March 18, 1947. C. A. LOVELL ET AL 2,417,425

POTENTIOMETER CIRCUIT

Filed June 9, 1944

FIG. 1

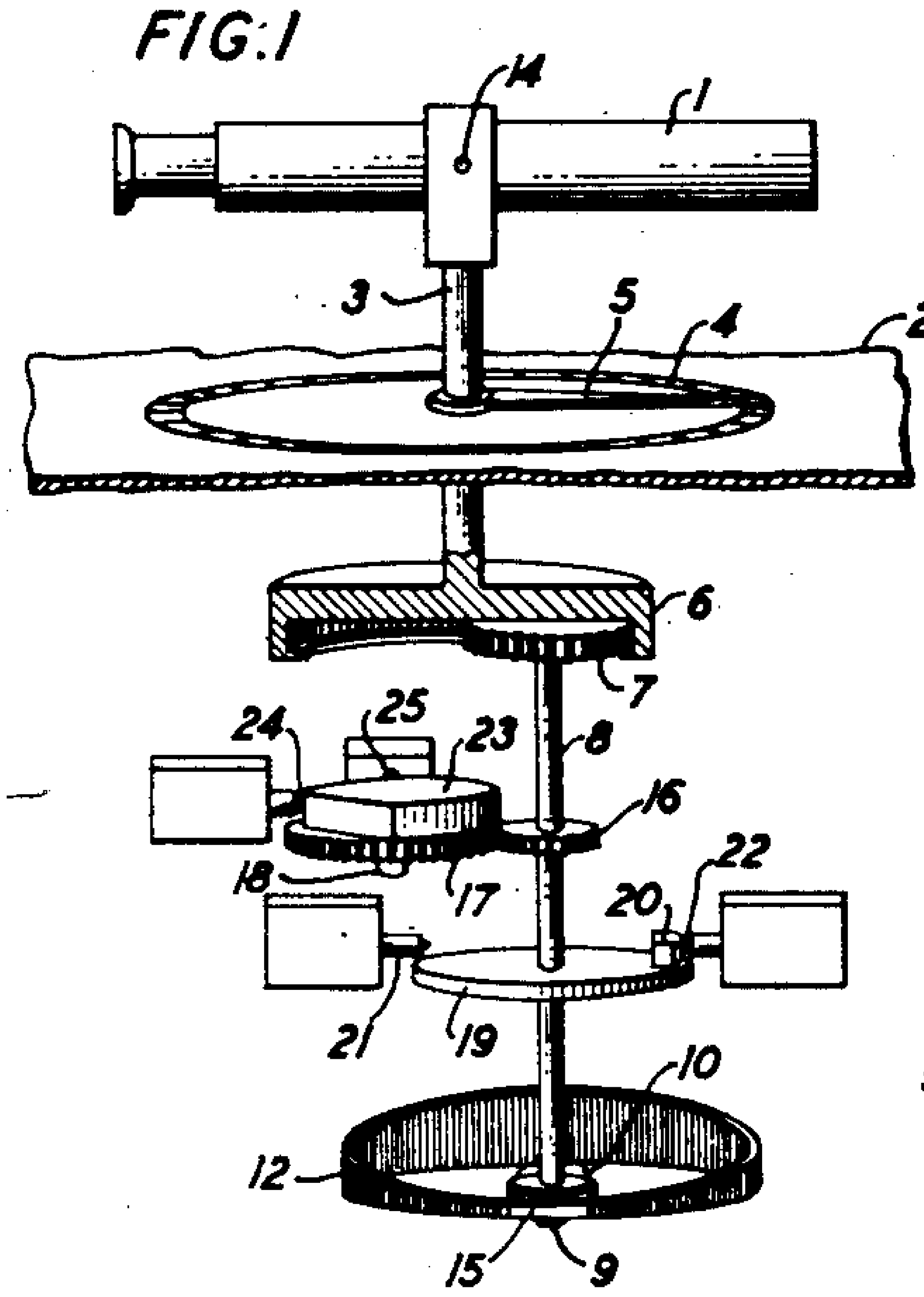


FIG. 2

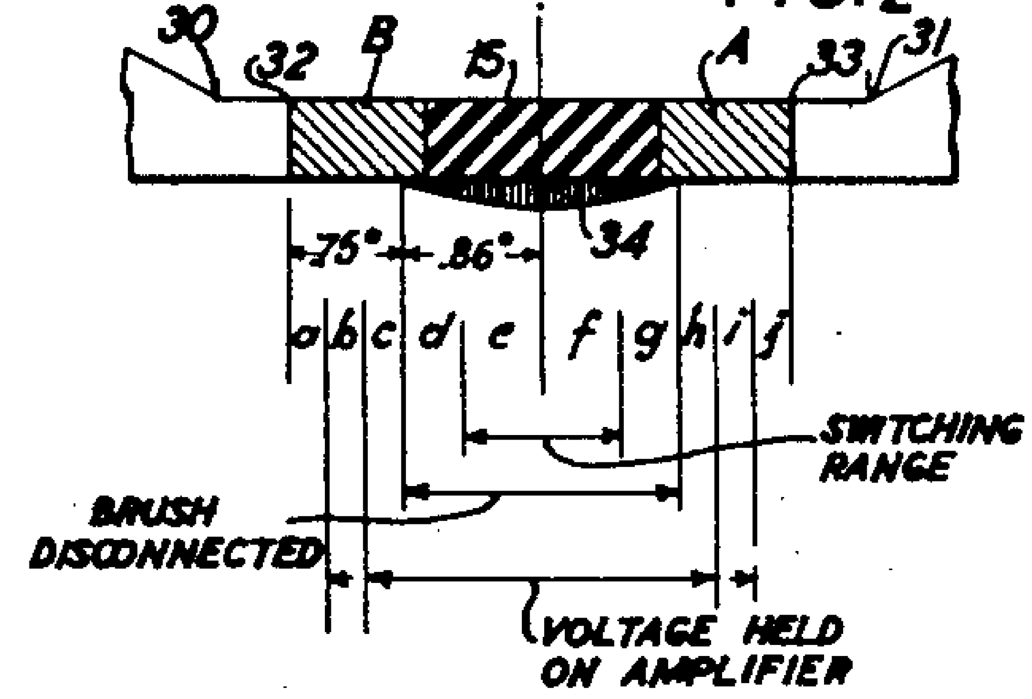


FIG. 3

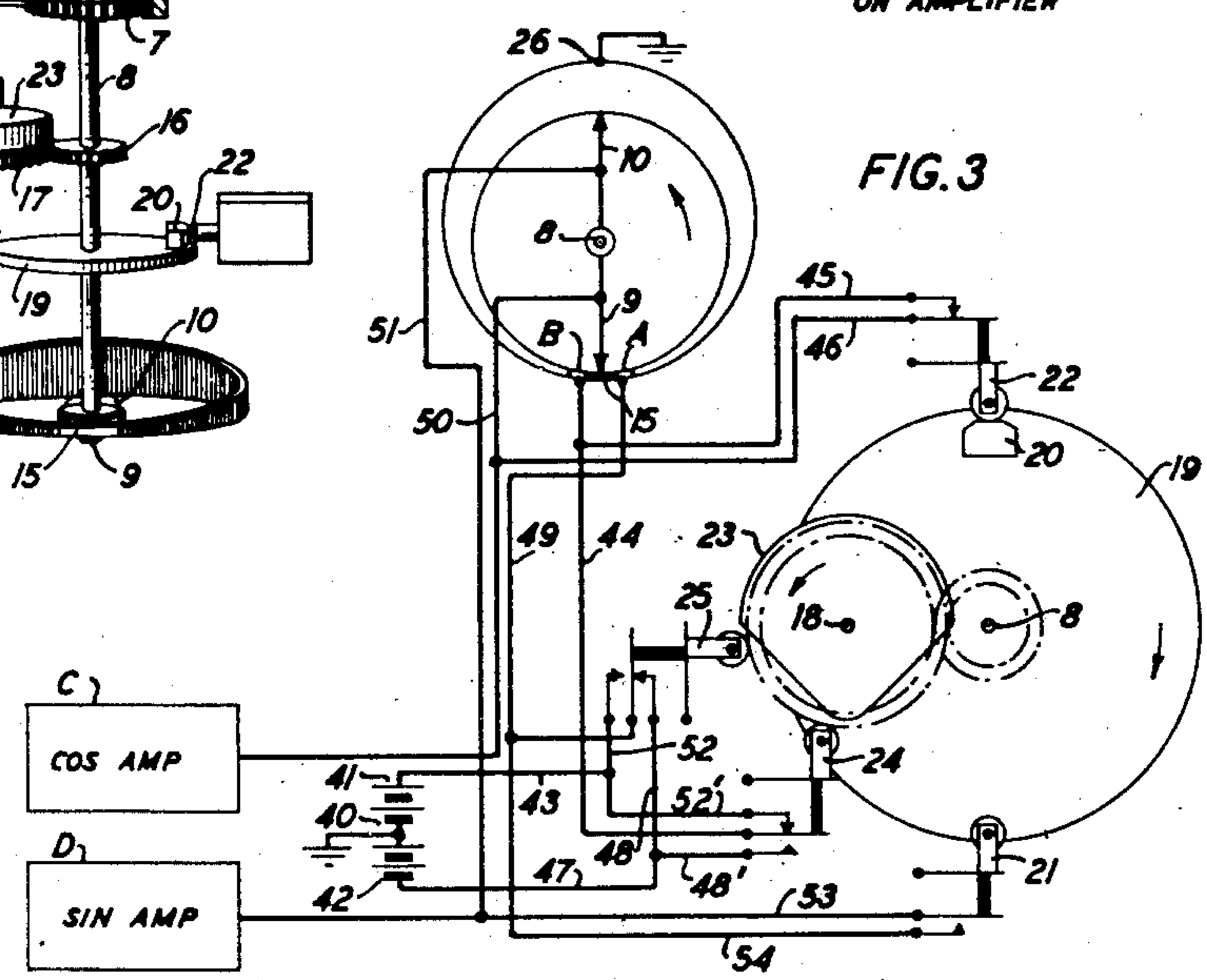
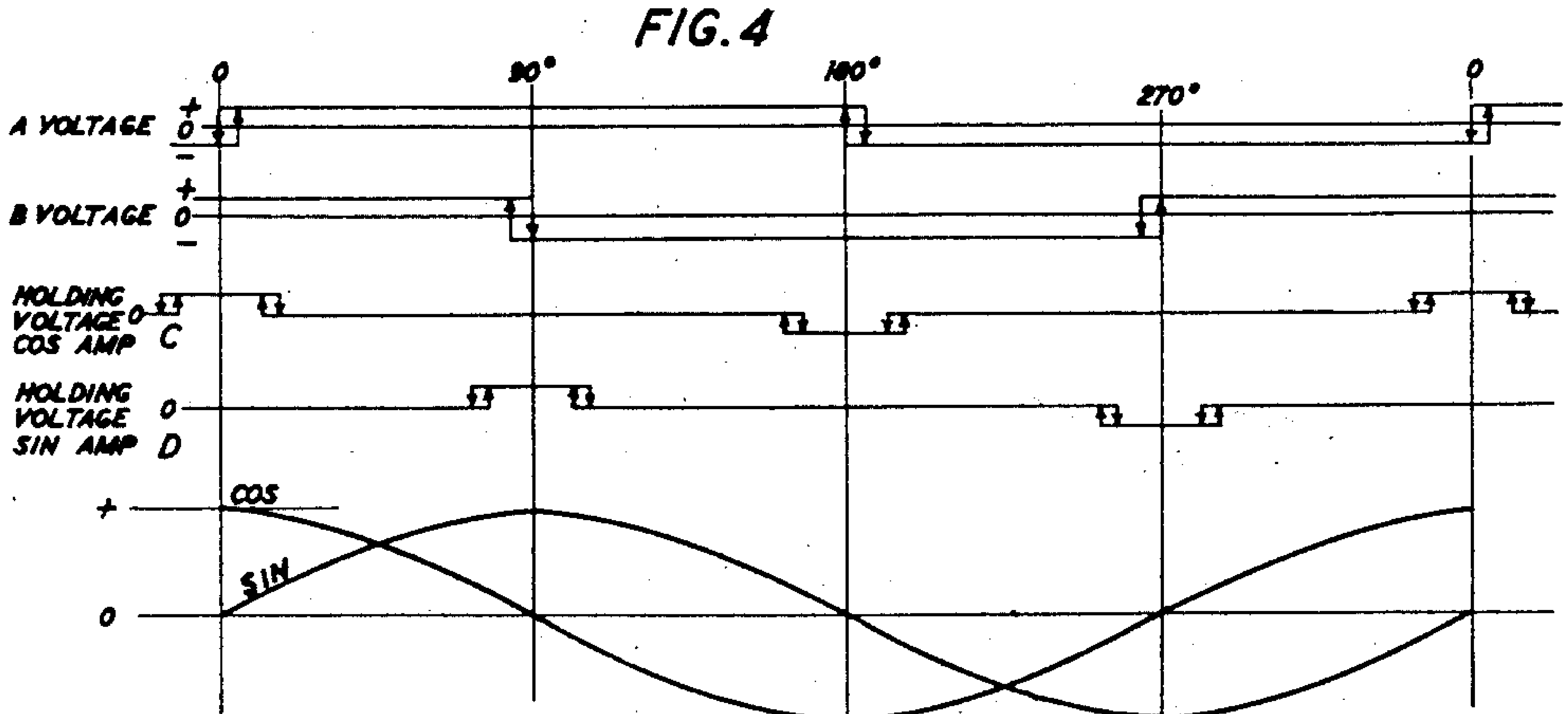


FIG. 4



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2,417,425

POTENTIOMETER CIRCUIT

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6 Claims. (Cl. 171—229)

1

This invention relates to an improvement in potentiometer cards and in the circuit thereto connected, especially useful where a trigonometric function is to be derived from a circular potentiometer. The invention provides a novel form of potentiometer card and system of circuit connections thereto whereby a circular card of a given size and fineness of winding may be made to furnish the desired function with the same accuracy as would twice as large a card of the usual shape in the usual circuit.

The object of the invention is to improve the scale factor of potentiometers which generate continuous functions and this object is accomplished by the use of switching means which makes possible the use twice-over of the potentiometer winding without breaking, at the time of switching, the continuity of the function generated. For this purpose advantage is taken of the fact that over one region of variation the function derived differs negligibly from its maximum value and the switching is effected in this region. During the switching operation continuity of the function is maintained through substitution of a constant value of the function, equal to this maximum, for the function derived from the potentiometer.

Special shapes of poteniometer cards are well known, among them the circular card wound according to a trigonometric function such as the sine of an angle. The usual form of such a card has a winding of which the resistance per turn varies from a minimum at each end of one of two mutually perpendicular diameters to a maximum at each end of the other diameter and is at any point proportional to the sine of the arc included between the point in question and the turn of minimum resistance. A source of direct voltage, grounded at the center, is connected across the windings at the ends of the first diameter while at the ends of the second diameter the winding is grounded. A radial brush sweeping over such a potentiometer picks off a voltage to ground proportional to the cosine of the angle through which the brush has turned from the point of connection to the positive voltage, or to the sine of the angle turned from a ground connection toward the point just mentioned.

For any practical application of such cards the accuracy with which the derived voltage follows the desired function is limited by the fineness of winding and the diameter of the card and to improve the accuracy obtainable from a card of given size it is necessary to resort to an appropriate circuit arrangement for supplying a reference voltage to the potentiometer and for connecting the brush-derived voltage to a utilization circuit and to provide an appropriate design of the potentiometer card. The present invention makes possible a doubling of the accuracy ordinarily to be expected from a potentiometer card of a given size used to derive a pair of voltages respectively representing, for example, the sine and the cosine of the azimuth of an object viewed in a sighting telescope, throughout a complete revolution of the telescope in either sense.

2

It is therefore the object of the invention to provide a potentiometer circuit, including a potentiometer card of novel construction, whereby fractional voltages may be derived with greatly increased accuracy as compared with known structures of comparable size designed for a like purpose.

A feature of the invention is the provision of a circular potentiometer card so wound over nearly its entire circle that the resistance per turn of the winding varies from a minimum to a maximum and back to a minimum at a point on the card nearly 360 degrees from the first minimum and is at any point proportional to the sine of the arc included between that point and a point of minimum resistance per turn. At each point of minimum resistance per turn the winding terminates in a short-circuited portion through an arc of about 0.75 degree. Between the short-circuited portions an insulating segment about 1.2 degrees in extent completes the potentiometer circle. This segment is provided with an insulating bridge overlapping the two shorted portions and over this bridge ride the radial brushes in progressing from one end to the other of the active winding. Two brushes directed radially opposite to each other and turning with a common shaft traverse the card and derive voltages proportional respectively to the sine and to the cosine of the angular position of a shaft turning through a half rotation for each complete rotation of the common shaft with which the brushes turn. Advantage is taken of the fact that near 90 degrees and 270 degrees the absolute value of the sine is substantially unity while near 0 degree and 180 degrees the same is true of the cosine. In following the sine and cosine, of the azimuth of a sighting telescope for example, the shaft carrying the radial brushes above mentioned turns through two revolutions for a single revolution of the telescope and the center of the insulating segment will represent 0 dgeree and 180 degrees of azimuth in alternation. As the cosine brush stands at this center the sine brush is at ground. The voltages to be derived by these brushes are then respectively unity and zero. A quarter turn of the telescope entails a half turn of the brush shaft, placing the cosine brush at ground and the sine brush centrally over the insulating segment and here the voltages to be derived are zero and unity, respectively, the cosine and the sine of 90 degrees.

When the cosine brush is approaching 0 degree from 355 degrees of telescope position, it is about to ride over the insulating bridge while the sine brush is about to reach ground. The value of the cosine is positive and increasing toward unity while that of the sine is negative and decreasing to zero. Positive battery voltage must therefore be on the half of the card supporting the cosine brush, negative battery on the other half supporting the sine brush, and it is evident that these polarities must be reversed as the cosine and sine brushes pass respectively the insulating segment and ground. This reversal of polarity must take place without affecting either by interruption or by shock the utilization circuits to which the fractional voltages are supplied. The switching sequence presently to be described, in conjunction with the insulating elements of the card above referred to, accomplish this result.

The invention will be understood from the following description, read with reference to the accompanying drawing in which:

Fig. 1 is a schematic of a mechanical arrangement suitable for the purpose of the invention when the azimuth of a telescope is concerned;

Fig. 2 shows in enlarged detail the cord ends and insulating segment 15 of potentiometer 12 of Fig. 1;

Fig. 3 is a diagram of the switching circuit of the invention; and

Fig. 4 illustrates the voltage reversals on card ends A and B in Fig. 2, together with the trigonometric functions derived by the brushes sweeping potentiometer 12 of Fig. 1.

In all figures, like numerals and letters designate like elements.

Referring now to Fig. 1, telescope 1 is so mounted on table 2 that it may be rotated about a vertical axis, that of shaft 3, and about a horizontal axis 14 at right angles to the axis of shaft 3. On table 2 is fixed circular dial 4 concentric with shaft 3 and graduated in degrees so that by noting the position of pointer 5 attached to and turning with shaft 3, an observer may read with reference to an arbitrary zero on dial 4, the azimuth of any object toward which telescope 1 is directed. For many purposes, for example in apparatus designed for the automatic computation of the range and bearing of a target from an observation station it is desired to obtain voltages proportional to the sine and cosine of the target azimuth. To this end, shaft 3 is continued downward through table 2 and carries on its lower end gear 6 within which is meshed gear 7 carried on shaft 8. The diameter of gear 7 is half that of gear 6 so that turning telescope 1 through any angle about the vertical axis causes shaft 8 to turn through twice that angle and in the same sense of rotation.

Shaft 8 carries at its lower end potentiometer brushes 9 and 10 insulated from each other and from shaft 8 and mutually oppositely directed. By the rotation of shaft 8, brushes 9 and 10 are caused to traverse circular potentiometer 12. It is clear that a complete rotation of telescope 1 entails two complete traverses by brushes 9 and 10 of potentiometer 12. There are omitted from the diagram of Fig. 1 the means of supporting table 2 and the bearings in which turn shafts 3 and 8; these supporting means and bearings are to be understood to be provided though not shown.

Potentiometer 12 is wound to constitute essentially two quadrants or one-half of the usual sine potentiometer. Its resistance per turn decreases from a maximum at a grounded center in accordance with the cosine of the angle subtended at the center of the potentiometer circuit down to a minimum after which it is constant for a short distance at each end of the winding. Forming such a card into a circle one obtains a winding such that the resistance between the mid-point and any other point varies as the sine of one-half the angle between these points at the center of the card circle. Thus for 180 degrees from mid-point to the junction of the two card ends the total resistance is proportional to the sine of 90 degrees. Two rotations of the brush over such a potentiometer will correspond to a complete rotation of the shaft of which the angular position is to be represented.

The short linear portion at each end of the winding is followed by a short-circuited portion and these shorted portions are separated by a block of insulation which completes the circle. The bridge from one short-circuited portion to the other is an insulating bridge in passing over which a brush is lifted from one short-circuited part later to descend to the other short-circuited part. The total angular extent in terms of telescope angle of the insulating block and short-circuited parts is approximately 3.2 degrees. The linear part of each end of the winding occupies about 0.5 degree as a concession to the impracticability of carrying the cosine variation of resistance per turn to the theoretical limit. Over the arc included by a linear portion of the winding, the trigonometric function to be derived, varies approximately linearly, wherefore the voltage derived by a potentiometer brush can follow the sine and cosine for approximately 176.8 degrees of telescope angle. This angle will hereinafter be called a. More plainly to illustrate the form of potentiometer 12, brushes 9 and 10 are shown below that potentiometer, brush 9 standing at the center of insulating segment 15 while brush 10 is directly opposite.

Shaft 8, turning at twice the angular speed of shaft 3 carries also gear 16 with which meshes gear 17 suitably carried by shaft 18 of which the supports are not shown. At any convenient distance between below gear 16, shaft 8 carries disc 19 provided with a lug 20. Lug 20, in the position shown in Fig. 1, operates to close switch 21. Switch 22, diametrically opposite switch 21, will be closed when shaft 8 has turned 180 degrees. Gear 17 is of a diameter twice that of gear 16, so that shaft 18 turns at the same angular speed as shaft 3 but in the opposite sense. Mounted on gear 17 concentrically with shaft 18 is cam 23, better illustrated in Fig. 3. Cam 23 in the position shown in Fig. 2 clears switch 24. Nearly but not quite 90 degrees beyond switch 24 is switch 25, invisible in Fig 1, but mounted similarly to switch 24 and also cleared by cam 23 in position shown in Fig 1. Disc 19 thus turns in the same sense as telescope 1 but twice as fast while cam 23 turns oppositely to the rotation of shaft 3 but at the same angular speed.

In the following description of potentiometer 12 and the circuits therewith associated the angular values stated refer to angles on dial 4 and thus to one-half the corresponding arcs on potentiometer 12 and disc 19.

As previously explained potentiometer 12 is nearly a complete circle and its winding has a resistance per turn which is a minimum at two points separated by insulating segment 15 increasing to a maximum to a point diametrically opposite to the segment 15. Referring now to Fig. 2 the details of segment 15 and the potentiometer winding adjacent thereto will be described. The arcs indicated in Fig 2 are given in terms of angles on dial 4, Fig. 1. The resistance per turn of the winding of potentiometer 12 decreases from a maximum at grounded point 26 in each direction from that point as above explained until at each of points 30 and 31 it becomes constant for an arc corresponding to about 0.5 degree of rotation of shaft 3. These linear portions of the winding are individually succeeded by short-circuited portions extending from point 30 to point 32 and from point 31 to point 33, respectively. The short-circuited portions occupy each an arc of about 1 degree of telescope angle. Between these short-circuited portions is interposed insulating segment 15 underlying which is insulating bridge 34. Segment 15 occupies an arc of about 1.2 degrees of azimuth. As will be shown in the description of Fig. 3, two voltage sources are connected, one between point 26 and point 32, the other between point 26 and point 33. Brush 10, for example, in its progress from point 26 to point 32 derives a fraction of the voltage therebetween proportional to the sine of one-half the angle from point 26 swept on the potentiometer card itself and so to sine of the whole angle though telescope 1 has turned in azimuth from zero degrees. This sine variation of the fractional voltage derived by brush 10 continues to a point 30, after which the derived voltage increases linearly with brush position to point 32. The sine of the telescope angle at point 30 is 0.9994 and at point 32 is 0.9997 so that from the latter to a corresponding position beyond segment 15, namely point 33, brush 10 may be connected directly to the ungrounded battery terminal and need not be in contact with the potentiometer winding. Bridge 34, as shown, overlaps segment 15 at each end thereof so that bridge 10 in passing segment 15 is elevated from contact with the potentiometer winding at a suitable point in the short-circuited portion following point 32 and descends to the corresponding point in the short-circuited portion beyond segment 15. The short-circuited portions are designated by letters A and B, A designating the portion between segment 15 and point 33, B that between segment 15 and point 32. The angular extent of segment 15, of portions A and B and of bridge 34 is indicated below in Fig 2 in terms of the rotation of shaft 3.

Referring now to Fig. 3, disc 19 carrying lug 20 rotates with shaft 8 twice for each rotation of telescope 1 and shaft 3. At 0 degree azimuth, lug 20 closes switch 22, leaving open switch 21. At 90 degrees azimuth, switch 21 is closed and switch 22 is open. Lug 20 closes switch 22 again at 180 degrees and switch 21 again at 270 degrees. Cam 23 is a circular cylinder of which one-half has been cut at opposite ends of a diameter of the circular section by opposing 45 degrees levels. The resulting plane faces parallel to the cylinder axis, instead of meeting in a line, are rounded off to join in a curved surface the apex of which is within the original circle. In consequence of this shaping, switches 25 and 24 are closed left and downward, respectively, when in contact with the unmodified semicircle of cam 23, and are oppositely closed when facing the beveled surfaces on the rounded junction thereof. Cam 23 rotates at half the speed of disc 19 and so turns once for each turn of telescope 1.

Battery 40 is grounded at its center and its positive and negative terminals, 41 and 42, respectively, are variously connected in the course of the switching sequence to be described below. At 0 degree azimuth, positive terminal 41 is connected via conductor 43, switch 24 and conductor 44 to card end B of potentiometer 12 and is at the same time connected via conductor 43, switch 24, conductor 44, conductor 45, switch 22 and conductor 46 to cosine brush 9, while negative terminal 42 is connected to card end A via conductors 47 and 48, switch 25 and conductor 49. Switches 25 and 24 are at this time closed right and upward, respectively, while switches 21 and 22 are respectively open and closed. Conductor 48, leading from conductor 47 to one pole of switch 25, has a branch 48' leading to one pole of switch 24. Similarly conductor 43 branches to conductor 52, leading to the other pole of switch 25, and 52' leading to the other pole of switch 24. The blade of switch 22 is connected by conductor 46 to conductor 50 and so to the input circuit of amplifier C. The blade of switch 21 is connected by conductor 53 to conductor 51 and so to the input circuit of amplifier D. Switches 21 and 22 are each single pole single throw. Their fixed contacts are connected, respectively, to conductor 49 by conductor 54, and to conductor 44 by conductor 45.

In Fig. 3, for convenient display of the circuit connections, brushes 9 and 10 and potentiometer 12 are viewed from below, while disc 19, cam 23 and the associated switches are viewed from above. So viewed, disc 19 turns clockwise, cam 23 and brushes 9 and 10 turn counter-clockwise, as telescope 1 turns from 0 degree toward 90 degrees on dial 4, Fig. 1.

Brush 9 is permanently connected via conductor 50 to a utilization circuit C, which may be an amplifier referred to as the cosine amplifier. Brush 10 is permanently connected via conductor 51 to a utilization circuit D, which may be a second amplifier referred to as the sine amplifier. From battery 40, brush 9 derives a voltage proportional to cos a, while brush 10 derives a voltage proportional to sin a where a is as above stated the azimuth read on dial 4, Fig. 1. By the sequence of switching presently to be described, brush 9 is connected also to positive terminal 41 near 0 degree, to negative terminal 42 near 180 degrees, while brush 10 is connected near 90 degrees to terminal 41, near 270 degrees to terminal 42.

It will be seen that the polarity of card end A is controlled by switch 25. When switch 25 is closed right end A is connected via conductors 49, 48 and 47 to negative terminal 42; closing switch 25 left connects end A via conductors 49, 52 and 43 to positive terminal 41. Switch 24 controls the polarity of card end B: when closed upward it connects end B via conductors 44 and 43 to positive terminal 41, when closed downward it connects end B via conductor 47 to negative terminal 42. As telescope 1 turns from 0 degree through 90 degrees to 0 degree again, card end A is positive from 0.5 degree to 180.5 degrees, negative elsewhere. Card end B is negative from 90 degrees to 270 degrees, positive elsewhere.

In the first quadrant, card ends A and B are both positive as are sin a and cos a. In the second quadrant, sin a is positive, cos a negative, end A is positive and end B negative. The polarity of end A follows the sign of sin a, that of end B the sign of cos a, so that A and B are both negative in the third quadrant while in the fourth A is negative and B positive.

As brushes 9 and 10 successively pass over insulating segment 15, each in turn is lifted by bridge 34 from contact with the potentiometer winding 0.86 degree before, and regains such contact 0.86 degree after, the center of segment 15. For an interval overlapping at each end such contact interruption, the appropriate battery terminal is connected directly to the corresponding utilization circuit. The direct battery connection exists from 1.11 degrees on one side to 1.36 degrees on the other side of the center of segment 15. Card ends A and B each change polarity twice in a complete rotation of telescope 1, end A at 0 degree and 180 degrees, end B at 90 degrees and 270 degrees. In each case, the change of polarity is effected while the brush concerned is on bridge 34, specifically within an arc centered on segment 15 and extending each side of that center 0.5 degree of azimuth.

It will be convenient in the following description of switching to follow the sequence from the position of telescope 1 at 270 degrees. The corresponding aspect of disc 19 would show lug 20 closing switch 21, and cam 23 would be placed with the junction of its beveled faces left instead of downward as in Fig. 3. The angular values to be stated refer to angles through which telescope 1 turns, and reference should be made to Fig. 2 where the arcs used for switching polarities of card ends and for holding voltages on amplifiers C and D are indicated. Polarity switching takes place inside the arc *ef*, extending 0.5 degree each side of the center of segment 15. Terminals 41, 42 of battery 40 are directly connected to the appropriate amplifiers C and D over the arc *cdefghi* in one direction of telescope rotation, namely, azimuth increasing from 0 degree, and over the arc *hgfedcb* in the opposite direction. The brush riding on bridge 34 is disconnected from the potentiometer winding over the arc *defg* in each direction of rotation. Arc portions *a*, *b*, *c*, *h*, *i* and *j* are each 0.25 degree, *d* and *g* each 0.36 degree, and *e* and *f* each 0.50 degree. The brush is thus disconnected from the potentiometer winding for 1.72 degrees in each direction of movement, an arc which overlaps by 0.72 degree the 1 degree polarity switching range *ef*. This brush disconnection is overlapped by a direct connection of the appropriate battery terminals to the utilization circuits, which begins 0.25 degree before and ends 0.50 degree after the brush passage over bridge 34.

At 270 degrees of azimuth cosine brush 9 is at ground and sine brush 10 is on bridge 34 over the center of segment 15 and so is off the card of which end A is on negative battery, switch 25 being closed right. End B has just been connected to positive battery by the release of switch 24 to close upward. Cosine amplifier C is connected only to cosine brush 9 while sine amplifier D is connected to negative battery.

A clockwise rotation of the telescope through 0.86 degree from this position drops sine brush 10 to the short-circuited part at end A, while cosine brush 9 picks off a small positive voltage, the cosine of 270.86 degrees, the end B having gone positive at 270 degrees. As long as sine brush 10 is on the short-circuited A part, the full negative battery voltage is on sine amplifier D. Just before sine brush 10 reaches the straight part of the effective winding, the holding voltage is released by the opening of switch 21 and the voltage on sine amplifier D is ready to follow sine brush 10 which picks off a numerically decreasing negative voltage from full negative battery at 271.61 degrees to 0 at 360 degrees as the rotation of the telescope continues. During this interval from 270 degrees to 360 degrees, cosine brush 9 has picked off for its amplifier an increasing positive voltage up to a point 1.61 degrees before 0 where it enters the short-circuited B portion. Thereafter cosine brush 9 lifts from the card at 359.14 degrees. Switch 22 is closed at 358.89 degrees to put positive battery and cosine brush 9 simultaneously on the cosine amplifier C. Switches 25 and 24 are closed right and upward, respectively, as they have been since 270 degrees.

Further rotation to 0.86 degree drops cosine brush 9 to the short-circuited A portion of the card, then switch 22 opens at 1.36 degrees to leave cosine amplifier C connected only to the cosine brush. In the meantime at 0.50 degree switch 25 has been operated left and card end A is made positive just before the cosine brush drops to the short-circuited A portion. Switch 24 is open and switch 25 is still closed upward so that while switch 22 was closed the cosine brush was connected to positive battery. After switch 22 opens, at 1.36 degrees, cosine brush 9 reaches at 1.61 degrees the effective winding at the A end and thereafter delivers to the cosine amplifier C a positive voltage decreasing to 0 when at 90 degrees the cosine brush 9 reaches the grounded mid-point.

The course of events so far described covered quadrants IV and I in succession. For quadrant IV beginning at 270 degrees card ends A and B were negative and positive, respectively. On the sine amplifier D was impressed a negative holding voltage, while the cosine amplifier received 0 voltage from the cosine brush 9 here at the grounded mid-point. The sine brush 10 continues the full negative battery voltage until 271.61 degrees after which it delivered a negative voltage varying substantially as sin a up to 0 voltage at 360 degrees when it reached the grounded mid-point. The cosine brush 9 in the meantime delivered to the cosine amplifier a positive voltage increasing as a cos a up to full positive voltage at 358.39 where it reached the short-circuited part near card end B.

For quadrant I, at 0 degree the sine brush 10 is at the mid-point and the cosine brush 9 is off the card, while on the cosine amplifier C is impressed a positive holding voltage from battery 40. Just after 0 card end A becomes positive, card end B remains positive. Then the sine brush 10 delivers a positive voltage to sine amplifier D varying as sin a from 0 degree to full battery voltage at 88.39 degrees when it comes again on the short-circuited part near card end B and is soon overlapped by a positive holding voltage on sine amplifier D. Meanwhile the cosine brush delivers a positive voltage decreasing as cos a from full battery voltage at 1.61 degrees to 0 at 90 degrees.

The cycle repeats as before for quadrants II and III. It is to be remarked that so far the rotation of the brushes has been counter-clockwise. The telescope azimuth increases from 0 through 90 to 360 degrees. In the reverse direction, allowance is made for the angular interval required for the operation of the switches. Switches 25 and 24 which have to move from one direction of closing to the reverse are allowed 0.5 degree of azimuth for the change, while switches 22 and 21 are allowed only 0.25 degree since they need move only from open to closing on one side.

Switch 25 operates at 0.50 degree and 180.50 forwards, at 0 degree and 180 degrees for reverse rotation. Switch 24 operates forward at 90 degrees and at 270, reversed at 89.50 and 269.50. These switches are, therefore, not 90, but 89.50 degrees apart around the cam 23. Switches 22 and 21 are 180 degrees apart around the disc 19. Each of the four switches thus operates twice in each rotation of its associated shaft.

Conveniently switches 21, 22, 24 and 25 are micro-switches such as are described in Patent 1,960,020 granted May 22, 1934, to P. K. McGall. They may, of course, be relay operated switches of any suitable description.

At 0 and 180 degrees the cosine brush 9 is off the card and the sine brush 10 is at the grounded mid-point. At 90 and 270 degrees the sine brush 10 is off the card and the cosine brush 9 is grounded. Positive battery voltage is impressed on the cosine amplifier C at 0 degree, on the sine amplifier D at 90 degrees. Negative battery voltage is on the cosine amplifier C at 180 degrees, on the sine amplifier D at 270 degrees. The duration of each holding voltage is 2.47 degrees and overlaps the interval of 1.72 degrees during which the corresponding brush is off the card.

Card end A changes from negative to positive at 0.50 degree, remaining positive until 180.50 degrees. This enables the cosine brush 9 to follow cos a from 0 to near 90 degrees and the sine brush 10 to follow sin a from 90 to 180 degrees approximately. End A changes back to negative at 180.50 remaining so until 0.50 degree enabling the cosine brush 9 to follow cos a from 180 to 270 degrees, the sine brush 10 to follow sin a from 270 to 0 degrees. When either sine or cosine is numerically increasing the corresponding voltage is taken from the card half between ground and end B; when either function is numerically decreasing, the voltage is taken from the card half between ground and end A.

At 0, 90, 180 and 270 degrees, there is a brush lifted from the card. It is the cosine brush 9 at 0 and 180 degrees, the sine brush 10 at 90 and 270 degrees. At 0 the cosine brush 9 is passing a positive maximum of cos a. It has left positive B and is approaching negative A which must become positive before the cosine brush 9 returns to the card. Overlapping this operation at each end, a positive holding voltage is impressed on the cosine amplifier C. At 180 degrees the cosine brush 9 is passing a negative maximum of cos a having left a negative B and is approaching a positive A which must change to negative. A negative holding voltage overlaps the change. Further description is unnecessary. It is sufficient to point out that the holding voltage on either amplifier has always the polarity of the card end which the brush has just left in either direction of rotation, whether the card end the brush is about to touch must change polarity or not.

To see how accurately the derived voltages follow the values of the functions, consider the sine brush 10 starting from the grounded mid-point at 0 degree. It derives an increasing positive voltage which varies as sin a, as closely as the potentiometer winding can be designed, until a equals about 87.92 degrees. The brush 10 then enters the straight portion of the winding and the

voltage increases linearly with a to 88.39 degrees, when the brush 10 touches the short-circuited portion near card end B, applying the full positive battery voltage to the sine amplifier D. From 88.89 to 91.36 degrees, this full positive voltage is applied to the sine amplifier D independently of the brush. Card end A has been positive since 0.50 degree and remains so until 180.50 degrees. Its polarity, therefore, need not change as the sine brush 10 passes 90 degrees and by it through the sine brush 10 from 90.36 degrees the full positive battery voltage continues to be delivered to the sine amplifier until a equals 91.61 degrees. After this the voltage drops linearly with a to about 92 degrees and thereafter as sin a to 180 degrees. The voltage wave is, therefore, of true sine shape from 0 to 87.92 degrees, straight but rising from 87.92 to 88.39 then a flat maximum from 88.39 degrees to 91.61 degrees, thence straight but falling to 92.08 degrees and thereafter of true sine shape to 180 degrees. The deviation from the sine form is confined to about 2 degrees each side of 90 degrees and is inappreciable. The same is true for the negative maximum of the sine for 2 degrees each side of 270 degrees and for the maxima of the cosine 2 degrees each side of 0 and of 180 degrees.

In Fig. 4 are shown the angular intervals during which card ends A and B are connected to one or the other terminal of battery 40, the direction of clockwise rotation of telescope 1 being represented from left to right. The uppermost curve A of Fig. 4 shows the polarity of end A positive from 0.5 degree to 180.5 degrees, negative from 180.5 degrees to 0.5 degree. The second curve B shows end B to change from positive to negative at 90 degrees, to positive again at 270 degrees. In the counterclockwise rotation of telescope 1 the polarity changes are the reverse of those just stated and take place at a reading on dial 4 0.5 degree less.

Curves C and D exhibit the intervals of application of holding voltages on the cosine and sine amplifier, respectively. In these operations switches 21 and 22 are allowed only 0.25 degree between clockwise and counter-clockwise operation. Clockwise, positive voltage is applied to cosine amplifier C from 358.89 degrees to 1.36 degrees, negative voltage from 178.89 to 181.36 degrees. To sine amplifier D positive voltage is applied from 88.89 degrees to 91.36 degrees, negative voltage from 268.89 degrees to 271.36 degrees. Subtracting 0.25 degree from each of these readings gives the azimuth at which the same changes of connection take place in counter-clockwise direction.

Finally, curves "cos" and "sin" below in Fig. 4 show the cosine and sine functions derived by brushes 9 and 10, respectively. The theoretical flattening of these curves at their respective positive and negative maxima is disregarded.

It will be noted that in the circuit described no provision is made for deriving simultaneously both direct and reverse values of sines and cosines in each quadrant but only the values of these functions with signs according to convention. To make available simultaneously sin a and $-$sin a, cos a and $-$cos a, a second potentiometer traversed by another pair of brushes could be mounted on shaft 8. The cams and switches already described could be duplicated and a voltage source grounded at its mid-point could be applied to the second potentiometer by a similar circuit to that described except that positive and negative are interchanged.

It will be clear that the described arrangement of apparatus permits the derivation of the desired fractional voltages with substantially complete accuracy throughout a complete rotation of the telescope. During this rotation the potentiometer brushes make two complete turns over a winding which, except for a short insulating segment, is the same as one-half the hitherto usual sine potentiometer. The invention therefore enables the space available for potentiometer installation, and the weight allowance therefor, to be used with double efficiency.

While the invention has been described as applied to the derivation of voltages proportional to the sine and cosine terms which may be required for an electrical computer, obviously any other circular function may equally well be provided by winding the potentiometers in accordance with the appropriate law.

What is claimed is:

1. In an electrical computer, a source of voltage, a potentiometer winding connected across said source, a brush selecting from said winding for one passage thereover a voltage proportional to a term required by said computer throughout a limited range of said term and switching means for modifying the connection of said source to said winding whereby on a subsequent passage over said winding said brush selects a voltage proportional to said term throughout a separate range thereof.

2. For a potentiometer winding having a grounded mid-point and constituting a circle interrupted by an insulating segment diametrically opposite said mid-point, a pair of brushes oppositely directed radially on said circle and sweeping said winding, a source of voltage having a grounded mid-point, a positive and a negative terminal, a pair of utilization circuits individually connected to said brushes, switching means for connecting said terminals individually to the ends of said winding adjacent to said segment and switching means for connecting said terminals individually to said brushes during passages thereof over said segment.

3. In a potentiometer winding having a grounded mid-point and constituting a circle interrupted by an insulating segment diametrically opposite said mid-point, a pair of brushes oppositely directed radially on said circle and sweeping said winding, a source of voltage having a grounded mid-point, a positive and a negative terminal, a pair of utilization circuits individually connected to said brushes, switching means for connecting said terminals individually to the ends of said winding adjacent to said segment, means for disconnecting said brushes from said winding over a first arc of said circle including said segment and each end of said winding, and switching means for connecting said terminals individually to said brushes during passage thereof over a second arc of said circle including and overlapping said first arc.

4. For a potentiometer winding having a grounded mid-point and constituting a circle interrupted by an insulating segment diametrically opposite said mid-point, a pair of oppositely directed radial brushes sweeping said winding, a source of voltage having a positive and a negative terminal and a grounded mid-point, a pair of utilization circuits individually connected to said brushes, means for connecting said terminals individually to the ends of said winding adjacent said segment and switching means for reversing the polarity of one of said ends during the passage of one of said brushes on said segment and for reversing the polarity of the other of said ends during the passage of the other of said brushes over said segment.

5. For a potentiometer winding having a grounded mid-point and constituting a circle interrupted by an insulating segment diametrically opposite said mid-point, a pair of oppositely directed radial brushes sweeping said winding, a source of constant voltage having a positive and a negative terminal and a grounded mid-point, a pair of utilization circuits individually connected to said brushes, means for connecting said terminals individually to the ends of said winding adjacent said segment, switching means for reversing the polarity of one of said ends during the passage of one of said brushes over said segment and for reversing the polarity of the other of said ends during the passage of the other of said brushes over said segment, and switching means for connecting one of said circuits alternately to said terminals during successive passages of one of said brushes over said segment and for connecting the other of said circuits alternately to said terminals during successive passages of the other of said brushes over said segment.

6. For a potentiometer winding having a grounded mid-point and constituting a circle interrupted by an insulating segment diametrically opposite said mid-point, the resistance per turn of said winding varying in each half thereof in accordance with a cosine between said mid-point and the center of said segment means for deriving from said potentiometer simultaneously a pair of voltages substantially continuously proportional to the sine and to the cosine respectively of an angle varying from 0 to 360 degrees including a pair of oppositely directed radial brushes sweeping said winding, a source of constant voltage having a positive and negative terminal and grounded mid-point, a pair of utilization circuits individually connected to said brushes, means for connecting said terminals individually to the ends of said winding adjacent said segment, switching means for reversing the polarity of one of said ends during the passage of one of said brushes over said segment and for reversing the polarity of the other of said ends during the passage of the other of said brushes over said segment and switching means for connecting one of said circuits alternately to said terminals during successive passage of one of said brushes over said segment and for connecting the other of said circuits alternately to said terminals during successive passages of the other of said brushes over said segment, whereby said one circuit receives a sine fraction of the voltage of said source through two successive sweepings of said winding by said one brush and said other circuit receives a cosine fraction of the voltage of said source through two successive sweepings of said winding by said other brush.

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