April 23, 1963 A. J. MONCRIEFF-YEATES 3,087,069

RADIATION-CONTROLLED VARIABLE RESISTANCE

Filed Aug. 12, 1959

FIG. 1.

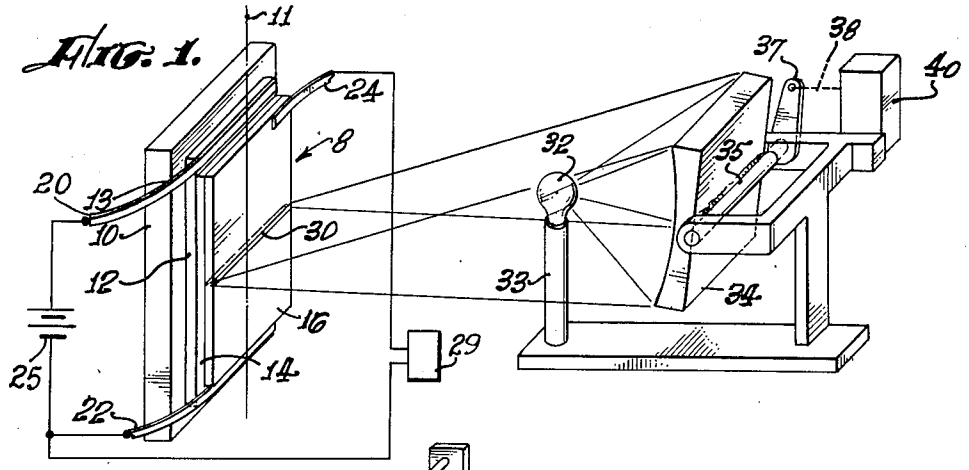


FIG. 2.

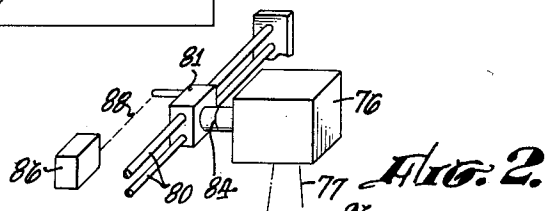


FIG. 3.

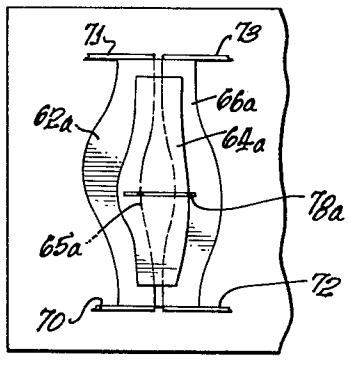
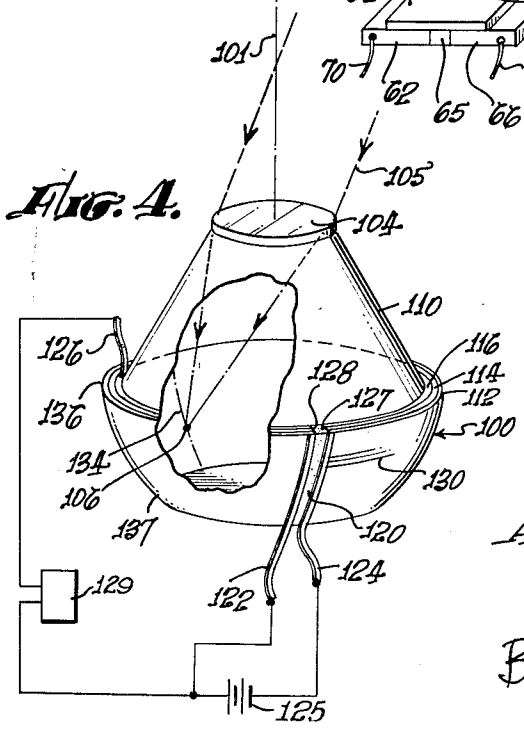


FIG. 4.



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United States Patent Office 3,087,069 Patented Apr. 23, 1963

3,087,069

RADIATION-CONTROLLED VARIABLE RESISTANCE

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Filed Aug. 12, 1959, Ser. No. 833,278
6 Claims. (Cl. 250—211)

This invention relates generally to a novel type of variable electrical resistance, such as may be used, for example, as a potentiometer or rheostat in an electrical circuit.

Previously available variable resistances ordinarily employ a resistance element of fixed magnitude in combination with a mechanically movable electrical contact, by which a variable fraction of the resistance may be introduced into an electrical circuit.

Rheostats and potentiometers of that conventional type are subject to a wide variety of well known practical disadvantages and difficulties resulting from the mechanical movement of the contact or brush. Among those difficulties are abrasion and wear of the resistive element, variation of the contact resistance at the sliding contact, and friction at the moving contact which typically causes it to move irregularly and increases the minimum power required to drive it.

The present invention provides means by which a variable fraction of a resistive element may be selected, for example for inclusion in a specific electrical circuit, without requiring mechanical movement of a brush or other contact member. By thus eliminating the usual sliding contact, all of the difficulties asssociated with it are avoided.

That is typically accomplished by providing a fixed body of photoconductive material which makes continuous electrical contact with the resistive element along the length of the latter, and is also in electrical contact with another element, which is capable of conducting electricity, though it may also offer appreciable resistance. The latter element will be referred to for convenience as an electrode. The normal resistance of the photoconductive body, when not illuminated, is preferably high enough to provide effective insulation of the resistive element from the electrode. It is then possible, in accordance with the present invention, by illuminating a suitably selected portion of the photoconductive body, to produce selectively an electrical connection between the resistive element and the electrode at any desired point along their length. The photoconductive body may be responsive to radiation of any desired type, including, in particular, electromagnetic radiation and radiation comprising rapidly moving particles such as electrons, protons and alpha particles, for example. For clarity of description, the invention will be described primarily as it relates to the use of electromagnetic radiation. Moreover, since it is usually more convenient to work with such radiation in or close to the visible region of the electromagnetic spectrum, the radiation may be referred to for definiteness in the present specification as "light," but without intending to limit the invention to any particular spectral region.

A particularly efficient and convenient manner of assembling the photoconductive body in electrical contact with the resistive element and electrode along parallel longitudinal contact surfaces is by depositing successive layers of suitable respective materials upon a carrier surface. The carrier surface may, if desired, also constitute one of the active elements of the assembly. For example, a flat surface of an elongated resistive element may be coated with a layer of photoconductive material, over which is applied a coating of material of relatively high conductivity to act as electrode. The latter layer is made

thin enough to transmit light freely, and the photoconductive layer or formation is preferably also thin enough to be effectively penetrated by incident light. When such an assembly is illuminated in such a way that light is confined to a narrow zone, the photoconductive formation is rendered conductive only substantially within that zone and transmits electricity between the overlying electrode layer and a specific limited portion of the underlying resistive element.

Electrical terminals may be connected to the electrode and to the resistive element at any desired points. For example, an electrical voltage may be supplied to the resistive element through terminals placed at its opposite ends, and the voltage tapped from the electrode element then corresponds to the longitudinal position of the illuminated zone in a manner that is generally analogous to the action of a conventional potentiometer.

A particularly useful form of the invention comprises a transducer for developing an electrical signal that represents the positions of a movable member. For that purpose a source of suitable radiation may be coupled directly to the movable member, or mounted directly on it, and arranged to irradiate a limited area on the face of the potentiometer assembly at a position that varies in accordance with movement of the member. That arrangement is particularly useful when it is not convenient to provide a direct mechanical connection to the movable body.

The invention further provides particularly convenient means for producing a desired functional response of a potentiometer or rheostat. As will become clear from the following description, the functional relation between the position of the irradiated zone on the resistive assembly and the resulting output signal may be modified by suitable variation of a number of different control factors, giving greater flexibility of the resulting functional output than is available with conventional potentiometric devices.

A full understanding of the invention, and of its further objects and advantages, will be had from the following description of certain illustrative examples. The particulars of that description, and of the accompanying drawings which form a part of it, are intended only as illustration and not as a limitation upon the scope of the invention.

In the drawings:

FIG. 1 is a schematic perspective, representing an illustrative embodiment of the invention;

FIG. 2 is a schematic perspective, representing another illustrative embodiment of the invention;

FIG. 3 is a schematic plan, representing a modification; and

FIG. 4 is a schematic perspective, representing a further illustrative embodiment of the invention.

FIG. 1 represents schematically an illustrative potentiometer assembly in accordance with the invention, designated generally by the numeral 8, and a typical manner of operating the potentiometer in response to rotation of a shaft. The numeral 10 indicates a support having a smooth support face, which may be of electrically insulative material such as glass, or may be made of any desired structural material coated with an insulative layer, not shown. An elongated layer of resistive material is formed on support 10, as indicated schematically at 12, with its longitudinal axis 11 shown vertical for illustration. Resistive layer 12 may comprise any suitable type of electrically resistive material, and may be formed by any of the many known techniques for producing and handling such materials. For example, the layer may comprise a block or sheet of conventional resistive material, such as carbon or a suitable metal alloy. Or, as a further example, layer 12 may comprise a very thin metallic film deposited chemically or by evaporation in vacuum on the face of support 10, such

a layer having relatively high electrical resistance by virtue of its extreme thinness. For clarity of description, it will be assumed that the electrical properties of layer 12 are uniform throughout its area, although non-uniform layers are also useful as will appear more fully below. Particularly if resistive layer 12 is structurally strong, support 10 may be omitted.

A photoconductive formation is represented as the layer 14, typically covering substantially the whole of resistive element 12 in direct face-to-face contact therewith. Photoconductive formation 14 may be formed of a wide variety of known photoconductive materials or combinations of such materials. Such materials include, for example, lead and cadmium sulphide and selenide, antimony trioxide, anthracene, zinc oxide and selenium. Such materials may be applied to a surface by many known procedures, including, for example, evaporation in vacuum, chemical deposition or application of a suitable paint-like composition comprising powdered or sintered material suspended in a suitable binder which will harden to form a solid coating. Such techniques for accurately forming bodies of photoconductive material are well known and do not require detailed description here.

On the face of photoconductive layer 14 opposite to resistive element 12 is placed a conductive layer 16, which may typically comprise an evaporated film of silver or other metal that provides suitably high conductivity in a layer that is still thin enough to transmit light readily. That layer, which will be referred to as an electrode, may be covered with a protective film of substantially transparent and preferably insulative material if desired.

When the device is to be used as a potentiometer, power input connections are typically provided at both ends of resistive layer 12 as indicated at 20 and 22; and an output terminal is connected at any convenient location on electrode 16, as at 24. The conductivity of the electrode is typically sufficient that the detailed position of the output terminal is immaterial electrically. To facilitate connection of the two power terminals, it is convenient to form resistive layer 12 with end portions 13 extending beyond the superposed layers, so that they are accessible as shown in the figure. The terminals may then extend in parallel relation and form continuous electrical contact across the full width of the resistive layer. Electricity from the terminal then enters the resistive layer uniformly across its width. When the two power connections are maintained at different potentials, as by the battery 25, the lines of equal potential within the resistive layer are then typically straight parallel lines at right angles to the longitudinal axis.

When potentiometer assembly 8 is not illuminated, resistive element 12 is effectively isolated electrically from electrode 16, due to the high dark resistance of photoconductive layer 14. However, when a portion of the photoconductive layer is illuminated, the resistance of the illuminated portion decreases sharply. Throughout the area of that illumination, resistive element 12 is therefore effectively connected directly to electrode 16. For most purposes it is desirable to limit the illumination to a narrow zone which follows substantially a line of uniform potential in the resistive element. That potential is then substantially delivered to the output terminal 24, and may be indicated or utilized in conventional manner by output means represented schematically at 29. In the present instance, the equipotential lines are straight lines parallel to terminals 20 and 22 and to the ends of the resistive layer. Accordingly, the illuminated zone is preferably a narrow slit of light extending across the assembly at right angles to its longitudinal axis. Such an illuminated zone, corresponding to a narrow rectilinear slit, is represented at 30.

Such an illuminated zone of slit-like form can be produced by many different types of optical system. For example, the light zone 30 may be produced by a physical slit mounted in closely spaced relation to assembly 8 and illuminated with generally parallel incident radiation. It is usually more convenient to produce at the assembly surface an optical image of an illuminated slit or other light source by suitable optical means. The slit or light source itself may be movable to vary the position of illuminated zone 30 along the length of axis 11. Alternatively, the movement of that zone can be produced by rotary or other movement of a mirror or other optical element which forms a part of the optical system.

In the system illustratively shown in FIG. 1, a source of light is shown schematically as an electric lamp at 32, mounted on a supporting post 33. A cylindrical mirror 34 is mounted on the horizontal shaft 35 with its cylindrical axis parallel to the shaft. The mirror forms an elongated astigmatic image of source 32 at 30 on the face of assembly 8. Additional optical elements may be added to such a system in known manner to increase the brightness and definition of the image at 30. Suitable screens, not explicitly shown, are provided to shield the resistive assembly from stray light.

Rotation of shaft 35 and mirror 34 causes the position of image 30 to move vertically across the face of assembly 8 parallel to axis 11. That movement may be driven by any suitable mechanism, indicated schematically by the crank 37 and the dashed line 38, under control of an input device 40. Device 40 may represent, for example, a movable element the position of which is to be indicated or recorded by first translating it into an electrical voltage signal. In the present embodiment, that movement is communicated as rotary movement to mirror 34, and causes light image 30 to sweep longitudinally over the face of potentiometer assembly 8. The conductive portion of photoconductive layer 14 is thereby shifted longitudinally of the resistive element of the potentiometer, varying the voltage that is tapped by electrode 16 and terminal connection 24. Hence that tapped voltage provides a signal representing the position of device 40.

The radiation beam for illumination of zone 30 of photoconductive layer 14 may be incident through support member 10, provided that member is constructed of suitably transparent material and that the intervening layer, shown as resistive layer 12 in the present embodiment, is also capable of conducting radiation. The arrangement of the layers may be reversed, if desired, so that the resistive layer is positioned on top of the photoconductive layer. It is then particularly convenient to utilize the support member directly as electrode. However, as before, the materials and arrangement must be so selected that the photoconductive layer is accessible to incident radiation from one side or the other.

FIG. 2 represents another illustrative embodiment of the invention in which the electrode and the resistive element are closely adjacent laterally and engage the same face of the photoconductive formation. The embodiment of FIG. 2 further illustrates the use of a second resistive element to perform the functions of an electrode. Resistive assembly 60 comprises the two similar flat elongated strips 62 and 66 of resistive material. Strips 62 and 66 are placed in parallel relation in a common plane, shown horizontal, with their adjacent longitudinal edges closely spaced. Those edges may be separated only by an air gap, or may be positively separated, as illustratively shown, by an intervening barrier 65 of suitable dielectric material. A flat formation of photoconductive material 64, shown as a continuous body, overlies the resistive strips, directly engaging their upper faces and forming a continuous bridge between the two strips 62 and 66. When the described assembly is to be used as a rheostat, only two connection terminals are required. Such terminals are indicated somewhat schematically at 70 and 72, electrically connected to adjacent ends of the respective resistive strips 62 and 66. As illustrated, the terminals

directly engage only a small area of each strip, but they may, instead, extend the entire width of those strips in the manner already described and illustrated in FIG. 1. If desired, terminals may be provided at both ends of one or both of the strips (FIG. 3). The effective resistivity of the strips need not be the same; and one of them may have negligible resistance and function solely as an electrode, as already described in connection with FIG. 1.

A movable source of radiation is represented schematically at 76, typically comprising an irradiated slit and means for projecting the radiation 77 from the slit to form an image on the upper surface of photoconductive layer 64, as represented at 78. Slit image 78 constitutes an irradiated zone of the photoconductive body, which extends transversely between the two resistive elements 62 and 66. The enhanced conductivity of the photoconductive material within that zone forms a conductive bridge between the two resistive elements. Current is therefore conducted between terminals 70 and 72 through that conductive bridge and the portions of both strips between that bridge and the terminals. The effective resistance of that conductive path between terminals 70 and 72 then depends directly upon the longitudinal position of irradiated zone 78.

That position is variable in the present embodiment by bodily movement of radiation source 76, for example along guide rails represented at 80. That movement may be driven in any desired manner, for example via a connection represented at 88 under control of an input or control mechanism 86. The mounting of radiation source 76 on carriage 81 may include two relatively rotatable members, as indicated at 84, thus permitting bodily rotation of the radiation source about a horizontal axis that is transverse of the length of the resistive assembly. The position of slit image 78 is then variable by swinging movement of the radiation source about that axis. Such swinging movement may be employed in place of the described translational movement of carriage 81; or may supplement that movement, thus conveniently providing variation of the effective resistance of the resistice assembly under joint control of two distinct input signals.

A mask 92 of any desired form may be inserted in radiation beam 77, as will be more fully described below.

FIG. 3 represents in plan a resistive assembly similar in general construction to that of FIG. 2, but illustrating the wide flexibility that is made available by the invention for providing any desired functional relation between the position of the irradiated zone 78*a* and the resulting effective resistance of the assembly. Such control of the output function can be obtained through a variety of variable factors. For example, each of the resistive elements 62*a* and 66*a* can be "shaped," that is, constructed with non-uniform cross-section. The area of the cross-section can be varied along its length, for example, by changing the width of each strip, as shown illustratively in FIG. 3, or by similarly varying the thickness of each strip. In the device as shown in FIG. 3, terminal connections 70 and 71 are provided at opposite ends of elements 62*a*, and terminal connections 72 and 73 at opposite ends of element 66*a*. The resistive elements of this and other embodiments of the invention may also be tapped at points intermediate their length as may be desired to increase the variety of available circuit connections.

Another type of variation in the overall function of the device may be obtained by varying the spacing between the two resistive strips, or between one resistive strip and an electrode. That is illustrated in FIG. 3 by the varying spacing between the inner edges of the strips 62*a* and 66*a*. That is particularly effective when the resistance of the irradiated zone of the photoconductive material is high enough to form an appreciable part of the total resistance between terminals of the device. The effective resistance contributed by the photoconductive strip increases with the path length through that strip, and is thus controllable by the spacing of the resistance elements.

A still further type of functional control that is made available by the present invention comprises suitable shaping of the photoconductive body itself. Such shaping permits variation of the degree of overlap of the photoconductive strip and the resistive strips. The smaller that overlap the greater the effective resistance to current passing through the limited irradiated zone. Similar control can be exercised by varying the thickness of the photoconductive layer.

A particularly convenient type of functional control is similar to the shaping of the photoconductive body, just described, but has the great advantage that it is more conveniently variable after construction of the resistive assembly and during its use. That control is accomplished by varying the intensity or form of the irradiated zone itself which serves as potentiometer brush. For example, variation of the length of the image 78*a* represented in FIG. 3 has much the same effect as the described variation in width of the photoconductive layer. By changing the image intensity at different points along the length of the resistive assembly, the conductivity of the irradiated bridge may be correspondingly changed. Such control may be accomplished conveniently by inserting a suitably graded filter or mask in the path of the incident radiation beam. Such a mask is represented schematically in FIG. 2, but is omitted in FIG. 3 to preserve clarity of that figure. Fixedly mounted slotted guide rails are represented at 90 and 91, adapted to receive a slide 92, on which a mask of any desired form and density may be formed. For example, for controlling typical electromagnetic radiation, slide 92 may be a glass plate on which the desired masking configurations are formed by known photographic procedures. The mask may include, for example, dense edge portions 94 and 95 whose boundaries limit the length of image 78. The area 96 between portions 94 and 95 may be uniformly transparent, or its density may vary along the length of the mask, thus providing a graded filter which varies the intensity of image 78 as any desired function of its longitudinal position. When it is desired to change the form of that function, it is only necessary to replace the mask, leaving the resistive assembly itself and the remainder of the system entirely undisturbed. When the effective resistance of the irradiated zone is controllably variable, as in the illustrative manners described, both the conductive elements, referred to above as the resistive element and the electrode, may have negligible resistance, so that both act substantially solely as electrodes, and the primary effective resistance of the device is that contributed by the photoconductive formation.

The specific methods of functional control described above are illustrative of the great flexibility of the invention in facilitating the production of resistances and potentiometers that are specially tailored to produce a required output function. Those methods of control are applicable in general to the type of assembly represented in FIG. 1, as well as to the specific arrangement selected in FIG. 3 for illustration. The actual functional output in any specific instance can be calculated to the required degree of approximation by known techniques of circuit analysis.

In order to obtain maximum resolving power in a potentiometer of the present type, that is, maximum responsiveness of the output voltage signal to small movements of the irradiated zone, it is desirable that the photoconductive layer be as thin as is practicable. Since the available photoconductive materials do not provide infinite resistance when in the dark, a very thin photoconductive layer ordinarily produces appreciable conductivity between the resistive layer and the electrode, even when not irradiated. For practical purposes, that is immaterial, so long as that conductivity is small compared to the conductivity of the resistive layer between its two end terminals. If that condition is met, and if

the conductivity within the irradiated zone of the photoconductive layer is large compared to that between ends of the resistive element, the output of the device will respond satisfactorily to movement of the irradiated zone, as already described. Stated in another way, it is essential for normal use of the device as a potentiometer that the resistance of the resistive layer between its opposite ends is small compared to the effective resistance of the unirradiated photoconductive layer between the resistive element and electrode; and at the same time is large compared to the resistance of the irradiated portion of the photoconductive layer.

A further illustrative embodiment of the invention is represented in FIG. 4, wherein the resistive assembly **100** has the general form of a surface of revolution with axis **101**, shown vertical for illustration. That surface is typically represented as being substantially spherical in form and occupying a spherical zone. Resistive assembly **100** is adapted for illumination at its inner face. That illumination is directed by axially positioned optical means, indicated schematically as a lens **104**, and adapted to receive parallel incident light, as indicated at **105**, and bring it to a focus as at **106** at the inner spherical surface of the resistive assembly. A generally conical shield **110** is provided to shield that surface from light that does not pass through the lens **104**.

Resistive assembly **100** typically comprises a resistive layer **112**, a photoconductive layer **114**, and an electrode layer **116**, arranged in superposition in the manner already described illustratively in connection with FIG. 1. The resistive layer is continuous around the circumference of the spherical zone, except for a single break at which the adjacent edges **127** and **128** of the layer are typically spaced apart by an insert **120** of dielectric material. Those edges extend generally parallel to a plane through axis **101** and are typically closely spaced. They may, however, be spaced apart by any desired angle. Thus, for example, the entire resistive assembly **100** may be limited to any desired angular sector about axis **101**. The input terminals **122** and **124** include connecting portions that engage resistive layer **112** continuously along the respective spaced edges **127** and **128**. When those terminals are connected to suitable sources of different voltage, for example to the opposite terminals of a battery **125**, current flows generally circumferentially through resistive layer **112**, forming equipotential lines that correspond approximately to intersections of axial planes with the spherical surface. One such line is indicated schematically at **134**. The accuracy of that form of the equipotential lines may be made essentially perfect by suitable design, for example by forming narrow circumferential slits in the resistive layer, as indicated schematically at **130**. Slits **130** divide the main body of resistive layer **112** into a plurality of relatively narrow circumferential strips. With that circumferential lamination of the resistive layer, the current in the layer can flow only in a circumferential direction.

An output terminal **126** is connected to conductive layer **116** at any convenient point of that layer. Illuminated zone **106** completes an electric circuit from that output terminal to a sharply limited area of resistive layer **112**, thereby supplying to the output terminal the voltage standing at that point of the resistive layer. That voltage can be indicated or utilized in conventional manner by output means represented schematically at **129**. The output voltage, due to the described form of the equipotential lines, represents the azimuth angle of the illuminated zone, and thus corresponds to the azimuth of the light source from which beam **105** originates. That light may originate from any desired source, such for example, as a celestial or other object in the night sky.

Alternatively, power terminals may be connected to resistive layer **112** of FIG. 4 along the upper and lower circumferential edges of that layer, indicated at **136** and **137**, making continuous contact with layer **112** along the full length of those edges. Slits **130** are then, of course, omitted. Dielectric insert **120** may also be omitted. With that arrangement the current flow at each point of the resistive layer is parallel to the axial plane through that point. The equipotential lines are then intersections of the spherical surface with planes perpendicular to axis **101**. The output voltage at terminal **126** then represents the elevation angle of the source of light **105**.

In the drawings the dimensions and proportions of the various parts are not necessarily drawn to scale, but are exaggerated for clarity of illustration. That is particularly true as to the thickness of the several layers, some of which are typically only a few thousandths of an inch thick, and may be of only molecular dimensions. For many purposes it is not essential that the photoconductive formation comprise a single continuous body of material, as in the embodiments selected for illustration. For example, in FIG. 4 the slits **130** in resistive layer **112** may extend also through photoconductive layer **114** and electrode layer **116** if desired. Such division of the photoconductive formation into more or less discrete elements does not affect the primary operation of the invention, so long as irradiation of a selected portion of the photoconductive formation provides a path for current flow to a localized portion of the resistive element. In general, however, maximum resolution is obtainable when the photoconductive formation is essentially continuous in the longitudinal direction.

Such terms as longitudinal and elongated are employed in the description and claims to denote a selected functional direction, typically the direction of movement of the irradiated zone. The longitudinal dimension is not necessarily greater in magnitude than a transverse dimension.

I claim:

1. An electrical resistive device, comprising in combination two elongated elements capable of conducting electricity, a solid body of photoconductive material electrically connected to said elements along substantially continuous respective contact surfaces that are mutually spaced, means for irradiating selectively a limited zone of the photoconductive body that extends continuously between said surfaces, the thickness of the photoconductive body in a direction transverse of said elements and of said irradiated zone varying longitudinally of said elements, and means for moving the irradiated zone longitudinally of said elements to vary the conductivity between the two elements.

2. An electrical resistive device as defined in claim 1, and including means for automatically varying the intensity of the irradiation as a predetermined function of the longitudinal position of the irradiated zone.

3. Electrical potentiometer means, comprising in combination a support member having a face in the form of a surface of revolution, a layer of resistive material, a layer of solid photoconductive material, and a layer of conductive material supported in superposition on said face, the layer of photoconductive material being intermediate the other two layers and spacing them apart, at least one of said other layers being capable of transmitting incident radiation, the resistive layer having two edges that lie substantially in respective axial planes and are circumferentially spaced, terminal means connected along the respective edges of the resistive layer, and terminal means connected to the conductive layer.

4. Electrical potentiometer means as defined in claim 3, and in which the main body of the resistive layer is circumferentially laminated.

5. Electrical potentiometer means, comprising in combination a support member having a face in the form of a surface of revolution, a layer of resistive material, a layer of solid photoconductive material, and a layer of conductive material supported in superposition on said face, the layer of photoconductive material being intermediate the other two layers and spacing them apart, at least one of said other layers being capable of transmit-

ting incident radiation, terminal means connected along respective axially spaced circumferential zones of the resistive layer, and terminal means connected to the conductive layer.

6. A system for developing an electrical signal representing the position of a movable member, said system comprising in combination a layer of solid photoconductive material having two opposite faces, an elongated resistive element in direct electrical contact with one of said faces, a conductive element in direct electrical contact with the other face in spacedly opposed relation to the resistive element, at least one of said elements being capable of transmitting incident radiation to the photoconductive layer, the body of the photoconductive layer having a volume resistance to current flow in both directions between said elements that is relatively high in the dark and relatively low when irradiated,

means for supplying different and substantially constant electrical voltages to the respective end portions of the resistive element to establish therein an electrical potential that varies longitudinally substantially independently of electrical conduction in the photoconductive layer,

means for selectively irradiating a narrow zone of the photoconductive layer that extends continuously between said elements, the last said means being actuable to vary the longitudinal position of the irradiated zone in response to movement of said movable member, and means for tapping from the conductive element a voltage signal that represents substantially the value of said potential at the irradiated zone.

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