United States Patent

[11] 3,571,778

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[21] Appl. No. 741,410
[22] Filed July 1, 1968
[45] Patented Mar. 23, 1971
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[54] OHMIC STANDARD APPARATUS

6 Claims, 5 Drawing Figs.

[52] U.S. Cl. 338/200
[51] Int. Cl. H01c 1/16
[50] Field of Search 338/134, 131, 128, 129, 200, 130, 132, 191, 198, 231; 200/11 (C), 11 (D)

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ABSTRACT: An ohmic standard apparatus having five rocker arm type switches and four resistors associated with each switch. The switches provide a digital readout of the total resistance for resistance settings from 0 to 99,999 ohms. A slide wire type resistor is interconnected with the resistors to provide resistance settings up to 100,000 ohms.

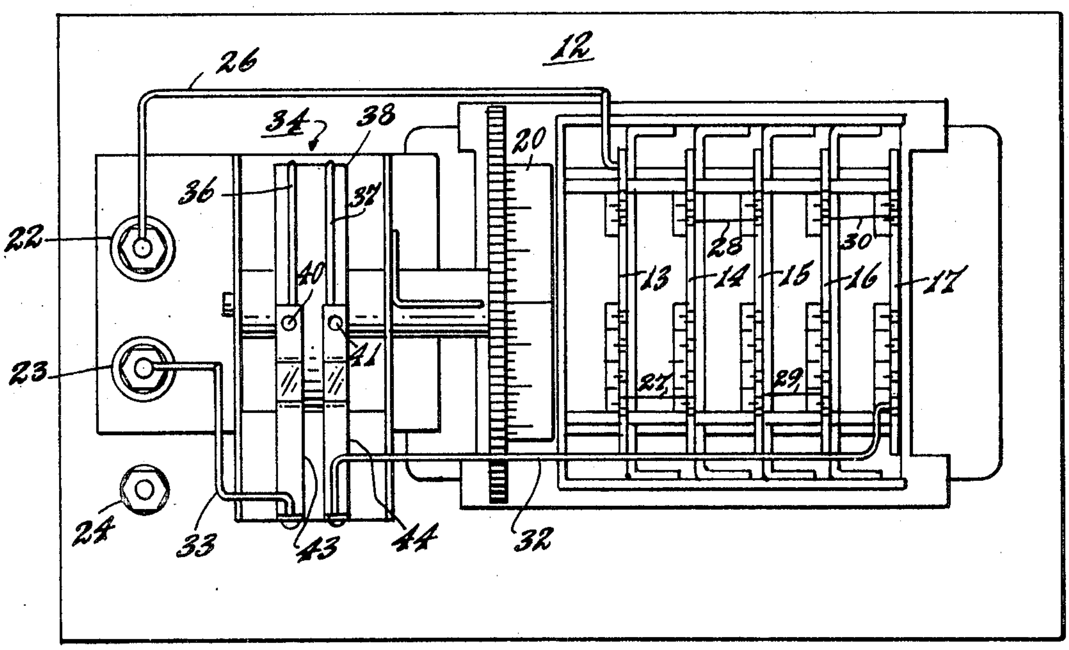

Fig. 1.

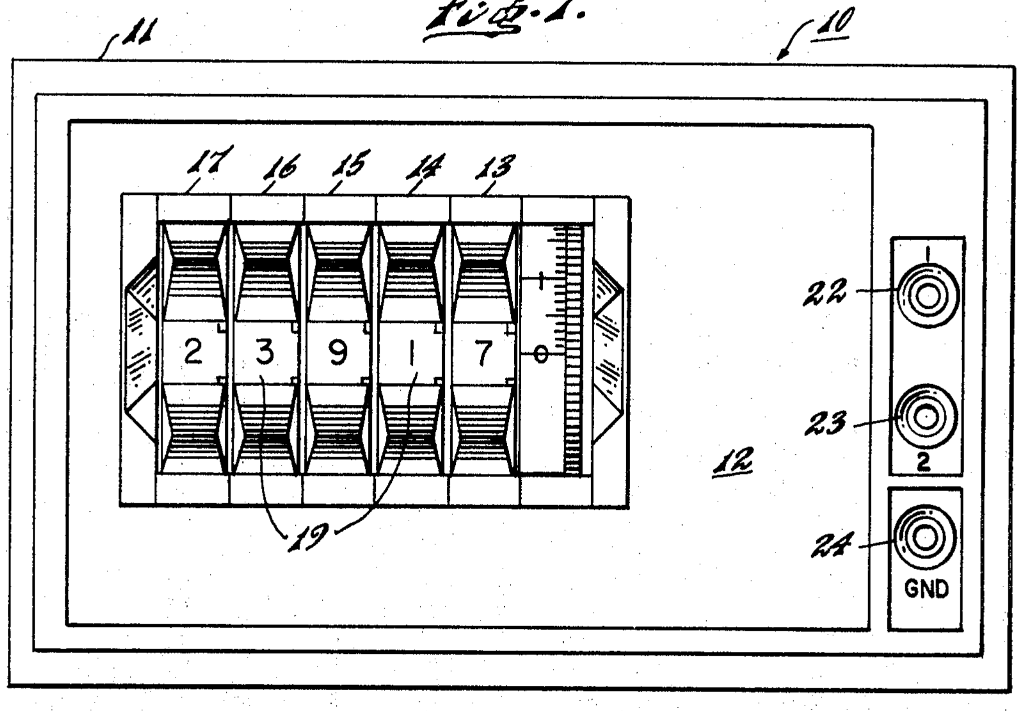

Fig. 2.

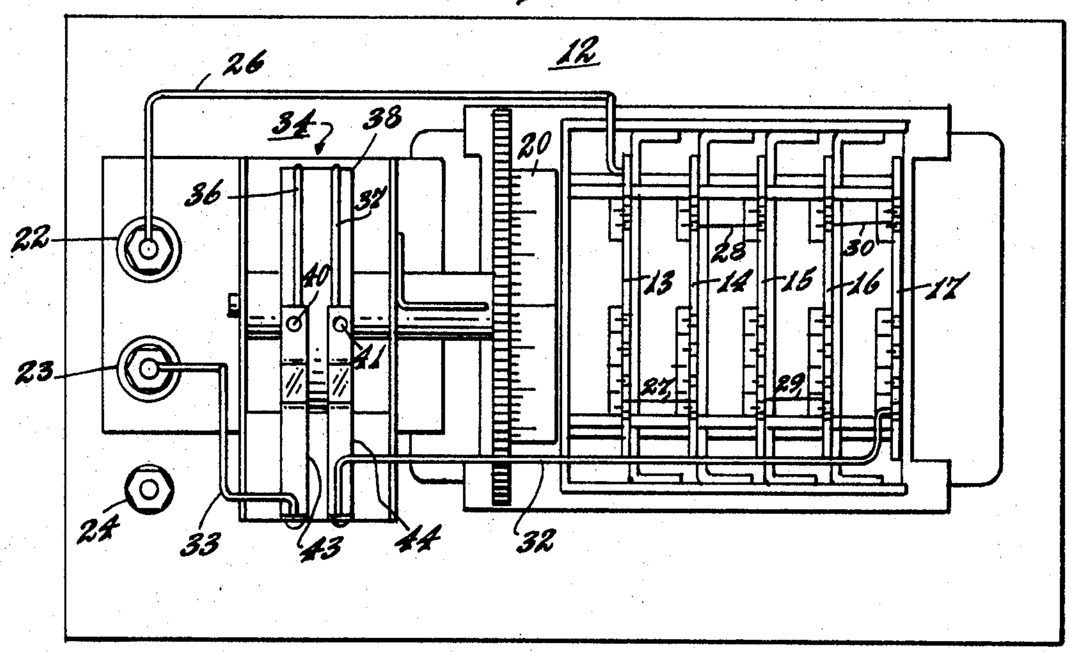

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Fig. 3.

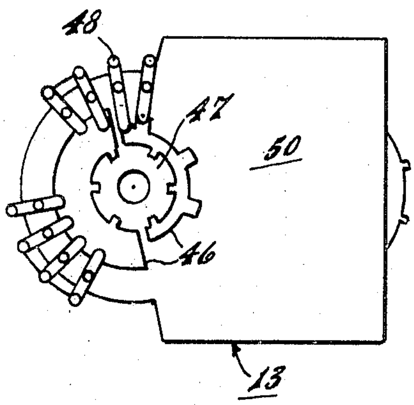


Fig. 4.

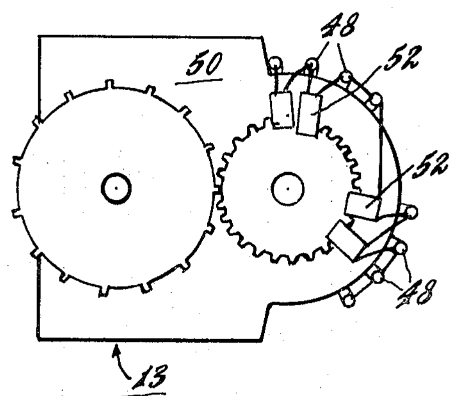
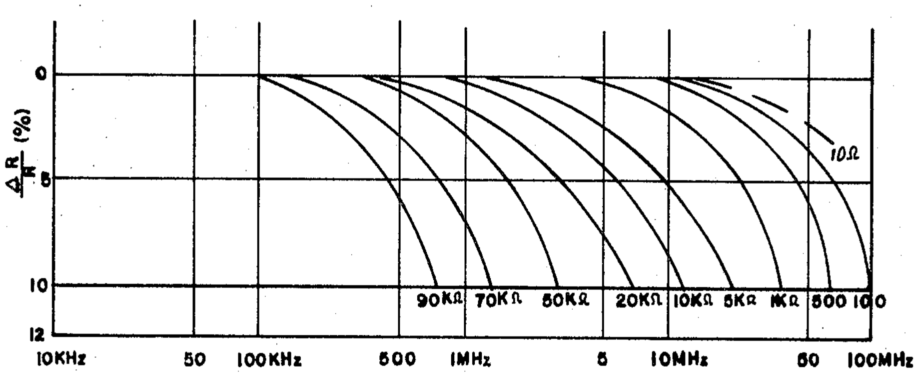


Fig. 5.



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OHMIC STANDARD APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to the commonly assigned applications of Felix Zandman and Branin A. Boyd, Ser. No. 453,098, filed May 4, 1965 (now Pat. No. 3,405,381) and John P. Smith Jr., Ser. No. 741,409 filed concurrently herewith (now Pat. No. 3,474,375).

BACKGROUND OF THE INVENTION

The present invention relates to ohmic standard apparatus and more particularly, to ohmic standard apparatus of extremely high accuracy, stability and versatility.

Conventionally, separate standard resistors, each having a single value, are employed for precise resistance measurements. A single laboratory standard resistor may be 1½to 3 inches in diameter and may be several inches in height. A laboratory set of such resistors could consist of several carefully chosen resistors having values in the fraction of an ohm range, several carefully chosen resistors having values in the unit ohm range, several carefully chosen resistors having values in the unit ohm range, several carefully chosen resistors having values in the range of tens of ohms, etc. Thus, in the past it has been necessary to have several shelves full of individual resistors in order to make precise resistance determinations. The use of these standard resistors, each having a single value, necessitates difficult and time consuming interconnections.

For applications in which the accuracy of standard resistors are not required resistance decade boxes have been used. Virtually all available conventional and specialized resistance decade boxes are subject to such art recognized problems as:

a. lack of instrument accuracy;

b. resistance shifts caused by load;

c. changes with temperature, moisture, or the pressure of surrounding media (e.g., atmospheric pressure); and

d. difficulty in the measurement of final digits.

The last problem is of particular importance since it constitutes an inherent limitation with resistance decade box performance as to usable frequency, size and ease of setting. The conventional approach to the performance of resistance decade boxes centers on the accuracy of discrete resistors (usually, inductive resistors) used in the boxes. This approach creates considerable confusion since the user has to add or subtract compensation values which often differ with various ranges of resistance values.

SUMMARY OF THE INVENTION

An object of the present invention is to provide ohmic standard apparatus having an unequalled combination of performance parameters, including accuracy, stability and versatility.

Another object of the present invention is to provide apparatus combining in a compact unitary structure, extreme reliability for precise resistance determinations to many significant figures with the flexibility, speed of use and convenience for changes of resistance values comparable to those afforded (without extreme accuracy) by resistance decade boxes.

Still another object of the present invention is to provide ohmic standard apparatus which has virtually infinite resolution in resistance settings up to 100,000 ohms.

Yet another object of the present invention is to provide ohmic standard apparatus in which changes of total resistance can be made simply and in which these changes can be read directly from the apparatus.

In accordance with the present invention, ohmic standard apparatus having noninductive precision resistors are connected to compact rocker-arm type switches which are arranged for digital readout of total resistance for resistance settings from 0 to 99,999 ohms. As an integral part of such apparatus a slide wire type resistor is interconnected with the aforementioned noninductive precision resistors to provide infinite resistance settings up to 100,000 ohms. The slide wire type resistor is interconnected to a vernier dial which is marked in 0.01 ohm divisions.

Thus, the ohmic standard apparatus of the present invention overcomes the bulk and interconnection problems of standard resistors. Moreover, the ohmic standard apparatus of this invention has the convenience of operation of conventional resistance decade equipment while retaining the accuracy of standard resistors.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, as well as its objects, advantages, features and aspects, will be more readily understood from the following detailed description thereof, when considered in conjunction with the drawings, in which:

FIG. 1 is a plan view which illustrates the faceplate of one embodiment of the present invention;

FIG. 2 illustrates the interconnection of the circuitry, resistors and switches which is mounted on the back of the faceplate shown in FIG. 1;

FIGS. 3 and 4 are fragmentary views illustrating opposite sides of the rocker actuated resistance switches shown in FIGS. 1 and 2; and

FIG. 5 is a graph showing the deviation from various resistance values at various frequencies.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and particularly to FIG. 1, ohmic standard apparatus **10** is shown housed in a sturdy insulated case **11**. The faceplate **12** of the apparatus contains five ten-position rocker actuated switches, respectively **13, 14, 15, 16** and **17**, having direct numeric readout **19** of total resistance values ranging from 1 to 99,999 ohms. In addition, the embodiment illustrated by FIG. **1** has a vernier dial **20** mounted on faceplate **12** and marked with 0.01 ohm divisions. Thus, the combination of switches **13** through **17** and dial **20** on apparatus **10** permit resistance values to be set (as described below) and read in 0.01 ohm divisions up to 100,000 ohms. Faceplate **12** is also provided with terminals **22** and **23**. A third terminal **24** can be provided, as required, for grounding.

Referring to FIG. 2, the interconnection of the circuitry, resistors and switches mounted to the back of faceplate **12** is shown. The circuitry comprises interconnection **26** between terminal **22** and switch **13**; interconnections **27, 28, 29** and **30** between switches **13, 14, 15, 16** and **17**; interconnection **32** between switch **17** and a slide wire type resistor **34**; and interconnection **33** between resistor **34** and terminal **23**. Resistor **34** comprises two wires **36** and **37** interconnected at one end and mounted on drum **38**. Movement of dial **20** turns drum **38** thereby increasing or decreasing the length of wires **36** and **37** in relation to pressure contacts **40** and **41**. Thus, resistor **34** is a slide wire type rheostat in which its resistance value is determined by the total length of wires **36** and **37** between contacts **40** and **41**. Contacts **40** and **41** are connected through conductive strips **43** and **44** with interconnections **32** and **33**.

The rocker actuated switches **13, 14, 15, 16** and **17** have bidirectional operation. Switch **13**, illustrated in FIG. **3**, is a typical example of these switches. Relatively large switch pads **46–46**, mounted on a rotating insulator **47**, are provided on one side of switch **13** to assure uniformly low switch resistance. Preferably, pads **46–46** are gold plated to maintain contact resistance at a minimum. Actuation of switch **13** rotates pads **46–46**, thereby bringing varying contact arms **48–48**, attached to stationary insulator **50**, into contact with pads **46–46**. Leakage is virtually eliminated through the use of insulators **47** and **50**.

As illustrated in FIG. **4**, the contact arms **48–48** shown in FIG. **3** are connected with noninductive precision resistors **52–52**. Examples of noninductive precision resistors which can be used are those described in the aforementioned Zandman et al. and Smith applications, which are hereby incorporated by reference. In accordance with the Zandman et al.

application, a high-precision resistor is constructed by supporting a thin film of a selected metal alloy upon a substrate having known physical properties, the substrate being many times thicker than the metallic film (preferably, of the order of 100 to 1,000 times thicker). The metallic film is caused to have a predetermined pattern, such that electric current flows along a conducting path of very great length and extremely small width, this pattern preferably including a great number of parallel narrow linear path portions in a planar array. The side of the substrate having thereon the resistor film of predetermined pattern is coated with an epoxy resin, and the opposite side of the substrate is similarly coated to equal thickness with epoxy resin of the same kind. These oppositely disposed coatings of epoxy resin provide symmetry with respect to their mechanical effects upon the substrate, so as to avoid any tendency to cause bending thereof. Similar balance can be obtained with unequal coatings of different characteristics. Moreover, the epoxy resin on the conductive layer reinforces the resistive path and protects it from mechanical damage, and also protects it from any skin acids which might otherwise reach it in the course of being handled.

In one embodiment, a resistor of the Zandman et al. application comprises a substrate having an etched-pattern resistor layer of bulk metal film fixed to one surface thereof. Coatings of a hard epoxy resin are applied to the resistor surface and the opposite surface of the substrate. The two opposite epoxy coatings are so related to each other as to result in a sandwich which does not bend or warp as a consequence of changes of temperature or moisture absorption by the coatings.

The substrate may be made of glass having a temperature coefficient of expansion of the order of 3 parts per million per degree F. In an illustrative resistor unit, the substrate may be of the order of one-fourth inch by one-fourth inch with a thickness of 0.04 inch.

The bulk metal film may be made from a resistive alloy such as one of the Nichrome alloys, wherein nickel and chromium are the principal metals. This film may be of the order of 0.0001 inch thick.

The metallic film is photoetched to a pattern which establishes a narrow conductive path of much greater total length that the dimensions of the face of the substrate. This step may be carried out after the film has been bonded to the substrate as by the layer of plastic thereunder, or it may be carried out when the metallic film is on a thin support such as a plastic layer but before being bonded to the substrate. To perform the photoetching, the face of the thin alloy film opposite the plastic layer is covered with a photosensitive masking medium such as Kodak Photo-Resist (KPR). By means of a photographic exposure and development, the KPR is retained in contact with the surface of the film only in the desired resistor pattern and is removed from those portions where the alloy film is to be etched away. An etching process is then used to remove the exposed portions of the thin alloy film.

The pattern in which the film is exposed and etched may include several wider portions and portions of shorter lengths, so that an operator is enabled to complete the steps of bringing about the desired resistance value with the inclusion of one or more of the lower-resistance increments as may be needed.

With the alloy film etched in the desired pattern and bonded to one surface of the substrate as by a suitable epoxy bonding cement, further epoxy material is added, covering the surface of the metal film. This precedes the adjusting of the resistance by cutting, referred to above. As the cut is being made through the outermost plastic and at least part way through the alloy film, either with a stylus or with an abrasive cutter or other tool, the plastic holds the film in position along the boundaries of the cut and resists any tendency for the film to be detached from the substrate.

The upper protective epoxy coating may have a total thickness of 0.001 inch. There is also applied to the opposite face of the substrate a further epoxy coating. The epoxy coatings may be of equal thickness and identical characteristics in order that the stress contributions which they make to the flat surfaces of the glass substrate shall be balanced, and shall not tend to cause bending or warping of the glass substrate. Along with this elimination of bending, any tendency toward longterm dimensional instability due to stress relaxation is substantially overcome. Alternatively, the same result can be obtained by coatings of different material characteristics provided that their thicknesses are properly related.

The glass substrate has a temperature coefficient of expansion of the order of 3 parts per million per degree F. The epoxy or other plastic coatings on top and bottom of the glass substrate have a much higher temperature coefficient of expansion, of the order of 40 parts per million per degree F. Furthermore, said epoxy coatings tend to expand or contract as their moisture content varies. Hence, the balanced application of the epoxy or other plastic to both sides prevents it from causing bending of the device.

The modulus of elasticity of the glass substrate is many times higher than that 10 the epoxy material. Hence, the expansion and contraction of the unit in length and width are determined mainly by the temperature coefficient of expansion of the glass. Inasmuch as the total thickness of the epoxy layers in the described embodiment is of the order of one-twentieth the thickness of the glass substrate, and the modulus of elasticity of the epoxy is of the order of one-thirtieth of the modulus of elasticity of the glass substrate, the tendency of the epoxy to expand with temperature by a factor of 10 times greater than the expansion of the glass is made comparatively small by the relative thinness of the epoxy material and its far lower modulus of elasticity.

The resistive alloy film, etched in its predetermined pattern and bonded to the glass substrate, being of the order of one hundredth to one thousandth the thickness of the glass, exerts minimal influence upon the dimensional responsiveness of the unit to the changes of temperature and moisture.

By the selection of a nickel chromium alloy with such minor alloy components as to provide a desired curve of resistivity versus temperature and a desired temperature coefficient of expansion, the resistor may be made to have a reliable temperature coefficient of resistivity as low as 1 part per million per degree C. in the vicinity of a desired design temperature such as 25° C., and to have an extremely low overall temperature coefficient of resistivity throughout a range from −55° C. to +175° C. In general, the alloy consisting primarily of nickel and chromium will have a greater temperature coefficient of expansion than the glass substrate. Hence, with increasing temperature, as the glass substrate elongates and carries with it the alloy film layer, the alloy film is subjected to compressive stress. Conversely, as the glass substrate contracts with decreasing temperature and the alloy layer tends to undergo greater contraction, the resistive metallic film which is bonded to the glass and constrained to duplicate the contraction of the glass is subjected to tensile stress.

Provided that the net sum effect of the resistance change component due to changing stress in the alloy film and the resistance change component due to expansion or contraction of the film is substantially equal to the temperature coefficient of resistivity of the alloy under stress-free conditions, and of opposite sign, the overall temperature coefficient of resistivity of the device is substantially zero. Since the last-named factor is not linear, the device will have a predictable variation of its temperature coefficient of resistivity throughout the design temperature range.

The resistor may be encapsulated in a plastic or metal housing wherein suitable potting material or materials are included to embed one or more resistor units such as that described above. In order to protect the resistor unit against any substantial mechanical forces exerted by or through the potting material, the resistor unit is provided with a sheath of soft rubber, polyurethane foam, or other very soft material. Such soft material may be used alone, filling the space surrounding the coated substrate, if desired; alternatively, the soft material may in turn be surrounded by a hard filler such as an epoxy. The soft material, with a thickness preferably many times greater than the thickness of the epoxy layers on the substrate, serves as a protective cushion by virtue of its very low modulus of elasticity.

By virtue of the soft cushion and flexible conductors, the dimensional changes in the hardened potting material, which may be of the order of 5 to 10 times greater than the dimensional changes which the resistor unit itself tends to undergo, are isolated and prevented from forcing the resistor unit to depart from its design characteristics.

In accordance with the teaching of the aforementioned Smith application, the resistor element consisting of the substrate and the resistive metallic film thereon, which has elastic properties obeying Hook's law in tension and compression, is immersed within a selected oil and housed in a hermetically sealed casing, the arrangement of the resistor element being such as to minimize the transmission of any mechanical forces to the element from the housing.

Specifically, a metallic cylinder is arranged to receive two end pieces, each of which consists of a glass disc having a surrounding metal ring fixed to its periphery by a glass-to-metal seal. Each disc also includes a metal eyelet centrally located therein, and similarly bonded to the glass by a glass-to-metal seal. The surrounding metal ring of each end of the disc is arranged to be bonded by solder at its periphery to an end of the metal cylinder. Preferably, a minute shoulder is formed in each end of the metal cylinder to facilitate the accurate positioning of the end disc with its surrounding metal ring. The central eyelet of each end disc is also arranged to project a short distance from the surface of the glass and is prepared to be bonded by solder to a terminal wire lead of the unit.

As one example of mutually compatible glass and metal materials, borosilicate glass can be used with kovar metal.

The assembly to be housed within the cylinder between the end discs consists of a very small printed circuit board upon which is supported, by its flexible leads, a resistor element comprising a rigid dielectric substrate having a resistive metallic film, having elastic properties which obey Hook's law in tension and compression, affixed thereon. The arrangement and construction of the resistive element, arranged for a relatively long conductive path between the junctions of the flexible leads is described in the aforementioned Zandman et al. application.

Also fixed to the printed circuit board are wires which are arranged to serve the dual purposes of supporting the printed circuit board, and constituting the ultimate terminal wires of lead wires of the completed resistor.

The enclosure, consisting of the metal cylinder and the end discs peripherally bonded to the cylinder and centrally bonded to the lead wires is almost entirely filled with a suitable oil, a suitable material for this purpose having been found to be Dow Corning 200 Silicone Oil. A very small pocket of gas, such as dry air, is provided in order to accommodate differential expansions or contractions of the housing and the oil contained therein.

The steps involved in assembling the resistor will now be described. Initially, one of the end discs is inserted in the cylinder and its metal ring is soldered in place, making a seal around the periphery. The resistor unit is connected to the printed circuit board. The leads are bent after being bonded to the respective conductor portions of the printed circuit board. Preferably, before inserting the assembly including resistor, printed circuit board, and the ultimate resistor terminal leads into the cylinder, this cylinder is lined with a thin layer of Teflon insulating material to insure against any accidental electrical contact between either of the units and the inner cylindrical wall of the housing.

The lead wire is inserted through the eyelet of disc as the subassembly, including the printed circuit board and the resistor is moved into the interior of the cylinder. When the subassembly is approximately centrally located within the cylinder, a soldered junction is formed between the central eyelet of disc and the lead, completing hermetic sealing of the left end of the resistor unit.

Next, the opposite end disc is slipped over a terminal lead wire and moved into position in the end of the cylinder opposite the first end disc. The peripheral metal ring of the end disc is soldered to the cylinder around its entire periphery by dipping this end of the cylinder (along with the projecting terminal lead) into a hot solder bath. During this operation, the solder is prevented from bonding the wire to the eyelet of the right hand disc by the heated air escaping through said eyelet from the interior of the cylinder.

The structure is then placed within an evacuation chamber in which is a reservoir of the silicone oil. In that chamber, the air contained within the structure is substantially completely exhausted, and by virtue of immersion of the unit in the silicone, restoration of atmospheric pressure causes the silicone oil to be drawn into the housing substantially filling it. Before making the final solder junction between the terminal lead wire and the right-hand end disc, the temperature of the unit is elevated to approximately 125° C., at which temperature the silicone is expanded to a greater than normal volume. Thereafter, cooling of the unit to room temperature results in the ingress of a very small amount of air, to provide the desired pocket for expansion and contraction. The product is completed by forming the solder junction between the terminal lead wire and the eyelet of the end disc.

For some ranges of resistance, and for increased heat dissipation capacity, it is desirable in some instances to use several resistor elements within the housing defined by cylinder and the end discs.

In an alternative construction of a resistor in accordance with the aforementioned Smith application, a single-cavity of a molded plastic container is arranged to accommodate a single film-on-substrate wafer resistor, the cavity again being substantially larger in all its dimensions than the dimensions of the resistance wafer element. The housing for the resistor comprises a relatively narrow metal cup open only at its lower end, and an end closure unit comprising a glass body having two eyelets bonded thereto by glass-to-metal seals, along with a peripheral metal band also joined to the glass in a glass-to-metal seal.

In this form of a resistor, the terminal lead wires are both extended downward from the bottom of the resistor unit parallel to each other.

The single-cavity body may omit any printed wiring pattern and rely instead upon mere passages or bottom holes through which the resistor terminal leads are to extend.

The assembly of the latter arrangement is made up by first bonding the ends of the relatively short flexible leads from the film-on-substrate resistor element to the upper ends of the terminal lead wires. These terminal lead wires are then passed downward through the cavity of the molded body, and extended through the holes in the bottom of said body. The terminal lead wires are then passed through the metal eyelets which are sealed to the glass of the end closure unit.

A very small layer of Teflon, or other suitable insulating material, is inserted within the metal can and made to lie against the closed end thereof. The molded body having the resistor wafer element enclosed therein is moved up into the interior of the can and the end closure unit is next brought into a position on the lower end of the can, where it is ready to be soldered in place.

The unit is then soldered by dip soldering, to form a continuous and complete bond between the lower end of the can and the metal ring bonded to the periphery of the lower end closure unit and forming a part thereof. In this dip-soldering process, one of the eyelets in the lower end of the closure unit will be solder-bonded to the terminal lead wire passing therethrough, but the other will be kept open by the emerging air due to the rising temperature within the can. Again, the process of substantial evacuation is followed by filling with the silicone filler at the elevated temperature, after which the silicone contracts leaving a small void sufficient to allow for the differential expansion and contraction of the case and the silicone filling. The final step, in this embodiment, as in the previous embodiment, is the soldering of the open eyelet to the terminal wire lead passing therethrough.

The resultant resistor in any of these embodiments is better capable of standing shock and vibration than any of the loosely wound wire precision resistors, and is at least as good as the spool-wound precision resistors. In contrast to both such types of wire resistors, it has a minimum of reactive effect, its inductance being typically as low as or lower than one-tenth microhenry, and its distributed capacitance being typically as low as or lower than one-half micro-microfarad. By virtue of such extremely low reactance factors, the resistor in accordance with the aforementioned Smith application remains at a substantially unity power factor at frequencies far greater than at the frequencies up to which the resistors constructed of wire may be used, with or without attempts at inductance cancellation arrangements.

Resistors **52–52** are so interconnected to contact arms **48–48** that four resistors provide the ten settings desired for each switch. For example, four resistors having, respectively, 1 ohm resistance (R_1), 2 ohms resistance (R_2), 3 ohms resistance (R_3) and 3 ohms resistance (R_3) can be combined in the following combinations to provide from 0 to 9 ohms resistance for switch **13**:

Desired resistance:	Resistor combinations
0	0
1	R_1
2	R_2
3	R_1 & R_2
4	R_1 & R_3
5	R_2 & R_3
6	R_1 & R_2 & R_3
7	R_1 & R_3 & R_3
8	R_2 & R_3 & R_3
9	R_1 & R_2 & R_3 & R_3

For some applications, apparatus **10** may be modified by connecting interconnections **32** and **33** directly to each other thereby eliminating resistor **34**. This modification converts the apparatus for solely digital readouts of total resistance for resistance settings of 1 ohm variation from 0 to 99,999 ohms.

FIG. **5** shows the deviation ($\Delta R/R$ in percent) from various resistance values (set on ohmic standard apparatus modified solely for digital readouts) at various frequencies. As shown in FIG. **5**, at 500 kHz., a 90K ohm resistance setting will deviate only about 5 percent from the set value. In conventional resistance decades boxes, a deviation of 5 percent will occur at approximately 50 kHz. for the same resistance setting. Thus, the apparatus of the present invention extends the range of useful frequency by as much as 10 times.

Moreover, the apparatus of the present invention eliminates or reduces to insignificance the following problems which are typically found in resistance decade boxes:

a. Resistance shift - The shelf stability of the apparatus of the present invention can be maintained as low as 5 ppm/yr.

b. Resistance Setting - An infinite resolution in resistance settings is obtained with the apparatus of the present invention which incorporates a slide wire type rheostat. Normally, resistance decade boxes have steps of resistance and with step type apparatus it is not possible to obtain a continuous setting.

c. Accuracy - The accuracy of the apparatus of the present invention has been shown to be within ±0.005 percent at the input terminals. Normally, the accuracy of resistance decade boxes is specified as the accuracy of individual resistors across the resistor terminals rather than the input terminals.

d. Temperature Coefficient (TC) Tracking - The TC tracking for the apparatus of the present invention is 2 ppm/°C. over the range of 0° C. to +60° C. for all resistance values above 100 ohms. In conventional resistance decade boxes each resistor has a different temperature characteristic.

e. Switching - Each switch of the apparatus of the present invention uses only four resistors to provide ten values.

F. Shunt Capacitance - Unlike conventional resistance decade boxes, the capacitance at the input terminals of the apparatus of the present invention remains essentially constant at 5 pf for all settings.

g. Size - The size of the apparatus of the present invention is as much as 2/3 smaller than conventional resistance decade boxes.

As a result of the unusually flat frequency response and other characteristics mentioned above, the ohmic standard apparatus of the present invention can be used in many applications previously considered impractical. Ohmic standard apparatus of this invention is used for: secondary stands; adjustable, direct-reading resistance substitution; components of bridges, voltage dividers, attenuators and multipliers; adjustable feedback resistors for use with operational amplifiers; and ladder or network elements.

It will be understood that various modifications can be made without departing from the invention.

I claim:

1. Ohmic standard apparatus comprising five switches and four resistors associated with each switch by adjustable connecting means; the resistors of the first switch consisting of one 1-ohm resistor, one 2-ohm resistor and two 3-ohm resistors; the resistors of the second switch consisting of one 10-ohm resistor, one 20-ohm resistor and two 30-ohm resistors; the resistors of the third switch consisting of one 100-ohm resistor, one 200-ohm resistor and two 300-ohm resistors; the resistors of the fourth switch consisting of one 1000-ohm resistor, one 2000-ohm resistor and two 3000-ohm resistors; and the resistors of the fifth switch consisting of one 10,000-ohm resistor, one 20,000-ohm resistor and two 30,000-ohm resistors.

2. The apparatus of claim **1** wherein the switches are rocker actuated switches.

3. The apparatus of claim **1** wherein the resistors comprise resistive metal film deposited on a rigid dielectric substrate.

4. The apparatus of claim **3** wherein the resistors are mounted inside a housing substantially impermeable to vapor transmission.

5. The apparatus of claim **4** in which the resistors are mounted inside a hermetically sealed oil-containing housing.

6. The apparatus of claim **1** which also includes a vernier dial marked with divisions of resistance value and connected to a slide-wire resistor, said slide-wire resistor being electrically connected to switches.

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,571,778 Dated March 23, 1971

Inventor(s) John P. Smith, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

The address of the inventor should be corrected by deleting "Elton" an inserting -- Exton --;

Column 4, line 18, change "10" to -- of --.

Signed and sealed this 19th day of October 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Pa