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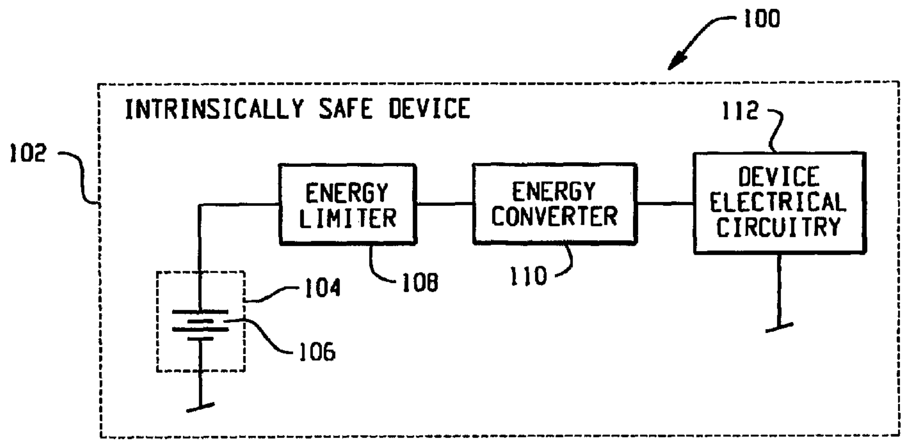

(57) Abstract: An intrinsically safe battery powered device (100) includes a housing (102), a battery receiving region (104), an intrinsically safe power supply (108, 110), and device electrical circuitry (112). The power supply (108, 110) uses energy from batteries (106) received in the batter receiving region (104) of the device (100) to power the circuitry (112). In one implementation, the power supply includes an intrinsically safe charge pump circuit.

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INTRINSICALLY SAFE BATTERY POWERED POWER SUPPLY

BACKGROUND

The present application relates to battery powered electrical devices for use in hazardous locations. While it finds particular application to hand-held and other readily transportable devices, the application also relates to stationary, battery-backed, and other battery powered electrical devices suitable for use in environments which present a risk of fire or explosion.

Battery powered electrical devices are ubiquitous. Indeed, such devices are widely used in home, commercial, industrial, and other environments to perform a wide variety of functions. Unless specifically designed, however, such devices are not typically suited for use in hazardous locations.

Hazardous (classified) locations include those locations in which ignitable concentrations of flammable or combustible materials are or may reasonably be expected to be present in the atmosphere. Such locations can be encountered, for example, in petrochemical, mining, agricultural, and industrial facilities. Depending on the classification scheme, hazardous locations may be classified in various ways. In North America, for example, a Class I, Division 1 hazardous location is a location where ignitable concentrations of flammable gases, vapors or liquids can exist under normal operating conditions, may frequently exist because of repair or maintenance operations or because of leakage, or may exist because of an equipment breakdown that simultaneously causes the equipment to become a source of ignition. Under a classification scheme which is used outside of North America, a Zone 0 hazardous location is a location where an explosive gas-air mixture is continuously present or present for long periods.

Various techniques have been used to render electrical equipment suitable for use in hazardous locations. One technique involves the use of explosion-proof housings. An explosion proof housing is designed to withstand an explosion occurring within it and to prevent the ignition of combustible materials surrounding the housing. Explosion-proof housings also operate at an external temperature below that which is sufficient to ignite surrounding materials. While explosion-proof housings can be quite effective, they tend to be both expensive and physically large, rendering them relatively unattractive for use in applications in which cost or physical size is a factor.

Another technique involves the use of purging, in which an enclosure is supplied with a protective gas at a sufficient flow and positive pressure to reduce the concentration of a flammable material to an acceptable level. However, purging systems can be relatively complex, and a source of purge gas may not readily available.

Another technique involves the use of intrinsically safe electrical circuits. Intrinsically safe circuits are typically energy limited so that the circuit cannot provide sufficient energy to trigger a fire or explosion under normal operating or fault conditions. One definition of an intrinsically safe circuit which is sometimes used in connection with the certification of intrinsically safe equipment is contained in Underwriters Laboratory (UL) Standard 913, entitled *Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations.* According to this definition, an intrinsically safe circuit is one in which any spark or thermal effect, produced normally or in specified fault conditions, is incapable, under the test conditions proscribed in [the UL 913] standard, of causing ignition of a mixture of a flammable or combustible material in air in the mixture's most easily ignitable concentration.

Various intrinsically safe battery powered electrical devices have been produced. Examples include flashlights, laser pointers, scales, digital voltmeters (DVMs), radios, clocks, and wall thickness monitors. One flashlight has included three (3) light emitting diodes (LEDs) each having a nominal forward voltage of about 3.6 volts direct current (VDC). The flashlight has been powered by three (3) 1.5VDC Type N batteries, with an energy limiting resistor disposed electrically in series between the batteries and the LEDs. A particular disadvantage of such a configuration, however, is that three (3) batteries are required to supply the nominal 3.6VDC forward voltage of the LEDs. A still further disadvantage is that the current supplied to the LEDs is a function of the battery voltage, the LED forward voltage, and the series resistance. As a result, the intensity of the light produced by the flashlight can vary significantly as the batteries discharge. Moreover, such a configuration utilizes the energy from the batteries relatively inefficiently, so that the flashlight is relatively bulky for a given light output and operating time.

Other intrinsically safe flashlights have included an incandescent or halogen bulb powered by two (2) AAA batteries, again connected electrically in series through a current limiting resistor. This configuration again suffers from variations in light intensity and a relatively inefficient utilization of the available battery energy. While the bulbs can be operated on the voltage supplied by only two batteries, devices containing such bulbs cannot readily be certified for use in Class I, Division I locations, thereby limiting their utility.

Still other devices have been powered by intrinsically safe lithium ion (Li Ion) batteries having a nominal voltage of about 3.6VDC. While the relatively higher output voltage of these batteries provides additional application flexibility, they tend to be less widely available than other battery types.

Moreover, some devices require multiple voltage and/or current supplies. While it is possible to provide different batteries for powering different parts of the device or to connect multiple batteries in series to provide different output voltages, it is generally desirable to reduce the number and/or types of batteries required to power a particular device.

SUMMARY

Aspects of the present application address these matters, and others.

According to one aspect, an intrinsically safe device includes a battery receiving region which accepts at least a first generally cylindrical battery, first device electrical circuitry, and a first boost converter which converts electrical energy from the at least a first battery to a voltage suitable for powering the first device electrical circuitry. The device is intrinsically safe for use in a hazardous location.

According to another aspect, an intrinsically safe, battery powered device includes first electrical circuitry which performs a function of the device, a battery receiving region, and an intrinsically safe, active power supply circuit which uses energy from a battery received in the battery receiving region to power the first electrical circuitry.

According to another aspect of the present application, a method of operating an electrical device includes receiving electrical energy from at least a first battery disposed in a battery receiving region of the device, using a first intrinsically safe active power supply circuit to supply electrical energy received from the at least a first battery to first electrical circuitry of the device.

According to another aspect, an intrinsically safe battery powered device includes a battery receiving region adapted to receive at least a first battery, first device electrical

circuitry, and a first intrinsically safe charge pump which uses energy from the at least a first battery to power the device electrical circuitry.

According to another aspect, a battery powered, intrinsically safe charge pump power supply which transfers electrical energy from at least a first battery to an electrical load is provided.

Those skilled in the art will recognize still other aspects of the present application upon reading and understanding the attached description.

BRIEF DESCRIPTION OF THE DRAWINGS

The present application is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

Figure 1 depicts an intrinsically safe, battery powered device.

Figure 2 depicts an energy limiter

Figure 3 depicts an energy converter.

Figure 4A, 4B, 4C, 4D, and 4E depict energy converters.

Figure 5 depicts an intrinsically safe, battery powered device.

Figure 6 depicts a method of operating an electrical device.

DETAILED DESCRIPTION

With reference to Figure 1, an intrinsically safe battery powered electrical device 100 includes a housing 102 which carries a battery receiving region 104 for receiving one or more batteries 106, an energy limiter 108, an energy converter 110, and device electrical circuitry 112 which performs a function of the device. The configuration of the housing 102 and characteristics of the electrical circuitry 112 are a function of the nature and function of the device 100.

The number and type of batteries 106 required to power the device 100 and hence the configuration of the battery receiving region 104 are likewise a function of the electrical characteristics of the device electrical circuitry 112, the desired operating time and size of the device 100, and similar factors. In one implementation, however, the battery receiving region 104 is configured to accept one (1) or more standard AAA, AA, C, or D-size batteries.

The batteries 106, energy limiter 108, energy converter 110, and device electrical circuitry 112 are configured as an intrinsically safe circuit which is suitable for use in hazardous locations. As the batteries 106 are typically capable of supplying energy sufficient to render the device 100 non-intrinsically safe, the energy limiter 108 limits the available energy so that any spark or thermal effect produced during normal operation of the device 100 or under fault conditions is incapable of causing ignition of a mixture of a flammable or combustible material in air in the mixture's most easily ignitable concentration. The energy limiter 108 should be located as near as practicable to the battery receiving region 104, and the requisite electrical connections should be suitably spaced and insulated so as to prevent or otherwise reduce the likelihood of shorts, opens, or other faults.

With reference to Figure 2, the energy limiter 108 includes a series connected resistor 202 and fuse 204. The resistor 202 is selected to limit the instantaneous current available to the energy converter 110 and device electrical circuitry 112 to a level which satisfies the requirements of intrinsic safety. The fuse 204, which is ordinarily implemented as a fast acting, encapsulated fuse, is selected primarily to limit thermal effects in the event of a fault condition. The energy limiter 108 may also be implemented as a fuse protected or resistor protected shunt diode barrier. The latter implementations are particularly attractive where the physical configuration of the battery receiving region 104 or the associated battery contacts is such that relatively higher voltages may be encountered.

The energy converter 110 includes active electrical circuitry such as a direct current to direct current (DC to DC) converter which converts energy from the batteries 106 to a form suitable for powering the device electrical circuitry 112. Where the device 100 is configured to accept both primary (non-rechargeable) and secondary (rechargeable) batteries, or otherwise having different chemistries, the converter 110 advantageously has an input dynamic range which accommodates the voltages produced by the relevant battery types. An alkaline battery, for example has a nominal open circuit voltage of about 1.5 volts direct current (VDC), whereas a nickel metal hydride (NiMH) battery has a nominal open circuit voltage of about 1.2VDC. In an implementation in which the battery receiving region 104 is configured to receive two (2) batteries connected electrically in series, the nominal open circuit input voltage would thus range between about 2.4 for a device containing two NiMH batteries and 3.0VDC for a device containing two alkaline batteries. Depending on the requirements of a particular application, it is also desirable that the input dynamic range accommodate decreases in input voltage which occur as the battery(ies) 106 are loaded and/or become discharged.

The energy converter 110 may be configured as a voltage source, a current source, or as having other output characteristics which are suitable for powering the device electrical circuitry 112. Note that the converter 110 need not function as an ideal voltage or current source. Thus, converter 110 is ordinarily designed to have an equivalent series or parallel resistance (as the case may be) which is compatible with the requirements of the device electrical circuitry 112.

In one implementation, and with reference to Figure 3, the energy converter 110 includes a charge pump which includes one more charge pump capacitors 302, one or more semiconductor or other switches 304, and a controller 308. Where closed loop control of the energy converter 110 output is provided, a feedback signal 308 is provided to the controller 306.

Figure 4A depicts a charge pump which is particularly well to situations requiring step down voltage conversion. As illustrated, the charge pump includes a charge pump capacitor 402, an output energy storage device such as a capacitor 404, a controller 406, and a semiconductor switch 408. The controller 406 varies the switch 406 between a first state (shown in Figure 4A) in which the charge pump capacitor 402 receives energy from the batteries 106 and a second state in which energy from the charge pump capacitor 402 is transferred to the output capacitor 404. The controller 406 may also include a control circuit which adjusts the operation of the switch 408 based on a measured value of the output voltage or current. Though illustrated as a single pole double throw (SPDT) switch, the switch 408 may also be implemented using semiconductor or other devices which function as single pole single throw (SPST) switches.

A charge pump which operates as a current source is shown in Figure 4B. As illustrated, the circuit includes a flying charge pump capacitor 402, an output capacitor 404, and a plurality of switches 408_1, 408_2, 408_3, 408_4. Energy from the charge pump capacitor 402 is transferred to the device electrical circuitry side when the switches 408_3, 408_4 are closed and switches 408_1, 408_2, are open (shown in Figure 4B); the flying capacitor 402 is charged when the switches 408_1, 408_2 are closed and the switches 408_3,

408_4 are open. A measurement apparatus such as a current sense resistor 410 connected electrically in series with the device electrical circuitry 112 provides a feedback signal indicative of the device electrical circuitry current. The controller 406 includes a control circuit 412 and an oscillator 414 which cooperate to control the operation of the switches 408 to provide the desired current output.

A charge pump which operates as a regulated voltage boost converter is shown in Figure 4C. As illustrated, the circuit includes first 402_1 and 402_2 second flying charge pump capacitors, an output capacitor 404, and a plurality of switches 408_1, 408_2, 408_3, 408_4, 408_5, 408_6, 408_7 which are configured as a voltage doubler. When connected to the output side (as shown in Figure 4C), the capacitors 402 are connected electrically in series; when connected to the input side, the capacitors 402 are connected electrically in parallel. Such a configuration provides up to about a two (2) times voltage boost. The controller 406 includes a control circuit 412 and an oscillator 414. As illustrated, the controller 412 receives a feedback signal 308 indicative of the converter 110 output voltage. The control circuit 412 and oscillator 414 cooperate to control the operation of the switches 408 to provide the desired output voltage. Note that a voltage divider may also be implemented by connecting the capacitors in series when connected to the input and in parallel when connected to the output.

A charge pump which operates as an inverting boost converter is shown in Figure 4D. As illustrated, the circuit includes a plurality of flying charge pump capacitors 402_n, an output capacitor 404, a plurality of switches 408_{1-m}, and a controller 406. As configured, the circuit provides up to approximately a negative n-times voltage boost. The controller 406 provides the desired output regulation, if any.

A charge pump which provides multiple operating modes is shown in Figure 4E. As illustrated, the circuit includes first 402_1 and second 402_2 flying capacitors, an output capacitor 404, a plurality of switches 408_{1-9}, and a controller 406. In one mode, the input is connected directly to the output by closing switches 408_1 and 408_5. In another mode, the circuit operates as a step down converter. More particularly, the switches 408_1 and 408_5 are operated in a manner similar to that described above in connection with Figure 4A so as to provide the desired output. In another mode, the capacitors 402 are charged in alternating clock phases so that the converter functions as a voltage doubler. In a first clock phase, the first capacitor 402_1 is connected to the input through switches 408_3 and

408_4, while the second capacitor 402_2 is stacked on top of the input and connected to the output through switches 408_5 and 408_6. In the second clock phase, the second capacitor 402_2 is connected to the input through switches 408_1 and 408_2, while the first capacitor 402_1 is stacked on top of the input and connected to the output through switches 408_7 and 408_8. In still another mode, the circuit functions as up to a one and one half times (1.5x) voltage converter. In such an implementation, the capacitors 402 are connected in series for charging and in parallel for transferring energy to the output. In still another mode, the capacitors 402 are connected in parallel for charging and in series for transferring energy to the output so that the circuit functions as a voltage tripler.

The desired operating mode may be dynamically selected by the controller 406 based on the feedback signal 308. Such an implementation is particularly attractive in situations where the operating characteristics of the device electrical circuitry 112 may change based on ambient conditions or otherwise as a function of time, or where it is desirable to account for changes in the input voltage, for example as the batteries 106 discharge. While described as a circuit having multiple dynamically selectable operating modes, those of ordinary skill in the art will recognize that the circuit may be configured to provide only one or a subset of the described modes.

As noted above, the characteristics of the load presented by the device circuitry 112 depend on the nature and function of the device 100. In this regard, the thermal characteristics of the various device 100 electrical components should be selected so that the temperature rise under both operating and fault conditions is insufficient to cause ignition of flammable or combustible materials in the applicable hazardous location. The values of reactive and other energy storage components should also be selected so that, in the event of a fault condition, the released energy is insufficient to cause ignition of flammable or combustible materials in the applicable hazardous location. Internal wiring and other connections should be insulated and spaced appropriately. One source of guidance with respect to acceptable temperatures, component values, spacing, and the like is the known UL 913 standard.

Variations are contemplated. For example, a particular device 100 may include a plurality of electrical circuits 112_0, 112_1, 112_2 . . . 112_p, each requiring a different supply voltage and/or current. As one non-limiting example, a given device 100 may include an input sensor or transducer circuit which operates at a first relatively high voltage, signal conditioning circuitry connected to the transducer and which also requires a negative supply voltage, logic circuitry for determining if the measured value reaches an alarm condition and which can operate directly from the voltage provided by the batteries 106, and an alarm output or indicator circuitry such as one or more light emitting diodes (LEDs) which are advantageously powered by a current source. In such a situation, and as illustrated in Figure 5, the device may be provided with a plurality of energy converters 110_1, 110_2 . . . 110_p, the number and function of which are determined based on the requirements of the various device electrical circuits 112.

More than one energy limiter 108 may be provided. In such an implementation, the device 100 is advantageously constructed so that each energy limited circuit can be evaluated separately for the purpose of evaluating intrinsic safety. More specifically, the separation and/or spacing of the various energy limited circuits is advantageously established so that the various circuits cannot reasonably be expected to become short circuited or otherwise so that a fault in one of the circuits cannot reasonably be considered to affect the intrinsic safety of another.

While the above discussion focused on standard AAA, AA, C, and D-size batteries, other battery sizes and form factors are also contemplated. Thus, for example, the battery receiving region may be configured to receive other generally cylindrical batteries, prismatic batteries, or coin cells. Other chemistries are also contemplated, including but not limited to carbon zinc, lithium ion (LiIon), lithium iron disulfide (Li/FeS_2), and nickel cadmium (NiCd), provided that the batteries are otherwise suitable for use in the desired hazardous location. The battery receiving region 104 may also be configured to accept only a single battery or three (3) or more batteries.

As noted above, the device 100 may be of a size and weight which are suitable for a hand-held or otherwise readily human portable device. In another variation, the device 100 may also be configured for fixed or semi-fixed operation. In such a situation, the device 100 may be provided with electrical connections which allow the device to be connected to fixed, external wiring. The device 100 may also be configured for operation with a transducer which is designed to be mounted at a fixed location.

Where the device 100 is ordinarily operated using power from an external source, the batteries 106 may be used to power the device 100 when the device is disconnected from the external source, in the event of a power failure, or otherwise in the absence of external power. In one such implementation, the device 100 is provided with an energy converter 110 configured to function as a battery charger. When external power is available, the converter 110 charges secondary battery(ies) 106 received in the battery receiving region 104. In still another configuration, the device 100 may be provided with external contacts which allow battery(ies) 106 received in the receiving region 104 to be connected to an external battery charger.

Still other variations in the energy converters 110 and converter topologies are contemplated. While energy converters 110 which use capacitive energy storage elements are especially well suited for intrinsically safe applications, converters 110 using inductive or other energy storage elements may also be implemented. Variations in the configuration of the controller 406 are also contemplated. For example, the controller 406 may include a constant or a variable frequency oscillator. Regulation of the output voltage and/or current may also be provided by varying a duty cycle of the energy transfer or otherwise without an oscillator. The energy converters 110 may be implemented using integrated circuits (ICs), discrete components, or combinations thereof. Those of ordinary skill in the art will also recognize that charge pump converter ICs are commercially available from a number of sources. Note also that the output capacitor 404 may be omitted, particularly where the device electrical circuitry 112 is tolerant of the resultant output swings.

In addition to being designed as intrinsically safe for use in Class I, Division I locations, the device 100 may be designed for use in other classes, divisions or groups (*e.g.*, classes II or III, Division 2, Groups B-G, or the like). The device 100 may also be designed to conform to IEC, ATEX/CENELEC, or other classification standards, for example in Zones 0, 1, or 2.

Various devices 100 are contemplated. Non-limiting examples include communication devices, user operable signaling devices, measurement devices, automatic alarm or warning devices, flashlights and other light sources, actuators, and other operating devices. Examples of communication devices include radio frequency or infrared receivers, transmitters, transceivers, pagers, wired or wireless intercoms, or other one or two-way communication devices. Signaling devices include visual, audible, radio frequency or other signaling equipment, for example for signaling a distress or other condition. Examples of measurement devices include devices for measuring ambient or operating conditions such as temperature, gas or other material concentrations, time, or the like. Exemplary actuators include pumps, fans, motors, actuators, and microelectromechanical systems (MEMS). Other measurement devices include digital voltmeters, ammeters, ohmmeters, scales, and the like. Note also that, depending on the nature of the device 100, the device may perform a function which is specific to a petrochemical, agricultural, mining, industrial, or other facility.

Operation of the device 100 will now be described in relation to Figure 6. At 602, electrical energy is received from a battery or batteries disposed in the battery receiving region 104 of the device 100. At 604, the energy converter(s) 110 supplies energy from the battery(ies) 106 to the device electrical circuitry 112. At 606, the device 100 is operated in a hazardous location. In the event of a fault condition such as a component failure or a short circuit, the energy limiter(s) 108 limit the available energy at step 608.

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

CLAIMS

What is claimed is:

1. An intrinsically safe device (100) comprising:

a battery receiving region (104) which accepts at least a first generally cylindrical battery (106);

first device electrical circuitry (112);

a power supply including a first boost converter which converts electrical energy from the at least a first battery to a level suitable for powering the first device electrical circuitry, wherein the first device electrical circuitry and the power supply form an intrinsically safe circuit.

2. The device of claim 1 wherein at a least a first battery is a AAA, AA, C, or D-size battery.

3. The device of any of claims 1-2 wherein the device is intrinsically safe for use in a location where ignitable concentrations of flammable gases, vapors, or liquids are present for long periods of time or continuously.

4. The device of any of claims 1-3 including second device electrical circuitry (112_0) which operates at a voltage produced by the at least a first battery (106).

5. The device of any of claims 1-3 including second device electrical circuitry (112_2) and a second converter (110_2) which converts electrical energy from the at least a first battery (106) to a level suitable for powering the second electrical circuitry (112_2).

6. The device of any of claims 1-5 wherein the converter includes a closed loop voltage controller (406).

7. The device of any of claims 1-6 wherein the converter includes a charge pump.

8. The device of claim 7 wherein the charge pump includes a plurality of flying capacitors (402_1, 402_2, 402_n).

9. The device of any of claims 1-8 wherein the converter operates in a first mode in which the converter functions as a voltage boost converter and a second mode in which a maximum output voltage of the converter is less than or equal to an input voltage of the converter.

10. The device of any of claims 1-9 wherein the device includes a battery charger for charging the at least a first battery.

11. The device of any of claims 1-10 further including an energy limiter (108) which limits an energy available from the at least a first battery.

12. The device of any of claims 1-11 wherein the device is a hand-held device.

13. The device of any of claims 1-12 wherein the device includes a wireless communication device.

14. The device of any of claims 1-11 wherein the device includes a transducer which, in operation, is mounted at a fixed location in the external environment.

15. The device of any of claims 1-11 wherein the device includes at least one of voltmeter, an ohmmeter, and an ammeter.

16. An intrinsically safe, battery powered device (100) including first electrical circuitry (112) which performs a function of the device, a battery receiving region (104), and an intrinsically safe, active power supply circuit (110) which uses energy from a battery received in the battery receiving region to power the first electrical circuitry (112).

17. The device of claim 16 wherein the battery receiving region receives exactly two generally cylindrical batteries and the power supply circuit (110) uses energy from the exactly two batteries to power the first electrical circuitry (112).

18. The device of claim 16 wherein the power supply circuit includes a passive electrical component (202, 204) which limits the energy from the battery so that, in the event of a device fault condition, the device is intrinsically safe for use in a hazardous location.

19. The device of claim 18 wherein the energy is limited so that the device is intrinsically safe for use in a hazardous location where ignitable concentrations of flammable gases, vapors or liquids can exist under normal operating conditions, may frequently exist because of repair or maintenance operations or because of leakage, or may exist because of an equipment breakdown that simultaneously causes the equipment to become a source of ignition.

20. The device of claim 16 wherein the power supply circuit (110) includes a capacitive charge pump.

21. The device of claim 20 wherein the charge pump includes first and second charge pump capacitors (402_1, 402_2), and wherein the first and second capacitors are connected electrically in parallel when connected to an input side of the charge pump and electrically in series when connected to an output side of the charge pump.

22. The device of claim 20 wherein the charge pump includes a charge pump capacitor (402), and wherein the charge pump capacitor is stacked on top of an input of the charge pump for supplying energy to an output of the charge pump.

23. The device of claim 20 wherein the charge pump includes a multiphase clock.

24. The device of claim 16 wherein the device includes an electrical connector for connecting the device to fixed, external wiring.

25. The device of claim 24 wherein the fixed, external wiring provides operating power to the device.

26. The device of claim 16 wherein the device includes a user operable signaling device.

27. The device of claim 16 wherein the device includes a warning device.

28. The device of claim 16 wherein the device is readily transportable by a human user.

29. The device of claim 16 wherein the active power supply circuit includes a closed loop output controller (406).

30. A method of operating an electrical device (100) comprising:

receiving electrical energy from at least a first battery (106) disposed in a battery receiving region (104) of the device;

using a first intrinsically safe active power supply circuit (110) to supply electrical energy received from the at least a first battery (106) to first electrical circuitry of the device (112).

31. The method of claim 30 wherein the device is intrinsically safe for use in a Group I, Division I hazardous location.

32. The method of claim 30 wherein the device is intrinsically safe for use in a Zone 0 hazardous location.

33. The method of claim 30 wherein the power supply circuit (110) includes at least one of a capacitive voltage doubler or a capacitive voltage divider.

34. The method of claim 30 wherein the power supply circuit (110) includes an input side for receiving energy from the at least a first battery (106) and an output side for providing energy to the first electrical circuitry and using an active power supply circuit (110) includes using a flying capacitor (402) to transfer energy from the input side to the output side.

35. The method of claim 30 including using a second active power supply circuit (110_2) to supply electrical energy to second electrical circuitry (112_2) of the device when the device is operated in the hazardous location.

36. The method of claim 30 wherein receiving includes receiving electrical energy from a plurality of secondary batteries.

37. The method of claim 30 including using the device to perform a measurement function.

38. The method of claim 30 including using the device to perform a communication function.

39. The method of claim 30 including using the device to perform an automatic warning function.

40. The method of claim 30 including using the device to perform a user-controlled visual or audible signaling function.

41. The method of claim 30 including fixedly mounting the device in the hazardous location.

42. The method of claim 30 including

measuring, during an operation of the device, a voltage supplied to the first electrical circuitry (112);

using the measured value to adjust the voltage supplied to the first electrical circuitry (112).

43. An intrinsically safe battery powered device (100) comprising:

a battery receiving region (104) adapted to receive at least a first battery (106);

first device electrical circuitry (112);

a first intrinsically safe charge pump (110) which uses energy from the at least a first battery (106) to power the device electrical circuitry (112).

44. The device of claim 43 including second device electrical circuitry (112_2) and a second intrinsically safe charge pump (110_2) which uses energy from the at least a first battery (106) to power the second device electrical circuitry (112_2).

45. The device of claim 43 wherein the device electrical circuitry includes an actuator.

46. The device of claim 43 wherein the device electrical circuitry includes a MEMS.

47. The device of claim 43 wherein the device performs a function specific to one of a petrochemical facility, a mine, an agricultural facility, or an industrial facility.

48. A battery powered, intrinsically safe charge pump power supply (108, 110) which transfers electrical energy from at least a first battery (106) to an electrical load (112).

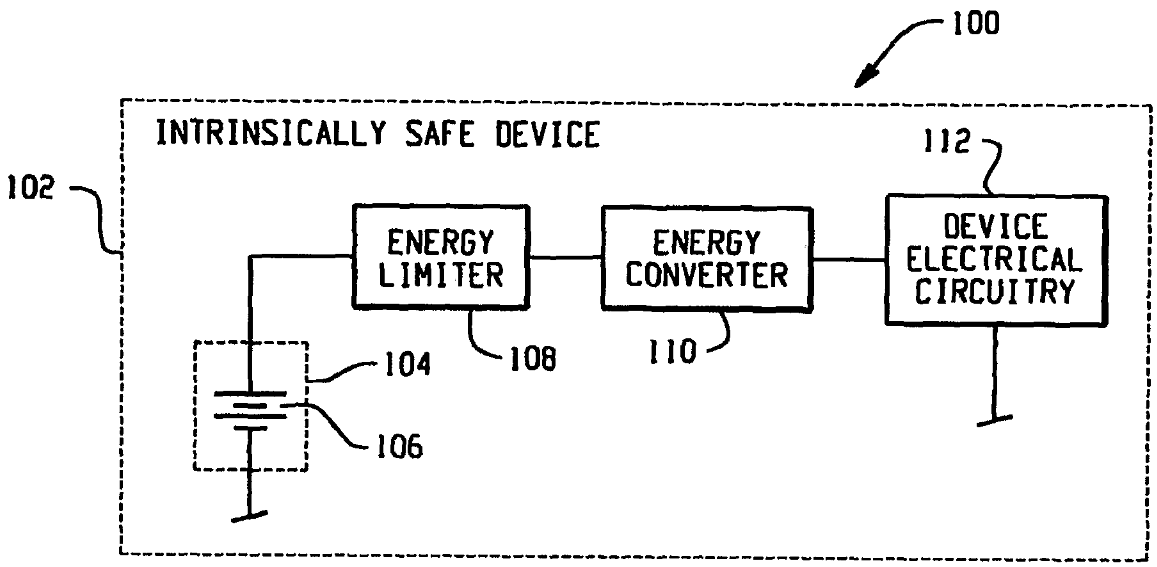


Fig. 1

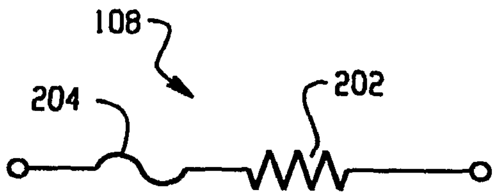


Fig. 2

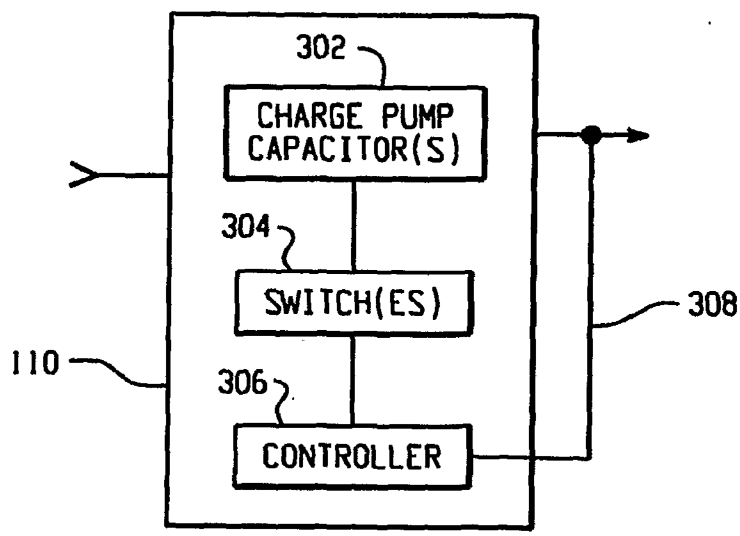


Fig. 3

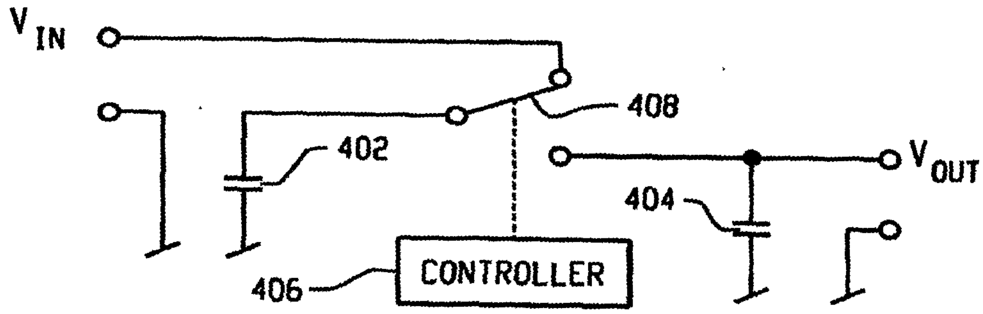


Fig. 4A

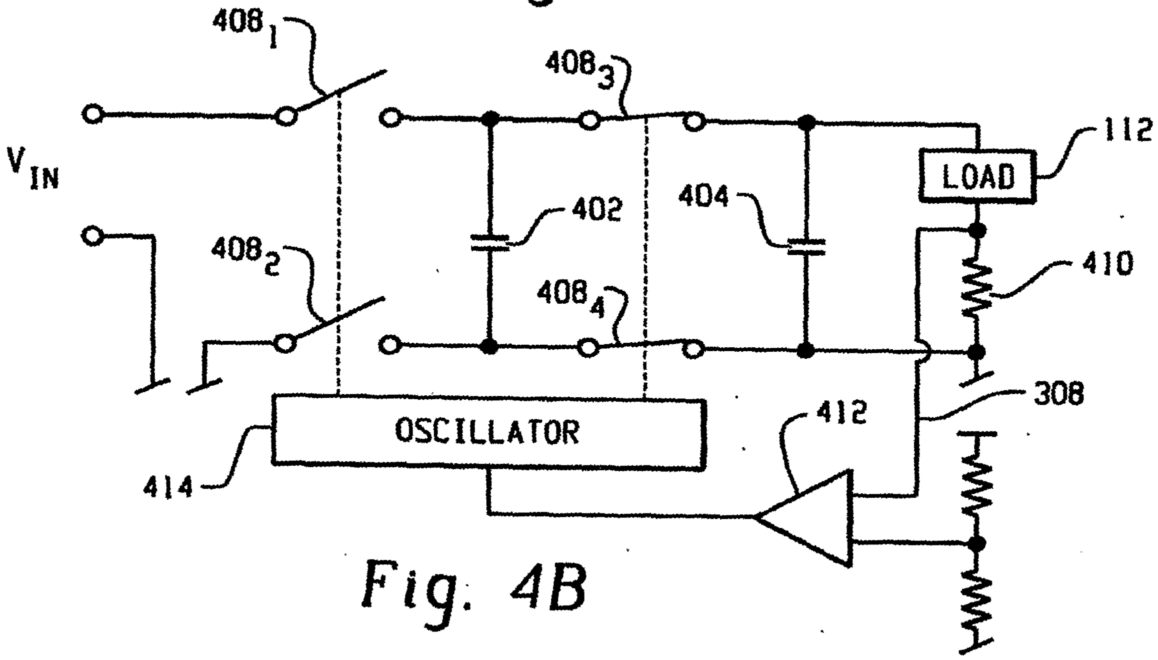


Fig. 4B

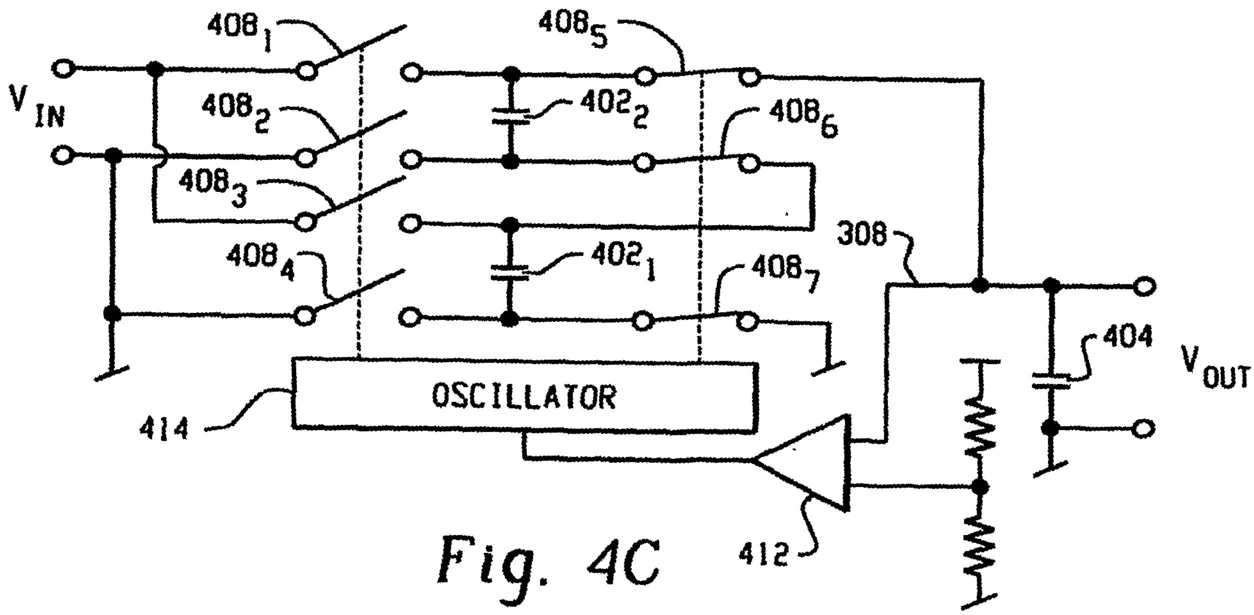
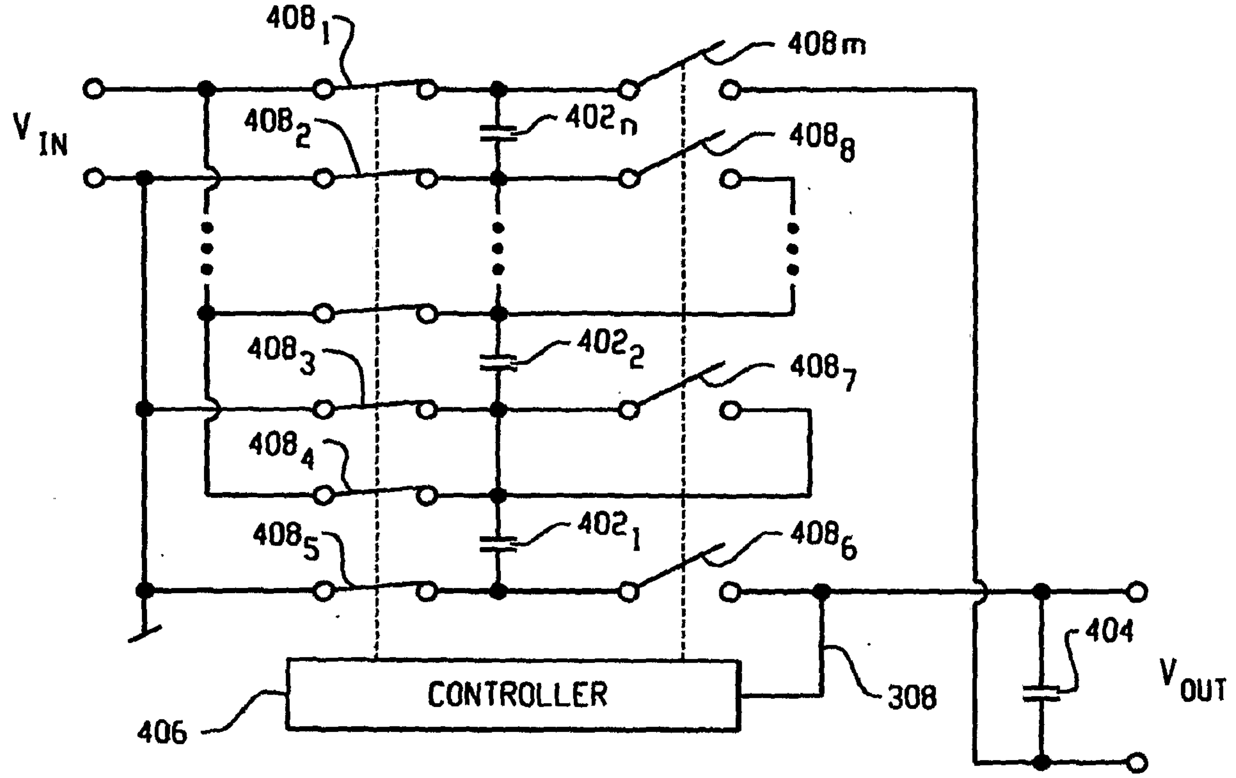
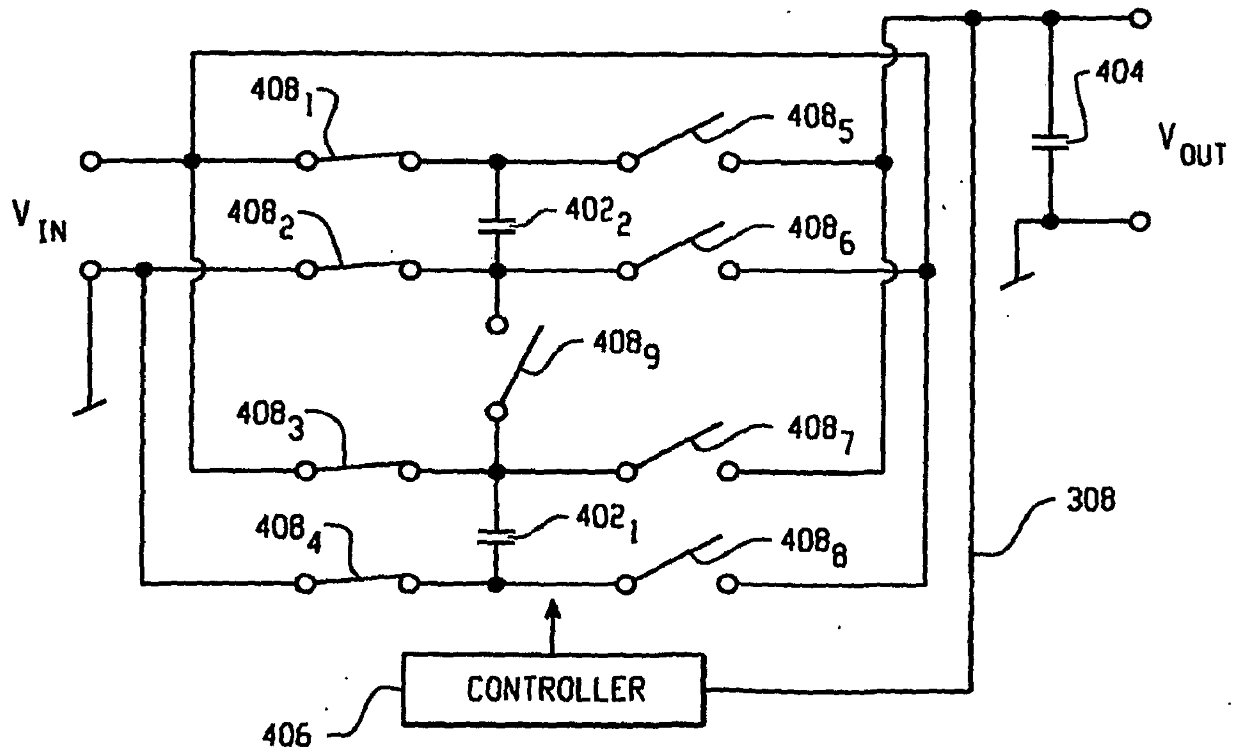


Fig. 4C



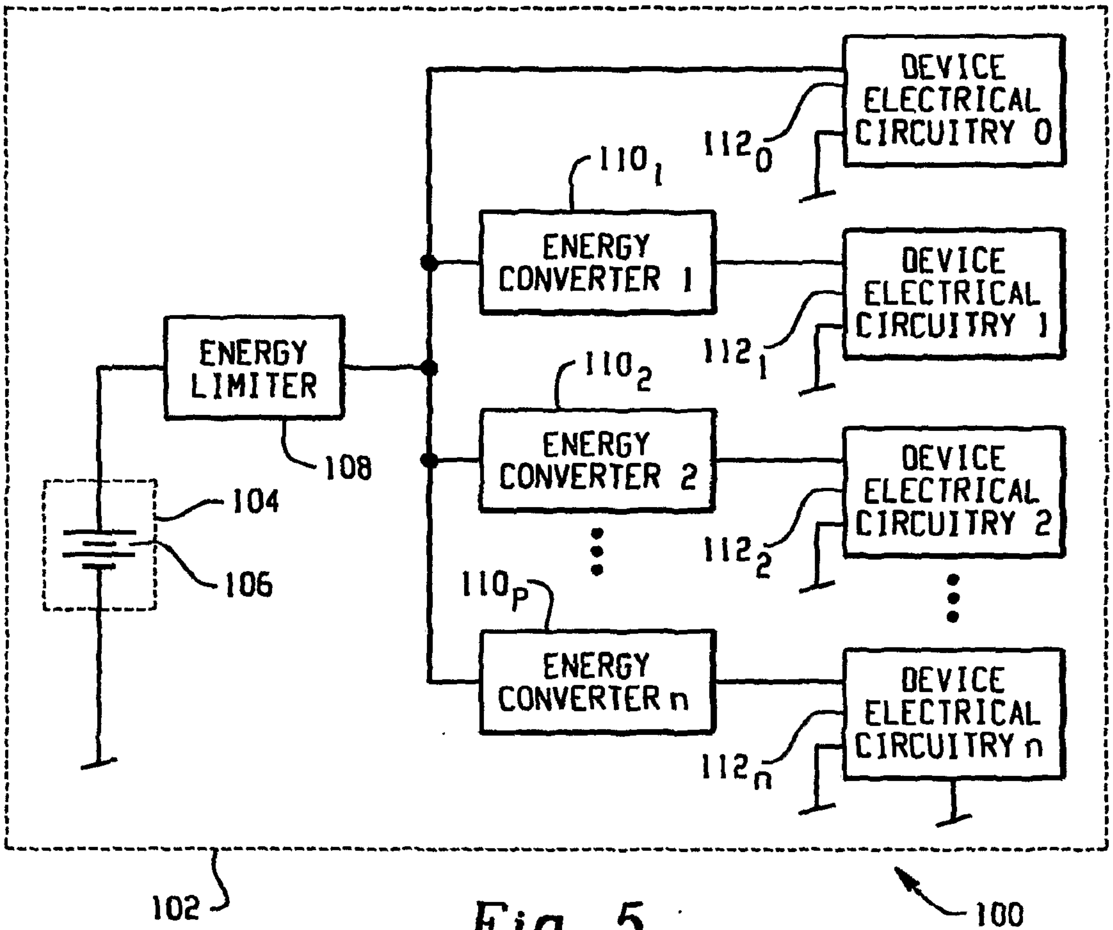
408 1
408m
V IN
408 2
402n
408 8
402 2
408 3
408 7
408 4
402 1
408 5
408 6
CONTROLLER
406
308
404
V OUT

Fig. 4D



404
V OUT
408 1
408 5
V IN
408 2
402 2
408 6
408 9
408 3
408 7
308
408 4
402 1
408 8
CONTROLLER
406

Fig. 4E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112₀
110₁
ENERGY CONVERTER 1
DEVICE ELECTRICAL CIRCUITRY 1
112₁
ENERGY LIMITER
110₂
ENERGY CONVERTER 2
DEVICE ELECTRICAL CIRCUITRY 2
108
104
106
112₂
110p
ENERGY CONVERTER n
DEVICE ELECTRICAL CIRCUITRY n
112n
102
100

Fig. 5

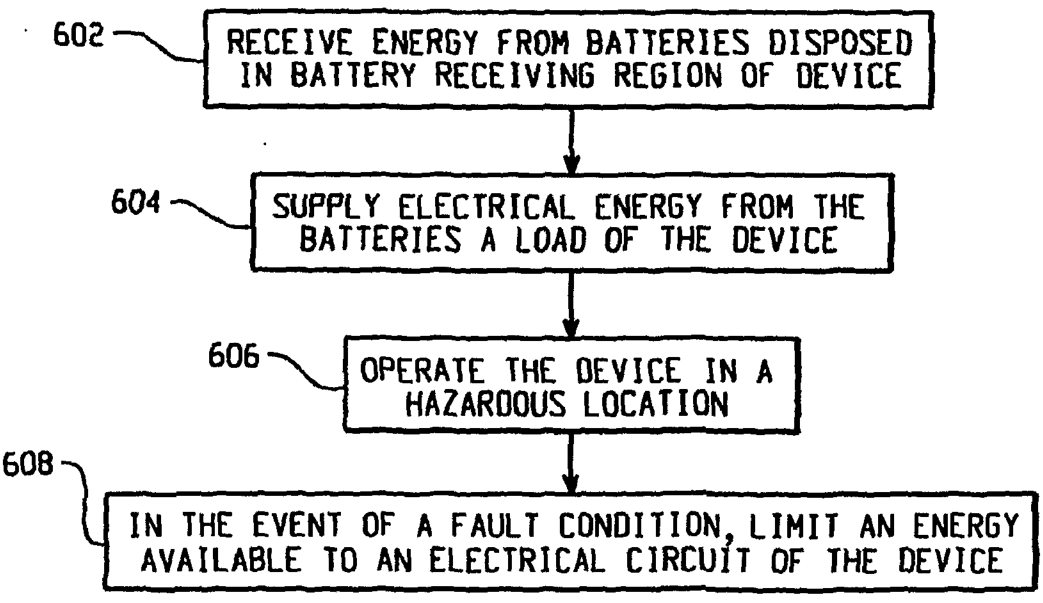
602
RECEIVE ENERGY FROM BATTERIES DISPOSED IN BATTERY RECEIVING REGION OF DEVICE
604
SUPPLY ELECTRICAL ENERGY FROM THE BATTERIES A LOAD OF THE DEVICE
606
OPERATE THE DEVICE IN A HAZARDOUS LOCATION
608
IN THE EVENT OF A FAULT CONDITION, LIMIT AN ENERGY AVAILABLE TO AN ELECTRICAL CIRCUIT OF THE DEVICE

Fig. 6