

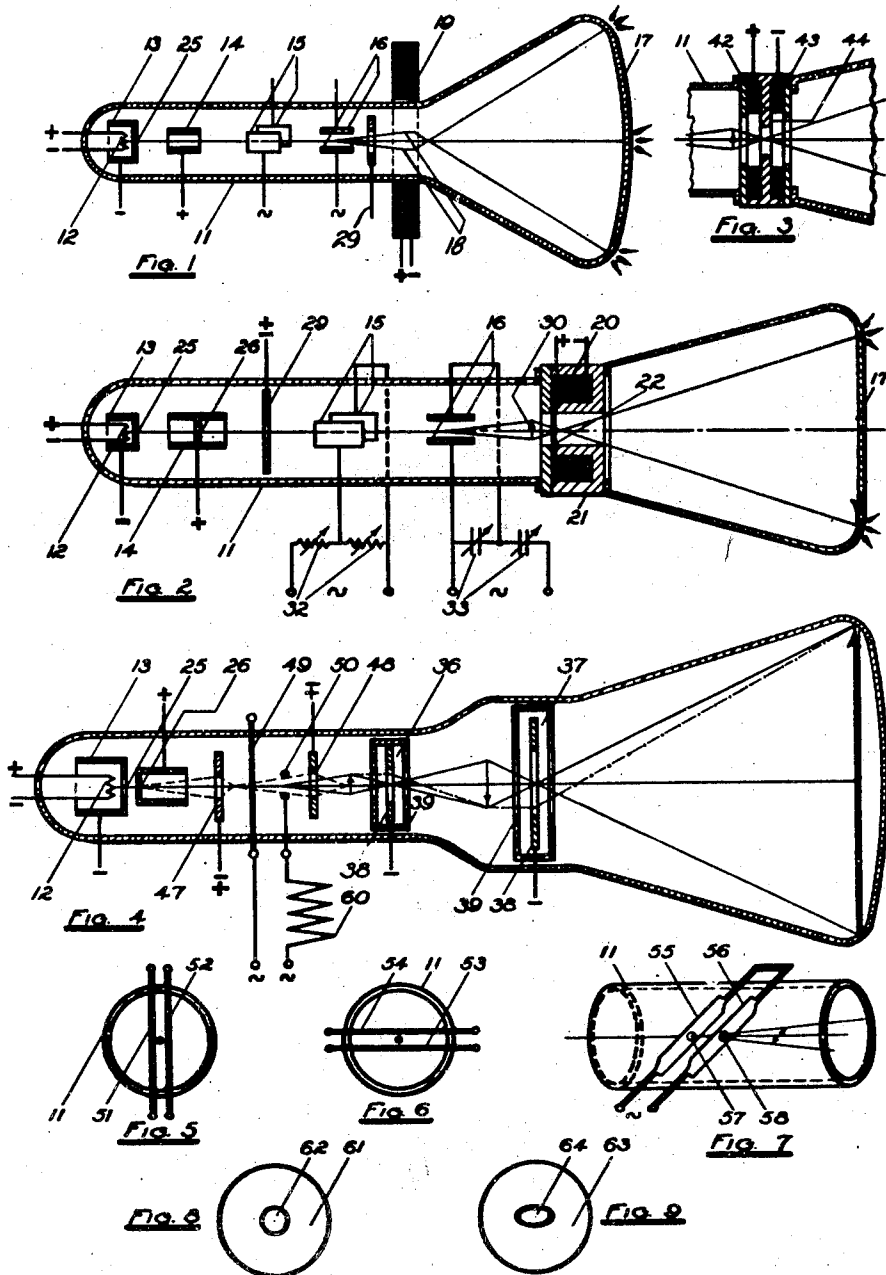
Nov. 23, 1948.

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2,454,345

CATHODE-RAY DEFLECTION TUBE WITH ELECTRON LENSES

Filed May 25, 1945



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2,454,345

CATHODE-RAY DEFLECTION TUBE WITH
ELECTRON LENSES

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Application May 25, 1945, Serial No. 595,850

14 Claims. (Cl. 250—160)

1

The invention refers to cathode-ray tubes such as oscillograph tubes, television tubes, or the like, and has for its object a new cathode-ray tube of extremely high sensitivity even for signals of small amplitude and of extremely rapid variation or change with time.

Generally, cathode-ray tubes make use of the deflections of an electron beam of high velocity for indicating or making visible, directly or indirectly, the variation or change with time of an electric signal, emanating from a phenomenon to be observed.

The sensitivity of such oscillograph or similar apparatus for these changes or variations with time of incoming signals is dependent mainly upon the time needed by the electrons to pass through the deflecting fields; the shorter the transit time, the more sensitive the oscillograph or other apparatus. This transit time depends on the dimensions of the deflection system and aside therefrom mainly on the velocity of the electrons and thus essentially on the voltage between cathode and anode; the higher the voltage, the greater the velocity of the electrons.

The amplitude of the deflections of this electron beam, on the other hand, depends upon the strength of the deflecting field produced by the incoming signals. As a rule, an electric field strength of many volts per centimeter or a magnetic field strength of many ampere-turns per centimeter will be necessary for producing a substantial deflection of the electron beam. The field strength for producing a deflection of sufficient amplitude will necessarily be the higher, the higher the voltage between cathode and anode is. The sensitivity of these tubes in respect of deflecting power or the "deflection-sensitivity" will thus decrease with increasing velocity of the beam, while the sensitivity in respect of variations or changes with time or the "time-sensitivity" is increasing with the velocity of the electron beam. The conditions, therefore, for a highly sensitive tube are contradictory.

A primary object of the invention, therefore, is to reconcile with each other these contradictory conditions.

More specifically, it is an object of the invention to make possible in a cathode-ray tube the amplification of the deflections of the incoming signals without the necessity of unduly decreasing the velocity of the electron beam or complicating the apparatus through application of amplifiers for the signals.

In known apparatus magnifying lens systems are employed between the deflecting system and

2

the beam-responsive member. When by deflections through the incoming signals the electrons are caused to pass eccentrically through the plane of the magnifying electron lens, this lens will cause a magnified deflection which when well-designed electron lenses are employed will be proportional to the eccentricity of the electron beam. Hence, with a sufficiently strong lens field, every incident beam will leave the lens under an angle greater than and proportional to the angle of incidence and will produce a magnified trace of the beam on the fluorescent screen or other beam-responsive member.

Through the magnification, however, the electron beam will diverge and the spot which describes on the screen or other beam-responsive member the deviations will be magnified too and blurred.

It is thus a more specific object of this invention to avoid the blurring of the electron spot on the beam-responsive member, but contrariwise, to reduce the electron beam to a fine spot on the beam-responsive member.

In accordance with the invention, these and other objects of the invention which will become apparent hereinafter as the description proceeds, are achieved in cathode-ray tubes, such as television tubes, oscillograph tubes, or the like, by the use of a reducing lens system arranged in the path of the electron beam between the conventional electron gun and the magnifying electron lens system.

In the embodiments of the invention, which will be hereinafter described in detail, the reducing electron lens system, which reduces the electron beam to a fine spot on the beam-responsive member, focusses said spot in the zone between the deflection system and the magnifying system.

The cathode-ray tube may thus be operated with small deflection which then, without blurring the image, may be enlarged within the tube, by magnification merely or substantially in space in contrast with amplification of the intensity of the signals in time as achieved in amplifiers conventional in the art.

When in the following specification and claims the term "beam responsive member" is employed, this term is intended to include any device which, as convenient or conventional in cathode-ray tubes; converts the beam impinging on said device into a directly visible, or luminous picture, or into a photograph or photogram of the phenomenon, or produces secondary light or electron emission or any other photo-active or electron-

active effect for rendering visible, or observing, recording, or imaging the phenomenon.

The deflections of the beam which are magnified may be of the order of one degree or even less, so that even small signals may be used to produce directly, without the use of amplifiers, deflections of the electron beams which will then be magnified by the magnifying lens system.

The magnifying fields and also the focussing fields may be used singly or in combination. Thus one lens may be employed in either case, or a cascade of more than one lens, for producing the focussing or the magnifying effect, or both. The magnifying field or fields when constant in time will produce a fixed magnification, or, when changed with time, a variable magnification.

Various embodiments, features and details of the invention will be set forth in the specification as it proceeds and will be illustrated by way of example in and by the accompanying drawings which form part of this specification and which are to be understood explicative of the invention and not limitative of its scope. Other embodiments incorporating the principles underlying my invention are feasible without departing from the spirit and ambit of my appended claims.

In the drawings:

Fig. 1 illustrates in longitudinal section a cathode-ray oscillograph with a reducing electron lens system and a magnifying magnetic electron lens system;

Fig. 2 illustrates in longitudinal section another embodiment of a cathode-ray oscillograph with an electric focussing electron lens system and a modified magnetic magnifying electron lens system;

Fig. 3 illustrates in longitudinal section another modification of a magnetic electron lens system;

Fig. 4 illustrates a longitudinal section of a cathode-ray oscillograph with electric reducing and magnifying cascades of electron lenses;

Figs. 5 and 6 show in sectional plan view the two sets of the deflection system of Fig. 4;

Fig. 7 shows a perspective view of a modified deflection set; and

Figs. 8 and 9 show plan views of a circular and an elliptic electron lens, respectively.

In the drawings, 11 is an oscillograph tube, 12 the cathode, 13 the grid, 14 the anode. The deviating system comprises two sets of plate pairs 15, 16, in crossed arrangement as conventional in cathode-ray oscillographs. The signs +, - and ~ indicate, as conventional, the circuits or their parts to which these elements are connected.

In order to obtain the electron beam in the form of a fine homogeneous pencil, grid 13 and anode 14 may be, as conventional in electron guns, in the form of diaphragms with a fine opening each, such as shown in the figures at 25, 26, respectively, in the axis of the beam.

In Fig. 1 the cathode-ray deflection tube 11 is shown with a magnifying electron lens system which comprises a single magnetic electron lens 19 which consists of a coil arranged outside of the tube and co-axial with the zero path of the electron beam. The lens, as indicated by the signs + - is excited by direct current. In the zero position of the beam the electron lens has no effect and the beam will hit the center of the screen 17. Any original deflection, however, of the beam, as indicated at 18, Fig. 1, will cause the electrons to pass eccentrically through the plane of the lens and will thus be submitted to a magnified deflection and a magnified trace of

the beam will thus be produced on the fluorescent screen 17 located at a suitable distance from lens 19. A system of one or more electrostatic lenses such as shown in Fig. 4, instead of a magnetic lens system, will have a corresponding effect on the beam.

Since, in conventional cathode-ray tubes, the original electron beam, as a rule, is slightly diverging or converging, this property will also be magnified by the lens effect and thus the image on the screen will become diffuse.

To avoid this blurring of the image lines, a reducing electron lens system is provided.

In the embodiments of Figs. 1 and 2 the reducing electron lens system comprises an electrostatic lens 29 properly charged with a positive or negative charge as indicated by the sign $\pm$. Electron lens 29 focusses the original electron beam in a plane located between the deflection elements 15, 16, and the magnifying electron lens 19 or 20, 21, 22, respectively. The magnifying electron lens is of short focal length and magnifies the trace in the focal plane, indicated by the arrow 30, Fig. 2, to a real image on screen 17. With such an arrangement the original beam may be of such convergence as may ever be produced by the effect of the electron gun or of additional electrodes or fields. The position of the focal spot will always appear magnified and sharply imaged on the screen if only the well-known relation between object distance, image distance and focal length of the magnifying lens is observed. With an arrangement as illustrated in Fig. 1 or 2, the magnification produced by the electron lens may easily be changed by variation of the lens current without the luminous spot on the screen being unduly blurred if only the focus of the original beam is kept in the object plane of the magnifying lens.

Electron lenses of the simplest form have circular symmetry and magnify, therefore, uniformly in all directions. In the two deflection sets, such as 15 and 16 of Fig. 2, of the deflection system, which are independently charged by different signals of the phenomenon to be observed, the signals incident upon the two deflection sets may have greatly differing magnitudes. In order to secure a suitable shape of the image on the screen without undue extension in one of the image axes, vertical or horizontal, Fig. 2 illustrates a development of the invention in accordance with which an attenuator is associated with either of the sets of deflection elements for reducing the stronger of the signals to the order of magnitude of the weaker of the signals so as to obtain magnifications of the original deflections in similar order of magnitude in both the axes of deflection.

Such reduction without distortion of the signals may be produced by ohmic or capacitive voltage dividers, as indicated by 32, 33, respectively, in Fig. 2, or by one of the well-known combinations of such devices. Any desired ratio of the deflections in both axes of the final trace on the beam responsive member, luminous screen, or the like, may so be arranged.

When, as in the examples of Figs. 1 and 2, magnetic lenses are used, twisting of the final image with change of the current may be avoided when, instead of an unsymmetrical lens as in Fig. 2, a neutral magnetic lens is employed as illustrated in Fig. 3. Neutral electron lenses, as is known, are such whose effect upon the electron beam passing through them takes place only within a narrowly limited zone whereas outside

5

said zone their effect is compensated. Within the zone, the radial field strength is exactly or substantially proportional to the distance from the axis, whereas in front and to the rear of the center the axial field of the lens is symmetrical so that additional acceleration and retardation or circumferential rotation of the electrons cancel each other.

The neutral magnetic electron lens as illustrated in Fig. 3 includes a pair of magnetic lenses for producing magnetic fluxes in opposite directions. These magnetic lenses may be built up, as Fig. 3 illustrates, from coils 42, 43, arranged in a common magnetic core 44, symmetrically arranged with regard to its median plane. Two separate magnetic lenses may also be used for this purpose the magnetic fluxes of which are oppositely directed.

In order to obtain a higher magnification than attainable with a single lens, Fig. 4 illustrates a system of two magnifying lenses, generally designated by 36, 37, in cascade. Here, as an example, the electrostatic type of lens is used which, in this use in a deflection tube, has the advantage of a fixed orientation of the image so that the two axes on the screen can easily be coordinated with the corresponding axes of the deflection elements.

In this example of Fig. 4 neutral electrostatic lenses are shown which consist of a metal electrode 38 and a metal casing 39 surrounding it, both differentially charged electrically by means of charges of different signs or by charges of the same sign but of different voltage. These lenses magnify at any time the position of a sharp spot in a plane between the deflection elements and the magnifying lens system in the manner of a compound projection microscope and produce on the screen a large image of the small movements of the original beam.

Since the area of the focal spot of the original deflected beam is also magnified by the electron lenses it is desirable to make this spot as fine as possible. It will therefore be expedient to employ instead of one reducing lens, as shown in Fig. 2, a cascade of reducing electron lenses in order to thus diminish the beam area in various successive steps, in the instance illustrated in two steps. In Fig. 4, the two electron lenses are designated by 47 and 48. The dashed lines in this figure indicate the geometric paths of the central electrons of the undeflected spot.

Generally, any type of electrostatic or magnetic lens system comprising one or more lenses may be employed for the purpose of reducing the beam area. The reducing lens system which focusses the electron beam in a plane located between the deflection system and the magnifying electron lens system may be so arranged with regard to the deflection system—which may be arranged anywhere along the path of the reducing beam—that when the lens system consists of one lens, this lens (Fig. 1), or when the lens system consists of a cascade of several lenses, at least the last lens (Fig. 4), is arranged following the path of the electrons, in the rear of the deviating system.

This is illustrated in Fig. 4 where the reducing electron lens 48 is arranged in the rear of the deflection system 49, 50, and electron lens 47 in front thereof.

Hence, through the arrangement of the invention, the electron beam will be diminished in its cross-sectional area by application of electrostatic or magnetic reducing lens systems, the beam will be deflected transversely by use of

6

electric or magnetic deflecting elements, and the deflections will be enlarged or magnified by application of electrostatic or magnetic electron lens systems.

It is well known that the reduction of the area of an electron beam is limited by mutual repulsion of the electrons. Thus, the actual size of the smallest spot behind the last reducing lens may be larger than determined merely by geometric optics. On the other hand, the extension of the spot due to electron repulsion at high current density will not be magnified by any lens. The repulsion effect, therefore, cancels out up to the last image on the screen.

In a conventional cathode-ray tube the highest frequency up to which the tube can be used without distortion is determined by the axial dimensions of the deflection elements. Since with the means available by this invention very small deflection angles can be utilized, the deflection elements, in accordance with a further development of the invention may be reduced as to their dimensions in the axial direction of the electron beam with the result that the transit time of the electrons will be further reduced. Therefore, in accordance with this feature of the invention it is admissible to reduce the deflecting elements, whether they be magnetic or electric, to systems of narrow parallel conductors arranged transversely of the electron beam.

Fig. 4 shows as an example two electrostatic deflection elements 49 and 50 each of which consists of a double-wire system, as shown separately in Figs. 5 and 6. Two wires 51, 52 and 53, 54, of small diameter and small clearance or separation transversely of the tube deflect the electron beam. The axial length of the deflecting zones is determined mainly by the separation of or the clearance between the wires and may therefore be kept very small in view of the very narrow electron beam which is being used. The transit time of the electrons flying through the deflection zone, thus, is extremely short and may be brought to an order of less than 10^{-9} seconds.

The deflecting wires of the arrangements of Figs. 4, 5 and 6 produce a purely electrostatic deflection since the magnetic effect of the wires is in the direction of the electron beam and therefore is inactive.

Fig. 7 illustrates a magnetic deflection element of short transit time based on the principle of the invention. This deflection element consists of two parallel conductors 55, 56, with an aperture 57, 58, respectively, in each of said conductors and a small clearance therebetween. These conductors are arranged transversely of the electron beam and will thus allow the beam to pass the apertures. The magnetic field of these conductors is transverse with respect to the electron beam and deflects the beam while the electric field is in the axis of the beam and therefore is inactive and does not deflect the beam.

These double conductor elements of the electrostatic or electromagnetic deflecting type can be used to great advantage for utilizing signals of very high frequency. Connected to any incoming line, the deflection elements may serve as receivers, their second terminals being open-circuited, short-circuited or resistance connected ever according to the type of measurement intended.

The transit time of the electrons due to their flight between the first and the second deflection sets causes an error of coordination in time between two signals which are impressed simul-

taneously on the two sets. This error, in accordance with a further development of the invention, may be compensated by leading the signals of the phenomenon to be observed to the second deflection set through a retardation element which provides a delay of the signal charges transmitted to the second deflection set. This delay is made substantially numerically equal to the transit time of the electron between the first and second of the sets of deflection elements. This transit time is determined essentially by the axial velocity of the electrons in the beam and the distance between the two deflection systems. If a simple conducting line 60 is employed for the retardation, as indicated in Fig. 4, its length (L) must be in the same relation to the distance (D) between the two deflection sets as the wave velocity (V) in the line (velocity of light) is with respect to the electron velocity (v) between the deflection sets:

$$L:D=V:v$$

For example, a distance, D between the deflection sets of 2 cm., through which the electron beam is the given type of tube, may move at a velocity of 3000 km./sec., would require a retardation line of a length

$$L = \frac{D \cdot V}{v} = \frac{2 \times 10^{-2} \text{ cm.} \cdot 3 \cdot 10^{10} \text{ cm./sec.}}{3 \cdot 10^9 \text{ cm./sec.}}$$

$$L = 200 \text{ cm.}$$

through which the signals travel at a velocity of 300,000 km./sec.

Through the use of this compensation of the transit time from the first deflection set to the second, the capability of the cathode-ray tube to image, free of distortion, the variation in time of voltages or currents of the signals, will be extended to extremely high frequencies, the limit of which is determined only by the very short transit time of the beam electrons as they fly through each individual deflection set. Rapidly varying signals of small amplitude corresponding to an electromagnetic wave length down to one centimeter or less may so be used or measured without the need of amplifiers for the signals.

The electron-microscopic imaging of the deflection is not restricted to linear deflection of the beam. Suitable elements, as is well known, may produce circular or radial deflection of the electron beam. Any small pattern produced, particularly if concentrated in a focal plane, can be magnified electronically by the use of field lens systems as described above and can thus be imaged on a luminous screen.

For certain purposes, such as when there are to be fed to the deflection sets two signals different in magnitude whose magnitudes however are in fixed or nearly fixed relation with each other, as is the case with voltage and current of a high frequency circuit, it may be useful to arrange for different magnification in two perpendicular axes. This can be achieved by using electron lenses of elliptical character.

Fig. 9 shows a plan view of such an electron lens in comparison with Fig. 8, the plan view of an electron lens 61 of circular aperture 62, thus of circular character. Electron lenses 63 of elliptical opening or aperture 64 produce fields of different intensities and thus differential magnification in their two perpendicular main axes or the two axes of the ellipse.

Cathode-ray tubes as described may be used for visual observation of the electron beam on a luminous screen, or for photographic fixation of the electron trace within or without the tube, or

for any other type of use of the magnified image of the trace of the electron beam.

Because of the high sensitivity of the tube with respect to incoming signals, it is advantageous to shield the tube, at least up the first magnifying lens, electrostatically and magnetically against distortions coming from foreign fields. Such shielding is well known in the art and therefore not shown in the drawings so as not to obscure the representation.

I claim:

1. In a cathode-ray tube, an electron gun for producing a substantially homogeneous electron beam, a deflection system adapted to be submitted to charges varying according to the change with time of incoming signals and to produce corresponding varying deflections of said beam, a beam-responsive member, and a magnifying electron lens system between said deflection system and said beam-responsive member for projecting, by means of the supplemental field produced by said magnifying lens system, a magnified image of said deflections upon said beam-responsive member; in combination with a reducing electron lens system disposed in the path of said electron beam, between said electron gun and said magnifying lens system and adapted to reduce said beam to a fine spot on said beam-responsive member.

2. In a cathode-ray tube, an electron gun for producing a substantially homogeneous electron beam, a deflection system adapted to be submitted to charges varying according to the change with time of incoming signals and to produce correspondingly varying deflections of said beam, a beam-responsive member, and a magnifying electron lens system between said deflection system and said beam-responsive member for projecting, by means of the supplemental field produced by said magnifying lens system, a magnified image of said deflections upon said beam-responsive member; in combination with a reducing electron lens system disposed in the path of said electron beam, between said electron gun and said magnifying lens system and adapted to reduce said beam to a fine spot and focus said spot to a point between said deflection system and said magnifying lens system for projecting said fine spot by means of said magnifying lens system on said beam-responsive member.

3. A cathode-ray tube as set forth in claim 2 wherein at least one of said electron lens systems is a magnetic electron lens included in said tube and adapted to produce the field of said lens as a magnetic field.

4. A cathode-ray tube as set forth in claim 2 wherein at least one of said electron lens systems is an electrostatic electron lens adapted to produce the field of said lens as an electrostatic field.

5. A cathode-ray tube as set forth in claim 2 wherein at least one of said electron lens systems comprises a cascade of electron lenses.

6. A cathode-ray tube as set forth in claim 2 wherein said reducing electron lens system is adapted to focus said electron beam in a plane located between said deflection system and said magnifying electron lens system.

7. A cathode-ray tube as set forth in claim 2 wherein said deflection system comprises two sets of deflection elements, independently charged by different signals of a phenomenon to be observed, and an attenuator is associated with at least one of said sets of deflection elements for reducing the stronger of said signals to the order of magnitude of the weaker of said signals.

8. A cathode-ray tube as set forth in claim 2 wherein said deflection system comprises two sets of deflection elements, independently charged by different signals of a phenomenon to be observed, and a delaying element is associated with the second of said sets of deflection elements so as to produce a retardation of the signal charges in said second set substantially equal to the transit time of the electron beam between the first and the second of said sets of deflection elements.

9. A cathode-ray tube as set forth in claim 2 wherein at least one of said electron lens systems includes at least one neutral electron lens.

10. A cathode-ray tube as set forth in claim 2 wherein said magnifying electron lens system includes magnetic lenses for producing two magnetic fluxes in opposite directions.

11. A cathode-ray tube as set forth in claim 2 wherein said magnifying electron lens system includes an electron lens of elliptical character by being adapted to magnify differentially in its two perpendicular main axes.

12. A cathode-ray tube as set forth in claim 2 wherein said reducing electron lens system comprises at least one lens and said lens is arranged along the path of said electron beam, between said deflection system and said magnifying electron lens system.

13. A cathode-ray tube as set forth in claim 2

wherein said deflection system includes a pair of narrow parallel conductors arranged in said tube transversely of the path of said electron beam.

14. A deflection system for use in a cathode-ray oscillograph as set forth in claim 2 including two parallel conductors with an aperture therein and small clearance therebetween and adapted to be arranged in said tube with both conductors, one behind the other, in the direction of said electron beam and transversely of said beam so as to allow said beam to pass said apertures, said conductors for producing a magnetic deflecting field transversely of said beam.

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