Nov. 3, 1959 J. C. MOLLEN ET AL 2,911,557

ANALOGUE COMPUTER

Filed Aug. 23, 1956 3 Sheets-Sheet 1

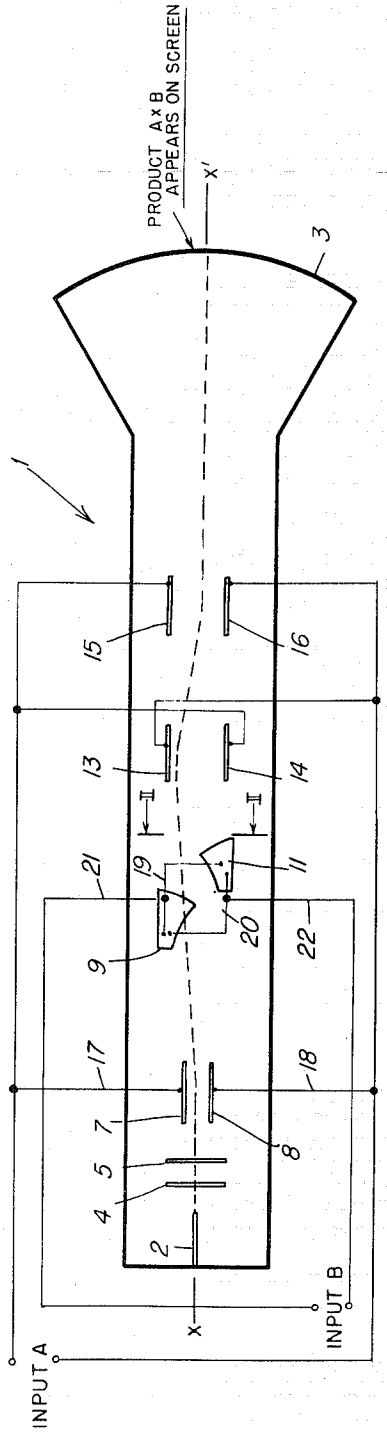
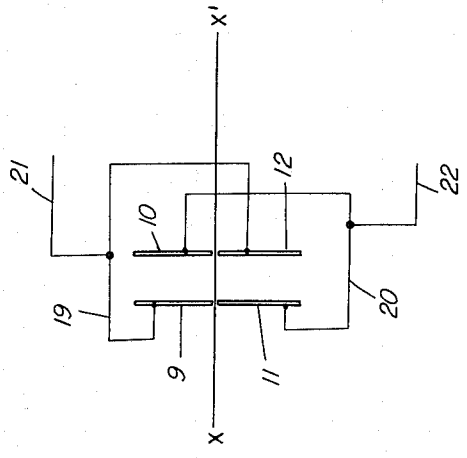


FIG. 1

FIG. 2



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ANALOGUE COMPUTER

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FIG. 3

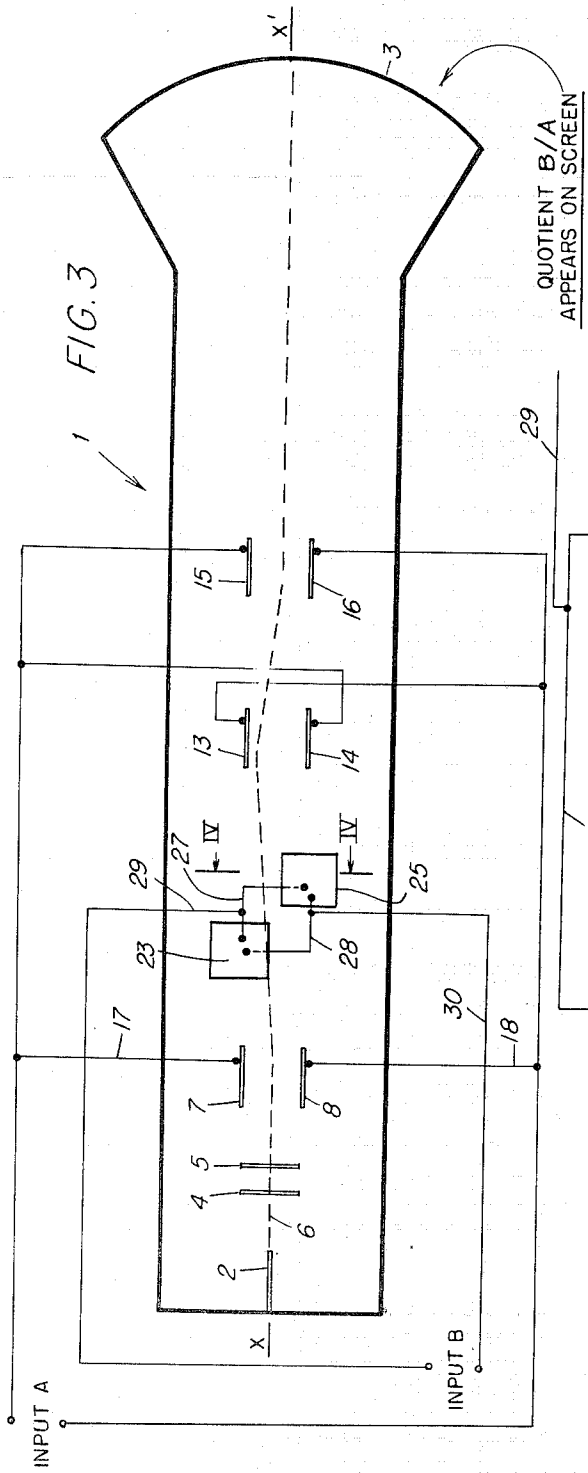
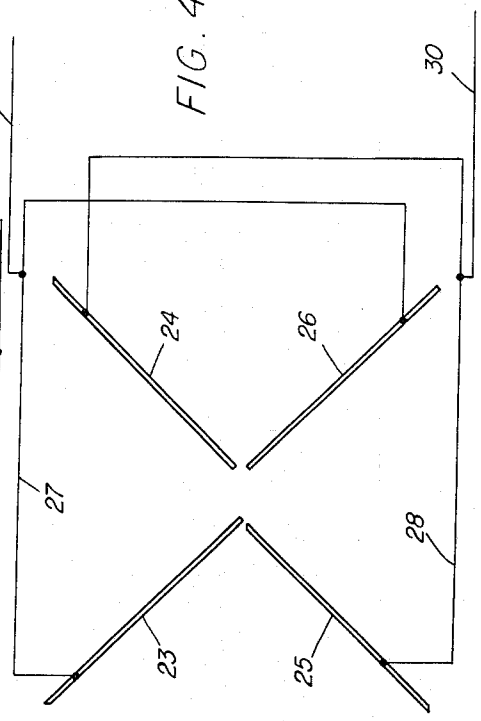


FIG. 4



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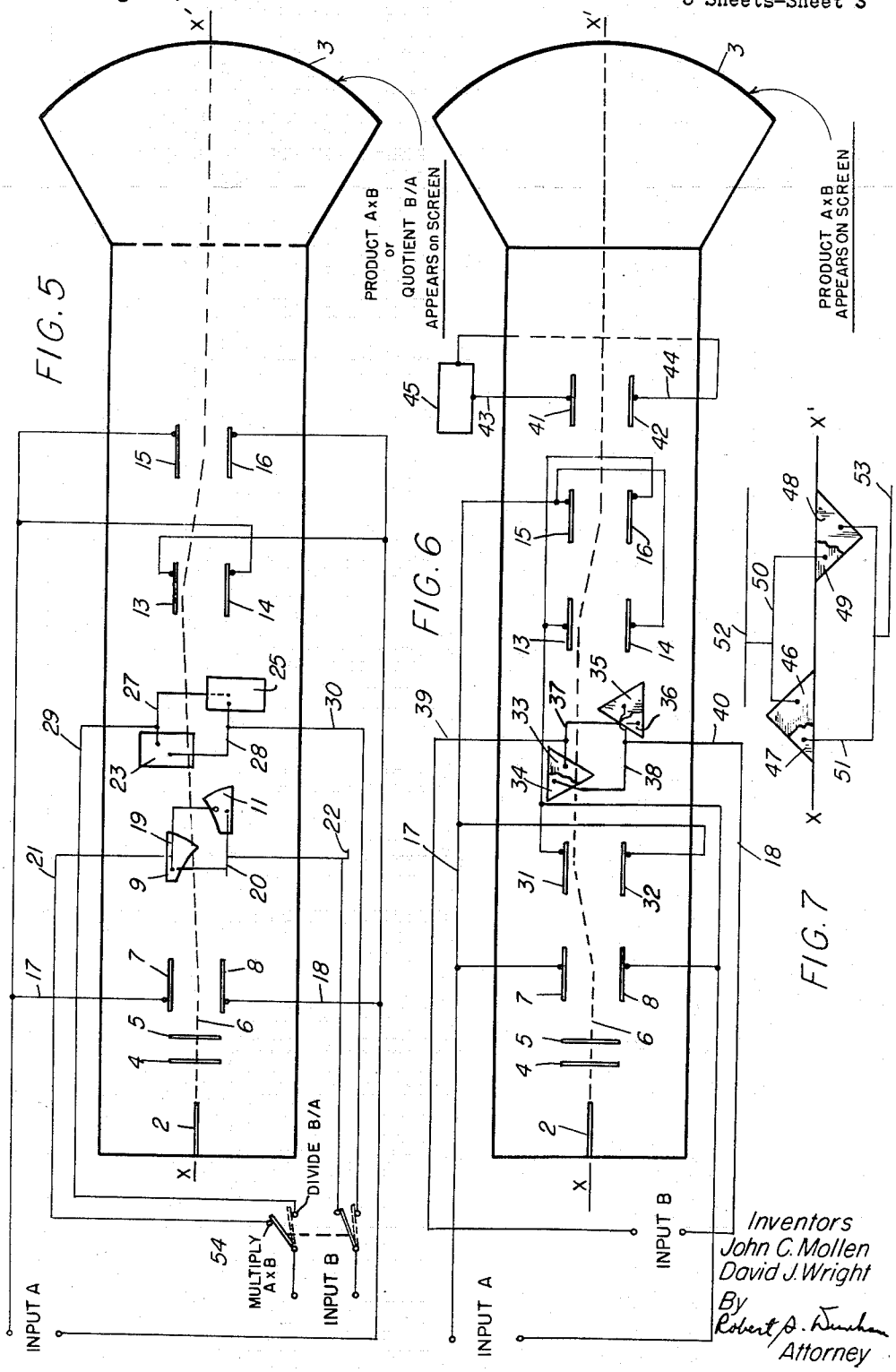
ANALOGUE COMPUTER

Filed Aug. 23, 1956 3 Sheets-Sheet 3



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2,911,557

ANALOGUE COMPUTER

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Application August 23, 1956, Serial No. 605,745

10 Claims. (Cl. 315—8.5)

This invention relates to analog computers generally and more particularly to cathode ray devices adapted to mutiply and/or divide a plurality of applied potentials.

Cathode ray tubes of the prior art have long been used to translate applied electric potentials into visible traces, and in some cases to make records of the variation of such potentials. They have also been operated to obtain the sum and difference of such potentials as well as to deflect electron beams according to some predetermined linear or non-linear function of an applied potential.

An object of the present invention is to provide a tube of the cathode ray type which is adapted to translate two electric potentials into a trace indicating the product or quotient of the two potentials.

A further object of the present invention is to provide a tube of the cathode ray type which is adapted to indicate as a function of time the product or quotient of two different electric potentials, one or both of which may vary with time.

A further object of the invention is to provide a cathode ray tube as above set forth wherein the polarity of the product or quotient obtained is always derived from the polarity of the applied potentials in accordance with the conventional system of Cartesian coordinates.

The foregoing and other objects of the invention are attained by providing a cathode ray tube having the usual electron emitting device, directing and accelerating anodes and a luminescent screen. In this tube, there are provided, in accordance with the present invention, at least two sets of plates adapted when supplied with electric potentials to create at least two electron beam deflecting electrostatic fields spaced in series to be traversed consecutively by the beam. Such sets of plates are positioned perpendicularly to each other. The electrostatic plates creating and defining said fields are so constructed that the deflection of an electron beam as it leaves the second field will be directly proportional to the product or quotient of the two potentials applied to the two sets of plates.

The ultimate deflection of the electron beam effected by the operation of the deflecting fields is assured a polarity consonant with the conventional system of Cartesian coordinates by forming the second set of plates from two pairs of plates, each pair of which is adapted when supplied with electric current to create one-half the electron beam deflecting electrostatic field created by such second set of plates. Such pairs of plates are positioned on opposite sides of a plane perpendicular to the plane of the plates and containing the tube axis. There are further provided electrical connections between the diagonally opposite plates of such second set of plates. The potential to be multiplied or divided is then applied directly across the two electric connections.

The invention will become apparent from the following description taken with reference to the acocmpanying drawings forming part of the specification, wherein:

Figure 1 is a somewhat schematic plan view of a cathode ray tube embodying the invention adapted to indicate the product of two applied potentials;

Figure 2 is an enlarged sectional view, taken on the line II—II of Fig. 1 illustrating one set of the deflecting plates;

Figure 3 is a plan view illustrating somewhat schematically a cathode ray tube constructed in accordance with another embodiment of the invention and adapted to indicate the quotient of two applied potentials;

Figure 4 is an enlarged sectional view, taken on the line IV—IV of Fig. 3, illustrating one set of the deflecting plates;

Figure 5 is a somewhat schematic plan view, generally similar to Figs. 1 and 3, illustrating a cathode ray tube employing another embodiment of the invention;

Figure 6 is a somewhat schematic plan view, with certain parts broken away, of a cathode ray tube illustrating the presently preferred embodiment of the invention adapted to indicate the product of two applied potentials, and

Figure 7 is an enlarged fragmentary view, similar to Fig. 6, with certain parts broken away, illustrating a modified form of one set of deflecting plates.

Figs. 1 and 2

Referring now to the drawings there is shown a cathode ray tube generally indicated by the numeral **1**, having a cathode **2** at one end of the tube and a luminescent screen **3**, at the opposite end.

Positively charged directing and accelerating electrodes **4** and **5** are provided adjacent cathode **2**. An electron beam **6** emitted from the cathode and directed and accelerated by electrodes **4** and **5** passes three successive electrostatic deflecting fields, each created by a set of electrically charged deflecting plates, shown in Figs. 1 and 3 of the accompanying drawings. The first of the three fields is created by a set of two plates shown at **7** and **8**, the second field by a set of four plates, **9**, **10**, **11** and **12** and the third field by another set of four plates **13**, **14**, **15** and **16**.

Deflecting plates **7** and **8** comprise a first set of plates and are arranged vertically, as viewed in Fig. 1, parallel to each other and to the axis of the tube, and are effective to create a horizontal electrostatic field which deflects beam **6** in a horizontal direction.

Leads **17** and **18** are connected respectively to plates **7** and **8** and also to a set of terminals marked "Input A" for applying to the computer one of two potentials representing two quantities whose product it is desired to determine.

Deflecting plates **9**, **10**, **11** and **12** together comprise a second set of plates and are arranged horizontally as viewed in Fig. 1, parallel to each other and to the axis of the tube and are effective to create a vertical electrostatic field comprised of two separate sections, one section being created by the pair of plates **9**, **10**, and the other section by the pair of plates **11**, **12**. Each of such separate vertical electrostatic field sections is adapted to deflect beam **6** in a vertical direction. The two separate vertical electrostatic field sections are further positioned on opposite sides of a plane perpendicular to the fields and containing the tube axis. Beam **6** traverses only one of the separate vertically deflecting field sections at any given moment, the particular section being determined by the polarity of the potential applied across horizontally deflecting plates **7** and **8**. Connecting wires **19** and **20** are attached at their opposite ends to diagonally opposite plates of the vertically deflecting set, as best illustrated in Fig. 2.

Leads **21** and **22** are connected respectively to wires **19** and **20** and to a set of input terminals marked "Input B" for applying to the computer the other of the two poten-

tials representing the two quantities whose product it is desired to determine.

In the embodiment of the invention shown in Figs. 1 and 2, plates 7 and 8 are substantially rectangular in shape and geometrically similar. Plates 9, 10, 11 and 12 are also geometrically similar but varying in width. The narrowest portion of each such plate lies nearest the tube axis, X—X', as best illustrated in Fig. 1.

It will be observed in Fig. 1 of the accompanying drawing that plates 9 and 11 are so constructed that the edges nearer the cathode 2 are slightly concave. Plates 10 and 12 are similarly constructed. The precise shape of these plates is determined by the principles of electron deflection which follow.

It is well understood that the angle of deflection of an electron passing through a deflecting field is proportional to the product of the field strength and the time spent by the electron in traversing the field. Further, the field strength varies directly with the potential difference existing between the plates. In the case of the plates 7 and 8, the time spent in the field by an electron may be assumed, without substantial error, to be substantially the same at all times, for all deflections introduced by those plates, within the operative range of the apparatus. Hence, the deflection of the beam as it leaves the space between the plates 7 and 8 varies only in accordance with the potential applied to those plates. Consequently, that potential determines the angle of horizontal deflection of the beam from the axis and the tangent of that angle determines the point where it enters the space between the plates 9 and 10 or 11 and 12.

Assuming constant velocity of an electron beam in the axial direction, the time spent by individual electrons of the beam in passing between a pair of plates is determined by the dimension of the plates in the direction parallel to the axis. This dimension is hereinafter termed the effective deflecting length of the plates.

The edges of the plates 9, 10 and 11, 12 should be contoured so that the time spent by an electron as it passes between the plates (or, the effective deflecting length) varies in direct proportion to the tangent of the angle of the horizontal deflection introduced by the plates 7 and 8, and hence in proportion to the potential applied across plates 7 and 8.

If the pairs of plates 9, 10 and 11, 12 are contoured as described above, then the vertical deflection effected by either pair of plates is proportional to the product of the potential between plates 7 and 8, times the potential between plates 9, 10 or 11, 12. This product deflection is indicated by the vertical displacement of the beam as it impinges upon luminescent screen 3.

It will be apparent, moreover, that only the deflection effected by the vertical deflecting plates represents the product of the potentials applied to both vertical and horizontal plates. In the measurement of that product, the horizontal deflection of the beam is without significance. Therefore the horizontal deflection may be, and indeed is preferably, eliminated after the beam passes the plates 9 and 10 or 11 and 12. For that purpose there is provided a set of horizontally deflecting plates 13, 14, 15 and 16 together constituting a converging electron lens having its focal plane on the screen and adapted to return the electron beam to a position of horizontal alignment with the tube axis. The "Input A" terminals are connected to plates 13 and 14 and 15 and 16, as shown in Fig. 1, by leads arranged to produce oppositely directed fields of suitable relative strengths, located successively in the path of the electron beam.

The spacings and dimensions of the various deflecting plates shown in the drawing are selected for purposes of schematic illustration only. Actual spacings and dimensions in any physical structure will depend on the geometry of the complete tube. In some tube configurations, it may be necessary to include shielding plates between various successive sets of deflecting plates, in a manner well-known in the art.

This adaptation makes possible a simplified reading of the product upon a vertical scale (not shown) provided upon the surface of screen 3.

There is thus disclosed a cathode ray tube adapted to multiply two applied potentials and to indicate the product thus obtained.

An additional feature of the invention insures that the resultant beam is always deflected in a direction depending upon the polarities of the potentials being multiplied, in accordance with the conventional system of Cartesian coordinates.

This improvement is attained by separating the set of vertically deflecting plates into two pairs, each such pair being positioned on either side of a vertical plane containing the tube axis, and connecting the input leads 21 and 22 for the potentials to be applied to connecting wires 19 and 20 attached at their opposite ends to the diagonally opposite plates of such vertically deflecting set, e.g. connecting wire 19 is attached to plates 9 and 12 and connecting wire 20 is attached to plates 10 and 11, as best illustrated in Fig. 2 of the accompanying drawings. It will be apparent that by this arrangement each pair of diagonally opposite plates of each set is at the same potential. In other words, the deflecting field sections between the pairs of plates positioned on opposite sides of the vertical plane through the tube axis are oppositely directed and of equal strength. Furthermore, as shown in Fig. 1, those field sections are spaced along the tube axis sufficiently distant to prevent any substantial distortion of either field by the other. In this manner, the direction of vertical displacement from the axis of the tube depends upon the direction of the previous horizontal displacement from that axis. It will be thus seen that by the proper connection of terminals, the indication obtained upon screen 3 will be polarly consonant with the conventional system of Cartesian coordinates, whatever the instantaneous polarity of the potentials applied to the vertically and horizontally deflecting plates at any given moment. In other words, when both potentials have the same polarity the indicating trace will be deflected in one direction, and when the potentials have opposite polarities the trace will be deflected in the opposite direction.

Figs. 3 and 4

Another feature of my invention is that the second set of deflecting plates may alternatively be shaped to obtain a deflection on the screen representing the quotient of the two applied potentials. The shape of such plates is best illustrated at 23, 24, 25 and 26 in Figs. 3 and 4 of the accompanying drawings. In these figures, those elements which are structurally and functionally the same as their counterparts in Fig. 1 have been given the same reference numerals, and will not be further described. The construction of these plates 23, 24, 25 and 26 is based upon the principle that the deflection effected by an electric field is directly proportional to the field strength, and therefore, for a given applied potential, inversely proportional to the distance between the plates. The vertically deflecting plates are constructed so that the distance between the plates of either pair varies directly with the tangent of the angle of horizontal deflection of the beam from the tube axis. Therefore, the vertical displacement of the beam produced by those plates is an inverse function of the tangent of that angle and hence of the potential applied to plates 7 and 8. It is also a direct function of the potential applied to plates 23, 24 and 25, 26. Consequently, the vertical displacement of the beam, as it leaves the plates 23 and 24 or 25 and 26, is a measure of the quotient of the potential applied to plates 23, 24 and 25, 26 divided by the potential applied to plates 7 and 8.

The potential representing the dividend in the required

computation is connected to the "Input B" terminals. The potential representing the divisor is connected to the "Input A" terminals. Wire leads **29** and **30** serve as input leads connecting the "Input B" to connecting wires **27** and **28** which in turn are connected at their opposite ends to the diagonally opposite plates of the vertically deflecting set in much the same manner as previously described with reference to plates **9**, **10**, **11** and **12**. The quotient indicating trace appearing upon screen **3** is thus assured a polarity consonant with the conventional system of Cartesian coordinates.

Fig. 5

It will be apparent moreover that, while I have set forth the divisional and multiplicational embodiments of my invention in separate tubes best illustrated in Figs. 1 and 2, both types of plates may be constructed in a single tube as illustrated in Fig. 5. When so constructed, both sets of product and quotient plates are adjacent each other and lie between plates **7** and **8**, and **13** and **14**. Product plates are shown in Fig. 5 at **9** and **11**, and quotient plates at **23** and **25**. Potential is applied to the product or the quotient plates (but not both) depending upon the mathematical operation desired.

As illustrated, the "Input A" terminals are permanently connected to the plates **7** and **8**. The "Input B" terminals are connected to a double pole, double throw switch, generally indicated by the reference numeral **54**, and shiftable between a full-line position identified by the legend "Multiply A×B," in which the B terminals are connected to the product plates **9**, **10**, **11** and **12**, and a dotted-line position identified by the legend "Divide B/A," in which the B terminals are connected to the quotient plates **23**, **24**, **25** and **26**.

Additional sets of product plates may be provided to include as many factors in the final result as seems desirable. If more than one divisional operation is required in one tube, then the beam must be corrected as to its horizontal displacement, i.e. its horizontal displacement must be reduced to zero, after each division operation.

Fig. 6

The preferred embodiment of the invention is shown in Fig. 6 of the accompanying drawings. In this figure as in Figs. 3 and 4 those elements which are structurally and functionally the same as their counterparts in Fig. 1 have been given the same reference numerals and will not be further described. Vertically arranged horizontally deflecting plates **31** and **32** are provided adjacent to and parallel with plates **7** and **8** and comprise, in conjunction therewith, a diverging electron lens, i.e., a lens tending to displace the beam parallel to the axis of the tube.

A set of product deflecting plates **33**, **34**, **35** and **36** are arranged horizontally, as viewed in Fig. 6, parallel to each other and to the axis of the tube and are effective to create a vertically deflecting electrostatic field comprising two separate vertical electrostatic field sections, each adapted to deflect beam **6** in a vertical direction. Each field section is positioned on opposite sides of a vertical plane containing the tube axis. Beam **6** traverses through only one of the vertically deflecting field sections at any given moment, the particular field traversed being determined by the polarity of the potential applied across horizontally deflecting plates **7** and **8** and **31** and **32**. Connecting wires **37** and **38** are attached at their opposite ends to diagonally opposite plates of the vertically deflecting set of plates, as best illustrated in Fig. 6. Leads **39** and **40** are connected respectively to wires **37** and **38** and are connected to the "Input B" terminals.

The effect of the diverging electron lens is first to deflect beam **6** horizontally from the tube axis and thereafter to align the deflected beam parallel to the axis. Stated in other words, the plates **7** and **8** deflect the beam

6 laterally through an angle in direct proportion to the potential applied to those plates. The plates **31** and **32** then correct the angle of horizontal deflection so that the beam as it leaves the plates **31** and **32** is travelling parallel to the tube axis. The potential applied to the plates **7**, **8** and **31**, **32** and the consequent horizontal displacement from the tube axis alone determines the point where an electron enters the space between plates **33** and **34** or **35** and **36**. Thus the distance an electron travels between the lens and the vertically deflecting plates **33**, **34**, **35** and **36** does not affect the point at which the beam enters the vertically deflecting field. In the preferred embodiment of my invention plates **33**, **34**, **35** and **36** are contoured solely to provide a direct proportion between the time spent by an electron as it passes between a pair of such plates and the distance from the tube axis where the electron enters the space between such pair. Specifically, the contour of the plates is triangular, with an angle of the triangle adjacent the tube axis.

This contour of the plates **33**, **34**, **35** and **36** makes the vertical deflection of the beam introduced thereby proportional to the horizontal displacement introduced by the plates **7**, **8**, **31** and **32**. The vertical deflection of the beam is also necessarily proportional to the field strength between the plates **33**, **34** and **35**, **36**. Consequently, the vertical deflection is proportional to the product of the potentials applied to the first and second sets of plates.

The converging electron lens provided by the plates **13**, **14**, **15** and **16** is effective to remove the horizontal displacement introduced by the first lens (plates **7**, **8** and **31**, **32**) and which is without significance, as far as an indication of the product is concerned.

There is also provided in Fig. 6 an additional set of deflecting plates **41** and **42** placed between plates **15** and **16** and screen **3**. Leads **43** and **44** are respectively connected to these plates and serve as a terminal for a sweep circuit of a type well known in the art and designated generally in Fig. 6 of the accompanying drawings as **45**.

Plates **41** and **42**, thus connected, produce a horizontally deflecting field which allows the vertically deflected beam to be indicated upon screen **3** as a function of time (horizontal displacement on the screen representing time) where either or both of the applied potentials varies with time.

Fig. 7

Another feature of the invention is that the set of vertically deflecting plates may alternatively be contoured to obtain a deflection upon the screen representing the quotient of two applied potentials. The contour of such plates, best illustrated at **46**, **47**, **48** and **49** in Fig. 7 of the accompanying drawings, is such that the time spent by an electron as it passes between either pair of plates varies in inverse proportion to the potential applied across the horizontally deflecting plates. This result is secured by making the effective deflecting length proportional to the distance from the tube axis at the point where the electron enters the space between the plates. That is, the plates are triangular with an angle thereof spaced from the tube axis and the side opposite such angle positioned along the axis. It is at once apparent that the set of product plates shown in Fig. 6 and the set of quotient plates shown in Fig. 7 are entirely similar except as to their position with respect to the tube axis. The product plate increases in its dimension parallel to the tube axis and the quotient plate decreases in such dimension in direct proportion to the potential applied to the horizontally deflecting plates and thereby to the horizontal displacement from the tube axis.

The quotient plates **23**, **24**, **25** and **26** of Figs. 3, 4 and 5 could be replaced by a set of flat plates similar to the plates **9**, **10**, **11** and **12**, but with their contours reversed with respect to the tube axis as the contours of plates

46, 47, 48 and 49 are based on contours of plates 33, 34, 35 and 36, but reversed with respect to the axis of the tube.

Wires 52 and 53 are connected to terminals for a potential to be applied and are attached to connecting wires 50 and 51 which in turn are connected at their opposite ends to the diagonally opposite plates of the vertically deflecting set of plates in much the same manner as previously described with reference to plates 33, 34, 35 and 36. It is further apparent that the sets of product and quotient plates may be constructed in separate tubes (as in Figs. 1 and 3) or in a single tube (as in Fig. 5). Where both sets are constructed in a single tube, they would be located adjacent each other and between plates 31 and 32 on the one hand and 13 and 14 on the other hand. The potential would be applied to the product or quotient plates (but not both), depending upon which mathematical operation was desired. Additional sets of product plates may be provided to include as many factors in the final result as seems desirable. If more than one division operation is required in one tube then the beam must be corrected to eliminate its horizontal displacement after each division operation.

Potentials applied to any of the embodiments of the invention may represent direct factors to be multiplied as voltage, current, etc., or they may represent various functions of outside systems.

For an example, in order to measure the power in an electrical circuit, a voltage measuring potential may be applied to the vertically deflecting plates and simultaneously therewith a current measuring potential to the horizontally deflecting plates. The measurement of the power represented by the product of the current and voltage will be indicated upon the screen. If either the voltage or the current being measured varies with time, then the concurrent variation of the power with time may be indicated by the use of a suitable sweep circuit, as described in connection with Fig. 6.

It is to be understood, however, that the invention is not to be limited by the exact embodiments of the devices shown which are by way of illustration and not limitation, as various and other forms of the device will be apparent to those skilled in the art without departing from the spirit of the invention or the scope of the claims.

What is claimed is:

1. A deflecting plate for use in conjunction with a similar and opposed plate to create a deflecting electrostatic field in a cathode ray tube having a normal beam axis, said plate and its opposed plate being offset from the tube axis, the edge of said plate first passed by a moving electron being concave and arcuate with respect to a center of curvature on the tube axis and the edge opposite said first edge being convex so that the dimension of said plate along the path of an electron moving at an angle to said axis passing between such plate varies in direct proportion to the tangent of said angle.

2. An analog computer comprising a cathode ray tube including means to direct a cathode ray beam along an axis, first and second sets of electrostatic deflecting plates spaced in succession along said axis, said first set comprising two flat plates located on opposite sides of and parallel to a first plane containing said axis, means for applying a first electric potential across said two plates, said two plates and said potential applying means cooperating to deflect said cathode ray beam from said axis along a path lying in a second plane containing said axis and perpendicular to said first plane, said path being spaced from said first plane by a distance which at any point along said path varies proportionally to variations in said first potential, said second set of plates comprising two flat plates located on opposite sides of said second plane, means for applying a second electric potential across the plates of said second set, said second set having a dimensional characteristic varying proportionally to the distance from said first plane at the locality along the beam path where the beam enters between said second set of plates, said dimensional characteristic proportionally affecting the deflection of said beam by said second set of plates, said second set of plates and said second potential applying means cooperating to deflect said beam from said second plane in a direction parallel to the first plane and along a path spaced from said second plane by a distance which at any point varies proportionally to variations of both said first and second potentials, and means spaced along the beam from said second set for exhibiting the deflection of said beam from said second plane.

3. An analog computer as defined in claim 2, in which said dimensional characteristic of said second set of plates is the effective deflecting length thereof and is directly proportional to said distance from the first plane, so that the deflection produced between said second set of plates is proportional to the product of said first and second potentials.

4. An analog computer as defined in claim 2, in which said dimensional characteristic of said second set of plates is the effective deflecting length thereof and is inversely proportional to said distance from the first plane, so that the deflection produced between said second set of plates is proportional to the quotient of said second potential divided by said first potential.

5. An analog computer as defined in claim 2, in which said dimensional characteristic of said second set of plates is the spacing between the plates and is directly proportional to said distance from the first plane, so that the deflection produced between said second set of plates is proportional to the quotient of said second potential divided by said first potential.

6. An analog computer as defined in claim 2, in which said first set of plates comprises said two flat plates and third and fourth flat plates parallel to said first plane and spaced along said axis from said two plates, means for applying said first potential across said third and fourth plates in a sense reversed as compared to its application across said two plates, all the plates of said first set cooperating as an electron lens to displace said beam so that it leaves said first set along a path parallel to said axis and displaced therefrom by a distance which varies proportionally to variations in said first potential.

7. An analog computer as defined in claim 2, including an electron lens between said second set of plates and said exhibiting means, means to apply said first potential to said lens in a sense to oppose and cancel the deflection introduced by said first set of plates, so that the only deflection exhibited by said exhibiting means is that produced between said second set of plates.

8. An analog computer as defined in claim 2, in which said second set of plates comprises two pairs of plates, the plates of each pair being located on opposite sides of said second plane, and the respective pairs being located on opposite sides of said first plane, and means for applying said second potential to the two pairs in opposite senses, so that the deflection of said beam from said second plane is in a direction determined by the polarities of said potentials in accordance with a system of Cartesian cordinates in which the intersection of said planes with a mutually perpendicular plane define the axes.

9. An analog computer as defined in claim 8, in which the two pairs of plates are spaced in succession along the beam axis, to inhibit distortion of the electrostatic field of one pair by the field of the other pair.

10. An analog computer as defined in claim 2, comprising a third set of electrostatic deflecting plates spaced along said axis from said first and second sets, said third set having a dimensional characteristic varying proportionally to the distance from said first plane at the locality along the beam path where the beam enters between said second set of plates, the dimensional characteristic of one of said second and third sets directly affecting the deflection of said beam as a function of said distance and the

dimensional characteristic of the other of said second and third sets inversely affecting the deflection of said beam as a function of said distance, said means for applying said second potential including means being selectively operable to apply said second potential to either said second set, whereupon the deflection between said second set is a measure of the product of said first and second potentials, or to said third set, whereupon the deflection between said third set is a measure of the quotient of said second potential divided by said first potential.

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