July 19, 1955 R. C. HERGENROTHER 2,713,647

BEAM DISPLACEMENT COMPENSATION IN IMAGE STORAGE TUBES

Filed May 12, 1951

3 Sheets-Sheet 1

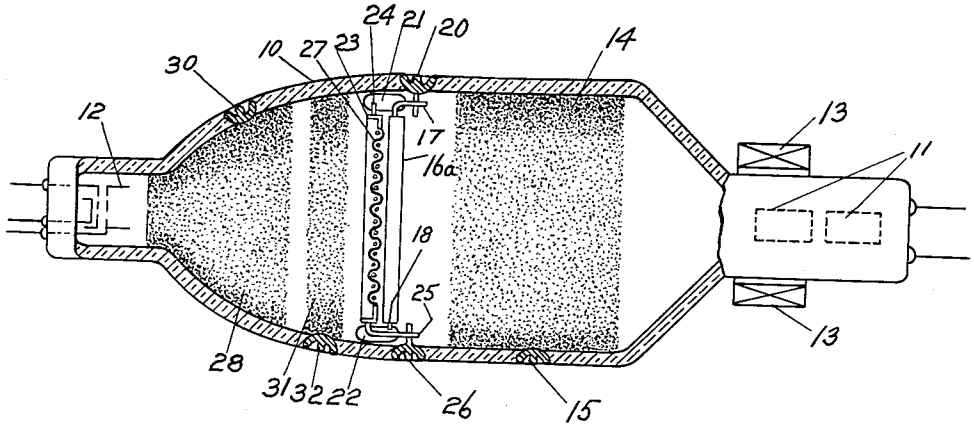


FIG. 1

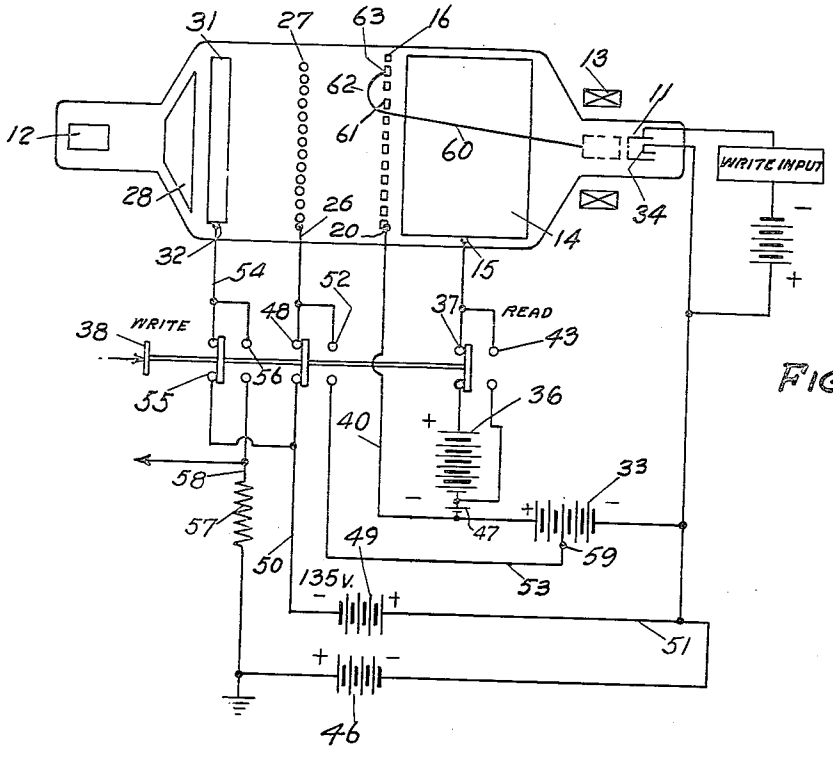


FIG. 2

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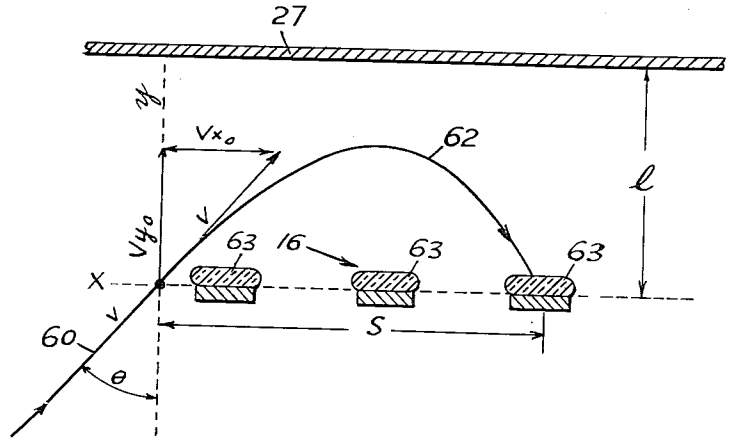


FIG. 3

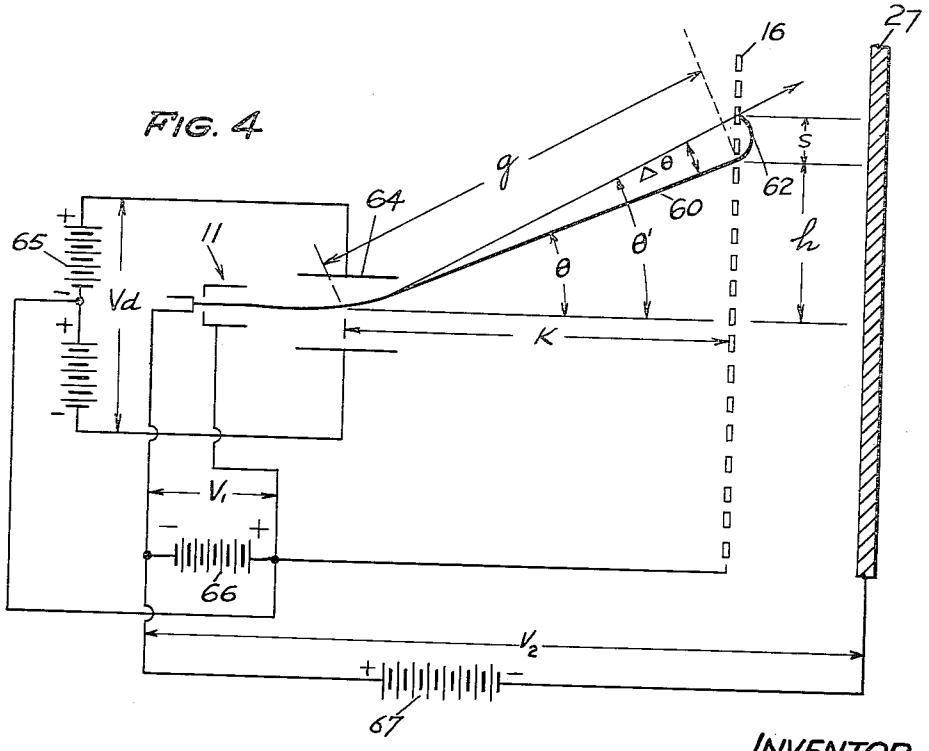


FIG. 4

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BEAM DISPLACEMENT COMPENSATION IN IMAGE STORAGE TUBES

Filed May 12, 1951 3 Sheets-Sheet 3

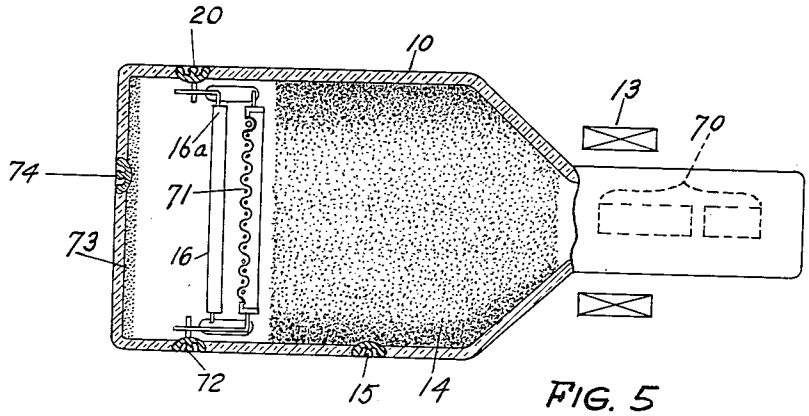


FIG. 5

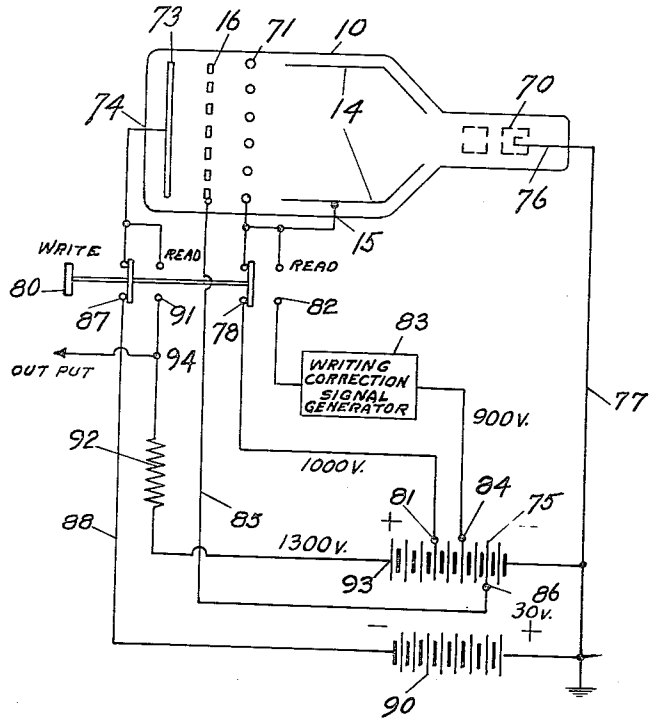


FIG. 6

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BEAM DISPLACEMENT COMPENSATION IN IMAGE STORAGE TUBES

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Application May 12, 1951, Serial No. 226,035

6 Claims. (Cl. 315—12)

This invention relates to electron tubes of the kind wherein an image can be stored in the form of an electrical charge pattern on a screen by a beam of electrons introduced from the opposite side and more particularly to the compensation for the displacement of this charge due to the varying angle of incidence of the charging beam upon the screen by the appropriate reduction of the beam voltage.

In image storage tubes of the type disclosed in United States Patent No. 2,547,638, issued April 3, 1951, to B. C. Gardner, where the writing beam passes through the screen from the conductive side and is reflected back by an appropriately charged electrode to the dielectric side where it deposits a charge, varying angles of approach of the electron beam result in the charge being deposited at varying displacements from the point where the beam passed through the screen. Only with an angle of attack substantially normal to the plane of the screen will the reflected beam strike the screen at its point of entry. If the reading beam is deflected through the same angle as the writing beam, the information read at a particular unit area will not be the information written when the writing beam was deflected at the same angle, but will be the information written when the writing beam was deflected by some lesser angle. In other words, the information written when the beam is deflected by a certain angle will not be read by deflecting the reading beam by the same angle in the electron mirror type of image storage tube.

This non-registry can be compensated for by increasing the deflection angle of the reading beam over that of the writing beam when it was writing the required information.

It is well known that the deflection of an electron beam can be varied by varying the accelerating potential on the electron beam, other factors remaining the same. By the present invention this fact is utilized to permit a greater deflection of the reading beam than of the writing beam by the same deflecting system and voltages. The accelerating potential is reduced by an amount sufficient to permit the reading beam to be deflected to the area where the desired writing charge actually arrived rather than to the area where it penetrated the screen. The foregoing and other objects and features of the invention will be appreciated from the detailed discussion of certain embodiments thereof that follows, reference being had to the accompanying drawings, wherein:

Fig. 1 is a longitudinal sectional view of a tube of the prior art suitable for use with the invention;

Fig. 2 illustrates schematically a circuit for the tube of Fig. 1;

Fig. 3 is a diagram of part of the trajectory of the electron in the tube of Fig. 1;

Fig. 4 is a diagram of certain of the electrons of the tube of Fig. 1, the potentials applied to them, and the trajectory of an electron during the writing and the reading operation to illustrate the principle of the invention;

Fig. 5 is a longitudinal sectional view of a second tube of the prior art suitable for use with the invention; and

Fig. 6 illustrates schematically a circuit for the tube shown in Fig. 5.

In general, tubes of the type in which the present invention is used employ an appropriate conductive screen electrode which is coated on one side with a nonconductive material functioning as a storage element, writing being accomplished by scanning the dielectric coated side of the screen, and reading being accomplished by scanning the uncoated side of the screen. Such a screen electrode as employed herein may also be termed a "target." The charge pattern on the coated side of the screen determines the current that flows to a collector electrode which is suitably positioned with relation to the storage screen. The charge pattern controls the passage to the collector electrode of secondary electrons formed when a high voltage reading beam strikes the uncoated side of the screen. A charge on the screen also may be used to directly control the passage of a low voltage reading beam through the screen.

Referring to Fig. 1, the reference numeral 10 refers to the envelope of the tube of glass, or the like, having in the right-hand end a reading and writing gun 11, and in the left-hand end an erasing gun 12. The reading and writing gun 11 is provided with deflection coil means 13 and a coated anode 14 inside of the envelope 10 in the right-hand portion thereof. The coated anode 14 is provided with a terminal 15 imbedded in the glass of the envelope and in electrical contact with the anode 14. The storage screen 16 shown more in detail elsewhere is mounted in ring 16a which is supported upon studs 17 and 18 of which stud 17 is electrically connected to terminal 20 mounted in the glass envelope 10. The stud 17 has fastened thereto an insulating bead 21 while the other stud 18 has fastened thereto a second insulating bead 22. A second ring 23 having two mounting studs 24 and 25 is supported in the beads 21 and 22 by the studs to maintain it in a plane parallel to that of the screen 16. The second stud 25 makes electrical contact with another terminal 26 mounted in the envelope 10. A metallic screen 27 is mounted in an opening of the second ring 23. The dielectric surface of the storage screen 16 faces toward the metallic screen 27.

The erasing gun 12 is fully described in the cited Gardner patent, and as it forms no part of the present invention, will not be described here. A coated anode 28 is provided for this gun on the inside of the left-hand end of the envelope 10 and is electrically connected to a terminal 30 mounted in the envelope 10.

A collector electrode 31 of annular form is coated inside the envelope 10 between the coated anode 28 and the reflector screen 27. This collector electrode is likewise provided with a terminal 32 mounted in the walls of the envelope 10.

The writing operation and circuit therefor can best be understood by reference to Fig. 2. The negative terminal of a battery 33 is connected to the cathode 34 of the reading and writing gun 11, and at its positive end is connected over a wire 35 to a second source of potential 36 and a normally-closed set of contacts 37 of a switch 38 to the terminal 15 of the anode 14 to place the anode 14 at a potential of 1,000 volts with respect to the cathode 34 in a representative case. The positive end of the battery 33 is also connected over a wire 40 to the terminal 20 of the screen 16 to place the screen at a positive potential with respect to the cathode 34 of 30 volts in a representative case. A less positive point 41 having a potential of 900 volts in a representative case with respect to the cathode on the battery 36 is connected over a wire 42 and normally-open contacts 43 to the terminal 15 of the anode 14.

These connections place the anode 14 at one high positive potential with respect to the cathode 34 of the gun 11 at the write position of the switch 38, and, at the read position of the switch 38, place the anode 14 at a lower potential, that of the point 41, with respect to the cathode 34. The reflector electrode 27 is connected through terminal 26 and normally-closed contacts 48 to the negative terminal of a battery 49 over a wire 50. The positive terminal of this battery 49 is connected over a wire 51 to the cathode 34 to give it a negative potential with respect to the cathode of 135 volts in a representative case. The screen 27 is also connected over normally-open contacts 52 and wire 53 to the point 59 on the battery 33. The effect of this connection is to place a negative potential on the reflector screen 27 during writing, and a positive potential on the screen during reading.

Collector anode 31 is connected through terminal 32 and over a wire 54 and normally-closed contacts 55 to the negative terminal of the battery 49. This anode is also connected over normally-open contacts 56 to ground through a resistor 57. The reading output is taken across this resistor at a terminal 58.

In the normal or writing position of the switch 37, a high positive potential appears on the accelerating anode 14 and a positive potential on the storage screen 16, while a negative potential appears on the reflecting screen 27 and the collector anode 31. The result is that a beam of electrons 60 is emitted from the gun 11 and, depending upon the state of deflecting fields produced by the coil 13, the beam 60 penetrates through a hole 61 in the screen 16. It then comes under the influence of the negative retarding field of the reflecting screen 27 and is turned back along a trajectory 62 to one of the dielectric deposits 63 on the screen 16. The details of this trajectory can best be seen in Figs. 3 and 4.

In Fig. 3, the beam of electrons 60 approaches the screen 16 which is at a positive potential V_1. For purposes of analyzing the trajectory of the electron beam, if the intersection of the plane of the screen 16 with the plane of the trajectory is taken to be x axis and a line perpendicular to the x axis at the point of intersection of the trajectory with the screen 16 is taken to be the y axis, the electron will have a velocity v with a component v_{x0} parallel to the x axis at the point of intersection with the screen 16 and a component v_{y0} parallel to the y axis at that point. The retarding electrode or electron mirror 27 is mounted in a plane parallel to that of the screen 16 and at a distance l from it. It is at a negative potential v_2.

The velocity component v_x of the electron remains constant, but the velocity component v_y is diminished at a steady rate by the retarding field on the screen. It can be shown that as a result the electron follows a parabolic trajectory represented by the equation:

$$y=-1/2a\frac{x^2}{v^2\sin^2\theta}+\frac{x}{\sin\theta}\cos\theta \qquad (1)$$

The acceleration a equals the force exerted by the retarding field on the electron by charge e divided by the electron mass m, or:

$$a=\frac{e(V_1+V_2)}{\frac{l}{m}} \qquad (2)$$

The velocity v which the electron reaches on going from zero potential to V_1 is given by the conservation of energy principle as:

$$1/2mv^2=V_1e \qquad (3)$$

or:

$$v^2=2V_1\frac{e}{m} \qquad (3a)$$

dividing (2) by (3a) and simplifying

$$\frac{a}{v^2}=\frac{V_1+V_2}{2lV_1} \qquad (4)$$

substituting (4) in (1) results in

$$y=-\frac{X^2(V_1+V_2)}{4lV_1\sin^2\theta}+\frac{x}{\sin\theta}\cos\theta \qquad (5)$$

if y in (5) is made equal to zero, x will equal the displacement s in Fig. 3. Thus (5) can be reduced to

$$\frac{(V_1+V_2)x}{4lV_1\sin\theta}=\cos\theta$$

or

$$s=x=4l\frac{V_1}{V_1+V_2}\sin\theta\cos\theta \qquad (6)$$

This displacement s represents a lack of register between the reading and writing operations and must be kept small in comparison to the spot size. This can be done by (1) reducing l, (2) reducing θ, and (3) by making V_2 large in comparison to V_1. The effect of varying these factors can best be seen by substituting hypothetical design data in the Formula 6. If s is not to exceed a third of the spot size of 0.003" or 0.001" and V_2 is taken as equal to twice V_1 and l as equal to 0.02"

$$0.001=4\times0.02\times1/3\sin\theta\cos\theta$$

$$\sin\theta\cos\theta=\frac{0.003}{0.08}=0.0375 \qquad \theta=2.15°$$

This gives a smaller deflection angle θ than is desired. Because of difficulties in construction, it is not possible to reduce l further. Greatly increasing the potential difference between the screens would cause obvious difficulties.

However, this displacement may be very simply compensated for by reducing the beam voltage from its value during writing.

How the amount of compensation to be applied to the reading beam is determined may best be seen by consideration of Fig. 4. This shows the electron gun 11, deflection plates 64, the accelerating electrode and the storage screen 16 schematically. The battery 65 supplies an appropriate deflection potential Vd to the deflection plate 64. The battery 66 supplies an appropriate accelerating potential V_1 to the screen 16. It will be noted that the same potential V_1 is applied to the first anode in the gun 11. This potential alone would be enough to accelerate the beam. It will be noted that in Fig. 2 the storage grid 16 is at a considerably lower potential with respect to the cathode than the first anode 14. The accelerating potential at the anode 14 is what gives the initial acceleration to the beam. The lower potential of the storage screen 16 effects the trajectory of the beam to some extent, but it is a minor effect not substantially affecting the accuracy of the following analysis, and thus this analysis and the resulting formula may be used to determine the appropriate potentials for the accelerating anode 14 in the circuit of Fig. 2. The battery 67 supplies an appropriate retarding potential V_2 to the electron mirror 27. The deflection potential Vd applied to the deflection plate 64 results in a writing beam deflection θ. As described before, the writing beam penetrates the screen 16 and is retarded by the electron mirror 27, and returns to the screen 16 at a point displaced at distance s from the point of penetration. In order for the reading beam to reach the location of the charge, it must be deflected through a larger angle θ' which is larger than θ by an amount $\Delta\theta$. The distance from the center of the deflection plates to the plane of the screen 16 along the axis of the tube is designated as k. The distance of the point of penetration of the writing beam from the center of screen 16 is designated as h. The distance from the center of the deflection plates to the point of penetration of the beam through the screen 16 measured along the writing beam is designated as g. From Equation 6:

$$s=K_1\sin\theta\cos\theta$$

where

$$K_1=4l\frac{V_1}{V_1+V_2} \tag{7}$$

From Fig. 4:

$$g \sin \Delta\theta=s \cos (\theta+\Delta\theta) \tag{8}$$

As $\Delta\theta$ is so small, the simple expression $s \cos \theta$ is used. As $\Delta\theta$ is small, in the order of 2°, $\sin \Delta\theta=\Delta\theta$ in radians so that (8) may be written:

$$g\Delta\theta=s \cos \theta \tag{9}$$

it will also be seen that

$$g=\frac{k}{\cos \theta} \tag{10}$$

from Fig. 4 and trigometry so that substituting (10) in (9)

$$\frac{k}{\cos \theta}\Delta\theta=s \cos \theta \tag{11}$$

which may be written:

$$\Delta\theta=\frac{s}{k} \cos^2 \theta \tag{12}$$

substituting (7) in (12) gives:

$$\Delta\theta=\frac{K_1}{k} \sin \theta \cos^3 \theta \tag{13}$$

Referring to Fig. 4 again, the deflection θ produced by the potential Vd applied to the deflection plates is given by:

$$\tan \theta=K_2\frac{Vd}{V_1} \tag{14}$$

where K_2 is a constant depending on plate geometry. To obtain the increase in the deflection $\Delta\theta$ produced by an increase ΔV_1 in the beam voltage, tan θ is differentiated with respect to

$$\theta \text{ and } K_2\frac{Vd}{V_1}$$

with respect to V_1 as follows

$$\sec^2 \theta\Delta\theta=-K_2\frac{Vd}{V_1^2}V_1 \tag{15}$$

substituting (14) in (15):

$$\sec^2 \theta\Delta\theta=-\tan \theta\frac{\Delta V_1}{V_1} \tag{16}$$

and transposing and simplifying

$$\Delta\theta=-\sin \theta \cos \theta\frac{\Delta V_1}{V_1} \tag{17}$$

equating (13) and (17):

$$\frac{K_1}{k} \sin \theta \cos^3 \theta=-\sin \theta \cos \theta\frac{\Delta V_1}{V_1} \tag{18}$$

$$\frac{\Delta V_1}{V_1}=-\frac{K_1}{k} \cos^2 \theta' \tag{19}$$

substituting the value of K_1

$$\frac{\Delta V}{V_1}=-4\frac{l}{k}\frac{V_1}{V_1+V_2} \cos^2 \theta \tag{20}$$

Equation 20 shows that the anode voltage change required for the displacement of the reading beam is dependent on the cosine squared of the deflection angle. Since the deflection angles contemplated are of the order of 12°, the cosine of which squared is approximately 0.96, it is readily seen that compensation within 4 per cent. of the true value will be obtained when the beam voltage during reading is decreased by a constant value given by Equation 20 above when $\theta=0$ or:

$$\frac{\Delta V_1}{V_1}=-4\frac{l}{k}\frac{V_1}{V_1+V_2} \tag{21}$$

In Fig. 2 it can be seen that the operation of the switch **37** opens the contact **36** and closes the contact **43** to apply a lower positive potential by an amount ΔV_1 to the accelerating anode **14**. The normal position of this switch is the writing position and the operating position is the reading position. The difference in potential applied to the anode **14** in these two positions of the switch **37** can be determined from the Equation 21. This correction will result in the correct register between the writing and reading signals at the point of maximum deflection. However, at an intermediate point there would be an over-correction. The average error could be less if the difference in potential between the reading and writing setting were made something less than that necessary to obtain correction at maximum deflection.

Figs. 5 and 6 show how the circuit of this invention may be used with the type of tube shown in Figs. 8, 9, 10 and 11 of the cited Gardner patent. In this type of tube all three operations, erase, write and read, are performed by a single gun **70** positioned at the right-hand end of the envelope **10** as shown in Fig. 5. An accelerating anode **14** is coated on the inside of the right-hand portion of the envelope **10** which is connected to the external circuit through a terminal **15**. The storage screen **16** is constructed and mounted like the previously described tube and connected to the external circuit through the terminal **20**. A screen **71** constructed like the electron mirror **27**, but used to accelerate the electron stream, is mounted similarly to the electron mirror **27** and connected to the external circuit through a terminal **72**. The electron mirror is applied in the form of a deposited layer **73** on the left-hand end of the tube envelope **10**, and is connected to the external circuit by a terminal **74** similar in construction to such terminals as **15**.

This tube is connected in an operating circuit as shown in Fig. 6. The negative terminal of a battery **75** is connected to the cathode **76** of the gun **70** by wire **77**. The anode **14** and the screen **71** are connected through a normally-closed contact **78** on a switch **80** to a positive terminal **81** of the battery **75** having a positive potential of 1,000 volts in a representative case. The anode **14** and the screen **71** are also connected through a normally-open set of contacts **82** on switch **80** through a writing correction signal generator **83** to another less positive terminal **84** of the battery **75** having a potential of 900 volts in a representative case. The storage screen **16** is connected by a wire **85** to a still less positive terminal **86** of the battery **75** having a potential of 30 volts in a representative case. The reflector coating **73** is connected through a normally-closed contact **87** on the switch and over wire **88** to the negative terminal of a battery **90** whose positive terminal is connected to the cathode **76** of the gun **70** to give this electrode a negative potential of 300 volts. The reflector coating **73** is also connected over a normally-open set of contact **91** on the switch **80** through a resistor **92** to the most positive terminal **93** of the battery **75** at a potential in a representative case of 1300 volts. The read signal output is taken from the upper terminal **94** of the resistor **92**.

It will thus be seen that with the switch **80** in the normal write position, a moderately high positive potential will be applied from the terminal **81** of the battery **75** to the anode **14** and the screen **71**. This serves to accelerate a stream of electrons emitted by the gun **70**. The screen **16** is at a somewhat less positive potential and the reflector electrode **73** is at a high negative potential so that, as before, a stream of electrons emitted from the gun **70** and deflected by the deflecting means **13** will pass through the screen in one area and be returned by

the repeller potential on screen 73 to another area of the screen 16.

When the switch 80 is moved to the reading position, the anode 14 and the screen 71 will be supplied with positive potential from terminal 84 somewhat less than that originally supplied from terminal 81 of the battery 75. These electrodes will also be supplied with a correction signal that varies as the cosine squared of the deflection angle. Such a signal can be closely approximated by sine wave of double the frequency of the deflection circuit superimposed upon a D. C. potential of one-half the maximum correction voltage required. For the reasons stated above, a fixed difference between the reading and writing accelerating potentials would be sufficient for most purposes with either type of tube.

Should the image storage tubes of the type herein described be used in an application where the reading and writing operations succeed each other in rapid succession and with a regular rate of recurrence, the correction voltage could be applied to the acceleration electrodes in the form of a square wave of voltage generated in any of the well-known manners and synchronized with the recurrence rate of the read and write cycle. Such a signal could be produced and synchronized by any of several well-known methods and thus will not be described here.

The broad principle of modifying the beam potential of a storage tube to compensate for the register error due to a charge being built up by a writing beam on a target at a point different from that at which the writing beam impinges on the target may be applied to types of storage tubes other than the types described in the cited Gardner patent. The principle of this invention may be applied to any image storage tube where this type of registration error may occur.

This invention is not limtied to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. In an electron storage device, a storage target, means providing an electron beam for scanning said target, means to cause a writing electron beam to impinge on the target in one area and build up a charge at another area somewhat removed from the impingement area, means including a source of potential to produce and deflect a reading electron beam to discharge said charged areas, switching means to selectively actuate as desired the reading and writing means, and means under control of said switching means to reduce the source of potential of said scanning means to cause the reading electron beam to impinge on the target in the area where the charge was built up.

2. In an electron storage device, a storage target, means including a source of potential providing an electron beam for scanning said target, means to cause a writing electron beam to impinge on the target in one area and build up a charge at another area somewhat removed from the impingement area, means to produce and deflect a reading electron beam to discharge said charged areas, switching means to selectively actuate as desired the reading and writing means, said reading and writing beam producing means comprising a source of accelerating potential, and means under control of said switching means to select a reduced accelerating potential for the reading beam to cause the reading electron beam to impinge on the target in the area where the charge was built up.

3. In an electronic charge storage device, a perforated storage target having an electrically conductive side and a dielectric side, means including a source of potential for producing an electron beam, means for deflecting said beam to scan said conductive side, means to cause an

electron of said beam to pass through said target, alter its course and impinge upon said dielectric side at an area somewhat removed from the region of passing through to deposit a charge on said area, a collector electrode, and means to connect said collector electrode to a source of potential and means to select a reduced potential for said electron beam providing means to direct the electron beam to an area where a particular charge is deposited to discharge that area rather than to the area of the target through which the electron beam passed to deposit that charge.

4. In an electronic charge storage device, a perforated storage target having an electrically conductive side and a dielectric side, means for producing an electron beam, means for deflecting said beam to scan said conductive side, the beam producing means comprising a source of accelerating potential, means to cause an electron of said beam to pass through said target, alter its course and impinge upon said dielectric side at an area somewhat removed from the region of passing through to deposit a charge on said area, said course altering means comprising an electrode adapted to be charged with a negative potential mounted parallel to the target and on its dielectric side, a collector electrode and means to actuate said collector electrode, reverse the course of said potential-altering means and reduce said source of accelerating potential by an amount sufficient to cause said deflecting means to direct the electron beam to an area where a particular charge is deposited to discharge said area rather than to the area of the target through which the electron beam passed to deposit that charge.

5. In an electronic charge storage device, a perforated storage target having an electrically conductive side and a dielectric side, means to maintain said target at a positive potential, V_1, means for producing an electron beam, means for deflecting said beam to scan said conductive side, the beam producing means comprising a source of accelerating potential, means to cause an electron of said beam to pass through said target, alter its course and impinge upon said dielectric side at an area somewhat removed from the region of passing through to deposit a charge on said area, said course altering means comprising an electrode adapted to be charged with a negative potential, V_2, mounted parallel to the target and on its dielectric side at a distance l from the target, a collector electrode, and means to actuate said collector electrode, reverse the potential of the said course-altering means and modify said source of accelerating potential to direct the electron beam to an area where a particular charge is deposited to discharge said area rather than to the area of the target through which the electron beam passed to deposit that charge, said deflecting means being located at a distance k from the said target, said modifying means for said electron beam providing means comprising means to reduce the accelerating potential, V_1, by an amount such that

$$\frac{\Delta V_1}{V_1} = -4\frac{l}{k}\frac{V_1}{V_1+V_2}$$

6. In an electronic charge storage device, a perforated storage target having an electrically conductive side and a dielectric side, means to maintain said target at a positive potential, V_1, means for producing an electron beam, means for deflecting said beam through an angle θ to scan said conductive side, the beam producing means comprising a source of accelerating potential, means to cause an electron of said beam to pass through said target, alter its course and impinge upon said dielectric side at an area somewhat removed from the region of passing through to deposit a charge on said area, said course altering means comprising an electrode adapted to be charged with a negative potential, V_2, mounted parallel to the target and on its dielectric side at a distance l from the target, a collector electrode, and means to actuate said collector electrode, reverse the potential of the

said course-altering means and modify said source of accelerating potential to direct the electron beam to an area where a particular charge is deposited to discharge said area rather than to the area of the target through which the electron beam passed to deposit that charge, said deflecting means being located at a distance k from the said target, said modifying means for said source of

accelerating potential comprising means to change the accelerating potential, V_1, by an amount such that

$$\frac{\Delta V_1}{V_1} = -4\frac{l}{k}\frac{V_1}{V_1+V_2}\cos^2\theta$$

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