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Jost et al.

[11] **3,846,679**

[45] **Nov. 5, 1974**

[54] **HIGH GAIN RELAYS AND SYSTEMS**

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[22] Filed: **Jan. 7, 1974**

[21] Appl. No.: **431,461**

Related U.S. Application Data

[62] Division of Ser. No. 351,683, April 16, 1973.

[52] **U.S. Cl.**..... **317/132**, 219/212, 219/505, 219/511, 219/516, 337/140

[51] **Int. Cl.**.... **H05b 1/02**, H01h 37/50, H01h 47/26

[58] **Field of Search**..... 337/140; 317/132; 219/212, 219/505, 511, 516

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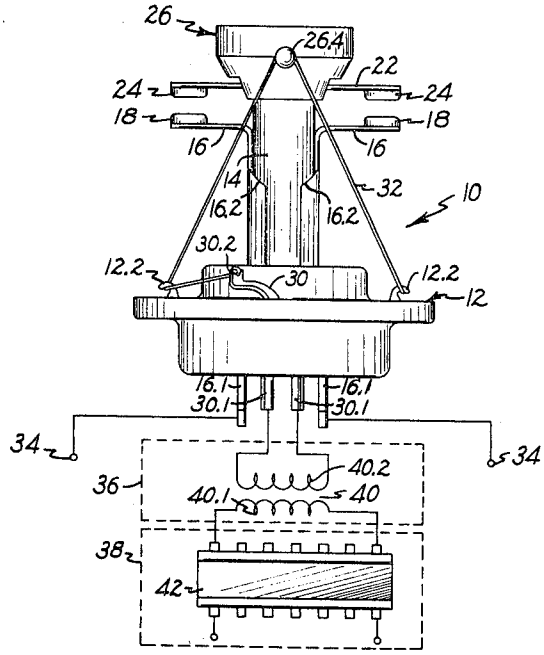
Primary Examiner—L. T. Hix

Attorney, Agent, or Firm—Harold Levine; John A. Haug; James P. McAndrews

[57] **ABSTRACT**

The disclosure relates to high gain electrical relays which are operable at very low power levels and which, when arranged in a relay system with impedance matching to an energizing power source, are operable at the low power levels used in energizing integrated circuits. The relays utilize nickel-titanium alloy wires which are conditioned and arranged to display sharp, reversible changes in shape and modulus of elasticity as the wires are heated and cooled through a temperature transition range, the alloy wires being disposed, preferably with impedance matching means between the wires and energizing power sources, to be heated through the noted transition temperature range by directing current from such low power sources through the wires, thereby to initiate relay operation. The relay construction provides unusually high gain so that relay operation from such low power sources is effective for regulating operation of various types of components used in electrical apparatus.

5 Claims, 17 Drawing Figures



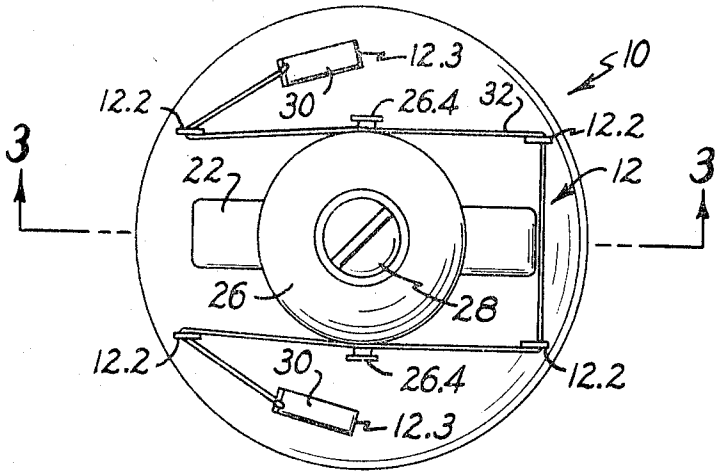

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Fig. 1.

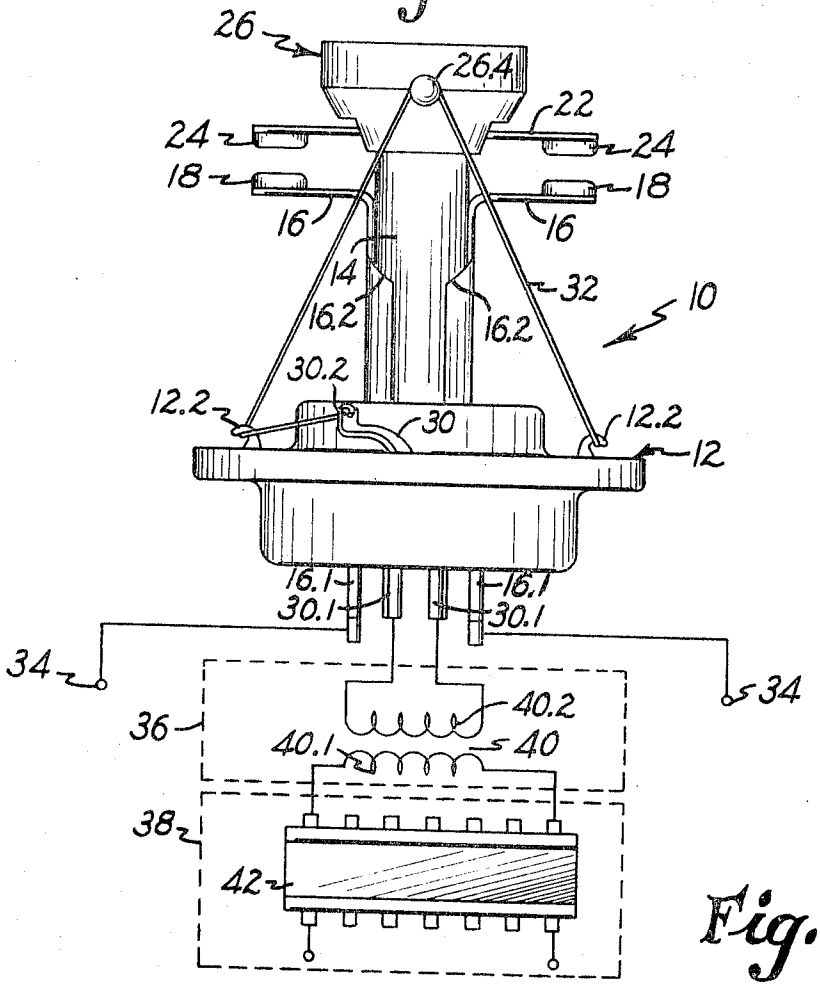

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Fig. 2.

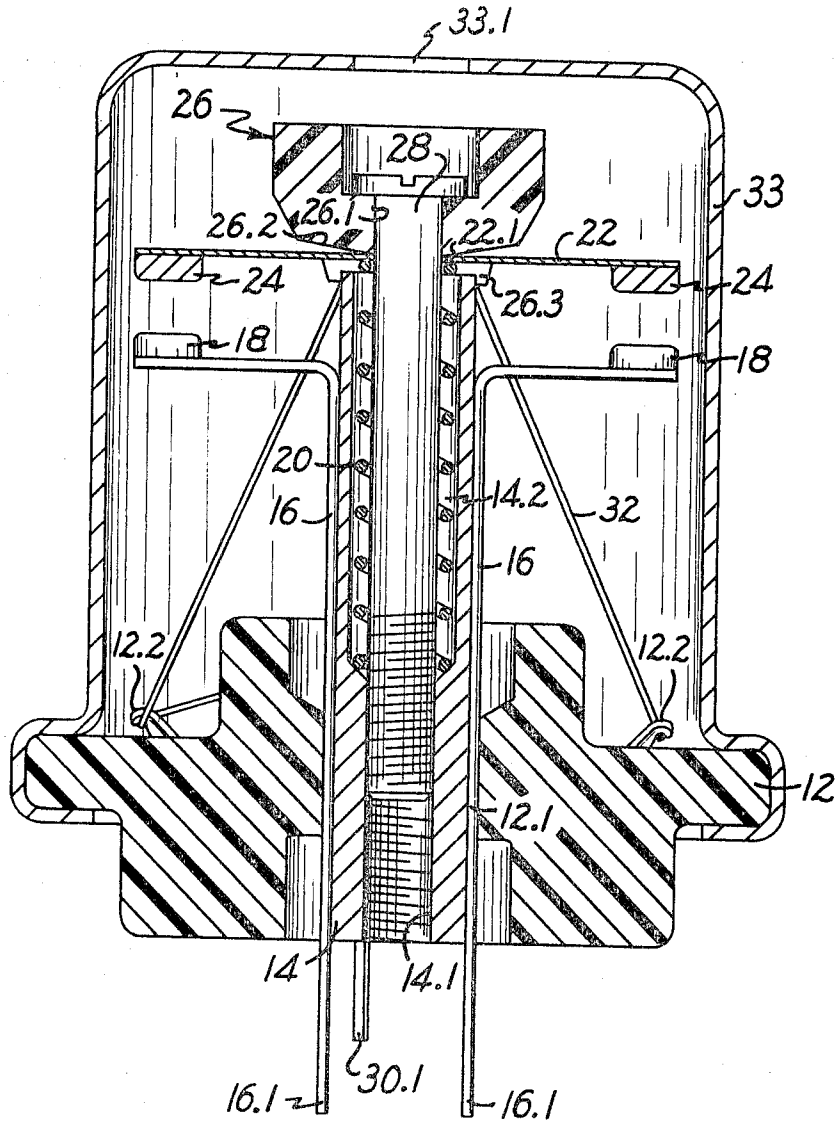

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Fig. 3.

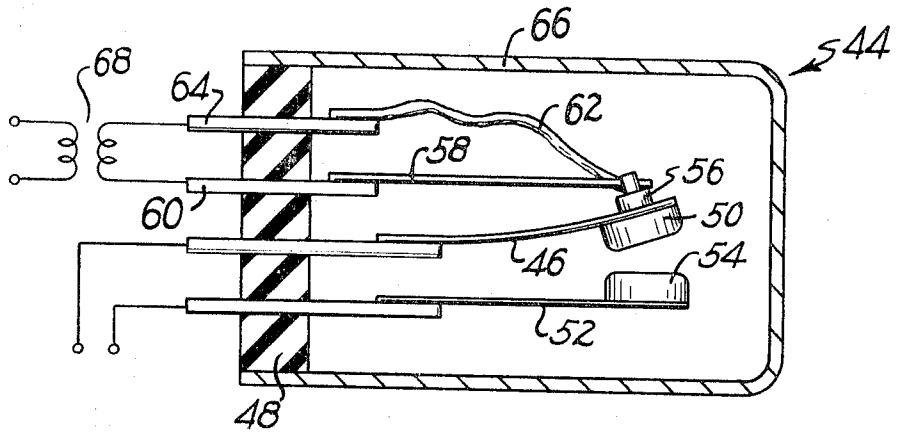


Fig. 4.

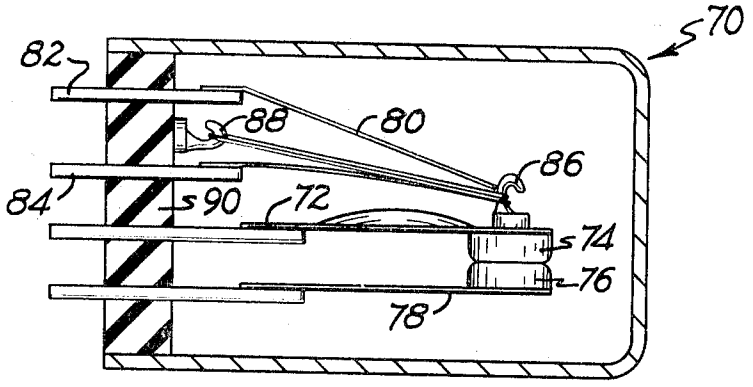


Fig. 5.

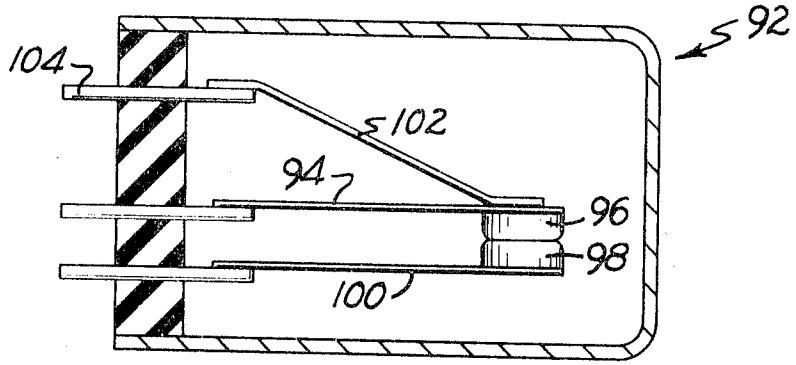


Fig. 6.

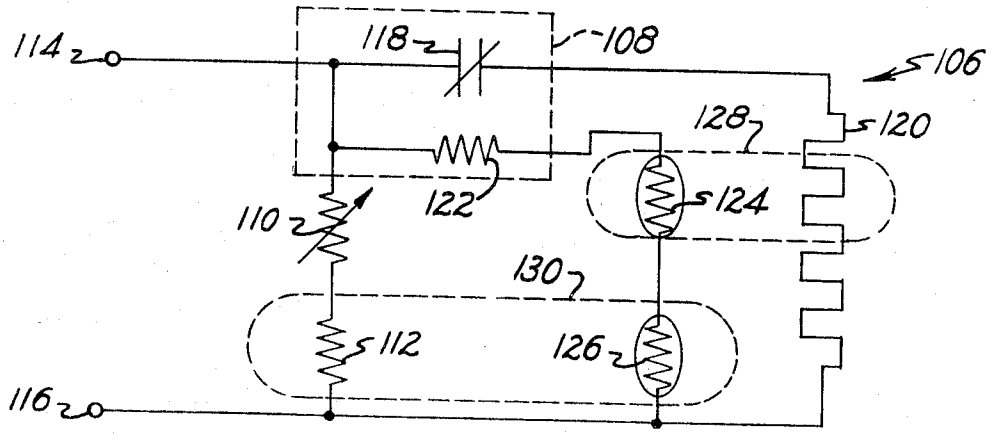


Fig. 7.

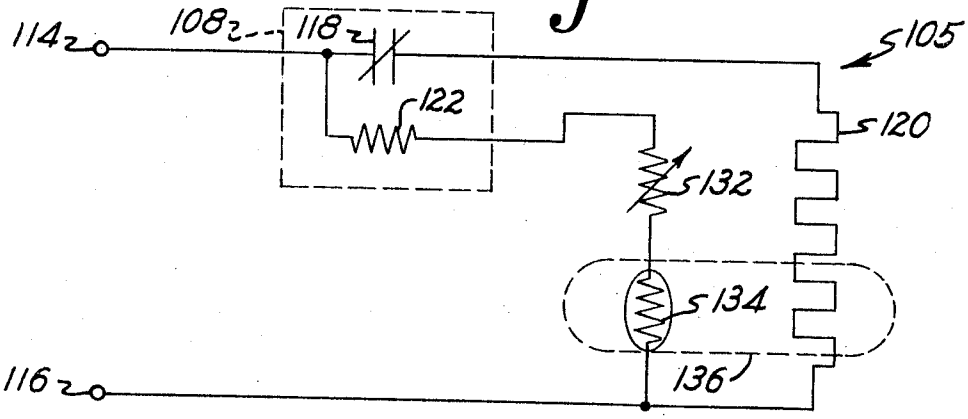


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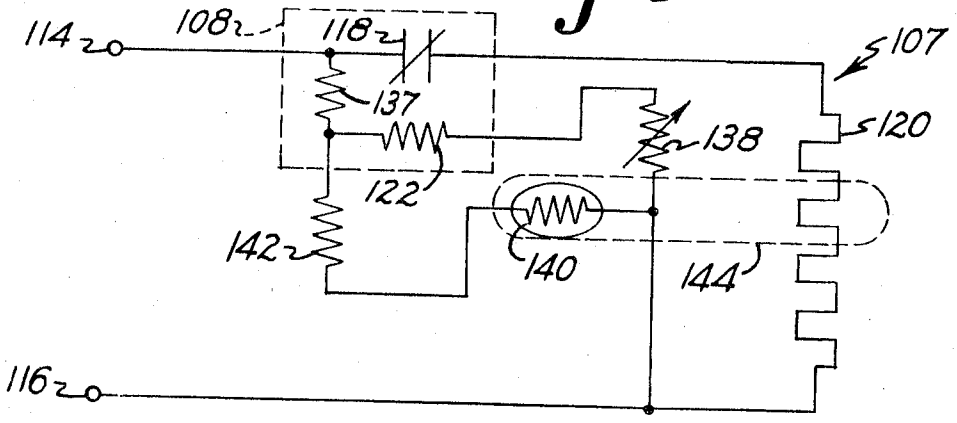


Fig. 9.

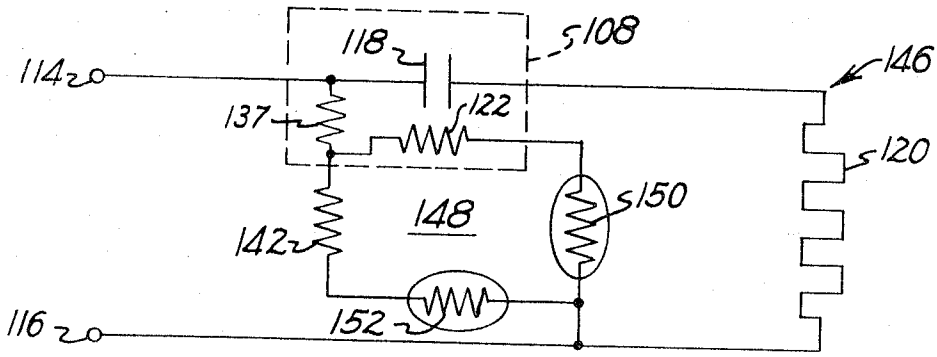


Fig. 10.

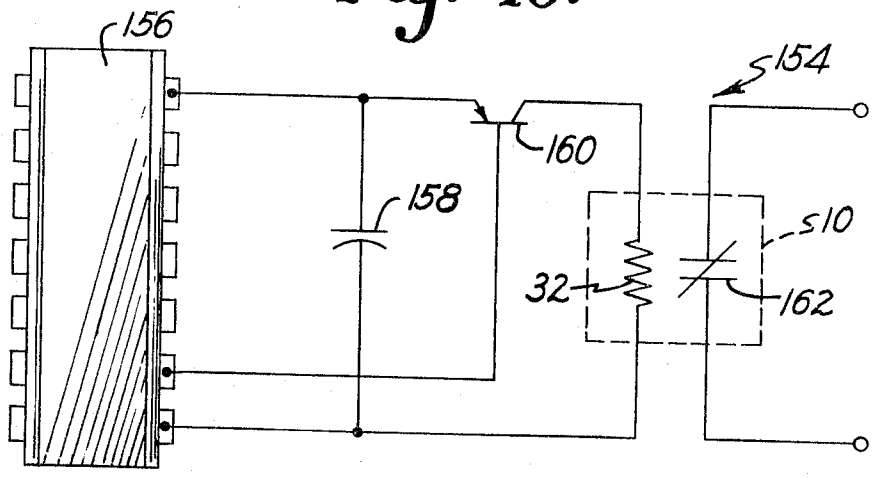


Fig. 11.

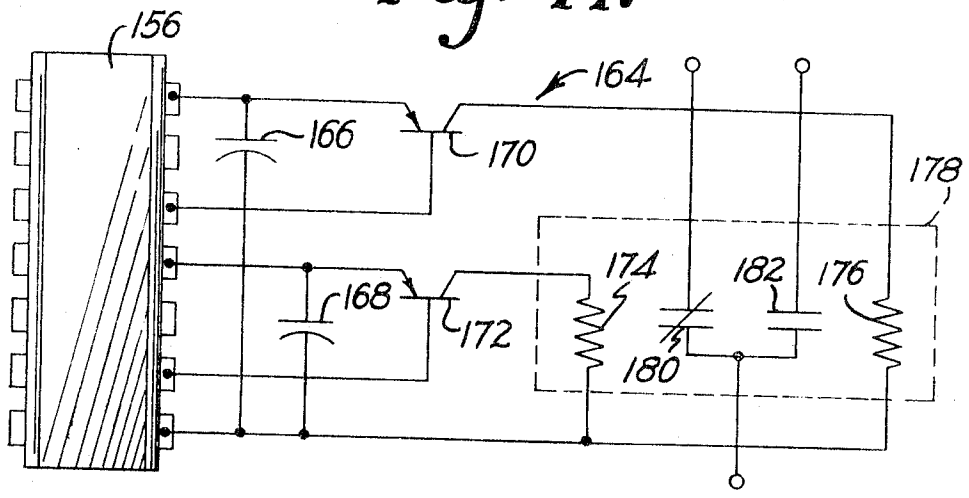


Fig. 12.

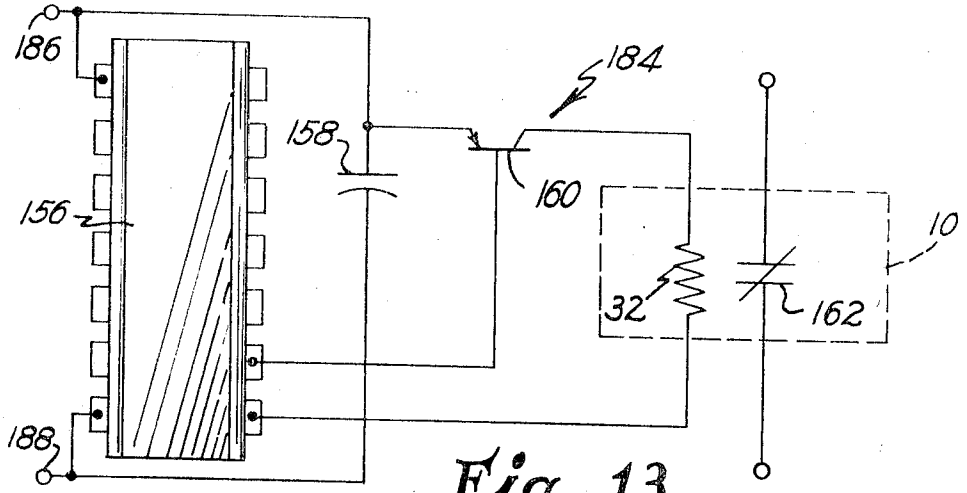


Fig. 13.

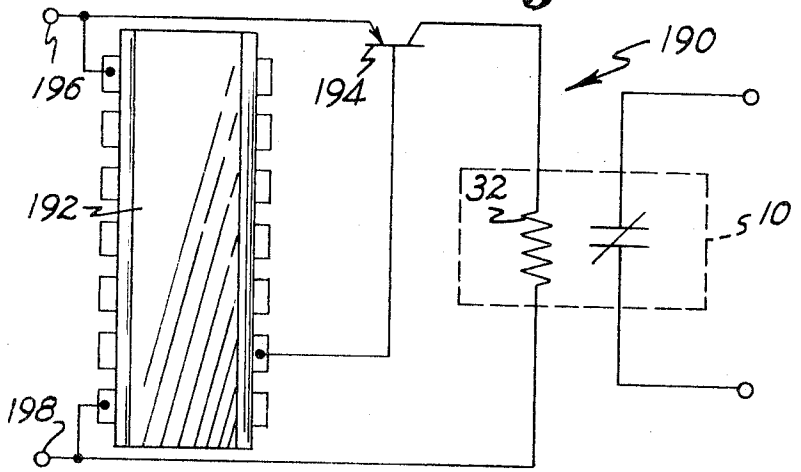


Fig. 14.

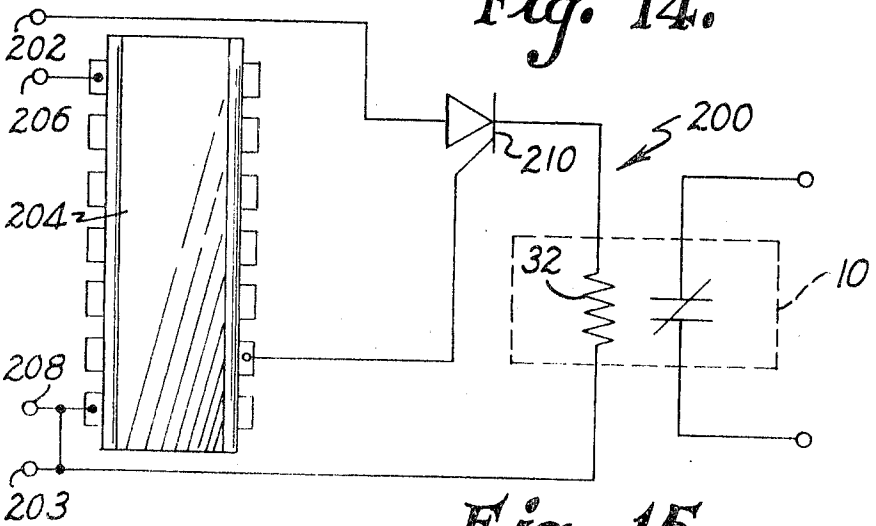


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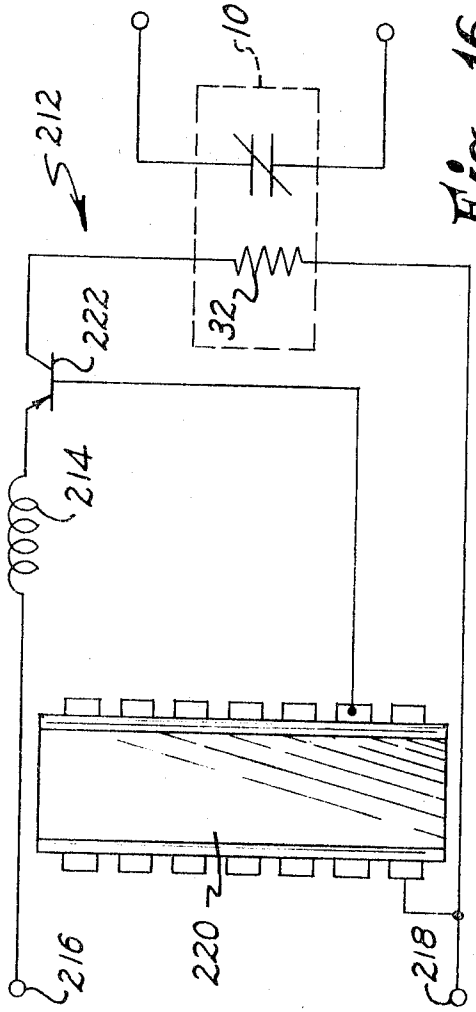

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Fig. 16.

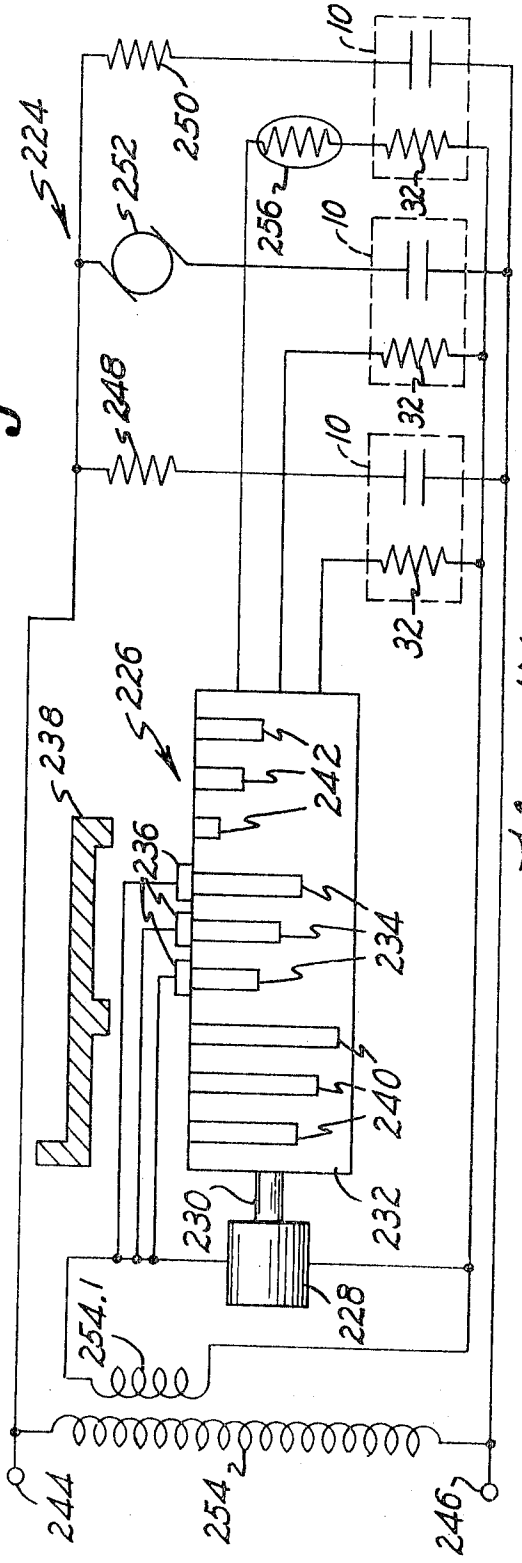

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Fig. 17.

HIGH GAIN RELAYS AND SYSTEMS

This is a division, of application Ser. No. 351,683, filed Apr. 16, 1973.

Various types of electrical apparatus could be provided with compact and inexpensive but highly sophisticated control systems through the use of integrated circuits which incorporate a number of circuit elements in a single integrated circuit chip. However, because such integrated circuits are conventionally operated at very low power levels, integrated circuit control systems as previously contemplated would often be effective in regulating such apparatus only where the control systems were provided with many additional and expensive circuit elements for amplifying control signals and for supplying the additional power required to operate the relatively large relays which have been conventionally used in regulating the operation of various components in such electrical apparatus.

It is an object of this invention to provide novel and improved electrical relays and relay systems; to provide such relays which are operable at very low power levels; to provide such relays which, when impedance matched to an energizing power source, are operable at the power levels used in energizing integrated circuits; to provide such relays and relay systems which display unusually high gain; to provide such relays which are operable at such low power levels but which display sufficiently high gain for economically regulating operation of a variety of electrical components in conventional electrical apparatus; to provide corresponding control devices of various types which are operable at such low power levels; and to provide such relays and devices which are of simple, economical and reliable construction.

Briefly described, the novel and improved relay of this invention employs a wire of a nickel-titanium alloy which has been conditioned and arranged so that the wire displays a sharp but reversible change in length and a sharp or abrupt increase in modulus of elasticity as the wire is heated to a relatively low transition temperature. The wire is provided with significant length and with a very fine cross-sectional size and is arranged within the relay so that wire is adapted to be heated to its transition temperature with a very small input of electrical energy and so that, as the wire is heated to its transition temperature, the wire is adapted to display its change of length and increase in modulus of elasticity and to apply a very substantial force and motion to a switching element, thereby to achieve unusually high gain to effect switching of sufficient power for economically regulating operation of various types of components in an electrical apparatus. In preferred embodiments of the invention, the high gain relay is combined with means matching the impedance of the fine alloy wire to a low power source such as is used in energizing integrated circuits.

Other objects, advantages and details of construction of the high gain relays and systems of this invention appear in the following detailed description of preferred embodiments of the invention, the detailed description referring to the drawings in which:

FIG. **1** is a plan view of a preferred embodiment of the high gain relay provided by this invention;

FIG. **2** is a side elevation view of the high gain relay shown in FIG. **1** and including diagrammatic illustration of use of the relay in a relay system;

FIG. **3** is a section view along ling **3—3** of FIG. **1**;

FIG. **4** is a section view along the central axis of another alternate embodiment of the relay of this invention;

FIG. **5** is a section view similar to FIG. **4** illustrating another alternate embodiment of the relay of this invention;

FIG. **6** is a section view similar to FIG. **4** illustrating another alternate embodiment of the relay of this invention;

FIG. **7** is a schematic diagram illustrating use of the relay of this invention as a relay system of this invention;

FIGS. **8–16** are schematic diagrams similar to FIG. **7** illustrating uses of relays of this invention in other alternate embodiments of relay systems of this invention; and

FIG. **17** is a schematic diagram illustrating use of the relays of this invention in an appliance timer relay system.

Referring to FIGS. **1–3** of the drawings, a preferred embodiment of the high gain relay **10** of this invention is shown to include a base member **12** which is formed of a rigid, strong, electrically insulating material such as a molded phenolic resin and which has a central bore **12.1** extending through the base member. The base member is provided with four bosses **12.2** of hook-like configuration spaced on the upper surface of the base member as shown. An upstanding rod **14** of the same insulating material is then secured within the base member bore **12.1** in any conventional manner along with a pair of upstanding, L-shaped, electrically-conductive contact arms **16,** each of which has a terminal portion **16.1** extending from the bottom of the base member and each of which extends upwardly to support a fixed contact **18** above the base member. Preferably, as indicated at **16.2** in FIG. **2,** each of the contact arms **16** has wing portions fitted around the rod **14** for securing the contact arms in spaced, electrically insulated relation to each other.

With the rod **14** internally threaded as indicated at **14.1** and provided with a counterbore **14.2,** a helical coil compression spring **20** is fitted within the counterbore, and a movable, bridging contact arm **22** formed of electrically conductive material is disposed on top of the compression spring to support a piar of movable contacts **24** to be engaged and disengaged with respective fixed contacts **18.** A relay cap member **26** of the previously noted insulating material is positioned as shown in the drawings to bear against the movable contact arm **22** and a threaded bolt **28** is fitted through an aperture **26.1** in the relay cap member and through an aperture **22.1** in the movable contact arm to extend through the counterbore **14.2** into threaded engagement with the rod **14.**

The relay cap member **26** is also provided with a pair of bossses **26.4** disposed on opposite sides of the cap member. A pair of input or energizing terminals **30** are secured in any conventional manner within respective slots **12.3** in the relay base member. Each of the terminals **30** is formed of a stiff but deformable, electrically conductive metal material and is provided with a terminal portion **30.1** extending from the bottom of the relay base member and with a tang portion **30.2** extending above the base member. Both terminal portions **30.1** of the input terminals are shown in FIG. **2** for clarity of illustration. A thermally-responsive metal actuator wire

32 is then secured at one end to a tang **30.2** of one of the input terminals and is arranged to extend tautly over the bosses **12.2** on the relay base member and over the bosses **26.4** on the cap member as shown in FIG. **3** to be attached at its other end to the tang **30.2** of the other input terminal. Preferably, a metal relay cover **33** or the like (shown only in FIG. **2**) having an adjusting aperture **33.1** is mounted on the relay base.

In the relay of this invention, the thermally-responsive wire **32** is formed of a nickel-titanium alloy commonly called Nitinol, the alloy preferably having a composition, by weight, of from about 54 to 56 percent nickel and the balance titanium. As is well known, this material is characterized in that, as the material is heated through a short transition temperature range, the material undergoes a crystalline transformation and displays a very sharp or abrupt change in physical properties including a very substantial increase in modulus of elasticity, these changes being reversible as the material is again cooled below its transition temperature range. When properly conditioned in well known manner, the material is also adapted to display remarkable shape memory properties as the material is heated through its transition temperature range. For example, when the alloy material of the wire **32** is deformed while below its transition temperature by drawing the wire to increase the wire length up to about **8** percent, the wire is adapted to subsequently display remarkable shape memory and to sharply shorten in length when the wire is thereafter heated above its transition temperature. After subsequent cooling of the wire below its transition temperature, the wire is again easily deformed by drawing or stretching to again prepare the wire for displaying its shape memory. Typically, for example, the wire **32** is formed of a nickel-titanium alloy comprising about 55 percent nickel, by weight, and the balance titanium, this alloy having a transition temperature at about 60°C. and having other physical properties as follows:

Ultimate tensile strength	125,000 psi
Density	6.5 g./cc.
Heat capacity	0.077 cal./degree C./g.
Resistivity	80×10^{-6} ohm-centimeters
Young's Modulus (below transition temperature)	3×10^{-6} psi
Young's Modulus (above transition temperature)	12×10^{-6} psi

In this arrangement of the relay **10** of this invention, the compression spring **20** is selected so that, with the material of the wire **32** below its transition temperature, the compression spring applies sufficient force to the wire to deform the wire to increase the wire length, preferably by at least about 4 percent, and to normally bias the movable contact arm **22** to the position shown in FIGS. **1–3** to hold the movable contacts **24** disengaged from the fixed contacts **18** of the relay. However, electrical current is adapted to be directed through the wire **32** between the input terminals **30** for electrically self-heating the material of wire **32** above its transition temperature so that the wire is sharply shortened in length and sharply increased in modulus of elasticity for moving the relay cap member **26** and the bridging contact arm **22** against the bias of the compression spring **20** to engage the movable contacts **24** with the fixed contacts **18** for closing a circuit between the fixed contacts. As will be understood, when the material of the wire **32** is thereafter permitted to cool below its transition temperature, whereby the modulus of elasticity of the wire material is returned to its low initial level, the compression spring **20** again deforms the wire **32** to increase the wire length and to return the bridging contact arm to its open circuit position as shown in FIGS. **1–3.** The threaded bolt **28** is adjustable for varying the spacing between the movable and fixed contacts in the relay when the contact arm **22** is in open circuit position. The input terminals **30** are also adapted to be deformed for adjusting tension in the wire **32** for adjusting contact pressure between the fixed and movable contacts when the contact arm **22** is in closed circuit position. Preferably the relay cap member **26** has sloping surfaces **26.2** and has flange portions **26.3** extending on either side of the contact arm **22** for assuring that the movable contact arm is maintained in proper alignment to bridge the fixed contacts **18.**

In accordance with this invention, the nickel-titanium material of the wire **32** is adapted to display very high strength when the wire is above its transition temperature and, accordingly, the wire used in the relay **10** is of very small cross-sectional area on the order of 1.5×10^{-5} square inches or less. On the other hand, the wire is provided with a relatively very long length. Typically, for example, the wire has a diameter of about 0.002 inches and a length of about 4 inches. In this arrangement, the material of the wire is adapted to be heated to its transition temperature with a very small input of electrical energy at low current levels and the wire is adapted to be heated to its transition temperature from a very low power source and, in preferred embodiments of this invention, the wire is proportioned as described so that the relays are operable at power levels of about 2 watts or less or even at about 0.5 watts or less. However, a number of lengths of the wire **32** are preferably arranged between the base and cap members of the relay so that, when the wire is heated to its transition temperature, substantial force is developed in the wire in the high strength state of the wire and a significant multiple of the force, at least about 15 grams and preferably on the order of 160 grams, is applied to the relay cap so that the relay contacts are held together with substantial contact pressure and are adapted to switch very substantial currents. In preferred embodiments of this invention, the relays of the invention are adapted to provide a gain of at least about 500 to 1 so that, although operable at the low power levels described above, are adapted to regulate operation of conventional components in various types of electrical apparatus. For example, where the alloy wire **32** has a diameter of 0.002 inches and a length of 4 inches as above described, the wire is adapted to be heated through its transition temperature in less than a second with 100 milliamperes of current at 5 volts whereas the relay **10** is adapted to switch 50 amperes at 120 volts between the terminals indicated at **34** in FIG. **2.** As a result, the relay is adapted to be operated from low power sources such as are used in energizing conventional bipolar integrated circuits and, with suitable impedance matching, is adapted to be powered from sources used in energizing the very low powered MOS integrated circuits. However, the gain achieved by the relay is on the order of ten thousand-to-one and the relay is adapted to directly regulate operation of a variety of components used in various types of electrical apparatus.

Preferably, as is best illustrated in FIG. 2, the relay 10 of this invention is utilized in a relay system with impedance matching means 36 between the input terminals 30 of the relay and the relay energizing source 38. For example, in a preferred embodiment of the invention, the impedance matching means 36 comprises a transformer 40 arranged with its secondary winding 40.2 connected across the relay input terminals and with its primary winding 40.1 connected to an alternating current, relay energizing, power source represented in FIG. 2 by the integrated circuit device 42, (or to the power source used in energizing the integrated circuit device), thereby to match the impedance of the integrated circuit to the wire 32 in the relay.

Another preferred embodiment of the high gain power relay of this invention is illustrated at 44 in FIG. 4. This relay 44 includes a movable spring contact assembly 46 which is cantilever mounted at one end to an electrically insulating header 48 and which carries a movable relay contact 50 at its opposite end. The relay also includes a similarly mounted spring contact assembly 52 supporting a stationary contact 54 for engagement with the movable contact to close a relay output circuit. In accordance with this invention, an insulator 56 is also mounted at the distal end of the contact assembly 46 and a thermally-responsive actuator wire 58 is connected at one end to the insulator 56 and at its opposite end to an input or energizing terminal 60 mounted on the header 48. In addition, a flexible wire conductor 62 is connected to the actuator wire and to a second input terminal 64 as shown. The relay is then encased in an inert-gas-filled tube 66 hermetically sealed to the header, the input terminals 60 and 64 as well as terminal portions of the two spring contact assemblies also being hermetically sealed to the header in passing to the exterior through the header. In this arrangement, the input terminals and the wires 58 and 62 form a relay energizing circuit for receiving power from the secondary of an impedance matching transformer 68. The actuator wire used in the relay 44 has been conditioned to display characteristics similar to the wire 32 discussed with reference to FIGS. 1–3 and the transformer 68 allows direct interface of the relay energizing circuit with an alternating current, integrated circuit power output or the like as previously discussed.

In operation, the contact spring assembly 46 is normally biased for engaging the fixed and movable relay contacts while the material of the actuator wire 58 is below its transition temperature and under stress applied by the spring assembly. However, when sufficient current appears at the secondary of the transformer, the wire 58 is heated to its transition temperature so that the wire abruptly shortens in length and pulls the contact assembly 46 upwardly to open the relay output circuit.

Referring now to FIG. 5, another practical embodiment of the relay of this invention is illustrated at 70. In this relay, which is otherwise similar to the relay 44 previously described with reference to FIG. 4, the spring contact assembly 72 is formed in a monometallic snap-acting disc configuration so that, when the contact 74 carried by this spring assembly is disengaged and engaged with the stationary contact 76 carried by the other spring assembly 78, the contact separation or engagement occurs with improved snap-action. Further, the thermally responsive actuator wire 80 formed of the nickel-titanium alloy previously described is attached at one end to the input terminal 82 and at its opposite end to the input terminal 84, the wire extending from the input terminals through a hook-shaped insulator 86 on the spring assembly 72 and through a similar hook-shaped boss 88 mounted on the header 90. In this arrangement, the wire displays greater electrical resistance and is adapted to apply substantially greater force in moving the spring assembly 72 when the wire is heated to its transition temperature.

In another embodiment of this invention illustrated at 92 in FIG. 6, a spring contact assembly 94 carrying a movable contact 96 for engagement with a stationary contact 98 carried by a second spring assembly 100 has its distal end secured in electrically conductive relation to a thermally-responsive actuator wire 102 of the noted nickel-titanium alloy, the opposite end of the actuator wire being attached to an input terminal 104. In this arrangement, current in the relay output circuit formed by the two contacts and spring assemblies is also directed through the actuator wire 102. As a result, when the wire is heated to the transition temperature of the wire material, the wire shortens in length to open the output circuit and to also deenergize the actuator wire. Upon cooling of the wire, the spring contact assemblies again closes both the relay output circuit and the circuit which heats the actuator wire.

The embodiment of this invention shown in FIG. 7 comprises a control system 106 for an electric blanket or the like utilizing a switching device 108 having a physical structure generally corresponding to the device 92 previously described with reference to FIG. 6 and utilizing current-regulating temperature-sensing elements that are particularly compatible with the switching device. As is diagrammatically illustrated in FIG. 7, the control 106 includes a variable resistor 110 and a resistance heater 112 arranged in series across terminals 114 and 116. The terminal 114 is also connected through the normally closed relay contacts 118 of the switching device 108 to the load 120. In addition, the thermally-responsive actuator wire 122 in the switching device 108 is arranged in series with a resistor 124 of negative temperature coefficient of resistivity (NTC) and with a resistor 126 of positive temperature coefficient of resistivity (PTC) as shown in FIG. 7, the NTC resistor being disposed in heat-transfer to the load 120 as indicated by the broken line 128 and the PTC resistor being in heat-transfer relation to the resistance heater 112 as indicated by the broken line 130.

In this arrangement, application of a voltage across the terminals 114 and 116 energizes the load 120 through the normally closed relay contacts 118 and energizes the resistance heater 112 in accordance with the setting of the variable resistor 110, the NTC resistor normally preventing sufficient current flow in the actuator wire 122 of the switching device. Then, the NTC resistor becomes heated as heat is generated by the load 120, and lowers in resistance, whereby the actuator wire 122 is heated to its transition temperature for opening the relay contacts to deenergize the load 120. After a cooling period, the NTC resistor increases in resistance to again reduce current in the actuator wire 122 until the relay contacts again close as will be understood. As will also be understood, adjustment of the variable resistor 110 adjusts heating of the resistance heater 112 which through heat-transfer to the PTC re-

sistor **126** adjusts the cycling rate of control system **106.**

Referring now to FIG. **8,** there is shown a second embodiment **105** of a control device similar to the device as set forth in FIG. **7,** corresponding elements being identified by the reference numerals used with regard to FIG. **7.** Here again the switch **108** is normally closed and supplies current to load **120.** Current also passes through the series circuit of actuator wire **122,** variable resistor **132** and NTC resistor **134.** As the load **120** heats up it heats up NTC resistor **134** as indicated by the broken lines **136,** thereby increasing the current through wire **122** until the wire lengthens and opens switch contacts **118.** Cooling of load **120** reverses the cycle. The point at which switch **108** opens and closes is determined by the setting of variable resistor **132.** This embodiment of the invention could be utilized, for example, as a fry pan control.

Referring now to FIG. **9,** there is shown a third embodiment **107** of a control device similar to the devices as set forth in FIGS. **7** and **8.** Hence again the switch **108** is normally closed. Current therefore passes through switch **108** and load **120** and through the series circuit of actuator wire **122,** the additional series resistor **137** incorporated in the switch **108,** and variable resistor **138** as well as through PTC resistor **140** and the resistor **142.** When the temperature at the load increases, it heats resistor **140** as indicated at **144,** thereby increasing the resistance and passing less current through the PTC resistor. This causes more current to pass through wire **122** until the wire shortens and opens switch contacts **118.** As the load **120** cools, the resistance of PTC resistor **140** decreases and diminishes the current passing through wire **122** so that the wire cools to the temperature where it lengthens and allows closing of the switch contacts **118.** The setting of variable resistor **138** determines the temperature of operation of the switch **108.** This embodiment of this invention could be used in an oven control.

Referring now to FIG. **10,** there is shown a fourth embodiment **146** of a control device similar to the devices as set forth in FIGS. **7** to **9.** Here the switch **108** incorporating the additional resistor **137** is normally open. In the device, as the temperature of a compartment indicated at **148** decreases, the resistance of the PTC resistor **150** decreases while the resistance of the NTC resistor **152** increases. This causes more current to pass through the actuator wire **122** and, upon reaching the transition temperature, closes the switch contacts **118** and connects power to the load **120.** Increase of temperature now causes more current to be shunted through resistor **142** and NTC resistor **152** and less current through resistor **150,** thereby causing the switch **108** to open due to lengthening of wire **122.** A device of this type has application as a refrigerator defrost control wherein buildup of ice causes the switch **108** to close and connect power to a heater, thereby allowing the refrigerator to defrost until sufficient frost is removed from the refrigerator to alter the cooling rate of resistors **150** and **152** and thus to change the cycle.

Referring now to FIG. **11,** there is set forth a circuit system **154** for utilizing a low power relay such as the relay **10** previously described with reference to FIGS. **1–3** with a high voltage-low current source such as an MOS type of integrated circuit device **156** without requiring use of a transformer.

In accordance with this embodiment of this invention, the MOS integrated circuit device **156,** which typically has an output of about 3 milliamps at 30 volts, is arranged to charge the capacitor **158** in about 60 milliseconds, for example, while the MOS integrated circuit device is arranged to apply a control pulse to the transistor **160** after the capacitor is charged for discharging the capacitor **158** through the actuator wire **32** of the relay **10** previously described. In this arrangement, the current directed through the wire **32** at 30 volts during capacitor discharge is adequate to heat the wire to its transition temperature for opening the contacts of the relay as indicated at **162.** The relay may then be latched open in any conventional manner, or, if desired, the control pulses are applied to the transistor **160** by the integrated circuit device at selected intervals for providing the relay with a selected duty cycle as will be understood. In this arrangement, the very low power MOS type of integrated circuit is arranged to operate the low power high gain relay of this invention.

Referring now to FIG. **12,** there is set forth another alternate embodiment **164** of this invention similar to the circuit system **154** described above. In this embodiment **164** of this invention, the MOS integrated circuit device **156** is arranged as shown in FIG. **12** to charge capacitors **166** and **168** while also being adapted to periodically apply control pulses to the transistor **170** and to the transistor **172** for periodically rendering the transistors conductive to discharge the capacitors through respective actuator wires **174** and **176** in a relay **178.** In this embodiment of this invention, the relay **178** comprises a single-pole, double-throw latching type of relay otherwise similar to the relays of this invention as previously described, having any conventional means releasably retaining the relay contacts in either of its two stable positions. That is, the relay **178** typically has one pair of relay contacts **180** which are normally closed and another pair of normally open relay contacts **182.** In this arrangement of system **164,** electrical energy accumulated in the capacitor **166** is periodically applied to an actuator wire **174** in the relay **178** in response to a control pulse from the integrated circuit device **156** for opening the relay contacts **180** and closing the relay contacts **182** for moving the relay from one of its stable positions to its second stable position as will be understood. A subsequent control pulse from the integrated circuit device is then adapted to discharge the capacitor **168** through the other actuator wire **176** in the relay for returning the relay to its original stable position.

In another alternate embodiment of this invention illustrated in FIG. **13,** the circuit system **184** is generally similar to the circuit system **154** except that the capacitor **158** is charged from the power source, indicated by terminals **186** and **188** in FIG. **13,** used in energizing the integrated circuit device **156.**

In another alternate embodiment of the circuit system of this invention, as illustrated at **190** in FIG. **14,** a relay **10** such as has been previously described with reference to FIGS. **1–3,** and which is preferably energized from a 6 volt source, is arranged to be operated from a 30 volt power source or the like such as is used in energizing the MOS integrated circuit device for operating the relay without excessive power loss. In this arrangement, the integrated circuit device **192** is adapted in any conventional manner to provide a series of control pulses to the transistor **194** so that current

from the 30 volt power source or the like indicated by the line terminals **196** and **198** is rapidly switched on and off to provide an effective (rms.) voltage of about 6 volts to the wire **32** in the relay **10** for heating the wire to its transistion temperature for opening the relay contacts. While this circuit system is adapted for use with various line voltages, greatest economy and efficiency is achieved where the line voltage is on the order of 24 to 30 volts.

In another alternate embodiment of this invention as indicated at **200** in FIG. **15,** the circuit system is arranged to match the impedance of a higher voltage power source such as a 110 volt a.c. line as indicated by the terminals **202** and **203** to the relay **10** by phase modulation. That is, the MOS integrated circuit device **204** is arranged to be energized from a 30 volt a.c. power source indicated by the terminals **206** and **208** which is synchronized with the 110 volt source, the integrated circuit device being adapted in any conventional manner to apply gating pulses to the SCR **210** only as the alternating line voltage and current approach zero, thereby to reduce the rms voltage applied to the actuator wire **32** in the relay **10** to about one-fifth of line voltage as required for heating the wire **32** to its transition temperature for opening the contacts of the relay **10.** In this arrangement, a relatively inexpensive circuit component **210** is adapted to be used even though the relay is being impedance matched to a 110 volt line. As will be understood, a triac can be substituted for the SCR **210** for providing operation during both halves of the circuit cycle.

In another alternate embodiment of this invention as illustrated at **212** in FIG. **16,** the relay **10** of this invention is impedance matched to a d.c. power source by use of an inductance coil **214.** That is, as is shown in FIG. **16,** an inductance coil **214** is arranged in series with the actuator wire **32** of the relay **10** and with a 30 volt d.c. power source or the like indicated by the terminals **216** and **218** whereas an MOS integrated circuit device **220** is adapted in any conventional manner to apply brief control pulses to the transistor **222** for periodically rendering the transistor conductive. In this arrangement, the inductive coil is selected to provide a selected phase relationship as the transistor is being briefly rendered conductive, thereby to apply significantly less than peak line current and voltage to the actuator wire **32** as required for heating the wire to its transition temperature for opening the contacts of the relay **10.**

In another embodiment of this invention indicated at **224** in FIG. **17,** the high gain relays **10** of this invention as previously described are arranged for use with a low voltage, low power appliance timer **226** of otherwise conventional design, whereby the timer contacts are adapted to be of very light construction while displaying a long service life. That is, as is shown in FIG. **17,** a low voltage low power appliance timer of conventional design is shown to include a synchronous motor **228** which rotates a drum **232** on a shaft **230** so that timer contacts **234** disposed at different locations on the surface of the drum **232** are sequentially engaged with respective wiping contacts **236.** As will be understood, a slide **238** is typically arranged for moving the wiping contacts **236** to engage other sets of timer contacts **240** or **242** for changing the program provided by the drum. As will be understood, a 110 volt a.c. power supply indicated by the terminals **244** and **246** is arranged to energize various electrical components such as the solenoids **248, 250** and the motor **252** through contacts of the respective relays **10.**

In accordance with this invention, a transformer **254** is connected across the line terminals and the transformer secondary **254.1** is arranged to energize a timer motor **228** at 12 volts for example. The actuator wires **32** of the relays **10** are then arranged to be sequentially connected to the transformer secondary through the timer drum contacts **234** and the wiping contacts **236** as the timer drum is rotated as will be understood. In this way, using the high gain relays **10** of this invention, it is possible to utilize a low voltage low power timer mechanism **226** which can be of very light construction in sequentially operating a variety of electrical components such as the solenoids **248, 250** and the motor **252.** Where desired, a resistor **256** of negative temperature coefficient of resistivity is arranged in series with the wire **32** to serve as a limit control.

It should be understood that although various embodiments of this invention have been described above by way of illustration, this invention includes all modifications and equivalents of the described embodiments falling within the scope of the appended claims.

We claim:

1. A control circuit system comprising a relay operable at low power levels having an insulating base, stationary contact means mounted on said base, movable contact means mounted on said base for movement between a closed circuit position engaging said stationary contact means and an open circuit position spaced from said stationary contact means, spring means mounted on said base biasing said movable contact means from one of said positions to the other of said positions, and a metal wire secured between said movable contact means and said base, said wire being of a selected metal alloy to be deformed from an original length to a second length by said spring bias as said movable contact means is moved from said one position to said other position by said spring bias while said alloy displays a relatively low modulus of elasticity below a transition temperature and to abruptly return to said original length and to display a relatively higher modulus of elasticity to move said movable contact means back to said one position against said spring bias when said wire is heated to said transition temperature, said wire having a selected cross-sectional size and length to be heated from room temperature to said transition temperature by passing electrical current through said wire with a power input of less than about 2 watts; a power source directing energizing current through said relay wire; a device to be energized from said power source through said relay contact means when said relay is in closed circuit position; and resistor means displaying varying resistance in response to temperature changes arranged to regulate said energizing current in said relay wire for operating said relay to energize said device at one temperature level and to deenergize said device at another temperature level.

2. A system as set forth in claim **1** wherein said relay is normally in closed circuit position and wherein said resistor means comprises a resistor of negative temperature coefficient of resistivity (NTC) and a selectively variable resistor arranged in series with said relay wire, said NTC resistor being disposed in heat-transfer relation to said device to regulate current in said relay wire to energize said device in response to decrease in de-

vice temperature below a selected temperature level and to deenergize said device in response to increase in device temperature above a selected temperature level, said variable resistor being adjustable for selecting said temperature level.

3. A system as set forth in claim **1** wherein said relay is normally in closed circuit position and wherein said resistor means comprises a resistor of negative temperature coefficient of resistivity (NTC) and a resistor of positive temperature coefficient of resistivity (PTC) connected in series with said relay wire and having a selectively variable resistor and a resistance heater connected in series across said relay wire and said NTC and PTC resistors, said NTC resistor being disposed in heat transfer relation to said device to regulate current in said relay wire to energize said device in response to decrease in device temperature below a selected temperature level and to deenergize said device in response to increase in device temperature above said selected temperature level, said PTC resistor being disposed in heat-transfer relation to said resistance heater so that adjustment of said selectively variable resistor is effective for selecting said temperature level.

4. A system as set forth in claim **1** wherein said relay is normally in closed circuit position and wherein said resistor means comprises a selectively variable resistor connected in series with said relay wire and having a resistor of positive temperature coefficient of resistivity (PTC) and a dropping resistor connected across said relay wire and selectively variable resistor, said PTC resistor being disposed in heat-transfer relation to said device to regulate current in said relay wire to energize said device in response to decrease in device temperature below a selected temperature level and to deenergize said device in response to increase in device temperature above a selected level, said selectively variable resistor being adjustable for selecting said temperature level.

5. A system as set forth in claim **1** wherein said relay is normally in open circuit position and wherein said resistor means comprises a resistor of positive temperature coefficient of resistivity (PTC) arranged in series with said relay wire and having a resistor of negative temperature coefficient of resistivity (NTC) and a dropping resistor connected in series across said relay wire and said PTC resistor, said NTC and PTC resistors being disposed in heat transfer relation to a selected chamber to regulate current in said relay wire to energize said device in response to increase in temperature in said chamber above a selected temperature level and to deenergize said device in response to decrease in temperature below said selected temperature level.

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