# United States Patent [19]

**Schwartz**

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[54] **LINEARIZATION OF MAGNETICALLY DEFLECTED CATHODE RAY TUBE WITH NON-AXIAL GUNS**


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[52] **U.S. Cl.** ..... **315/27 GD,** 315/24

[51] **Int. Cl.** ..... **H01j 29/70**

[58] **Field of Search** ..... 315/27 GD, 27 TD, 315/31 R, 24



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,517,252 | 6/1970 | Williams | 315/24 |
| 3,422,305 | 1/1969 | Infante | 315/31 R |



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[57] **ABSTRACT**

Linearization means permitting the use of a plurality of magnetically deflected electron guns within a single Cathode-Ray Tube in which at least one of the guns is displaced from the longitudinal tube or screen axis, and in which the yoke deflection currents are compensated to allow proper registration between images formed by separate guns. The corrective function, for a laterally displaced gun, which is mathematically complex is simplified to a form more readily produced by a function generator, and is used to modify the uncorrected deflection voltages which control the beam deflection currents. A means for extending this technique to electron guns which are not parallel to the longitudinal or screen axis is also provided.


**5 Claims, 5 Drawing Figures**

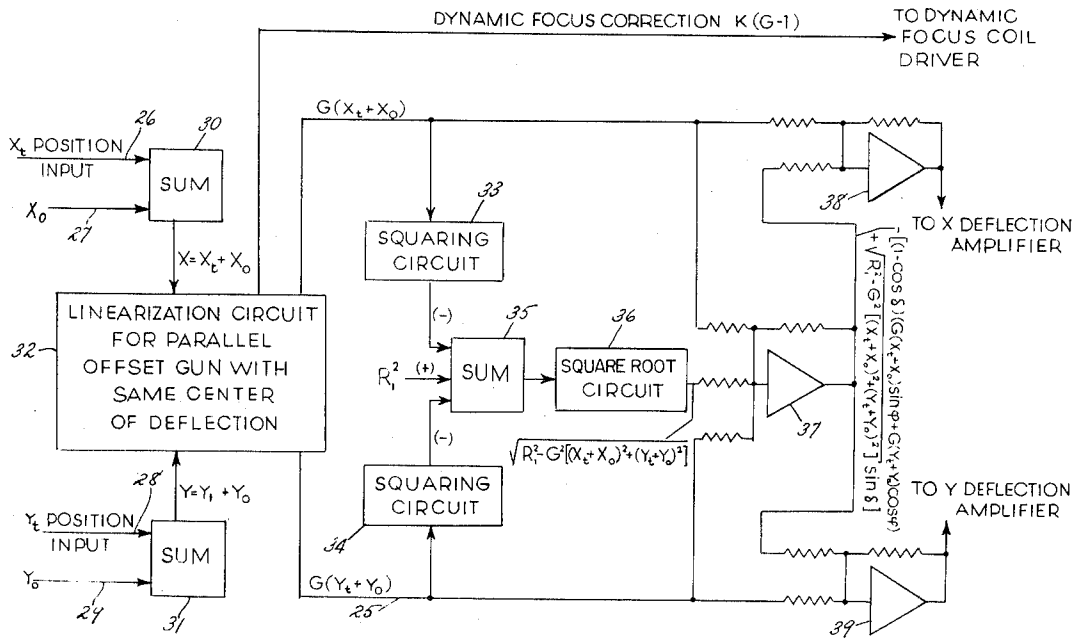
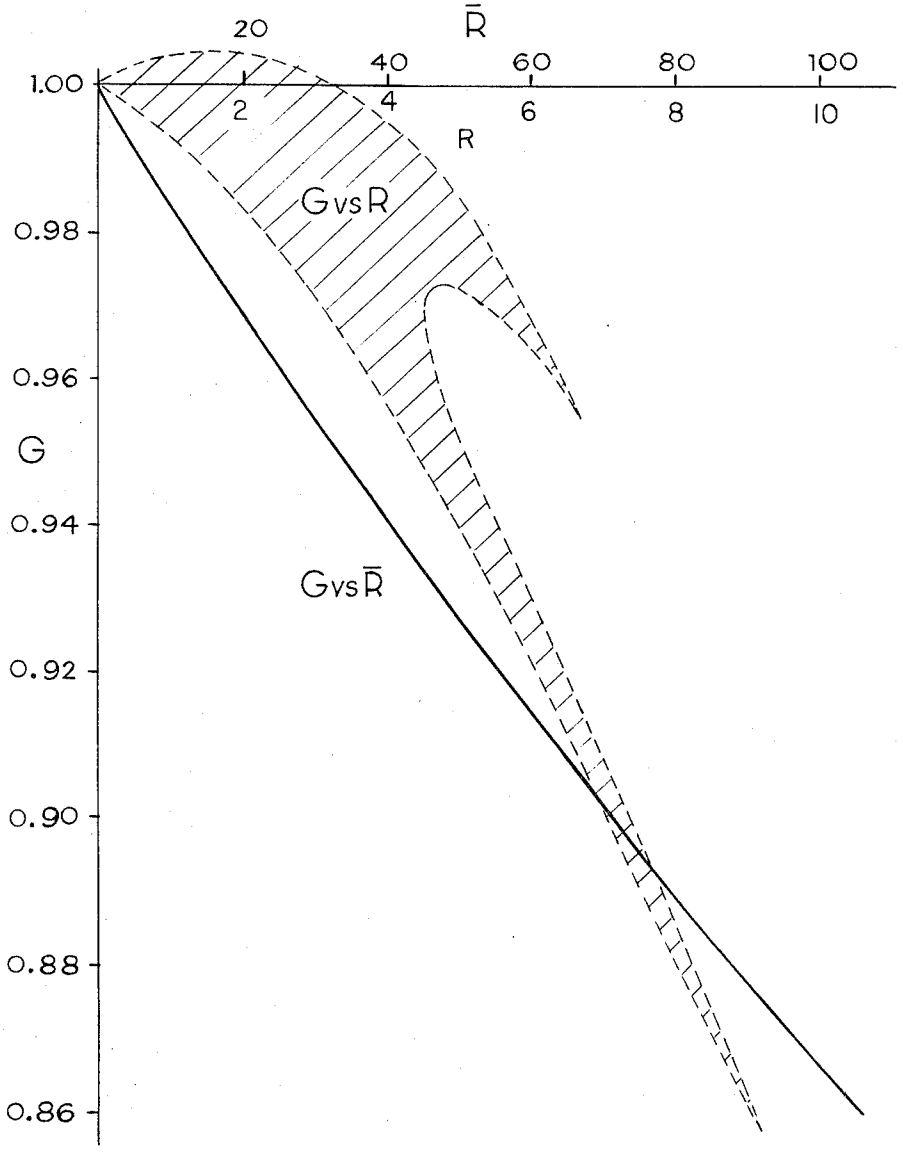


*Fig. 1*


R̄
20
40
60
80
100
1.00
2
4
6
8
10
R
G vs R
0.98
0.96
G
0.94
G vs R̄
0.92
0.90
0.88
0.86

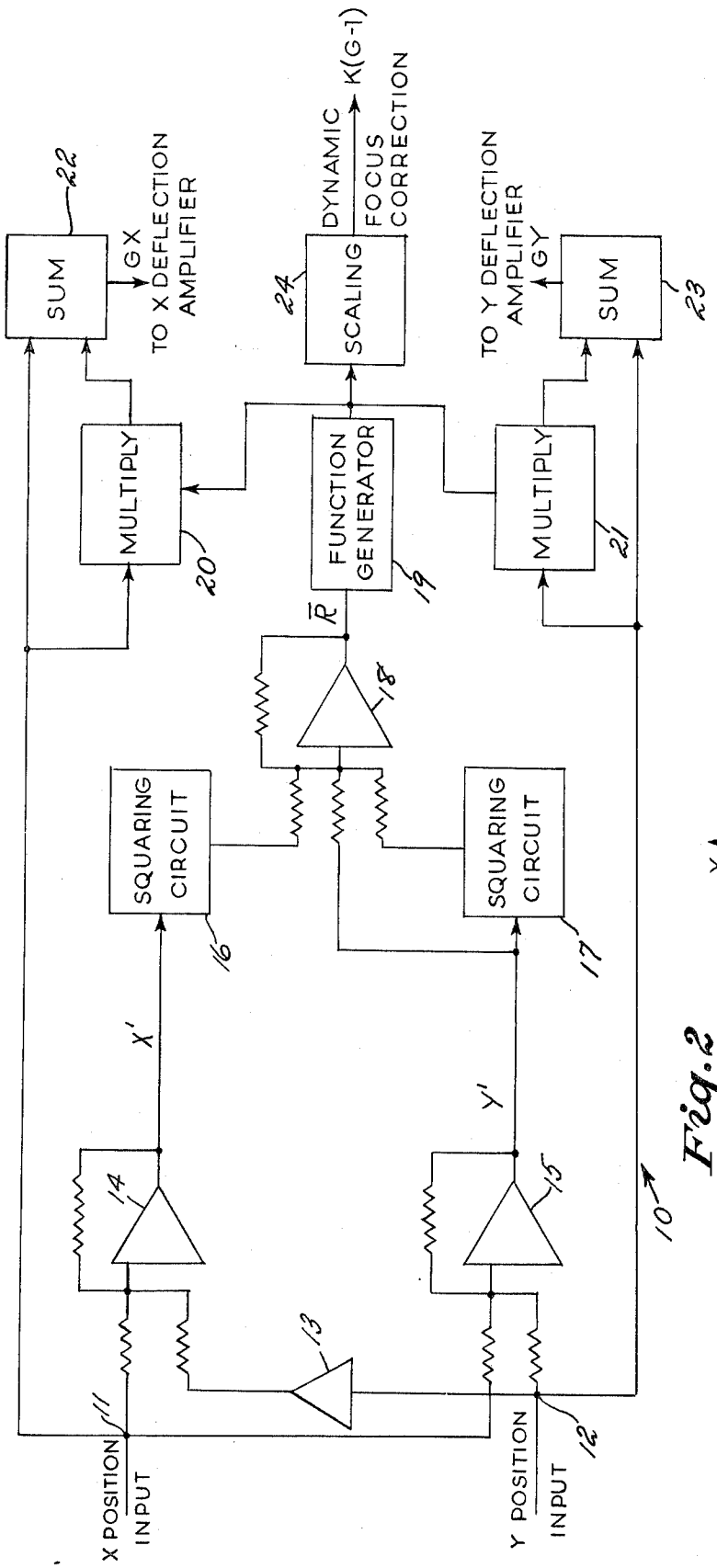

SUM
22
GX
TO X DEFLECTION AMPLIFIER
DYNAMIC FOCUS CORRECTION
K(G-1)
24
SCALING
TO Y DEFLECTION AMPLIFIER
GY
SUM
23
MULTIPLY
20
FUNCTION GENERATOR
19
MULTIPLY
21
R
18
SQUARING CIRCUIT
16
SQUARING CIRCUIT
17
X'
Y'
14
15
13
10
11
12
X POSITION INPUT
Y POSITION INPUT

Fig. 2

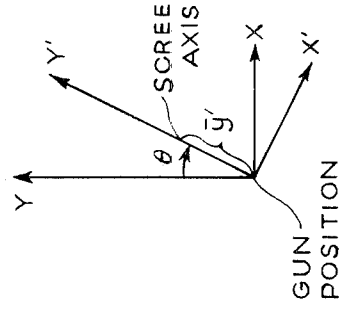

Y'
SCREEN AXIS
X
X'
θ
y'
Y
GUN POSITION

Fig. 3

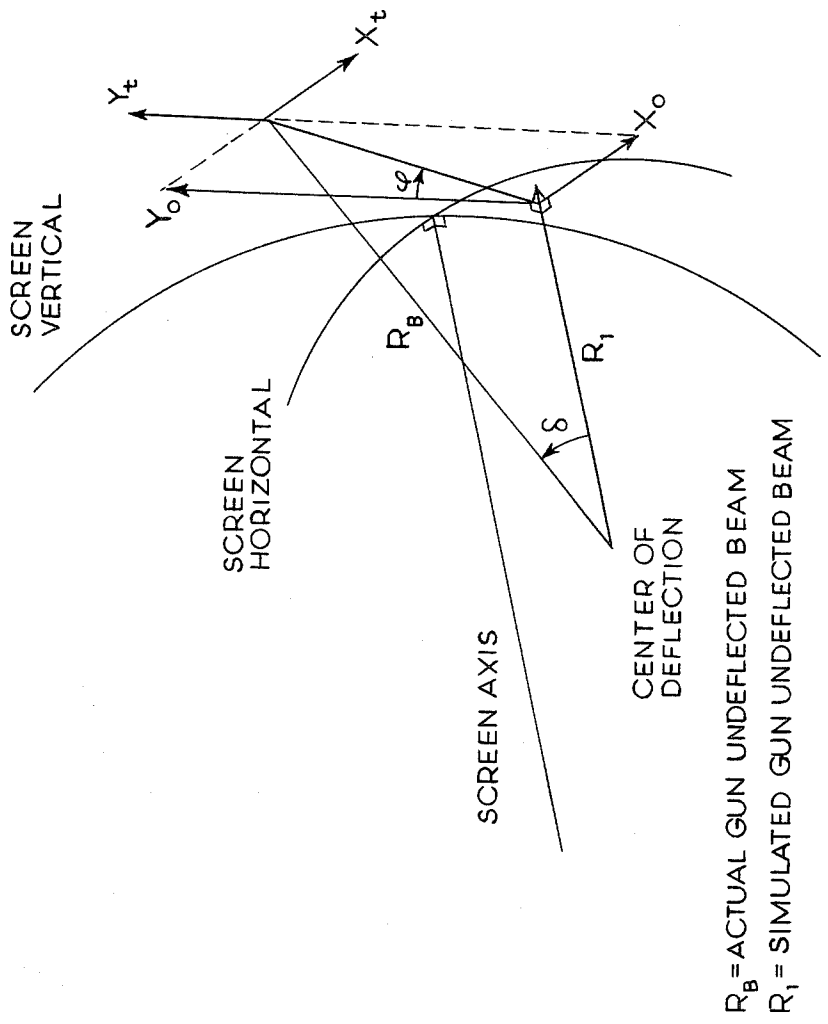

$X_t$
$Y_t$
$X_o$
$Y_o$
$\varphi$
SCREEN VERTICAL
SCREEN HORIZONTAL
$R_B$
$R_1$
$\delta$
SCREEN AXIS
CENTER OF DEFLECTION
$R_B$ = ACTUAL GUN UNDEFLECTED BEAM
$R_1$ = SIMULATED GUN UNDEFLECTED BEAM

*Fig. 4*

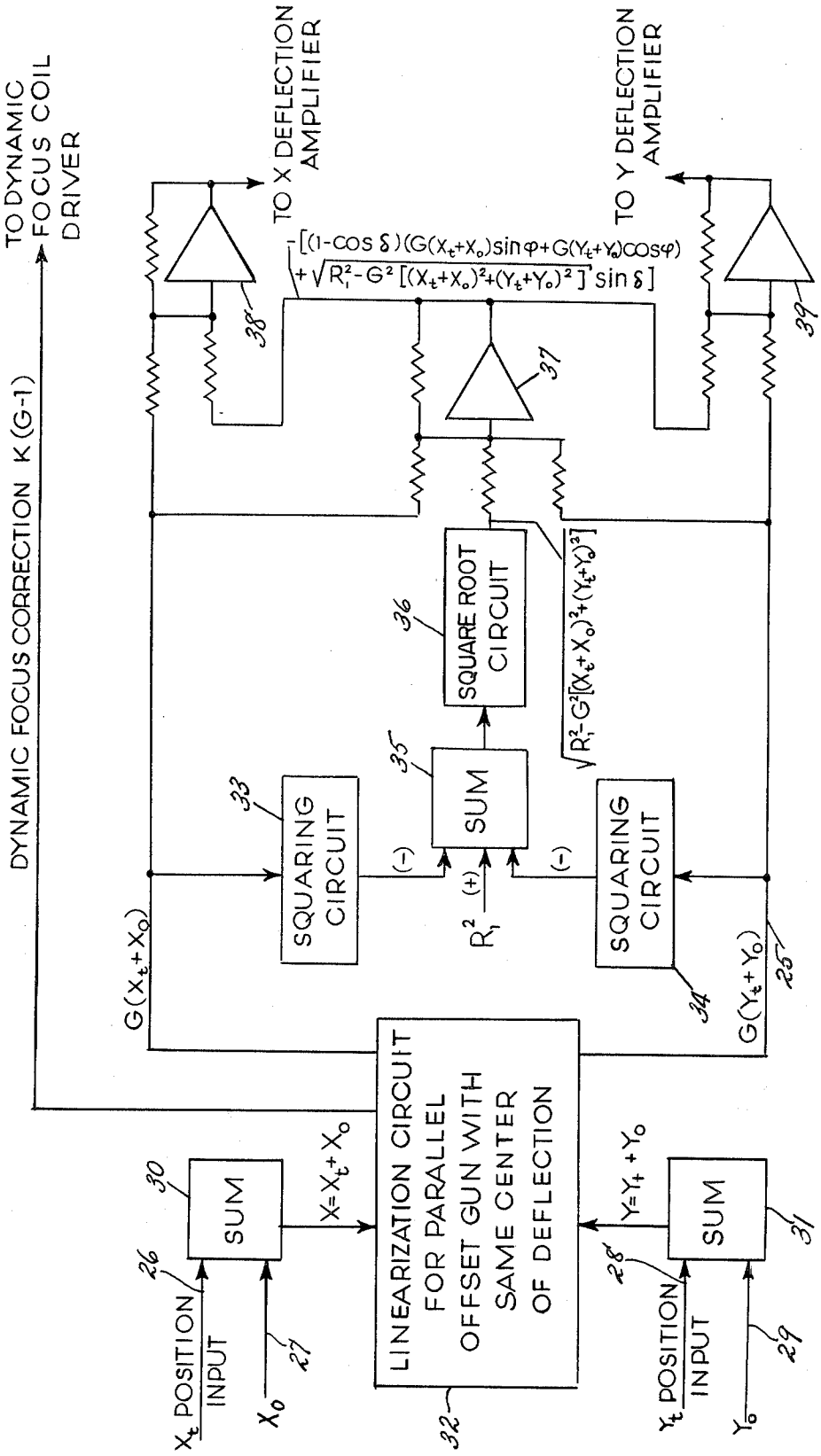

TO DYNAMIC FOCUS COIL DRIVER
DYNAMIC FOCUS CORRECTION K (G-1)
TO X DEFLECTION AMPLIFIER
TO Y DEFLECTION AMPLIFIER
$[(1-\cos\delta)(G(X_t+X_o)\sin\varphi+G(Y_t+Y_o)\cos\varphi)$
$+\sqrt{R_1^2-G^2[(X_t+X_o)^2+(Y_t+Y_o)^2]}\sin\delta]$
$\sqrt{R_1^2-G^2[(X_t+X_o)^2+(Y_t+Y_o)^2]}$
$G(X_t+X_o)$
$G(Y_t+Y_o)$
$R_1^2$ (+)
(-)
(-)
SQUARING CIRCUIT
SQUARING CIRCUIT
SUM
SQUARE ROOT CIRCUIT
LINEARIZATION CIRCUIT FOR PARALLEL OFFSET GUN WITH SAME CENTER OF DEFLECTION
SUM
SUM
$X=X_t+X_o$
$Y=Y_t+Y_o$
$X_t$ POSITION INPUT
$X_o$
$Y_t$ POSITION INPUT
$Y_o$
26
27
28
29
30
31
32
33
34
35
36
37
38
39
25

Fig. 5

# LINEARIZATION OF MAGNETICALLY DEFLECTED CATHODE RAY TUBE WITH NON-AXIAL GUNS

This invention relates to magnetically deflected cathode-ray tube (CRT) displays which are required to present a great variety of information (from many diverse sources) simultaneously on a single cathode-ray tube, at normal refresh rates, and more particularly to an improved linearization circuit for use in correcting the deflection of the electron beam from any of a plurality of guns which is mounted in offset relation with respect to the principal tube or screen axis.

As the amount of information to be displayed on a single gun cathode-ray tube increases, a point is soon reached where considerations of writing speed, brightness and flicker bring about a condition of saturation of the data processing capability of the tube. Clearly, this information display capability can be extended (at a rate of 100 percent per electron gun) if additional guns are added within the cathode-ray tube envelope. However, since physical constraints limit the minimum separation between electron guns to about 3 inches (to allow adequate space for separate deflection coils) and only one electron gun can be mounted axially with the cathode ray tube screen, a severe linearity problem is created for the off-axis electron guns. Moreover, without good linearity, registration between images produced by the separate guns is poor, and the advantage of any additional electron guns within the cathode-ray tube envelope is lost.

It is therefore among the principal objects of the present invention to provide an improved electronic circuit for providing a corrective signal to modify the normal deflection voltage for a given gun, whereby proper linearity is obtained.



FIG. 4 is a perspective drawing, illustrating the deflection geometry for a non-axial gun CRT.

FIG. 5 is a schematic block diagram of a circuit embodying the invention as applied to a tilted electron gun.

Briefly stated, the invention comtemplates the provision of a circuit which will supply small corrective voltages added to the uncorrected deflection voltages for any gun of a multi-gun cathode-ray tube, whereby linearity with respect to a plane perpendicular to the screen axis is obtained. As a true corrective function is difficult to generate, a simplification, more readily producable is substituted therefore, this function being multiplied by the uncorrected deflection voltages, and added to the same to provide corrected deflection voltages.

Before entering into a detailed consideration of the structural aspects of the invention, a review of the theory of operation is considered apposite.

With magnetic beam deflection, the relation between deflection current I (in the deflection yoke) and electron beam deflection angle $\gamma$ is given by $I = K \sin \gamma$, where $K$ is a constant of proportionality. If the cathode-ray tube screen radius of curvature is $R_2$, and the electron gun is displaced parallel to the screen axis (defined as a line perpendicular to the cathode-ray tube screen at its center) a distance $\bar{y}$ along the negative Y display axis, then the angle at which the undeflected electron beam impinges upon the screen is $90°-\mu$, where $\mu =$ arc sin $\bar{Y}/R_2$. If the distance along the undeflected electron beam between the center of deflection and the screen is $R_1$, and the uncorrected horizontal and vertical deflection currents ($I_x$ and $I_y$, respectively) are modified by the correction function $G$ where

$$G=\frac{1}{\sqrt{1+2\frac{Iy}{K}n\sin\mu+2(n\cos\mu-1)\left(n\cos\mu-\sqrt{n^2\cos^2\mu-\left[\frac{(Ix)^2}{K}+\frac{(Iy)^2}{K}\right]+2\frac{Iy}{K}n\sin\mu}\right)}}$$

Another object of the invention lies in the provision of circuitry as above described, in which the corrective function produced by circuit is relatively simple to generate, as contrasted with an exact function of greater complexity.

These objects, as well as other incidental ends and advantages, will more fully appear in the progress of the following disclosure, and be pointed out in the appended claims.

In the drawing, to which reference will be made in the specifications:

FIG. 1 is a graph comparing the characteristics of the exact parallel offset gun deflection signal correction factor $G$ in terms of spot deflection distance $R$, and a close, readily generated approximation of this function in terms of a systhetic variable $\bar{R}$ for a typical rectangular CRT screen size.

FIG. 2 is a schematic block diagram of a circuit embodying the invention as applied to a parallel offset gun.

FIG. 3 is a vector diagram, showing the position of an alternate system of coordinates for use where a given additional gun is laterally displaced to a position other than along either the $X$ or the $Y$ coordinate axis of the screen.

and $n = R_2/R_1$, the deflection sensitivity for this offset gun (with respect to a plane perpendicular to the undeflected electron beam) will remain constant over the entire cathode ray tube screen area.

The function G above is exact, but since it is dependent upon both the horizontal and vertical deflection inputs, it is very difficult to generate. A great simplification occurs if it were possible to redefine the function in terms of a single, easily obtainable, variable. Such a transformation, in accordance with the invention, has been obtained. A new variable $\bar{R}$ is synthesized, where

$$\bar{R} = [(Ix)^2/K + P(Iy)^2/K + Q/R_1 \cdot Iy/k\ ]\ R_1^2$$

and P and Q are constants which may be approximated by the relations

$$P \approx 1 - [(n \sin \mu)/(n \cos \mu - 1)]^2$$

$$Q \approx 2R_1\ (n \sin \mu)/(n \cos \mu - 1)$$

The value of $P$ is almost unity. The value of Q must be optimized for best overall display accuracy, using the relation given above as a starting point. In a more sophisticated design, the value of Q may be permitted to vary slightly as a function of $\bar{R}$ (using feedback or stepped levels.). Making the substitutions $I_x/K = X/R_1$, and $I_y/K = Y/R_1$ (where $X$ and $Y$ are the instantaneous spot deflection coordinates) we may rewrite $\bar{R}$ as

$$\bar{R} = X^2 + P\ Y^2 + Q\ Y$$

and $G$ as

$$G=\frac{1}{\sqrt{1+2\frac{Y}{R_1}n\sin\mu+2(n\cos\mu-1)\left(n\cos\mu-\sqrt{n^2\cos^2\mu-(X^2+Y^2)/R_1^2+2\frac{Y}{R_1}n\sin\mu}\right)}}$$

The design method consists of selecting a test value for $Q$ and, for a number of equally spaced values of $\bar{R}$ over the range of interest, determining the boundary values for both $x$ and $Y$ at each $\bar{R}$. The values of $G$ at these boundary points are then computed giving the maximum spread in G value at each $\bar{R}$. The value of $Q$ is readjusted until a minimum spread in the $G$ function over the entire range of $\bar{R}$ is achieved. The $G$ function generator is designed to reproduce the mean values of the optimized band function obtained above as a function of $\bar{R}$.

A plot of the function $G$ versus $\bar{R}$ is illustrated in FIG. 1. Also plotted is the function $G$ versus $R$ where

$$R=\sqrt{X^2+Y^2}$$

It is clear from this figure that the use of the synthetic variable $\bar{R}$ makes possible the collapse of the area function G into an easily generated, almost linear, line function. The variable $\bar{R}$ is derived from the $X$ and $Y$ position input signals by means of a pair of squaring circuits and a summing amplifier.

For simplicity, the discussion above is limited to the case of an electron gun offset along the $Y$ coordinate axis. This may now be generalized to apply to a gun offset at any point on the cathode-ray tube screen, but with the electron gun axis maintained parallel to the screen axis. Assume that the gun is offset a distance $\bar{y}'$ from the screen axis (center) in a direction making an angle $\theta$ with respect to the deflection vertical ($Y$) axis. If the electron beam is deflected through a deflection angle $\gamma$ in a given plane of deflection, it can be demonstrated that the applicable value of the correction function G is fixed and is independent of the coordinate system which was used to cause the beam deflection. Hence, any coordinate system may be used to derive the value of G.

If the position deflection input coordinate system is $X,Y$, a rotation of coordinates through the angle is performed to obtain the new coordinate system $X'$, $Y'$, where the $Y'$ axis intersects the screen axis. (See FIG. 3.) The equations for the correction function G and the synthetic variable $\bar{R}$ given above, may be used directly for the coordinate system $X'$, $Y'$, after the substitution of $X'$ for $X$ and $Y'$ for $Y$. The values of the position coordinates $X'$ and $Y'$ are obtained from the input position coordinates $X$ and $Y$ by use of the coordinate rotation equations

$$X'=X\cos\theta-Y\sin\theta$$

$$Y'=X\sin\theta+Y\cos\theta$$

The values of sin $\theta$ and cos $\theta$ are constant for a specified gun position and $\mu=\arcsin\bar{y}'/R_2$ for this case. Therefore, the circuit design for this generalized gun position case is identical to that for the simplified case with the addition of a standard coordinate rotation section.

Alternatively, if a slight reduction in accuracy is acceptable, the value of P may be set to unity making $\bar{R}=X^2+Y^2+QY\cos\theta+QX\sin\theta$ and eliminating the need for coordinate conversion.

With the foregoing discussion in mind, reference may now be made to a block diagram of an offset gun cathode-ray tube deflection linearization circuit embodying the invention for the generalized case shown in FIG. 2. Coordinate conversion is accomplished using a pair of summing amplifiers and an inverter. If the coordinate rotation angle $\theta$ is zero, or some multiple of 90°, this structure may be liminated. The value of $\bar{R}$ is synthesized from the $X'$ and $Y'$ coordinates using a pair of squaring circuits and a summing amplifier. The remainder of the circuit operates with the original position coordinates X and Y. Since the correction function G varies over a small range, the linearity correction function generator is designed to generate the magnitude $G-1$ corresponding to the input value of $\bar{R}$. The quantity $G-1$ is then multiplied by each of the two position inputs, producing the correction terms $GX$ -$X$ and $GYY$, which, when added to the corresponding uncorrected inputs produces the corrected position signals GX and GY, respectively. Since the corrected position signals are obtained by the summation of small correction terms to the actual position inputs, any errors in the linearity circuit are reduced by almost an order of magnitude in terms of full scale deflection output. The almost linear relationship between G and $\bar{R}$ assures minimum distortion of displayed conic figures and vectors, since the function generator breakpoint slope transitions can be kept shallow. The disclosed deflection linearization circuit also generates the cathode-ray tube dynamic focus correction signal which is extracted by simply rescaling the $G-1$ signal.

Thus, the circuit, generally indicated by reference character **10**, includes $X$ and $Y$ position inputs **11** and **12**, as well as inverter **13** and summing amplifiers **14** and **15**, the last three elements being optionally deletable. The summing amplifiers feed squaring circuits **16** and **17**, the outputs of which in combination with the unsquared input to **17** are fed to a summing amplifier **18** to generate the synthetic variable $\bar{R}$. This in turn is connected to the function generator **19** which generates the above described function $G-1$. The output of the function generator **19** is fed to multipliers **20** and **21** where the function is multiplied by the deflection voltages from the inputs **11** and **12**, and the products are summed with these same inputs in amplifiers **22** and **23** producing the required corrected position signals $GX$ and $GY$. A scaling device **24** is also driven by the function generator **19** to provide a dynamic focus correction signal in a manner more fully described and claimed in my copending application Ser. No. 103,374, filed Jan. 4, 1971.

A computer analysis of the disclosed linearization technique shows that the maximum theoretical spot position error can be suppressed to within 3 mils for a 15 inch diagonal cathode-ray tube with gun position offset by 1.5 inches from the screen center.

The technique disclosed above may be extended to the still more general case of an electron gun which is not parallel to the screen axis, by simulating an imaginary electron gun which is parallel to the screen axis and which operates through the same center of deflection as the actual non-paralled electron gun. If the distance $R_B$ (along the actual undeflected beam) between the center of deflection and the point where the beam impinges on the CRT screen is known, the value of $R_1$ for the simulated parallel gun may be computed for use in the expression for $G$. (see FIG. 4.) Since the undeflected spot of the actual beam falls some distance away from the zero position of the simulated electron

gun, the incremental deflection coordinates $X_o$ and $Y_o$ of the actual undeflected spot with respect to the simulated gun coordinate system must also be computed. The values of $R_1$, $X_o$ and $Y_o$ are constants for a given electron gun configuration.

If the values of $X_o$ and $Y_o$ are added to the actual $X_t$ and $Y_t$ position inputs, respectively, (where $X_t$ and $Y_t$ are the instantaneous spot deflection coordinates for the tilted gun) the required correction function G (or $G-1$) may be obtained directly using the circuit illustrated in FIG. 2, by letting $X = X_t + X_o$ and $Y = Y_t + Y_o$. The outputs of this circuit would then be $G(X_t + X_o)$ and $G(Y_t + Y_o)$. These outputs, however, are not directly applicable to the tilted gun deflection circuits without some additional processing. If the position of the actual electron gun is tilted upward through an angle $\delta$ with respect to the simulated parallel gun in a plane which makes an angle $\phi$ counterclockwise with respect to the vertical when viewed from the face of the CRT, the required corrected $X$ and $Y$ deflection signals for the tilted gun are:

$$X \text{ deflection} = G(X_t + X_o) - [(1 - \cos\delta)(G(X_t + X_o) \sin\phi + G(Y_t + Y_o)\cos\phi) + \sqrt{R_1^2 - G^2[(X_t + X_o)^2 + (Y_t + Y_o)^2]}\sin\delta]\sin\phi$$

$$Y \text{ deflection} = G(Y_t + Y_o) - [(1 - \cos\delta)(G(X_t + X_o) \sin\phi + G(Y_t + Y_o)\cos\phi + \sqrt{R_1^2 - G^2[(X_t + X_o)^2 + (Y_t + Y_o)^2]}\sin\delta]\cos\phi$$

Since $\delta$ and $\phi$ are constants for a given electron gun, all of the terms in these expressions are readily available except for the term $\sqrt{R_1^2 - G^2[(X_t + X_o)^2 + (Y_t + Y_o)^2]}$ which may be derived using standard computing modules or, if accuracy limitations permit, by simpler approximate means. For a flatfaced CRT screen this square root term is simple $R_1G$. If the electron gun is tilted in one axis only, e.g., $\phi = 0$, $X_o = 0$, the above expressions simplify to:

$$X \text{ deflection} = GX_t$$

$$Y \text{ deflection} = G(Y_t + Y_o)\cos\delta - \sqrt{R_1^2 - G^2[X_t^2 + (Y_t + Y_o)^2]}\sin\delta$$

With the foregoing discussion in mind, reference may now be made to a block diagram of a completely generalized non-axial and non-parallel electron gun cathode-ray tube deflection linearization circuit embodying the invention, shown in FIG. 5. Translation of actual gun deflected spot coordinates $X_t$, $Y_t$ to simulated parallel gun coordinates $X$, $Y$ is accomplished using a pair of summing amplifiers which add the displacement coordinates of the undeflected spot $X_o$, $Y_o$, with respect to the simulated gun, to the input deflection signals. The summed signals are applied as inputs to a linearization circuit designed for the simulated parallel offset gun as described above and as illustrated in FIG. 2. The dynamic focus correction output of this linearization circuit may be used directly. The deflection outputs $G(X_t + X_o)$ and $G(Y_t + Y_o)$ must be transposed back to the coordinates of the actual gun. This is accomplished by squaring the deflection signals and subtracting the results from the constant $R_1^2$ using a pair of squaring circuits and a summing amplifier. The square root of this signal is summed with the deflection signals, using appropriate scaling, to develop the correction term

$$-[(1 - \cos\delta)(G(X_t + X_o)\sin\phi + G(Y_t + Y_o)\cos\phi) + \sqrt{R_1^2 - G^2[(X_t + X_o)^2 + (Y_t + Y_o)^2]}\sin\delta$$

where, as noted above, $\delta$ and $\phi$ are constants. This correction term is added to the deflection signals $G(X_t + X_o)$ and $G(Y_t + Y_o)$, with appropriate scaling, to produce the required corrected $X$ and $Y$ deflection outputs for the tilted gun.

Thus, the circuit, generally indicated by reference character 25, includes $X_t$ and $Y_t$ position inputs 26 and 28, displacement coordinate inputs $X_o$, $Y_o$ of the undeflected spot 27 and 29, and summing amplifiers 30 and 31 which feed a linearization circuit 32, designed for a parallel offset gun (with the same center of deflection as the actual tilted gun) according to the method described earlier in this disclosure. The deflection outputs of the linearization circuit $G(X_t + X_o)$ and $G(Y_t + Y_o)$ are fed to squaring circuits 33 and 34, which feed summing amplifier 35 where the squared deflection signals are substracted from the constant $R_1^2$, followed by derivation of the square root of this result in the square root circuit 36. This square root signal is added to the deflection signals $G(X_t + X_o)$ and $G(Y_t + Y_o)$, with appropriate scaling, in summing amplifier 37 which feeds the final correction signal to summing amplifiers 38 and 39 which also accept the deflection signals $G(X_t + X_o)$ and $G(Y_t + Y_o)$, respectively, to produce the required corrected X and Y deflection outputs for the tilted gun. The linearization circuit 32 also provides the dynamic focus correction signal which may be used directly without further processing.

It may thus be seen that I have invented novel and highly useful improvements in a cathode-ray tube deflection linearization circuit for use with a laterally offset or tilted gun which provides a simple, highly accurate, solution to a complex linearity problem. The disclosed embodiment includes means for linearizing imagery from independently deflected electron guns located anywhere within the cathode-ray tube envelope, making possible the design of a multi-gun cathode-ray tube display without serious registration problems between separate superimposed images. Additionally, a dynamic focus correction signal for each electron gun is provided without additional computational hardware. Correction is accomplished in a manner to incidently provide for minimum distortion of displayed conics and vectors.

I wish it to be understood that I do not consider the invention limited to the precise details of structure shown and set forth in this specification, for obvious modifications will occur to those skilled in the art to which the invention pertains.

I claim:

1. A circuit for providing correctional voltages whereby in a magnetically deflected multi-gun cathode-ray tube, an electron gun having a principal axis laterally displaced with respect to a principal screen axis may be linearized with respect to said principal axis, said circuit comprising: X and Y signal position inputs, first and second squaring circuits connected respectively to said X and Y signal position inputs, a summing amplifier summing the outputs of said squaring circuits and a position input coordinate $Y_1$ corresponding to the direction of gun displacement, to produce the synthetic variable:

$$\overline{R} = X^2 + PY^2 + QY$$

where $X$ and $Y$ are input coordinates system variables, $P$ is a constant approximated by the relation

$$P \approx 1 - [n \sin\mu/n \cos\mu - 1]^2$$

$Q$ is a constant approximated by the relation

$$Q \approx 2R_1 (n \sin \mu / n \cos \mu - 1)$$

and optimized to produce best linearity

$R_1$ = the distance along the undeflected electron beam between the center of deflection and the screen,

$$\mu = \text{arc sin } \bar{Y}/R_2,$$

$R_2$ = the radius of screen curvature,

$\bar{Y}$ = the distance through which the gun is displaced from the screen axis

$$n = R_2/R_1,$$

a function generator connected to the output $\bar{R}$ of said summing amplifier, and generating an optimized but simplified corrective function $G-1$, where G approximates the true but complex function:

$$G = \frac{1}{\sqrt{1+2\frac{Y}{R_1} n \sin \mu + 2(n \cos \mu - 1)\left(n \cos \mu - \sqrt{n^2 \cos^2 \mu - (X^2+Y^2)/R_1^2 + 2\frac{Y}{R_1} n \sin \mu}\right)}}$$

multiplier means connected to the output of said function generator and said signal position inputs producing a product proportional to the correction voltage required, and means summing the corrective voltage and the deflection voltage.

**2.** Structure in accordance with claim **1**, including scaling means connected to said function generator to provide a dynamic focus correction signal.

**3.** Structure in accordance with claim **1**, including rotational coordinate conversion means comprising a pair of summing amplifiers and an inverter interconnecting the said position inputs and said squaring circuits.

**4.** A circuit for providing correctional voltages whereby an electron gun having a principal axis which is not parallel to the principal screen axis may be linearized with respect to said principal axis, by simulating a laterally displaced gun with the same center of deflection as the actual tilted gun, said circuit comprising: $X_t$ and $Y_t$ signal position inputs with respect to the tilted gun, $X_o$ and $Y_o$ constant incremental coordinate inputs corresponding to the coordinates of the actual undeflected spot with respect to the simulated gun coordinates, summing means to add the incremental coordinates to the inputs producing the simulated coordinates $X_t + X_o$ and $Y_t + Y_o$, a linearization circuit designed for the simulated laterally displaced gun according to claim **1**, accepting said simulated coordinates as inputs and providing the corrected deflection outputs $G(X_t + X_o)$ and $G(Y_t + Y_o)$ for the simulated electron gun and the dynamic focus correction, first and second squaring circuits connected to said corrected deflection outputs, a summing amplifier to subtract the outputs of said squaring circuits from the constant $R_1^2$, a square root circuit connected to the output of said summing amplifier to develop the term $\sqrt{R_1^2 - G^2[(X_t + X_o)^2 + (Y_t + Y_o)^2]}$ and summing means with appropriate scaling connected to the output of said square root circuit and the deflection outputs $G(X_t + X_o)$ and $G(Y_t + Y_o)$ of the linearization circuit to produce the corrected deflection outputs for the actual tilted gun such that

$$X \text{ output} = G(X_t + X_o) - U \sin \phi$$
$$Y \text{ output} = G(Y_t + Y_o) - U \cos \phi$$

where $U = (1 - \cos \delta)(G(X_t + X_o) \sin \phi + G(Y_t + Y_o) \cos \phi) + \sqrt{R_1^2 - G^2[(X_t + X_o)^2 + (Y_t + Y_o)^2]} \sin \delta$

$\phi$ = angle with repsect to vertical of plane in which gun is tilted

and $\delta$ = angle of tilt of actual electron gun.

**5.** Structure in accordance with claim **4**, in which linearization correction for any non-axial electron gun is developed in terms of a simulated electron gun with the same center of deflection as the tilted gun but with principal axis parallel to the screen principal axis, the resulting correction signals subsequently being converted to the form required for the actual tilted gun in terms of the angles $\phi$ and $\delta$, defining the orientation of the tilted gun with respect to the simulated gun.

* * * * *