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(71) Applicant: HYDRA-ELECTRIC COMPANY [US/US];  
3151 Kenwood Street, Burbank, CA 91505-1052 (US).

(72) Inventor: GUZIAK, Robert, Andrew; 2111 Peak Place,  
Thousand Oaks, CA 91362-4666 (US).

(74) Agent: ZARRABIAN, Michael; BROOKS ACORDIA IP  
LAW, P.C., 31365 Oak Crest Drive, Suite 225, Westlake  
Village, CA 91361 (US).

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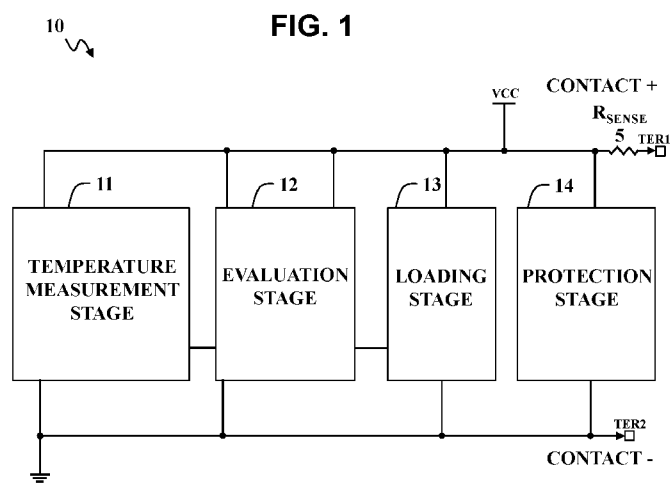
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(57) Abstract: An electronic temperature switch (10), comprises a measurement circuit (11) that measures temperature and generates an temperature signal corresponding to the sensed temperature; an evaluator circuit (12) that receives said temperature signal and compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value; and a loading circuit (13) that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value.

## **ELECTRONIC TEMPERATURE SWITCH**

### CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** This application claims the priority benefit of U.S. Provisional Patent Application Serial Number 62/173,287, filed June 9, 2015, incorporated herein by reference in its entirety.

### **TECHNICAL FIELD**

**[0002]** The present disclosure relates to electronic switches, and more particularly to electronic temperature switches.

### **BACKGROUND**

**[0003]** In conventional mechanical temperature switch designs, a temperature sensing element senses rise or drop in temperature, which results in the increase and decrease of internal pressure of liquid or gas such as in liquid filled temperature switches. This variation in pressure then mechanically actuates a mechanical switch. Mechanical temperature switches are susceptible to shock, vibration, acoustic noises, etc. Further, the size of conventional mechanical temperature switches limits their application.

### SUMMARY

**[0004]** An electronic temperature switch embodiment may include: a measurement circuit that measures temperature and generates an temperature signal corresponding to the sensed temperature; and an evaluator circuit that receives said temperature signal and compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value.

**[0005]** In additional electronic temperature switch embodiments, the evaluator circuit may have an evaluation circuit ratio independent of power supply voltage. In additional electronic temperature switch embodiments, the measurement circuit

may comprise an enhancement circuit that enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit. In additional electronic temperature switch embodiments, the switch may derive essentially all operating power from a 2-wire sense circuit. In additional electronic temperature switch embodiments, the electronic temperature switch may comprise a 2-wire device powered by a power supply with a series resistance, where the evaluation signal indication is at the junction of the series resistor and the power supply input. In additional electronic temperature switch embodiments, the measurement circuit may comprise a temperature sensor with variable resistance based on temperature.

**[0006]** In additional electronic temperature switch embodiments, the temperature sensor may comprise a resistive element with variable resistance based on temperature. In additional electronic temperature switch embodiments, the evaluator circuit may comprise a window comparator circuit configured for: comparing the temperature signal to a lower reference value corresponding to the lower temperature threshold value; and comparing the temperature signal to a higher reference value corresponding to the higher temperature threshold value; where the window comparator indicates when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value. In additional electronic temperature switch embodiments, the comparator circuit window may be adjustable between about  $\frac{1}{2}^{\circ}$  and  $6^{\circ}$ . In additional electronic temperature switch embodiments, the window comparator circuit may comprise: a first comparator for comparing the temperature signal to the lower reference value corresponding to the lower temperature threshold value, and a second comparator for comparing the temperature signal to the higher reference value corresponding to the higher temperature threshold value.

**[0007]** In additional electronic temperature switch embodiments, comparator hysteresis may be reduced by amplifying the generated temperature signal via an operational amplifier to improve a signal to noise ratio of the generated temperature signal. Additional electronic temperature switch embodiments may include: a loading circuit that in response to the evaluator circuit, generates a first

pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value. Additional electronic temperature switch embodiments may include a protection circuit that provides over-voltage protection.

**[0008]** An electronic temperature switch device embodiment may include: an electronic temperature switch circuit; a temperature sensor; and a housing for housing the electronic temperature switch circuit and at least a portion of the temperature sensor; where the electronic temperature switch circuit, includes: a measurement circuit that measures temperature and generates an temperature signal corresponding to the sensed temperature; and an evaluator circuit that receives said temperature signal compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value.

**[0009]** In additional electronic temperature switch device embodiments, the evaluator circuit may have an evaluation circuit ratio independent of power supply voltage. In additional electronic temperature switch device embodiments, the measurement circuit may comprise an enhancement circuit that enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit. In additional electronic temperature switch device embodiments, the circuit may derive essentially all operating power from a 2-wire sense circuit. In additional electronic temperature switch device embodiments, the circuit may further include: a loading circuit that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value. In additional electronic temperature switch device embodiments, the housing may have dimensions of about 1.25 cm by 4.5 cm.

**[0010]** An electronic temperature switch device embodiment may include: an electronic temperature switch circuit; a temperature sensor; and a housing for housing the electronic temperature switch circuit and at least a portion of the temperature sensor; where the electronic temperature switch circuit, includes: a measurement circuit that measures temperature and generates an temperature signal corresponding to the sensed temperature; an evaluator circuit that receives said temperature signal compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value; and a loading circuit that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value; and where the evaluator circuit has an evaluation circuit ratio independent of power supply voltage, the measurement circuit enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit, and the electronic temperature switch circuit derives essentially all operating power from a 2-wire sense circuit.

**[0011]** This brief summary has been provided so that the nature of this disclosure may be understood quickly. A more complete understanding of the disclosure can be obtained by reference to the following detailed description of the various aspects thereof in connection with the attached drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** The foregoing features and other features will now be described with reference to the drawings of various aspects. In the drawings, the same components have the same reference numerals. The illustrated aspects are intended to illustrate, but not to limit the present disclosure. The drawings include the following Figures:

**[0013]** FIG. 1 shows a functional block diagram of an embodiment of an electronic temperature switch, disclosed herein;

**[0014]** FIG. 2 shows a circuit diagram of an exemplary implementation of the electronic temperature switch of FIG. 1;

**[0015]** FIG. 3A shows a top view of an embodiment of an assembled electronic temperature switch device employing the electronic temperature switch of FIG. 1, disclosed herein;

**[0016]** FIG. 3B shows a side view of the assembled electronic temperature switch device of FIG. 3A;

**[0017]** FIG. 3C shows a front view of the assembled electronic temperature switch device of FIG. 3A;

**[0018]** FIG. 3D shows a detail view about A of the assembled electronic temperature switch device of FIG. 3A;

**[0019]** FIG. 4A shows a graph of a closing and opening of the electronic temperature switch device at different temperatures;

**[0020]** FIG. 4B shows a wiring diagram of the electronic temperature switch device;

**[0021]** FIG. 5A shows a temperature sensor (RTD) as a core temperature sensor element in the electronic temperature switch device; and

**[0022]** FIG. 5B shows a detail view about A of the RTD of FIG. 5A.

### DETAILED DESCRIPTION

**[0023]** The description herein is made for the purpose of illustrating the general principles of the embodiments disclosed herein and is not meant to limit the concepts disclosed herein. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations. Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the description as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc.

**[0024]** Embodiments of an electronic temperature switch device comprising a temperature sensor and an electronic temperature switch circuit, are disclosed herein. In one embodiment, the electronic temperature switch device indicates when a fluid temperature falls within a fault condition range.

**[0025]** An electronic temperature switch 10 embodiment, comprising: a measurement circuit 11 that measures temperature and generates an temperature signal corresponding to the sensed temperature; and an evaluator circuit 12 that receives said temperature signal and compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value.

**[0026]** In additional electronic temperature switch embodiments, the evaluator circuit has an evaluation circuit ratio independent of power supply voltage. In additional electronic temperature switch embodiments, the measurement circuit comprises an enhancement circuit 34 that enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit. In additional electronic temperature switch embodiments, the switch derives essentially all operating power from a 2-wire sense circuit. In additional electronic temperature switch embodiments, the electronic temperature switch comprises a 2-wire device

powered by a power supply with a series resistance, where the evaluation signal indication is at the junction of the series resistor and the power supply input. In additional electronic temperature switch embodiments, the measurement circuit comprises a temperature sensor 54 with variable resistance based on temperature. In additional electronic temperature switch embodiments, the temperature sensor comprises a resistive element with variable resistance based on temperature.

**[0027]** In additional electronic temperature switch embodiments, the evaluator circuit comprises a window comparator circuit configured for: comparing the temperature signal to a lower reference value corresponding to the lower temperature threshold value; and comparing the temperature signal to a higher reference value corresponding to the higher temperature threshold value; where the window comparator indicates when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value. In additional electronic temperature switch embodiments, the comparator circuit window is adjustable between about  $\frac{1}{2}^{\circ}$  and  $6^{\circ}$ . In additional electronic temperature switch embodiments, the window comparator circuit comprises: a first comparator 36 for comparing the temperature signal to the lower reference value corresponding to the lower temperature threshold value, and a second comparator 37 for comparing the temperature signal to the higher reference value corresponding to the higher temperature threshold value. In additional electronic temperature switch embodiments, comparator hysteresis is reduced by amplifying the generated temperature signal via an operational amplifier 34 to improve a signal to noise ratio of the generated temperature signal.

**[0028]** Additional electronic temperature switch embodiments may further include: a loading circuit 13 that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value. Additional electronic temperature switch embodiments may include a protection circuit 14 that provides over-voltage protection.

**[0029]** An electronic temperature switch device 30 embodiment may include: an electronic temperature switch circuit 10; a temperature sensor 54; and a housing 65 for housing the electronic temperature switch circuit 10 and at least a portion of the temperature sensor 54; where the electronic temperature switch circuit 10, includes: a measurement circuit 11 that measures temperature and generates an temperature signal corresponding to the sensed temperature; and an evaluator circuit 12 that receives said temperature signal compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value.

**[0030]** In additional electronic temperature switch device embodiments, the evaluator circuit has an evaluation circuit ratio independent of power supply voltage. In additional electronic temperature switch device embodiments, the measurement circuit comprises an enhancement circuit that enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit. In additional electronic temperature switch device embodiments, the circuit 10 derives essentially all operating power from a 2-wire sense circuit. In additional electronic temperature switch device embodiments, the circuit 10 further comprises: a loading circuit 13 that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value. In additional electronic temperature switch device embodiments, the housing has dimensions of about 1.25 cm by 4.5 cm.

**[0031]** An electronic temperature switch device 30 embodiment may include: an electronic temperature switch circuit 10; a temperature sensor 54; and a housing 65 for housing the electronic temperature switch circuit 10 and at least a portion of the temperature sensor 54; where the electronic temperature switch circuit 10, includes: a measurement circuit 11 that measures temperature and generates an temperature signal corresponding to the sensed temperature; an evaluator circuit

12 that receives said temperature signal compares said temperature signal to a lower threshold value and an upper threshold value, and generates an evaluation signal indicating when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value; and a loading circuit 13 that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value; and where the evaluator circuit has an evaluation circuit ratio independent of power supply voltage, the measurement circuit enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit, and the electronic temperature switch circuit derives essentially all operating power from a 2-wire sense circuit.

**[0032]** Referring to the drawings, FIG. 1 shows a functional block diagram of an embodiment of an electronic temperature switch circuit 10. FIG. 2 shows a circuit diagram of an exemplary implementation of the electronic temperature switch circuit 10 of FIG. 1.

**[0033]** FIG. 1 shows a functional block diagram of an embodiment of said electronic temperature switch circuit 10 which monitors temperature change via a temperature sensor (RTD) element. In one embodiment, the temperature sensor comprises a resistive element with variable resistance based on temperature, whereby a resistance value due temperature is detected in the circuit 10 by detecting a voltage drop across the RTD element. In one embodiment, the disclosed electronic temperature switch 10 provides an indication of sensed temperature being within a specified temperature range or outside the temperature range.

**[0034]** FIG. 2 shows a circuit diagram of an example implementation of the electronic temperature switch circuit 10 of FIG. 1. The electronic temperature switch circuit 10 comprises a temperature measurement stage (module or circuit)

11, an evaluation stage 12, a loading stage 13 and an optional protection stage 14.

**[0035]** In one embodiment, the temperature measurement stage 11 comprises an electronic circuit that is configured to draw a small amount of current to sense the voltage drop across the RTD therein. In one example, the current draw increases as fluid temperature sensed by the RTD decreases, but not large enough to change the output state of circuit 10, or affect the circuit 10 by any significant amount.

**[0036]** The temperature measurement stage 11 develops a window output signal below a first sensed temperature (e.g., below freezing) to obtain a high voltage indication (e.g., the switch is turned off). Above a second temperature (e.g., 175° F), there is also a high voltage indication from the temperature measurement stage 11. Between the first and second temperatures, there is a low voltage indication from the temperature measurement stage 11. An example of a low voltage indication is about 4 Volts (i.e., 4V) at terminal 1 (TER1) relative to terminal 2 (TER2), and an example of a high voltage indication is about 8V at TER1 relative to TER1, in the circuit 10.

**[0037]** In one embodiment, a platinum resistor is utilized as a temperature sensor (RTD) 54, also called a thermocouple, wherein said platinum changes its resistance over a temperature range. For example, at about 25°C a PT1000 resistor exhibits 1000  $\Omega$  (i.e., 1000 Ohm). The RTD is connected in series with a resistor 42 ( $R_4$ ), forming a voltage divider relative to ground, on feeds into an amplifier 34 ( $U_1$ ) in the stage 11. The voltage across the RTD is so measured, and is very closely linear with temperature changes. As the resistance for the temperature sensor changes value, temperature sensor causes a different temperature signal (output voltage) at the input to the amplifier 34, which is then amplified by the amplifier 34 to improve the signal-to-noise ratio.

**[0038]** In one implementation, the evaluation stage 12 comprises an electronic circuit that is configured to evaluate the amplified RTD signal from the temperature measurement (sensor) stage 11, which represents the sensed fluid temperature by the RTD. The evaluation stage 12 utilizes a window comparator for the evaluation which in the example implementation described herein comprises the two comparator integrated circuits 36 ( $U_2$ ) 36 and 37 ( $U_3$ ) connected as shown.

**[0039]** The evaluation stage 12 comprises an evaluator that evaluates the temperature signal by comparing the temperature signal to a lower threshold value and an upper threshold value, and generating an evaluation signal indicating when said temperature signal is between the lower threshold value and an upper threshold value. In one embodiment, the evaluation stage 12 receives the amplified temperature sensor voltage signal from the amplifier 34 of stage 11, which indicates an amplified voltage proportional to the sensed temperature. The amplified voltage is fed into an electronic window comparator circuit comprising comparators 36 and 37. A first comparator 37 is to sense the low temperature (i.e., lower threshold value) based on the sensed voltage, and the other comparator 36 is to sense the high temperature (i.e., upper threshold value) based on the sensed voltage from the measurement stage 11.

**[0040]** Whenever the sensed voltage from the measurement stage 11 rises above a first level (lower level) indicating sensing a first temperature threshold value T1 (e.g., above a freezing point of water), then the voltage is sensed by a first comparator and trips that comparator. When the sensed voltage from the measurement stage 11 raises further above a second level (higher level) indicating sensing a second temperature threshold value T2 (e.g., above 175° F), then that voltage is sensed by a second comparator and trips the second comparator.

**[0041]** The window comparator determines whether the output from the measurement stage 11 is between two threshold reference voltages (corresponding to said two reference threshold temperatures), by detecting over-

voltage or under-voltage. As shown in FIG. 2, each single comparator detects a common input voltage  $V_s$  from measurement stage 11 against one of two reference voltages  $V_1$  and  $V_2$ . The voltage  $V_s$  represents the sensed temperature by the RTD from the measurement stage 11. The reference voltages  $V_1$  and  $V_2$  are established by the series connected resistors 50, 52, 53 that form a first comparison reference voltage-divider, and the series connected resistors 43, 45, 49 that form a second comparison reference voltage-divider.

**[0042]** An upper level voltage at  $V_1$  (corresponding to e.g. a higher temperature threshold) is sensed by comparator 36, and a lower voltage at  $V_2$  (corresponding to e.g. a lower temperature threshold) is sensed by compactor 37.

**[0043]** In one embodiment, the comparator outputs are fed to a logic gate (e.g., AND or NAND) that detect the input as in range of the so-called "window" between upper and lower reference voltages.

**[0044]** The comparator outputs drive the loading stage 13. Based on the comparison of  $V_s$  with  $V_1$  and  $V_2$ , the two comparator outputs 36 and 37 provide a high voltage condition (e.g., such as 4V) sufficient to turn on the loading stage transistors  $Q_1$  and  $Q_2$  in the loading stage 13, or a low voltage condition sufficient to turn off the loading stage transistors  $Q_1$  and  $Q_2$ .

**[0045]** The comparator output from stage 12 is fed into the loading stage 13 which in one embodiment comprises two transistors 60 and 61. The transistors 60 and 61 function as a loading switch that is turned on or off (based on comparator window signal from stage 11) to generate pre-set output voltages of low such as 4V, or high such as 8V, at TER1 relative to TER2. In other embodiments, the two pre-set output voltages could be other pre-set voltages (e.g., as low as 0.7 V and up to about 28V, or higher as needed). The two transistors in the stage 12 may be simplified to one transistor in some embodiments.

**[0046]** The protection stage 14 protects against transient signals or electrical noise in the overall circuit (e.g., lightning strikes, ringing effects from turning a switch on or off, etc.).

**[0047]** The disclosed electronic temperature switch 10 enables adjustment of comparator hysteresis to as much or as little as desired by a user (e.g., about  $\frac{1}{2}^\circ$  or  $6^\circ$ ). A series sensing resistor 5 (i.e.,  $R_{\text{SENSE}}$ ) may be located at TER1 to sense a voltage at TER1 with respect to TER2.

**[0048]** The output voltage of temperature measurement stage 11 and all measurements are performed ratiometrically (output is directly proportional to input). The output voltage at TER1 ( $V_{\text{input}}$ ) is referenced to a supply voltage VCC at  $R_{\text{SENSE}}$ . The ratio of RTD resistance to a fixed value resistor 42 ( $R_4$ ) essentially does not vary with voltage. The evaluator stage 11 is established using an evaluation circuit ratio independent of power supply voltage.

**[0049]** In one implementation, the temperature measurement stage 11 utilizes said active component 34 comprising an op-amp  $U_1$  configured to amplify the sensed values by the RTD, and operate at low voltage levels (e.g., less than 2 Volts) while drawing low current (e.g., less than 2 micro-Amp of quiescent current). Preferably, an op-amp 34 ( $U_1$ ) has low input offset, low current draw and “zero-drift”, and can use a single-supply power. The measurement state 11 enhances the temperature sensor signal-to-noise-ratio using an enhancement circuit comprising the component 34, for presentation to the evaluator stage 12.

**[0050]** In one implementation, the evaluation stage 12 utilizes said active component comprising said window comparator configured to operate at less than e.g. about 4V as depicted, with typical operating ranges extending to lower and higher voltages, and draw less than e.g. about 1 milliamp of quiescent current.

**[0051]** The loading stage 13 comprises an electronic circuit that in one example provides switching between high (8 Volts) and low (4 Volts), and logic inversion. The logic of the evaluation stage 12 can be inverted from the desired output by

stage 13 as depicted, and a pull-up resistor 39 ( $R_1$ ) in stage 13 is set large enough to provide operating voltage to the electronic circuits of 10 and small enough to provide a significant load with transistors  $Q_2$  and  $Q_1$  on, to cause a detectable voltage drop across  $R_{SENSE}$ . Example sensed voltage across TER1 and TER2 are 4V with transistors  $Q_2$  and  $Q_1$  on, and 8V with transistors  $Q_2$  and  $Q_1$  off.

**[0052]** The optional protection stage 14 comprises an electronic circuit 59 that provides over-voltage protection, comprising back-to-back connected Zener diode circuit 59 ( $D_1$ ), or a Transient Voltage Suppressor, that clips voltage.

**[0053]** An external power supply VCC (e.g., 15 Volts) is coupled to the circuit 10 via the external  $R_{SENSE}$  resistor (e.g., 1.5 K $\Omega$ ), whereby the electronic temperature circuit 10 operates by drawing more, or less current to alter the voltage measured at the terminals TER1 and TER2. The electronic switch circuit 10 derives essentially all operating power from a 2-wire sense circuit.

**[0054]** Under normal operating conditions, the value of the RTD 54 in stage 11, and said pull-up resistor 42 in stage 13, result in a voltage divide ratio that does not vary with voltage. The resulting voltage across the RTD 54 is amplified by the operational amplifier (op-amp) 34 to swamp out the effects of comparator hysteresis and improve the signal to noise ratio.

**[0055]** The amplified temperature voltage  $V_s$  signal from the measurement stage 11 is fed into said window comparator comprising the two comparator integrated circuits 36 ( $U_2$ ) and 37 ( $U_3$ ) in the evaluation stage 12. The outputs of the window comparators drive a set of MOSFET transistors 60 ( $Q_1$ ) and 61 ( $Q_2$ ) that are driven in series. In the active region of operation, the transistors 60 ( $Q_1$ ) and 61 ( $Q_2$ ) are active and draw current through both resistors 5 and 39 ( $R_{SENSE}$  and  $R_1$ ).

**[0056]** In one embodiment, the outputs of the window comparators are first NAND gated together. In one embodiment, an open collector output may be used instead of the NAND circuit implemented by MOSFETS 60 and 61. As such, for the output circuit, a low power NAND with open collector output may be used instead of MOSFETS.

**[0057]** The resistors RTD 54 and resistor 42 form a measurement voltage divider at an input of the amplifier to measure voltage drop across RTD 54 indicative of sensed temperature. The series connected resistors 50, 52 and 53 form a first comparison voltage divider. The series connected resistors 43, 45 and 49, form a second comparison voltage divider.

**[0058]** As the voltage drops across the entire circuit, all ratios of measurement resistors (i.e., RTD 54 and resistor 42), and comparison resistors ( $R_{12}$  50,  $R_{14}$  52,  $R_{15}$  53 and  $R_5$  43,  $R_7$  45,  $R_{11}$  49) are held constant by their component values, thus the evaluation performed by the window comparator is unaffected, and the circuit is stable.

**[0059]** Hysteresis of the comparators 36 and 37 provides stability by applying internal positive feedback that latches the window comparator output into a discrete state. This affects the temperature transition point temperatures T1 and T2 (e.g., T1 about 37 °F to T2 about 175 °F) introducing a hysteresis or change in the set point when the temperature change reverses direction.

**[0060]** Preferably, comparators 36 and 37 in the circuit 10 have high input impedance, low current draw, and operate from low voltage. The same applies to the operational amplifier 34 (op-amp  $U_1$ ). In one embodiment, large value resistors 50, 52, 53 and 43, 45, 49 are coupled to the comparators 36, 37, and large value resistors 54, 42 are coupled to the op-amp 47, since the input impedances of the comparators and op-amp is not infinite.

**[0061]** For the comparators 36 and 37, a amount of hysteresis is desired to prevent the circuit 10 from oscillating at said trip points T1 and T2 (e.g., T1 about

37 °F to T2 about 175 °F). In one example, a comparator with about 2mV of hysteresis yields about 6 °F hysteresis.

**[0062]** In one example each comparator 36, 37 preferably operates down to less than 2 Volts, or ideally 1 Volt. Each op-amp comparator preferably draws less than 1 mA of current.

**[0063]** The high voltage protection circuit 14, and a voltage regulator circuit comprising MOSFET 33 ( $M_1$ ) and micropower voltage reference unit 38 ( $U_4$ ), is also included in the front end to provide +5V power to the comparators and op amps.

**[0064]** The doubled up resistors (50, 52, 53 and 43, 45, 49) for the window comparator allow the selection of standard value resistors for a wide range of set point temperature set threshold values T1 and T2 to be achievable. Effectively with a set of three resistors, the ratio of these three resistor values define said temperature set thresholds (T1 and T2). To implement a specific temperature switch point, two standard resistor values that combine in parallel, or series can be selected to produce the desired temperature switch or thresholds set point value.

**[0065]** As noted, in one embodiment, the electronic temperature circuit 10 indicates when a sensed fluid temperature X falls within a fault condition range (e.g., less than 37 °F or greater than 175 °F). This will be indicated by a high voltage limit (e.g., 8 Volts). When the fluid is within a range of  $37\text{ °F} < X < 175\text{ °F}$ , a low voltage (e.g., 4 Volts) will be presented at the terminal 1 (TER1) to terminal 2 (TER2) point. In one implementation, the electronic temperature switch 10 comprises a two-wire device powered by a 15 Volt supply VCC with a 10 K $\Omega$  series resistor  $R_{\text{SENSE}}$  (i.e., 2-wire sense circuit). That is  $R_{\text{SENSE}}$  bottom at TER1 with respect to power return at TER2. The voltage indication of whether the sensed fluid temperature X falls inside or outside a fault condition range is taken at the junction of the 10 K $\Omega$  resistor  $R_{\text{SENSE}}$  at TER1 with respect to TER2.

**[0066]** In one embodiment of the electronic temperature circuit 10, at specific temperature set points T1 and T2 the window comparators 36 and 37 change output state. The state change indicates the condition with two set point temperatures T1 and T2 (such as less than 37 °F or greater than 175 °F), or combining the two comparator states between the two set point temperatures. In one embodiment, the window comparators comprise two high temperature comparator integrated circuits with corresponding all high temperature resistors and capacitors (e.g., about 150 °C).

**[0067]** In one embodiment, the design of the electronic switch circuit 10 is modeled with all switching to be ratiometric to the input power. Based on power supply variations, changes in power supply series resistance or stability factors, a voltage reference may be added.

**[0068]** In one embodiment, a comparator IC can be configured in either a switch on high voltage or switch on low voltage. This provides a configuration to sense voltages representing temperatures below a first temperature set point T1 (e.g., 37 °F) or above a second temperature set point T2 (e.g., 175 °F). The comparators 36 and 37 in stage 11 feed a logic circuit 13 that detects when both signals are between a first temperature set point T1 and a second temperature set point T2 (i.e., within temperature range from T1 and T2).

**[0069]** When the sensed temperature is within said temperature range, the logic output 13 is set to draw increased current. In one example implementation, by pulling increased current, the voltage drop across a resistor e.g.,  $R_{SENSE}$  10 K $\Omega$  external switch circuit 10) in series with a power supply, causes the switch sense voltage to drop below a low voltage (e.g., about 4 Volts). For all other conditions, the current draw is kept low enough to cause the sense voltage to be greater than high voltage (e.g., about 8 Volts).

**[0070]** In one example implementation, the circuit 10 is configured to operate on about 3.3 Volts to about 12 Volts and less than about 1.5 mA (milliamps). This allows the circuit 10 to be powered whether the logic 12 is in the on or off state.

The protection circuit 14 may be added to limit the maximum internal voltage to less than (e.g., about 12 Volts) in case of a fault condition of the power supply.

**[0071]** In one example implementation, a 1.5 K $\Omega$  resistor may be used in place of the 10 K $\Omega$  series resistor  $R_{\text{SENSE}}$ . This would increase the current to (15-4) volts/ 1.5 K $\Omega$  or 7.3 mA. With this current level, other electronic switch IC designs may be utilized.

**[0072]** In one example, the excitation voltage VCC for the circuit 10 may be 15 VDC at 1.5 mA. The actuation temperature may be T1 at about 37°F (2.78 °C) +/- 5°F to T2 at about 175°F (79.4 °C) +/- 5°F. The RTD 54 at 32°F (0 °C) may be 1000  $\Omega$ . The RTD at 37°F (2.78 °C) may be 1010.85  $\Omega$ . The RTD at 175°F (79.4 °C) may be 1306.85  $\Omega$ . One embodiment of the switch 10 in FIG. 2 may have the following passive component approximate values: resistor  $R_1$  39 is 976  $\Omega$ , resistor  $R_2$  40 is 100  $\Omega$ , resistor  $R_4$  42 is 23.7 K $\Omega$ , resistor  $R_5$  43 is 147 K $\Omega$ , resistor  $R_7$  45 is 30.1 K $\Omega$ , resistor  $R_9$  47 is 200 K $\Omega$ , resistor  $R_{10}$  48 is 23.7 K $\Omega$ , resistor  $R_{11}$  49 is 71.5 K $\Omega$ , resistor  $R_{12}$  50 is 76.8 K $\Omega$ , resistor  $R_{13}$  51 is 100 K $\Omega$ , resistor  $R_{14}$  52 is 14.7 K $\Omega$ , resistor  $R_{15}$  53 is 71.5 K $\Omega$ , capacitor  $C_1$  55 is 0.1  $\mu$ F, capacitor  $C_2$  56 is 0.1  $\mu$ F, capacitor  $C_3$  57 is 0.1  $\mu$ F and capacitor  $C_{15}$  58 is 0.1  $\mu$ F. Op-amp U1B 35 may be (e.g., OPA2333AMDREP by Texas Instruments). The components and values used in the electronic temperature switch circuit 10 are by way of example, and those skilled in the art recognize that other components and values can be used which achieve the functions of the disclosed switch device, described herein. Although in the embodiment of circuit 10 shown in FIG. 2, TER2 is shown grounded, in another embodiment TER2 can be coupled to a voltage source that is not zero (i.e., not grounded).

**[0073]** FIG. 3A shows a top view of an assembled electronic temperature switch device 30 which may include the electronic temperature switch circuit 10 in FIG. 2. FIG. 3B shows a side view of the assembled electronic temperature switch device 30 of FIG. 3A. FIG. 3C shows a front view of the assembled electronic temperature switch device 30 of FIG. 3A. FIG. 3D shows a detail view about A of the assembled electronic temperature switch device 30 of FIG. 3A.

**[0074]** In one embodiment, RTD element 54 is located within the stub 62 of the electronic temperature switch device 30 as shown in FIGS. 3B-3C. In one embodiment, the electronic temperature switch circuit 10 is implemented on a printed circuit board (PCB), depicted by dashed lines, located within the body 64 of the temperature switch device 30, on a round PCB board 63 within the plane perpendicular to the drawing of the electronic temperature switch device 30, as shown in FIG. 3C.

**[0075]** In one embodiment, the switch device 30 may have a housing 65 including a generally cylindrical body 64 with an extension stub 62, and a generally cylindrical connector tube 66 extending transversely from a side of the body 64. The electrical connections to the circuit 10 are via pin contacts 67 at an outlet of the connector 66. The RTD element is disposed in the stub 62 and electrically connected to the circuit 10 disposed in the body 64. Example geometry and dimensions of the housing are provided herein (others within the scope of the disclosed switch are possible).

**[0076]** In one example, the housing 65 has one or more of the following exterior approximate dimensions, wherein: dimension A is 0.495 in. (1.2573 cm.) max, dimension B is R.031 in. (.07874 cm.) to .061 in. (1.5494 cm.), dimension C is .180 in. (.4572 cm.) to .190 in. (.4826 cm.), dimension D is R.010 in. (.0254 cm.) to .015 in. (.0381 cm.), dimension E is .135 in. (.3429 cm.) to .145 in. (.3683 cm.), dimension F is .415 in. (1.0541 cm.) to .425 in. (1.0795 cm.), dimension G is .9375 in. (2.38125 cm.) max, dimension H is 2x .435 in. (1.1049 cm.) to .440 in. (1.1176 cm.), dimension I is a master keyway +/- 5°, dimension J is 1.226 in. (3.11404 cm.) to 1.236 in. (3.13944 cm.), dimension K is R.625 in. (1.5875 cm.) max, dimension L is .177 in. (.44958 cm.) to .187 in. (0.47498 cm.), dimension N is 2x R.695 in. (1.7653 cm.) to .705 in. (1.7907 cm.), dimension O is 1.029 in. (2.61366 cm.) to 1.039 in. (2.63906 cm.), dimension P is 1.029 in. (2.61366 cm.) to 1.039 in. (2.63906 cm.), dimension Q is 2 x Ø.216 in. (.54864 cm.) to .226 in. (.57404 cm.), dimension M is R.219 in. (.55626 cm.) min clearance for socket 2 PL, dimension S is a connector per EN29997YE-1-1006MN, dimension T is 44° to

46°, dimension U is Ø1.181 in. (2.99974 cm.) to 1.183 in. (3.00482 cm.), dimension V is Ø1.017 in. (2.58318 cm.) to 1.020 in. (2.5908 cm.), dimension W is .135 in. (.3429 cm.) to .145 in. (.3683 cm.), dimension X is 2x R.020 in. (.0508 cm.) to .040 in. (.1016 cm.), dimension Y is 2x R.003 in. (.00762 cm.) to .010 in. (.0254 cm.), and dimension Z is .03 in. (.0762 cm.). An electrically conductive material 32 may be bonded on upper and lower flange surfaces at both fasteners hole locations. The operating pressure may be 60 pounds per square inch absolute (PSIA). The proof pressure may be 120 PSIA. The burst pressure may be 195 PSIA.

**[0077]** In one embodiment, the switch device 30 has a smaller size than convention mechanical temperature switches, wherein dimension A is about 1.25 cm, and combination of dimensions H, G, F is about 4.5 cm. The RTD is about 1.27 cm long. Main body 64 is about 4.6 cm long. Tube diameter is about 1.9 cm to 2.5 cm. Connector tube about 1.3 cm long.

**[0078]** In one embodiment, the electronic temperature switch circuit 10 functions as a fluid temperature switch such as a fuel temperature switch, in one example being an indicator of an acceptable fluid temperature range T1 to T2 (e.g., T1 about 37 °F to T2 about 175 °F), and an unacceptable fluid temperature range (e.g., less than about 37 °F and greater than about 175 degrees °F). In one example, an example acceptable range of sensed temperature is indicated by the output of circuit 10 as an 8 Volt signal and an unacceptable indication is shown as a less than a 4 Volt signal, output from circuit 10 at terminal TER1. FIG. 4A shows an example output voltage graph 70 of a closing (e.g., acceptable indication) and opening (e.g., unacceptable indication) of the disclosed electronic temperature circuit 10 at different threshold temperatures.

**[0079]** FIG. 4B shows a wiring diagram 71 of the electronic temperature switch 30, as input and output to circuit 10 (i.e., excitation and excitation return). The electronic temperature switch circuit 10 operates in place of a mechanical switch functioning from a 2-wire sense circuit. The electronic switch circuit 10 derives all operating power from the 2-wire sense circuit.

**[0080]** In one embodiment, the electronic temperature switch device 30 utilizes a robust Thin film PT1000 RTD 54 as the core temperature sensor. FIG. 5A shows a temperature sensor (RTD) 54 as a core temperature sensor element in the electronic temperature switch device. FIG. 5B shows a detail view about A of the RTD 54 of FIG. 5A.

**[0081]** In one embodiment, the electronic temperature switch device 30 assembly is thermally compensated to desired requirements of accuracy, and output level. The electronic temperature switch device design utilizes machined, all welded construction with a sealed thermo-well welded to the interface port. The thermo-well 54 is connected to the envelope in such a manner as to be immersed in the fluid media where temperature is to be sensed. The RTD element senses temperature by increasing resistance with temperature.

**[0082]** The electronic temperature switch device comprising said electronic temperature circuit monitors the resistance change by detecting a voltage drop across the RTD element. This voltage is appropriately amplified to increase the sensitivity of temperature to utilize an integrated circuit based window comparator circuit, as described herein. The electronic temperature switch device 10 can be utilized in many applications such as aircraft fuel in fuel lines or tanks, engine oil, bleed air, etc.

**[0083]** Those skilled in the art will appreciate that various adaptations and modifications of the described preferred embodiments can be configured without departing from the scope and spirit of the electronic temperature switch device and circuit described herein. Therefore, it is to be understood that, within the scope of the embodiments, the electronic temperature switch device may be practiced other than as specifically described herein.

## CLAIMS

### What is claimed is:

- 5 1. An electronic temperature switch (10), comprising:  
a measurement circuit (11) that measures temperature and generates an  
temperature signal corresponding to the sensed temperature; and  
an evaluator circuit (12) that receives said temperature signal and  
compares said temperature signal to a lower threshold value and an upper  
10 threshold value, and generates an evaluation signal indicating when said  
temperature signal is between the lower temperature threshold value and an  
higher temperature threshold value.
2. The electronic temperature switch of claim 1, wherein the evaluator circuit  
15 has an evaluation circuit ratio independent of power supply voltage.
3. The electronic temperature switch of claim 1, wherein the measurement  
circuit comprises an enhancement circuit (34) that enhances signal-to-noise-ratio  
of the temperature signal for input to the evaluator circuit.  
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4. The electronic temperature switch of claim 1, wherein the switch derives  
essentially all operating power from a 2-wire sense circuit.
5. The electronic temperature switch of claim 4, wherein the electronic  
25 temperature switch comprises a 2-wire device powered by a power supply with a  
series resistance, wherein the evaluation signal indication is at the junction of the  
series resistor and the power supply input.
6. The electronic temperature switch of claim 1, wherein the measurement  
30 circuit comprises a temperature sensor (54) with variable resistance based on  
temperature.
7. The electronic temperature switch of claim 1, wherein the temperature

sensor comprises a resistive element with variable resistance based on temperature.

8. The electronic temperature switch of claim 1, wherein the evaluator circuit  
5 comprises a window comparator circuit configured for:

comparing the temperature signal to a lower reference value corresponding to the lower temperature threshold value; and

comparing the temperature signal to a higher reference value corresponding to the higher temperature threshold value;

10 wherein the window comparator indicates when said temperature signal is between the lower temperature threshold value and an higher temperature threshold value.

9. The electronic temperature switch of claim 10, wherein the comparator  
15 circuit window is adjustable between about  $\frac{1}{2}^{\circ}$  and  $6^{\circ}$ .

10. The electronic temperature switch of claim 8, wherein the window comparator circuit comprises: a first comparator (36) for comparing the temperature signal to the lower reference value corresponding to the lower  
20 temperature threshold value, and a second comparator (37) for comparing the temperature signal to the higher reference value corresponding to the higher temperature threshold value.

11. The electronic temperature switch of claim 10, wherein comparator  
25 hysteresis is reduced by amplifying the generated temperature signal via an operational amplifier (34) to improve a signal to noise ratio of the generated temperature signal.

12. The electronic temperature switch of claim 1, further comprising:  
30 a loading circuit (13) that in response to the evaluator circuit, generates a first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and

the higher threshold value.

13. The electronic temperature switch of claim 1, further comprising a protection circuit (14) that provides over-voltage protection.

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14. An electronic temperature switch device (30), comprising:  
an electronic temperature switch circuit (10);  
a temperature sensor (54); and  
a housing (65) for housing the electronic temperature switch circuit (10)

10 and at least a portion of the temperature sensor (54);

wherein the electronic temperature switch circuit (10), includes:

a measurement circuit (11) that measures temperature and  
generates an temperature signal corresponding to the sensed temperature;  
and

15 an evaluator circuit (12) that that receives said temperature signal  
compares said temperature signal to a lower threshold value and an upper  
threshold value, and generates an evaluation signal indicating when said  
temperature signal is between the lower temperature threshold value and  
an higher temperature threshold value.

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15. The electronic temperature switch device of claim 14, wherein the evaluator circuit has an evaluation circuit ratio independent of power supply voltage.

16. The electronic temperature switch device of claim 14, wherein the  
25 measurement circuit comprises an enhancement circuit that enhances signal-to-noise-ratio of the temperature signal for input to the evaluator circuit.

17. The electronic temperature switch device of claim 14, wherein the circuit  
(10) derives essentially all operating power from a 2-wire sense circuit.

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18. The electronic temperature switch device of claim 14, wherein the circuit  
(10) further comprises:

a loading circuit (13) that in response to the evaluator circuit, generates a

first pre-set output signal indicating when the temperature signal is between the lower threshold value and the higher threshold value, and a second pre-set output signal when the temperature signal is not between the lower threshold value and the higher threshold value.

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19. The electronic temperature switch device of claim 14, wherein the housing includes a body that is about 4.6 cm long, and connector tube about 1.3 cm long.

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20. An electronic temperature switch device (30), comprising:  
an electronic temperature switch circuit (10);  
a temperature sensor (54); and  
a housing (65) for housing the electronic temperature switch circuit (10)  
and at least a portion of the temperature sensor (54);  
wherein the electronic temperature switch circuit (10), includes:

15

a measurement circuit (11) that measures temperature and  
generates an temperature signal corresponding to the sensed temperature;

20

an evaluator circuit (12) that that receives said temperature signal  
compares said temperature signal to a lower threshold value and an upper  
threshold value, and generates an evaluation signal indicating when said  
temperature signal is between the lower temperature threshold value and  
an higher temperature threshold value; and

25

a loading circuit (13) that in response to the evaluator circuit,  
generates a first pre-set output signal indicating when the temperature  
signal is between the lower threshold value and the higher threshold value,  
and a second pre-set output signal when the temperature signal is not  
between the lower threshold value and the higher threshold value; and

30

wherein the evaluator circuit has an evaluation circuit ratio independent of power  
supply voltage, the measurement circuit enhances signal-to-noise-ratio of the  
temperature signal for input to the evaluator circuit, and the electronic temperature  
switch circuit derives essentially all operating power from a 2-wire sense circuit.

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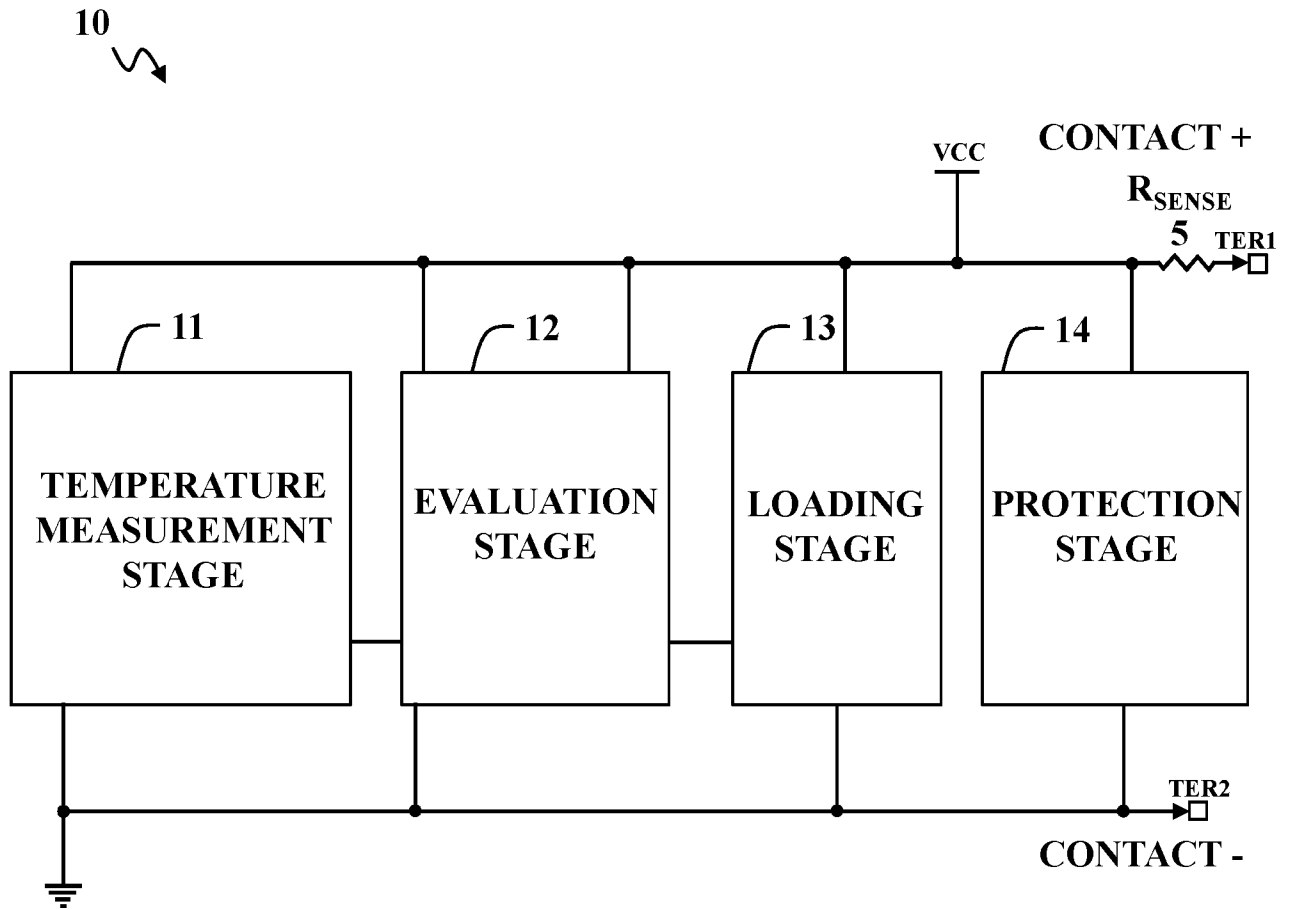


FIG. 1

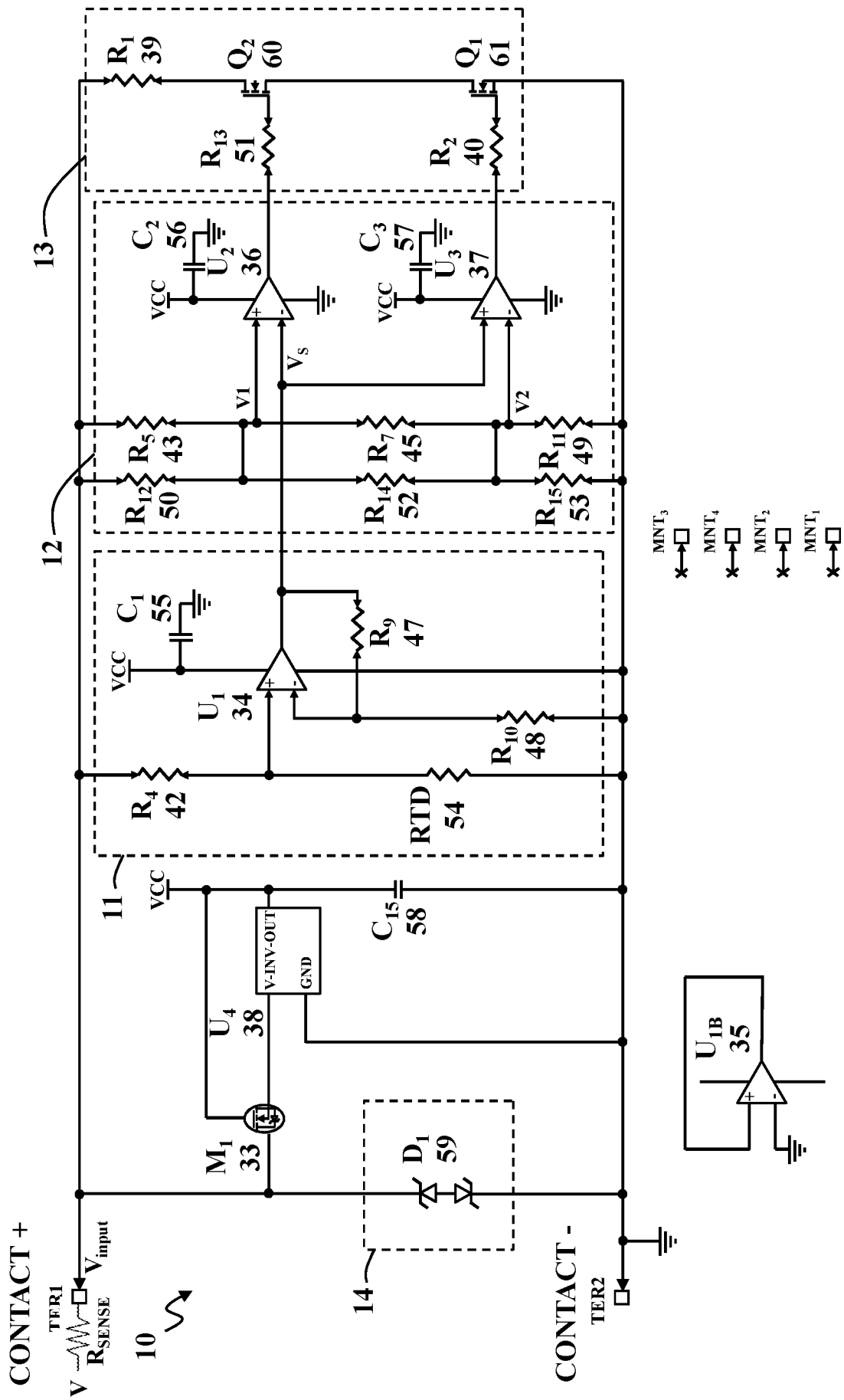


FIG. 2

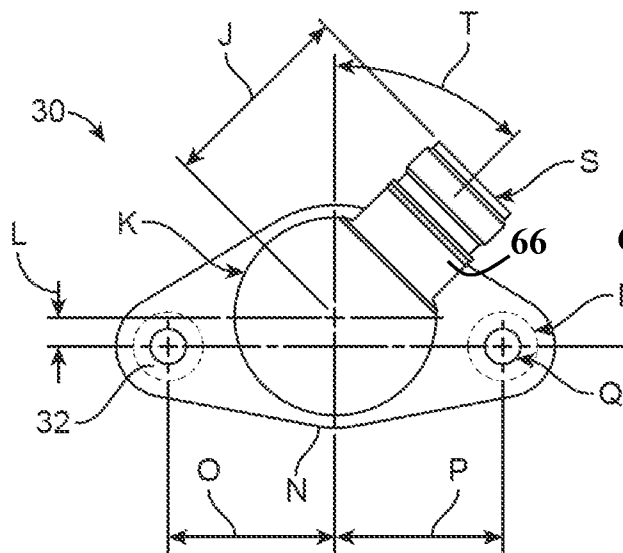


FIG. 3A

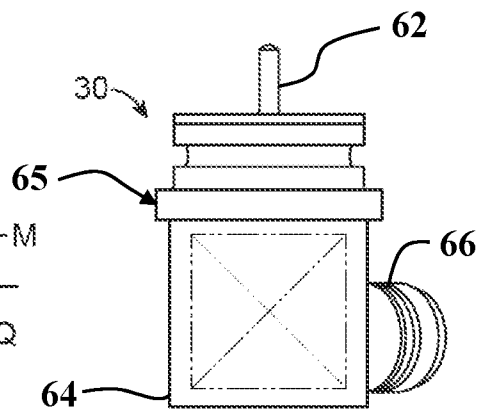


FIG. 3B

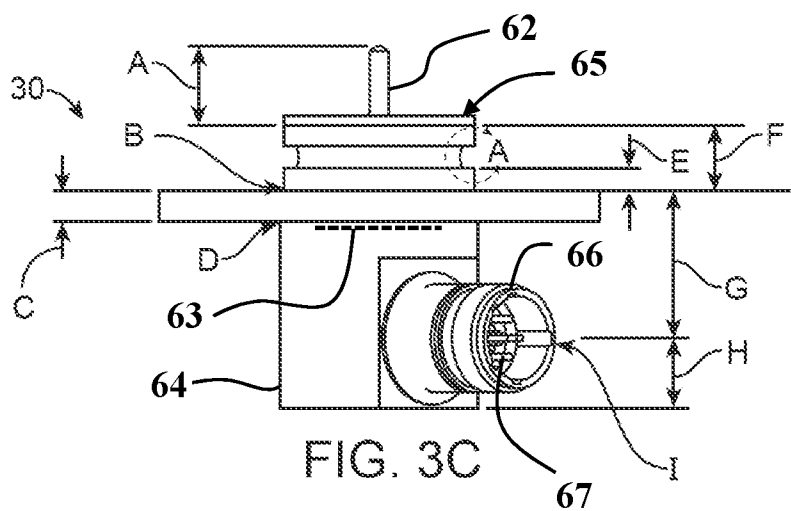
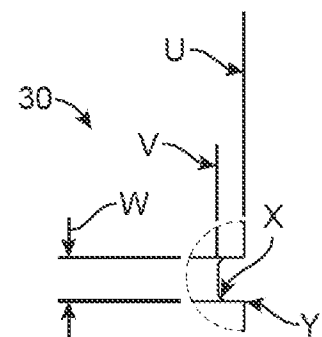


FIG. 3C



## DETAIL A

FIG. 3D

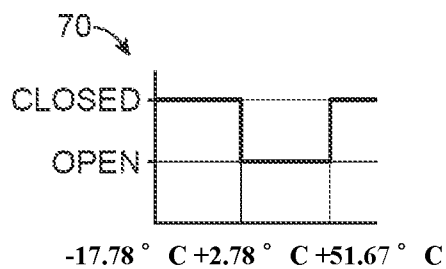
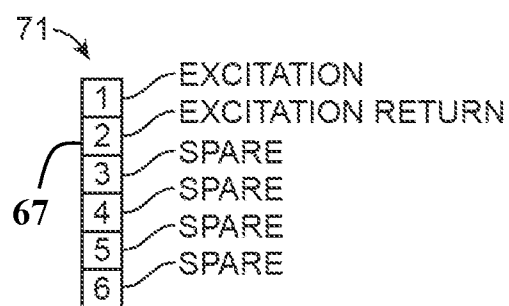


FIG. 4A



## WIRING DIAGRAM

FIG. 4B

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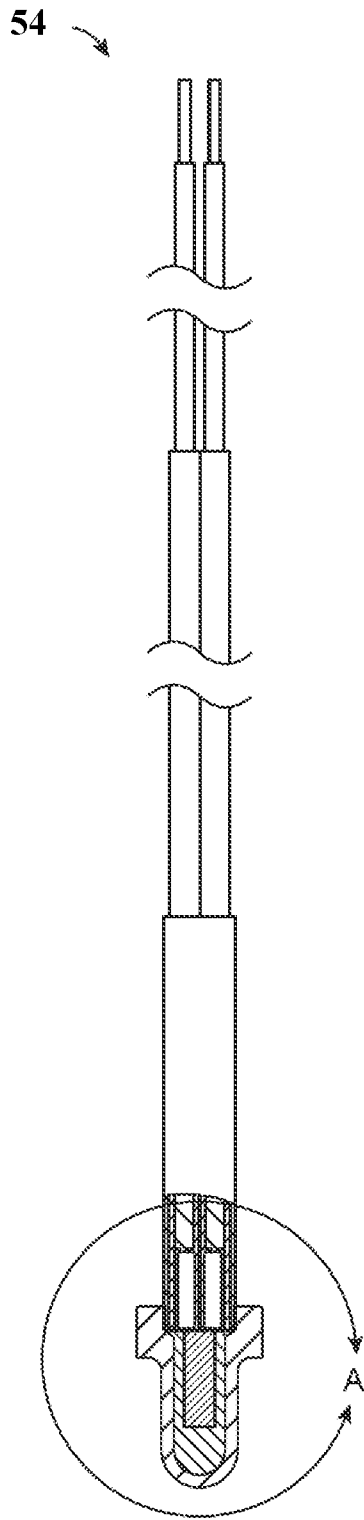
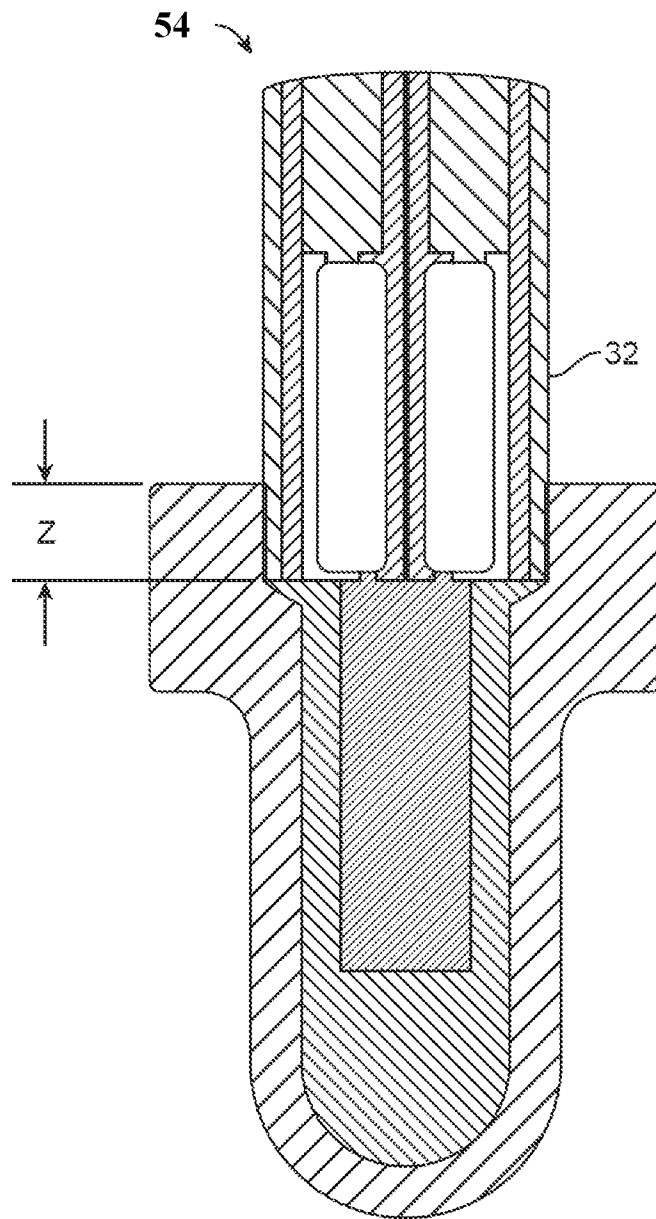


FIG. 5A



DETAIL A

FIG. 5B

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2016/036477

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01K 7/02; F22B 35/00; G01F 1/68; G01K 7/01; G11C 7/04; H01H 37/14 (2016.01)

CPC - H02H 5/047; H02H 5/042; H02H 5/044; H02H 5/046; H02H 5/048 (2016.05)

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC - F22B 35/00; G01F 1/68; G01K 7/01; G01K 7/02; G11C 7/04; H01H 37/14; H02H 3/36; H02H 5/04; H04J 7/00

CPC - H02H 5/042; H02H 5/044; H02H 5/046; H02H 5/047; H02H 5/048

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 337/298; 337/333; 337/376; 337/401; 365/211; 365/212; 702/127; 702/130; 702/182; 702/183; 702/189; 702/190  
702/191; 702/193 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Orbit, Google Patents, Google

Search terms used: temperature, thermal, switch, comparator, operational amplifier, differential amplifier, window, threshold, reference, set point, operating range, operating region, operating zone FET, MOSFET, transistor, thermocouple, liquid, fluid, water

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                     | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2004/0008460 A1 (ENGEL) 15 January 2004 (15.01.2004) entire document                                                                                                                                                                                                                                                                                                                | 1-20                  |
| Y         | COOK, G. Forrest. 12 volt differential temperature controller. 08 January 2012 (08.01.2012) [retrieved on 2016-08-02]. Retrieved from the Internet: <URL: <a href="http://www.solarb.com/elect/solarcirc/diftemp2/">http://www.solarb.com/elect/solarcirc/diftemp2/</a> >. entire document                                                                                             | 1-20                  |
| Y         | US 2014/0230543 A1 (EATON CORPORATION) 21 August 2014 (21.08.2014) entire document                                                                                                                                                                                                                                                                                                     | 4, 5, 17, 20          |
| A         | ECIRCUIT CENTER. BJT Differential Amplifier. 17 December 2014 (17.12.2014) [retrieved on: 08.02.2016] Retrieved from the Internet: <URL: <a href="http://www.ecircuitcenter.com/Circuits/BJT_Diffamp1/BJT_Diffamp1.htm">http://www.ecircuitcenter.com/Circuits/BJT_Diffamp1/BJT_Diffamp1.htm</a> >. entire document                                                                    | 3, 11, 16, 20         |
| A         | Learning About Electronics. 25 June 2013 (25.06.2013) [retrieved on 2016-08-02]. Retrieved from the Internet: <URL: <a href="https://web.archive.org/web/20130625075829/http://www.learningaboutelectronics.com/Articles/Diode-resistance.php">https://web.archive.org/web/20130625075829/http://www.learningaboutelectronics.com/Articles/Diode-resistance.php</a> >. entire document | 7                     |
| A         | TEXAS INSTRUMENTS. LM324-Quadruple Operational Amplifier. 27 February 2015 (27.02.2015) [retrieved on 2016-08-02]. Retrieved from the Internet: <URL: <a href="http://www.ti.com/product/lm324">http://www.ti.com/product/lm324</a> >. entire document                                                                                                                                 | 11                    |
| A         | US 4,282,718 A (KOUNTZ et al) 11 August 1981 (11.08.1981) entire document                                                                                                                                                                                                                                                                                                              | 1-20                  |
| A         | US 6,512,444 B1 (MORRIS, JR. et al) 28 January 2003 (28.01.2003) entire document                                                                                                                                                                                                                                                                                                       | 1-20                  |
| A         | WO 89/01132 A1 (SOLID STATE FLOWMETERS PTY LTD) 09 February 1989 (09.02.1989) entire document                                                                                                                                                                                                                                                                                          | 1-20                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search

03 August 2016

Date of mailing of the international search report

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