April 28, 1959 H. G. COOPER, JR., ET AL 2,884,559

ELECTRON LENS SYSTEMS

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FIG. 1

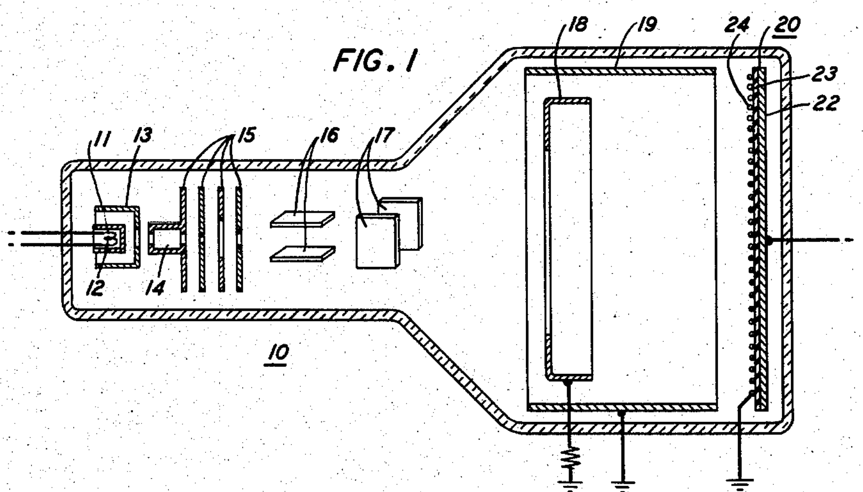

FIG. 2

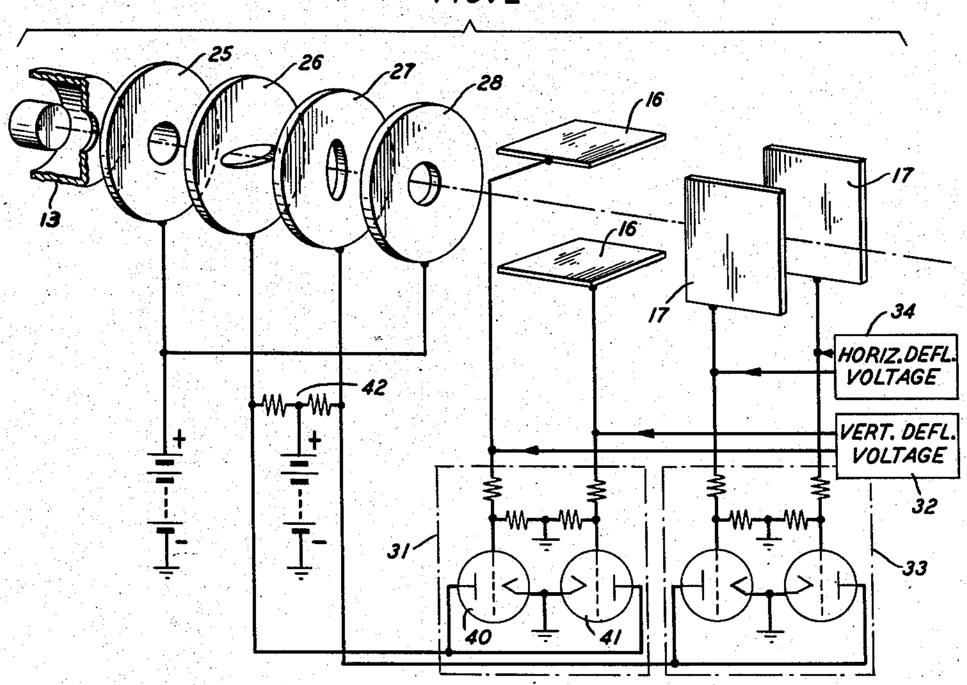

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FIG. 3

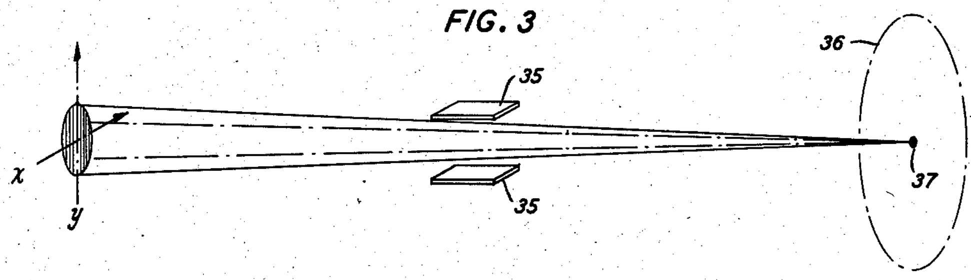


FIG. 4

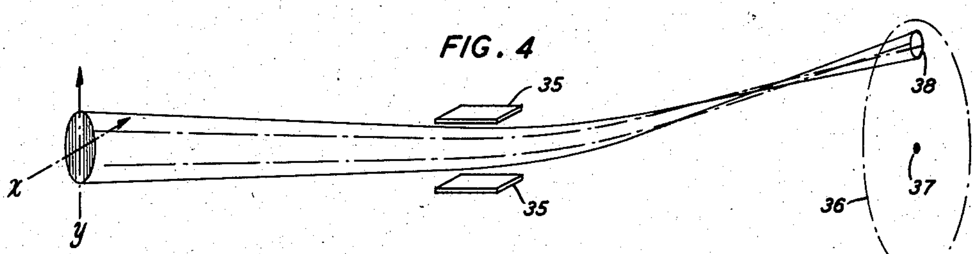


FIG. 5

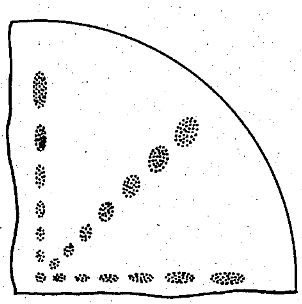


FIG. 6

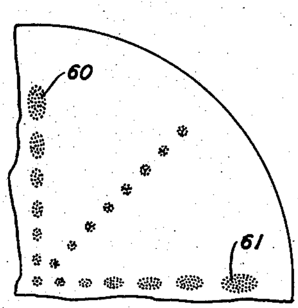
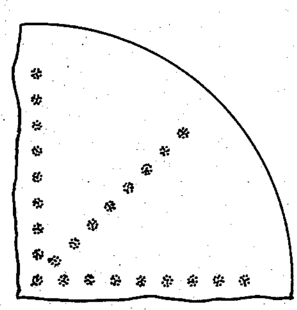


FIG. 7



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ELECTRON LENS SYSTEMS

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Application September 7, 1956, Serial No. 608,532

5 Claims. (Cl. 315—14)

The present invention relates to electron-optical devices and more particularly to electron discharge devices of the cathode ray type having means for correcting deflection defocusing of the electron beam.

In cathode ray tube operation, an electron beam is shaped to a desired configuration and directed toward a target structure where impinging electrons provide a visual or electrical indication thereof dependent on the particular application. In most instances the electron beam is deflected by suitable electrostatic or electromagnetic means so as to strike the target surface at any one of a plurality of discrete areas, each providing a distinct output signal. Such deflection presents serious problems in instances demanding minimum size and precise uniformity of beam configuration at each point of impingement.

Whereas an undeflected beam emanating from the electron gun is readily focused on a small diameter circular spot at the center of the target surface, an out of round enlargement or defocusing of the beam develops as it is deflected away from the target center. This effect is more pronounced with electrostatic deflection than with magnetic deflection. A certain measure of such deflection defocusing is tolerable in many applications and may be limited in such applications to the maximum allowable proportions by correction methods available in the prior art. Such methods include various electron lens configurations and combinations of such electron lenses with dynamic correction in which the mean potential of a pair of deflection plates can be varied according to a nonlinear function of the deflection voltage and relative to the electron lenses. Such systems, while reducing distortion in one manner, may tend to produce other distortions which offset a portion of the correction attained. Thus in systems demanding uniform control of an electron beam having an extremely small cross section, such as required in electrostatically deflected storage tube applications for example, the degree of deflection distortion correction realized by the correction systems of the prior art may be unacceptable.

It is a general object of this invention to provide an improved deflected beam electron discharge device. More particularly, it is an object of this invention to provide and maintain a uniformly small diameter of the electron beam as it impinges the device target in any deflected position.

It is another object of this invention to provide a more compact storage device while maintaining uniform beam dimensions.

It is another object of this invention to provide a simple, compact and efficient electron-optical system.

It is another object of this invention to provide a dynamically controllable electron lens arrangement coupled with control of the deflection system in an electron discharge device.

These and other objects of this invention are attained in one specific embodiment wherein a cathode ray storage tube of the barrier grid type comprises an electron lens system positioned in the beam path between the electron

gun and electrostatic deflection system, the lens system including a series of electrodes having aligned apertures in the beam path and energized to produce electric fields in the apertures tending to converge the electron beam passing therethrough.

It is essential in many storage and related tube applications that overall tube dimensions be kept at a minimum. To achieve such restricted tube dimensions while maintaining uniformity of beam focus at all deflection positions involves manipulation of a number of variables, the cardinal ones being described briefly hereinafter.

Deflection defocusing is inversely proportional to the length of the deflection field through which the electron beam must travel. Thus it is advantageous to make the deflection system as long as possible commensurate with overall tube length requirements. Also deflection defocusing increases with beam deflection angle so that the maximum required deflection angle should be small. Increasing the length of tube from deflection system to target will assist in maintaining a small deflection angle and is thus advantageous within overall tube dimension requirements. Thus the deflection defocusing problem may be reduced by increasing the length of deflection system and of beam travel from deflection system to target surface. In order to maintain a restricted overall tube length while satisfying these defocusing improvement factors, the portion of the tube containing the electron gun, lens and deflection system must be made shorter. Unfortunately, shortening the tube between cathode and lens increases the magnification factor and in turn the area of beam impingement at the target surface. Thus, for proper operation of the lens, the distance from the tube cathode to the lens must be greater than one half of the lens length. In view of these factors, it can be seen that optimum performance is obtained by incorporating the smallest possible lens length.

An effective electron lens, such as the "einzel" lens, serves to converge an electron beam to form a circular spot at the center of the target surface of a cathode ray tube. Such a lens normally comprises a pair of circular apertured electrodes at a potential highly positive with respect to the cathode and an intermediate circular apertured electrode at a potential intermediate the cathode potential and the potential of the outer lens electrodes. This configuration is analogous to the spherical lens of light optics and is effective to form a pencil shaped beam limited in cross section by the outer electrodes and subjected to the converging action of the low potential inner electrode in conjunction with the adjacent high potential outer electrodes. A three electrode einzel lens as described cannot completely control deflection defocusing of a beam deflected in a single coordinate. Such a lens employing slit apertures rather than circular apertures provides better control in a single coordinate, and two such lenses in turn will maintain a measure of uniformity in a beam deflected in two coordinates. However, aberrations are greater in a slit aperture or cylindrical lens than in a spherical lens of the same focal length, and six electrodes comprise the two coordinate lens structure thus requiring a substantially greater tube length to accommodate the lens.

Our invention, as illustrated in the specific embodiment described herein, satisfies the restricted lens length requirement to achieve reduced overall tube length while providing a uniformly small spot diameter at any point on the target surface.

In accordance with one aspect of the invention, the lens system comprises a pair of outer electrodes having circular apertures, which electrodes enclose a second pair of electrodes having elliptical apertures with their major axes parallel to opposite cartesian coordinates. The arrangement effectively presents a crossed elliptical lens forming a a unique intermediate portion for the familiar "einzel" lens in which the outer electrodes advantageously are placed at anode potential. A compact and highly effective lens is presented permitting a marked reduction in overall tube dimensions.

In accordance with another aspect of this invention the crossed elliptical lens has each inner electrode connected through a nonlinear circuit to a respective coordinate deflection potential source such that dynamic deflection defocusing correction may be provided. Accordingly, changes in deflection potential tending to strengthen the electrostatic field in the deflection system of one coordinate will tend to weaken the field established by the elliptical lens electrode controlling that coordinate.

It is a feature of this invention that an electron discharge device of the deflected cathode ray type comprise an electron lens system having a pair of control electrodes having aligned apertures arranged to pass a portion of the electron stream and a pair of focus electrodes interposed between the control electrodes and having apertures of substantially elliptical configuration aligned with the control electrode apertures.

It is another feature of this invention that the major axes of the ellipses formed by the control electrode apertures be mutually perpendicular.

It is a further feature of this invention that the control electrodes be connected through a nonlinear circuit to a respective coordinate deflection voltage source.

A complete understanding of this invention and of these and other features thereof may be gained from consideration of the following detailed description and the accompanying drawing in which:

Fig. 1 is a diagrammatic representation of a barrier grid storage tube incorporating one specific illustrative embodiment of this invention;

Fig. 2 is a schematic diagram of one illustrative embodiment including a perspective view of the lens system for the embodiment of Fig. 1 greatly enlarged in relation to adjacent elements;

Figs. 3 and 4 are diagrammatic views of an undeflected and vertically deflected electron beam, respectively, focused at the target structure;

Figs. 5, 6 and 7 are views of a quadrant of the target structure illustrating respectively the impinging electron beam without defocusing correction, with defocusing correction utilizing an einzel lens with circular apertured electrodes, and with defocusing correction in accordance the embodiment of Fig. 1 of this invention.

Referring now to the drawing, Fig. 1 depicts an illustrative embodiment of this invention utilizing a barrier grid storage tube **10**. As known in the art, the tube **10** may advantageously comprise within an evacuated envelope, such as glass, an electron gun including a cathode **11**, heater **12**, control grid **13**, accelerating anode **14**, focusing electrodes **15** defining an electron lens, deflection plates **16** and **17**, a collector electrode **18**, a shield **19**, and a target assembly **20**. The target assembly **20** is a sandwich of three elements including a back plate **22**, a dielectric sheet **23**, and a barrier grid **24** positioned directly in front of the dielectric sheet **23**.

The dielectric sheet **23** holds an electrostatic charge deposited on its surface by the electron beam for extended periods of time, thereby performing the storage function of the tube. The back plate **22** is insulated from the barrier grid **24**, and its potential may be varied to control the charge pattern laid down by the electron beam. The charge deposited at any discrete area of the dielectric sheet **23** is subsequently detected by returning the electron beam to the discrete area.

The size and proximity of discrete storage areas on a given target surface are dependent in part on the size, intensity and uniformity of the incident electron beam. The beam is necessarily deflected to reach any one of the discrete storage areas, but inherent in electrostatic

deflection is a certain measure of beam defocusing which tends to restrict the number of possible discrete storage areas.

As shown in Fig. 3 an electron beam converges to a point **37** on a target **36**. A cross section of the beam preceding the vertical deflection plates **35** is substantially circular as is indicated by the shaded area. With equal potentials on vertical deflection plates **35**, the beam is unaffected thereby and passes to its focal point **37**. In Fig. 4 the same electron beam is deflected vertically by a potential difference applied between the plates **35**. Rather than converging to a point at the target **36**, the beam now is subjected to a focusing effect by the deflection field tending to produce a cross over of electrons in the vertical plane prior to reaching the target **36** and resulting in an oblong rather than circular target impingement area **38** which is appreciably enlarged over the impingement area of Fig. 3. Thus the deflection plates acting as a cylindrical converging lens tend to restrict the magnitude of storage in the barrier grid tube, since discrete storage areas must be spaced far enough apart to prevent possible overlap due to the enlarged beam cross section toward the target extremities. Such overlap would tend to destroy the information stored at adjacent areas of the dielectric surface. One possible solution to the problem is to space the target sufficiently far from the deflection plates as to reduce the deflection angle required to reach the target extremities. Also it is possible to reduce the defocusing effect by increasing the deflection plate length in the direction of the beam axis. Unfortunately such expedients alone would result in a greatly enlarged tube unsuitable for many applications and would present additional problems of beam magnification at the target surface.

We have found that an electron lens arrangement in accordance with this invention will satisfy the requirements of uniformly small spot diameter at any deflection angle and will permit a reduction in overall tube length without increasing the deflection angle in comparison with other arrangements known in the art.

In Fig. 2 there is shown the principal elements of the embodiment of Fig. 1 which provide the desired deflection defocusing correction in a two coordinate deflection system. The electron lens there depicted comprises a first limiting electrode **25** having a circular aperture therein and placed at a high positive potential with respect to the cathode. Electrodes **26** and **27** have elliptical apertures and each obtain a variable potential from respective coordinate deflection voltage sources through nonlinear circuits which potential is advantageously between that of the cathode and that of electrode **25**. Thus electrode **26**, having the minor axis of its elliptical aperture in a vertical plane, is connected through nonlinear circuit **31** to the vertical deflection system input circuit **32**. Similarly, electrode **27** has its minor elliptical axis in a horizontal plane and is connected through nonlinear circuit **33** to the horizontal deflection system input circuit **34**. Electrode **28** completes the electron lens and resembles electrode **25** in configuration and applied potential.

In the absence of deflection fields, electrodes **25**, **26**, **27** and **28** coact to focus the electron beam, formed from electrons emitted by the tube's thermionic cathode, in a spot of minimum size at the center of the target screen. The focusing action of these electrodes in this instance is comparable to that of one or more spherical-surfaced optical lenses and to the well known einzel electrostatic lens. The focusing action is effected by maintaining a potential difference between adjacent electrodes. It is also influenced to some extent by the mutual separation of the electrodes. The lens electrodes are adjustable without changing their physical arrangement, just by changing the potentials and relative potentials of the constituent electrodes.

Each elliptical apertured lens electrode **25** and **26** bears a similarity in operation to the cylindrical optical lens in which equal convergence or divergence may be effected between parallel planes, the major axis of the ellipse being perpendicular to the parallel planes. A pure cylindrical electron lens is one dimensional and is formed by a pair of coplanar plates of infinite length separated to form a slit of infinite length across which the electrostatic focusing field is developed. Obviously the slit length is dictated by maximum permissible tube proportions so that in operation the ends are closed to form a compromise rectangular aperture. Such a compromise, however, results in interaction between focus control in the desired and perpendicular planes. It is possible in accordance with this invention to reduce this interaction by shaping the aperture in the form of an ellipse so as to remove any sharp corners about which such interaction occurs. Any interaction due to the proximity of the two elliptical focus electrodes **26** and **27** may be minimized by proper selection of the major to minor axis ratio of each elliptical aperture, the aperture dimensions and lens electrode spacing.

Upon application of a signal to the deflection plates **16** and **17**, the electron beam will be deflected to impinge the dielectric target surface at a spot other than the target center. As shown in Fig. 4 and again in Fig. 5, the cylindrical focusing effect of the deflection plates **16** and **17** will distort the beam such that a circular spot on the target becomes elliptical with deflection of the beam away from the center of the target. The distortion due to the deflection system alone, as seen in Fig. 5, increases proportionate to the deflection angle and, in fact, proportionate to the square of the mean deflection angle.

In Fig. 6 the deflected beam distortion is shown which results from the employment of an einzel lens with circular apertured electrodes preceding the deflection plates in the tube structure. The spherical converging action of the electrostatic field developed in such a lens prefocuses the beam to compensate for the cylindrical lens effect of the deflection plates. By adjusting the lens field to compensate for changes in the deflection field, the distortion at the target is corrected to some extent.

There are two major disadvantages to einzel lens arrangements. A spherical lens arrangement introduces a pencil shaped beam to the deflection system and cannot completely correct for the one-dimensional deflection defocusing effects on such a beam configuration at all points on the target. Correction will be least when the beam is deflected to maximum in one coordinate and undeflected in the other coordinate as at points **60** and **61** in Fig. 6.

Provision of an einzel lens comprising three slit apertured electrodes for each deflection coordinate may overcome the first difficulty when coupled with dynamic correction circuitry, but the length of tube required to accommodate six spaced electrodes is prohibitive in the limited tube dimensions of many storage tube applications. Compensating for this lens space requirement by shortening the deflection plates and their distance from the target would further aggravate the deflection defocusing problem as described hereinbefore. Additionally, aberrations are greater in the slit electrode cylindrical lens making it less attractive in this respect than the circularly apertured spherical lens.

Fig. 7 illustrates the results obtained utilizing the arrangement in accordance with the embodiment of this invention illustrated in Fig. 2. A spot size compatible with the rigid requirements of the barrier grid tube for large scale storage is obtained at the target center, and the identical spot size is maintained at every deflected beam position about the target surface. The unique crossed elliptical lens arrangement utilizes a single elliptical lens electrode in each coordinate serving to converge the beam only in that coordinate and coacting on an undeflected beam to converge the beam at the center of the target.

An electrical circuit provided between the lens and deflection systems weakens the electrostatic field at each elliptical electrode as its corresponding deflection plates are energized. To a first approximation the dynamic voltage applied to each lens is proportional to the square of the voltage difference between the deflection plates which act in that plane. One manner of accomplishing this dynamic field variation is shown in Fig. 2 wherein balanced push-pull deflection is utilized. A sample of the vertical deflection voltage from source **32** is applied to the grids of parallel connected vacuum tubes **40** and **41** of nonlinear circuit **31**. The grid voltages vary in a balanced manner, but the sum of the plate currents should, to a first approximation, vary as the square of the deflection voltage. The combined plate current of tubes **40** and **41** produces a voltage across resistance **42** which varies in the desired manner and is applied to the electrode **26**. A similar circuit is provided to control electrode **27** in accordance with the horizontal deflection voltage. As shown in Fig. 2 the focus electrodes **26** and **27** are operated at a positive potential to obtain the basic focusing. If negative voltages are employed, a phase inverter stage may be utilized to weaken the electrostatic fields at electrodes **26** and **27** when deflection voltages are applied.

The crossed elliptical lens with electrostatic fields compensated dynamically as described serves to converge the beam to a uniform small spot diameter at any deflected position. Also, with only four electrodes comprising the lens structure a minimum tube diameter and length is achieved.

In one specific illustrative embodiment of this invention wherein the lens structure is as shown in Fig. 2, the various lens elements had the following dimensions and spacing:

	Inch
Aperture diameter:	
Electrode **25**	.048
Electrode **28**	.075
Electrodes **26**, **27**—	
Major axis	.287
Minor axis	.217
Thickness of electrodes	.012
Spacing between adjacent electrodes	.210

Electrodes **25** and **28** were placed at a potential 1000 volts above that of the cathode. Electrodes **26** and **27** are placed at 420 volts and 470 volts above that of the cathode, respectively, to obtain initial undeflected focusing in both horizontal and vertical coordinates. With these values, 90% of the electron beam will pass through a square .007 inch on a side. Thus a beam diameter at the target of approximately .007 inch was obtained, which diameter remained constant and uniform at every deflected position of the beam on the target.

Accordingly we have found it advantageous to have the dimensions of the various components of the electro-optical system specifically related to each other. More specifically we have found it advantageous to position the electrodes **25**, **26**, **27**, and **28** so as to be spaced apart by equal distances and to have the minor axis diameter of the elliptical apertures of the electrodes **26** and **27** substantially equal to this spacing between adjacent electrodes of the lens. Further we have found it advantageous to have the ratio of the major axis diameter to minor axis diameter of the elliptical apertures of electrodes **26** and **27** be of the order of 1.3.

It is to be understood that the above-described examples and arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. A cathode ray tube comprising means for projecting a beam of electrons along a path, means for deflecting the projected beam in mutually perpendicular directions, and means for focusing said beam prior to deflection comprising a pair of equipotential control electrodes having circular apertures and a pair of focus electrodes having

apertures of uniformly varying width elongated in mutually perpendicular directions parallel to respective deflection directions, each of said focus electrodes being positioned between one of said control electrodes and the other of said focus electrodes and coupled through a non-linear circuit to the source of deflection voltage.

2. An electron discharge device comprising target means, means for providing an electron beam and means for deflecting said electron beam over said target means including means for producing a pair of mutually perpendicular deflection fields with separate coordinate deflection voltage sources, an electron optical system comprising a pair of control electrodes having circular apertures aligned to pass a portion of said electron beam, a first focus electrode having an elliptical aperture elongated perpendicular to one of said deflection fields and a second focus electrode having an elliptical aperture elongated perpendicular to the other of said deflection fields, said focus electrodes being positioned between said control electrodes.

3. A cathode ray device in accordance with claim 1 wherein said focus electrode apertures are substantially

elliptical in configuration with the major axes mutually perpendicular and the ratio of major axis diameter to minor axis diameter of the order of 1.3.

4. A cathode ray device in accordance with claim 3 wherein adjacent ones of said electrodes are equally spaced apart.

5. A cathode ray device in accordance with claim 4 wherein the ratio of the minor axis diameter of said elliptical apertures to said spacing between adjacent electrodes is substantially unity.

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