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(54) **Title**: ELECTRICAL MEANS TO LIMIT LEAKAGE CURRENT IN BATTERY OPERATED PATIENT-CONNECTED MEDICAL DEVICES

(57) **Abstract**: A system (116, 120) for electrically limiting leakage current in a patient- connected medical device (100). The system (116, 120) includes a first set (116) of one or more switching devices (118) that selectively connect a first power output (124) of a battery compartment (110) of the patient-connected medical device (100) with a first power input (126) of electronic components (102) of the patient-connected medical device (100) based on a first polarity of input voltage from the battery compartment (110). The system (116, 120) further includes a second set (120) of one or more switching devices (122) that selectively connect a second power output (128) of the battery compartment (110) of the patient-connected medical device(100)with a second power input (130) of the electronic components (102) based on a second polarity of the input voltage, wherein the first polarity is opposite the second polarity.

# ELECTRICAL MEANS TO LIMIT LEAKAGE CURRENT IN BATTERY OPERATED PATIENT-CONNECTED MEDICAL DEVICES

## DESCRIPTION

The present application relates generally to battery operated patient-connected medical devices. It finds particular application in conjunction with limiting leakage current for patient-connected medical devices, and will be described with particular reference thereto. However, it is to be understood that it also finds application in other usage scenarios, and is not necessarily limited to the aforementioned application.

Patient-connected medical devices must generally meet safety standards limiting leakage current on patients. For example, medical markets throughout the world use International Standard IEC 60601-1, Second Edition, 1988-12 as a basis for approval of medical products. IEC 60601-1 requires that any exposed live component of a medical device be isolated from a patient connection and specifies the level of isolation required. 10 microamps, for example, is the limit on patient leakage current for cardiac function (CF) rated devices. Limits on leakage current are important for, *inter alia*, patients with internal connections where skin impedance does not limit leakage current and patients with sensitive medical implants, which could be life sustaining.

When changing batteries in a medical device with a power source including one or more batteries, battery connection terminals for batteries not yet installed may be accessible and live due to a series connection of batteries already installed. If a patient attached to the medical device were to come in contact with one of these battery connection terminals, the resultant leakage current could exceed safety limits. The only limitations on current flow would be the source impedance of the batteries, the patient impedance, indirect path impedance, and the patient connection impedance. Contact with a live battery connection terminal could occur from the patient touching the battery connection terminal directly or indirectly through a care-giver who is changing the batteries.

To limit patient leakage current, mechanical means inhibiting access to the battery connection terminals could be employed. However, mechanical means are cumbersome for users and expensive to manufacture. Another way to limit patient leakage current would be to increase the patient connection impedance. However some patient parameter measurements, such as respiration, necessarily require low input impedance. Yet another potential way to limit patient leakage current would be to isolate patient inputs by galvanic means, such as transformers and/or optical isolators. However, these approaches are expensive, power consuming, and require valuable space. They defeat a major advantage of a small, light-weight, battery-operated medical device.

The present application provides new and improved systems and methods employing electrical means to overcome the above-referenced problems and others.

In accordance with another aspect, a system for electrically limiting leakage current in a patient-connected medical device is provided. The system includes a first set of one or more switching devices that selectively connect a first power output of a battery compartment of the patient-connected medical device with a first power input of electronic components of the patient-connected medical device based on a first polarity of input voltage from the battery compartment. The system further includes a second set of one or more switching devices that selectively connect a second power output of the battery compartment of the patient-connected medical device with a second power input of the electronic components based on a second polarity of the input voltage, wherein the first polarity is opposite the second polarity.

In accordance with one aspect, a method for electrically limiting leakage current in a patient-connected medical device is provided. The patient connected medical device includes a first set of one or more switching devices that selectively connects a first power output of a battery compartment of the patient-connected medical device with a first power input of electronic components of the patient-connected medical device based on a first polarity of input voltage from the battery compartment and a second set of one or more switching devices that selectively connects a second power output of the battery compartment with a second power input of the electronic components based on a second polarity of the input voltage. The second polarity is opposite the first polarity. Further, a patient of the patient connected medical device is electrically connected to the electronic components via one or more patient connections. The method includes inserting a battery into the battery compartment, such that the battery is electrically connected to a power output and one or more battery connection terminals of the battery compartment. The power output is one of the first power output and the second power output. The method further includes electrically connecting one of the battery connection terminals and the patient. The electrical connection is independent of the patient connections. Even more, the method includes obstructing current flow between the power output and a corresponding power input until the input voltage is total input voltage. The first set and/or the second set facilitate obstruction of the current flow.

In accordance with another aspect, a patient-connected medical device is provided. The patient-connected medical device includes a battery compartment for one or more batteries. The battery compartment connects the batteries in series and includes a first power output and a second power output. The system further includes electronic components including a first power input and a second power input. Even more, the system includes a first set of one or more switching devices that selectively connect the first power output with the first power input based on a first polarity of input voltage from the battery compartment. Moreover, the system includes a second set of one or more switching devices that selectively connect the second power output with the second power input based on a second polarity of the input voltage. The first polarity is opposite the second polarity.

One advantage resides in limiting leakage current on a patient.

Another advantage resides in adaptability to any number of batteries.

Another advantage resides in functionality when batteries are inserted in any order.

Another advantage resides in patient protection even if one or more batteries are not properly oriented.

Another advantage resides in amenability to inexpensive manufacturing techniques.

Another advantage resides in small size.

Another advantage resides in ease of use.

Another advantage resides in functionality with low impedance patient connections.

Another advantage resides in low power consumption.

Still further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 is a conceptual view of a patient-connected medical device according to aspects of the present disclosure.

FIGURE 2 is a detailed view of one embodiment of the patient-connected medical device of FIGURE 1.

FIGURE 3 is a detailed view of another embodiment of the patient-connected medical device of FIGURE 1.

FIGURE 4 is a detailed view of yet another embodiment of the patient-connected medical device of FIGURE 1.

FIGURE 5 illustrates a method of limiting leakage current according to aspects of the present disclosure.

With reference to FIGURE 1, a conceptual view of a patient-connected medical device **100** according to aspects of the present disclosure is provided. The patient-connected medical device **100** is suitably employed to monitor and/or provide life support functions. Further, the patient-connected medical device **100** is suitably mobile, worn on the patient's person. It is contemplated that, in certain embodiments, the patient-connected medical device **100** is one of a patient monitor, a pacemaker, and the like.

The patient-connected medical device **100** includes electronic components **102** connected to a patient **104** via one or more patient connections **106**. It is contemplated that the patient connections **106** connect to the patient **104** via one or more of sensors and/or electrodes **108**. In certain embodiments, the electronic components **102** receive patient data from the patient connections **106**. Additionally or alternatively, in certain embodiments, the electronic components **102** provide signals to the patient connections **106**. For example, if the patient **104** suffers from dysrhythmias, signals can be provided to one of the patient connections **106** to control an associated electrode of the sensors and/or electrodes **108**, so as to shock the patient's heart and maintain a proper heart beat.

A battery compartment **110** of the patient-connected medical device **100** receives one or more batteries **112** and provides power from the batteries **112** to the electronic components **102** of the patient-connected medical device **100**. Suitably, the battery compartment **110** includes one or more battery connection terminals **114** that interface with terminals of the batteries **112** and connect the batteries **112** in series. In certain embodiments, when the batteries **112** are inserted into the battery compartment **110**, the battery connection terminals **114** are externally inaccessible. That is to say, one cannot access the battery connection terminals **114** of the batteries **112** from outside the battery compartment **110**. While this is typically accomplished by with the physical design of the battery compartment **110**, mechanical and/or electro-mechanical approaches to accomplishing this are also contemplated.

Disposed between the electronic components **102** and the battery compartment **110**, the patient-connected medical device **100** includes a first set **116** of one or more switching devices **118** and a second set **120** of one or more switching devices **122**. Each of the switching devices **118, 122** includes one or more electronic switches, such as field effect transistors (FETs), Triodes for Alternating Current (TRIACs), relays, and the like. Further, typically, the switching devices **118** of the first set **116** are connected in series and/or the switching devices **122** of the second set **120** are connected in series.

The first set **116** and the second set **120** are wired so current is inhibited from accidentally flowing from any of the battery connection terminals **114** to the patient **104**, regardless of the order of installing the batteries **112** and/or the polarity (correct or incorrect) of the batteries **112**. The first set **116** selectively connects, directly or indirectly, a first power output **124** of the battery compartment **110** to a first power input **126** of the electronic components **102**, and the second set **120** selectively connects, directly or indirectly, a second power output **128** of the battery compartment **110** to a second power input **130** of the electronic components **102**. By indirectly, it is contemplated that additional electronic components, such as resistors, are disposed between ones of the switching devices **118, 122** and one or more of the power inputs **126, 130**, the power outputs **124, 128**, and others of the switching devices **118, 122**. Typically, the first power output **124** and the first power input **126** are positive and the second power output **128** and the second power input **130** are negative. However, in certain embodiments, the polarity of the batteries **112** can be reversed, whereby the first power output **124** and the first power input **126** can be negative and the second power output **128** and the second power input **130** can be positive.

The first set **116** and the second set **120** are electronically controlled by opposite polarity of total input voltage, so the sets **116, 120** do not connect their respective power inputs with their respective power outputs until all the batteries **112** are installed. That is to say, the first set **116** is electronically controlled by a first polarity of the total input voltage, and the second set **120** is electronically controlled by a second polarity, opposite the first polarity, of the total input voltage. The total input voltage is the voltage output by the battery compartment **110** (i.e., the voltage across the first power output **124** and the second power output **128**) when completely filled with all the batteries **112**. In certain embodiments, this control is implemented by controlling the first set **116** with the second power output **128** of the battery compartment **110** and the second set **120** with the first power output **124** of the battery compartment **110**, as illustrated.

Without the switching devices **118, 122** and assuming fewer than all the batteries **112** are installed in the battery compartment **110**, the patient **104** could come in contact with one of the battery connection terminals **114** and leakage current could result. For example, if a third one **132** of the batteries **112** was not installed, current could flow from the other ones **134** of the batteries **112** to the patient by way of a first path **136** and one of the patient connections **106**. It is contemplated that the first path **136** could result from the patient **104** directly contacting one **138** of the battery connection terminals **114** of the third one **132** of the batteries **112** or indirectly by, for example, a caregiver simultaneously touching the one **138** of the battery connection terminals **114** and the patient **104**.

With reference to FIGURE 2, a detailed embodiment of the patient-connected medical device **100** according to aspects of the present disclosure is provided. The first set **116** includes a first switching device **140**, and the second set **120** includes a second switching device **142**. The first switching device **140** includes two p-channel FETs **144** connected back-to-back and a resistor **146**, and the second switching device **142** includes two n-channel FETs **148** connected back-to-back and a resistor **150**. The FETs **144, 148** are connected back-to-back to prevent current from flowing in both directions through the switching devices **140, 142**, because each of the FETs **144, 148** includes a substrate diode **152**, which allows current to flow in one direction through the FET regardless of whether it is closed or open. The resistors **146, 150** are employed in conjunction with the substrate diodes **152** to bias the FETs **144, 148**.

A control signal **154** from the second power output **128** of the battery compartment **110** electronically controls the p-channel FETs **144**, and a control signal **156** from the first power output **124** of the battery compartment **110** electronically controls the n-channel FETs **148**. In other words, the control signals **154, 156** for the switching devices **140, 142** are cross coupled to opposite polarities of the total input voltage. So long as the total input voltage when all the batteries **112** are installed in the battery compartment **110** is above the gate-to-source turn-on voltage of the FETs **144, 148**, current can flow. Cross-coupling the control signals **154, 156** of the FETs **144, 148** isolates the control signals **154, 156** so that there can be no completed path through the patient **104** and back to the batteries **102**.

One problem with employing FETs as provided in FIGURE 2 is that there are unintended return paths. For example, if the third one **132** of the batteries **112** was not installed and the patient were to touch the one **138** of the battery connection terminals **114**, current could flow out the first power input **126** through one **158** of the substrate diodes **152** and the resistor **146** of the first switching device **140** to the second power output **128**. Accordingly, this embodiment is primarily used with a mechanical interlock or construction for blocking access to the battery connection terminals **114** or in devices that are not cardiac function (CF) rated. The solution is described hereafter in FIGURES 3 and 4. The potential unintended return path is a result of the substrate diodes **152**, whereby it is to be appreciated that it is not necessarily applicable to other electronic switches.

While the switching devices **140, 142** disclosed in connection with FIGURE 2 are tailored to FETs, it is to be appreciated that other electronic switches, such as relays and TRIACs, can be employed in lieu of FETs. Further, it is to be appreciated that when other electronic switches are employed, the circuits embodying the switching devices **140, 142** will vary from what is illustrated. For example, there is not necessarily a one-to-one mapping between other electronic switches and the FETs **144, 148**. Each of the switching devices **140, 142** has a plurality of FETs because the substrate diodes **152** allow current flow in one direction. Other electronic switches, such as relays, may not suffer from such a limitation, whereby only a single electronic switch would be required.

With reference to FIGURE 3, another detailed embodiment of the patient-connected medical device **100** according to aspects of the present disclosure is provided. The first set **116** includes a first switching device **160** in series with a second switching device **162**, and the second set **120** includes a third switching device **164**. The first switching device **160** and the second switching device **162** each includes two p-channel FETs **166** connected back-to-back, a resistor **168**, and an optional capacitor **170**. Further, the third switching device **164** includes two n-channel FETs **172** connected back-to-back, a resistor **174**, and an optional capacitor **176**. The FETs **166, 172** are connected back-to-back to prevent current from flowing in both directions through the switching devices **160, 162, 164** because each of the FETs **166, 172** includes a substrate diode **178**, which allows current to flow in one direction through the FET regardless of whether it is closed or open. The resistors **168, 174** are employed in conjunction with the substrate diodes **178** to bias the FETs **166, 172**. The capacitors **170, 176** are optionally included to stabilize the switching behavior.

A control signal **180** from the second power output **128** of the battery compartment **110** electronically controls the p-channel FETs **166** of the first switching device **160**, and a control signal **182** from the output or input (depending upon the flow of current) of the first switching device **160** electronically controls the n-channel FETs **172** of the third switching device **164**. Further, a control signal **184** from the output or input (depending upon the flow of current) of the third switching device **164** electronically controls the p-channel FETs **166** of the second switching device **162**. In other words, the first set **116** is electronically controlled by an opposite polarity of the total input voltage as the second set **120**. So long as the total input voltage when all the batteries **112** are installed in the battery compartment **110** is above the gate-to-source turn-on voltage of the FETs **166, 172**, current can flow.

As noted above, the embodiment of FIGURE 2 suffers from unintended return paths when employing FETs because of the substrate diodes **152**. The present embodiment prevents these unintended return paths by employing an additional switching device. For example, if the third one **132** of the batteries **112** was not installed and the patient were to touch the terminal **138** of the battery connection terminals **114**, current could not flow out the first power input **126** through one **186** of the substrate diodes **178** and the resistor **168** of the second switching device **162** to the second power output **128** because of the third switching device **164**.

While the switching devices **160, 162, 164** disclosed in connection with FIGURE 3 are tailored to FETs, it is to be appreciated that other electronic switches, such as relays and TRIACs, can be employed in lieu of FETs. Further, it is to be appreciated that when other electronic switches are employed, the circuits embodying the switching devices **160, 162, 164** will vary from what is illustrated. For example, there is not necessarily a one-to-one mapping between other electronic switches and the FETs **166, 172**. Each of the switching devices **160, 162, 164** required a plurality of FETs because the substrate diodes **178** allow current flow in one direction. Other electronic switches, such as relays, may not suffer from such a problem, whereby only a single electronic switch would be required.

With reference to FIGURE 4, yet another detailed embodiment of the patient-connected medical device **100** according to aspects of the present disclosure is provided. The first set **116** includes a first switching device **188**, and the second set **120** includes a second switching device **190** in series with a third switching device **192**. The first switching device **188** includes two p-channel FETs **194** connected back-to-back, a resistor **196**, and an optional capacitor **198**. Further, the second switching device **190** and the third switching device **192** each include two n-channel FETs **200** connected back-to-back, a resistor **202**, and an optional capacitor **204**. The FETs **194, 200** are connected back-to-back to prevent current from flowing in both directions through the switching devices **188, 190, 192** because each of the FETs **194, 200** includes a substrate diode **206**, which allows current to flow in one direction through the FET regardless of whether it is closed or open. The resistors **196, 202** are employed in conjunction with the substrate diodes **206** to bias the FETs **194, 200**. The capacitors **198, 204** are optionally included to stabilize the switching behavior.

A control signal **208** from the output or input (depending upon the flow of current) of the second switching device **190** electronically controls the p-channel FETs **194** of the first switching device **188**. Further, a control signal **210** from the first power output **124** of the battery compartment **110** electronically controls the n-channel FETs **200** of the second switching device **190**, and a control signal **212** from the output or input (depending upon the flow of current) of the first switching device **188** electronically controls the n-channel FETs **200** of the third switching device **192**. In other words, the first set **116** is electronically controlled by an opposite polarity of the total input voltage as the second set **120**. So long as the total input voltage when all the batteries **112** are installed in the battery compartment **110** is above the gate-to-source turn-on voltage of the FETs **194, 200**, current can flow.

As noted above, the embodiment of FIGURE 2 suffers from unintended return paths when employing FETs because of the substrate diodes **152**. The present embodiment prevents these unintended return paths by employing an additional switching device. For example, if the third one **132** of the batteries **112** was not installed and the patient were to touch the one **138** of the battery connection terminals **114**, current could not flow out the first power input **126** through the one **214** of the substrate diodes **206** of the third switching device **192** to the first power output **124** and/or the second power output **128** because of the first switching device **188** and/or the second switching device **190**.

While the switching devices **188, 190, 192** disclosed in connection with FIGURE 4 are tailored to FETs, it is to be appreciated that other electronic switches, such as relays and TRIACs, can be employed in lieu of FETs. Further, it is to be appreciated that when other electronic switches are employed, the circuits embodying the switching devices **188, 190, 192** will vary from what is illustrated. For example, there is not necessarily a one-to-one mapping between other electronic switches and the FETs **194, 200**. Each of the switching devices **188, 190, 192** required a plurality of FETs because the substrate diodes **206** allow current flow in one direction. Other electronic switches, such as relays, may not suffer from such a problem, whereby only a single electronic switch would be required.

With reference to FIGURE 5, a method **500** for electrically limiting leakage current in the patient-connected medical device **100** is illustrated. A battery **112** is inserted **502** into the battery compartment **110** such that the battery **112** is electrically connected to a power output **124, 128** and one or more battery connection terminals **114** of the battery compartment **110**. The power output **124, 128** is one of the first power output **124** and the second power output **128**. Contemporaneous with or subsequent to the insertion **502**, one of the battery connection terminals **114** is connected **504** with the patient **104**, where the electrical connection is independent of the patient connections **106**. For example, a nurse touches the battery connection terminal and the patient **104** while changing the batteries

**114**. As another example, the patient **104** accidently touches the battery connection terminal. Thereafter, current flow between the power output **124, 128** and a corresponding power input **126, 130** is obstructed **506** until the input voltage is total input voltage. Typically, the first set **116** and/or the second set **120** facilitate obstruction of the current flow by only closing associated switching devices when total input voltage is total input voltage. Further, the total input voltage is the voltage output by the battery compartment **110** when fully loaded with batteries.

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

## CLAIMS

Having thus described the preferred embodiments, the invention is now claimed to be:

1. A system **(116, 120)** for electrically limiting leakage current in a patient-connected medical device **(100)**, comprising:

a first set **(116)** of one or more switching devices **(118)** that selectively connect a first power output **(124)** of a battery compartment **(110)** of the patient-connected medical device **(100)** with a first power input **(126)** of electronic components **(102)** of the patient-connected medical device **(100)** based on a first polarity of input voltage from the battery compartment **(110)**; and,

a second set **(120)** of one or more switching devices **(122)** that selectively connect a second power output **(128)** of the battery compartment **(110)** of the patient-connected medical device **(100)** with a second power input **(130)** of the electronic components **(102)** based on a second polarity of the input voltage, wherein the first polarity is opposite the second polarity.

2. The system **(116, 120)** according to claim 1, wherein the battery compartment **(110)** is designed so battery connection terminals **(114)** are inaccessible when all batteries **(112)** of a specified type are installed in the battery compartment **(110)**.

3. The system **(116, 120)** according to either one of claims 1 and 2, wherein the first power output **(124)** and/or the second power output **(128)** are connected to the first power input **(126)** and/or the second power input **(130)** using one or more electronic switches (**118, 122)**.

4. The system **(116, 120)** according to claim 3, wherein the electronic switches **(118, 122)** include one or more of field effect transistors (FETs), Triodes for Alternating Current (TRIACs), and relays.

5. The system **(116, 120)** according to any one of claims 1-4, wherein the first power output **(124)** is connected with the first power input **(126)** and/or the second

power output **(128)** is connected with the second power input **(130)**, when the input voltage is total input voltage.

6. The system **(116, 120)** according to claim 5, wherein the total input voltage is a voltage output by the battery compartment **(110)** when completely filled with batteries.

7. The system **(116, 120)** according to any one of claims 1-6, wherein the first power output **(124)** is indirectly connected with the first power input **(126)** and/or the second power output **(128)** is indirectly connected with the second power input **(130)**.

8. The system **(116, 120)** according to any one of claims 1-7, wherein the first power output **(124)** and the first power input **(126)** are positive and the second power output **(128)** and the second power input **(130)** are negative.

9. The system **(116, 120)** according to any one of claims 1-8, wherein the first set **(116)** selectively connects the first power output **(124)** with the first power input **(126)** based on the second power output **(128)**, and the second set **(122)** selectively connects the second power output **(128)** with the second power input **(130)** based on the first power output **(124)**.

10. The system **(116, 120)** according to any one of claims 1-8, wherein the first set **(116)** includes a first switching device **(160)** in series with a second switching device **(162)** and the second set **(120)** includes a third switching device **(164)**, wherein the first switching device **(160)** is controlled by the second power output **(128)**, the second switching device **(162)** is controlled by third switching device **(164)** and/or the second power output **(128)**, and the third switching device **(164)** is controlled by the first switching device **(160)** and/or the first power output **(124)**.

11. The system **(116, 120)** according to any one of claims 1-8, wherein the first set **(116)** includes a first switching device **(188)** and the second set **(120)** includes a second switching device **(190)** in series with a third switching device **(192)**, wherein the first switching device **(188)** is controlled by the second switching device **(190)** and/or the third switching device **(192)**, the second switching device **(190)** is controlled by first power

output **(124)** and/or the first switching device **(188)**, and the third switching device **(192)** is controlled by the first switching device **(188)** and/or the first power input **(126)**.

12. A patient-connected medical device **(100)** comprising:

the battery compartment **(110)** for one or more batteries **(112)**, wherein the battery compartment **(110)** connects the batteries **(112)** in series and includes the first power output **(124)** and the second power output **(128)**;

the electronic components **(102)** including the first power input **(126)** and the second power input **(130)**; and,

the system **(116, 120)** according to any one of claims 1-11.

13. A method of manufacturing the system **(116, 120)** according to any one of claims 1-11.

14. A method **(500)** for electrically limiting leakage current in the patient-connected medical device **(100)**, according to any one of claims 1-12, said method comprising:

inserting a battery **(112)** into the battery compartment **(110)**, the battery **(112)** electrically connected to a power output **(124, 128)** and one or more battery connection terminals **(114)** of the battery compartment **(110)**, wherein the power output **(124, 128)** is one of the first power output **(124)** and the second power output **(128)**;

establishing an electrical conduction path between one of the battery connection terminals **(114)** and the patient **(104)**, wherein the electrical conduction path is independent of the patient connections **(106)**;

obstructing current flow between the power output **(124, 128)** and a corresponding power input **(126, 130)** until the input voltage is a preselected operating input voltage, wherein the first set **(116)** and/or the second set **(120)** of switching devices facilitate obstruction of the current flow.

15. The method according to claim 14, wherein the obstructing includes:

closing the switching devices **(118)** of the first set **(116)** when the input voltage of the first polarity is the total input voltage; and,

closing the switching devices **(122)** of the second set **(120)** when the input voltage of the second polarity is the total input voltage.

16. The method according to claim 14, wherein the first set **(116)** includes a first switching device **(160)** in series with a second switching device **(162)** and the second set **(120)** includes a third switching device **(164)**, wherein the first switching device **(160)** is controlled by the second power output **(128)** and/or the third switching device **(164)**, the second switching device **(162)** is controlled by third switching device **(164)** and/or second power input **(130)**, and the third switching device **(164)** is controlled by the first switching device **(160)** and/or the second switching device **(162)**, wherein the obstructing includes:

opening the first switching device **(160)** until the input voltage of the first polarity is the preselected operating input voltage;

opening the second switching device **(162)** until the input voltage of the first polarity is the total input voltage and both the first switching device **(160)** and the third switching device **(164)** are closed; and,

opening the third switching device **(164)** until the input voltage of the second polarity is the total input voltage and the first switching device **(160)** is closed.

17. The method according to claim 14, wherein the first set **(116)** includes a first switching device **(188)** and the second set **(120)** includes a second switching device **(190)** in series with a third switching device **(192)**, wherein the first switching device **(188)** is controlled by the second switching device **(190)** and/or the third switching device **(192)**, the second switching device **(190)** is controlled by first power output **(124)** and/or the first switching device **(188)**, and the third switching device **(192)** is controlled by the first switching device **(188)** and/or the first power input **(126)**;

closing the first switching device **(188)** when the input voltage of the first polarity is the total input voltage and second switching device **(190)** is closed;

closing the second switching device **(190)** when the input voltage of the second polarity is the total input voltage; and,

closing the third switching device **(192)** when the input voltage of the second polarity is the total input voltage and both the first switching device **(188)** and the second switching device **(190)** are closed.

18. The method **(500)** according to any one of claims 14-17, wherein the preselected operating input voltage is a voltage output by the battery compartment **(110)** when completely filled with batteries.

19. The method **(500)** according to any one of claims 14-17, wherein the obstructing **(506)** includes:

obstructing unintended return paths through substrate diodes **(152, 178, 206)** of the switching devices **(118)** of the first set **(116)** and the switching devices **(122)** of the second set **(120)**.

20. A patient-connected medical device **(100)**, comprising:

a battery compartment **(110)** for one or more batteries **(112)**, wherein the battery compartment **(110)** connects the batteries **(112)** in series and includes a first power output **(124)** and a second power output **(128)**;

electronic components **(102)** including a first power input **(126)** and a second power input **(130)**;

a first set **(116)** of one or more switching devices **(118)** that selectively connect the first power output **(124)** with the first power input **(126)** based on a first polarity of input voltage from the battery compartment **(110)**; and,

a second set **(120)** of one or more switching devices **(122)** that selectively connect the second power output **(128)** with the second power input **(130)** based on a second polarity of the input voltage, wherein the first polarity is opposite the second polarity.

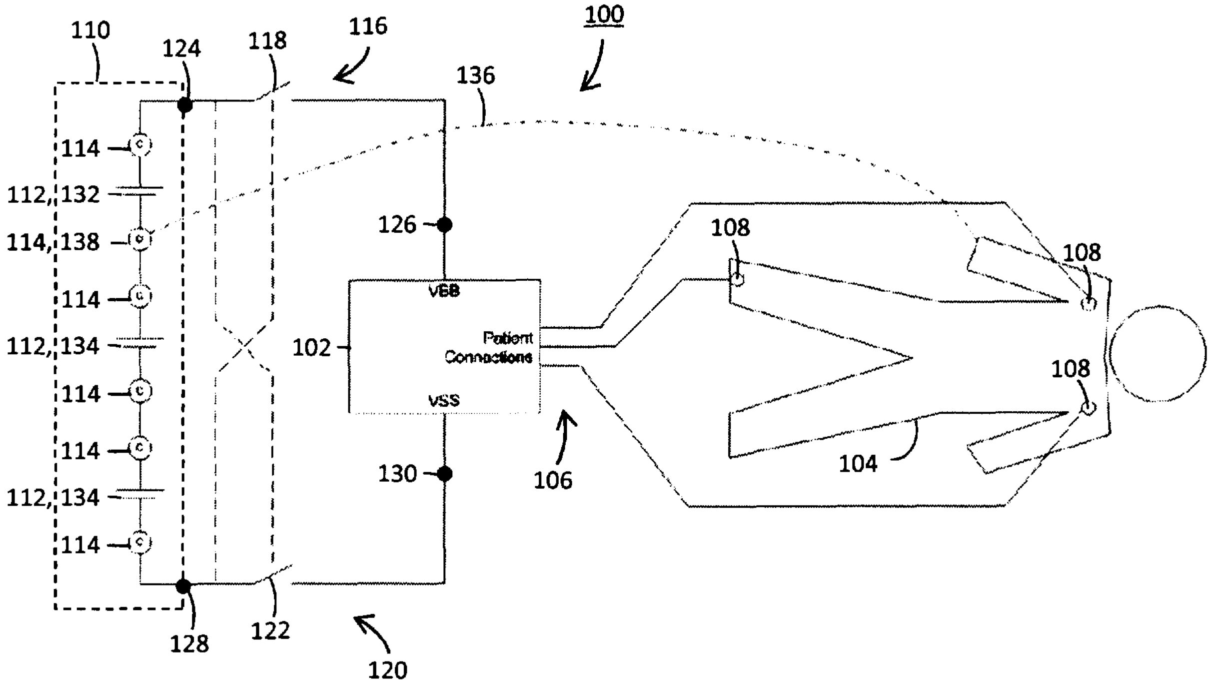

100
110
124
118
116
136
114
112, 132
114, 138
112, 134
126
108
102
VBB
Patient Connections
VSS
130
106
104
128
122
120

FIG. 1

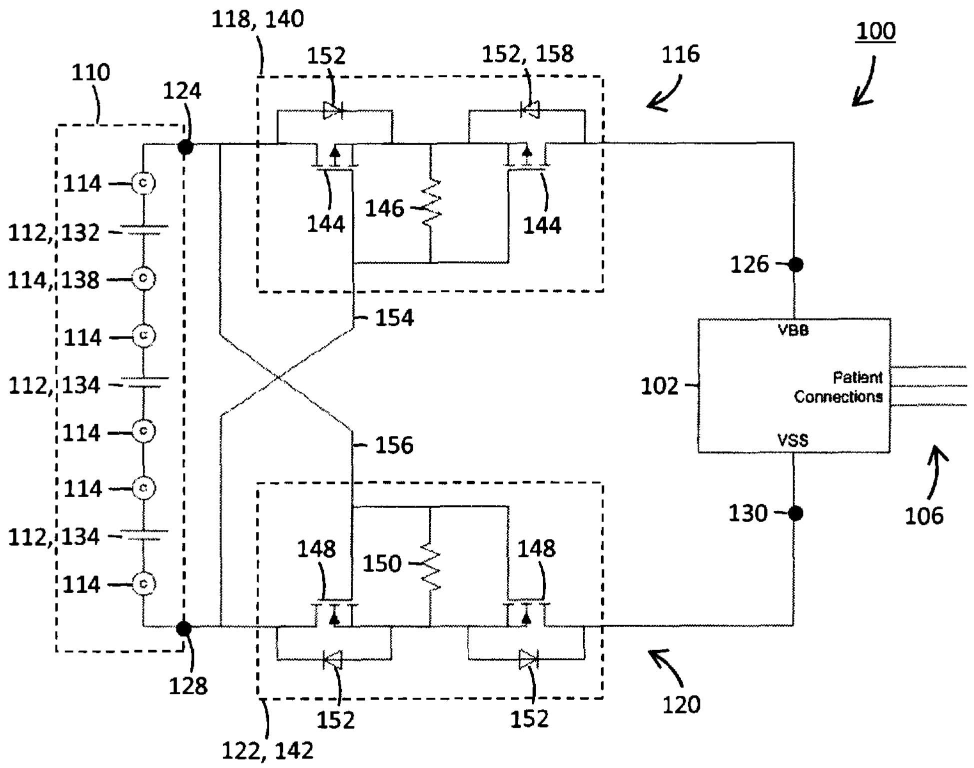
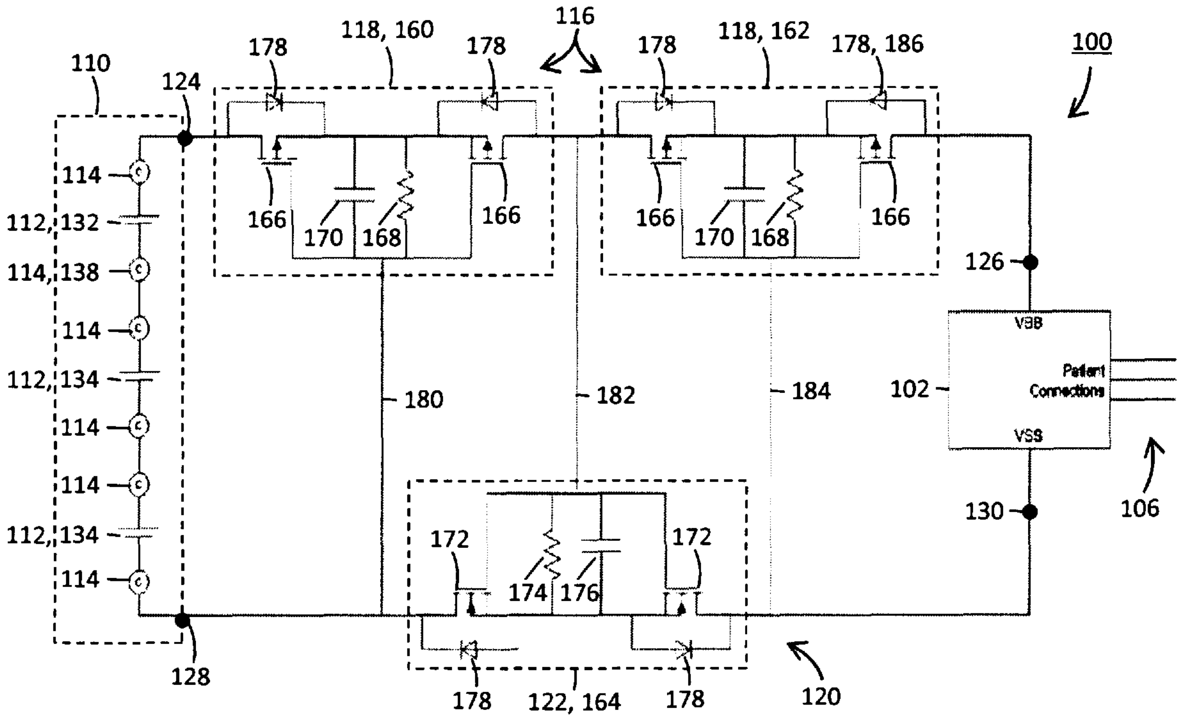
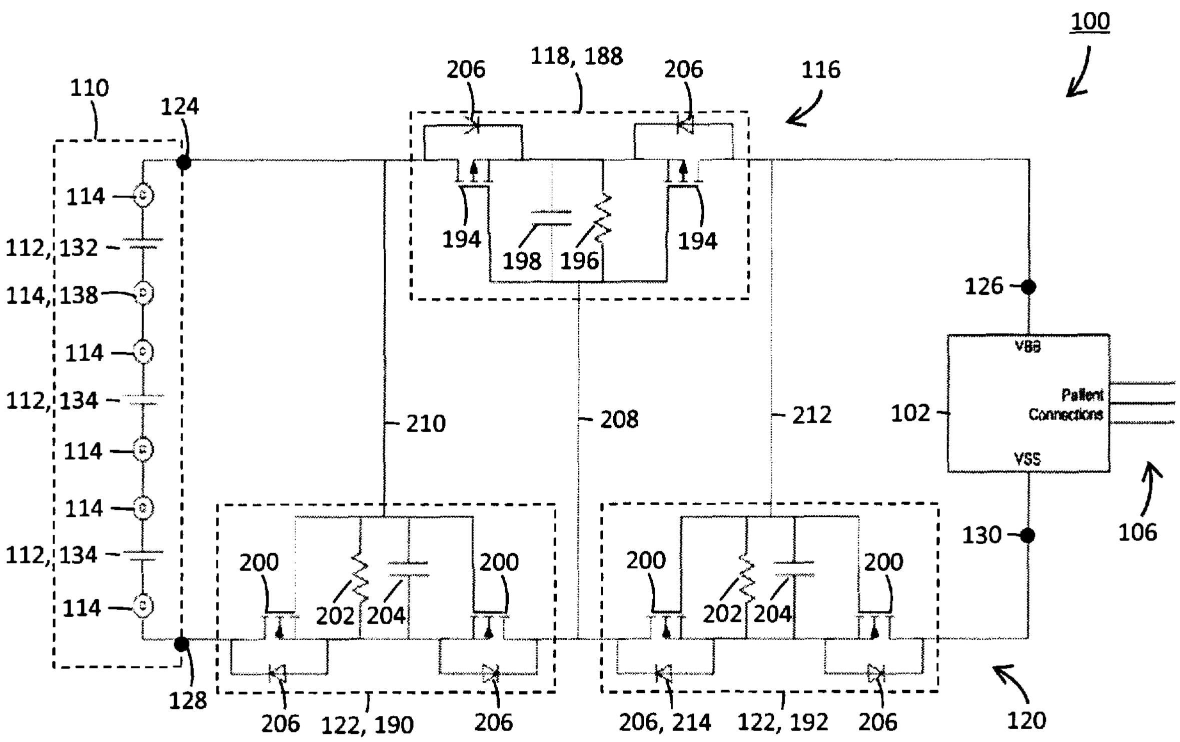

118, 140
152
152, 158
116
100
110
124
114
112, 132
114, 138
112, 134
144
146
154
126
VBB
102
Patient Connections
VSS
156
130
106
148
150
128
122, 142
120

FIG. 2



116
118, 160
118, 162
178
178, 186
110
124
100
114
112, 132
114, 138
112, 134
166
170
168
126
VBB
Patient Connections
VSS
102
180
182
184
106
130
172
174
176
128
122, 164
120


FIG. 3



100
118, 188
206
116
110
124
114
112, 132
114, 138
112, 134
194
198
196
126
VBB
Patient Connections
VSS
102
210
208
212
106
130
200
202
204
128
122, 190
206, 214
122, 192
120


FIG. 4

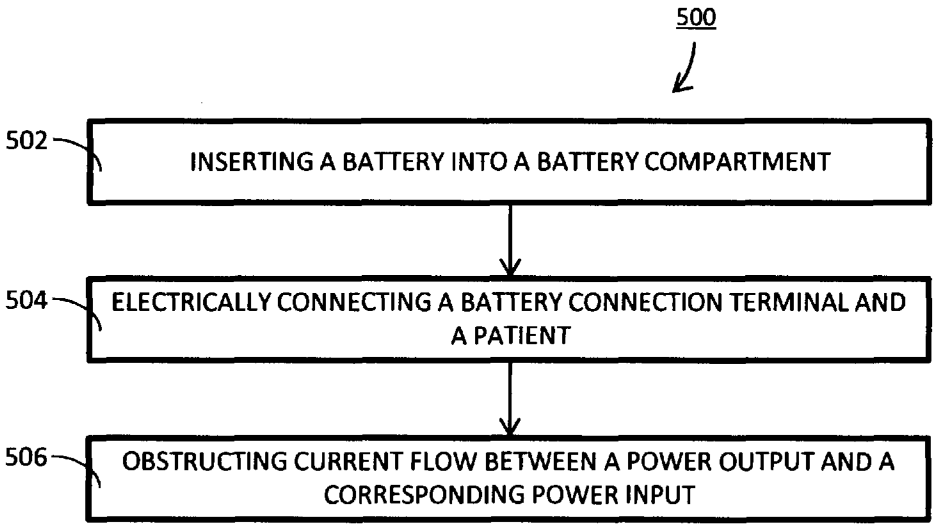

500
502
INSERTING A BATTERY INTO A BATTERY COMPARTMENT
504
ELECTRICALLY CONNECTING A BATTERY CONNECTION TERMINAL AND A PATIENT
506
OBSTRUCTING CURRENT FLOW BETWEEN A POWER OUTPUT AND A CORRESPONDING POWER INPUT

FIG. 5