

Aug. 16, 1966

H. HIERONYMUS

3,267,404

CONTINUOUSLY ADJUSTABLE CONTACTLESS POTENTIOMETER

Filed March 11, 1964

5 Sheets-Sheet 1

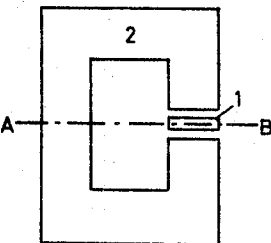


Fig. 1

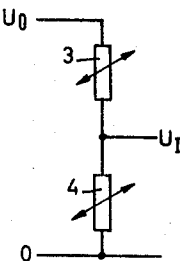


Fig. 2

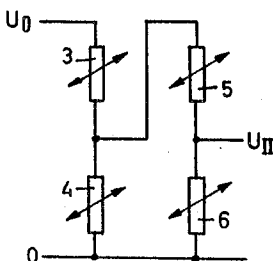


Fig. 3

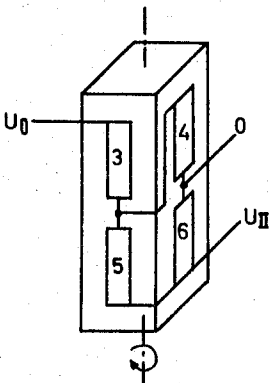


Fig. 4

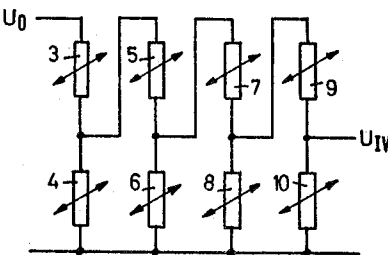


Fig. 5

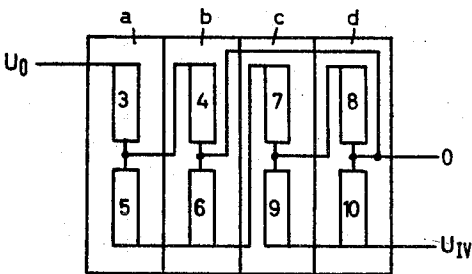


Fig. 6

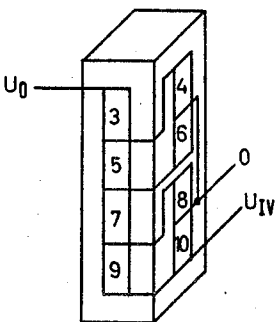


Fig. 7

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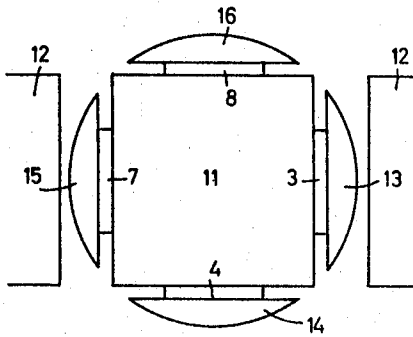


Fig. 8

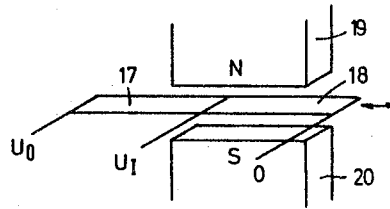


Fig. 9

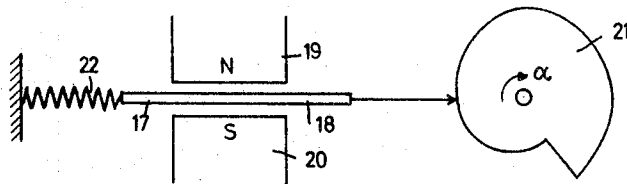


Fig. 10

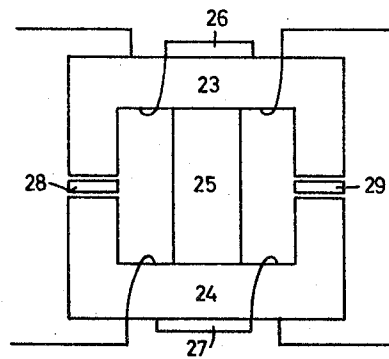


Fig. 11

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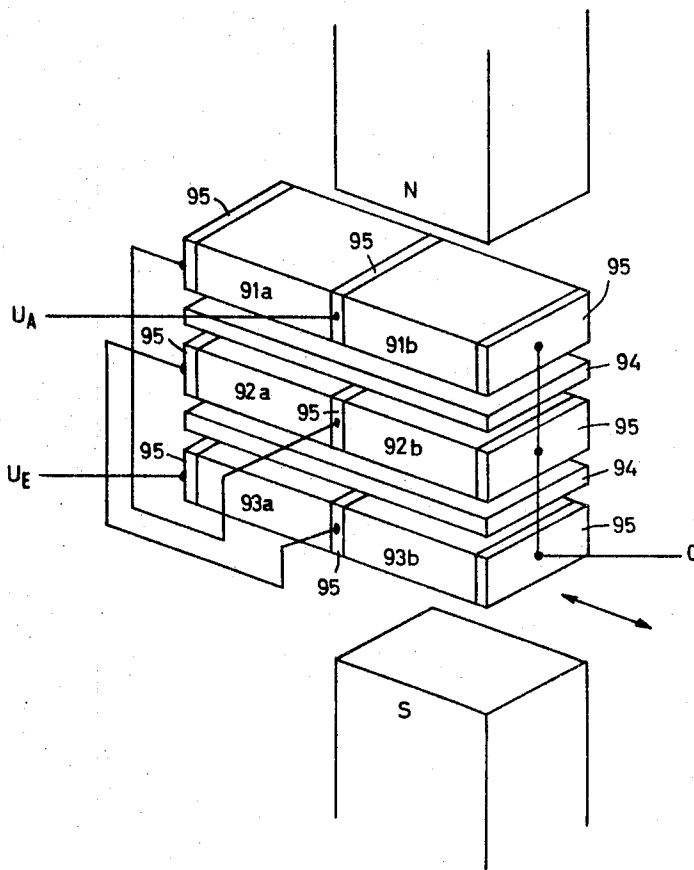
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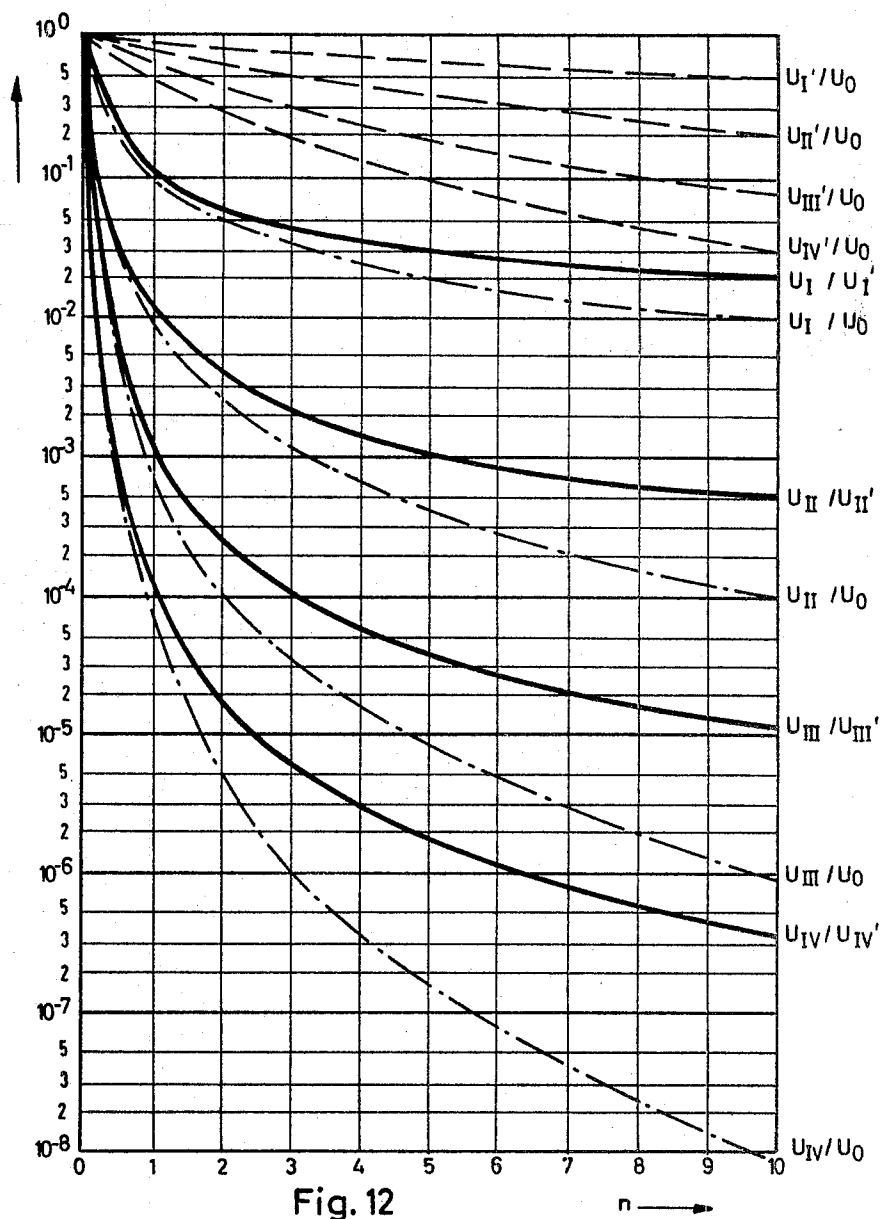
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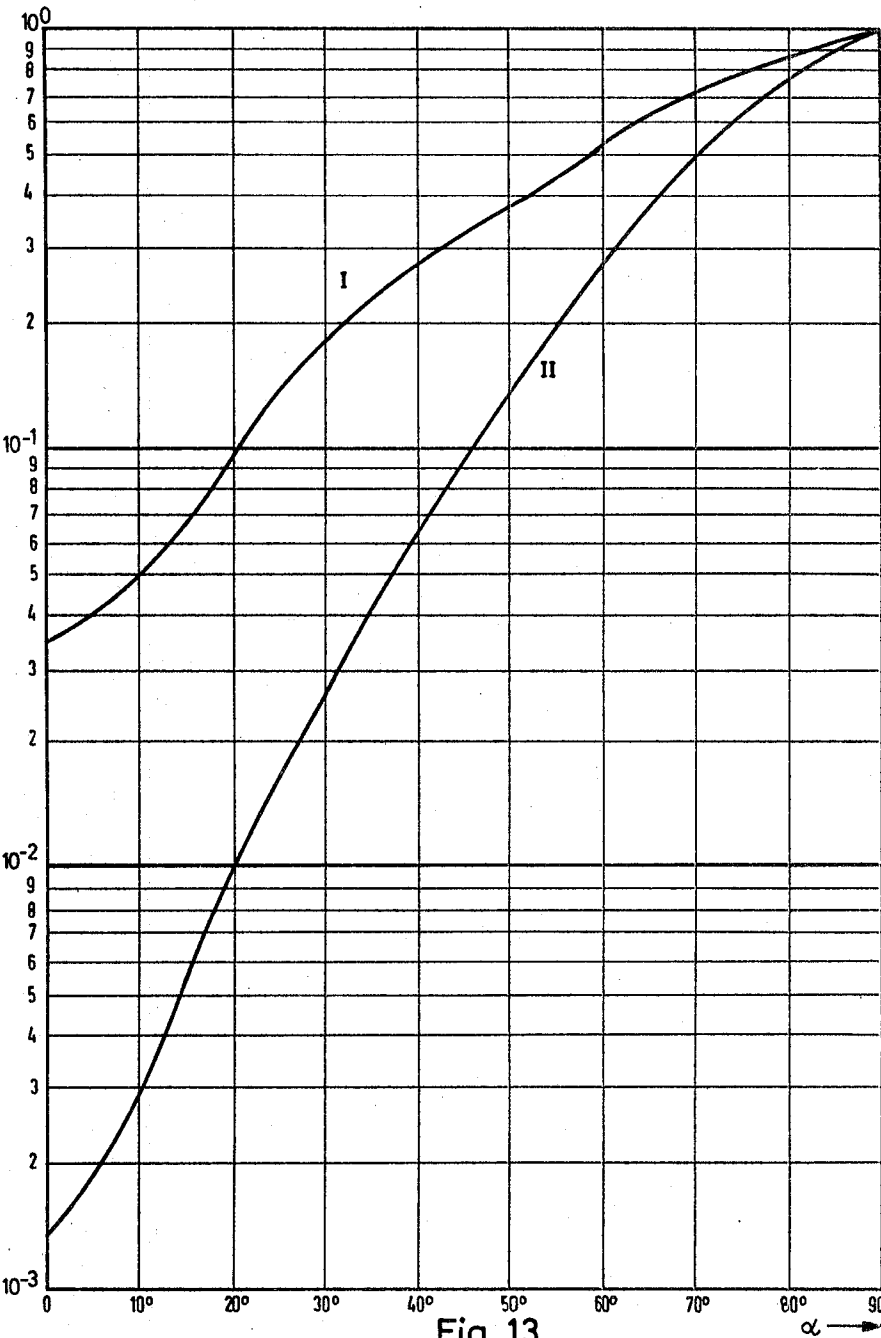


Fig. 13

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CONTINUOUSLY ADJUSTABLE CONTACTLESS
POTENTIOMETER

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Claims priority, application Germany, Mar. 13, 1963,
S 84,125

17 Claims. (Cl. 338—32)

My invention relates to potentiometers whose resistance bodies consist of semiconductor material and greatly vary their electric resistance under the effect of a magnetic field. Such "galvanomagnetic" resistors are known from U.S. Patent 2,894,234 of H. Weiss and H. Welker, assigned to the assignee of the present invention. Among the known resistors of this kind are so-called "field plates" of indium antimonide (InSb). When, for example, such a plate is subjected to a magnetic field of 10,000 gauss, the ohmic resistance of the plate changes to a value 10 to 20 times larger than the resistance at zero field.

Referring to such galvanomagnetic resistors, it is an object of my invention to provide a potentiometer whose voltage dividing circuit is entirely free of mechanical contacts and which affords a fully continuous adjustment of the output voltage.

Another object of the invention is to devise a continuously adjustable potentiometer which possess a virtually unlimited lifetime, free of any wear, regardless of the frequency of its use within the rated limits of its electrical rating, and which exhibits a substantially logarithmical resistance characteristic without the aid of any additional circuit components.

Still another object of my invention is to devise a potentiometer that, by virtue of an extremely small inherent capacitance, is particularly well suitable for dividing alternating voltages of high frequency.

A further object of my invention is to provide a continuously adjustable potentiometer which, in addition to meeting one or more of the aforestated objects, permits obtaining any desired high ratio of voltage division.

According to my invention, I connect two galvanomagnetic resistance members in series with each other so as to form a voltage divider circuit with an intermediate tap, and I dispose the two members in the field of a magnetic field structure so that the respective resistance values are dependent upon the magnetic flux traversing the two members. Furthermore, I mount the two galvanomagnetic resistance members in fixed relation to each other in respectively different positions relative to the magnetic field structure, and provide the device with continuously adjustable means for inversely controlling the amounts of magnetic flux through the respective members, so that increased flux through one member coincides with decreased flux in the other.

According to another feature of my invention, the two galvanomagnetic resistance members of the voltage divider circuit are mounted on a carrier structure at respectively different locations, and the carrier structure with the attached resistance members is displaceable with respect to the magnetic field structure, or vice versa, to thereby provide for the above-mentioned inverse control of the respectively increasing and decreasing amounts of magnetic flux passing through the two members.

According to still another feature of my invention, the two galvanomagnetic resistance members consist of flat bodies and are mounted on a carrier structure of elongated prismatic shape, namely on different lateral prism surfaces extending at a right angle to each other, the carrier structure or field structure being rotationally adjustable about the longitudinal axis of the carrier structure for

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varying the magnetic flux to increase in one member as it decreases in the other.

According to a further feature of my invention, I provide at least one additional pair of serially interconnected galvanomagnetic resistance members, and electrically connect each such pair in parallel relation to one of the galvanomagnetic resistance members in a preceding voltage divider circuit, the resistance members of all pairs thus interconnected being distributed over the above-mentioned two different localities or surfaces of the carrier structure so that, during a change in potentiometric adjustment, the magnetic flux through one group of galvanomagnetic members increases while the flux in the other group decreases.

According to still another feature of my invention, the two galvanomagnetic resistance members of the above-mentioned voltage divider circuit or circuits are located in respective field gaps of the two outer legs formed by a three-legged magnetizable core whose center leg comprises magnetizing means for passing magnetic flux through both field gaps, and which is provided with control winding means to superimpose upon the outer legs another magnetic flux, thus boosting the field intensity in one gap and reducing it in the other.

The invention will be further described with reference to embodiments of potentiometers according to the invention illustrated by way of example on the accompanying drawings in which:

FIG. 1 shows schematically a potentiometer device having a generally C- or O-shaped magnet in whose gap a galvanomagnetic assembly is rotationally adjustable.

FIGS. 2 and 3 are respectively different circuit diagrams of galvanomagnetic resistors applicable in a device according to FIG. 1.

FIG. 4 is a schematic and perspective view of the galvanomagnetic assembly according to FIGS. 1 and 3.

FIG. 5 shows another modification of a potentiometer circuit applicable for the purposes of the invention.

FIG. 6 is a planar development of a carrier structure equipped with galvanomagnetic resistor members; and FIG. 7 is a perspective view of a similar, but somewhat modified assembly.

FIG. 8 is a partial view of another embodiment, also comprising a rotationally adjustable galvanomagnetic resistor assembly.

FIG. 9 shows schematically a galvanomagnetic potentiometer which is adjustable by means of a translatable motion, FIG. 9a shows a similar modification, and FIG. 10 illustrates a control mechanism for imparting such motion to the assembly.

FIG. 11 shows a galvanomagnetic potentiometer according to the invention operating without any movable parts.

FIGS. 12 and 13 are explanatory graphs relating to the performance of potentiometers according to the invention.

The potentiometer device shown in FIG. 1 comprises a carrier structure 1 for a plate-shaped resistance member. The carrier 1 is rotationally adjustable about an axis A-B and is located in an air gap of a permanent magnet 2. When the resistance carrier 1 or the magnet 2 is rotated about the axis A-B to a different angular position, the magnetic flux traversing the resistance members on the carrier 1 changes, each member then exhibiting a different resistance value depending upon the relative position of that member to the permanent magnet 2. As mentioned, the resistance members used for this purpose consist preferably of indium antimonide or indium arsenide, although other semiconductor substances are also applicable. In this respect reference may be had to the above-mentioned patent.

FIG. 2 shows the simplest form of an applicable voltage divider circuit comprising only two galvanomagnetic resistance members 3 and 4. The input voltage $0-U_0$ is impressed across a series connection of the two members. The continuously variable output voltage U_I is tapped off the terminals of resistance member 4. The two resistance members have the form of flat plates (field plates). Their planes are perpendicular to each other in the air gap of the magnet 2. Preferably, the two plates are cemented to respective mutually perpendicular surfaces of a prismatic rod having a rectangular or preferably square cross section, corresponding to the insulating carrier structure 1 shown in FIG. 4. When rotating the rod-shaped carrier about its longitudinal axis A-C which is parallel to the surfaces upon which the field plates are attached and which is also perpendicular to the direction of the magnetic flux in the air gap of the permanent magnet 2, the resistance of one field plate increases and the resistance of the other field plate simultaneously decreases. With such a galvanomagnetic assembly, a considerable ratio of voltage division can already be achieved, this ratio denoting the relation of the highest to the lowest attainable output voltage.

The division ratio depends upon the ratio n of the respective base resistances exhibited by the two galvanomagnetic plates employed when no magnetic field is effective. This will be further explained with reference to the graph shown in FIG. 12 where the abscissa denotes the base-resistance ratio n (on a linear scale) and the ordinate indicates relative output voltages (on a logarithmic scale). The dot-and-dash curve U_I/U_0 represents the lowest output voltage U_I relative to the input voltage U_0 in dependence upon the base-resistance ratio n , relating to a resistance assembly according to FIGS. 1 and 2 in which a rotational change of 90° results in a resistance change by the factor 10. The broken-line curve U_I'/U_0 represents the ratio of the highest adjustable output voltage to the input voltage U_0 , likewise as a function of the base ratio n which is always somewhat smaller than unity. The full-line curve U_I/U_I' shows the ratio of the lowest to the highest adjustable output voltage, likewise in dependence upon the ratio n of the base resistances. It will be recognized, for example, that at the value $n=3$, the output voltage can be varied in the ratio of 1:25. At that output-voltage ratio, the highest output voltage U_I' amounts to 80% of the input voltage. From then on, the gain in attainable voltage-division ratio increases only little with increasing n , whereas the highest possible value of output voltage still continues to decrease considerably.

If the ratio of the output voltage U_I to the attainable maximum of output voltage U_I' is plotted over the rotational angle of the square carrier 1, the curve I shown in the graph of FIG. 13 is obtained, based upon the base ratio $n=3$. In FIG. 13 the abscissa denotes the angle of rotational adjustment (linear scale) and the ordinate indicates output voltage (logarithmic scale).

A further increase in voltage-division ratio is obtained by multiple voltage division. Thus, FIG. 3 shows an applicable divider circuit with a double division. The galvanomagnetic members 3 and 4 are connected and mounted in the same manner as described above with reference to FIGS. 1 and 2. Connected in parallel relation to the resistance member 4 is a pair of series-connected galvanomagnetic resistance members 5 and 6. The output voltage U_{II} appears between the terminals of member 6. The four galvanomagnetic members are mounted on two mutually perpendicular surfaces of the carrier structure 1 according to FIG. 4.

The diagram in FIG. 12 also shows curves corresponding to the double voltage division just described, these curves being marked by the index II. The base resistances of the galvanomagnetic members 3 and 5 are chosen to be equal and in each case are n -times larger than the base resistances of the members 4 and 6 respectively. The curves apply to the case that the resistance values of all four resistance members change by the factor 10 when

the assembly is turned 90° in the magnetic field. It will be recognized from FIG. 12 relative to the divider circuit of FIG. 3, that with a double voltage division a voltage-divider ratio of 1:500 can be achieved, relating to a base-resistance ratio of $n=3$. The highest possible output voltage in this case is approximately 50% of the input voltage U_0 . Curve II in FIG. 13 indicates, for the same values, the ratio of output voltage to attainable maximum of output voltage in dependence upon the angular position of the assembly.

As mentioned, FIG. 4 exemplifies a preferred geometrical arrangement of the four galvanomagnetic members 3, 4, 5 and 6. The members 3 and 5 are cemented to one surface of a rod-shaped carrier having a square cross section, the members 4 and 6 are attached to an adjacent surface and hence extend perpendicularly to the plane of members 3 and 5. In this embodiment the arrangement of the connecting leads between the individual semiconductor plates is so chosen that a minimal amount of wiring suffices and the terminals for the input and output voltages U_0 and U_{II} are located at the respective ends of the rod-shaped carrier. Thus the terminals are kept spacially most remote from each other on the carrier, which is of advantage when using the potentiometer for high-frequency purposes.

FIG. 12 further shows corresponding curves for potentiometer devices with triple and quadruple voltage division, comprising six and eight galvanomagnetic resistors respectively. An example for a circuit with eight galvanomagnetic members is shown in FIG. 5. The members are connected pairwise in series, and each following pair of members lies in parallel to one member of the preceding resistance pair. Thus, the galvanomagnetic members 7 and 8 are connected in parallel to member 6, and members 9 and 10 are in parallel to member 8. The output voltage U_{IV} is taken from the terminals of member 10.

As shown in FIG. 6, the eight resistors are preferably distributed uniformly over the four lateral surfaces a, b, c, d of a square rod-shaped carrier structure. The surfaces a and c are parallel to each other and carry the flat field plates 3, 5, 7, 9 and consequently one member from each of the four pairs. The other members 4, 6, 8 and 10 are mounted on the surfaces b and d extending perpendicular to the surfaces a and c . Thus, the two series-connected members of each individual pair, for example 5 and 6, are always fastened to mutually perpendicular surfaces. As mentioned with reference to FIG. 4, the wiring is effected in such a manner that the terminals for the input voltage U_0 and the output voltage U_{IV} are most remote from each other.

As will be seen from FIG. 12 for the quadruple voltage division according to FIGS. 5 and 6, the output voltage U_{IV} can be varied in the range of 1:180,000 for the base-resistance ratio $n=3$.

The embodiment shown in FIG. 7 also comprises eight resistance members. However, the members 3, 5, 7 and 9 are combined to a single semiconductor strip which is provided with corresponding taps and mounted on a single lateral surface of the square carrier. An adjacent lateral surface of the carrier 1, perpendicular to the one first mentioned, is provided with the other four galvanomagnetic members. The members 4 and 6 are combined to a single semiconductor plate which is provided with a mid-tap, and the members 8 and 10 are analogously combined to a single field plate with a mid-tap. When producing the assembly, the members 4, 6, 8 and 10 are preferably made of a single semiconductor strip, similar in shape to that comprising the members 3, 5, 7 and 9. After the single strip is cemented to the carrier 1, it is separated between members 6 and 8 into the illustrated two parts. The connecting wires are mounted, in analogy to FIGS. 4 and 6, so as to provide for lowest possible inherent capacitance of the assembly.

For shielding purposes, the carrier structure may also

be made of metal or other conducting material if the galvanomagnetic members are insulated from the carrier material. If it is desired to reduce the effective air gap and to also decouple the individual galvanomagnetic members with respect to alternating voltages, it is preferable to make the carrier structure of a ferromagnetic and electrically conducting material. Thus, in the embodiment according to FIG. 8, the carrier 11 consists of an elongated rod having a square cross section and consisting of ferromagnetic and electrically conducting material such as magnetically soft iron, sintered iron powder or ferrite. The carrier is rotatable about its longitudinal axis between the poles 12 of the permanent magnet, or vice versa. Galvanomagnetic field plates are cemented upon the four lateral surfaces of the carrier, only four such field plates being shown at 3, 4, 7 and 8 in FIG. 8, corresponding to those denoted by the same respective numerals in FIGS. 5 and 6. Cemented upon the resistance members are cylindrical segments 13, 14, 15 and 16 which consist likewise of ferromagnetic and electrically conducting material. The radius of these segments is so chosen that the overall cross section, formed by the segments together with the square cross section of the rod 11, is circular, thus resulting in a generally cylindrical shape of the assembly in the air gap.

In the potentiometer shown in FIG. 9, two galvanomagnetic resistance plates 17 and 18 are fixed to each other in a plane longitudinally beside each other. They are jointly displaceable in the air gap of a magnet whose pole shoes are denoted by 19 and 20. The direction of displacement, indicated by a double-headed arrow, is transverse and perpendicular to the direction of the magnetic flux in the gap. The pole faces of pole shoes 19 and 20 have substantially the same dimensions as the areas of the resistance plates. Hence, depending upon the relative position between the pole shoes and the resistance plates, either plate 17 or plate 18 is more or less located in the magnetic field, it being irrelevant whether the galvanomagnetic assembly is displaced with respect to the magnet, or the magnet is displaced relative to the assembly.

By placing several pairs of adjoining galvanomagnetic members of this type on top of each other, the device of the type shown in FIG. 9 can also be employed for having a single magnet effect a multiple voltage division to obtain a higher division ratio. A mutual shielding of the individual pairs of resistance members, located closely above each other, can be effected by interposing a metal foil.

The device shown in FIG. 9a exemplifies a modification of the just-mentioned kind. It comprises a sandwich assembly of three pairs of galvanomagnetic resistance members 91a and b, 92a and b, 93a and b. The zero potential is denoted by 0, the input voltage by U_E , and the output voltage by U_A . The contacts 95 serve for supplying current as well as for interconnecting the individual resistance members. The members are inserted into the air gap between the poles N and S of a magnet and are displaceable in a direction perpendicular to the lines of magnetic force, this direction being indicated by an arrow. The pole faces of the magnets have approximately the same area dimensions as the individual resistance members. The respective pairs of members are shielded from each other by interposed foils 94 of nonmagnetic metal, for example copper.

As shown in FIG. 10, the displacing motion of the field plates 17 and 18 can be controlled mechanically, such as by the illustrated cam 21. Depending upon the cam contour, a desired control or regulating characteristic in dependence upon the angle of cam setting is thus obtained. A spring 22 presses the carrier of the resistance members proper toward the cam 21, so that each angular position of the cam corresponds to a definite position of the resistance assembly 17, 18 relative to the magnetic field.

A potentiometer according to the invention can further be designed in such a manner that it need not be actuated mechanically but can be controlled directly by an electrical magnitude, for example in dependence upon variation of an electric current. The embodiment illustrated in FIG. 11 affords such a performance. It comprises a three-legged ferromagnetic core structure which has respective field gaps in the two outer legs. In the illustrated embodiment the two outer legs are constituted by two soft-magnetic U-shaped yokes 23 and 24 which form the above-mentioned air gap between each other and close a split magnetic circuit for a permanent magnet 25 which in this example constitutes, or forms part of, the center leg. The outer legs are energized within the unsaturated and linear range of their magnetic characteristic by means of two excitation windings 26 and 27 which are shown series connected but may also be connected in parallel relation to each other.

When the windings 26, 27 are excited, the resulting flux is in boosting relation to the permanent flux at one gap but in bucking relation to the permanent flux at the other gap. Consequently, now one of the gaps between yokes 23 and 24 is traversed by a magnetic flux which constitutes the sum of the permanent flux from magnet 25 and the variable flux produced by the winding, whereas the field in the other gap constitutes the difference between the two magnetic fluxes. When no current passes through the windings 26 and 27, the magnetic induction in both field gaps is the same because it is due only to the permanent-magnet flux, and the resistance members 28 and 29 located in the respective gaps have median resistance values. Consequently, when current passes through the windings, the resistance value of the member located in the gap of the higher induction increases, whereas the resistance of the other member now subjected to a lower amount of induction, decreases. The two members are connected in a divider circuit corresponding to FIG. 2. However, multiple divider circuits according to FIGS. 3, 5 and 6 are analogously applicable.

An electromagnet can also be used for producing the magnetic field in a potentiometer according to the invention, instead of a permanent magnet as exemplified in the above-described embodiments. When employing an electromagnet, the division ratio can be further increased by varying the excitation of the field-producing magnet in dependence upon the position of the galvanomagnetic assembly relative to the direction of the magnetic field. If desired, the output voltage of the potentiometer can be made dependent not only upon the positional or other potentiometric adjustment mentioned in the foregoing, but can also be varied in response to another control magnitude. Thus, when employing an electromagnet for producing the magnetic field, the additional voltage control is readily obtained by varying the excitation current for the magnet coil. For example, when the magnet in FIG. 1 consists of a soft-magnetic core with an excitation coil, an additional control and variation is afforded by varying the excitation current for that coil; and the same applies to an embodiment of the type shown in FIG. 11 if the permanent magnet 25 is substituted by a soft-magnetic core with an excitation coil.

To those skilled in the art it will be obvious upon a study of this disclosure that my invention permits of various modifications and hence can be given embodiments other than particularly illustrated and described herein, without departing from the essential features of the invention and within the scope of the claims annexed hereto.

I claim:

1. A contactless potentiometer, comprising magnetic field structure, voltage supply leads, a voltage divider circuit having two galvanomagnetic resistance members connected in series with each other between said leads and having a tap between said two members to provide a variable output potential at said tap, said two resistance members being disposed in the field of said structure to have

their respective resistances dependent upon the magnetic flux traversing said members and being fixed with respect to each other in respectively different positions relative to said field structure, and means for simultaneously controlling the amounts of flux through said respective members in mutually inverse relation so that increased flux through one member coincides with decreased flux in the other.

2. A contactless potentiometer, comprising magnetic field structure having a field gap, a voltage divider circuit having a pair of galvanomagnetic resistors connected in series with each other and having between said two members a tap for providing a variable output voltage, said two resistance members being disposed in said field gap to have respective resistances dependent upon the magnetic flux traversing said resistors, a carrier structure joining said two resistors to each other in respectively different positions relative to said gap, one of said structures being displaceable relative to the other for increasing the flux through one of said resistors while simultaneously decreasing the flux in the other.

3. A contactless potentiometer according to claim 2, comprising at least one pair of galvanomagnetic resistors in addition to the first-mentioned pair, the two resistors of each additional pair being fixedly joined with said first pair in said field gap and disposed in respectively different positions corresponding to those of said first-pair resistors, and the two resistors of each additional pair being serially connected with each other in parallel relation to one of the two resistors of the next preceding pair.

4. In a contactless potentiometer according to claim 2, said two galvanomagnetic resistors having respectively different zero-field resistance values.

5. A contactless potentiometer, comprising a magnetic field structure having a field gap, a carrier structure in said gap, one of said two structures being angularly displaceable relative to the other about an axis transverse to the flux direction, a voltage divider circuit having two galvanomagnetic resistors connected in series with each other and having between said two members a tap for providing a variable output voltage, said resistors having substantially flat shape and extending on said carrier in respective planes parallel to said axis and angularly related to each other so that said angular displacement causes the flux through one resistor to increase while simultaneously decreasing in the other.

6. A contactless potentiometer, comprising a magnetic field structure having a field gap, a carrier structure in said gap, said carrier structure having elongated prismatic shape and a square cross section, one of said two structures being rotatably displaceable relative to the other about an axis transverse to the flux direction in said gap and coincident with the axis of said prismatic carrier structure, a voltage divider circuit having a pair of galvanomagnetic resistors of flat shape connected in series with each other and mounted on respective mutually perpendicular surfaces of said carrier, so that angular displacement causes the magnetic flux through one resistor to increase while simultaneously decreasing in the other resistor of said pair.

7. A contactless potentiometer according to claim 6, comprising at least one pair of galvanomagnetic resistors in addition to the first-mentioned pair, the two resistors of each additional pair being also mounted on respective mutually perpendicular surfaces of said carrier structure, the two resistors of each additional pair being serially connected with each other in parallel relation to one of the two resistors of the next preceding pair, and the series-connected resistors located on the same one of said carrier surfaces being formed of a single galvanomagnetic resistance member having a plurality of taps.

8. In a contactless potentiometer according to claim 7,

the mutually series-connected ones of said resistors on the same surface of said carrier structure being joined together to form a single integral resistance member having a tap.

9. In a contactless potentiometer according to claim 2, said carrier structure consisting of electrically conductive material so as to have a shielding effect.

10. In a contactless potentiometer according to claim 2, said carrier structure consisting of ferromagnetic material for reducing the active width of said field gap.

11. In a contactless potentiometer according to claim 2, said carrier structure consisting of ferromagnetic material, and cylinder segments of ferromagnetic and electrically conductive material mounted on the lateral surfaces of the carrier and covering said resistors, said segments supplementing the carrier structure to a substantially circular over-all cross section.

12. In a contactless potentiometer according to claim 2, said field structure having in said gap a field area corresponding in size substantially to the area of one of said two galvanomagnetic resistors, said two resistors consisting of planar plates mechanically joined beside each other in a single plane, the direction of relative displacement between said two structures being perpendicular to the flux direction in said gap.

13. A contactless potentiometer according to claim 12, comprising at least one additional pair of galvanomagnetic resistors corresponding in area to the two aforesaid resistors and being mechanically joined with said carrier structure, the respective resistors of each additional pair and the respective afore-said two resistors being arranged above one another.

14. A contactless potentiometer according to claim 12, comprising a metal foil between each two pairs of said galvanomagnetic resistors.

15. A contactless potentiometer according to claim 12, comprising a rotatable drive cam, and translatory transmission means connecting said cam to said displaceable structure for controlling the voltage division in dependence upon the rotational cam position.

16. A contactless potentiometer, comprising a magnetic field structure having a three-legged core whose two outer legs have respective field gaps and whose center leg has magnetic excitation means for passing pre-magnetizing flux through said two gaps, two galvanomagnetic resistance members connected in series with each other and disposed in said respective gaps to have their respective resistances dependent upon the magnetic flux traversing said members, and a control winding mounted on said structure and inductively linked with both of said outer legs to provide, when energized, a control flux bucking said pre-magnetizing flux in one leg and boosting it in the other, whereby the resultant fluxes in said resistance members and thus their resistance values are controlled in mutually inverse relation to each other.

17. In a contactless potentiometer according to claim 16, said magnetic excitation means of said center leg being a permanent magnet.

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