that all of the electrons incident on the square hole shall be limited to a certain angular spread about the axis, such that they will also pass through the circular hole in plate P_2', which constitutes the first lens of the projector system. There is the further restriction that the magnification of the projector lens system shall be about 5 which, in conjunction with the overall length of the tube helps to determine the distance between S and P_2'; and also a restriction is imposed on the F-numbers of the projector lenses. Finally, there are the restrictions of space charge limitation of emission from the filament, and, perhaps, of power dissipation by plate P_1 which, however, is not a limit in this tube. The geometry of Figs. 1 and 2 is an optimum design, the only more or less arbitrary restriction being that on the F-numbers of the electron lenses. The recommended spacing between the elements of the electron gun, as shown in Fig. 2, is as follows; between the back electrodes P_1' and the filament F, 2 millimeters; between the filament F and the first accelerating anode P_1, 6 millimeters; between the first accelerating anode P_1 and the diaphragm P_2 of the second accelerating anode, 4 millimeters; between the diaphragm P_2 and the diaphragm S, 10 millimeters; between the diaphragm S and the diaphragm P_2', 25 millimeters; between the diaphragm P_2' and the apertured diaphragm P_3, comprising the third accelerating anode, 15 millimeters; and between the third accelerating anode P_3 and the fluorescent screen **11**, 30 centimeters. With these spacings and with voltage ratios which will be given below, a very fine intense spot is produced on the fluorescent screen **11**.

The remaining design problems are those of the modulating plates and of the deflecting plates. The former are made as large as geometry will permit and are adequately spaced; their sensitivity will be discussed below. The latter find their sensitivity fixed by the distance to and the diameter of the fluorescent screen.

The diameters of the circular plates have not been mentioned for the reason that these are not critical.

In operation, the potentials V_1, V_1', V_2 and V_3 are supplied from the alternating current rectifier **31** which is connected to the voltage divider circuit **33** of about 1 megohm total resistance. Changes in output voltage do not change voltage ratios, except temporarily due to condensers in the circuit. Electron optical solutions are always in terms of voltage ratios; changes in absolute value over wide ranges of voltage do not affect the electron focussing.

The focussing ratio

$$\frac{V_3}{V_2}$$

for the projector lens system is 4.2. This was determined by visual observation of the spot at low intensity, that is, with filament current low. This ratio is not dependent upon any other factor, either number of electrons in the beam, absolute value of voltage, or other voltages, such as V_1, V_1', or modulating and deflecting voltages, within the limits of operation of these factors.

The correct voltage ratio

$$\frac{-V_1'}{V_1}=\frac{Z_1'}{Z_1}$$

is similarly practically independent of all other factors. By geometry

$$\frac{Z_1'}{Z_1}=\frac{1}{3}$$

approximately, but a slight filament displacement can make relatively large changes in the ratio, and it appeared that the correct ratio was about ¼. At about this ratio the current i_1 to plate P_1 is but half of the total filament emission (temperature-limited), a condition usually satisfied. The shape of the i_1 versus V_1' curve confirms the value ¼, and visual observation of short images of the filament, which may be formed on the screen if desired, also leads to the value of ¼. But in any event, for the spot, what happens between the filament and S is of no importance. The criterion is that maximum beam current should be obtained and the secondary consideration is that i_1 should be as small as practicable to reduce the power dissipated on the plate P_1. Fig. 3 shows beam current as a function of

$$\frac{-V_1'}{V_1}$$

for (1) temperature limited and (2) space charge limited emission. It will be seen from these curves that a value of

$$\frac{-V_1'}{V_1}$$

of approximately 0.25 or 0.26 is the optimum value.

It seems advisable to specify the method employed in measuring the beam current. Ideally, a Faraday box which could be moved to intercept the beam would be used. It is observed, however, that plate P_3 and the aquadag coated tube itself comprise a good Faraday box, and the current measured in the lead to P_3 is the beam current provided (A) that all electrons passing through S and lens P_2' also pass through lens P_3, (B) that the current measured is not effectively reduced by current to the deflecting plates and (C) the leakage currents are taken into account. All of these conditions can be fulfilled so that the beam current i_3 is therefore the current to plate P_3 and the aquadag coated bulb.

The next set of curves, as shown in Fig. 4 shows beam current as a function of the condensing voltage ratio

$$\frac{V_2}{V_1}$$

when V_1 is held constant. Curve **1** is taken for a value of $V_1=132$ volts and a value of I_a (the filament current) $=4.40$ amperes. Under these conditions the current to the plate P_1 is limited by space charge. Curve **2** is taken for a value of $V_1=240$ volts and a value of $I_a=3.60$. Under these conditions the current to plate P_1 is limited by the temperature of the filament. The maximum of these curves is attained at a value of

$$\frac{V_2}{V_1}$$

of around 7.1 for a wide range of values of

$$\frac{-V_1'}{V_1}$$

The possibility remains that with emission limited by space charge, the optimum ratio of

$$\frac{V_2}{V_1}$$

for constant V_2 might be considerably different but Fig. 5 shows the optimum to be nearly the same. In taking the curve shown in Fig. 5, V_2 was held constant at 1,000 volts, filament current being 4.40 amperes and the ratio of $-V_1'$ to V_1 being held constant at 0.25.

Thus far, the data have shown that there exist optimum values of the voltage ratios

$$\frac{-V_1'}{V_1}=0.26,\ \frac{V_2}{V_1}=7.1$$

and that these ratios are essentially independent of filament emission and of absolute values of voltage. Thus, the condensing lens system is focussed so that maximum intensity occurs at S. Also when

$$\frac{V_3}{V_2}$$

is equal to 4.2, the projector lens system focusses this spot on the fluorescent screen.

The data on deflection and on modulation will now be considered. The two pairs of deflecting plates are distinguished by subscripts h and v; the latter are nearest to the screen and produce vertical deflection while the former produce horizontal deflection, the tube being mounted horizontally. If all plates, both deflecting and modulating, are insulated, it will be necessary to specify the average potential of each pair and the potential difference between them. The average potentials are designated

$$\overline{V}_h,\ \overline{V}_v,\ \overline{V}_m$$

The potential differences are designated V_h, V_v, V_m, the subscript m, of course, applying to the modulating plates. Thus deflecting and modulating voltages refer to potential differences, and not to potential as measured from the zero potential, namely, the filament. The spot is distorted when either $\overline{V}_h$ or $\overline{V}_v$ is different from V_3; consequently, in all tests

$$\overline{V}_h=\overline{V}_v=V_3$$

V_m is made equal to V_2. In some cases V_2 may be made greater than $\overline{V}_m$ as for example in an arrangement shown in Patent 2,168,760, issued August 8, 1939 to C. J. Calbick.

The deflection sensitivities S_h and S_v may be defined by the equations

$$S_h=\frac{\overline{V}_h}{V_h}\cdot d_h \quad S_v=\frac{\overline{V}_v}{V_v}\cdot d_v$$

where d_h and d_v are the deflections in centimeters on the fluorescent screen produced by deflecting voltages V_h, V_v, respectively. Ideally these sensitivities are constant over the deflection range limited by the screen. More generally, the formulae

$$S_h=\overline{V}_h\times\frac{\Delta d_h}{\Delta V_h}$$

$$S_v=\overline{V}_v\times\frac{\Delta d_v}{\Delta V_v}$$

will define the sensitivities over the screen range. Conceivably S_v may also depend on d_h, since the electrons pass between the horizontal deflecting plates before passing between the vertical deflecting plates. Since

$$\overline{V}_h=\overline{V}_v=V_3,$$

the question of what happens when these conditions are not satisfied does not arise. The sensitivities were determined by photographing the spot in several deflected positions. From this photograph $S_h=68.9$, $S_v=64.0$, and $\theta=0°15'$. Here θ is the angular departure from mutual orthogonality. The horizontal sensitivity is constant to within the accuracy of measurement, about one-half of 1 per cent; the vertical sensitivity changes from 63 on one edge of the screen to 65 at the other, i. e., it shows a measurable variation across the screen. Over the television image field, its extreme variation is less than 2 per cent and is quite undetectable in the image field. By making V_v an alternating potential, the spot sweeps out a vertical line, which is straight for all values of V_h; consequently S_v does not depend on V_h.

Fg. 6 shows a modulation curve taken with $V_2=1000$ volts and the filament current $I_a=4.0$ amperes this curve being plotted with beam current in microamperes as ordinates versus V_m in volts as abscissae. It will be observed that the peak of the modulation curve does not occur at $V_m=0$ but at a slightly positive value and also that a longer linear region is available on the right than on the left side of the maximum. This region is therefore selected for operation.

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 relatively free from distortions commonly present. The tube is especially adapted for monitoring or in other places where especially high quality results are desired.

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, means for generating a beam of electrons, a cylindrical electrode located in such a position that its axis coincides with the longitudinal axis of said device which also passes through the center of said beam generating means, said cylindrical electrode having three apertured diaphragms located transversely of the axis thereof and each being placed at the potential of the cylinder, the aperture in each diaphragm being placed to surround the axis of said cylinder, and a pair of plates between said first and second apertured diaphragms to modulate said beam by varying the portion thereof which passes through the aperture of the second of said apertured diaphragms, the plates being located on opposite sides of said beam.

2. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, a screen, means for concentrating said

stream upon the aperture of said apertured diaphragm, means for deflecting said stream in accordance with a variable modulating voltage to cause varying portions of said stream to pass through said aperture in accordance with the variations of said modulating voltage, and means for forming an electron image of said aperture upon said screen whereby the shape of said image varies in accordance with said modulating voltage.

3. In a cathode ray tube, a cathode for emitting electrons, an anode comprising a metallic cylinder having three diaphragms, each diaphragm arranged in a plane which is transverse of the axis of the cylinder and each having an aperture located so as to surround said axis, means for imparting a positive potential to said cylinder with respect to that of said cathode, means including the apertured diaphragm nearest said cathode for focusing electrons upon the plane of the middle diaphragm, a screen, and means including the remaining apertured diaphragm for focusing an image of said middle diaphragm on said screen.

4. In a cathode ray device, a pair of electrodes, a cathode placed between said pair of electrodes, and means for applying potentials to said electrode members and to said cathode of such value that said cathode is in a substantially uniform field between said electrode members.

5. In a cathode ray device, an electron emitting electrode, a second electrode, an apertured plate on the side of said electron emitting electrode remote from said second electrode, means for applying a negative potential with respect to the potential of said electron emitting electrode to said second electrode, and means for applying a positive potential with respect to that of said electron emitting electrode to said apertured plate, the ratio of the magnitudes of the potentials applied to the second electrode and to the apertured plate being made substantially equal to the ratio of the distances of these members from the electron emitting electrode.

6. An electron gun arrangement comprising a back electrode, a cathode, a first accelerating anode, a second accelerating anode, and a third accelerating anode.

7. An electron gun system comprising a planar cathode, a back electrode parallel to said cathode, a first accelerating anode comprising an apertured diaphragm, a second accelerating anode comprising a metallic cylinder having three apertured diaphragms, each diaphragm located transversely of the axis of said gun system and spaced along it, means including said first accelerating anode and the diaphragm of said second accelerating anode nearest said first accelerating anode for concentrating the beam of electrons upon the plane of the middle diaphragm of said second accelerating anode, a third accelerating anode comprising a metallic apertured diaphragm, and means including said third accelerating anode and the apertured diaphragm in said second accelerating anode farthest removed from said first accelerating anode for projecting an electron image of the aperture in said middle diaphragm of said second accelerating anode upon said screen.

8. In a cathode ray device, a cathode, a back electrode, an accelerating electrode, means for applying a positive potential to said accelerating electrode with respect to the potential of said cathode, and means for imparting a negative potential with respect to the potential of said cathode to said back electrode, the ratio of the voltage applied to the back electrode to that applied to the accelerating electrode being approximately 1 to 4.

9. In a cathode ray device, a ribbon filament, an anode, and a plate located on the side of said filament remote from said anode, the plane of said plate being parallel to the plane of said filament.

10. In a cathode ray device, a tungsten ribbon filament, an anode, and a plate located on the side of said filament remote from said anode, the plane of said plate being parallel to the plane of said filament.

11. In combination, an apertured member located in a space free from fields caused by potentials applied to elements outside said space, an electron emitting element, a back electrode, and two apertured elements between the apertured member and the electron emitting element, one of the latter defining a boundary of said space.

12. In a cathode ray device, a ribbon filament, an anode, and a plate located on the side of said filament remote from said anode, the plane of said plate being parallel to the plane of said filament, and means for applying potentials to the filament, the plate and the anode, said potentials being of such value that a substantially uniform field exists between the plate and the anode.

13. In a cathode ray device, a pair of electrodes, a cathode in the form of perpendicularly crossed elements placed between said pair of electrodes, and means for placing said electrode members and said cathode at such potentials that said cathode is in a substantially uniform field between said electrode members.

14. An electron gun arrangement comprising a back electrode, a cathode, a first accelerating anode, a second accelerating anode comprising a metallic cylinder having three apertured diaphragms therein each diaphragm having an aperture surrounding the axis of said cylinder, and a third accelerating anode.

15. In an electron optical system comprising means including a pair of electrodes on opposite sides of a flat cathode for forming a beam of parallel electron rays, a first apertured diaphragm, means for forming a field free space around said first apertured diaphragm, a screen or target, electrostatic means for converging said beam so that in the absence of deflecting fields substantially all of said electrons pass through the aperture in said diaphragm, means for deflecting said beam within said field free space in accordance with signals so as to vary the number of electrons passing through said aperture, and means including a pair of apertured diaphragms for causing said electrons to form a diverging beam to form an enlarged electron image of the aperture in said first apertured diaphragm upon said screen or target.

16. In an electron optical system comprising means including a pair of electrodes on opposite sides of a flat cathode for forming a beam of parallel electron rays, an apertured diaphragm, a screen, means for converging said beam so that in the absence of deflecting fields substantially all of said electrons pass through the aperture in said diaphragm, means for moving said converging beam in accordance with signals so as to vary the number of electrons passing through said aperture, and means for causing said electrons to form a diverging beam to form an enlarged electron image of said aperture upon said screen.

17. In an electron optical system comprising

means including a pair of electrode members on opposite sides of a flat cathode for forming a beam of parallel electron rays, an apertured diaphragm, means for forming a field free space around said apertured diaphragm, a screen or target, electrostatic means for converging said beam so that in the absence of deflecting fields substantially all of said electrons pass through the aperture in said diaphragm, means for deflecting said beam within said field free space in accordance with signals so as to vary the number of electrons passing through said aperture, and means for causing said electrons to form a diverging beam to form an enlarged electron image of said aperture upon said screen.

18. In an electron optical system comprising means including a pair of electrode members on opposite sides of a flat cathode for forming a beam of parallel electron rays, an apertured diaphragm, means for forming a field free space around said apertured diaphragm, a screen or target, electrostatic means for converging said beam so that in the absence of deflecting fields substantially all of said electrons pass through the aperture in said diaphragm, means for deflecting said beam within said field free space in accordance with signals so as to vary the number of electrons passing through said apertures, and electrostatic means for causing said electrons to form a diverging beam to form an enlarged electron image of said aperture upon said screen.

19. An electrode arrangement of an electron beam device comprising a cathode member, an anode member and a backing member for said cathode, said members being spaced apart with said cathode between the others of said members, and means for applying potentials to said members respectively having the relationship that the ratio of the potential applied to said backing member to that applied to said anode is substantially equal to the ratio of the distance between said cathode and said backing member to the distance between said cathode and said anode.

20. An electrode arrangement of an electron beam device comprising a cathode member, an anode member and a backing member for said cathode, said members being spaced apart with said cathode between the others of said members, and means for applying potentials to said members respectively having the relationship that the ratio of the potential applied to said backing member to that applied to said anode is substantially equal to the ratio of the distance between said cathode and said backing member to the distance between said cathode and said anode, said backing member and said anode being substantially parallel to each other throughout their extents.

21. A cathode ray device comprising means for generating a beam of cathode rays, an apertured element through the aperture of which said beam passes, a pair of deflecting plates, one on each side of the beam emerging from said aperture and equidistant therefrom, means for applying modulating potential across said plates to deflect said beam a small amount in accordance with variations in said modulating potential, a second apertured element adjacent said plates with its aperture positioned to receive said beam as it emerges from the space between said plates and to pass a portion only of said beam for certain values of said modulating potential so that the number of electrons passing is under control of the modulating potential, and means for causing the average of the potentials applied to said plates to be at all times substantially equal to the potential of said second apertured element.

22. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, the aperture in said diaphragm having at least one straight boundary across which said stream is swept by deflecting means, a screen, means for concentrating said stream upon the aperture of said apertured diaphragm, means for deflecting said stream in accordance with a variable modulating voltage to cause varying portions of said stream to pass through said aperture in accordance with the variations of said modulating voltage, said stream having a substantially rectangular cross-sectional area immediately after passing through said aperture with one dimension only of said area varying in accordance with said modulating voltage, and means for forming an electron image of said aperture upon said screen, whereby the shape of said image varies in accordance with said modulating voltage.

23. In a cathode ray device, means for generating a stream of electrons, an apertured diaphragm, the aperture in said diaphragm having at least one straight boundary across which said stream is swept by deflecting means, a screen, means for concentrating said stream upon the aperture of said apertured diaphragm, means for deflecting said stream in accordance with a variable modulating voltage to cause varying portions of said stream to pass through said aperture in accordance with the variations of said modulating voltage, said stream having a substantially rectangular cross-sectional area immediately after passing through said aperture with one dimension only of said area varying in accordance with said modulating voltage, means for forming an electron image of said aperture upon said screen whereby the shape of said image varies in accordance with said modulating voltage, and additional deflecting means for deflecting said stream after it is modulated to cause it to scan said screen in parallel elemental strips extending in the direction of said varying dimension of the cross-sectional area of said stream.

24. A cathode ray device comprising means for generating a beam of cathode rays, a first apertured element through the aperture of which said beam passes, a pair of deflecting plates, one on each side of the beam emerging from said aperture and equidistant therefrom, means for applying modulating potential across said plates to deflect said beam a small amount in accordance with variations in said modulating potential, a second apertured element adjacent said plates with its aperture positioned to receive said beam as it emerges from the space between said plates and to pass a portion only of said beam for certain values of said modulating potential so that the number of electrons passing is under control of the modulating potential, means for placing the first apertured element at the same potential as the second apertured element, and means for causing the average of the potentials applied to said plates to be at all times substantially equal to the potential of said apertured elements.

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