Aug. 18, 1942. A. M. SKELLETT 2,293,567

ELECTRON DISCHARGE APPARATUS

Filed June 27, 1940 3 Sheets-Sheet 1

FIG. 2

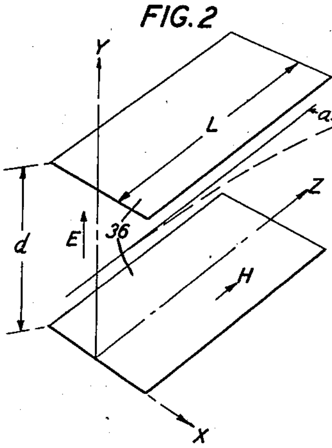



FIG. 1

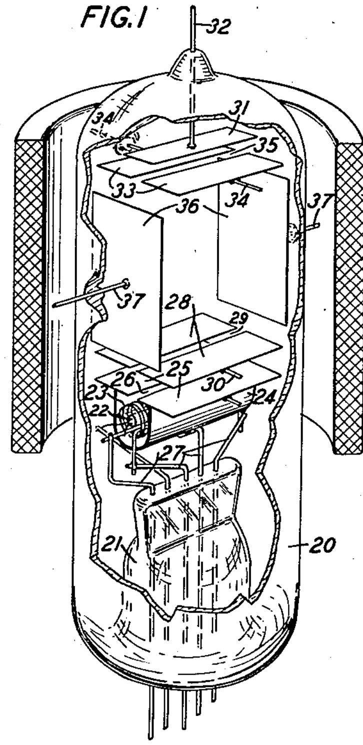



FIG. 3

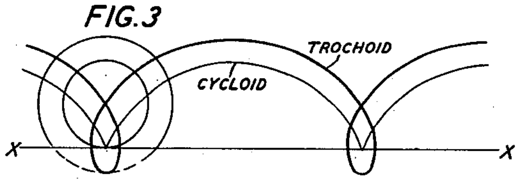



FIG. 4

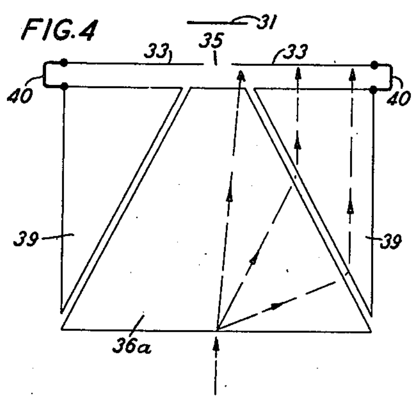
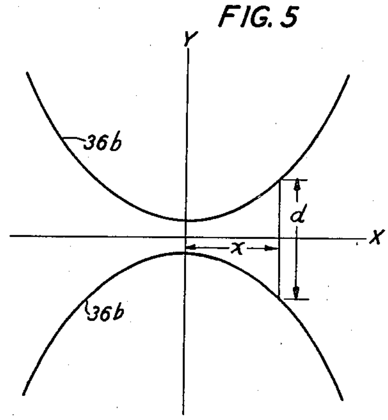



FIG. 5




INVENTOR
A. M. SKELLETT
BY
Walter C. Kiesel
ATTORNEY

Aug. 18, 1942. A. M. SKELLETT 2,293,567

ELECTRON DISCHARGE APPARATUS

Filed June 27, 1940 3 Sheets-Sheet 2

FIG. 6

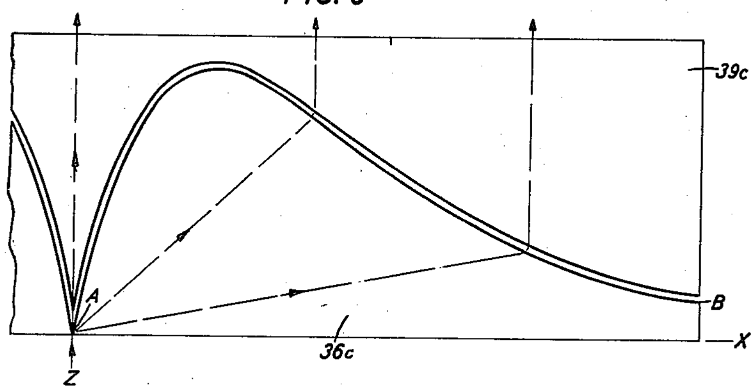



FIG. 7

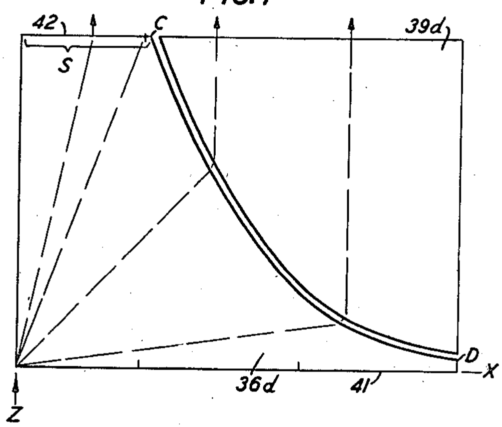



FIG. 8

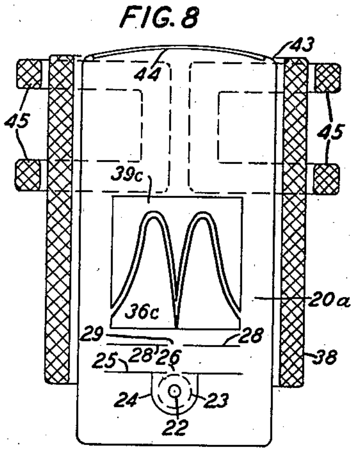
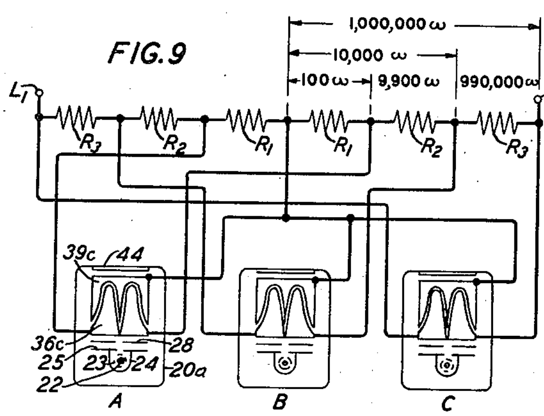



FIG. 9




INVENTOR
A. M. SKELLETT
BY
Walter C. Kiesel
ATTORNEY

Aug. 18, 1942. A. M. SKELLETT 2,293,567

ELECTRON DISCHARGE APPARATUS

Filed June 27, 1940 3 Sheets-Sheet 3

FIG. 10

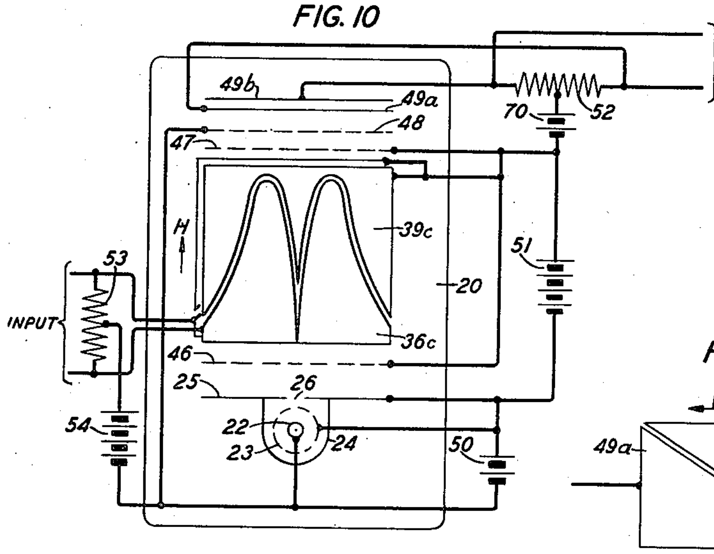



FIG. 11

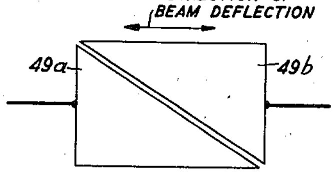



FIG. 12

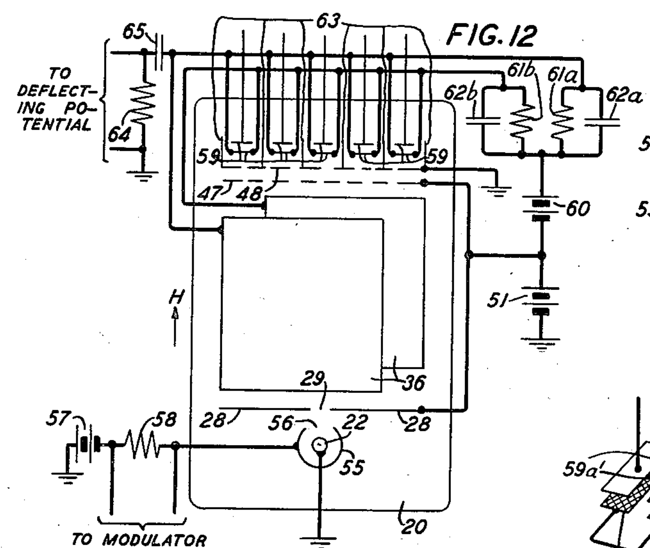



FIG. 13

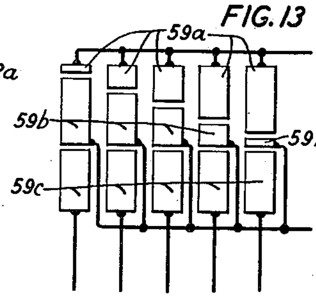
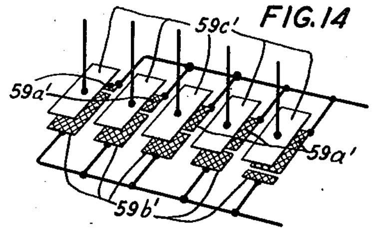



FIG. 14




INVENTOR
A. M. SKELLETT
BY
Walter C. Kiesel
ATTORNEY

# UNITED STATES PATENT OFFICE

2,293,567

## ELECTRON DISCHARGE APPARATUS

Albert M. Skellett, Madison, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 27, 1940, Serial No. 342,601

20 Claims. (Cl. 250—157)

This invention relates to electron discharge apparatus and more particularly to such apparatus including a device or devices of the cathode ray or electron beam type.

Electron discharge devices of the beam type are utilizable in a variety of applications, such as oscillographs, amplifiers, oscillators, harmonic generators and electronic switches, and comprise, in general, an electrode or electrode system, such as an electron gun, for producing a beam of electrons, an electron receiving element or series of such elements, such as a fluorescent screen or one or more targets, upon which the beam impinges, and means for deflecting the electron beam so that it sweeps across the screen or target or shifts from one target to another.

In such devices, among the principal problems encountered are the realization of a sharp focus of the electron beam upon the electron receiving element, the maintenance of such sharp focus during the deflection of the beam, and the attainment of deflection of the beam with small expenditure of power in the deflecting system. In devices operable at relatively low voltages, it has been found that magnetic focusing is advantageous in that it enables bringing to a focus electrons which emanate at widely different angles from the cathode. On the other hand, electrostatic deflection of the beam is more advantageous in most cases than magnetic deflection, principally because of the relatively large power losses associated with magnetic deflection. When electrostatic fields are utilized for deflecting magnetically focused beams, the electron trajectories are somewhat complex so that in devices used heretofore, sharp focusing of the beam has not been maintained.

Furthermore, in cathode ray or electron beam devices of the deflection type known heretofore, the deflection of the beam is more or less linearly proportional to the deflecting field so that the potential range of the devices has been limited and in such devices utilized for harmonic generation and oscillation, the ratio of the duration of the pulse produced to the interval between pulses has been relatively low.

A further limitation of cathode ray or electron beam discharge devices encountered heretofore is that of power capacity due to the restrictions of beam current occasioned by the small cross-sectional area of the electron beams employed.

One general object of this invention is to improve the operating characteristics of electron discharge devices of the cathode ray or electron beam type.

More specifically, objects of this invention are to:

Increase the power capacity and efficiency of electron discharge devices of the cathode ray or electron beam type;

Enable the realization and maintenance of a sharp focus of electron beams which are focused magnetically and deflected electrostatically;

Reduce the magnitude of the beam deflection for a given deflecting potential whereby the ratio of the duration of the pulse, in devices such as harmonic generators, to the interval between pulses is increased;

Obtain a non-linear, e. g., logarithmic or exponential relation between beam deflection and deflecting potential; and

Improve the operation of electronic switches of the electron beam type.

In accordance with one feature of this invention, an electron discharge device of the general construction described hereinabove comprises an electrode system including a cathode for producing a beam of thin rectangular cross-section, means for producing a magnetic field having its lines of force parallel to the direction of travel of the undeflected beam and a pair of electrostatic deflector plates parallel to the shorter cross-sectional dimension of the beam, the magnetic field and accelerating potential upon the electrons in the beam being so related that the beam is sharply focused immediately adjacent the end of the deflecting plates remote from the cathode.

In accordance with another feature of this invention, field plates may be associated with the deflector plates to reduce the ratio of beam deflection to deflecting potential and to avoid effects at the ends of the deflector plates.

In accordance with a further feature of this invention, the deflector plates are so constructed and arranged that the beam deflection is an exponential or logarithmic function of the deflecting potential.

In accordance with still another feature of this invention, in an electronic switch of the beam type, means are provided for automatically holding the beam upon a desired one of a series of targets when the beam is deflected to impinge upon this target.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is a perspective view of electron discharge apparatus illustrative of one embodiment of this invention, a portion of the enclosing vessel of the electron discharge device and a portion of the focusing coil being broken away to show details of the construction more clearly;

Fig. 2 is a diagrammatic view illustrating the beam deflecting system in the apparatus shown in Fig. 1 and indicating the direction of deflection with respect to the axes of the system;

Fig. 3 is a diagrammatic view showing the electron trajectories of the deflected beam as projected upon a plane normal to the direction of travel of the beam from the electron gun to the target or anode;

Fig. 4 is a detail plan view of a modification of the beam deflecting system in the apparatus shown in Fig. 1;

Fig. 5 is an end view of another beam deflecting system constructed in accordance with this invention wherein the deflection of the beam is proportional to the logarithm of the deflecting potential;

Fig. 6 is a partial plan view of another beam deflecting system constructed in accordance with this invention wherein the deflection is proportional to the logarithm of the deflecting potential;

Fig. 7 is a plan view of still another beam deflecting system constructed in accordance with this invention wherein, throughout a portion of the beam swing, the deflection is linear with respect to the deflecting potential and throughout another portion the deflection is proportional to the logarithm of this potential;

Fig. 8 is an elevational view, partly diagrammatic, of a cathode ray oscillograph including a beam deflecting system constructed in accordance with this invention;

Fig. 9 is a circuit diagram of cathode ray oscillograph apparatus including devices of the construction illustrated in Fig. 8;

Fig. 10 is a diagrammatic view of a deflection type amplifier illustrative of another embodiment of this invention;

Fig. 11 is a detail plan view showing the configuration and relation of the targets or anodes in the device illustrated in Fig. 10;

Fig. 12 is a view, partly diagrammatic and partly schematic, of an electronic switch illustrative of another embodiment of this invention;

Fig. 13 is a detail view illustrating the construction and relation of the electron receiving elements in the device shown in Fig. 12; and

Fig. 14 is a detail view in perspective illustrating a modification of the electron receiving element structure shown in Fig. 13.

Referring now to the drawings, the electron discharge device shown in Fig. 1 comprises an evacuated enclosing vessel 20 having at one end thereof an inwardly extending stem 21 from which an electrode system or electron gun for producing a concentrated electron beam of elongated rectangular cross-section is supported.

The electron gun comprises an elongated linear cathode 22, which may be of the indirectly heated equipotential type as shown or may be of other forms, for example filamentary, a cylindrical grid 23 coaxial with the cathode 22, and a shield electrode including a U-shaped portion 24 coaxial with the cathode 22 and a pair of coplanar plates 25 extending normal to the longitudinal axis of the envelope 20 and spaced from each other to define an elongated linear aperture or slit 26 parallel to and in alignment with the cathode 22. The various electrodes enumerated may be supported by leading-in conductors 27 sealed in the stem 21 as shown.

Mounted parallel to the plates 25 are a pair of coplanar plates 28 spaced to define an elongated aperture or slit 29 parallel and in alignment with the cathode 22 and the slit 26. The plates 28 may be supported by rigid leading-in conductors 30, only one of which is shown, sealed in and extending from the side wall of the vessel 20.

An anode or target 31 is mounted adjacent the other end of the vessel 20, in parallel alignment with the apertures or slits 26 and 29, and is supported by a leading-in conductor 32 sealed in the end of the vessel 20. A pair of coplanar barriers or screens 33 are supported opposite the electron receiving face of the target or anode 32 by leading-in conductors 34 sealed in the side wall of the vessel 20 and are spaced from each other to define an elongated aperture or slit 35 in alignment with the slits 26 and 29.

Extending between the plates 28 and barriers 33 are a pair of parallel, rectangular deflector plates 36 which are positioned normal to the major dimension of the slits 29 and 35 and are supported by rigid lead-in conductors 37 sealed in and extending from the side wall of the enclosing vessel 20.

The vessel 20 is encompassed by a cylindrical coil 38 which, when energized, produces a magnetic field having its lines of force parallel to the plane of the deflector plates 36 and directed toward the target or anode 31.

During operation of the device, the shield electrode 24 may be maintained at a small positive potential with respect to the cathode. The plates 28 may be connected together and maintained at a higher positive potential with respect to the cathode. The barrier plates 33 likewise may be connected together electrically and maintained at the same potential as that of the plates 28. The target or anode 31 is maintained at a still higher positive potential. The deflector plates 36 are maintained, for zero deflection, at the positive potential of plates 28 and 33. Thus the electron is not accelerated or decelerated in the Z direction in passing between the deflectors 36.

The electrons emanating from the cathode 22 are concentrated into a relatively thin beam emerging from the slit 29 and this beam is focused, by the magnetic field produced by the coil 38 first upon slit 29 and again upon the slit 35. The intensity of the beam may be controlled by suitable potentials, positive or negative, impressed upon the grid 23. When the deflector plates 36 are at the same potential, the beam will pass through the slit 35 and impinge upon the target or anode 31. However, if a potential difference is established between the two deflector plates 36 (one plate above and one below the zero deflection potential), the beam will be deflected parallel to the plates 36, that is, normal to the electric field between the plates, and impinge upon one or the other of the barriers or screens 33. If a sinusoidally varying potential is impressed between the deflector plates 36, the beam will be deflected back and forth across the slit 35 so that the current to the target or anode 31 will be composed of a plurality of pulses occurring at a frequency twice that of the deflecting potential. It will be noted that the beam is moving at its greatest speed when the pulses are generated so that the pulses are sharp and rich in harmonics.

The operation of the device will be understood more clearly from Fig. 2 wherein the X, Y and Z directions indicated correspond respectively to the shorter dimension of the slits **29** and **35**, the direction of the electric field E between the deflector plates **36** and the direction of the undeflected beam. The magnetic field H is parallel to the Z direction as shown. L is the length of the deflector plates and $d$ is the distance between the plates.

It will be noted that electrons projected between the plates **36** in the Z direction are influenced by two fields, namely, the magnetic field H parallel to the Z direction and an electric field in the Y direction. Hence, the electrons will traverse the spiral paths in passing between the deflector plates **36** in the Z direction. The trajectories of the electrons may be determined mathematically in the following manner. Assuming, for the moment, that the electrons injected between the deflector plates **36** have no velocity in the XY plane it can be shown that the equations for the electron motion are

$$x=\frac{E}{d\omega H}(\omega t-\sin \omega t) \qquad (1)$$

and

$$y=\frac{E}{d\omega H}(1-\cos \omega t) \qquad (2)$$

where $\omega$ is the angular velocity with which the electrons spiral around the magnetic lines of force. These, as will be apparent, are the equations of a cycloid and represent a combination of translational and rotating motions. The translational motion, it will be noted, is in the X direction, that is, at right angles to the electric field. When $\omega t=90$ degrees, the rotational velocity is in the Y direction and its X component is zero so that at this point in the trajectory the X velocity is equal to the translational velocity. The translational velocity, $v_t$, may be expressed as

$$v_t=\frac{Ec}{dH} \qquad (3)$$

where $c$ is the velocity of light and the remaining characters are as defined heretofore.

It is a known property of cycloidal motion that the rotational velocity $v_r$ is equal to the translational velocity. The radius $r$ of the rotating motion, then, can be shown to be

$$r=\frac{Emc^2}{dEH} \qquad (4)$$

where $m$ is the electron mass and the other characters are as defined heretofore.

In an actual discharge device, most of the electrons injected into the region between the deflector plates **36** will have some velocity in the XY plane. For this condition, the trajectories of the electrons as projected on the XY plane are trochoids, as illustrated in Fig. 3. The translational velocity for the trochoid is the same as that for a cycloid so that the Equation 3 still applies. However, the radius of curvature as given by Equation 4 will be changed because of the increase in length of the rotating vector. The radius $r'$ can be shown to be, in practical units,

$$r'=\frac{3.37\sqrt{E'}}{H}+\frac{5.68E}{dH^2} \qquad (5)$$

where E' is the component of voltage in the XY plane through which an electron would have to fall in order to receive the initial velocity in the XY plane.

Now, if the deflector plates are made of such length that in passing through their field an electron completes an integral number of revolutions, the beam will be deflected at right angles to the deflecting field and parallel to the plates with no apparent deflection in any other direction. This condition may be realized, of course, by correlating the magnetic field and the electric field through which the electrons fall with the geometry of the device. The relative values of potential and field requisite to produce the desired focusing may be calculated. After the electron beam leaves the region between the deflector plates it suffers no more deflection and the electron receiving element, therefore, may be mounted in proximity to or remote from the end of the deflector plates depending upon the particular requirements of the device. In all cases, the coil **38** preferably is coextensive with the entire electron path from the cathode to the electron receiving electrode, or longer than this path.

The deflection sensitvity may be determined from the ratio of the transverse to the longitudinal velocities, thus

$$\frac{a}{L}=\frac{v_t}{v_l}=\frac{Ec}{dH}\sqrt{\frac{m}{2Ve}} \qquad (6)$$

where $a$ is the deflection, V is the voltage on the electron in the Z or longitudinal direction, $v_l$ is the electron velocity corresponding to the voltage V, $e$ is the electron charge and the remaining characters are as defined heretofore. In practical units, Equation 6 becomes

$$a=\frac{1.688EL}{dH\sqrt{V}}cm. \qquad (7)$$

From Equation 7, it will be noted that for deflector plates of a given length, the sensitivity of deflection varies inversely with the distance $d$ and field H. Hence, these parameters preferably are made as small as practical subject to the limitation, however, that the field H shall not be smaller than that for which $r'$, as given by Equation 5 is of the same order of magnitude as the distance $d$.

As noted heretofore, in the device illustrated in Fig. 1 there will be two pulses of current to the anode **31** for each cycle of the deflecting voltage. The ratio of the duration of each pulse to the time interval between them may be expressed as

$$\frac{t_p}{t_1}=\frac{2 \text{ arc sin } \frac{a}{b}}{\pi} \qquad (8)$$

where

$t_p$= duration of each pulse
$t_1$= interval between pulses
$a$= one-half the width of the slit **35** and
$b$= maximum deflection of the beam to one side or the other of the center of the slit **35**.

The magnitude of this ratio, which defines the sharpness of the pulses, it will be seen, can be increased by decreasing the value of $b$. One deflection system for obtaining a smaller maximum deflection than is obtainable with the parallel rectangular deflector plates shown in Fig. 1 comprises, as illustrated in Fig. 4, parallel trapezoidal deflector plates **36a** and triangular field plates **39** coplanar with the deflector plates, the hypothenuse of each field plate **39** being opposite and parallel to an inclined side of the deflector plate coplanar therewith. The field plates may be connected as shown to the shield or barrier plates **33** by conductors **40**. The trajectories of the beam for several values of deflecting potential are indicated by the broken lines in Fig. 4, from which the decrease in deflection will be apparent.

The deflection amplitude may be made to vary other than linearly with respect to the deflecting potentials. For example, as illustrated in Fig. 5, the deflector plates **36b** may be rectangular and curved so that the distance between them varies with the X distance. If the spacing between the plates **36b** varies in the relation

$$d=e^x$$

where $d$ is the spacing, $e$ the Naperian base and $x$ distance along the X axis, the deflection $x$ may be expressed by the relation

$$x=\log_e E+\log_e \frac{Tc}{H} \qquad (9)$$

where T is the time required for an electron to pass between the plates in the Z direction and the remaining characters are as defined heretofore. Inasmuch as T, $c$ and H are constants in any particular device, the second term on the right in Equation 9 will be a constant and, therefore, the deflection will be proportional to the logarithm of the deflecting potential.

Although the Naperian base has been utilized in the foregoing, it will be understood, of course, that the base **10** also may be employed, in which case the shape of the deflector plates will be given by the relation

$$y=\tfrac{1}{2}\ 10^x$$

It will be understood further that the deflector plates may be shaped so that the deflection varies as any other desired function, other than the exponential ones noted specifically, or the deflecting potential.

A logarithmic relationship between the deflection and the deflecting potentials may be obtained also by varying the length of the deflector plates, in the Z direction, in an appropriate manner, as will be seen from Equation 7. For example, if the deflector plates are so shaped that

$$L=\frac{x}{e^x}$$

then

$$e^x=\frac{1.688E}{dH\sqrt{V}} \qquad (10)$$

from which it will be apparent that the deflection $x$ will be proportional to the logarithm of the deflecting voltage E. The edges of the deflector plates on either side of the YZ plane, then should follow the relation

$$Z=\frac{x}{e^x}$$

Of course, here again, the base **10** may be employed instead of the Naperian base. The configuration of the deflector plates in such a device, that is wherein the deflection is proportional to the logarithm to the base **10** of the deflecting potential, is illustrated in Fig. 6. Each deflector plate comprises two similar halves, the edge AB of which follows the relation

$$Z=K\frac{x}{10^x} \qquad (11)$$

where K is a constant. The edges of the field plates **39c** will follow similar curves as shown. These plates **39c**, similarly to the plates **39** in Fig. 4, are coplanar with the corresponding deflector plate and are maintained at the accelerating potential of the electrons. For example, they may be connected directly to the baffle or shield plates **33**.

In Fig. 6, the broken lines indicate the beam paths for various deflecting potentials.

The actual configuration of the curved edges AB may be varied over a wide range by varying the constant K in Equation 11. If this constant is made unity, the deflector plates **36c** will be relatively short as shown in Fig. 6. If K is made greater than unity, these plates will be elongated as illustrated in Figs. 8 and 10.

The deflection may also be made proportional to negative values of the exponent, $e$ or 10. In this case, as shown in Fig. 7 wherein half of a deflector plate **36d** and field plate **39d** are illustrated, each deflector plate comprises a plane plate having parallel sides **41** and **42** and similar curved sides CD, only one of which is shown. The curved side CD is of the form given by the relation

$$x=S+\log E=\frac{1.688Ez}{dH\sqrt{V}} \qquad (12)$$

where S is the distance from the Z axis to the end of the side **42** as shown in Fig. 7. The field plates **39d** are coplanar with the corresponding deflector plate **36d** and are maintained at the accelerating potential of the electrons. To the left of point C in Fig. 7, the deflection will be linear with respect to the deflecting potential; to the right of this point, the deflection will be proportional to the logarithm of the deflecting voltage and, on a decibel scale, the decibel units will be linearly placed.

It will be understood that if deflections to only one side of the axis are to be utilized, the deflection system may be of the construction illustrated in Fig. 7. If, however, deflections to both sides of the axis are utilized, the deflection system would include deflector and field plates composed of two portions of the form shown in Fig. 7 and symmetrical with respect to the Z axis.

Deflector plates of such construction that the deflection is proportional to the logarithm of the deflecting potential, as described hereinabove, may be used to advantage in cathode ray oscillographs inasmuch as, in effect, compression of a large range of voltages may be achieved and, furthermore, the deflection can be calibrated in decibel units. Illustrative oscillograph apparatus is shown in Figs. 8 and 9. The device shown in Fig. 8 includes a beam producing system or electron gun similar to that shown in Fig. 1 and a deflection system similar to that illustrated in Fig. 6 of such construction that the deflection of the beam is proportional to the logarithm of the deflecting voltage. The end wall **43** of the enclosing vessel **20a** has thereon a fluorescent screen **44** upon which the beam will impinge and the outer face of this wall may have thereon a scale in decibel units. The potential to be measured is impressed between the deflector plates **36c**. The field plates **39c** may be maintained at a suitable positive potential such that, as described heretofore, the beam is brought to a sharp focus as it issues from between the field plates and onto the fluorescent screen.

Fig. 9 illustrates apparatus suitable for measuring a wide range of potentials, for example from 0 up to 1,000,000 volts. As shown, it comprises three devices of the construction illustrated in Fig. 8, each device being utilized to cover a range of two logarithmic decades of potential. That is, device A is utilized to cover the first two decades, i. e., 0 volts to 100 volts, device B covers the next two decades, i. e., 100 volts to 10,000 volts, and device C covers the next two decades, i. e., 10,000 volts to 1,000,000 volts.

The voltage to be measured is impressed between the terminals $L_1$ and $L_2$ of a potentiometer shown as composed of resistances $R_1$, $R_2$ and $R_3$, typical values of which are indicated on the drawings, it being understood that the resistances identified by the same reference character have the same resistance. The deflector plates of device A are connected across the resistances $R_1$, those of device B are connected across the outer terminals of resistances $R_2$, and those of device C are connected across the outer terminals of resistances $R_3$, so that, as will be apparent, the deflection potential impressed across the deflector plates of device B will be one-hundredth of that across the deflector plates of device A and that impressed across the deflector plate of device C will be one ten-thousandth of that impressed across the deflector plates of device A.

Any potential impressed across the terminals $L_1$ and $L_2$ will be indicated only upon the proper device inasmuch as the deflection will be off the scale of the more sensitive device or devices and will be substantially zero on the less sensitive device or devices.

It will be understood, of course, that although three devices have been shown in Fig. 9, a greater or lesser number of devices may be employed. Also, although the devices illustrated in Fig. 9 have been shown as including deflection systems of the type illustrated in Fig. 6, deflection systems of the type shown in Fig. 7 also may be employed.

In some applications, it may be desirable to have an indication of the variations in the deflecting voltage in relation to some other variable, such as time. This may be realized by varying the direction of the magnetic field in accordance with variations in such other variable. This, in turn, may be accomplished by a pair of coils **45**, shown in Fig. 8, energized to deflect the beam at right angles to the deflection caused by the deflecting voltage impressed between the deflector plates of the device.

The invention may be embodied also in amplifiers as illustrated in Fig. 10 wherein the device includes an electron gun of the construction shown in Fig. 1 and described heretofore, a deflection system similar to that shown in Figs. 6 and 8, an accelerating grid **46** parallel to the plates **25**, a screen grid **47** and a suppressor grid **48** both parallel to the grid **46**, and an anode **49** parallel to the grids **47** and **48** and which, as shown in Fig. 11, comprises a pair of right triangular portions **49a** and **49b** having their hypotenuses in juxtaposition. The anode portions **49a** and **49b** are mounted so that the longer sides of the right angle are parallel to the direction of deflection of the beam.

During operation of the device, the grid **23** and shield electrode **24**, **25** are maintained at a positive potential, for example of the order of 15 to 20 volts positive, with respect to the cathode **22**, as by a battery **50**, and the accelerating grid **46**, screen grid **47**, field plates **39c** and anode **49** are maintained at a higher positive potential, for example of the order of 100 to 150 volts, with respect to the cathode **22**, as by a battery **51**. If desired, the anode **49** may be maintained at a somewhat higher potential as by a battery **70**. An output resistor **52** is connected between the portions **49a** and **49b**. The suppressor grid **48** may be connected to the cathode as shown. An input resistor **53** is connected between the deflector plates **36c** and these plates have applied thereto a positive potential, as by a battery **54**, of the same magnitude as that upon the grids **46** and **47**, for example of the order of 100 to 150 volts. A magnetic field (indicated in Fig. 10 by the arrow H) is provided as by a coil, not shown, similar to that illustrated in Fig. 1 and is of such strength that the beam is focused adjacent the end of the deflector plates **36c** toward the anode **49**.

When a signal potential is impressed across the input resistor **53**, the electron beam will be swept back and forth across the anode portions **49a** and **49b** so that as the current to one portion increases, that to the other portion decreases whereby a balanced output across the output resistor **52** is obtained. Because of the configuration of the deflector plates **36c**, the output signal will be proportional to the logarithm of the input signal.

The invention may be embodied also in an electronic step-by-step switch as illustrated in Figs. 12, 13 and 14. As shown in Fig. 12, the cathode **22**, which may be similar to that shown in Fig. 1, is partially surrounded by a cylindrical electrode **55** coaxial with the cathode and having a longitudinal aperture or slot **56** therein. The cylindrical electrode **55** may be biased negatively with respect to the cathode, as by a battery **57** in series with a resistor **58**. A variable potential, which may correspond to a speech or music signal, may be impressed across the resistor **58** whereby the intensity of the beam is modulated in accordance with such signal.

The device includes also an accelerating electrode **28**, similar to that shown in Fig. 1, having therein an aperture or slit **29** in parallel alignment with the cathode **22** and the aperture or slit **56**, a pair of parallel deflector plates **36** similar to those shown in Fig. 1 and described heretofore, and a screen grid **47** parallel to the plate accelerating electrode **28**.

Mounted opposite the screen grid **47** and parallel thereto are a plurality of coplanar electron receiving units **59**, each of which, as shown in Fig. 13, comprises three portions **59a**, **59b** and **59c**, corresponding portions **59a** and **59b** being connected together. As shown clearly in Fig. 13, the portions **59a** vary in area and the portions **59b** also vary in area but in the inverse manner. The portions **59c** may be of equal areas and like dimensions.

A suppressor grid **48** is mounted between the screen grid **47** and the electron receiving units **59** and is provided with vanes or projections **63** extending beyond the plane of the units **59**.

The accelerating electrode **28** and screen grid **48** are maintained at a positive potential with respect to the cathode, as by a battery **51**, and the deflector plates **36** and anode portions **59a** and **59b** are biased positively with respect to the cathode **22**, as by a battery **60**, one deflector plate being connected to all of the portions **59a** and thence to the battery **60** through a resistance **61a** shunted by a condenser **62a**, and the other deflector plate being connected to the portions **59b** and thence to the battery **60** by a similar resistance-condenser combination **61b**, **62b**.

Each of the portions **59c** serves as an anode or output element and may be connected to an individual output circuit.

A deflecting potential may be impressed between the deflector plates 36 through an input resistor 64 connected in series with a condenser 65 and the resistance-condenser combination 61*a*, 62*a*.

A magnetic field, indicated by the arrow H in Fig. 12, is produced parallel to the longitudinal axis of the device, as by a coil, not shown, similar to that illustrated in Fig. 1.

The deflection of the beam at any particular instant will be determined by the potential difference, at that instant, between the deflector plates 36, and this potential difference will be dependent upon the potential impressed across resistor 64 and the potential drops across the resistances 61*a* and 61*b* which are dependent in turn upon the current flowing therethrough. These resistances are made of such magnitude and the areas of the portions 59*a* and 59*b* are so related that when, with zero potential across resistor 64, the beam is impinging upon any electron receiving unit 59, the division of current between the portions 59*a* and 59*b* of this unit is such that the potential drops across the resistances 61*a* and 61*b* are so related that the potential difference between the deflector plates is of the magnitude requisite to hold the beam upon the unit upon which it is impinging.

By changing the potential impressed across the resistor 64, the beam may be shifted progressively from one electron receiving unit to the next so that at each portion of the beam a circuit is closed, by the beam, between the cathode 22 and one of the units 59, the output current being drawn off from the section 59*c*. The condensers 62*a* and 62*b* serve to slow up the movement of the beam so that in the time of a pulse across the resistor 64, the beam will be deflected just the correct amount to shift its terminus from one unit to the next. The vanes 63 shield adjacent units from one another and also assure an abrupt changing of the connection, by the beam, from one unit to the other.

At each position, the beam density may be modulated in accordance with a signal potential impressed across the resistor 58.

Although resistances 61*a* and 62*b* have been shown in Fig. 12, each common to one set of the portions 59*a* and 59*b* respectively, individual resistances may be employed in association with these portions to provide the potential drops requisite to hold the beam on the unit upon which it is impinging at any particular instant.

Fig. 14 illustrates a modification of the electron receiving structure in the apparatus shown in Fig. 12, wherein each unit comprises two reticulated portions 59*a*′ and 59*b*′ and on output plate portion 59*c*′ mounted opposite the face of the reticulated portions remote from the deflecting system. The various portions illustrated in Fig. 14 are connected in the same manner as the corresponding portions in Fig. 12.

It will be noted that in devices constructed in accordance with this invention, relatively large output currents can be realized inasmuch as beams of substantial cross-sectional area and high current density may be employed. Furthermore, in such devices the losses in the deflection system are small so that high operating efficiencies are obtained. Also, as noted heretofore, high deflection sensitivity and accurate correspondence between beam deflection and deflecting potential are realized.

Although several embodiments have been shown and described, it will be understood that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising a cathode, means for concentrating the electrons emanating from said cathode into a thin beam of rectangular cross-section, an electron receiving element in alignment with said cathode, means for producing a magnetic field having its lines of force parallel to the line of alignment of said cathode and said element, and means for deflecting said beam normal to the longer cross-sectional dimension thereof including means for producing an electrostatic field having its lines of force crossing and normal to the lines of said magnetic field and normal to the shorter cross-sectional dimension of the electron beam.

2. Electron discharge apparatus comprising a cathode, means for concentrating the electrons emanating from said cathode into a thin beam of rectangular cross-section, an electron receiving element in alignment with said cathode, means for producing substantially parallel electrostatic and magnetic fields between said cathode and said element, parallel to the line of alignment thereof and of such relative intensity that the electrons in said beam are sharply focussed on said element, and a pair of deflector plates mounted to produce when energized an electrostatic field crossing said magnetic field and having its lines of force parallel to the longer cross-sectional dimension of said beam whereby said beam will be deflected normal to its longer cross-sectional dimension in accordance with variations in the potential between said deflector plates.

3. Electron discharge apparatus comprising a cathode, an electron receiving element spaced from said cathode, means for producing a magnetic field having its lines of force substantially parallel to the electron path between said cathode and said element, and a pair of deflector plates mounted on opposite sides of the electron path and so constructed and arranged that when a potential difference is established therebetween the electric field between said plates varies in intensity normal to said electron path.

4. Electron discharge apparatus comprising a cathode, an electron receiving element spaced from said cathode, means for producing a magnetic field between said cathode and said element and having its lines of force substantially parallel to the discharge path between said cathode and said element, and a pair of deflector plates on opposite sides of said path, each deflector plate tapering toward said element.

5. Electron discharge apparatus in accordance with claim 4 wherein the sides of said plates extending in the direction of the discharge path conform substantially to exponential curves.

6. Electron discharge apparatus in accordance with claim 4 wherein the sides of said plates extending in the direction of the discharge path conform substantially to logarithmic curves.

7. Electron discharge apparatus comprising a cathode, means for concentrating electrons emanating from said cathode into a beam, an electron receiving element in alignment with said cathode, means for producing a magnetic field having its lines of force parallel to the line of alignment of said cathode and said element, and means for deflecting said beam normal to said

line of alignment comprising a pair of deflector electrodes so constructed and arranged that the beam deflection varies as an exponential function of the potential difference between said deflector electrodes.

8. Electron discharge apparatus comprising a cathode, an electron receiving element in alignment with said cathode, means for producing a magnetic field having its lines of force parallel to the line of alignment of said cathode and said element, and a pair of parallel deflector plates between said cathode and said element, each of said plates comprising two similar portions symmetrical with respect to said line of alignment and the edge of each of said portions toward said element conforming to an exponential curve having its zero point in a plane passing through said line of alignment and normal to said plates.

9. Electron discharge apparatus comprising means including a cathode for producing an electron beam, an electron beam receiving element spaced from said cathode, means for producing a magnetic field along and having its lines of force parallel to the discharge path between said cathode and said element, means for producing an electric deflecting field crossing and at substantially right angles to said magnetic field including a pair of parallel deflector plates on opposite sides of said discharge path, and means for limiting the deflection of said beam in response to said deflecting field comprising two pairs of field plates, each pair of field plates being substantially coplanar with a corresponding one of said deflector plates and immediately adjacent the opposite sides thereof extending in the direction of said discharge path.

10. Electron discharge apparatus comprising a cathode, an electron receiving element spaced from said cathode, means for producing a magnetic field having its lines of force parallel to the discharge path between said cathode and said element, a pair of deflector plates on opposite sides of said discharge path, the edges of said plates extending in the direction of said discharge path including portions converging toward the element end of said discharge path, and field plates opposite said portions of said deflector plates and substantially coplanar with said deflector plates.

11. Electron discharge apparatus in accordance with claim 10 wherein said portions conform to exponential curves and each of said field plates has an edge opposite one of said portions and conforms thereto.

12. Electron discharge apparatus comprising a cathode, an electron receiving element spaced from said cathode, means for producing a magnetic field having its lines of force substantially parallel to the discharge path between said cathode and said element, a pair of parallel trapezoidal deflector plates on opposite sides of said discharge path, the longer parallel side of each deflector plate being toward said cathode, and two pairs of triangular field plates, the field plates of each pair being coplanar with one of said deflector plates and mounted at opposite sides thereof, and each field plate having its hypothenuse opposite and parallel to one inclined side of the deflector plate coplanar therewith.

13. Electron discharge apparatus comprising a cathode having an elongated emissive surface, means for concentrating electrons emanating from said surface into a beam of rectangular cross-section, an electron receiving means in alignment with said cathode including a pair of triangular coplanar sections having corresponding sides in juxtaposition and inclined to the plane of the longer dimension of said beam, means for producing a magnetic field having its lines of force parallel to the line of alignment of said cathode and said electron receiving means, and a pair of deflector plates on opposite sides of the path of said beam and parallel to the shorter dimension of said beam, each of said plates comprising a pair of electrically integral portions symmetrical with respect to a plane passing through said line of alignment and tapering toward said electron receiving means, and the edges of each of said portions extending toward said electron receiving means conforming to exponential curves.

14. Electron discharge apparatus comprising a cathode, means for concentrating electrons emanating from said cathode into a thin rectangular beam, a plurality of electron receiving members mounted in a row normal to the longer cross-sectional dimension of said beam, means for focusing said beam upon said members including means for producing a magnetic field having its lines of force substantially parallel to the discharge path between said cathode and said members, and means for shifting said beam normal to the longer cross-sectional dimension thereof including a pair of electrostatic deflector plates on opposite sides of said discharge path and parallel to the shorter cross-sectional dimension of said beam.

15. Electron discharge apparatus comprising means for producing an electron beam, a plurality of electron receiving elements mounted in a line, means for deflecting said beam to shift its terminus from one element to another, and means for holding said beam in impinging relation upon each of said elements when said beam is shifted thereto by said deflecting means comprising a plurality of pairs of auxiliary electron receiving members, each pair of auxiliary members being adjacent a corresponding one of said elements.

16. Electron discharge apparatus comprising means for producing an electron beam, a plurality of anodes mounted in a line, means for focusing said beam upon said anodes, means for deflecting said beam to shift its terminus from one anode to another, a series of auxiliary electrodes one opposite each of said anodes, said electrodes decreasing in area from one end of said line to the other, and a second series of auxiliary electrodes each in alignment with a corresponding one of said first auxiliary electrodes, said second auxiliary electrodes increasing in area from said one end of said line to the other.

17. Electron discharge apparatus in accordance with claim 16 wherein each of said auxiliary electrodes is reticulated and is mounted in front of the electron receiving portion of the corresponding anode.

18. Electron discharge apparatus comprising a row of parallel electron receiving units each comprising an anode portion, a first auxiliary portion and a second auxiliary portion, the first auxiliary portions of said units varying progressively in area and the second auxiliary portions varying progressively in area and in the reverse manner to the first auxiliary portions, means for producing an electron beam, and means for deflecting said beam to shift its terminus from one of said units to another.

19. Electron discharge apparatus comprising

a cathode, means for concentrating the electrons emanating from said cathode into a beam of rectangular cross-section, a row of electron receiving units mounted in a line extending normal to the longer cross-sectional dimension of said beam, each of said units including an output portion, a first auxiliary portion and a second auxiliary portion, corresponding portions of said units being in alignment, said first auxiliary portions increasing progressively in area from one end of said line and said second auxiliary portions decreasing in area from said one end of said line, means for producing a magnetic field having its lines of force substantially parallel to the discharge path between said cathode and said units, and means for deflecting said beam normal to the longer cross-sectional dimension thereof including a pair of deflector plates on opposite sides of said path and extending parallel to the shorter cross-sectional dimension of said beam.

20. Electron discharge apparatus comprising a cathode, means for concentrating electrons emanating from said cathode into a beam, an electron receiving element in alignment with said cathode and upon which said beam impinges, and means for producing, in the region between said cathode and said element, crossed magnetic and electric fields so related that the beam will be deflected at right angles to the electric field in accordance with variations in said electric field.

ALBERT M. SKELLETT.