

March 23, 1943.

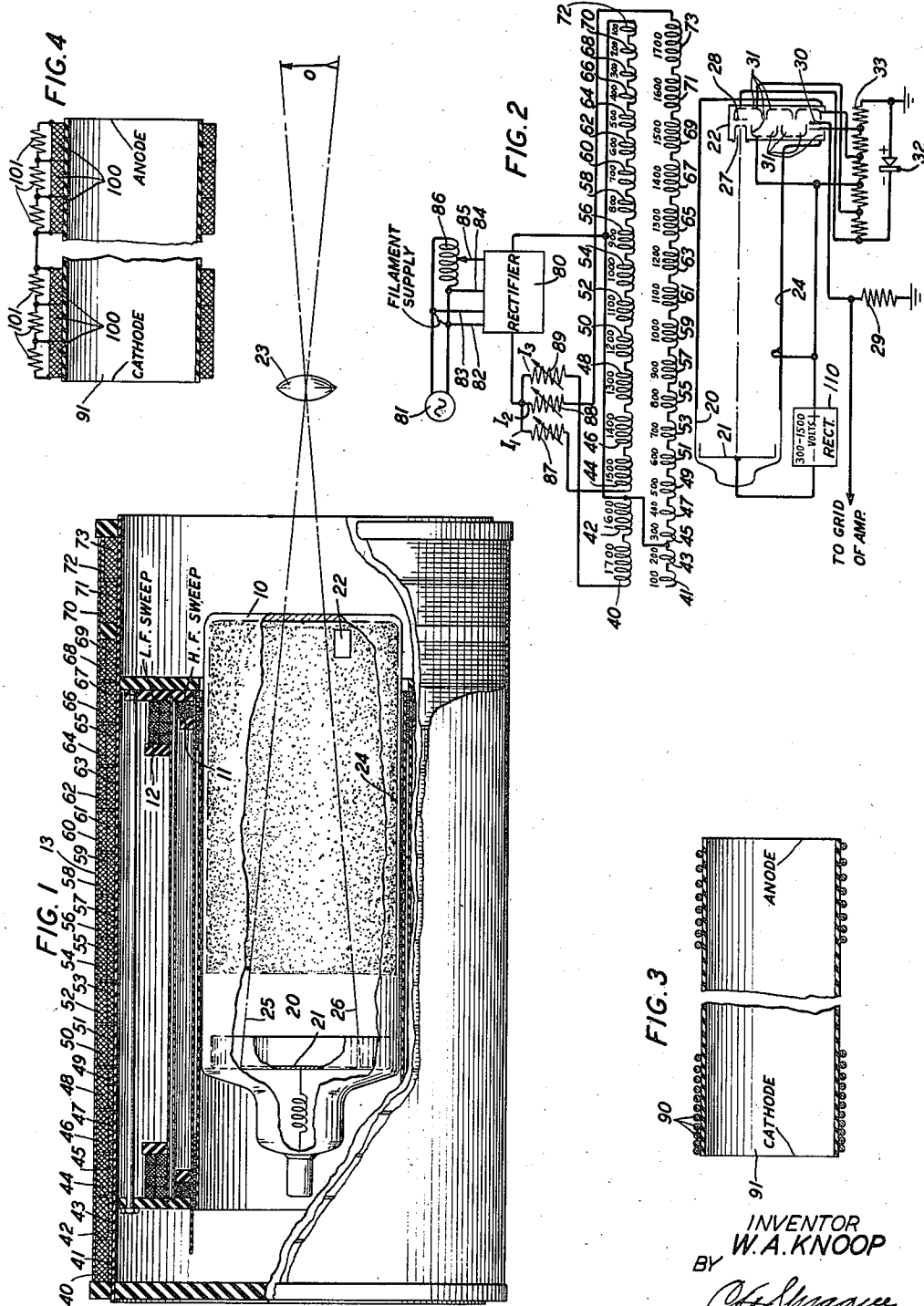
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2,314,409

MAGNETIC COIL STRUCTURE

Filed Sept. 28, 1940

3 Sheets-Sheet 1



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FIG. 5

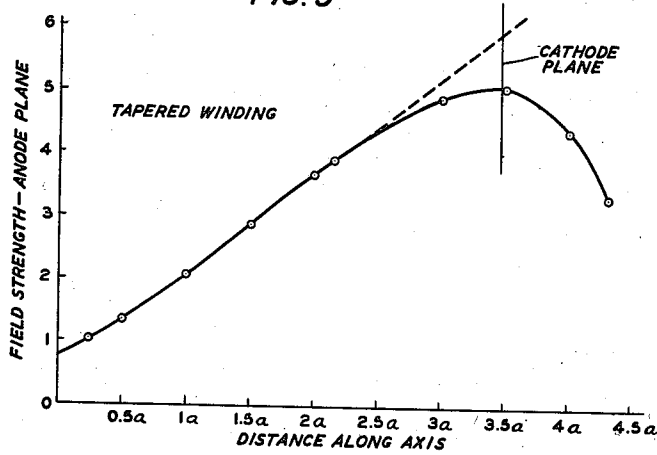
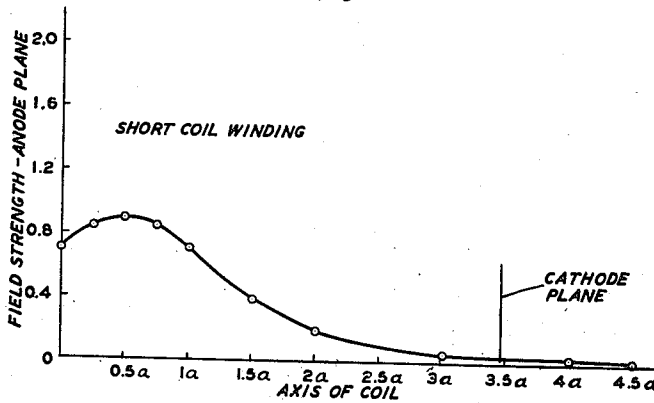


FIG. 6



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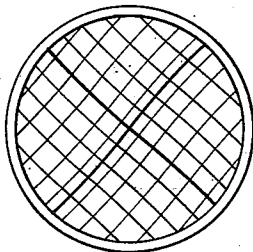
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MAGNETIC COIL STRUCTURE

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FIG. 7B



ANODE
PLANE

FIG. 7A

CATHODE
PLANE

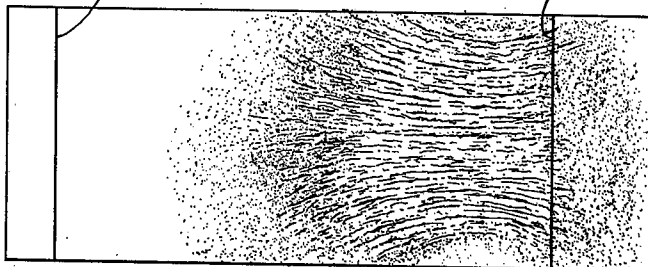
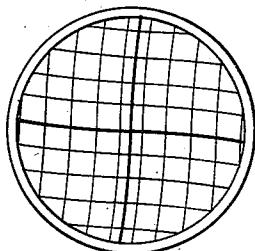


FIG. 8B



ANODE
PLANE

FIG. 8A

CATHODE
PLANE

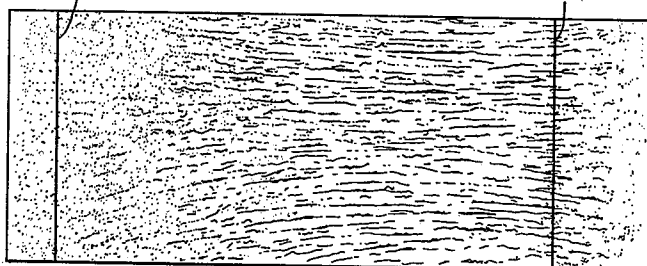
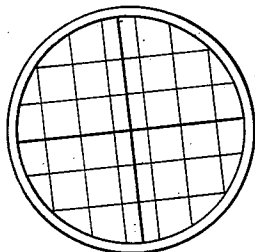


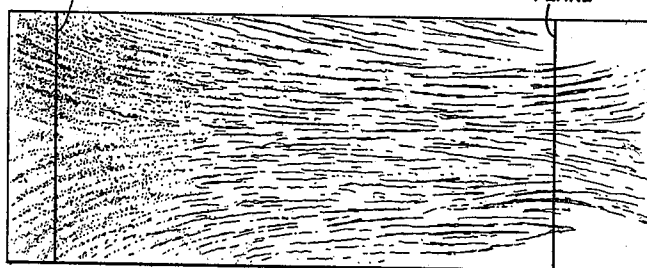
FIG. 9B



ANODE
PLANE

FIG. 9A

CATHODE
PLANE



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UNITED STATES PATENT OFFICE

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MAGNETIC COIL STRUCTURE

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Application September 28, 1940, Serial No. 358,795

13 Claims. (Cl. 250—161)

This invention relates to electron discharge devices and more specifically to magnetic focusing coil arrangements for cathode ray tubes used in television.

One well-known form of cathode ray pick-up device is called the dissector. In the usual dissector tube, an image of the object is formed on a photoelectric cathode thereby giving rise to a stream of electrons, various elemental portions of a cross-section of which correspond respectively to the corresponding elemental areas of the object. By means of suitable electromagnet deflecting coils, this stream is caused to move across a scanning aperture in such a way that each elemental portion of the stream passes in front of the aperture during each scanning interval. The electrons passing through the scanning aperture strike an anode member which usually is the first electrode of an electron multiplier in the output circuit of which is connected a signal resistance through which a television image current passes. When, for purposes of focusing, a magnetic field is produced by a short coil located near the cathode, the electron image is magnified, twisted as a whole, and the portions most distant from the center are twisted more than the central portion. This is because a velocity component at right angles to their previous direction is imparted to the electrons in the stream as they move across the lines of force just inside and outside the coil. As the field is not uniform in its curvature, the inside of the image is not twisted as much as the outside. The last-mentioned distortion is termed "S" distortion and can be easily observed on the screen of a receiving tube used to reproduce an image of the scanned object.

It is an object of this invention to reduce such distortions in cathode ray tubes, particularly in those of the dissector type.

In order to better understand the present invention, consider a tube of the well-known dissector type and, for simplification of the problem, let it be considered that all of the electrons emerge from the photosensitive cathode at right angles to the surface. Each electron will be accelerated by the electric field until it intersects the plane of the anode. This does not mean that it continues its original direction but rather that it tends to follow the lines of the electrostatic field. (There is no space charge.) Under these conditions the electrons form a density pattern at the plane of the anode and this pattern may be analyzed by moving it over an aperture. The trajectories followed by the above postulated electrons will be considered "ideal" trajectories. If a

solenoid is constructed and placed around the dissector tube so that the lines of force coincide with the "ideal" trajectories, the electrons will not be affected by the magnetic field. This is obvious when the moving charge or electron is considered as an element of conductor carrying a current. The force upon such a conductor tending to move it at right angles to a magnetic field is proportional to the magnitude of the current, the strength of the field and the sine of the angle between the conductor and a line of the magnetic field. If the angle is zero, the force is zero. The electron image in the scanning plane will have no twist and distortion imparted to it by the application of the magnetic field when the magnetic field has such form that its flux lines and the trajectories which the electrons would have in the electrostatic field alone coincide.

Although the electrons were assumed to be emerging from the cathode at right angles to the surface (and some of them actually do), by far the greater number of electrons emerge at other angles and at random velocities. These will move across the magnetic field and the result is that they are forced into a spiral path which encloses the central "ideal" trajectory. By adjusting the fields, all of the electrons from a given element on the cathode may be brought to a focus at the anode plane. It should be noted that although the electrons which are emitted with a radial component of velocity are constrained to follow spiral paths, the electron image as a whole when focussed does not experience any material twisting as long as the flux lines of the magnetic field coincide with the trajectories which the electrons would have in the electrostatic field alone.

In the dissector tube having a unipotential conducting coating on the inside walls thereof, the electric field expands between the cathode and anode plane in the direction of electron flow. In accordance with this invention, means are provided for creating a magnetic field of such a form that its lines of force substantially coincide with the trajectories which the electrons would have in the electric field alone. In the embodiment of the invention herein described, the specific means for producing such a field is a "tapered" winding.

It has been discovered that if a long "tapered" winding is used, a uniform radial field component can be attained and hence the twist of the image as a whole does not take place, contrary to what takes place when a short coil is used. In accordance with this invention, several types of long (approximately the length of the dissector, or longer) "tapered" windings are provided, the

strength of the field of the tapered coil preferably changing linearly with distance from the cathode plane over a wide range of distance in the direction of the anode. End correction windings may also be used or, if extra ampere turns are added at the high density end only, the linearity of this variation in strength of field can be extended over an even wider range.

In one embodiment of the invention, the "tapered" winding comprises two coils each having a plurality of sections, the number of turns per section in one of the coils decreasing uniformly from one end of the coil to the other end thereof and the number of turns of the other section increasing uniformly from the first end of the coil to the other end thereof. By controlling the current flow through each of these two coils any degree of taper in the strength of the magnetic field can be obtained. As a simplification only one coil may be used, the number of turns varying uniformly from one end of the coil to the other end thereof.

In another embodiment of the invention, the "tapered" winding comprises a coil in which the turns are spaced much closer together at one end than at the other end thereof. If desired, two such coils may be used in a manner similar to that of the first embodiment.

In a third embodiment of the invention, a coil is provided having a plurality of sections uniformly spaced and wound with equal numbers of turns, the sections being shunted so that the ampere turns per section decrease from one end of the coil to the other end thereof. Obviously, other means of forming "tapered" windings may be used and still be within the scope of this invention.

Each of the "tapered" windings of this invention is, in practice, adapted to magnify the electron image at the dissector aperture by a factor of approximately two substantially without any of the twist and end distortion resulting when short uniformly wound coils are used for magnification.

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 shows, in plan view, a dissector tube within a core structure which supports sweep and "tapered" focusing windings;

Fig. 2 is a schematic representation of an elevation of a dissector tube and one form of "tapered" winding;

Fig. 3 represents schematically a second type of "tapered" focusing winding;

Fig. 4 represents a third type of "tapered" winding; and

Figs. 5, 6 and 7 are graphical and pictorial representations to assist in the understanding of this invention.

Referring more specifically to the drawings, Fig. 1 shows, by way of example to illustrate the features of this invention, a dissector tube 10 contained within a core structure which acts as a support for a high frequency sweep winding 11, a low frequency sweep winding 12, and a "tapered" focussing winding 13.

The dissector 10 preferably comprises an envelope 20 having a photosensitive cathode 21 at one end thereof and a pick-up finger 22 at the other end thereof. The pick-up finger 22 preferably includes an electron multiplier as diagrammatically shown in Fig. 2. Radiations from an object O are projected by means of a suitable

optical system represented by the single lens 23 upon the photosensitive cathode 21. In order to prevent distortion caused by the curved field lines set up between the photosensitive cathode 21 and the near-end portion of the conducting coating 24 on the inside walls of the envelope 20 by the source of potential indicated schematically by the box 110, only a portion of the cathode is used as indicated by the boundary lines 25 and 26 of the cone of light from the lens system 23. The dissector operates in the usual manner, that is, a stream of photoelectrons from the photosensitive coating 21 is attracted toward the end of the tube containing the pick-up finger 22 behind an aperture 27 in which is located the first anode 28 of the electron multiplier shown in Fig. 2. The electron stream is caused to be deflected by the high frequency and low frequency sweep windings 11 and 12 so that every elemental portion of the stream in turn passes across the aperture 27 in the pick-up finger 22. Any suitable sweep windings may be used to which are applied currents of suitable frequency and of saw-toothed wave form to cause scanning. The electrons in the stream are multiplied in the multiplier to cause an output signal to flow in the resistance 29, which is connected to the output electrode 30 of the electron multiplier and to the grid of an amplifier tube. Appropriate potentials are applied to the electrodes 28, 30 and to the other electrodes 31 of the electron multiplier by any suitable means such as the rectifier 32 and potentiometer 33 containing a plurality of taps.

It is desirable to produce an enlarged electron image because of the relatively small portion of the cathode used. Accordingly, a "tapered" focusing winding in accordance with this invention is used. This winding produces a magnetic field, the lines of force of which tend to coincide with the trajectories which the electrons would have in the electrical field alone within the tube 20. One form which this winding may take is represented by the winding 13 in Figs. 1 and 2. This winding is divided into seventeen sections of two coils each, the top coils being indicated by the even reference characters 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70 and 72 while the lower coils are designated by the odd reference characters 41, 43, 45, 47, 49, 51, 53, 55, 57, 59, 61, 63, 65, 67, 69, 71 and 73. As an example of a suitable "tapered" focusing winding, reference is made to Fig. 2 which shows an arrangement in which the even-numbered coils 40 to 72, inclusive, progressively decrease in turns from 1700 to 100 while the odd-numbered coils 41 to 73, inclusive, increase in numbers of turns from 100 to 1700. As shown in Figs. 1 and 2 the total length of the winding 13 is much greater than the length of the dissector tube 10, which feature causes a decrease in the twist and "S" distortion. Current is supplied to the various sections of the coil 13 by means of a rectifier 80 which is supplied with alternating current from a source 81 acting through leads 82 and 83 to supply current to the filament of the rectifier and through leads 84 and 85 and an adjustable autotransformer 86 to supply power to the rectifier. Contained in the output circuit of the rectifier are three variable resistances 87, 88 and 89, the purpose of which is to control three currents designated respectively I₁, I₂ and I₃. Current I₁ passes through the even-numbered coil sections 44 to 72, inclusive. Current I₂ passes through the odd-numbered coils 45 to 73, inclusive, while current I₃ passes through coil sections 40 and 42.

By varying currents I_1 and I_2 , any desired degree of taper in the ampere-turns per coil section can be produced while variation of I_3 changes the magnetic field at one end of the coil 13 and thus produces end correction. A similar arrangement can be used at the other end of the coil, if desired.

In order to more fully understand how a tapered magnetic field can be produced with the coil shown in Figs. 1 and 2, consider first the coil section comprising the coils 44 and 45. The total ampere-turns for this coil section can be written, $1500 \times I_1 + 300I_2$ (plus the field from the other sections which for the moment will be neglected). Similarly the total ampere-turns for the section comprising the coils 46 and 47 can be written, $1400I_1 + 400I_2$ and the total ampere-turns for the section comprising the coils 48 and 49 can be written, $1300I_1 + 500I_2$. It is clear that the difference in ampere-turns between each adjacent coil section in the series is substantially $100(I_1 - I_2)$. It is thus clear that by varying I_1 and I_2 , a winding which will produce a tapering of ampere-turns in either direction may be produced, the direction being determined by the relative strengths of I_1 and I_2 . It is obvious that a variety of values may be assigned to the numbers of turns in the various coil sections, it being merely convenient for purposes of experiment and test to make the successive even-numbered windings differ by a hundred turns and each successive odd-numbered winding differ by the same amount. In the diagram shown in Fig. 2, the coils 41 and 43 are not connected to any source of current but it is obvious that they may be so connected, if desired.

The field produced at the center of coils 44 and 45 is that due to $1500I_1 + 300I_2$ plus the field from all the other sections. Calculating the field by the point-to-point method (using the formula given on page 359 of Foster and Porter's book "Electricity and Magnetism") and plotting field strength against distance along the axis between cathode and anode gives a curve which has uniform slope, i. e., is linear, over a large portion of the solenoid. Another way to calculate the field at any point is to use Laplace's rule. The departures from linearity at one end or the other of the curve can be corrected by the fields produced by end-correcting windings. In order to understand how the field differs in the "tapered" focusing coil from that produced by a short coil, Fig. 5 should be compared with Fig. 6. Both plots represent field strength in arbitrary units along the axis of the coil. The strength of the field of the tapered coil changes linearly with position along the axis over a wide range. If an "end-correction" winding is used or if extra ampere-turns are added at the high density end, the upper part of the curve shown can be raised (as indicated by the dashed lines) to make it linear to the point marked "cathode plane." In fact experiment shows this corrects the last vestiges of the "S" distortion. The same result could be attained by using a longer coil so that the demagnetizing effect of the end would not spoil the linearity at the cathode.

Figs. 7 to 9, inclusive, are reproductions of photographs of three field conditions made visible by the use of iron filings in a dummy dissector. Fig. 7A shows the field distribution when a short focusing coil is used and Fig. 7B shows the twist and "S" distortion produced by such a field. Fig. 8A shows the field of the tapered coil and Fig. 8B the corresponding electron-optical image produced on the screen of the dummy dissector.

Figs. 9A and 9B show the result of adding end-corrections to the tapered coil. The current in the last section at the cathode end was made five times that in the remainder of the "tapered" winding. Additional turns were added at the weak or anode end. The same current used in the tapered section was passed through the anode end-correction coil. The magnification was controlled by altering the current through the correction winding at the cathode end without causing much distortion.

By means of this long tapered magnetic field, the lines of which substantially coincide with the trajectories which the electrons would have in the electric field alone, that is, the field produced within the dissector tube 10 by the potentials applied to the cathode 21, the anode 22 and the conducting coating 24, the image observed at the receiving station is an accurate reproduction of the object at the transmitting station, there being no twist or S distortion.

Another form of "tapered" winding is shown in Fig. 3. In this figure a plurality of windings 99 have been shown, these being wound closer together at the left-hand side of the core 91 than at the right-hand side of the core. The windings 99 are merely schematic as it is obvious that each of the windings 99 may constitute a coil of many turns. The cathode and anode ends of the dissector have been indicated in Fig. 3, the dissector with its sweep windings being in practice inserted within the core 91 as in the case of the core shown in Fig. 1. With a uniform variation in spacing of the winding, there will be a uniform taper to the magnetic field produced by these windings. The arrangement shown in Fig. 3 is not as flexible as the arrangement shown in Figs. 1 and 2, however, as in the arrangement shown in these figures it is only necessary to vary the resistances 87, 88 and 89 to change the degree of taper (of ampere-turns) or even to reverse it in direction.

Fig. 4 shows another form of a "tapered" winding, the cathode and anode ends of which are indicated as in Fig. 3. In this arrangement a plurality of coils 100 having equal numbers of turns are wound on the core 91. Each of the coils 100 is shunted by a resistor 101 which may be varied to change the amount of current flowing through each of its corresponding windings 100 and thus to vary the ampere-turns for each section. In this way a tapered magnetic field can be produced.

It is obvious that many changes may be made in the embodiments herein described and other modifications may be made without departing from the spirit of the invention the scope of which is indicated by the appended claims.

What is claimed is:

1. In combination, a cathode ray television transmitter tube, and an electromagnetic coil disposed thereabout, said coil having an axial dimension at least substantially equal to the ray path in said tube, and means including apparatus for passing current through said coil to produce a field which decreases uniformly from a plane near one end of the tube to a plane near the other end thereof.

2. In combination, a cathode ray tube of the type wherein a beam of relatively large cross-sectional area compared with the size of an elemental area of an object to be televised is formed, and an electromagnetic coil disposed thereabout, said coil having an axial dimension at least substantially equal to the ray path in said tube and

which produces a field which decreases uniformly from a plane perpendicular to the axis of the tube and near one end of the tube to a parallel plane near the other end thereof.

3. Means for producing a magnetic field, comprising a magnetic coil characterized in that the number of turns per unit axial length of said coil increases from one point thereof to a second point thereof, a second magnetic coil coaxial with said first coil and characterized in that the number of turns per unit axial length of said coil decreases from a point thereof adjacent said first point on the first coil to a second point thereof adjacent said second point on the first coil, means for passing current through each coil, and means for varying the current through one coil independently of the current through the other.

4. In combination, a cathode ray tube, an electromagnetic focusing coil disposed thereabout, said coil having an axial dimension at least substantially equal to the ray path in said tube and having a plurality of sections uniformly spaced and wound with the same number of turns, and means for shunting certain of said sections at least so that the ampere-turns per section decrease from one end of said coil to the other end thereof in substantially equal steps.

5. In combination, a cathode ray tube, an electromagnetic focusing coil disposed thereabout, said coil having an axial dimension at least substantially equal to the ray path in said tube and being so wound that the turns thereof are spaced closer together at one end thereof than at the other end thereof, the distance between adjacent turns being a maximum at one end of the coil and a minimum at the other end thereof.

6. In combination, a cathode ray tube of the dissector type, an electromagnetic focusing coil disposed thereabout, said coil having an axial dimension at least substantially equal to the ray path in said tube and also having a density of windings which is tapered from one end thereof to the other end thereof, and additional windings at at least one end of said coil to correct for end distortion within said tube.

7. In an electron camera tube arrangement, a photoelectric cathode, an electron collecting electrode, and means surrounding at least the greater portion of the space between said cathode and said collecting electrode for creating a focusing magnetic field the strength of which is a maximum at a plane transverse to the axis of said tube near said cathode and which decreases at a substantially uniform rate from said plane to the region of said collecting electrode.

8. In an electron camera tube arrangement, a photoelectric cathode, an electron collecting electrode, and means surrounding at least the greater portion of the space between said cathode and said collecting electrode for creating a focusing magnetic field the strength of which is a maximum at a plane transverse to the axis of said tube near said cathode and which decreases at a substantially uniform rate from said plane to the region of said collecting electrode, said means comprising a coil having a plurality of sections of increasingly greater number of turns in the direction from the cathode to the collecting electrode and a second coil of increasingly greater number of turns in the direction from the collecting electrode to the cathode.

9. In an electron camera tube arrangement, a photoelectric cathode, an electron collecting electrode, and means surrounding at least a greater

portion of the space between said cathode and said collecting electrode for creating a focusing magnetic field the strength of which is a maximum at a plane transverse to the axis of said tube near said cathode and which decreases at a substantially uniform rate from there to the region of said collecting electrode, said means comprising a coil having a plurality of sections of increasingly greater number of turns and a second coil of increasingly lesser number of turns, and means for varying the current through each of said coils to vary the number of ampere-turns for an element consisting of one section of each of said coils.

10. In combination, a cathode ray tube of the dissector type, an electromagnetic focusing coil disposed thereabout, said coil having an axial dimension at least substantially equal to the ray path in said tube and arranged so that the number of ampere-turns per section of said coil is tapered from one end thereof to the other end thereof, and additional windings at at least one end of said coil, and means for varying the current through said additional windings to correct for end distortion within said tube.

11. The method of varying the taper of a magnetic field produced by two coils each comprising a plurality of sections and in one of which the number of turns per section increases from one point thereof to another point thereof in progressive steps while in the other coil the number of turns per section decreases between these same two points at the same rate, which comprises varying the current through one coil independently of the current through the other.

12. A television transmitter arrangement comprising a cathode ray device having a photo-sensitive cathode, means for projecting radiations from an object upon a portion only of said cathode, means to produce thereby a stream of electrons, the electron charge at any elemental portion of a cross-section of which corresponds respectively to the light-tone value of a corresponding elemental area of an object or field of view, a pick-up electrode for said stream, an apertured diaphragm in front of said electrode, means for causing said stream to be deflected so that every elemental area in turn of said stream passes across said aperture, and means for producing an enlarged electron image of said photo-sensitive cathode at a plane closely adjacent said aperture, said means comprising an electromagnetic coil having an axial dimension at least substantially equal to the distance between said cathode and said apertured diaphragm.

13. A television transmitter arrangement comprising a cathode ray device having a photo-sensitive cathode, means for projecting radiations from an object upon a portion only of said cathode, means to produce thereby a stream of electrons, the electron charge at any elemental portion of a cross-section of which corresponds respectively to the light-tone value of a corresponding elemental area of an object, a pick-up electrode for said stream, an apertured diaphragm in front of said electrode, means for causing said stream to be deflected so that every elemental area in turn of said stream passes across said aperture, and means for producing an enlarged electron image of said photosensitive cathode at a plane closely adjacent said aperture, said means comprising an electromagnetic winding which produces a magnetic field tapering in intensity from the region near the cathode to the region near the apertured diaphragm.

14. In combination, supporting means defining a space to receive a tube having means for setting up an electrostatic field therein, a photoelectric cathode arranged within said tube at one end thereof in such a position that electrons emitted therefrom are acted upon by said electrostatic field, a target member, an electromagnetic focussing winding carried by said supporting means, the axis of said winding coinciding with that of the tube and said winding being so disposed that the magnetic flux therefrom substantially coincides with the trajectories electrons from said cathode would have in the electrostatic field alone between said cathode and a plane containing said target member.

15. The combination with a tube in which a space current flows, of means for producing an electrostatic field through which said current passes of such form that the current density would change progressively in a direction parallel to that of the center line of current flow if said field were acting alone, and means for setting up a magnetic field in the space through which the current flows the strength of which latter field varies progressively in said parallel direction and in the same sense as would the current density under influence of said electrostatic field alone.

16. The combination with an electronic beam tube, of means for producing an electrostatic field through which said beam passes of such form that the beam density would change pro-

gressively in a direction parallel to the beam axis if said field were acting alone, and means for setting up a magnetic field through which said beam passes the strength of which field varies progressively in said parallel direction and in the same sense as would the beam density under influence of said electrostatic field alone.

17. The combination of claim 16 in which said means for producing said two fields cause the lines of force of the one to substantially coincide with those of the other.

18. In combination, supporting means defining a space to receive a tube having means for setting up an electrostatic field therein, a photoelectric cathode arranged within said tube at one end thereof in such a position that the electrons emitted therefrom are acted upon by said electrostatic field, a target member, and an electromagnetic focussing winding carried by said supporting means, the axis of said winding coinciding with that of the tube and said winding being so disposed that the magnetic flux therefrom substantially coincides with the trajectories electrons from said cathode would have in the electrostatic field alone between said cathode and a plane containing said target member, the strength of the magnetic field produced by the electromagnetic focussing winding decreasing substantially linearly from a point near said cathode to a point near the end of said tube remote from said cathode.

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