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(54) **EQUIPMENT GROUND FAULT DETECTION CIRCUIT**

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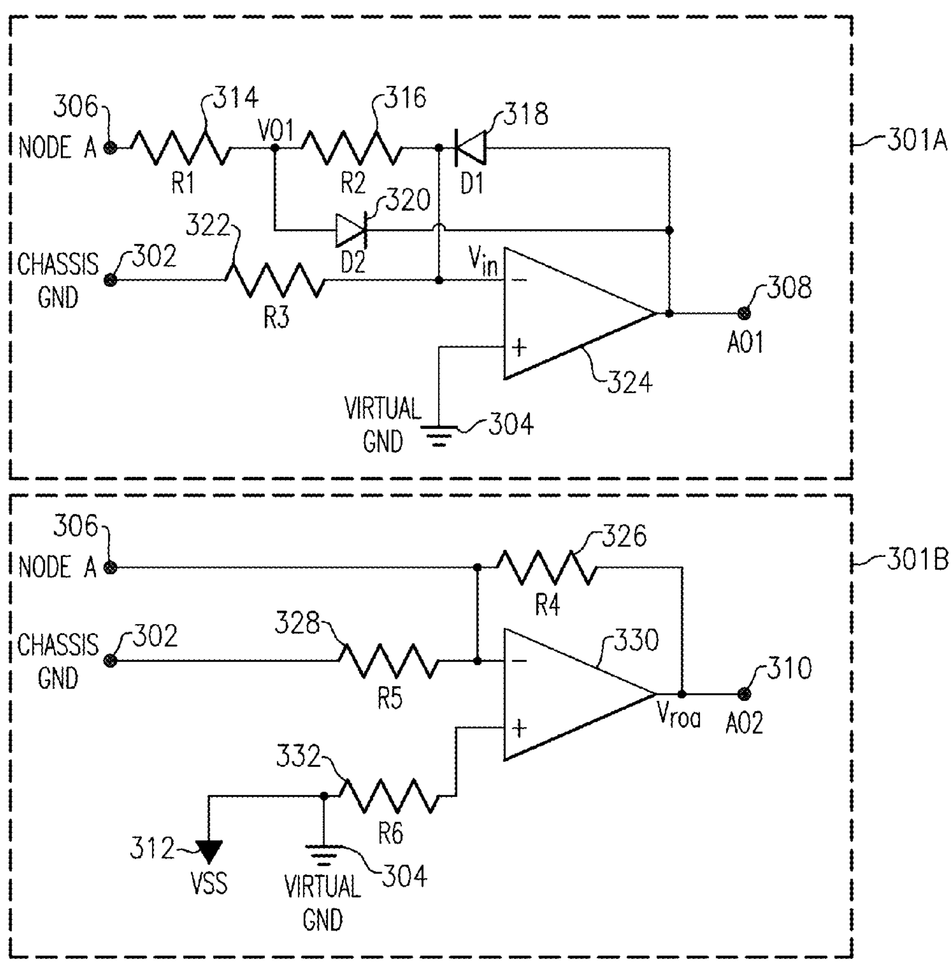
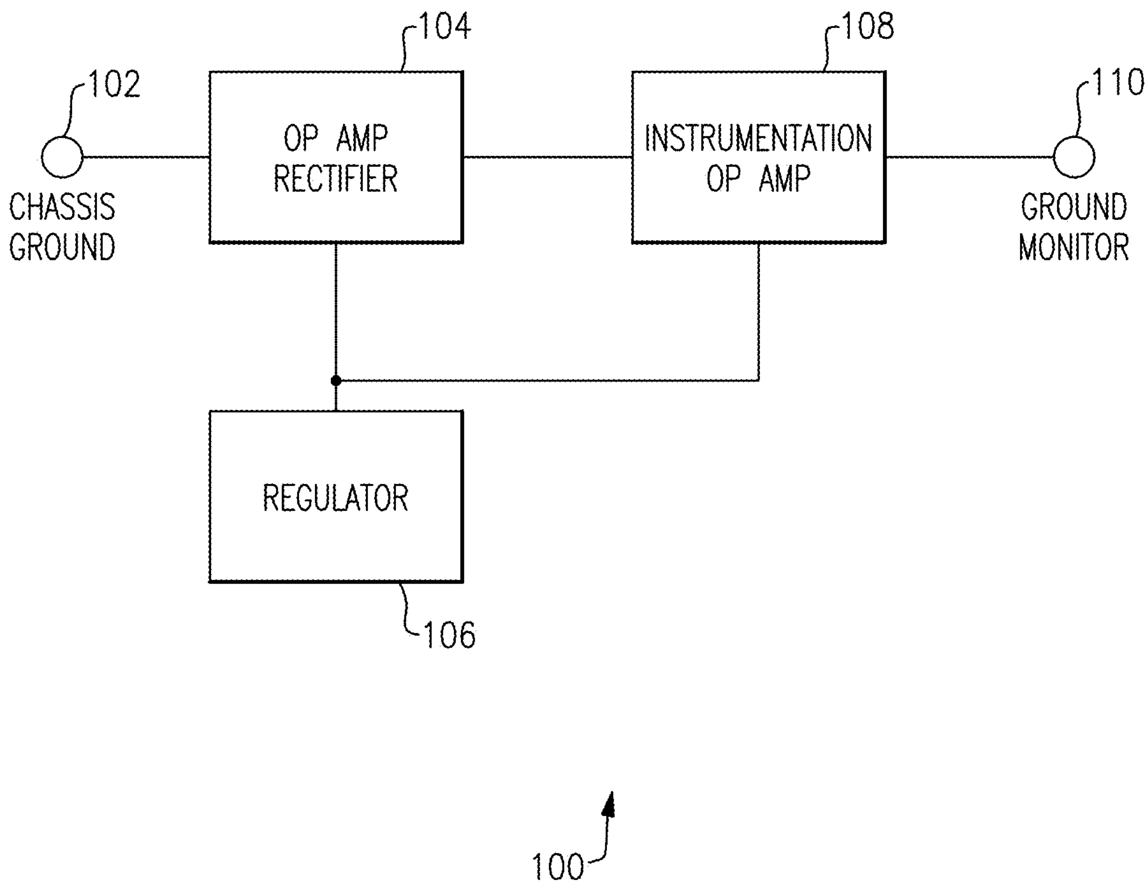
CPC ***G01R 31/52*** (2020.01); ***H02H 1/0007*** (2013.01); ***H02H 3/16*** (2013.01)

(57) **ABSTRACT**

A system for monitoring a ground connection on electrical equipment is presented, the system including: a chassis ground; a virtual ground; a rectifier coupled to the chassis ground and configured to output a first voltage based on a virtual ground voltage and a chassis ground voltage; an instrumentation amplifier coupled to the rectifier to receive the first voltage and a second voltage, the instrumentation amplifier configured to output a third voltage based on the first voltage and a second voltage; and a controller coupled to the instrumentation amplifier. The controller is configured to receive the third voltage, determine whether the ground connection of the electrical equipment to the chassis ground is adequate based on the third voltage, and deactivate power to the electrical equipment responsive to determining that the ground connection is inadequate.



104



102
CHASSIS GROUND
104
OP AMP RECTIFIER
108
INSTRUMENTATION OP AMP
110
GROUND MONITOR
REGULATOR
106
100

FIG.1A

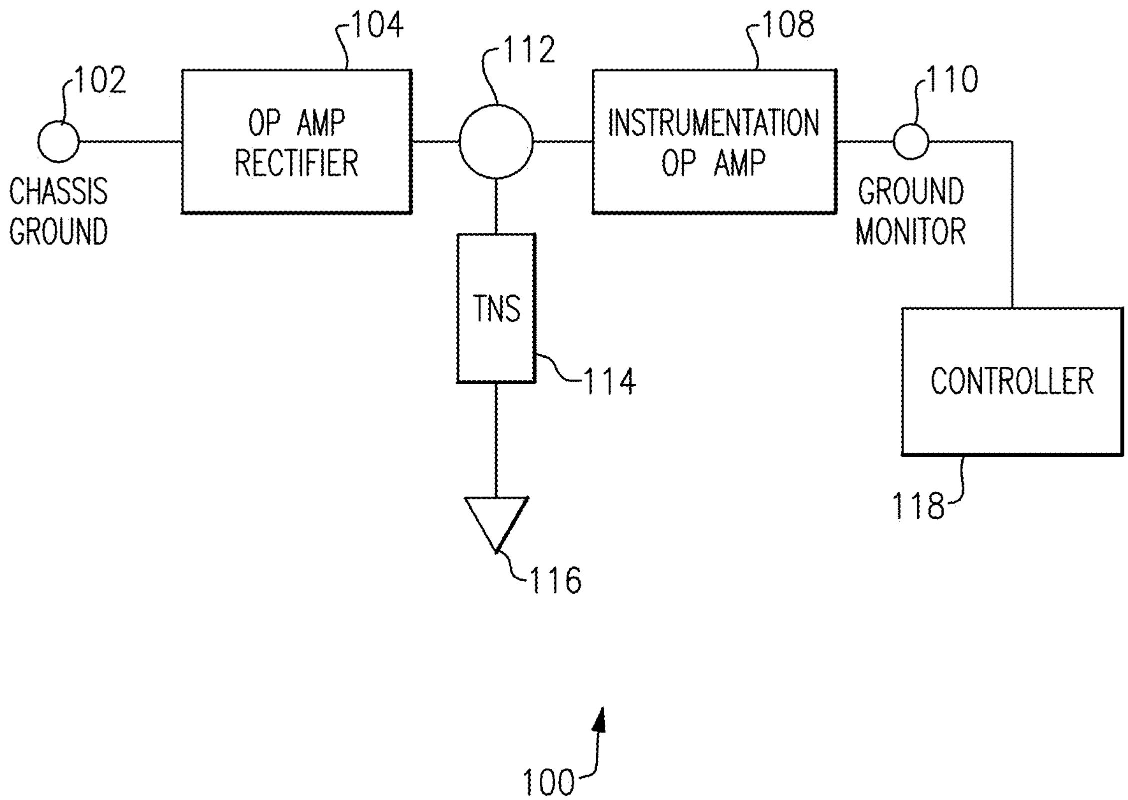

102
CHASSIS GROUND
104
OP AMP RECTIFIER
112
108
INSTRUMENTATION OP AMP
110
GROUND MONITOR
TNS
114
116
CONTROLLER
118
100

FIG. 1B

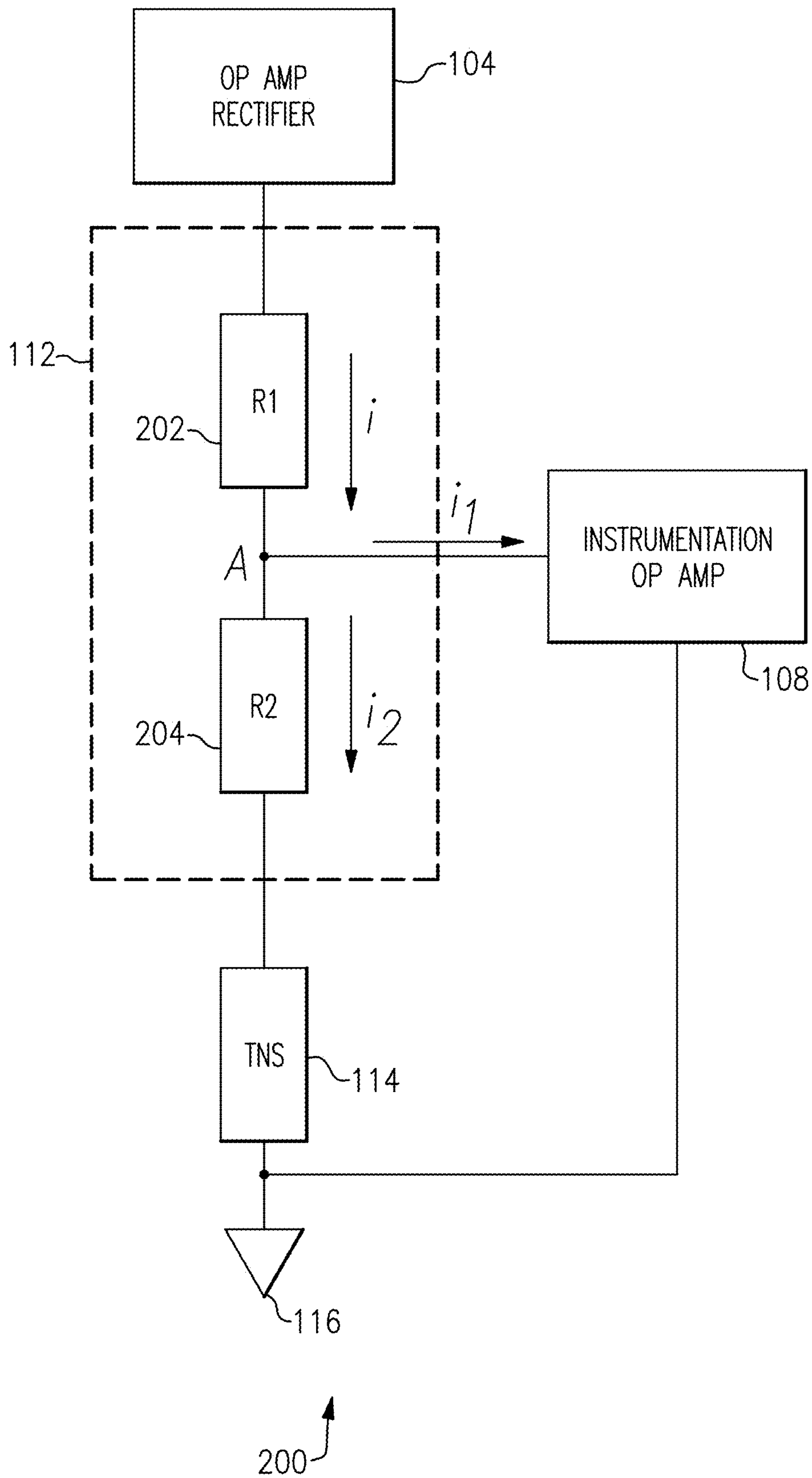

OP AMP
RECTIFIER
104
112
R1
202
i
i1
A
INSTRUMENTATION
OP AMP
108
R2
204
i2
TNS
114
116
200

FIG.2

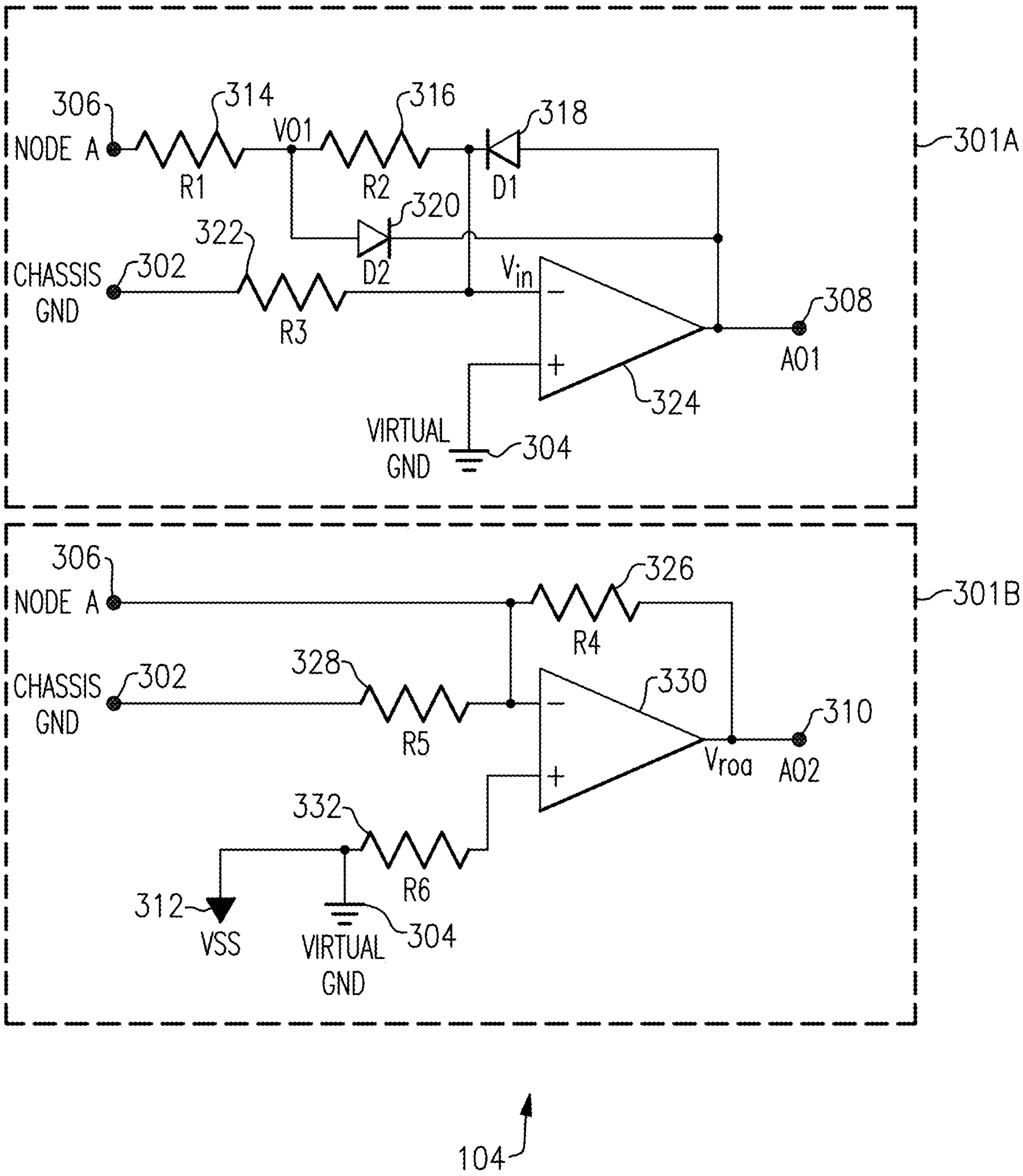
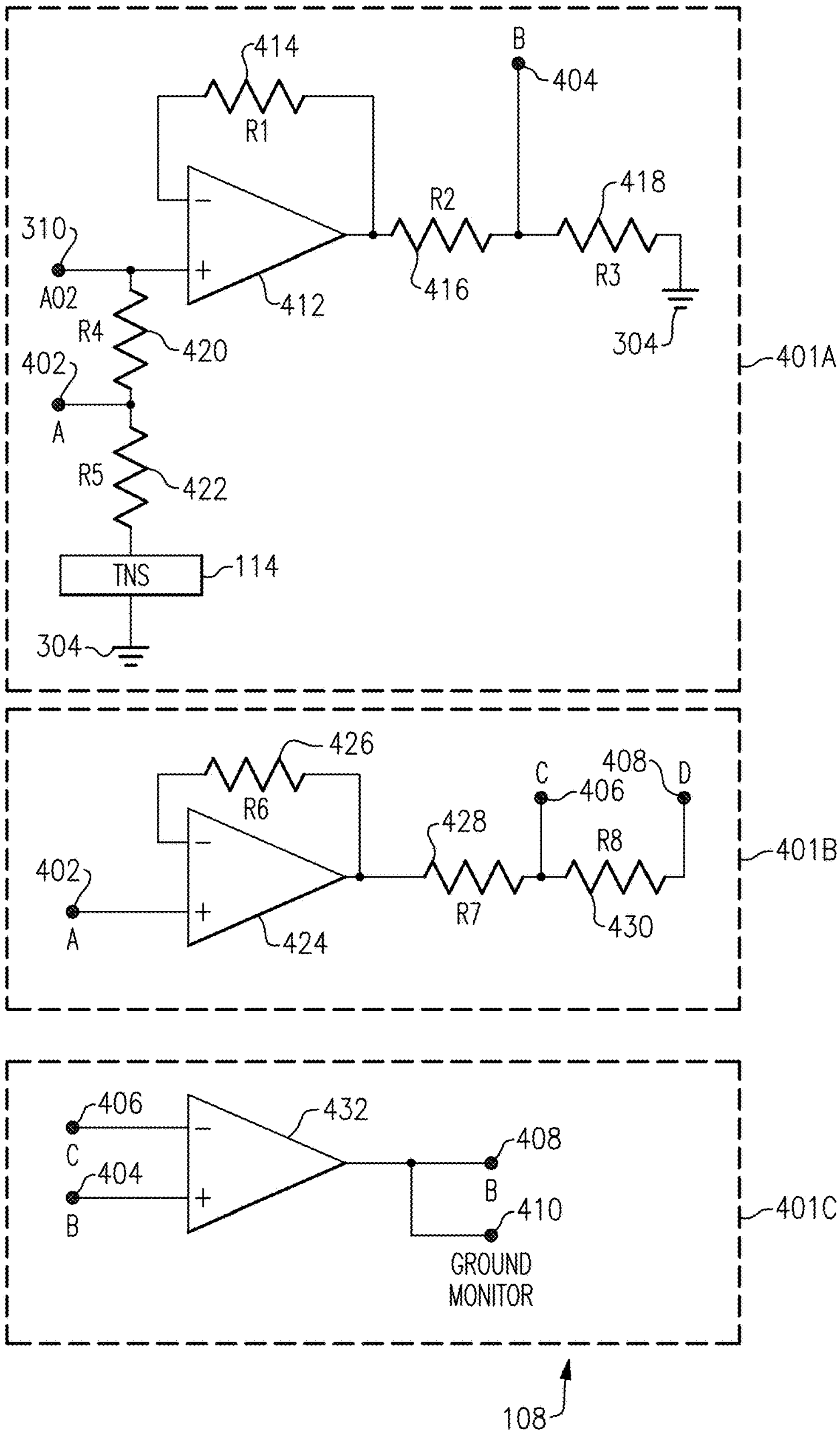

306
NODE A
314
R1
V01
316
R2
318
D1
301A
320
D2
322
CHASSIS GND
302
R3
Vin
308
A01
324
VIRTUAL GND
304
306
NODE A
326
R4
301B
CHASSIS GND
302
328
R5
330
Vroa
310
A02
332
R6
312
VSS
VIRTUAL GND
304
104

FIG.3



414
R1
B
404
R2
418
310
A02
412
416
R3
304
R4
420
402
A
401A
R5
422
TNS
114
304
426
R6
C
406
408
D
428
R8
402
A
424
R7
430
401B
406
C
432
408
404
B
B
410
GROUND
MONITOR
401C
108

FIG.4

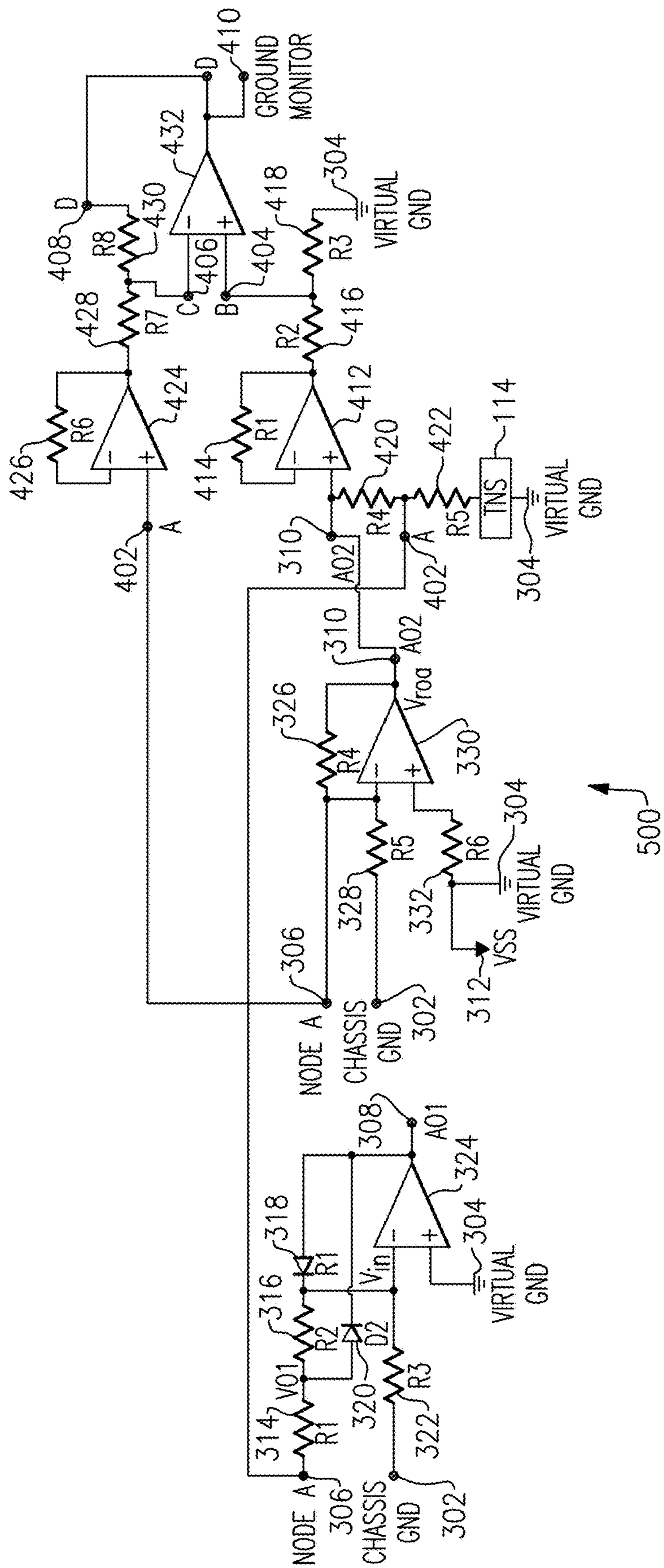

410
GROUND MONITOR
432
D
408
R8
430
C
406
B
404
R7
428
R2
416
R3
418
304
VIRTUAL GND
426
R6
424
414
R1
412
402
A
310
A02
R4
420
R5
422
TNS
114
326
330
Vroa
328
332
306
NODE A
CHASSIS GND
302
VSS
312
500
308
A01
324
318
316
314
V01
320
D2
322
R3
Vin

FIG.5

EQUIPMENT GROUND FAULT DETECTION CIRCUIT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application 63/553,176 titled EQUIPMENT GROUND FAULT DETECTION CIRCUIT, filed on Feb. 14, 2024, and hereby incorporated by reference in its entirety for all purposes.

BACKGROUND

1. Field of the Disclosure

[0002] At least one example in accordance with the present disclosure relates generally to continuously detecting faults in electrical systems.

2. Discussion of Related Art

[0003] Electrical equipment usually has a ground connection. Ground connections may be used to ground electrical currents, and can have safety applications.

SUMMARY

[0004] According to at least one aspect of the present disclosure, a system for monitoring a ground connection on electrical equipment is presented, the system comprising: a chassis ground; a virtual ground; a rectifier coupled to the chassis ground and configured to output a first voltage based on a virtual ground voltage and a chassis ground voltage; an instrumentation amplifier coupled to the rectifier to receive the first voltage and a second voltage, the instrumentation amplifier configured to output a third voltage based on the first voltage and the second voltage; and a controller coupled to the instrumentation amplifier, the controller configured to receive the third voltage, determine whether the ground connection of the electrical equipment to the chassis ground is adequate based on the third voltage, and deactivate power to the electrical equipment responsive to determining that the ground connection is inadequate.

[0005] In some examples, the rectifier is a two stage amplifier having a first stage including a first-stage amplifier and a second stage including a second-stage amplifier. In some examples, the first stage comprises a first chassis ground connection configured to be coupled to the chassis ground, and a first virtual ground connection configured to be coupled to the virtual ground, wherein the first-stage amplifier is configured to provide a fourth voltage based on the virtual ground voltage and the chassis ground voltage. In some examples, the first stage further comprises a node; a first resistor coupled between the first chassis ground connection and the first-stage amplifier; a second resistor coupled to the node; a third resistor coupled to the second resistor and to a first diode, the first diode being coupled to an output of the first-stage amplifier; a second diode coupled to the second resistor and third resistor and further coupled to the output of the first-stage amplifier; and an inverting input of the rectifier coupled to the first diode and the first resistor. In some examples, the second stage comprises a second chassis ground connection configured to be coupled to the chassis ground; a second virtual ground connection configured to be coupled to the virtual ground; and a low voltage connection configured to be coupled to a low voltage, wherein the second-stage amplifier is configured to output the first voltage based on a node voltage of the node, the virtual ground voltage, and the chassis ground voltage. In some examples, the second stage further comprises a first resistor coupled between an output of the second-stage amplifier and the node; a second resistor coupled between the second chassis ground connection and an inverting input of the second-stage amplifier; and a third resistor coupled between the second virtual ground connection and a noninverting input of the second-stage amplifier, wherein the node is coupled to the inverting input of the second-stage amplifier. in some examples, the instrumentation amplifier is a three stage amplifier having a first stage including a first-stage amplifier, a second stage including a second-stage amplifier, and a third stage including a third-stage amplifier. In some examples, the first stage comprises a first connection configured to provide a first input voltage; a second connection configured to provide a second input voltage; a transient noise suppressor; a virtual ground connection coupled to the transient noise suppressor and configured to be coupled to the virtual ground; a first node configured to provide a fourth voltage based on an output voltage; and a first-stage amplifier, the first-stage amplifier configured to provide the output voltage based on the first input voltage. In some examples, the first input voltage is the first voltage. In some examples, the first stage further comprises a first resistor coupled between the first connection and the second connection; a second resistor coupled between the second connection and the transient noise suppressor; a third resistor coupled between the first node and an output of the first-stage amplifier; a fourth resistor coupled between the output of the first-stage amplifier and an inverting input of the first-stage amplifier; and a fifth resistor coupled between the first node and the virtual ground connection. In some examples, the second stage comprises the second connection; a second-stage amplifier configured to provide a second output voltage based on the second voltage; a second node configured to provide a fifth voltage based on the second output voltage; and a third node configured to provide a sixth voltage based on the second output voltage. In some examples, the second stage further comprises: a first resistor coupled between an output of the second-stage amplifier and an inverting input of the second-stage amplifier; a second resistor coupled between the output of the second-stage amplifier and the second node; and a third resistor coupled between the second node and the third node. In some examples, the third stage comprises: the first node; the second node; the third node; a fourth node; a controller connection configured to be coupled to the controller; and a third-stage amplifier configured to provide the third voltage based on fifth voltage and the sixth voltage. In some examples, the first node is coupled to a non-inverting input of the third-stage amplifier; the second node is coupled to an inverting input of the third-stage amplifier; the third node is coupled to an output of the third-stage amplifier; and the controller connection is coupled to the output of the third-stage amplifier. In some examples, the second voltage is based on the virtual ground voltage, the chassis ground voltage, and the first voltage.

[0006] According to at least one aspect of the present disclosure, a method for monitoring a ground connection of electrical equipment is presented, comprising: providing a first signal based on a chassis connection to a first amplifier; adjusting the first signal in the first amplifier; outputting a current from the first amplifier responsive to adjusting the first signal, the current being based on the first signal; splitting the current into a first current and a second current responsive to outputting the current; providing the first current to a second amplifier responsive to splitting the current; providing the second current to an impedance responsive to splitting the current; and providing a second signal at an output of the second amplifier responsive to providing the first current to the second amplifier, the second signal being based on the first current and the second current.

[0007] In some examples, the method further comprises, adjusting the second current by removing one or more transient elements of the second current and then providing the second current to a virtual ground responsive to providing the second current to the impedance. In some examples, adjusting the first signal includes: amplifying the first signal in a first stage of the first amplifier wherein a non-inverting input of the first stage is derived from a virtual ground; and amplifying the first signal in a second stage of the first amplifier responsive to amplifying the first signal in the first stage. In some examples, adjusting the second signal includes: amplifying the second signal in a third stage of the second amplifier wherein a non-inverting input of the third stage is derived from an output of the second stage; amplifying the second signal in a fourth stage responsive to amplifying the second signal in the third stage; and amplifying the second signal in a fifth stage responsive to amplifying in the second signal in the fourth stage. In some examples, amplifying the second signal in the fifth stage includes providing an output of the third stage to a non-inverting input of the fifth stage, and providing an output of the fourth stage to an inverting input of the fifth stage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Various aspects of at least one embodiment are discussed below with reference to the accompanying figures, which are not intended to be drawn to scale. The figures are included to provide an illustration and a further understanding of the various aspects and embodiments, and are incorporated in and constitute a part of this specification, but are not intended as a definition of the limits of any particular embodiment. The drawings, together with the remainder of the specification, serve to explain principles and operations of the described and claimed aspects and embodiments. In the figures, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every figure. In the figures:

[0009] FIG. **1**A illustrates a fault detection system according to an example;

[0010] FIG. **1**B illustrates a fault detection system according to an example;

[0011] FIG. **2** illustrates subsystem of a fault detection system according to an example;

[0012] FIG. **3** illustrates a two-stage operational amplifier rectifier according to an example;

[0013] FIG. **4** illustrates a three-stage instrumentation amplifier according to an example; and

[0014] FIG. **5** illustrates a combination of the first and second stages of the operational amplifier rectifier of FIG. **3** combined with the first, second and third stages of the instrumentation operational amplifier of FIG. **4**.

DETAILED DESCRIPTION

[0015] Electronic device processing equipment that is used to manufacture, test, package, etc. electronic devices that are sensitive to electrostatic discharges (ESD) often use robust ground connections to provide a degree of protection to the device and personnel. A robust ground connection will direct charge (often in the form of a current) from the equipment to Earth (or to another charge reservoir) where it can be safely absorbed.

[0016] In some examples, the processing equipment may have a dedicated ground connection, such as a wire or metal rod, that connects the equipment to ground. Oftentimes, the dedicated ground connection will attach to the chassis of the equipment, as an external connection can be easier to manage or access. However, because the equipment chassis acts as an intermediary element between the ground connection and the electrical circuit elements within the electronic device, it is possible for the electrical circuit elements to become separated from the ground connection. For example, the electrical circuit elements of the device may be connected to the chassis of the equipment by an internal wire or other connection that could come loose from the chassis or otherwise maintain a poor connection (e.g., a connection with a high level of resistance compared to other paths to ground, or an intermittent connection, and so forth).

[0017] Aspects and elements of the present disclosure relate to a system for improving the accuracy and consistency of the ground connection, reducing ground faults (such as single phase faults in small current grounding systems), and improving disconnection detection so that safeguards may be taken. In some examples, the ground connection is incorporated into the power connection (e.g., the power line connection), eliminating the need for an external ground connection.

[0018] FIG. **1**A illustrates a fault detection system **100** ("system **100**") according to an example. The system **100** includes a chassis connection **102**, an operational amplifier (operational amplifier) rectifier **104**, a regulator **106**, an instrumentation operational amplifier, and a monitor connection **110**.

[0019] The chassis connection **102** is coupled to the operational amplifier rectifier **104**. The operational amplifier rectifier **104** is coupled to the chassis connection **102** at a first connection, the instrumentation operational amplifier **108** at a second connection, and the regulator **106** at a third connection. The regulator **106** is coupled to the operational amplifier rectifier **104** and instrumentation operational amplifier **108**. The instrumentation operational amplifier **108** is coupled to the operational amplifier rectifier **104** at a first connection, the regulator **106** at a second connection, and the monitor connection **110** at a third connection.

[0020] The chassis connection **102** may be a connection to a ground of the equipment chassis or to another ground connection. The chassis connection **102** is used as an input to the operational amplifier rectifier **104**. Thus, in some examples, voltage and/or current at the chassis connection **102** may be used as an input to the operational amplifier rectifier **104**.

[0021] The operational amplifier rectifier **104** is an active rectifier that amplifies an input voltage and/or current and provides an output voltage and/or current to the instrumentation operational amplifier **108**. In some examples, the operational amplifier rectifier **104** is a two stage amplifier, having at least a first stage amplifier and a second stage amplifier. In examples where the operational amplifier rectifier **104** is a two stage amplifier, the first stage may act as a buffer and rectifier with an expected voltage level equal to an input voltage modified by a scaling constant, G. Thus, the first stage of the amplifier may provide an output voltage, V_1, such that

$$V_1 = G \cdot V_{in} \tag{1}$$

where V_{in} is the input voltage. In some examples, the voltage V_1 may be provided only when V_{in} is greater than zero. In some examples, G may be based on the impedances (e.g., resistance and/or reactance) of one or more impedances coupled to the first stage amplifier of the operational amplifier rectifier **104**. The second stage of the operational amplifier rectifier **104** may amplify a differential voltage based on the output of the of the first stage amplifier and the input voltage and a scaling constant, K, such that:

$$V_{roa} = K \cdot (V_{in} + V_1) \tag{2}$$

where V_{roa} is the output voltage of the operational amplifier rectifier **104** that is provided to the instrumentation operational amplifier **108**. In some examples, K may be based on the impedances of one or more impedances coupled to the second stage amplifier of the operational amplifier rectifier **104**.

[0022] The instrumentation operational amplifier **108** amplifies a differential voltage and/or current and rejects large common mode voltages and/or currents. In some examples, the instrumentation operational amplifier **108** may include three or more operational amplifiers and may have two or more stages. In examples where the instrumentation operational amplifier **108** has three stages, the instrumentation operational amplifier **108** may use two operational amplifiers (a first and a second operational amplifier) and various impedances to amplify the differential voltages and/or currents while keeping common mode voltage and/or current gain to a minimum (e.g., amplifying the common mode voltages and/or currents by an absolute value of 0 to 1). The instrumentation operational amplifier **108** may use a third operational amplifier and various impedances to amplify the difference mode voltage and/or current and reject the common mode voltage and/or current (e.g., not amplify the common mode voltage and/or current or amplify the common mode voltages and/or currents by an absolute value of 0 to 1). The instrumentation operational amplifier **108** may then provide the output of the third operational amplifier to the monitor connection **110**.

[0023] In various examples, the reference (or ground) connections of the instrumentation operational amplifier **108** are coupled to a virtual ground.

[0024] The regulator **106** may provide power to the operational amplifier rectifier **104** and instrumentation operational amplifier **108**. In some examples, the regulator **106** may provide power (e.g., VDD) to each operational amplifier of the operational amplifier rectifier **104** and instrumentation operational amplifier **108**. In some examples, the regulator **106** may be a linear regulator, or a Low Dropout Regulator (LDO).

[0025] The monitor connection **110** is configured to receive the output of the instrumentation operational amplifier **108** and provide the voltage to a ground monitoring system, as will be discussed in greater detail herein.

[0026] In some examples, at least some and possibly all of the resistors and/or resistances within the operational amplifier rectifier **104** are equal. In some examples, at least some, and possibly all of the resistors and/or resistances within the instrumentation operational amplifier **108** are equal. The same may be true with respect to the reactances and/or impedances of one or both of the operational amplifier rectifier **104** and the instrumentation operational amplifier **108**. However, the instrumentation operational amplifier **108** and operational amplifier rectifier **104** may have different resistances and/or impedances from one another.

[0027] FIG. **1**B illustrates the system **100** according to an example. FIG. **1**B expands upon the system **100** as it was presented in FIG. **1**A by adding a current sensor **112**, a transient noise suppressor **114**, a virtual ground **116**, and a controller **118**. FIG. **1**B omits the regulator **106** of FIG. **1**A for clarity, however, the regulator **106** can be included. The monitor connection **110** is now additionally coupled to the controller **118**.

[0028] While the operational amplifier rectifier **104** and the instrumentation operational amplifier **108** remain coupled together, a current sensor **112** now sits between them, configured to detect a current and/or voltage passing between the operational amplifier rectifier **104** and the instrumentation operational amplifier **108**. The current sensor **112** is coupled to a transient noise suppressor **114**. The transient noise suppressor **114** is coupled to the virtual ground **116**.

[0029] The current sensor **112** senses a current and/or voltage between operational amplifier rectifier **104** and instrumentation operational amplifier **108**. The current sensor **112** may be implemented in a number of ways. For example, the current sensor **112** may be implemented using a current transformer, or may be implemented using one or more resistors or other impedances. Thus, the current sensor **112** may be physically coupled to the connection between the operational amplifier rectifier **104** and the instrumentation operational amplifier **108**, or may be electromagnetically coupled to said connection without a component in direct physical contact with said connection.

[0030] The transient noise suppressor **114** provides transient noise suppression to provide a more accurate reading of the current and/or voltage. Virtual ground **116** may act as a ground point with a lower voltage than the chassis connection **102** and/or the ground connection of the device chassis.

[0031] The controller **118** may be implemented as one or more processors, microcontrollers, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or other circuits. The controller **118** is configured to receive the output of the instrumentation operational amplifier **108** and interpret that output. In some examples, the controller **118** may determine the state of the ground connection (e.g., whether the ground connection is consistent, intermittent, missing, and so forth), may determine whether a fault has occurred, and may determine whether any anomalies are occurring or have occurred (and whether those anomalies are indicative of a fault or an undesirable state of the ground connection). The controller **118** may include machine learning software or other software that is configured to interpret the output of the instrumentation operational amplifier **108**. The controller **118** may also be configured to provide an output signal to a switching device. The switching device may be configured to connect or disconnect the equipment or equipment chassis to power, and may be used to protect the equipment from fault conditions and to protect users from undesirable conditions that may apply to the equipment. In some examples, the controller **118** may be configured to control the switch to disconnect the equipment or equipment chassis from power for a predetermined amount of time (e.g., 1 ms, 5 ms, 1 second, 5 seconds, and so forth). The controller **118** may also issue an alert or alarm (e.g., via a siren, sending a message to an administrator, and/or using other methods) to indicate a fault condition or potential undesirable condition without manual interference. In some examples, the controller **118** may ensure that the electrical equipment is never disconnected from the earth ground.

[0032] Furthermore, most fault detection systems and ground connections are checked for issues during maintenance, but are not typically monitored between maintenance intervals. The fault detection system **100** of the present disclosure allows for continuous monitoring of the equipment and ground connections in real-time.

[0033] FIG. **2** illustrates a subsystem **200** of the system **100** of FIGS. **1**A and **1**B according to an example. The subsystem **200** adds a first sense impedance **202** ("first impedance **202**") and a second sense impedance **204** ("second impedance **204**") to the system **100** as part of the current sensor **112**. The first impedance **202** may have a lower resistance and/or impedance compared to the second impedance **204**. For example, the first impedance **202** may have a resistance less than 1 Ohm and the second impedance **204** may have a resistance greater than 1 Ohm. In some examples, the first impedance **202** may have a resistance of 0.4 Ohms, and the second impedance **204** may have a resistance of 5 Ohms. In some examples, the first impedance **202** may have approximately $1/10^{th}$ the resistance of the second impedance **204**. The first impedance **202** and the second impedance **204** act or may act as a voltage divider.

[0034] The operational amplifier rectifier **104** is coupled to the first impedance **202**. The first impedance **202** is coupled at a first terminal to the operational amplifier rectifier **104** and at a second terminal to the second impedance **204** and instrumentation operational amplifier **108** (e.g., at node A). The second impedance **204** is coupled at a first terminal to the first impedance **202** and to the instrumentation operational amplifier **108** (e.g., at node A), and at a second terminal to the transient noise suppressor **114**. The transient noise suppressor **114** is coupled to the instrumentation operational amplifier **108** at a first connection and to the second impedance **204** at a second connection. The connection that the transient noise suppressor **114** and instrumentation operational amplifier **108** share is also coupled to the virtual ground **116**.

[0035] The operational amplifier rectifier **104** may provide a current, i, to the current sensor **112**. The current, i, may be provided to the first impedance **202** and may enter node A. In node A, the current may split, with a first portion, i_1, going to the instrumentation operational amplifier **108**, and a second portion, i_2, going to the second impedance **204** and to the transient noise suppressor **114**. Alternatively, the current i and i_2 may be combined at node A to produce i_1.

[0036] The transient noise suppressor **114** may attenuate transients (e.g., transient voltages and/or currents) that may be present in and/or related to the currents i, i_1, and/or i_2.

[0037] FIG. **3** illustrates the two-stage operational amplifier rectifier **104** according to an example. The operational amplifier rectifier **104** may include a first stage **301**A and a second stage **301**B. The operational amplifier rectifier **104** may include, in some examples, a chassis ground connection **302**, a virtual ground connection **304**, a first node **306** ("node A"), a first output **308**, a second output **310**, a low voltage connection **312**, a first resistor **314**, a second resistor **316**, a first diode **318**, a second diode **320**, a third resistor **322**, a first amplifier **324**, a fourth resistor **326**, a fifth resistor **328**, a second amplifier **330**, and/or a sixth resistor **332**. Any of the resistors **324**, **326**, **322**, **326**, **328**, and/or **332** may be impedances (e.g., have both resistance and reactance).

[0038] The operational amplifier rectifier **104** may act as a full-wave rectifier, with the first stage **301**A acting as a half-wave rectifier, and the second stage **301**B acting to complete the full-wave rectification (e.g., rectifying the portions of the current and/or voltage not rectified during the first stage **301**A). The second stage **301**B may subtract V_{in} from the output signal, where V_{in} may be at least an input voltage and/or current to the first stage **301**A of the operational amplifier rectifier **104**.

[0039] The chassis ground connection **302** is coupled to the third resistor **322** and to the fifth resistor **328**. The virtual ground connection **304** is coupled to the low voltage connection **312**, the sixth resistor **332**, and to an input of the first amplifier **324**. In some examples, the virtual ground connection **304** is coupled to the positive input (e.g. the non-inverting input) of the first amplifier **324**. The first node **306** is coupled to the first resistor **314**, the fourth resistor **326**, and the fifth resistor **328**.

[0040] The first output **308** is coupled to an output of the first amplifier **324**, to the first diode **318**, and to the second diode **320**. In some examples, the first output **308** is coupled to the anode of the first diode **318** and to the cathode of the second diode **320**.

[0041] The second output **310** is coupled to an output of the second amplifier **330** and to the fourth resistor **326**. In some examples, the second output **310** is the output of the operational amplifier rectifier **104** and provides a voltage and/or current to the instrumentation operational amplifier **108**, current sensor **112**, and/or transient noise suppressor **114**.

[0042] The low voltage connection **312** is coupled to the virtual ground connection **304** and to the sixth resistor **332**.

[0043] The first resistor **314** is coupled, at a first terminal, to the first node **306**, and at a second terminal to the second resistor **316** and to the second diode **320**. In some examples, the first resistor **314** is coupled to an anode of the second diode **320**. The second resistor **316** is coupled at a first terminal to the first resistor **314** and to the second diode **320**, and at a second terminal to the first diode **318**, the third resistor **322**, and an input of the first amplifier **324**. In some examples, the second resistor **316** is coupled to a cathode of the first diode **318**, an anode of the second diode **320**, and a negative (e.g., inverting) input of the first amplifier **324**.

[0044] The first diode **318** is coupled at a first terminal to the second resistor **316** and the third resistor **322**, at a second terminal to the first output **308**, and at one or more terminals to the first amplifier **324**. In some examples, an anode of the first diode **318** is coupled to the first output **308** and to an output of the first amplifier **324**, and a cathode of the first diode **318** is coupled to the second resistor **316**, the third resistor **322**, and to a negative (e.g., inverting) input of the first amplifier **324**.

[0045] The second diode **320** is coupled at a first terminal to the first resistor **314** and the second resistor **316**, and at a second terminal to the first amplifier **324** and the first output **308**. In some examples, an anode of the second diode **320** is coupled to the first resistor **314** and the second resistor **316**, and a cathode of the second diode **320** is coupled to the first output **308** and to an output of the first amplifier **324**.

[0046] The third resistor **322** is coupled at a first terminal to the chassis ground connection **302**, and at a second terminal to the second resistor **316**, first diode **318**, and first amplifier **324**. In some examples, the third resistor **322** is coupled to a cathode of the first diode **318** and to a negative (e.g., inverting) input of the first amplifier **324**. The fourth resistor **326** is coupled at a first terminal to the second output **310**, at a second terminal to the first node **306** and the fifth resistor **328**, and at one or more terminals to the second amplifier **330**. In some examples, the fourth resistor **326** is coupled to an output of the second amplifier **330** and to a negative (e.g., inverting) input of the second amplifier **330**. The fifth resistor **328** is coupled at a first terminal to the chassis ground connection **302**, and at a second terminal to the first node **306**, the fourth resistor **326**, and the second amplifier **330**. In some examples, the fifth resistor **328** is coupled to a negative (e.g., inverting) input of the second amplifier **330**. The sixth resistor is coupled at a first terminal to the virtual ground connection **304** and to the low voltage connection **312**, and at a second terminal to the second amplifier **330**. In some examples, the sixth resistor is coupled to a positive (e.g., non-inverting) input of the second amplifier **330**.

[0047] The selection of diodes and/or resistors for the operational amplifier rectifier **104** may be determined based on the frequency range and/or bandwidth of noises associated with the electrical equipment, which may be variable or constant.

[0048] The first stage **301**A, as mentioned above, may operate as a half-wave rectifier. The output voltage of the first amplifier may be expressed as:

$$VO1 = V_{in} \cdot \frac{R3}{R2} \tag{3}$$

where VO1 is the voltage at node VO1 (the node linking the first resistor **314**, the second resistor **316**, and the second diode **320**), R2 is the resistance of the second resistor **316**, R3 is the resistance of the third resistor **322**, and V_{in} is an input voltage (e.g., a voltage at the negative or inverting input of the first amplifier **324**). In some examples, the first amplifier **324** may only provide an output when V_{in} is greater than and/or equal to zero.

[0049] The second stage **301**B operates to complete the rectification of the input and to capture the voltage difference between the chassis ground and the virtual ground. In particular, the second stage **301**B amplifies the difference between the chassis ground and virtual ground before providing that difference (in the form of the output of the second amplifier **330**) to the instrumentation operational amplifier **108**.

[0050] The output of the second amplifier **330** is based on the inputs provided to its first and second input, and may represent a sum of V_{in} and VO1 modified by the scaling factor, K. K may be greater than zero. Thus, the output of the second stage, V_{roa} may be expressed as:

$$V_{roa} = K \cdot (V_{in} + VO1) \tag{4}$$

[0051] The first input may be the negative (or inverting) input, and the second input may be the positive (or non-inverting) input. The voltage at the inverting input is based upon the voltage at node VO1, the chassis ground connection **302**, and the second output **310**, each of which are connected to the first node **306** via a resistor (e.g., the first resistor **314**, the fourth resistor **326**, and the fifth resistor **328**). The voltage at the non-inverting input is based upon the voltage at the virtual ground **304** and/or the low voltage connection **312** because those are connected to the non-inverting input via the sixth resistor **332**. The low voltage connection **312** may be tied to the lowest voltage provided to the system, rather than to a reference voltage. Thus, the low voltage connection **312** may be coupled to a positive voltage, the ground (zero voltage), and/or a negative voltage.

[0052] FIG. **4** illustrates the instrumentation operational amplifier **108** according to an example. The instrumentation operational amplifier **108** may have three stages, including a first stage **401**A, a second stage **401**B, and a third stage **401**C.

[0053] The instrumentation operational amplifier **108** may be coupled to the virtual ground (e.g., virtual ground connection **304** of FIG. **3**). That is, the instrumentation operational amplifier **108** may use the virtual ground connection **304** to provide a reference voltage rather than using the chassis ground. As a result, the instrumentation operational amplifier **108** may be able to differentiate the effect of the virtual ground compared to that of the chassis ground, which allows the instrumentation operational amplifier **108** to detect and/or determine the voltage difference between the potential at the chassis ground and the potential at the virtual ground. The instrumentation operational amplifier **108** may generate an output signal based on the differential between the chassis ground and virtual ground and/or based on a signal corresponding to the potential of the chassis ground and a signal corresponding to the potential of the virtual ground.

[0054] The instrumentation operational amplifier **108** may provide an output to the ground monitor **110** and may be used by the controller **118** to determine if variances between the chassis ground and virtual ground exist and require the electrical equipment to be deactivated and/or stopped until the variances stop.

[0055] The instrumentation operational amplifier **108** includes the second output **310**, the virtual ground connection **304**, a first node **402** ("node A"), a second node **404** ("node B"), a third node **406** ("node C"), a fourth node **408** ("node D"), a ground monitor connection **410**, a first amplifier **412**, a first resistor **414**, a second resistor **416**, a third resistor **418**, a fourth resistor **420**, a fifth resistor **422**, a second amplifier **424**, a sixth resistor **426**, a seventh resistor **428**, an eighth resistor **430**, and a third amplifier **432**.

[0056] The first amplifier **412** is coupled to the second output **310**, the first resistor **414**, the second resistor **416**, and the fourth resistor **420**. In some examples, the non-inverting input of the first amplifier **412** is coupled to the second output **310** and to the fourth resistor **420**, the inverting input is coupled to the first resistor **414**, and the output is coupled to the first resistor **414** and the second resistor **416**. The second resistor **416** is coupled at a first terminal to the first resistor **414** and the amplifier **412**, and at a second terminal to the second node **404** and the third resistor **418**. The third resistor **418** is coupled at a first terminal to the second resistor **416** and the second node **404**, and at a second terminal to the virtual ground connection **304**. The fourth resistor **420** is coupled at a first terminal to the first amplifier **412** and the second output **310**, and at a second terminal to the first node **402** and the fifth resistor **422**. The fifth resistor is further coupled to the transient noise suppressor **114**, and the transient noise suppressor **114** is coupled to the virtual ground connection **304**.

[0057] The second amplifier **424** is coupled to the first node **402**, the sixth resistor **426**, and the seventh resistor **428**. In some examples, the non-inverting input of the second amplifier **424** is coupled to the first node **402**, the inverting input is coupled to the sixth resistor **426**, and the output is coupled to the sixth resistor **426** and the seventh resistor **428**. The sixth resistor **426** is coupled at a first terminal to the amplifier **424**, and at a second terminal to the amplifier **424** and the seventh resistor **428**. The seventh resistor **428** is coupled at a first terminal to the amplifier **424** and the sixth resistor **426**, and at a second terminal to the third node **406** and the eighth resistor **430**. The eighth resistor **430** is coupled at a first terminal to the seventh resistor **428** and the third node **406**, and at a second terminal to the fourth node **408**.

[0058] The third amplifier **432** is coupled to the second node **404**, the third node **406**, the fourth node **408**, and the ground monitor **410**. In some examples, the non-inverting input of the third amplifier **432** is coupled to the second node **404**, the inverting input is coupled to the third node **406**, and the output is coupled to the fourth node **408** and the ground monitor **410**.

[0059] The output of the second output **310** is provided to the non-inverting input of the first amplifier **412**. A voltage and/or current based on the output at the second output **310** is also provided to the non-inverting input of the second amplifier **424**. The output of the first stage **401**A is provided at the second node **404** to the non-inverting input of the third amplifier **432**. The output of the second stage **401**B is provided to the third node **406** and the fourth node **408**. Because the third node **406** and fourth node **408** are separated via at least the eighth resistor **430**, the current and/or voltage at the third node **406** may differ from that at the fourth node **408**. The current and/or voltage at the third node **406** is provided to the inverting input of the third amplifier **432**. The current and/or voltage at the fourth node **408** is provided to the ground monitor **410**. The third amplifier **432** provides an output current and/or voltage to the fourth node **408** and ground monitor **410**. Whether the third amplifier **432** provides an output may depend on the difference in voltage between the second node **404** and third node **406**. Likewise, the output of the third amplifier **432** may depend on the voltages and/or currents at the second node **404** and third node **406**.

[0060] As a result, the final output of the third amplifier **432** may be a signal that represents a difference between the voltage at the chassis ground and the voltage at the virtual ground **304**. Should the signal generated by the third amplifier **432** fall outside a given range and/or exceed a given threshold, the ground monitor **110** (receiving said signal from the ground monitor connection **410**) may disable the electrical equipment temporarily or permanently (e.g., until the signal returns to the given range and/or falls below the threshold).

[0061] FIG. **5** illustrates a combination of the first stage **301***a* and second stage **301***b* of the operational amplifier rectifier **104** combined with the first stage **401***a*, second stage **401***b*, and third stage **401***c* of the instrumentation operational amplifier **108**. FIG. **5** is equivalent to FIGS. **3** and **4**, except that it explicitly shows connections between the stages **301***a*, **301***b*, **401***a*, **401***b*, **401***c* rather than using node labels to illustrate said connections.

[0062] Examples of the methods and systems discussed herein are not limited in application to the details of construction and the arrangement of components set forth in the following description or illustrated in the accompanying drawings. The methods and systems are capable of implementation in other embodiments and of being practiced or of being carried out in various ways. Examples of specific implementations are provided herein for illustrative purposes only and are not intended to be limiting. In particular, acts, components, elements and features discussed in connection with any one or more examples are not intended to be excluded from a similar role in any other examples.

[0063] Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. Any references to examples, embodiments, components, elements or acts of the systems and methods herein referred to in the singular may also embrace embodiments including a plurality, and any references in plural to any embodiment, component, element or act herein may also embrace embodiments including only a singularity. References in the singular or plural form are not intended to limit the presently disclosed systems or methods, their components, acts, or elements. The use herein of "including," "comprising," "having," "containing," "involving," and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

[0064] References to "or" may be construed as inclusive so that any terms described using "or" may indicate any of a single, more than one, and all of the described terms. In addition, in the event of inconsistent usages of terms between this document and documents incorporated herein by reference, the term usage in the incorporated features is supplementary to that of this document; for irreconcilable differences, the term usage in this document controls.

[0065] Various controllers, such as the controller **118**, may execute various operations discussed above. Using data stored in associated memory and/or storage, the controller **118** also executes one or more instructions stored on one or more non-transitory computer-readable media, which the controller **118** may include and/or be coupled to, that may result in manipulated data. In some examples, the controller **118** may include one or more processors or other types of controllers. In one example, the controller **118** is or includes at least one processor. In another example, the controller **118** performs at least a portion of the operations discussed above using an application-specific integrated circuit tailored to perform particular operations in addition to, or in lieu of, a general-purpose processor. As illustrated by these examples, examples in accordance with the present disclosure may perform the operations described herein using many specific combinations of hardware and software and the disclosure is not limited to any particular combination of hardware and software components. Examples of the disclosure may include a computer-program product configured to execute methods, processes, and/or operations discussed above. The computer-program product may be, or include, one or more controllers and/or processors configured to execute instructions to perform methods, processes, and/or operations discussed above.

[0066] Having thus described several aspects of at least one embodiment, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of, and within the spirit and scope of, this disclosure. Accordingly, the foregoing description and drawings are by way of example only.

1. A system for monitoring a ground connection on electrical equipment, the system comprising:
- a chassis ground;
- a virtual ground;
- a rectifier coupled to the chassis ground and configured to output a first voltage based on a virtual ground voltage and a chassis ground voltage;
- an instrumentation amplifier coupled to the rectifier to receive the first voltage and a second voltage, the instrumentation amplifier configured to output a third voltage based on the first voltage and the second voltage; and
- a controller coupled to the instrumentation amplifier, the controller configured to
  - receive the third voltage,
  - determine whether the ground connection of the electrical equipment to the chassis ground is adequate based on the third voltage, and
  - deactivate power to the electrical equipment responsive to determining that the ground connection is inadequate.

2. The system of claim **1** wherein the rectifier is a two stage amplifier having a first stage including a first-stage amplifier and a second stage including a second-stage amplifier.

3. The system of claim **2** wherein the first stage comprises
- a first chassis ground connection configured to be coupled to the chassis ground, and
- a first virtual ground connection configured to be coupled to the virtual ground, wherein the first-stage amplifier is configured to provide a fourth voltage based on the virtual ground voltage and the chassis ground voltage.

4. The system of claim **3** wherein the first stage further comprises
- a node;
- a first resistor coupled between the first chassis ground connection and the first-stage amplifier;
- a second resistor coupled to the node;
- a third resistor coupled to the second resistor and to a first diode, the first diode being coupled to an output of the first-stage amplifier;
- a second diode coupled to the second resistor and third resistor and further coupled to the output of the first-stage amplifier; and
- an inverting input of the rectifier coupled to the first diode and the first resistor.

5. The system of claim **3** wherein the second stage comprises
- a second chassis ground connection configured to be coupled to the chassis ground;
- a second virtual ground connection configured to be coupled to the virtual ground; and
- a low voltage connection configured to be coupled to a low voltage,
- wherein the second-stage amplifier is configured to output the first voltage based on a node voltage of the node, the virtual ground voltage, and the chassis ground voltage.

6. The system of claim **5** wherein the second stage further comprises
- a first resistor coupled between an output of the second-stage amplifier and the node;
- a second resistor coupled between the second chassis ground connection and an inverting input of the second-stage amplifier; and
- a third resistor coupled between the second virtual ground connection and a noninverting input of the second-stage amplifier, wherein the node is coupled to the inverting input of the second-stage amplifier.

7. The system of claim **1** wherein the instrumentation amplifier is a three stage amplifier having a first stage including a first-stage amplifier, a second stage including a second-stage amplifier, and a third stage including a third-stage amplifier.

8. The system of claim **7** wherein the first stage comprises
- a first connection configured to provide a first input voltage;
- a second connection configured to provide a second input voltage;
- a transient noise suppressor;
- a virtual ground connection coupled to the transient noise suppressor and configured to be coupled to the virtual ground;
- a first node configured to provide a fourth voltage based on an output voltage; and
- a first-stage amplifier, the first-stage amplifier configured to provide the output voltage based on the first input voltage.

9. The system of claim **8** wherein the first input voltage is the first voltage.

10. The system of claim **8** wherein the first stage further comprises
- a first resistor coupled between the first connection and the second connection;
- a second resistor coupled between the second connection and the transient noise suppressor;
- a third resistor coupled between the first node and an output of the first-stage amplifier;
- a fourth resistor coupled between the output of the first-stage amplifier and an inverting input of the first-stage amplifier; and
- a fifth resistor coupled between the first node and the virtual ground connection.

11. The system of claim **8** wherein the second stage comprises

the second connection;

a second-stage amplifier configured to provide a second output voltage based on the second voltage;

a second node configured to provide a fifth voltage based on the second output voltage; and

a third node configured to provide a sixth voltage based on the second output voltage.

12. The system of claim **11** wherein the second stage further comprises:

a first resistor coupled between an output of the second-stage amplifier and an inverting input of the second-stage amplifier;

a second resistor coupled between the output of the second-stage amplifier and the second node; and

a third resistor coupled between the second node and the third node.

13. The system of claim **11** wherein the third stage comprises:

the first node;

the second node;

the third node;

a fourth node;

a controller connection configured to be coupled to the controller; and

a third-stage amplifier configured to provide the third voltage based on fifth voltage and the sixth voltage.

14. The system of claim **13** wherein:

the first node is coupled to a non-inverting input of the third-stage amplifier;

the second node is coupled to an inverting input of the third-stage amplifier;

the third node is coupled to an output of the third-stage amplifier; and

the controller connection is coupled to the output of the third-stage amplifier.

15. The system of claim **1** wherein the second voltage is based on the virtual ground voltage, the chassis ground voltage, and the first voltage.

16. A method for monitoring a ground connection of electrical equipment, comprising:

providing a first signal based on a chassis connection to a first amplifier;

adjusting the first signal in the first amplifier;

outputting a current from the first amplifier, the current being based on the first signal;

splitting the current into a first current and a second current;

providing the first current to a second amplifier;

providing the second current to an impedance; and

providing a second signal at an output of the second amplifier, the second signal being based on the first current and the second current.

17. The method of claim **16** further comprising, adjusting the second current by removing one or more transient elements of the second current and then providing the second current to a virtual ground.

18. The method of claim **16** wherein adjusting the first signal includes:

amplifying the first signal in a first stage of the first amplifier wherein a non-inverting input of the first stage is derived from a virtual ground; and

amplifying the first signal in a second stage of the first amplifier.

19. The method of claim **18** wherein adjusting the second signal includes:

amplifying the second signal in a third stage of the second amplifier wherein a non-inverting input of the third stage is derived from an output of the second stage;

amplifying the second signal in a fourth stage; and

amplifying the second signal in a fifth stage.

20. The method of claim **19** wherein amplifying the second signal in the fifth stage includes providing an output of the third stage to a non-inverting input of the fifth stage, and providing an output of the fourth stage to an inverting input of the fifth stage.

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