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(54) **WETTING CURRENT DIAGNOSTICS**

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G01R 19/165	(2006.01)
G01R 31/50	(2020.01)
H03K 17/18	(2006.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC G01R 31/3278; G01R 19/16571; G01R 31/3277; G01R 31/025; H03K 17/18; H03K 2217/0027

USPC 324/418

See application file for complete search history.

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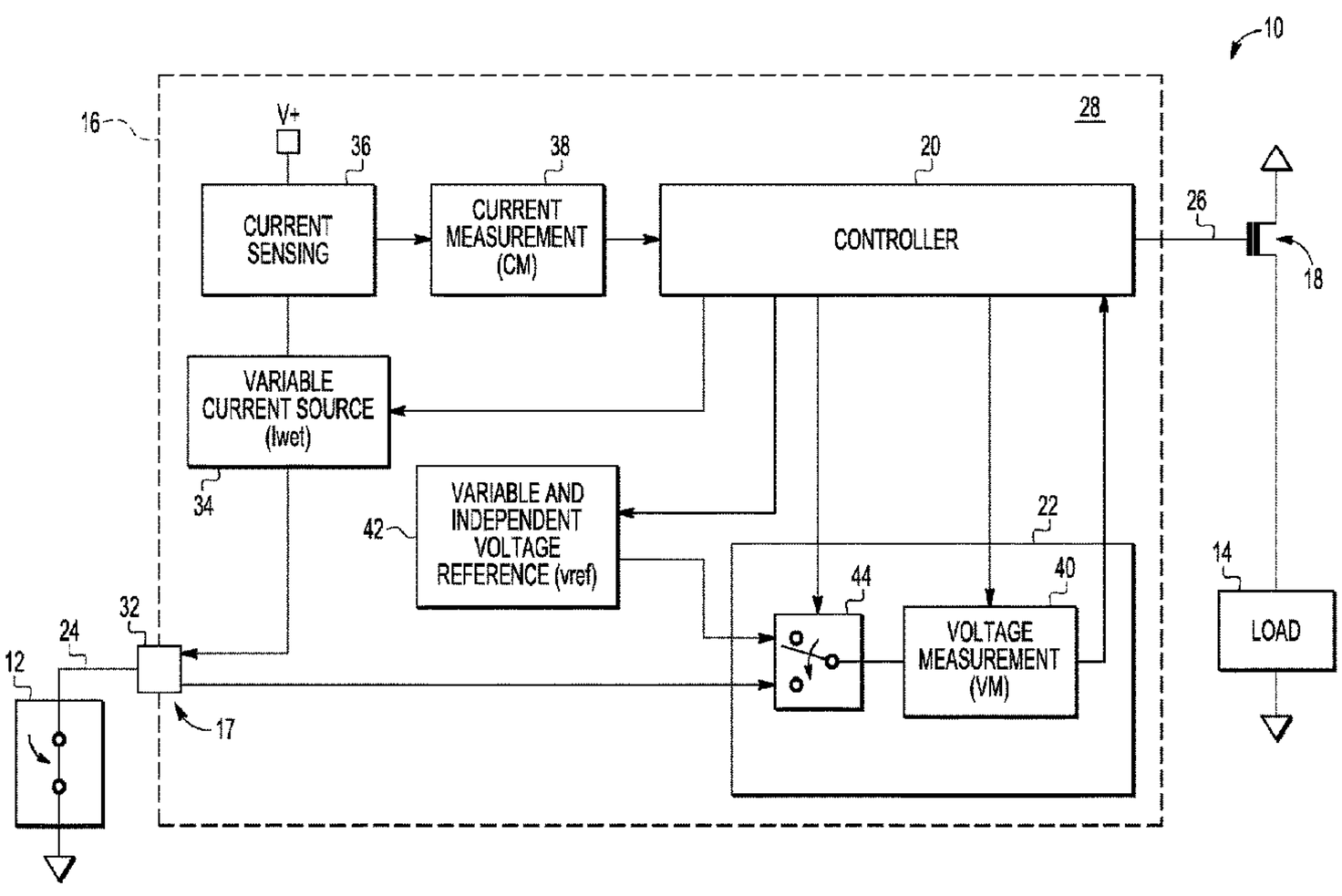
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Primary Examiner — Christopher P McAndrew

(57) **ABSTRACT**

A circuit for diagnostic testing includes a current source coupled to a power source and configured to provide wetting current along a path to a load control switch, a current sensor connected in series with the current source along the path, the current sensor being configured to generate a current sensor signal indicative of a current level along the path, a voltage measurement unit having an input terminal coupled to a node along the path through which the wetting current flows to reach the load control switch, the voltage measurement unit being configured to detect a state of the load control switch based on a voltage at the node, and a controller coupled to the current sensor and the voltage measurement unit, the controller being configured to determine a wetting current diagnostic condition in accordance with the current level and the detected state.

18 Claims, 4 Drawing Sheets



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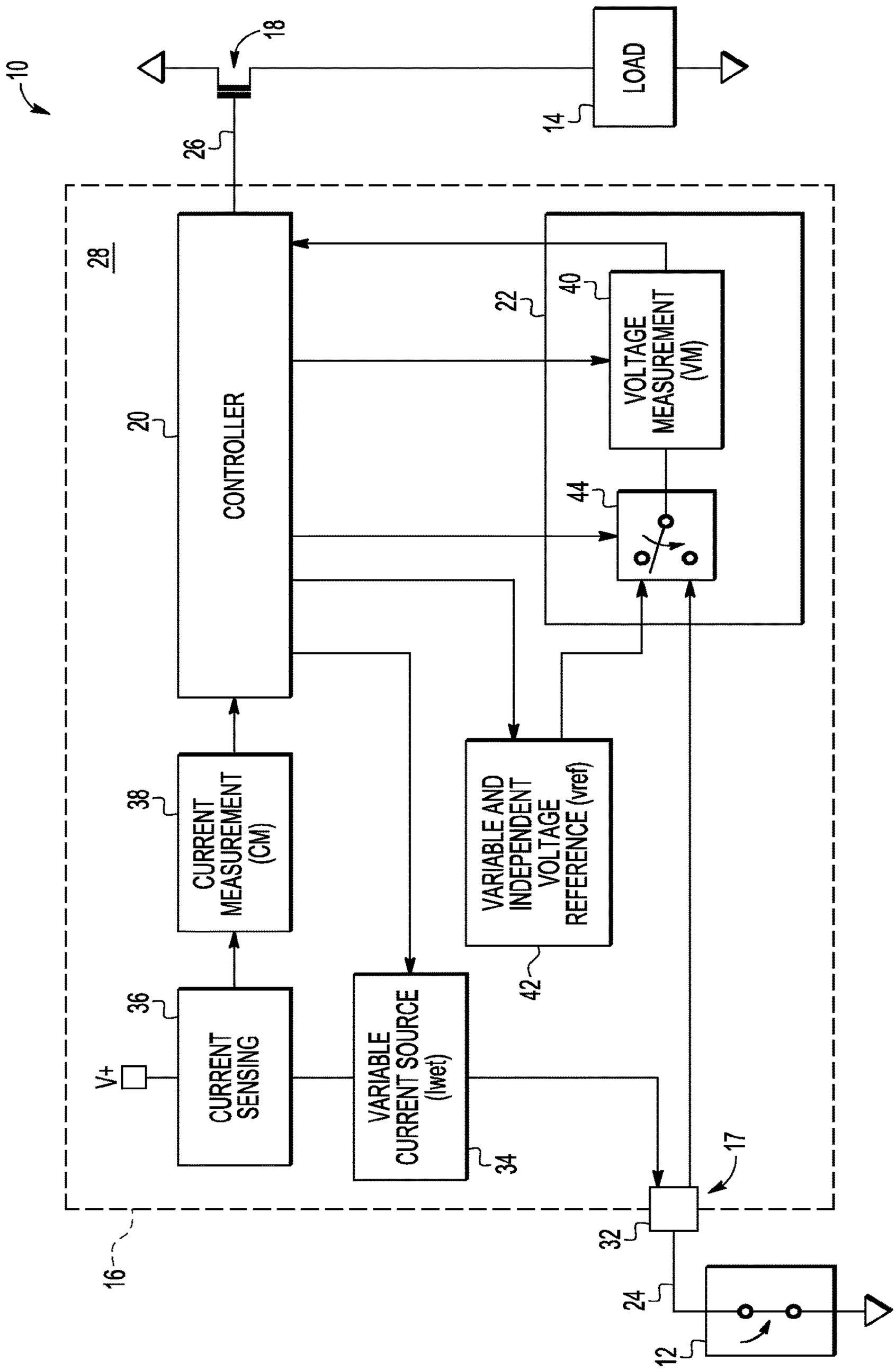

10
18
LOAD
14
26
28
20
CONTROLLER
22
40
VOLTAGE MEASUREMENT (VM)
44
38
CURRENT MEASUREMENT (CM)
VARIABLE AND INDEPENDENT VOLTAGE REFERENCE (vref)
42
36
V+
CURRENT SENSING
VARIABLE CURRENT SOURCE (Iwet)
34
17
32
16
24
12

FIG. 1

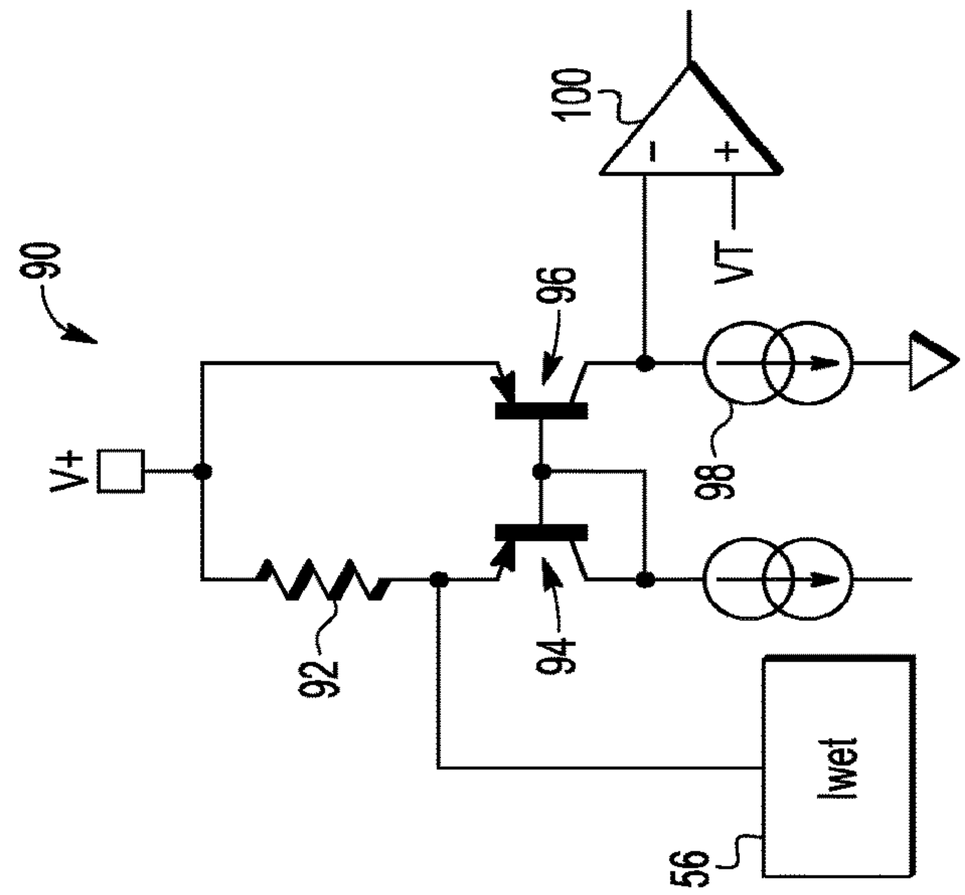


FIG. 4

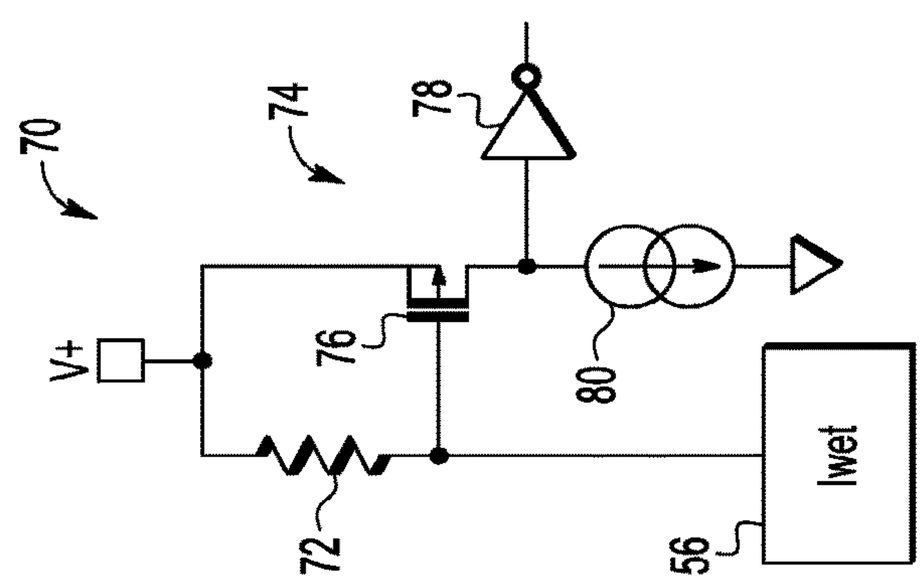


FIG. 3

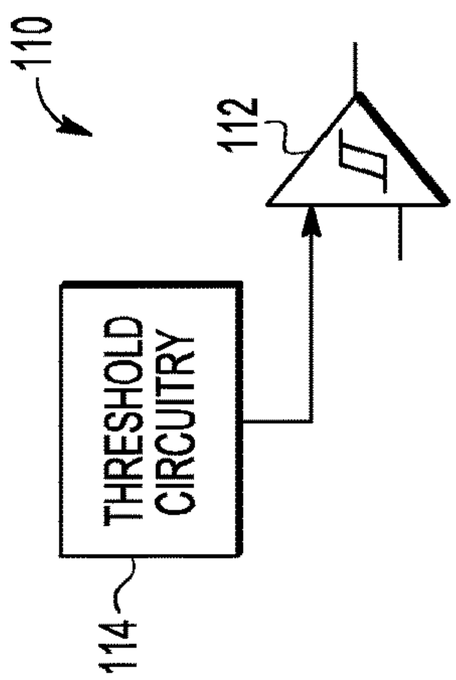


FIG. 5

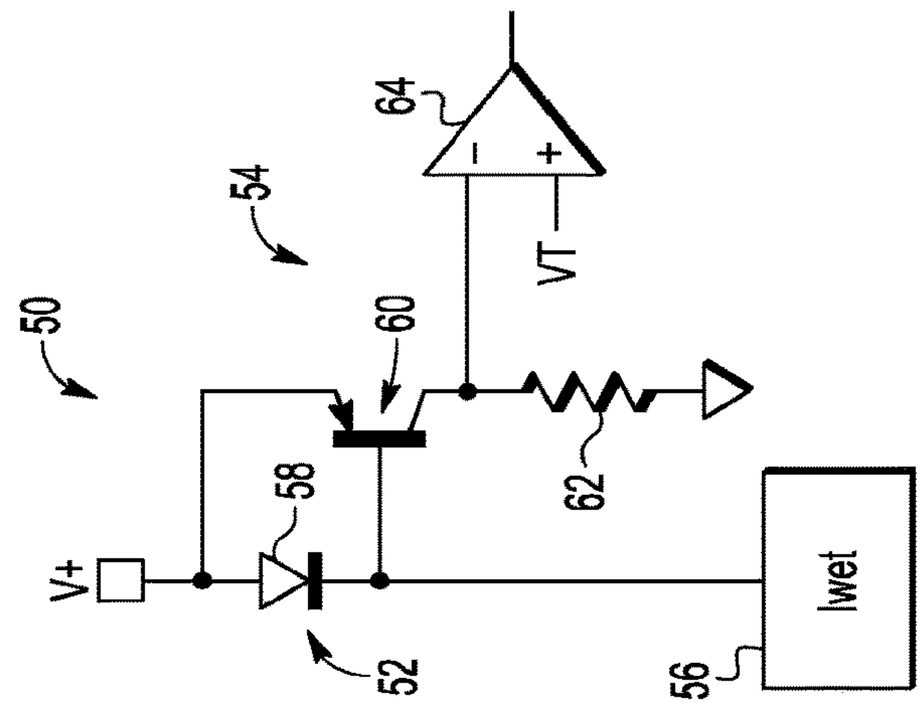


FIG. 2

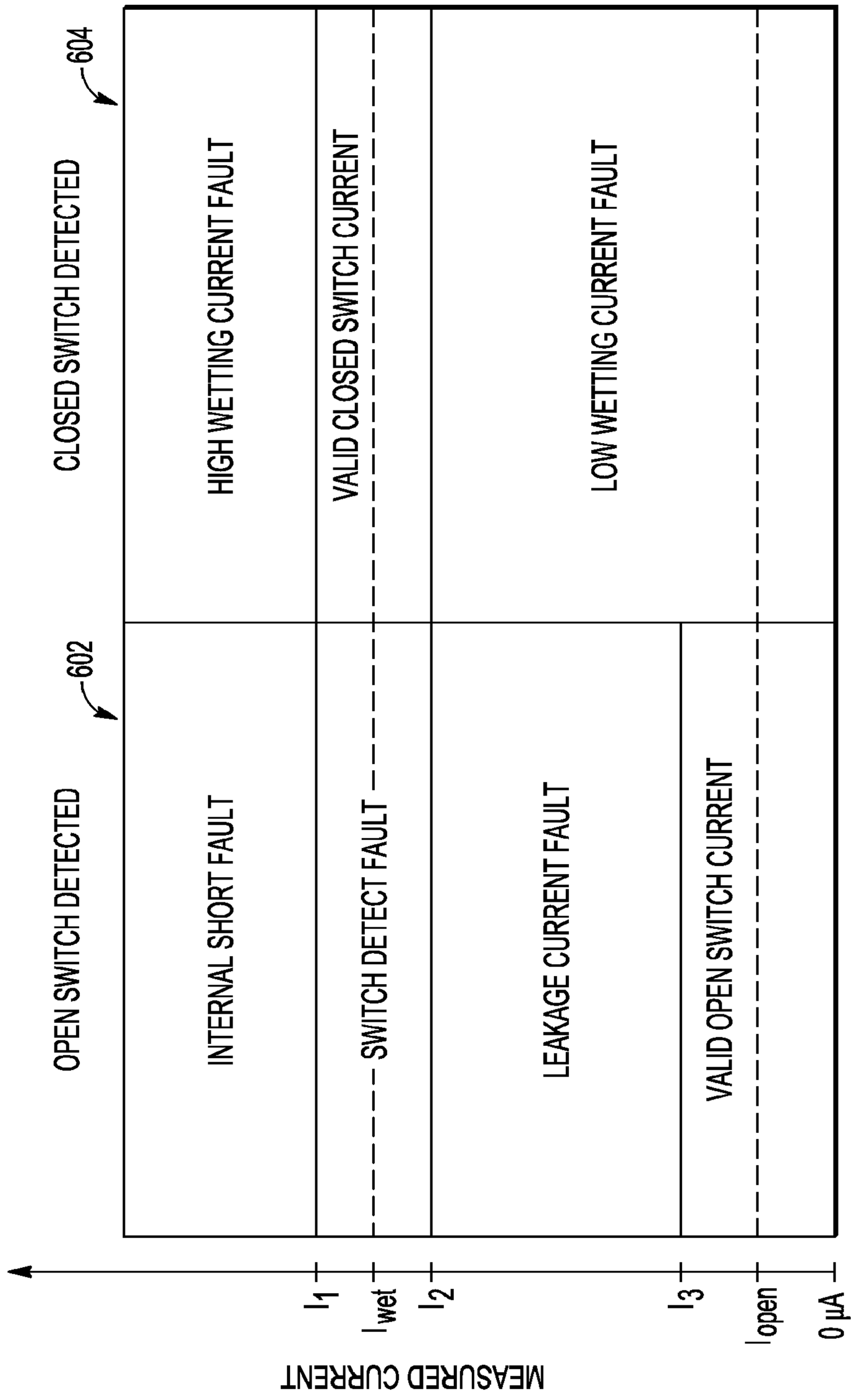

600
602
604
OPEN SWITCH DETECTED
CLOSED SWITCH DETECTED
INTERNAL SHORT FAULT
SWITCH DETECT FAULT
LEAKAGE CURRENT FAULT
VALID OPEN SWITCH CURRENT
HIGH WETTING CURRENT FAULT
VALID CLOSED SWITCH CURRENT
LOW WETTING CURRENT FAULT
I_1
I_{wet}
I_2
I_3
I_{open}
0 µA
MEASURED CURRENT

FIG. 6

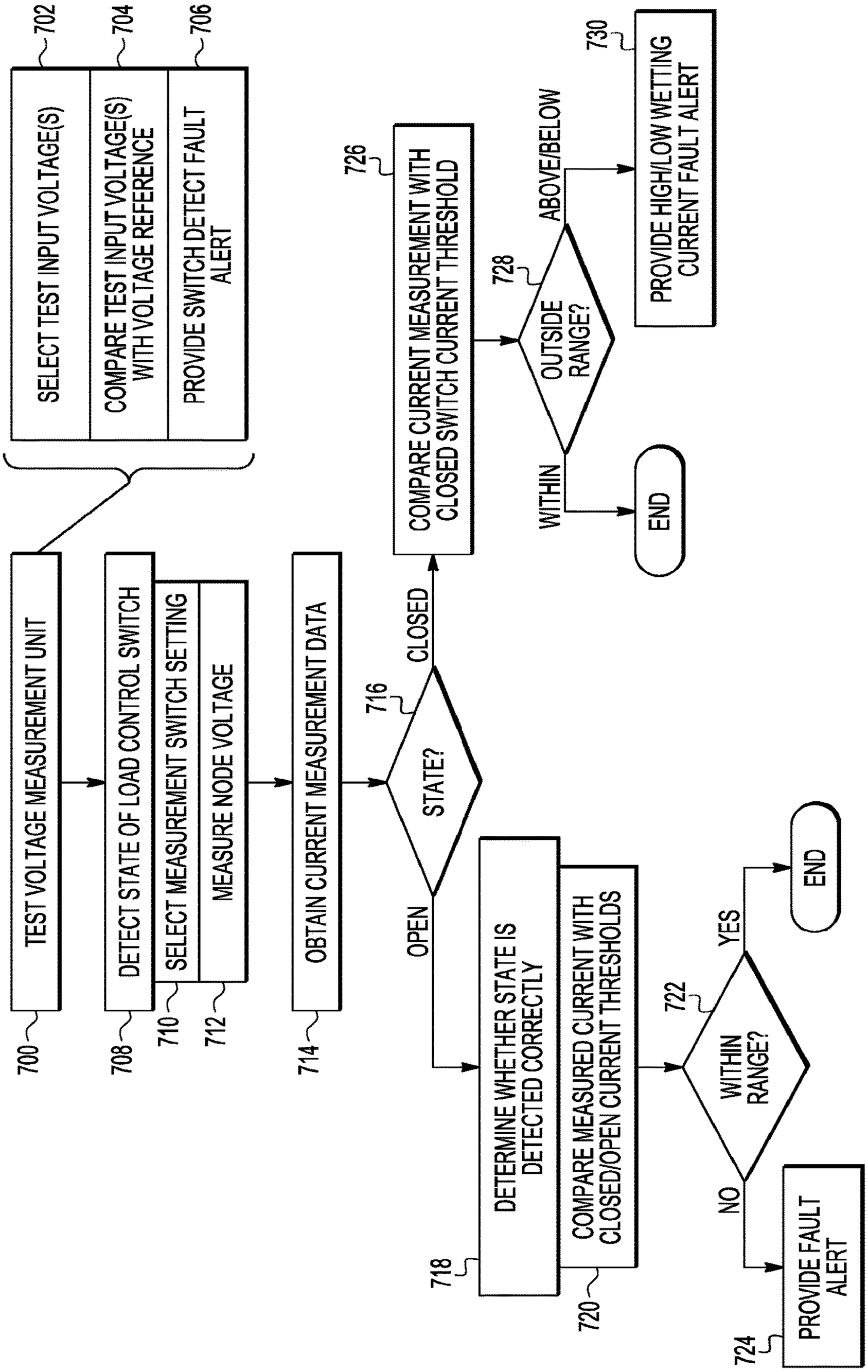

700
TEST VOLTAGE MEASUREMENT UNIT
708
DETECT STATE OF LOAD CONTROL SWITCH
710
SELECT MEASUREMENT SWITCH SETTING
712
MEASURE NODE VOLTAGE
714
OBTAIN CURRENT MEASUREMENT DATA
716
STATE?
OPEN
CLOSED
718
DETERMINE WHETHER STATE IS DETECTED CORRECTLY
720
COMPARE MEASURED CURRENT WITH CLOSED/OPEN CURRENT THRESHOLDS
722
WITHIN RANGE?
NO
YES
724
PROVIDE FAULT ALERT
END
726
COMPARE CURRENT MEASUREMENT WITH CLOSED SWITCH CURRENT THRESHOLD
728
OUTSIDE RANGE?
ABOVE/BELOW
WITHIN
730
PROVIDE HIGH/LOW WETTING CURRENT FAULT ALERT
END
702
SELECT TEST INPUT VOLTAGE(S)
704
COMPARE TEST INPUT VOLTAGE(S) WITH VOLTAGE REFERENCE
706
PROVIDE SWITCH DETECT FAULT ALERT

FIG. 7

WETTING CURRENT DIAGNOSTICS

RELATED APPLICATION

This patent application is a divisional of co-pending, U.S. patent application Ser. No. 14/624,778, filed on Feb. 18, 2015.

FIELD OF INVENTION

The present embodiments relate to sensed switching.

BACKGROUND

Sensed switches are often used to control the operation of loads instead of powered switches. Powered switches are disposed serially with a load to directly control current delivered to the load. In contrast, sensed switches control the load current indirectly. The state of the switch is instead sensed with a low current signal. The opportunity to use a low current voltage measurement leads to reduced wiring harness complexity, weight, and costs. In complex electrical systems with numerous switch-controlled loads, such as automobile vehicles, the cost savings may be considerable.

Determining the state of a sensed switch typically involves a voltage comparison. For example, a voltage level dictated by the state of the switch is compared with a threshold voltage. The voltage level is ideally not dependent on the voltage drop across the switch contacts. But unfortunately, the switch contacts oxidize over time due to humidity and contamination, increasing the resistance presented by the switch itself. The increased resistance results in an increased sensed voltage, thereby increasing the risk of incorrect operation. Switch contact oxidation may be especially challenging in connection with normally open switches, i.e., switches with contacts that close upon application of an external force.

The oxidation challenge presented by sensed switches is not applicable to the powered switch approach. In powered switches, the current levels are high enough to burn off any oxidation of the switch contacts. Because the current levels may be much lower with sensed switches, a wetting current is used to remove the oxidation from the switch contacts. The wetting current is typically a temporary current level of the current that flows through the switch contacts when the switch transitions from open to closed. The temporary current level is sufficient to remove the oxidation. A circuit used to detect the state of the switch may also be configured to control the application of the wetting current.

Unfortunately, over time, faults may develop along the current path to the switch. For example, a fault may arise in the wiring harness between the control circuit and the switch. Some faults may inhibit the delivery of the wetting current to the switch.

BRIEF DESCRIPTION OF THE DRAWINGS

The components and the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the various embodiments. Moreover, in the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. **1** is a schematic circuit diagram of an exemplary circuit configured to provide wetting current diagnostics for an external load control switch in accordance with one embodiment.

FIGS. **2-4** are schematic circuit diagrams of exemplary current sensor and measurement units of the circuit of FIG. **1** in accordance with various embodiments.

FIG. **5** is a schematic circuit diagram of an exemplary voltage measurement unit of the circuit of FIG. **1** in accordance with one embodiment.

FIG. **6** is a graphical representation of exemplary current level ranges associated with a number of valid and fault operating conditions in accordance with one embodiment.

FIG. **7** is a process flow diagram of an exemplary method of wetting current diagnostics testing in accordance with one embodiment.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

Embodiments of methods, circuits, and other devices or units for wetting current diagnostic testing are described. The diagnostic testing may be directed to determining or confirming that a wetting current for a load control switch flows when the load control switch is closed. The method may be implemented by a circuit or other unit or device directed to sensing the state of the switch. The wetting current diagnostic testing circuitry may be integrated with circuitry configured to detect the state of the load control switch and/or provide the wetting current. The devices, units, or circuits described herein may thus provide the capability for built-in self testing.

The diagnostic testing may be correlated with the state of the load control switch (e.g., open or closed). The correlation may involve detecting the state of the load control switch and/or the condition when wetting current is flowing. The diagnostic testing may be configured such that the wetting current may be detected when (e.g., only when) the load control switch is closed. In these and other ways, the testing may distinguish between wetting current and other current flows. Additional aspects of the diagnostic testing may involve other examples of coordinated voltage and current measurements. Through such coordination, diagnostic testing may be implemented when the load control switch is open. Such testing may include, for example, diagnosing the operation of a voltage measurement unit and/or diagnosing a leakage current fault condition and/or one or more other open switch fault conditions.

The disclosed embodiments may have a circuit topology that senses current along the current path to the load control switch. A variety of different current sensors may be used. The sensed current may be measured against multiple current thresholds.

The diagnostic testing may be directed to detecting, and differentiating between, several different fault conditions. Exemplary fault conditions include high and low wetting current faults, a switch detection fault, a leakage fault, and a system (e.g., voltage) offset fault. The fault conditions may involve both current and voltage measurements. Additional, alternative or fewer fault conditions may be tested. For example, in some cases, the presence of a leak is not tested.

FIG. **1** depicts an electrical system **10** in which a load control switch **12** is provided to control the operation of a load **14**. The load **14** may be a motor, lamp, or any other type of load. The load **14** may be configured for direct current (DC) or alternating current (AC) operation. In this embodiment, the load **14** is powered by a DC power source V+ that also provides power for the load control switch **12**. In other cases, different voltage sources are used. For example, the power source for the load **14** may be a high voltage AC power source, and the power source for the load control

switch **12** may be a low voltage DC power source, which may or may not be derived from or otherwise related to the high voltage AC power source.

In some cases, the electrical system **10** is a vehicular electrical system. The DC power source V+ may be a 12 Volt vehicular battery. In these and other cases, the load **14** is one of a number of loads controlled by respective load control switches **12**. The nature and characteristics of the electrical system **10** may vary considerably.

The load control switch **12** is a sensed switch. The state of the load control switch **12** determines whether power is delivered to the load **14**. As a sensed switch, the load control switch **12** is not disposed in the current path of the power delivered to the load **14**. In some cases, the load control switch **12** is a push-button switch or other normally open load control switch. For example, in vehicular embodiments, the load control switch **12** may be a push-button switch, such as a power window push-button switch, directly actuated by an operator or other occupant of the vehicle. The load control switch **12** may be actuated in a variety of other ways. For example, the load control switch **12** may be actuated through the opening of a vehicle door or other indirect actuation mechanism.

In the embodiment of FIG. **1**, the load control switch **12** is configured as a switch to ground. As a switch to ground, the closure of the load control switch **12** establishes a connection to ground. The connection to ground lowers a voltage level, which is sensed to control the delivery of power to the load **14**. In other embodiments, the load control switch **12** is configured as a switch to battery or other voltage source. The load control switch **12** may be configured to establish a connection to any reference voltage.

A control module, unit, or circuit **16** senses the connection to ground (or other voltage change) at an evaluation node **17** of the control circuit **16**. The load control switch **12** is coupled to the node **17**. During operation, a wetting current I_{wet} for the load control switch **12** flows through the node **17** when the load control switch **12** is closed. In the switch to ground example of FIG. **1**, the connection to ground lowers the voltage level at the node **17**. The control unit **16** is configured to detect the lowered voltage level at the node **17** and, thus, the state of the load control switch **12**.

The control circuit **16** controls the delivery of power to the load **14** in accordance with the state of the load control switch **12**. The control circuit **16** may thus be referred to or configured as a switch detection unit. In the switch to ground example of FIG. **1**, the control circuit **16** allows power to reach the load **14** upon detecting the lowered voltage level at the node **17**. To this end, the control circuit **16** includes a power transistor **18** that acts as a switch to allow current to flow through the load **14**.

Activation of the power transistor **18** is controlled by a logic controller **20** (or other controller) and a detection circuit **22** of the control circuit **16**. The logic controller **20** activates and deactivates the power transistor during a non-diagnostic mode of operation in response to a control signal provided by the detection circuit **22**. In the example of FIG. **1**, the logic controller **20** also controls operation of the detection circuit **22** and other components of the control circuit **16** during a diagnostic mode of operation. For example, the functioning of the control circuit **16** may be dictated by the state of the load control switch **12** in both non-diagnostic and diagnostic modes of operation.

The power transistor **18** is disposed in the current path of the load **14** rather than the load control switch **12**. In this example, the power transistor **18** is a discrete power field effect transistor (FET) device. In other examples, the power FET device is part of an integrated circuit. Other types of transistor devices may be used, such as bipolar junction transistor devices. Other types of switches may be used, including relays.

The control circuit **16** may be one of several circuits in the electrical system **10**. Multiple loads **14** may be controlled by each control circuit **16**. Some of the components of the control circuit **16** may be replicated, with a respective instance of the component being provided for each load **14**. For example, the control circuit **16** may include multiple power transistors **18**, one for each load **14**. Alternatively, a single control circuit **16** may control multiple loads **14**.

In the example of FIG. **1**, the logic controller **20**, the detection circuit **22**, and other components of the control circuit **16** are disposed on a single integrated circuit (IC) chip **28**. In other cases, multiple IC chips may be used. For example, the logic controller **20** and the detection circuit **22** may be disposed on respective IC chips. The logic controller **20**, the detection circuit **22**, the FET device **18**, and any other components of the control unit **16** may be mounted on a common circuit board, and/or disposed in a common housing, and/or otherwise integrated in any other manner or to any other desired extent. The load control switch **12** and the load **14** may be external to the board or housing of the control unit **16**, or be otherwise disposed remotely from the control unit **16**. Wiring **24**, **26** may be used to establish connections between the control unit **16** and the load control switch **12** and the load **14**, respectively. For example, a wiring harness may be used to carry the wiring **24**, **26** from a door, dashboard, or other panel or portion of a vehicular interior, to another location in the vehicle at which the control unit **16** is located, such as an electronics cabinet under the dashboard. The manner in which the load control switch **12** and the load **14** are connected to the control unit **16** may vary. For example, components in addition to the wiring harness may be used, including, for instance, fuses.

The length of the wiring **24** may be sufficiently extensive to present significant parasitic capacitance and resistance. In some cases, one or more external capacitors and/or one or more external resistors are disposed in series with the wiring **24**. For example, a series resistor may be included for purposes of electrostatic discharge (ESD) protection.

The wiring **24** couples the load control switch **12** to a pin **32** of the control circuit **16**. The pin **32** may be one of a set of pins of the IC chip in which the control circuit **16** is integrated. The packaging of the control circuit **16** and the components thereof may vary. The nature of the pin **32** may thus be configured as a post, solder bump, or other connection point of the packaging of the detection circuit **22**. In the embodiment of FIG. **1**, the pin **32** corresponds with the node **17**. The pin **32** and the node **17** may thus be disposed at the same voltage level. In other cases, the node **17** and the pin **32** may not constitute a common node. For example, a series resistor may be disposed between the node **17** and the pin **32**.

The logic controller **20** may be configured to implement a number of logic functions. The functions include controlling the power transistor **18**. To that end, a control signal may be generated by the control circuit **20** and provided to a gate or other control terminal of the power transistor **18**. The functions also include analysis of the state of the load control switch **12**. The state of the load control switch **12** is used to determine whether to generate or change the control signal to the power transistor **18**. The logic controller **20** and the detection circuit **22** are also responsive to the state of the load control switch **12** to provide the wetting current.

The logic controller **20** performs functions directed to wetting current diagnostics. The logic controller **20** may

implement one or more diagnostic routines of the wetting current function as described below. Each function or routine may be implemented by a separate logic block, software or firmware module, or other component of the logic controller **20**. The logic blocks or other components of the logic controller **20** directed to implementing these functions may be integrated to any desired extent. For example, a single routine may be implemented by the logic controller **20** to provide all of the functions.

The control circuit **16** includes a current source **34** coupled to a power source V+. The current source **34** is configured to provide the wetting current along a path to the load control switch **12**. The current source **34** may be a variable current source to provide different levels of current to the load control switch **12**, including, for instance, wetting and sustaining current levels. Any number of current levels may be supported. The current source **34** may be or include an active circuit, such as current amplifier or other active current source circuit. In other cases, the current source **34** may be or include a passive circuit, such as a resistor or resistor network.

The control circuit **16** includes a current sensor **36** connected in series with the current source **34** along the path to the load control switch **12**. The current sensor **36** generates a signal (e.g., a voltage signal) indicative of the current flowing along the path to the load control switch **12**. In this example, the current sensor **36** is disposed between the current source **34** and the power source V+. In other cases, the current sensor **36** is disposed between the current source **34** and the pin **32**. The relative positions of the current source **34** and the current sensor **36** along the path may thus vary from the example shown.

The current sensor **36** may include an active circuit, examples of which are provided in connection with FIGS. **2-4**. In the example of FIG. **1**, the logic controller **20** provides a current control signal to the current source **34** to establish the current level. Alternatively or additionally, the current sensor **36** may be or include a passive circuit, such as a resistor. The voltage generated across the resistor is indicative of the current flowing along the path to the load control switch **12**. In some cases, the same resistor(s) may serve as both the current source **34** and the current sensor **36**.

In the embodiment of FIG. **1**, the control circuit **16** also includes a current measurement unit **38** coupled to the current sensor **36** to receive the current sensor signal. The current measurement unit **38** compares the current level indicated by the current sensor signal with one or more threshold current levels. The current measurement unit **38** is configured to generate one or more output signals indicative of the comparison(s). The output signal(s) may be provided to the logic controller **20**. The current measurement unit **38** may be integrated with the current sensor **36** and/or the logic controller **20** to any desired extent. For example, the logic controller **20** may include a comparator, analog-to-digital convertor, and/or other circuitry to perform the comparison(s). Examples of current measurement units **38** are shown and described in connection with FIGS. **2-4**.

The detection circuit **22** includes a voltage measurement unit **40** to detect the closure of the load control switch **12**. The voltage measurement unit **40** has an input terminal coupled to the node **17** (e.g., the pin **32**). The voltage measurement unit **40** is configured to detect a state of the load control switch **12** based on a voltage at the node **17**. An output signal indicative of the state of the load control switch **12** (and/or the measured voltage) is provided by the voltage measurement unit **40** to the logic controller **20**.

The voltage at the node **17** may be compared to a reference voltage level. In some cases, a source of the reference voltage is coupled to another input terminal of the voltage measurement unit **40**. In such cases, the voltage measurement unit may include a comparator, as shown in the example of FIG. **5**. Alternatively, the reference voltage may be compared to an internal or inherent reference voltage level. For example, the voltage measurement unit **40** may include an analog-to-digital converter.

The logic controller **20** is coupled to the current sensor **36** and the current measurement unit **38** to receive a signal indicative of the current level along the wetting current path. The logic controller **20** is configured to determine a wetting current diagnostic condition in accordance with the current level. The wetting current diagnostic condition may be determined relative to one or more threshold current levels. For example, a desired range for the wetting current may be specified via two threshold current levels. The logic controller **20** may then provide a low current fault alert if the current level falls below the current range, and provide a high current fault alert if the current level is above the range. Alternatively, the current range may be specified by a single threshold current level along with an acceptable amount of deviation above and below the threshold current level, such as plus or minus 1 milliamp.

The logic controller **20** is also coupled to the voltage measurement unit **40** to provide the wetting current diagnostics in accordance with the detected state. The wetting current diagnostic condition may thus be based on both the output signal from the voltage measurement unit **40** as well as the output generated by the current sensor **36**. For example, the logic controller **20** may be configured to implement one or more diagnostic routines (a first set) when the voltage measurement unit **40** detects that the state of the load control switch **12** is open, and then one or more diagnostic routines (a second set) when the state of the load control switch **12** is closed. As described below, the first set may be configured to confirm a low current level with an open switch, and to determine whether the state of the load control switch is detected correctly. The second set may be configured to compare the current level with the threshold current level(s).

The correlation between the voltage and current measurements may be based on the following assumptions, or desired or expected operational characteristics. Little to no current is expected when the load control switch **12** is open (i.e., open switch testing in the first set). For example, any current level below about 50 microAmperes for a 12 Volt automotive system may be considered acceptable. A desired level of wetting current is expected when the load control switch **12** is closed (i.e., closed switch testing in the second set). The diagnostic routines may be configured to implement the open switch testing first, e.g., as a preliminary matter to confirm that the switch state is being detected properly.

FIG. **6** is a chart **600** depicting one example of how the logic controller **20** correlates operation of the voltage measurement unit **40** and the current measurement unit **38**. Details regarding the open switch testing in the first set is shown in a column **602**. Details regarding the closed switch testing in the second set is shown in a column **604**. Various fault conditions may be identified in each set based on the measured current level.

The diagnostic routine(s) in the open switch testing may proceed as follows. While receiving an indication of an open state of the load control switch **12**, the logic controller **20** may provide a switch detection fault if the current level falls

between a current threshold I_1 and a current threshold I_2. Measured current levels between the current thresholds I_1 and I_2 are within a range of an expected wetting current level I_{wet} (i.e., the current level expected to be reached with the load control switch **12** closed). The logic controller **20** may be configured to interpret current levels within that range as indicative of the voltage measurement unit **40** and/or some related component of the control circuit **16** falsely indicating switch closure. Alternatively or additionally, the current levels in that range may be considered the result of an internal short. In the example of FIG. **6**, however, the logic controller **20** provides an internal short fault if the current level exceeds the current threshold I_2.

The diagnostic routine(s) in the open switch testing may also attempt to identify one or more additional fault conditions. In the example of FIG. **6**, the logic controller **20** tests for a leakage current fault condition in which current levels fall between threshold current levels I_2 and I_3 correspond with the leakage current fault condition. The threshold current level I_3 corresponds with the maximum current allowed with the load control switch **12** open. Alternatively, a leakage current fault is found when the measured current exceeds the threshold current level I_3. The threshold current level I_3 may be greater than a valid (or desired) open switch current level I_{open} to account for noise or other factors. The leakage current fault may be indicative of leakage current occurring at some point downstream of the current sensor **36**.

The diagnostic routines in the closed switch testing may also involve one or more threshold current levels. The threshold current levels may correspond with the threshold current levels used in connection with the open switch testing. In other cases, one or more different threshold current levels are used. In the example of FIG. **6**, the threshold current levels I_1 and I_2 are used to distinguish between valid closed switch current and two different fault conditions. A low wetting current fault is generated or provided when measured currents fall below the threshold current level I_2. A high wetting current fault is generated or provided when measured currents are above the threshold current level I_1. The threshold current levels I_1 and I_2 may thus define a range of acceptable wetting current levels. The threshold current levels may be spaced from the desired or optimal closed switch current level I_{wet} to account for noise or other factors. In other embodiments, the range of acceptable current levels is established by the closed switch current level I_{wet} and an acceptable offset amount.

The control circuit **16** and the logic controller **20** may also be configured to test the voltage measurements apart from the current measurements. In the example of FIG. **1**, the control circuit **16** includes a voltage reference source **42** and a switch **44** that selectively couples the voltage reference source **42** to the voltage measurement unit **40**. The logic controller **20** may be configured to select a state of the switch **44**. In the example of FIG. **1**, the switch **44** is controlled with a switch control signal generated by the logic controller **20**. During normal operation, the switch **44** is positioned to couple an input terminal of the voltage measurement unit **40** to the pin **32** and, thus, the node **17**. During testing, the switch **44** is positioned to couple the input terminal of the voltage measurement unit **40** to the voltage reference source **42**.

The voltage measurement testing may include one or more voltage reference levels. For example, the voltage reference source **42** may be configured to generate multiple reference voltages (e.g., 3 and 6 Volts). The logic controller **20** may select one of the reference voltages or otherwise direct the operation of the voltage reference source **42** via a reference control signal, as shown in FIG. **1**. The reference voltages may be independently generated from the power source so that any faults in the other components of the control circuit **16** are not introduced into the voltage measurement testing. The reference control signal may specify a reference voltage level from a predetermined set of discrete reference voltage levels or from a continuous range of reference voltage levels.

The logic controller **20** and the detection circuit **22** may be integrated to any desired extent. For example, a comparator and/or other circuitry of the detection circuit **22** may be integrated with the logic controller **20**. In some cases, a microcontroller, such as a mixed signal FPGA, may include both an analog-to-digital converter to act as the voltage measurement unit **40** and/or one or more logic blocks to implement the logic functionality of the logic controller **20**.

Additional functions may also be provided by the logic controller **20**. For example, the control circuit **20** may be configured to select one of multiple levels of the current to be provided to the load control switch **12**. The wetting current is provided to the load control switch **12** to burn off the oxidation on the contacts of the load control switch **12**. After the wetting current is applied for a period of time, the logic controller **20** may be configured to lower the current level for, e.g., power savings. The lower current level may be associated with, or configured as, a sustaining current, i.e., a current level sufficient to maintain the closed state of the load control switch **12**. Multiple sustaining current levels (or other current levels) may be used. Other aspects of the wetting current may be controlled, including, for instance, the duration of application of the wetting current. In other cases, the duration and/or other aspects of the wetting current are determined passively. The term wetting current is used herein to refer to either the current and/or voltage level sufficient to remove the oxidation, but the actual level, duration, and/or other characteristics of the wetting current may vary.

The logic controller **20** may be or include a microcontroller or other controller, or a general microprocessor or an application-specific microprocessor, such as an application-specific integrated circuit (ASIC). In other embodiments, a field-programmable gate array (FPGA) or other controller may be used as the logic controller **20**. The logic controller **20** may include one or more processors and one or more memories in which instructions to configure the processor are stored. The instructions are executed by the processor of the logic controller **20** to implement the logic used during the non-diagnostic and diagnostic modes of operation. The logic controller **20** may include any combination of firmware and general-purpose memory to store instructions to be executed during operation.

The configuration of the current source **34** may vary. For example, the current source **34** may be or include various types of pull-up circuitry to support the operation of the load control switch **12**. The pull-up circuitry may include a resistor or other circuit between the voltage source V+ and the node **17**. In some examples, the pull-up circuitry may be configured as or include a current source or current regulating loop. The resistor or other circuit thus pulls up the voltage level at the node **17** to or toward the power source when the load control switch **12** is open. The pull-up circuitry may include additional circuitry (e.g., one or more active circuits, including one or more transistor devices) to establish multiple levels of current provided via the node **17** to the load control switch **12**. The multiple current levels may include a wetting current level (e.g., 15-20 milliamps),

and one or more lower current levels (e.g., 1-2 milliamps) sufficient to sustain the closure of the switch. The load control switch **12** may be closed, and a wetting current may be applied for a predetermined time period (e.g., 20 milliseconds). After the predetermined time period, a sustaining current (or sealing current or fret current) may be applied. Changing from the wetting current to the sustaining current lowers power dissipation, which may be useful in conserving charge stored in the battery. In the example of FIG. **1**, the pull-up circuitry is responsive to a current control signal generated by the logic controller **20**. The current control signal may be provided to lower the current that flows through the load control switch **12** from the level of the wetting current to the lower level of the sustaining current after operation for a predetermined amount of time at the wetting current level.

FIGS. **2-5** depict various exemplary configurations of the current sensor **36**, the current measurement unit **38**, and the voltage measurement unit **40**. Other configurations may be used. For example, the disclosed embodiments are not limited to the specific sensor-measurement unit pairings shown in FIGS. **2-4**. Other pairings may be used, such that a current sensor shown in one figure may be paired with a measurement unit shown in another figure.

FIG. **2** depicts a circuit **50** configured to provide current sensing and current measurement unit. The circuit **50** includes a current sensor **52** and a current measurement unit **54** to generate an output signal indicative of the current flowing through a current source **56**. In this example, the sensing element of the current sensor **52** is a diode **58**. The diode **58** is disposed in the path along which the wetting current flows to reach the load control switch **12** (FIG. **1**). A bipolar transistor **60** of the current measurement unit **54** is connected as a current mirror across the diode **58** in a current mirror arrangement. In this example, the current mirror drives a resistive load **62**. A voltage across the resistive load **62** is developed at the collector of the bipolar transistor **60**. The current measurement unit **54** further includes a voltage comparator **64** (e.g., an operational amplifier) to compare the voltage across the resistive load **62** with a reference voltage, VT. In this example, the collector is connected to the inverting terminal of an operational amplifier of the voltage comparator **64** to measure the voltage (e.g., through comparison with a reference voltage provided at the non-inverting terminal). The output of the voltage comparator **64** is thus indicative of the current level in the path relative to a reference current level represented by the reference voltage.

FIG. **3** depicts a circuit **70** that includes a resistive current sensor **72** and an inverter-based measurement unit **74**. In this example, the current sensor **72** includes a single resistor but other resistor arrangements may be used. The measurement unit **74** includes a field effect transistor (FET) device **76**, a digital inverter **78**, and a current source **80** as the load. In operation, the current source **56** in the wetting current path causes a voltage drop across the resistive current sensor **72**. The voltage drop modifies the extent to which the FET device **76** is activated. If activated enough, the FET device **76** pulls up the voltage at the input terminal of the digital inverter **78** to the power source. The input terminal voltage is then inverted in accordance with the built-in threshold of the digital inverter **78** to produce the output signal. The configuration of the current source **80** may vary, as a variety of active loads may be used.

FIG. **4** depicts a circuit **90** configured to provide current sensing and measurement via a common base amplifier arrangement. In this example, the sensing element is provided by a resistor **92** disposed in the wetting current path with the current source **56**. As the current through the resistor **92** increases, the voltage at the emitter of a bipolar transistor **94** drops. Eventually, the bipolar transistor **94** activates, which activates another bipolar transistor **96** having a base terminal in common with the bipolar transistor **94**. With a current sensor **98** as an active load, the extent to which the bipolar transistor **96** is activated changes the voltage at the inverting input terminal of an operational amplifier **100**. The operational amplifier **98** then compares the voltage with a reference voltage, VT, to generate an output signal indicative of the wetting current level. The configuration of the current source **98** may vary, as a variety of active loads may be used.

FIG. **5** depicts an exemplary voltage measurement circuit **110** having a comparator **112** and reference voltage circuitry **114**. A reference voltage (or threshold) is generated by the reference voltage circuitry **114** and provided to one of the input terminals of the comparator **112**. A voltage to be measured, such as the voltage at the node **17** (FIG. **1**) or a test voltage, is provided to the other input terminal of the comparator **112**. In one example, the comparator **112** is or includes an operational amplifier. In such cases, either one of the input terminals may be configured as an inverting input terminal, while the other is configured as a non-inverting input terminal. During operation, the voltage to be measured is compared to the level of the threshold voltage. The logic controller **20** (FIG. **1**) is communicatively coupled to an output terminal of the comparator **112** to determine whether to activate the power transistor **18** (FIG. **1**) and provide other control signaling (e.g., wetting current diagnostics-related signaling).

The reference voltage may be generated in various ways. The reference voltage circuitry **114** may be coupled to the power source V+ to establish the reference voltage. In some cases, the reference voltage circuitry **114** is or includes a voltage divider arrangement. Other types of circuit arrangements may be used. For example, the threshold circuitry may include one or more active devices.

Other types of voltage measurement circuits may be used. For example, the voltage measurement unit may be or include various types of analog-to-digital converters. In analog-to-digital converter examples, the voltage measurement unit may not include reference voltage circuitry, insofar as the reference voltage is built-in or inherent to the analog-to-digital conversion.

FIG. **7** shows an exemplary method for wetting current diagnostic testing. The method may be implemented by the control circuits and/or controllers described above. In some cases, another processor or controller may be used to implement the method either in conjunction with the above-described controllers or separately therefrom. The method includes a sequence of acts or steps, only the salient of which are depicted for convenience in illustration. Additional, fewer, or alternative acts may be included. For example, the test sequence may include only testing acts related to current measurement. The ordering of the acts may vary in other embodiments. For example, current measurement data may be obtained before or during the detection of the state of the load control switch. As another example, the test sequence may include conducting closed switch testing before open switch testing, if, for instance, a load control switch is closed at the point at which the method is initiated.

The method is described in connection with a switch to ground load control switch arrangement (e.g., as in the embodiment illustrated in FIG. **1**). In the following description, the "node" is an evaluation node, such as the node **17**

of FIG. **1**. The method may alternatively be applied in connection with a switch to battery arrangement.

The method may be applied to test the wetting current for a normally open load control switch. With the load control switch normally open, oxidation of the switch contacts may occur over time. The contacts of the load control switch may thus benefit from the application of the wetting current each time that the load control switch is closed. The method is directed to testing whether the wetting current is actually provided to the load control switch. Additional aspects of the operation of the wetting current circuitry may also be tested, as described herein.

The method may begin with, or include, an act **700** directed to testing a voltage measurement unit of the control circuit. In the example of FIG. **7**, the act **700** includes selecting one or more test input voltages in an act **702**, comparing the test input voltage(s) with a voltage reference in an act **704**, and generating or otherwise providing a switch detection fault alert in an act **706** if the output of the comparison is incorrect. The test input voltage(s) may be generated by an independent reference voltage source. The selection of the test input voltage(s) may involve controlling an input selection switch as described above. The voltage measurement unit testing may not occur in other embodiments, or may, for instance, be implemented only occasionally (e.g., upon system startup) relative to the other diagnostic testing.

In act **708**, a state of the load control switch is detected. The state detection may include selecting a measurement switch setting in an act **710** if, for instance, the operation of the voltage measurement unit was previously tested against one or more test input voltages. The state detection may also include measuring a voltage at the node through which the wetting current passes to the load control switch in an act **712**. Such voltage measurement may involve a comparison with a reference voltage (e.g., using a comparator) or a circuit involving an inherent comparison (e.g., using an analog-to-digital converter).

Current measurement data may be obtained in an act **714**. The act **714** may occur before, during, or after detection of the state of the load control switch. The act **714** may include measuring a current level of the wetting current using a current sensor and a current measurement unit, as described above.

When the detected state is an open state, control is redirected by a decision block **716** to an act **718**, in which the controller attempts to determine whether the voltage measurement unit is operating correctly. The controller may thus determine whether the state of the load control switch is detected correctly. The determination may be based on the measured current level. In this example, the act **718** may include comparing in act **720** the measured current level to one or more current thresholds. The current thresholds may correspond with the current thresholds described in connection with FIG. **6**. In this case, a decision block **722** determines whether the measured current is within a desired range, such as below the current threshold I_3 (FIG. **6**). If the measured current is within the desired range (i.e., below the current threshold I_3), then the procedure may end. Otherwise, control passes to an act **724**, in which a fault alert is provided. The fault condition may depend on the measured current level, as described above. For instance, if the measured current is below the current threshold I_1, then an internal short fault alert may be provided. If the measured current falls between the current thresholds I**1** and I**2**, then a switch detection fault alert may be provided. If the measured current falls between the current thresholds I**2** and I**3**, then a leakage current fault alert may be provided. Additional, alternative, or fewer fault conditions may be identified. For instance, in some cases, the method may only provide a single leakage current fault alert if the measured current is outside of the desired range.

In other embodiments, some or all of the open switch diagnostic testing is not implemented. For instance, the open switch diagnostic testing may be conducted only periodically or occasionally to save power.

The closed switch diagnostic testing may begin with an act **726**, in which the measured current is compared with one or more closed switch current thresholds. A decision block **728** may then determine whether the measured current is outside of an acceptable range of current levels. The acceptable range may be defined by upper and lower threshold current levels, such as the levels I_1 and I_2 (FIG. **6**). In the example of FIG. **7**, if the measured current falls within the acceptable range, then the wetting current circuitry is operating properly, and the method may restart or terminate. Otherwise, a wetting current fault notification is provided in an act **730** when the measured current level falls outside of the range of current levels relative to the closed switch current threshold(s). A high current fault alert may be provided if the measured current exceeds the upper closed switch current threshold. A low current fault alert may be provided if the measured current is below the lower closed switch current threshold.

In a first aspect, a circuit for diagnostic testing regarding wetting current provided to a load control switch includes a current source coupled to a power source and configured to provide the wetting current along a path to the load control switch, a current sensor connected in series with the current source along the path, the current sensor being configured to generate a current sensor signal indicative of a current level along the path, a voltage measurement unit having an input terminal coupled to a node along the path through which the wetting current flows to reach the load control switch, the voltage measurement unit being configured to detect a state of the load control switch based on a voltage at the node, and a controller coupled to the current sensor and the voltage measurement unit, the controller being configured to determine a wetting current diagnostic condition in accordance with the current level and the detected state.

In a second aspect, a circuit for diagnostic testing regarding wetting current provided to a load control switch includes a current source coupled to a power source and configured to provide the wetting current along a path to the load control switch, a current sensor connected in series with the current source along the path, the current sensor being configured to generate a current sensor signal indicative of a current level along the path, a current measurement unit coupled to the current sensor to receive the current sensor signal, the current measurement unit being configured to implement comparisons of the current level with an open switch threshold and a closed switch threshold, a voltage measurement unit having an input terminal coupled to a node along the path through which the wetting current flows to reach the load control switch, the voltage measurement unit being configured to detect a state of the load control switch based on a voltage at the node, and a controller connected to the current measurement unit and the voltage measurement unit, the controller being configured to determine a wetting current diagnostic condition in accordance with the comparisons and the detected state.

In a third aspect, a method of providing wetting current diagnostics for a load control switch includes detecting a state of the load control switch, and measuring a current

level of a wetting current. When the detected state is an open state, a determination is made, based on the measured current level, whether the state of the load control switch is detected correctly. When the detected state is a closed state, the measured current level is compared to a closed switch current threshold.

Although described in connection with load control switches for use in vehicles, the disclosed embodiments are not limited to any particular type or application of load control switches. The load control switches may be used to control any type of load. The load control switches are thus not limited to motors (AC or DC motors), lamps, or other types of loads commonly present on vehicles. The load control switches are thus also not limited to uses involving 12-Volt batteries or other batteries.

The disclosed embodiments are also compatible with a variety of different load control switch environments. The wetting current diagnostics may be provided regardless of the external resistance and/or capacitance presented by the wiring harness and/or other components or aspects of the system in which the load control switch is disposed. The disclosed embodiments may utilize a voltage threshold established for the comparator of the detection unit to avoid any requirements for customization to a specific switch environment.

Although described in connection with single-pole, single-throw switches, the disclosed embodiments are not limited to any particular type of switch. The number of poles may vary. The number of connection options may also vary. For example, the disclosed embodiments may be configured for use with double-throw or triple-throw switches.

The wetting current diagnostic testing disclosed embodiments may be useful in a wide variety of automotive and industrial switching applications. The diagnostic testing is well-suited for multi-channel systems, such as those presented by automotive applications.

While the wetting current diagnostics are useful for normally open switches, the disclosed embodiments may be used in connection with normally closed switches and/or other types of switches. The extent to which wetting current is useful for the load control switch may vary.

The present invention is defined by the following claims and their equivalents, and nothing in this section should be taken as a limitation on those claims. Further aspects and advantages of the invention are discussed above in conjunction with the preferred embodiments and may be later claimed independently or in combination.

While the invention has been described above by reference to various embodiments, it should be understood that many changes and modifications may be made without departing from the scope of the invention. It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting, and that it be understood that it is the following claims, including all equivalents, that are intended to define the spirit and scope of this invention.

The invention claimed is:

1. A method of providing wetting current diagnostics for a load control switch, the method comprising:

detecting a state of the load control switch;

measuring a current level of a wetting current;

when the detected state is an open state, determining, based on the measured current level, whether the state of the load control switch is detected correctly by comparing the measured current level to first and second open switch current thresholds;

when the detected state is a closed state, comparing the measured current level to a closed switch current threshold; and

providing at least one of: (i) a voltage offset fault alert if the measured current level falls between the first and second open switch current thresholds and if a measured voltage is above a voltage reference, the measured voltage measured at a node through which the wetting current passes to the load control switch, and (ii) a leakage fault alert if the measured current level falls between the first and second open switch current thresholds and the measured voltage is below the voltage reference.

2. The method of claim **1**, further comprising providing a wetting current fault notification when the measured current level falls outside of a range of current levels relative to the closed switch current threshold.

3. The method of claim **1**, further comprising:

selecting a test input voltage; and

testing operation of a voltage measurement unit by comparing the test input voltage with a voltage reference.

4. A method of providing wetting current diagnostics for a load control switch, the method comprising:

providing, by a current source coupled to a power source, a wetting current along a path to the load control switch;

generating, by a current sensor connected in series with the current source along the path, a current sensor signal indicative of a current level along the path;

detecting, by a voltage measurement unit having an input terminal coupled to a node along the path through which the wetting current flows to reach the load control switch, a state of the load control switch based on a voltage at the node;

determining, by a controller coupled to the current sensor and the voltage measurement unit, a wetting current diagnostic condition in accordance with the current level and the detected state of the load control switch;

if the current level is above an open threshold current level with the load control switch in an open position, deactivating, by the controller, the current source to determine a voltage level at the node with the current source deactivated;

generating, by the controller, a voltage offset fault alert if the voltage level remains above a threshold voltage level upon deactivation; and

generating, by the controller, a leakage fault alert if the voltage level falls below the threshold voltage level upon deactivation.

5. The method of claim **4**, further comprising:

receiving, by a current measurement unit coupled to the current sensor and to the controller, the current sensor signal;

generating, by the current measurement unit, an output signal indicative of a comparison of the current level with a threshold current level; and

determining, by the controller, the wetting current diagnostic condition based on the output signal.

6. The method of claim **5**, further comprising:

correlating, by the controller, operation of the voltage measurement unit and the current measurement unit.

7. The method of claim **5**, further comprising:

implementing, by the controller, first and second diagnostic routines when the voltage measurement unit detects that the state of the load control switch is open and closed, respectively,

wherein the first diagnostic routine is configured to determine whether the voltage measurement unit is operating correctly, and

wherein the second diagnostic routine is configured to compare the current level with the threshold current level.

8. The method of claim **4**, further comprising:

providing a low current alert, by the controller, if the current level falls below a current range; and

providing a high current alert, by the controller, if the current level is above the range.

9. The method of claim **4**, further comprising:

providing a switch detection fault alert, by the controller, while receiving an indication of an open state of the load control switch, if the current level is within a range of current levels expected to be reached with the load control switch closed.

10. The method of claim **4**, further comprising:

selecting, by the controller, a state of a switch that couples the input terminal of the voltage measurement unit to either a voltage reference source or the node.

11. A method of providing wetting current diagnostics for a load control switch, the method comprising:

providing, by a current source coupled to a power source, a wetting current along a path to the load control switch;

generating, by a current sensor connected in series with the current source along the path, a current sensor signal indicative of a current level along the path, the current sensor comprising a diode disposed in the path and a current mirror connected across the diode;

receiving, by a current measurement unit coupled to the current sensor, the current sensor signal;

comparing, by the current measurement unit, the current level with an open switch threshold and a closed switch threshold, the current measurement unit comprising a voltage comparator and a resistive load driven by the current mirror;

detecting, by a voltage measurement unit having an input terminal coupled to a node along the path through which the wetting current flows to reach the load control switch, a state of the load control switch based on a voltage at the node;

determining, by a controller connected to the current measurement unit and the voltage measurement unit, a wetting current diagnostic condition in accordance with the comparisons and the detected state; and

comparing, by the voltage comparator, a voltage across the resistive load with a reference voltage.

12. The method of claim **11**, wherein:

implementing, by the controller, first and second diagnostic routines when the voltage measurement unit detects that the state of the load control switch is open and closed, respectively,

wherein the first diagnostic routine is configured to detect whether the state of the load control switch is detected correctly based on the comparisons of the current level with the open and closed switch thresholds, and

wherein the second diagnostic routine is configured to compare the current level with the closed switch threshold.

13. The method of claim **11**, wherein the current sensor comprises a common base amplifier circuit.

14. The method of claim **11**, wherein the current measurement unit comprises an active load.

15. A method of providing wetting current diagnostics for a load control switch, the method comprising:

providing, by a current source coupled to a power source, a wetting current along a path to the load control switch;

generating, by a current sensor connected in series with the current source along the path, a current sensor signal indicative of a current level along the path;

receiving, by a current measurement unit coupled to the current sensor, the current sensor signal;

comparing, by the current measurement unit, the current level with an open switch threshold and a closed switch threshold;

detecting, by a voltage measurement unit having an input terminal coupled to a node along the path through which the wetting current flows to reach the load control switch, a state of the load control switch based on a voltage at the node; and

determining, by a controller connected to the current measurement unit and the voltage measurement unit, a wetting current diagnostic condition in accordance with the comparisons and the detected state;

wherein the current sensor comprises a resistor disposed in the path and a transistor coupled to the resistor such that a voltage drop across the resistor controls an extent to which the transistor is activated.

16. The method of claim **15**, wherein:

implementing, by the controller, first and second diagnostic routines when the voltage measurement unit detects that the state of the load control switch is open and closed, respectively,

wherein the first diagnostic routine is configured to detect whether the state of the load control switch is detected correctly based on the comparisons of the current level with the open and closed switch thresholds, and

wherein the second diagnostic routine is configured to compare the current level with the closed switch threshold.

17. The method of claim **15**, wherein the current sensor comprises a common base amplifier circuit.

18. The method of claim **15**, wherein the current measurement unit comprises an active load.

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