May 3, 1960 B. J. OPPENHEIM ET AL 2,935,712

MULTI-TERMINAL NON-LINEAR RESISTORS

Filed Feb. 4, 1958 2 Sheets-Sheet 1

Fig. 1

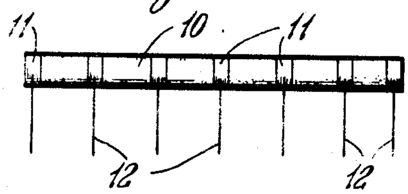


Fig. 2

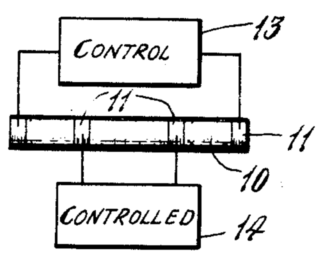


Fig. 3

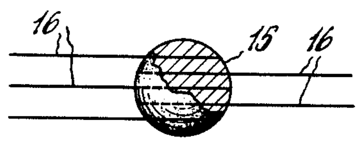


Fig. 4

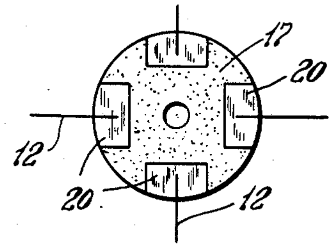


Fig. 5

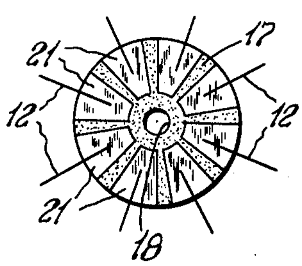


Fig. 6

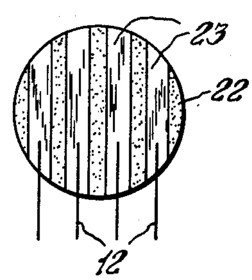
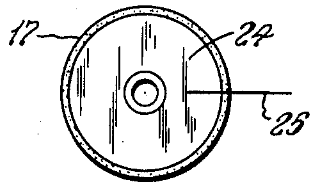


Fig. 7



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Filed Feb. 4, 1958 2 Sheets-Sheet 2

Fig. 8

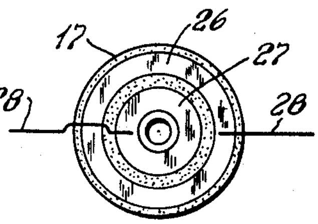


Fig. 9

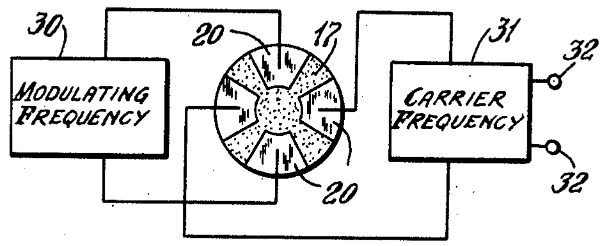
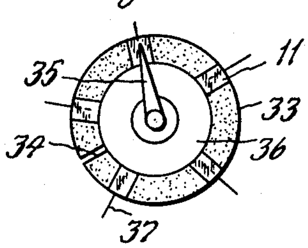


Fig. 10



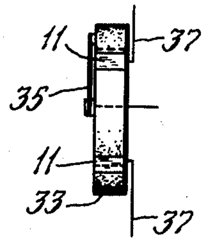
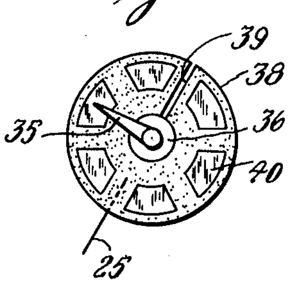


Fig. 11

Fig. 12



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MULTI-TERMINAL NON-LINEAR RESISTORS

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2 Claims. (Cl. 338—20)

This invention relates to a multi-terminal non-linear resistor of the type whose resistance varies considerably with the applied voltage. It also relates to similar resistors made of material whose resistance varies substantially with the temperature. The invention also has particular reference to control and modulating circuits using the multi-contact resistors for application in communication and other controllable electrical circuits.

The resistor units herein described are generally classified as thermistors and varistors. Both these types are generally made by sintering a composition of resistor material into a desired shape. By choosing the composition of the resistor material, resistors may be fabricated which vary substantially with the applied voltage in the case of varistors or vary substantially with the temperature for thermistors.

Prior art resistors have been made by either forming the resistor material around a pair of conductors during the fabrication process, or else forming the resistor material into a suitable shape, firing a contact onto the surface and applying the conductors to the contact surfaces by means of soldering or brazing or by means of pressures. However, it was not heretofore possible to vary the resistance in such articles.

It has been found that the most satisfactory method of applying a contact to the surface of a non-linear semiconductor type resistor and especially to thermistors and varistors, is to deposit, spray, or fire a metallic or some electrically conductive coating onto the surface of the body. This method produces a contact which reduces the extremely high contact resistance brought about by a direct application of the contact to the surface of the resistor. By applying a number of discrete coatings and then soldering or otherwise securing a lead to each coating, a number of resistance values may be obtained from a single rod, disk or washer shaped structure. Such multi-contact resistors may be used in control and modulating circuits for a wide variety of electrical applications. They are also useful where precise values encountered during experimental development cannot be predetermined. In such applications, a broad range of experimental values can be used without removing the thermistor or varistor from the circuit. The user therefore has a convenient means to rapidly determine precisely what value is most advantageous for his circuit configuration. With the use of the herein described devices it is now possible to place a single unit of multiple values in an installation or test device or similar apparatus and make a large series of tests in a comparatively short period of time. Such a procedure would, in many cases, be impossible if individual units had to be installed and removed repeatedly to perform the same task. In the performance of a series of experiments to determine the suitability of a given thermistor or varistor resistance value, there are generally a large number of parameters which may vary during the course of the experiment, other than the resistance value of the thermistor or varistor which is intentionally varied.

Since the variation of the other parameters may not be constant for each individual experiment, the results obtained are sometimes confusing and misleading. It is now possible with the use of the present invention to obtain test results during an interval of time for which other parameters are essentially constant. For example, if a thermistor is utilized in an environment in which the temperature can be controlled, but other factors such as the thermal conductivity of the medium cannot be controlled, such factors such as response time would change during the interval of time required to change thermistor units to simulate the tests.

In utilizing thermistors or varistors, circuit requirements are such that it is often desirable to restrict the range of resistance variation obtained for a specified temperature range or voltage range respectively to a narrow band without reducing the inherently high sensitivity of the component. In the past, this was accomplished by using several elements having different resistance values at a specified reference condition. In many applications space requirements prohibit the use of several elements. Also, when using thermistors it is often essential that the temperature measurement be restricted to a very small volume or preferably to a single point. In such cases, even when sufficient space is available, the physical measurement loses all significance when more than one element is used. With the use of the present invention, it is now possible, with the use of a single element, to expand the range of temperature for a thermistor or voltage for a varistor for a specified resistance range without any resulting loss in sensitivity.

Accordingly, an object of the present invention is to provide an improved multi-contact non-linear semi-conductor resistor which eliminates many of the limitations of prior art non-linear semi-conducting resistors.

Another object of the present invention is to increase the flexibility and adaptability of non-linear resistors to a wide variety of electrical circuits.

Another object of the present invention is to make possible a variable non-linear resistor by connecting the plurality of contacts to a dial switch.

Still another object of the present invention is to provide a multi-contact non-linear resistor which may be used in modulating circuits, either for direct current modulation or for any of the frequencies generally used by communication systems.

The invention involves the use of a resistor having a body of a material with non-linear electrical characteristics. A plurality of electrically conducting or suitable metallic films or a plurality of electrical conductors are sintered into the body and a plurality of leads or conductors are secured in conducting relationship to the films. The non-linear resistors may include the type whose resistance varies with the applied voltage or with the temperature of the resistor. In addition, connection between the various leads may be made by means of switch controls or some movable contact arm device.

For a better understanding of the present invention, together with other and further objects thereof, reference is made to the following description taken in connection with the accompanying drawings.

Figure 1 is a side view of a non-linear resistor having a body of rod-like shape.

Figure 2 is a schematic diagram of a control circuit using a resistor similar to that shown in Figure 1.

Figure 3 is a plan view of a non-linear resistor having a bead of resistor material with five conductors penetrating the body of the bead.

Figure 4 shows a plan view of a washer of resistor material having four metallized films deposited on one side of the washer.

Figure 5 is a plan view of a washer similar to that shown in Figure 4 but having a greater number of films, each with a different shape.

Figure 6 is a plan view of a non-linear resistor having a disk-like body and four metallized strips deposited thereon.

Figure 7 is a bottom view of a non-linear resistor which may contain contacts on the other side thereof as shown in Figures 4, 5 and 6.

Figure 8 is a bottom view of a washer resistor similar to Figure 7 but showing the annular metallized films.

Figure 9 is a schematic diagram of connections showing a disk type non-linear resistor used in a modulating circuit.

Figure 10 is a plan view of a washer shaped variable resistor employing a movable contact arm.

Figure 11 is a view in side elevation of the resistor shown in Figure 10.

Figure 12 is a top plan view of another form of variable resistors employing a movable contact arm.

Referring to Figure 1, one form of the resistor includes a cylindrical rod-like body **10** of resistor material which may exhibit non-linear characteristics varying with temperature or applied voltage. A plurality of spaced conducting films **11** is deposited on the rod **10** as indicated, the deposited areas generally forming a complete ring around the rod. Each film is connected to a conductor **12** by soldering, welding, or other suitable connecting means. Since the resistivity of the material forming the rod is much higher than the metallized films, the resistance between conductors is proportional to the distance between adjacent films. This resistor may be used in a number of different circuits applications such as a variable resistor component when connected to suitable switching means or as a control component when connected as a coupling means between two circuits.

The circuit shown in Figure 2 includes a non-linear resistor body **10** having contact rings **11**, two of which are connected to a control circuit **13** which may be a variable voltage, direct current source or it may comprise a system of communication which employs modulated frequencies of any type. A controlled circuit **14** is connected to two contact rings **11** which are spaced between the contact rings connected to control circuit **13**. When the control circuit **13** changes its voltage, the resistance of the entire resistor unit **10** is changed and the resistance between the two intermediate conducting rings are changed in proportion. This change in resistance may be applied to any type of controlled circuit such as the grid of a vacuum tube, the base voltage of a transistor, or to the control winding of a saturable reactor.

Figure 3 shows a bead type resistor **15** formed with five conducting leads **16** in the body thereof. This type of non-linear resistor may be used in the circuit shown in Figure 2; it may be used as a variable temperature responsive unit or as a temperature responsive element with a plurality of conductive leads running to a number of indicating instruments or to other linear resistors. The incorporation of the plurality of leads within the bead **15** lends heat dissipating properties to the bead permitting the application of higher voltages (or power) to the bead without appreciably self-heating it.

It is often convenient to fabricate non-linear resistors in disk form since this shape is more easily adaptable to the deposition of conducting films. The disks **17** shown in Figures 4 and 5 can be formed with a central hole **18** for convenient mounting. The widely separated conducting areas **20** shown in Figure 4 or closely spaced areas **21** shown in Figure 5 are used as resistor terminals. This form of resistor is employed in a manner similar to that shown in Figure 2 or it may be used as a variable resistor with some suitable form of switching arrangement.

The resistor shown in Figure 6 comprises a disk **22** of resistor material having conducting strips **23** deposited on one surface of the disk. This form of resistor is adaptable for use in any circuit which will accommodate the resistor shown in Figure 1.

The resistors shown in Figures 4, 5 and 6, may have conducting films as indicated, deposited on a single side of the disk or each disk may have similar coatings on both sides. It has been found that a wide variety of circuit applications are possible when a plurality of conducting areas **21** are deposited on one side of a disk and a single annular area **24** (see Figure 7), is deposited on the other side of the disk, terminated by conductor **25**. It will be obvious that the resistance paths between areas **21** and area **24** produce a wide variety of coupling combinations.

Figure 8 shows an alternate form of bottom conducting arrangement wherein two annular conductive films **26** and **27** are deposited on the lower disk surface. Each annular area is connected to its conductor **28** to give additional combinations of resistance values.

The circuit shown in Figure 9 shows an additional application of a resistor disk **17** having four conductive areas **20**. A source of modulating frequency power **30** is applied to opposite areas **20** on the disk thereby producing a variable resistance between the other two opposite areas. These latter two areas are connected to a source of carrier frequency power **31** to modulate its amplitude, frequency, or phase. The carrier frequency power is delivered to output terminals **32** for application to a transmission circuit.

Referring to Figures 10 and 11, there is shown a resistor made in accordance with the present convention which is formed in the shape of a ring. The ring **33** is slit as indicated at **34** to provide an air gap. Conductive films **11**, similar to those shown and described in connection with Figure 1, are placed around the resistor **33**. The conductive films **11** are spaced from one another in any suitable manner and at any desired interval. A contacting arm **35** is pivotally mounted upon a dielectric disk **36** located in the center of the ring **33**. A lead **37** is connected to one of the conductive films **11** and a second lead may be connected to the arm **35**. By swinging the arm **35** from conductive film to conductive film, a wide variety of resistance values may be selectively achieved. The properties of this embodiment of this invention are similar to that shown in Figure 1, except that the ring shape permits the use of a wiping arm type of switching arrangement.

Where a multi-contact non-linear resistor is made in the form of an elongated bar as shown in Figure 1, or a ring as shown in Figures 10, 11, the presence of the intermediate conductive bands **11**, control the effective length of the thermistor or varistor. It has been found that in such structures the width of the band must be subtracted from the actual length between the bands which are being used to give the effective resistor length. In calibrating and manufacturing articles in accordance with the present invention, therefore, it is necessary to take into consideration the effect of the intermediate bands of conductive material.

Referring to Figure 12 there is shown a disk type resistor **38** which is provided with an air gap **39** and a plurality of segments **40** on one face thereof. The conductive segments **40** are selectively engageable by the contact arm **35** which is centrally disposed within a dielectric disk **38**. The lower side of the disk **38** may be provided with a conductive layer (not shown) similar to that illustrated at **24** in Figure 7. A lead **25** may be connected to the conductive layer **24** so that the resistance of the member can be measured from the segments **40** through the resistor to the conductive layer **24**.

It will be evident from the foregoing description that multi-contact non-linear resistor elements may be used in a variety of ways as modulators, control elements, and as variable resistors to increase the usefulness of electric circuits.

Having thus fully described the invention, what is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A non-linear resistor comprising, a disk of material having non-linear electrical characteristics, a plurality of discrete conducting films arranged adjacent to the periphery of the disk, and spaced from each other, an annular conductive film deposited on the opposite flat surface of the disk, and a plurality of conductors secured in conducting relationship to said films.

2. A non-linear resistor comprising, a disk of material having non-linear electrical characteristics, an air gap in said disk from the center thereof to the periphery of the disk, a plurality of discrete conducting strips deposited on one surface of said disk, said strips comprising,

metallic areas having parallel, straight, spaced borders, a conductive film deposited on the opposite flat surface of the disk, and a conductor secured in conducting relationship to each of said strips.

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