

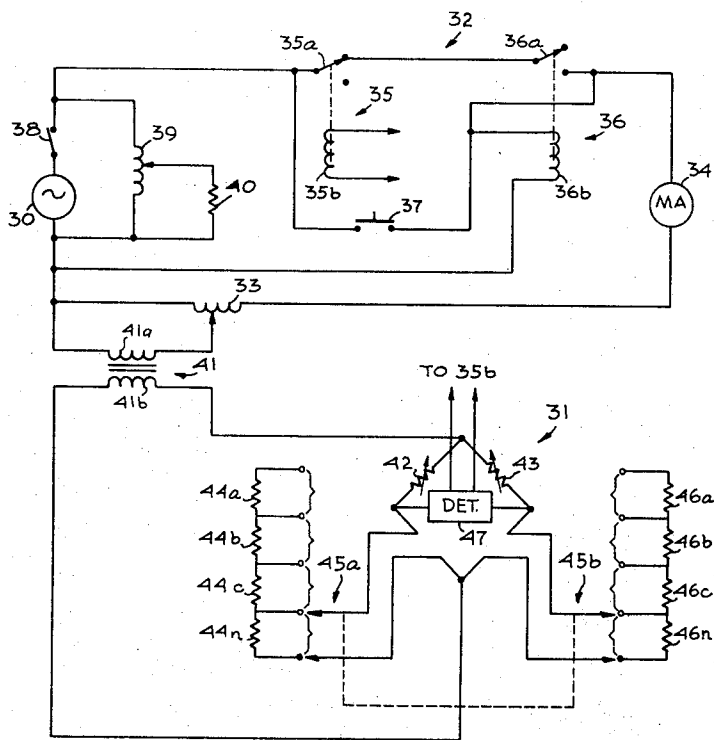
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[21] Appl. No. **852,132**
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Pat. No. 3,457,636
[45] Patented **Sept. 7, 1971**
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[54] **THIN-FILM RESISTOR ADJUSTMENT**
10 Claims, 11 Drawing Figs.

[52] U.S. Cl..... 219/499,
324/62
[51] Int. Cl..... H05b 1/02
[50] Field of Search..... 219/499;
323/75; 374/62 B, 63

ABSTRACT: An apparatus for adjusting the resistance values and temperature coefficients of resistance of thin-film resistors within very close tolerances. The adjustment is achieved through heating of the thin-film resistors to a very high temperature for very short periods of time.



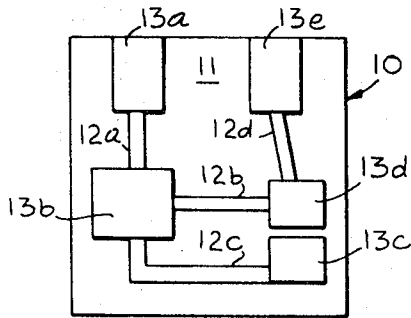


Fig. 1

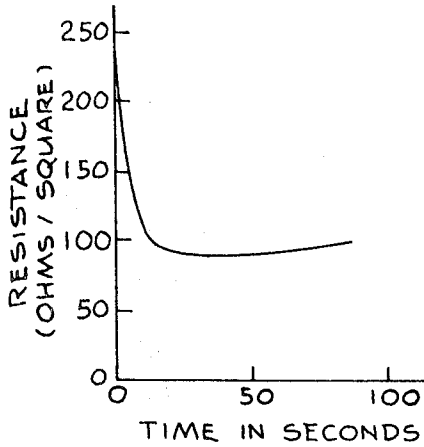
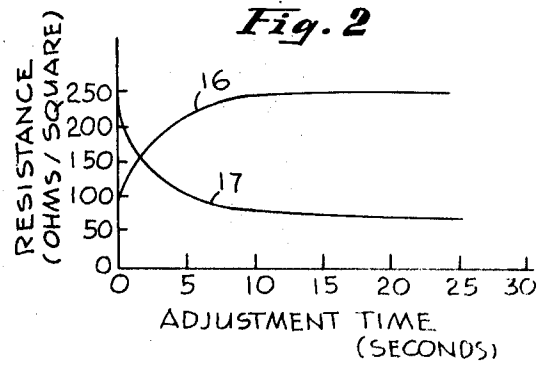


Fig. 3

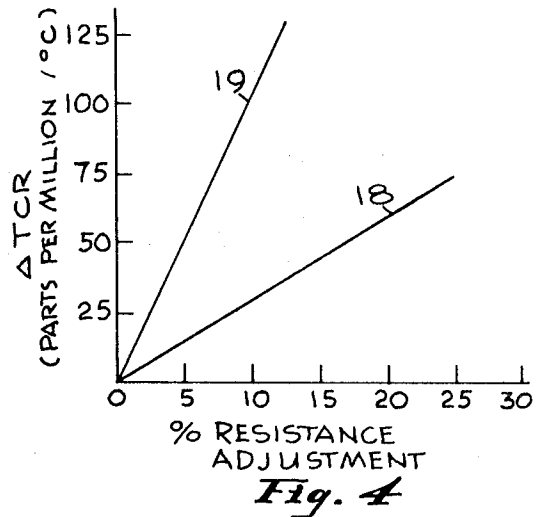


Fig. 4

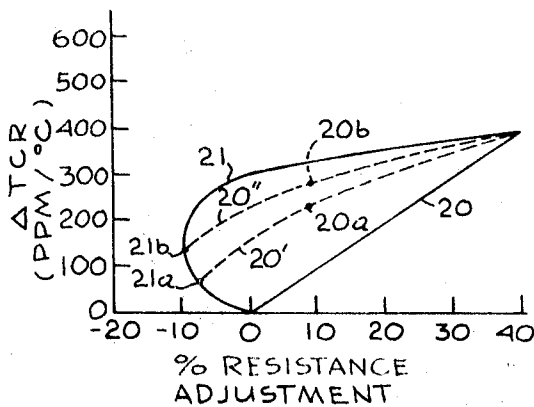


Fig. 5

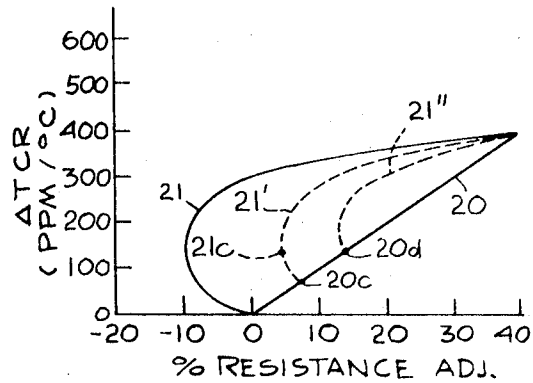


Fig. 6

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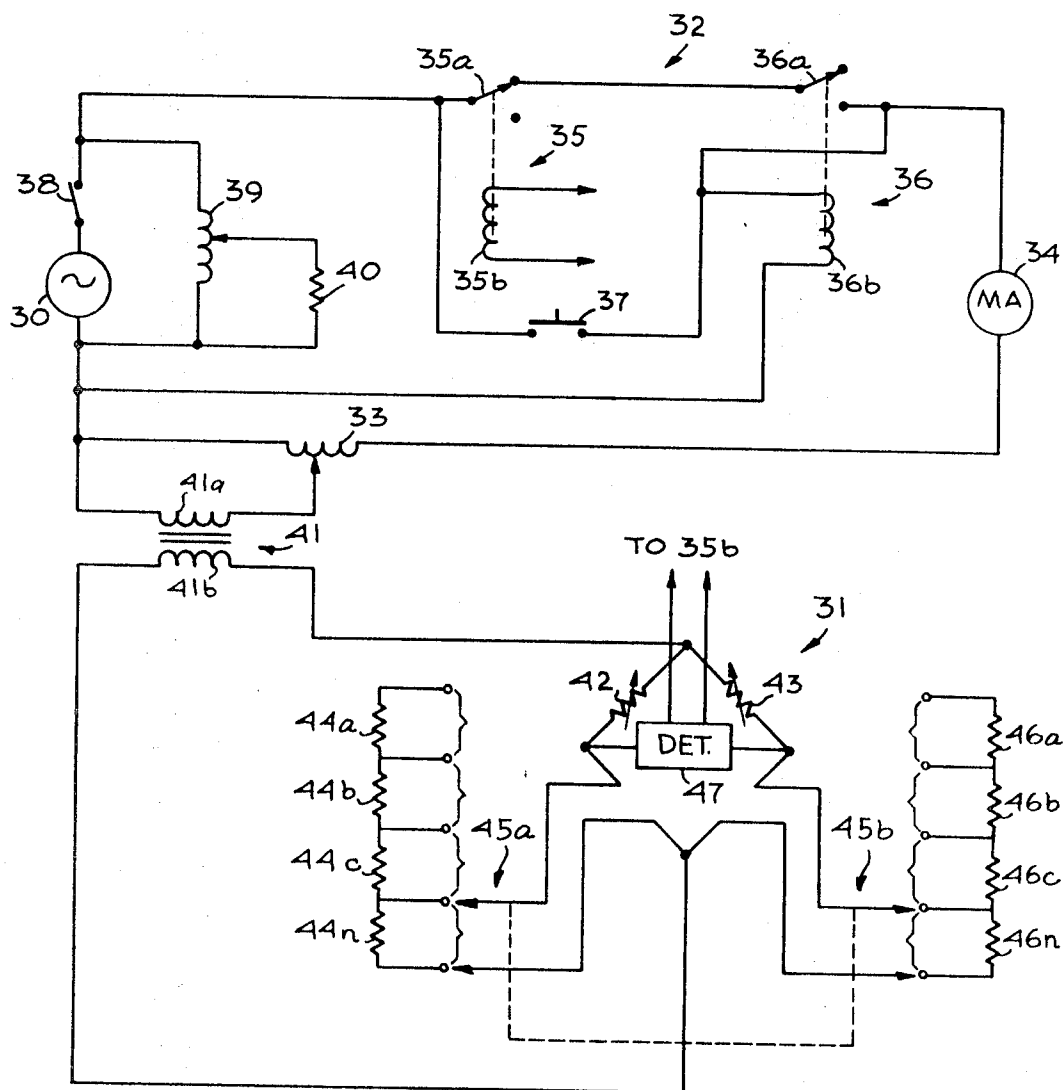


Fig. 7

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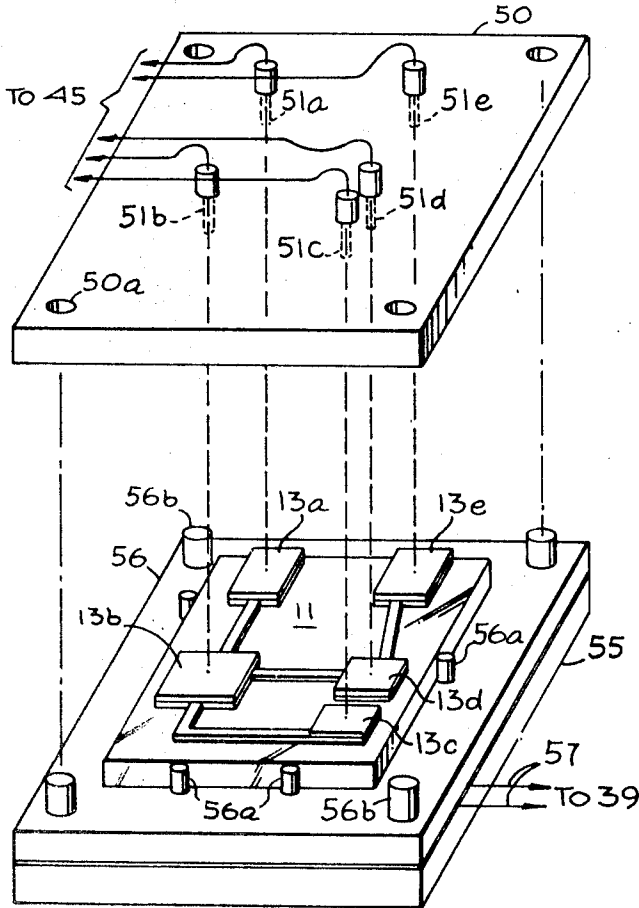


Fig. 9

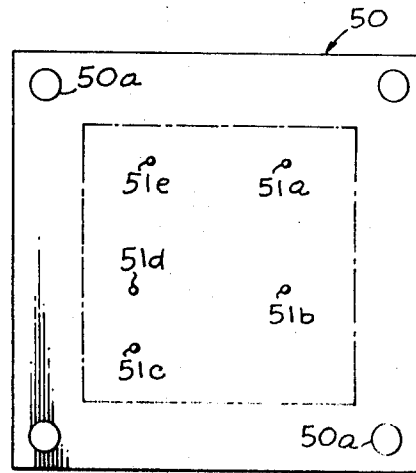


Fig. 8

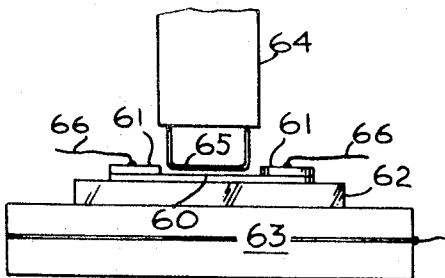


Fig. 10

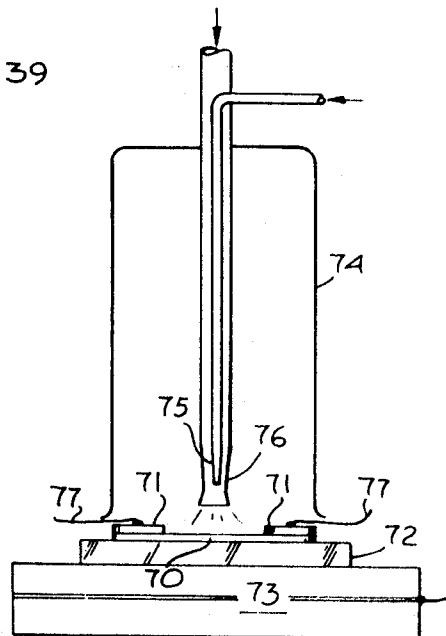


Fig. 11

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THIN-FILM RESISTOR ADJUSTMENT

This application is a division of copending application Ser. No. 410,439, filed Nov. 12, 1964, and now U.S. Pat. No. 3,457,636.

This invention relates to thin-film resistors, and, more particularly, to methods and means for adjusting the resistance values and temperature coefficients of resistance of such resistors.

Thin-film resistors per se are known in the art. Such resistors generally comprise a very thin film of metal coated on a glass or ceramic substrate. Various metals have been used for the resistive film, among them being chromium, Chromel-C (a member of the Nicrome family comprising chromium, nickel and iron) and Cermet (comprising chromium and silicon oxide). Such resistors, as manufactured, do not normally provide better than a ± 5 percent tolerance. This, of course, has imposed severe limitations on circuits requiring more precise resistor tolerances, and has required that the resistors be physically altered to bring them to closer tolerances. Such alteration has generally been accomplished by removing material from the resistor itself by scribing, etching, or cutting, or by the use of shorting bars, that is, conductors deposited across the resistor at points between the end electrodes. Scribing and cutting tend to promote unpredictable aging effects and hence loss of tolerance, and etching is not easily controllable. Shorting bars cannot provide tolerances that are sufficiently close for modern military circuits, say ± 1 percent. Furthermore, such physical alteration does not affect the temperature coefficient of resistance of the resistor in any way.

Recent techniques have led to the development of integral thin-film networks, in which the substrate carries both resistors and conductors. Heretofore, no technique has been available for altering the values of individual resistors in such a multiresistor network except those techniques previously mentioned which involve physically altering each resistor. The present invention eliminates the disadvantages of such techniques and provides methods and means for adjusting the resistance values of thin-film resistors quickly and with a high degree of accuracy. Furthermore, the invention provides a technique whereby the temperature coefficient of resistance of a thin-film resistor may be adjusted independently of the resistance value.

The invention is based on the discovery that the resistance of a thin-film resistor may be adjusted to close tolerance by heating the resistor to a high temperature for a very short period of time. While the resistance of the resistor is being adjusted, the temperature coefficient of resistance (TCR) of the resistor may also be adjusted to very close tolerance. Furthermore, the TCR of the resistor may be adjusted without permanently changing the resistance value of the resistor, or, with a change in resistance value of a predetermined amount.

Each resistor of a multiresistor thin-film network may be individually adjusted utilizing the teachings of the invention. Each resistor may be heated in various ways, such as by passing a relatively high electrical current through the resistor, by bringing a hot probe adjacent it, or by subjecting the resistor to a flow of hot gas. If the resistor is made of an oxidizable metal such as chromium, and the heating is carried out in an oxidizing atmosphere, the resistance value of the resistor will rise as it is heated. It is assumed, of course, that the resistor is uncoated so that it is oxidizable. If an uncoated resistor is heated in an inert atmosphere, its resistance value will decrease initially and then will start to rise with the passage of time. In both cases, the TCR of the resistor increases. If a coated resistor is heated according to the invention, its resistance value will decrease while its TCR will increase. This is believed to be due to annealing of the resistor material.

According to another feature of the invention, an uncoated oxidizable resistor may be heated in inert and oxidizing atmosphere, one after the other, to adjust the TCR of the resistor to a desired value. During that process, the resistance value of the resistor may be adjusted to a predetermined

desired value, or the process may be so carried out as to produce no permanent change in the resistance value of the resistor.

In the event that individual resistors are heated by passing electrical current through them, means are provided for automatically monitoring the resistance value as the resistor is being heated, and for terminating the heating when a desired value has been attained.

The invention, together with further advantages and features thereof, will be better understood from the following description of several embodiments, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a plan view of a simplified multiresistor thin-film network;

FIG. 2 is a graph showing typical resistance adjustments as a function of adjustment time;

FIG. 3 is a graph showing resistance adjustment as a function of adjustment time of a specific thin-film resistance material;

FIG. 4 is a graph showing the change in TCR as a function of resistance adjustment of two specific thin-film resistance materials;

FIGS. 5 and 6 are graphs useful in understanding the simultaneous adjustment of resistance and TCR;

FIG. 7 is a circuit diagram of means for individually adjusting a plurality of resistors by passing electric current through them;

FIG. 8 is a perspective view of a multiprobe head useful in conjunction with the circuit of FIG. 7;

FIG. 9 is a perspective view of an adjustment assembly useful with the circuitry shown in FIG. 7; and

FIGS. 10 and 11 are elevational views of apparatus useful in adjusting resistances according to other embodiments of the invention.

FIG. 1 illustrates a multiresistor thin-film network 10, shown in much simplified form. In actual practice, such networks are usually quite complex and comprise many resistors and conductors. As shown, the network 10 comprises a substrate 11, which carries a plurality of resistors 12a-12d, and a plurality of conductors 13a-13e. The substrate 11 generally consists of glass or glazed ceramic, with glass being used in most instances because of its lower cost and smoother surface.

The resistors 12 may consist of a relatively high-resistance material such as chromium, Chromel-C, or Cermet, the latter two materials also containing chromium. The particular type of resistive material used is dependent upon the desired characteristics of the final resistor, and the present invention is in no way limited to the use of any particular resistive material. Characteristics of three typical resistive materials are shown in Table I. Particular values within the various ranges shown in the table may be obtained by control of the process by means of which the material is deposited on the substrate, as is well known in the art.

TABLE I

Material	Resistance (Ohms/Square)	TCR (parts per million/ $^{\circ}$ C.)
Chromel-C	25 to 500	-25 to +25
Chromium	25 to 500	-250 to 0
Cermet	100 to 10,000	-500 to -50

The conductors 13 generally consist of a very low resistance material such as gold or gold-copper. Here again, however, the invention is not limited to the use of any particular materials for the conductors.

The resistors 12 and the conductors 13 may be deposited on the substrate 11 by any one of various known means. For example, they may be vacuum deposited by evaporation or by sputtering, or they may be plated on the substrate. In addition,

the resistors may be left uncoated or they may be coated with a protective material such as silicon monoxide, depending upon the use to which the network is to be put and the atmosphere in which it will be used. The problem that the present invention solves is that of individually adjusting the resistors 12a-12d quickly and to very close tolerances. As previously mentioned, adjusting the resistors has heretofore been done by physically altering their geometry such as by abrading or etching the individual resistors. Such processes are time consuming and do not provide resistance value tolerances sufficiently low for use in many modern day circuits.

A solution to the foregoing problem is provided by the present invention, which is based upon the discovery that the resistance values of the various resistors of the network can be individually adjusted in a matter of seconds by heating the individual resistors, one at a time, to a high temperature. The heating process may be accomplished either by passing an electrical current through each resistor, by bringing a small heated filament over the resistor, or by applying hot gas directly on the resistor. The specific methods and means used in heating the resistors will be described in detail hereinafter. First, however, the temperature to which each resistor is heated, the period of time for which it is heated, and the result on the characteristics of the resistor will be considered.

It is well known that the resistance value of a thin-film resistor is relatively unstable without further treatment after deposition. This condition, of course, cannot be tolerated in precision circuitry. Therefore, the resistor is aged at an elevated temperature to stabilize its resistance value so that it will undergo very little, if any, change during the life of the resistor. In the present case stabilizing is accomplished by aging the resistor for 18 or 20 hours at a temperature of 250° C. It may conveniently be accomplished by placing the substrate containing the entire network in an oven for the required length of time. During the aging and stabilizing process, the resistance and the TCR of an uncoated resistor increase; during that process the resistance of a silicon-monoxide coated resistor decreases while its TCR increases. Thus, caution must be taken to insure that the initial resistance values are not too high or too low to permit proper stabilizing without the resistance and TCR values exceeding the desired values.

It has been discovered that, after a thin-film resistor has had its resistance value stabilized, its resistance value may be adjusted by further heating the resistor at a more elevated temperature for a short period of time. Although the temperature to which the resistor is heated and the length of time for which it is heated vary inversely with each other (although not proportionally) for a given change in resistance, it is preferred that the resistor be heated at a relatively high temperature for a relatively short period of time. For example, if the resistor is heated to a temperature higher than 300° C. a period of less than 30 seconds is required to change its resistance by the maximum extent possible. FIG. 2 represents curves showing the amount of resistance adjustment possible utilizing the method of the invention. A curve 16 shows the increase in resistance of an uncoated resistor as it is heated for various periods of time, and a curve 17 shows the decrease in resistance of a coated resistor as it is heated for various periods of time. As shown, the resistance value of a resistor may be adjusted by more than 100 percent. However, in practice, resistors are not adjusted by more than about 25 percent of their initial value. In other words, the adjustment takes place on the relatively steep portion of the curves 16 and 17 in a time of 5 seconds or less. FIG. 3 shows an actual curve of resistance versus adjustment time for Chromel-C which was heated by passing current through the resistor.

As previously noted, whether the resistance value of a resistor is adjusted upwardly or downwardly, its TCR always increases. This is shown by FIG. 4, which represents the change in TCR as a function of the percent resistance adjustment for a coated resistor made of Chromel-C and for an uncoated chromium resistor. The increase in TCR for Chromel-C is approximately 3 parts per million (p.p.m.) per degree centigrade

for each 1 percent change in resistance, as shown by a curve 18. The change in TCR for chromium is much greater, as shown by a curve 19, and approximates 10 parts per million per degree centigrade for each 1 percent change in resistance.

One of the outstanding features of the invention is that the TCR of a resistor may be adjusted independently of adjustment of the resistance value of the resistor. This is shown graphically by the curves presented in FIGS. 5 and 6. These figures are based on data derived from heating uncoated chromium resistors in oxidizing and in inert atmospheres. Looking first at FIG. 5, a curve 20 represents the change in TCR versus the percent resistance adjustment of the chromium resistor when it is heated to a temperature in the range of 425° C. to 450° C. in an oxidizing atmosphere. Similarly, a curve 21 represents the change in TCR versus percent resistance adjustment when the resistor is heated in an inert atmosphere. It is apparent from the curve 21 that the resistance value of the resistor first decreases and then increases as the TCR increases with continued heating of the resistor. By combining the effects of heating in inert and oxidizing atmospheres, various changes in TCR and resistance can be obtained simultaneously. For example, if it is desired to increase the resistance value of a resistor by approximately 9 percent and increase its TCR by approximately 225 parts per million, the resistor could first be heated in an inert atmosphere until its characteristics correspond to those indicated at point 21a and then could be heated in an oxidizing atmosphere until the desired characteristics are obtained at point 20a on curve 20'. Similarly, if it is desired to adjust the resistance upwardly by approximately 10 percent and the TCR upwardly by approximately 280 parts per million, the resistor could be heated in an inert atmosphere until its characteristics are as indicated at point 21b, and then heated in an oxidizing atmosphere until its characteristics reached their desired values at point 20b on curve 20'. Of course, the resistor could be entirely adjusted in an inert atmosphere or in an oxidizing atmosphere if the desired characteristics could be obtained in that manner.

FIG. 6 represents a situation which is the reverse of that shown in FIG. 5, in that a resistor is first adjusted in an oxidizing atmosphere so that its characteristics follow along the curve 20 and is then further adjusted in an inert atmosphere. For example, if it is desired to increase the TCR of a resistor by approximately 130 parts per million and increase its resistance by approximately 5 percent, the resistor might first be heated in an oxidizing atmosphere until its characteristics correspond to those at point 20c on the curve 20 and then further heated in an inert atmosphere until its characteristics are as represented by the point 21c on curve 21'. If it is desired to increase the TCR and resistance of the resistor by a greater amount, it might be treated in an oxidizing atmosphere until its characteristics correspond to the point 20d, after which it would be treated in an inert atmosphere until its characteristics corresponded to the desired point on curve 21'.

It is understood, of course, that the particular curves presented in FIGS. 5 and 6 are merely representative ones and that many other changes in TCR and resistance value can be obtained by sequentially heating a resistor in inert and oxidizing atmosphere, one after the other.

As was previously mentioned, heating of a resistor to the desired temperature range of 425° C. to 450° C. may be accomplished by passing electrical current through the resistor, by bringing a hot probe adjacent to the resistor, or by directing hot gases against the resistor. FIG. 7 is a circuit diagram of means for individually adjusting a plurality of resistors by passing electrical current through them. Although direct current can be used for heating a thin-film resistor in accordance with the invention, it has been found that alternating current is preferable. Therefore, power is supplied to the circuitry shown in FIG. 7 by an alternating current source 30, which may be a conventional 60-cycle, 110-volt supply.

Essentially, the circuitry shown in FIG. 7 comprises a bridge arrangement, indicated generally by the numeral 31, and means for selectively energizing and deenergizing the bridge

arrangement, such means being indicated generally by the numeral 32.

Consider first the means 32 for selectively energizing and deenergizing the bridge arrangement 31. The means 32 comprise an autotransformer 33 connected in series with a milliammeter 34 across the alternating current source 30 through a normally closed contact 35a of a relay 35, a normally open contact 36a of a relay 36, and a line switch 38. Relay 35 has a coil 35b which is energized from the bridge arrangement 31 in a manner to be hereinafter described, and the relay 36 has a coil 36b which is connected across the alternating current source 30 through a momentary contact switch 37 and through the line switch 38. Also connected across the alternating current source 30 is an autotransformer 39, between whose movable arm and one end is connected a resistance heater shown as a resistor 40, the purpose of which will be later described. A primary winding 41a of a transformer 41 is connected between the movable arm and one end of the autotransformer 33 and power for the bridge arrangement 31 is derived from a secondary winding 41b of the transformer 41.

The bridge arrangement 31 comprises a Wheatstone bridge having four arms, two adjacent arms of which comprise variable resistors 42 and 43. The other two arms of the bridge arrangement 31 are adapted to have resistors to be tested and standard wire-wound resistors, respectively, sequentially switched into them. As shown, a plurality of resistors 44a—44n, whose resistance values are to be adjusted, are respectively connected between pairs of contacts of a first section 45a of two-section stepping switch. A second section 45b of the stepping switch, which is mechanically connected to the first section 45a, has connected between its plurality of pairs of contacts a plurality of standard resistors 46a—46n. Each section of the switch is provided with a pair of poles which may be sequentially moved between the various pairs of contacts. The resistors 44 to be adjusted and the standard resistors 46 are so arranged with respect to each other that when a switch is positioned to put, for example, the resistor 44n into the Wheatstone bridge, the standard resistor 46n is placed in the adjacent arm of the bridge. The standard resistor, of course, represents the resistance value to which the resistor 44 is to be adjusted.

The bridge 31 is energized from the transformer 41 by connecting points between the variable resistors 42 and 43 and between the resistors 44 and 46 to opposite ends of the secondary winding 41b of the transformer. Detector means 47, such as a null detector or a phase detector, is connected between the other two juncture points of the bridge. The detector means 47 functions to provide an output signal when the bridge 31 is balanced. The output signal of the detector means 47 is connected to energize the coil 35b of the relay 35 in the energizing section 32.

To operate the adjusting means shown in FIG. 7, the line switch 38 is first closed and then the momentary contact switch 37 is closed. This energizes the coil 36b of the relay 36, which in turn closes the normally open contact 36a, which energizes the autotransformer 33 and the transformer 41. When the contact 36a is closed, power is supplied to the relay coil 36b until the contact of 35a of relay 35 opens. It is assumed, of course, that the resistors 44 to be adjusted and the standard resistors 46 have been properly connected into the stepping switch 45 and the switch set to a desired position before the circuit is energized.

Current from the secondary winding 41b of the transformer 41 flows through the bridge arrangement 31, including a resistor to be adjusted, and a standard resistor. The current flowing through the resistor to be adjusted heats the resistor to be adjusted so that its resistance value and TCR are varied in the manner heretofore described. The amount of current flowing through the resistor to be adjusted is controlled by the setting of the autotransformer 33. An indication of that current is provided by the milliammeter 34 in series with the autotransformer 33.

When the resistance value of the resistor 44 being adjusted has reached that of the standard resistor 46 to which it is being compared, the detector means 47 provides an output which energizes the coil 35b of the relay 35. This, in turn, opens the normally closed contact 35a of the relay and deenergizes the circuit. The stepping switch 45 may then be advanced to the next position and another resistor adjusted in the manner previously described. The process is thus continued until all of the resistors 44 have been adjusted. The standard resistors 46 are much larger physically than the resistors 44. Thus they easily dissipate the heat caused by the current flowing through them and their values remain unchanged.

It is pointed out that resistor adjustment using circuitry such as shown in FIG. 7 may be carried out in either an inert or an oxidizing atmosphere in the manner heretofore described.

One of the features of the present invention is that the circuitry shown in FIG. 7 can be used to individually adjust each resistor in a multiresistor thin-film network of the type shown in FIG. 1. Electrical contact may be made with the resistors on a substrate by using a multiple-probe fixture such as is shown in FIG. 8, which is designed for the particular resistor configuration on the substrate. The multiple-probe fixture may comprise a plate of insulating material 50 having a plurality of spring-loaded electrical probes 51a—51e extending through holes in the plate. The probes 51 are so arranged that when the fixture is placed in contact with a substrate bearing a multiresistor network, each of the probes contacts one of the conductors. The probes are so arranged in the fixture shown in FIG. 8 that if it is used to test the network shown in FIG. 1, the probes 51a through 51e respectively contact the conductors 13a through 13e on the substrate. The probes are electrically connected to the contacts of the switch section 45a of the switch 45 shown in FIG. 7. It is particularly pointed out that a fixture must be specially designed for each substrate network configuration. The plate 50 also has a plurality of apertures 50a therein which are used for registration purposes as will be later described.

FIG. 9 illustrates an adjustment assembly utilizing the multiple-probe fixture 50 previously described with reference to FIG. 8. The assembly comprises a base 55 made of a suitable material on which is mounted a substrate holder and heater 56. The substrate holder and heater 56 may consist of a stainless steel plate which is heated by an electrically insulated nichrome ribbon. The heater ribbon is not shown but conductors thereto are indicated by the numeral 57. The conductors 57 are connected to the autotransformer 39 shown in FIG. 7, wherein the heater ribbon is represented by the resistor 40.

It has been found desirable to heat the substrate during the resistor adjustment process to reduce thermal stress in the substrate and also to aid in the adjustment itself. Also, by heating the substrate, a lower current through the resistor under adjustment may be used to achieve a given rate of adjustment. Typical temperatures for the substrate holder and heater 56 for various resistor material configurations are shown in Table II.

TABLE II

Material	Heater Temp.
Silicon oxide coated Chromel-C	200°–225° C.
Silicon oxide coated Cermet	200°–225° C.
Silicon oxide coated chromium	200°–225° C.
Uncoated chromium	140°–160° C.

The substrate holder and heater 56 is provided with a plurality of pins 56a extending from its upper surface which define the position of the substrate 11 and between which the substrate fits. The substrate holder and heater 50 is also provided with a second plurality of pins 56b, which fit into the openings 50a in the multiple-probe fixture 50 to insure proper

registration of the probes 51b with the conductors on the substrate 11. After the substrate is properly positioned on the holder and heater 56, the multiple-probe fixture 50 is lowered into position so that the electrical probes 51b engage the conductors of the multiresistor network carried by the substrate. The fixture 50 may be held in position, while the adjustment of the resistor proceeds, by conventional means such as springs, weights or clamps.

Table III presents data relating to six typical resistors whose resistance values were adjusted by passing electrical current through the resistors. All of the resistors were adjusted in an oxidizing atmosphere so that the resistance values of the uncoated resistors increased. The data relating to the power in watts per square inch dissipated by the resistor being adjusted relates to the power dissipation at the beginning of the adjustment period. Of course, assuming that the voltage across the resistor is maintained constant, as the resistance value increases, the power dissipated decreases. Conversely, if the resistance value is adjusted downwardly, as in the case of a coated resistor, the power dissipation increases during the adjustment process.

TABLE III

Material	Resistance, Ω		Adjustment time, sec.	Power in watts/sq. inch
	Before	After		
Uncoated chromium	1,927	2,156	13	570
Do	1,943	2,151	5	615
Do	975	1,095	15	570
Coated cement	72	59	4	990
Do	8,250	8,190	3	407
Coated Chromel C	1,950	1,879	2	565

As was previously mentioned, each resistor of a multiresistor thin-film network may be heated by means other than by passing electrical current through it. FIG. 10 illustrates, in diagrammatic form, an arrangement whereby a resistor 60 having end conductors 61 is adjusted by means of radiant heat. The resistor 60 is carried on a substrate 62 which is mounted on a heated holder 63. The resistor is heated for adjustment by bringing a probe 64 having a heating element 65 adjacent the surface of the resistor. The heating element 65 may conveniently be a nicrome wire which is heated to a temperature of 900°-1,000° C. by passing electrical current through it. The heating element is brought to within an approximately 0.01 inches of the resistor surface to effect the adjustment. During the adjustment process, the resistance value of the resistor 60 may be monitored by an ohmmeter (not shown) connected between the end conductors 61 by means of leads 66. Of course, when the resistance value has reached the desired value the probe and heating element are removed from the vicinity of the resistor. Again, as with the electrical adjustment method previously described, the holder 63 on which the substrate is mounted is heated to reduce the stress in the substrate and aid in the adjustment process.

Table IV presents data for four typical uncoated chromium resistors which have been adjusted by means of radiant heat as shown in FIG. 10. The data relating to TCR is in parts per million per degree centigrade change in temperature.

TABLE IV

Before Adjustment		After Adjustment	
Resistance	TCR	Resistance	TCR
6,733 Ω	-460	10,000 Ω	-66.5
6,759 Ω	-450	10,000 Ω	-66.5
2,496 Ω	-448	3,317 Ω	-184
6,881 Ω	-435	10,010 Ω	-68

FIG. 11 illustrates diagrammatically still another method for adjusting the resistance value of a thin-film resistor. As shown,

a thin-film resistor 70 having end conductors 71 is carried by substrate 72. During the adjustment procedure, the substrate 72 is mounted on a heated holder 73 as in the methods previously discussed. This embodiment differs from those previously described, however, in that hot gases are directed against the resistor to heat it to the proper temperature for adjustment. A cylinder 74 of glass or other appropriate material is placed about the resistor 70 with sufficient space being left between the bottom of the cylinder and the top of the substrate 72 for gas to escape freely. Hot gas is directed against the surface of the resistor 70 through nozzles 75 and 76. One of the nozzles 75 and 76 may be connected to a source of hot inert gas, such as hydrogen, helium, argon or neon, and the other nozzle may be connected to a source of hot oxidizing gas such as air. Thus, the resistance value of the resistor 70 may be adjusted in either an inert or an oxidizing atmosphere or in both, one after the other, as previously described. The resistance value may be monitored during the adjustment process by means of an ohmmeter (not shown) connected between leads 77 which are electrically connected to the end conductors 71.

It is now apparent that the invention provides methods and means for quickly and accurately adjusting the values of resistors in an integral thin-film network. Each resistor in the network has its resistance value adjusted independently of all other resistors in the network. Resistors so adjusted have been found to maintain their resistance values to better than ± 0.1 percent after thousands of hours of use. Furthermore, the TCR of a resistor may be adjusted without permanently altering the resistance value. It is pointed out that various parameters of the adjustment process may be determined empirically to fit different situations without departing from the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for automatically adjusting the impedance value of a heat-adjustable impedance, said apparatus comprising in combination:

impedance bridge means to which said heat-adjustable impedance is electrically connected so as to permit Measurement of the impedance thereof

power source means for energizing said bridge means and for heating said heat-adjustable impedance so as to cause its impedance value to vary in a predetermined manner, detector means coupled to said bridge means for detecting when said heat-adjustable impedance reaches a desired predetermined value and for providing an output indication in response thereto, and

means coupled to said power source means and to said detector means for terminating the heating of said heat-adjustable impedance in response to the occurrence of said output indication.

2. The invention in accordance with claim 1, wherein said heat-adjustable impedance is a thin-film resistor supported on a substrate, and wherein said apparatus includes electrical probes for electrically connecting said resistor to said bridge means.

3. The invention in accordance with claim 2, wherein said apparatus includes means for heating said substrate during adjustment of said resistor.

4. The invention in accordance with claim 2, wherein the heating of said resistor is obtained as a result of the current flowing therein when said bridge means is energized by said power source means.

5. The invention in accordance with claim 4, wherein the heating of said resistor is terminated by interrupting the flow of current therein.

6. The invention in accordance with claim 5, wherein said power source means supplies an alternating current to said bridge means.

7. The invention in accordance with claim 5, wherein said apparatus includes means for selectively energizing and deenergizing said bridge means, and wherein the deenergizing of said bridge means is caused to

occur in response to the occurrence of said output indication.

8. The invention in accordance with claim 2,

wherein said apparatus is constructed and arranged for automatically adjusting the resistance value of each of a plurality of heat-adjustable thin-film resistors supported on a common substrate, and

wherein said apparatus includes automatically operating switch means for successively connecting each of said re-

sistors to said bridge means for adjustment thereof.

9. The invention in accordance with claim 8, wherein the heating of each resistor when connected to said bridge means is obtained as a result of the current flowing therein when said bridge means is energized by said power source means.

10. The invention in accordance with claim 9, wherein said apparatus also includes means for heating said substrate during adjustment of said resistors.

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