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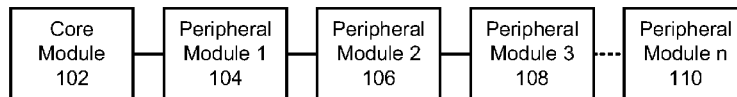
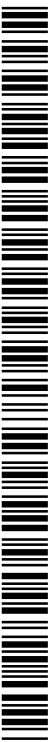


FIG. 1

(57) Abstract: Some implementations can include battery powered systems, battery modules and methods of battery management for providing power to various modules of a wearable smart band. The smart band can include a core module having a battery and a power section. The smart band can also include one or more optional extra battery modules connected to a power and communication bus coupled to the core module.



MODULAR BATTERY SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/274,035, filed on December 31, 2015 and entitled “Modular Battery System,” which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Some implementations relate to energy storage systems, and in particular, to a modular expandable battery system for a mobile electronic device, such as a wearable smartband.

SUMMARY

[0003] Some implementations can include an electrical power storage element such as a battery module or a built-in battery power section, or in some instances, multiple electrical power storage elements configured to provide electrical power to an electronic device such as a wearable electronic device, a modular wearable smart band, a smart watch, etc. A wearable electronic device can include a main battery power section (e.g., a main battery power section in the watchface or core module of the wearable device) and be expandable via one or more extra (or additional) connectable and interchangeable battery power sections (e.g., extra battery modules external to the main battery power section in the core module). Some implementations can provide autonomous switching between extra battery modules on the wearable device when a monitored voltage level (e.g., VBUS voltage level, as described below) reaches a certain level or threshold. Some implementations can include a circuit that detects when a battery drains (e.g., a core module battery or an extra battery module) and reaches a certain voltage level, and switches to a next extra battery module. In some implementations, when the power is drained from the extra battery modules, the main battery in the core module becomes the power source.

[0004] Some implementations can include a system comprising a core module having a main battery power section. The core module can include a core module controller, a core module charging section having a control line connected to the core module controller, a core module battery connected to the core module charging section, a core module converter

connected to the core module battery, and a core module protection circuit connected to the core module battery and a power bus. The system can also include one or more additional battery modules coupled to the core module via a communication bus and coupled to the power bus. Each additional battery module can include an additional battery module controller, an additional battery module charging switch connected to the additional battery module controller, an additional battery module charging section connected to the additional battery module controller, the additional battery module charging switch and the power bus, an additional battery module battery connected to the charging section of the additional battery module, an additional battery module discharging switch connected to the additional battery module controller, the additional battery module battery, and the power bus, and an additional battery module protection circuit connected to the additional battery module discharging switch and the power bus.

[0005] The one or more additional battery modules can include a first analog to digital converter connected to the power bus and to the additional battery module controller, and a second analog to digital converter connected to the additional battery module battery of the additional battery module and the additional battery module controller. The core module converter can include a buck converter. The core module controller can include a microcontroller. The additional battery module controller can include a microcontroller. The one or more additional battery modules can be configured to supply power to the power bus when voltage on the power bus falls below a threshold value.

[0006] The additional battery module controller can be configured to perform operations including initializing to an offline state upon being connected to the power bus, detecting a voltage level of the power bus, and, when the voltage level of the power bus is below a threshold, transitioning to an offline discharging state. The operations can also include when the voltage level of the power bus is at or above the threshold, transitioning to an online idle state, and receiving a command from the core module to transition from the online idle state to an online discharging state, and in response, transitioning from the online idle state to an online discharging state when instructed by the core module. The operations can further include transitioning from the online discharging state to the online idle state when instructed by the core module or when a low voltage in the additional battery module battery of the additional battery module is detected, transitioning from the online idle state to the online charging state when the voltage level on the power bus is at a threshold and when instructed by the core

module, and transitioning from the online charging state to the online idle state when the additional battery module battery of the additional battery module is charged or when instructed by the core module.

[0007] Some implementations can include a system comprising one or more additional battery modules. Each additional battery module can include an additional battery module controller, an additional battery module charging switch connected to the additional battery module controller, an additional battery module charging section connected to the additional battery module controller, the additional battery module charging switch and a power bus, an additional battery module battery connected to the additional battery module charging section, an additional battery module discharging switch connected to the additional battery module controller, the additional battery module battery, and the power bus, and an additional battery module protection circuit connected to the additional battery module discharge switch and the power bus. The one or more additional battery modules can include a first analog to digital converter connected to the power bus and to the additional battery module controller, and a second analog to digital converter connected to the additional battery module battery and the additional battery module controller.

[0008] The additional battery module controller can include a microcontroller. The one or more additional battery modules can be configured to supply power to the power bus when voltage on the power bus falls below a threshold value.

[0009] The additional battery module controller can be configured to perform operations including initializing to an offline state upon being connected to a power bus, detecting a voltage level of the power bus, and, when the voltage level of the power bus is below a threshold, transitioning to an offline discharging state. The operations can also include when the voltage level of the power bus is at or above the threshold, transitioning to an online idle state, and transitioning from the online idle state to an online discharging state when instructed by a core module. The operations can further include transitioning from the online discharging state to the online idle state when instructed by the core module or when a low voltage in the additional battery module battery of the additional battery module is detected, transitioning from the online idle state to the online charging state when the voltage level on the power bus is at a threshold and when instructed by the core module, and transitioning from the online charging state to the online idle state when the additional battery module battery of the additional battery module is charged or when instructed by the core module.

[0010] The system can also include a core module having a power section, where the core module can be coupled to the one or more additional battery modules. The core module can include a core module controller, a core module charging section having a control line connected to the core module controller, a core module battery connected to the core module charging section, a core module converter connected to the core module battery, and a core module protection circuit connected to the core module battery and a power bus. The core module can be configured to perform operations including transmitting instructions to the one or more additional battery modules. The instructions cause the one or more additional battery modules to perform one or more of transitioning from the online idle state to an online discharging state, transitioning from the online discharging state to the online idle state, transitioning from the online idle state to the online charging state, and transitioning from the online charging state to the online idle state.

[0011] Some implementations can include a wearable computing system comprising a core module having a main power section. The core module can include a core module controller, a core module charging section having a control line connected to the core module controller, a core module battery connected to the core module charging section, a core module converter connected to the core module battery, and a core module protection circuit connected to the core module battery and a power bus. The wearable computing system can also include one or more additional battery modules.

[0012] The additional battery modules can each include an additional battery module controller, an additional battery module charging switch connected to the additional battery module controller, an additional battery module charging section connected to the additional battery module controller, the additional battery module charging switch and the power bus, an additional battery module battery connected to the additional battery module charging section, an additional battery module discharging switch connected to the additional battery module controller, the additional battery module battery, and the power bus, and an additional battery module protection circuit connected to the additional battery module discharge switch and the power bus.

[0013] The one or more additional battery modules can include a first analog to digital converter connected to the power bus and to the additional battery module controller, and a second analog to digital converter connected to the additional battery module battery and the additional battery module controller. The core module converter can include a buck converter.

The core module controller can include a microcontroller. The one or more additional battery modules can be configured to supply power to the power bus when voltage on the power bus falls below a threshold value.

[0014] The additional battery module controller can be configured to perform operations including initializing to an offline state upon being connected to a power bus, and detecting a voltage level of the power bus. The operations can also include when the voltage level of the power bus is below a threshold, transitioning to an offline discharging state, and when the voltage level of the power bus is at or above the threshold, transitioning to an online idle state. The operations can further include transitioning from the online idle state to an online discharging state when instructed by the core module, and transitioning from the online discharging state to the online idle state when instructed by the core module or when a low voltage in the additional battery module battery of the additional battery module is detected. The operations can also include transitioning from the online idle state to the online charging state when the voltage level on the power bus is at a threshold and when instructed by the core module, and transitioning from the online charging state to the online idle state when the additional battery module battery of the additional battery module is charged or when instructed by the core module.

[0015] It is understood that other configurations of the subject technology will become readily apparent to those skilled in the art from the following detailed description, wherein various implementations or configurations of the subject technology are shown and described by way of illustration. The subject technology is capable of other and different configurations and its several details are capable of modification in various respects without departing from the scope of the subject technology. Accordingly, the detailed description and drawings are to be regarded as illustrative and not restrictive in nature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Certain features of the subject technology are set forth in the appended claims. However, the accompanying drawings, which are included to provide further understanding, illustrate disclosed aspects and together with the description serve to explain the principles of the subject technology. In the drawings:

[0017] FIG. 1 is a diagram of example connectivity between one or more modules and a core, in accordance with some implementations.

[0018] FIG. 2 provides an example schematic diagram illustrating electrical connectivity between module controllers and a core controller, in accordance with some implementations.

[0019] FIG. 3 illustrates a block diagram of example hardware modules used for implementing an extra battery module, in accordance with some implementations.

[0020] FIG. 4 illustrates a block diagram of example hardware modules used for implementing a core module, in accordance with some implementations.

[0021] FIG. 5 illustrates an Extra Battery Module (EBM) control state diagram, in accordance with some implementations.

[0022] FIG. 6 illustrates a block diagram of an example power system, in accordance with some implementations.

DETAILED DESCRIPTION

[0023] The detailed description set forth below is intended as a description of various configurations of the subject technology and is not intended to represent the only configurations in which the subject technology can be practiced. The appended drawings are incorporated herein and constitute a part of the detailed description. The detailed description includes example specific details for the purpose of providing a more thorough understanding of the subject technology. However, it will be clear and apparent that the subject technology is not limited to the example specific details set forth herein and may be practiced without these details. In some instances, structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology.

[0024] Some implementations may address some limitations that may be present in some conventional energy storage solutions. In particular, aspects of the technology provide various modules for a wearable smartband, including one or more fixture units (i.e., a core module) configured to provide a user interface (e.g., to a wearable user), regarding one or more interchangeable modules for implementing, or expanding, functionality of the wearable device. A wearable system can include one or more extra (or additional) battery modules that can include additional batteries having the same capacity or different capacity than the main battery.

[0025] In some aspects, the various modules are connected one after another, wherein a core module 102 is connected to a first peripheral module 104, which is in turn connected to a second peripheral module 106, a third peripheral module 108, and so on, as shown in FIG. 1. Depending on implementation, modules may be connected serially (as shown in FIG. 1), or connected in parallel on a bus (e.g., as shown in FIG. 2).

[0026] In some aspects, the various modules are configured to be hot swappable (e.g., configured for insertion or removal without the need for powering down the host wearable device). Hot swappable modules, in turn, provide the wearable with hot swapping features and expanded functionality. In some implementations an Extra Battery Module (EBM) is provided, e.g., one or more of the peripheral modules 104-110 includes an extra battery.

[0027] Although an EBM can contain various software and/or hardware modules, in some aspects EBMs can include a battery with one or more cells and control circuits (e.g., as shown in FIG. 3). Some implementations can also include devices for power generating and/or harvesting such as solar cells, kinetic motion to electrical devices, body heat to electric converters, etc. The power generating or harvesting components can be integrated into an EBM or in separate modules form the EBM and/or core module. In practice, multiple EBMs can be attached into the system and identified individually. EBMs can also be attached to and detached from the core module without affecting the rest of the system.

[0028] In some implementations, each of the EBMs can be controlled by the core module, for example, to turn on or turn off the charging and discharging functions. The remaining battery levels of the EBMs (e.g., as a percentage of battery power used or remaining) can be fetched by the core module by querying each EBM over the communications bus, for example. In some implementations, an EBM can also communicate its power status without being queried (e.g., via an interrupt, etc.) periodically or in response to a detected condition (e.g., battery voltage level dropping below a threshold level). The microcontroller in an EBM can obtain the battery voltage level via a circuit element for measuring voltage (e.g., an analog to digital converter or ADC). The EBM microcontroller can then provide the battery voltage level to the core module via a communication bus in response to a request from the core module, periodically, or based on another parameter (such as battery voltage, bus voltage, etc.). The microcontroller mentioned in the EBM and core module descriptions is used as an example controller. It will be appreciated that other types of controllers could be used including one or more of an application specific integrated circuit (ASIC), a programmable logic device, a

microprocessor, a digital signal processor (DSP), or the like. The controller can have internally stored, programmed or wired instructions or may access a nontransitory computer readable memory (or media) either internal or external to the controller.

[0029] In some implementations, the core module and the EBMs can utilize a four line (or conductor, wire, etc.) power and communication interface including one pair of power supply lines and one pair of I2C signal bus lines (e.g., as shown in FIG. 2). By way of example, the four lines can include VBUS (202) or positive voltage supply line, GND (204), I2C_SCL (206) and I2C_SDA (208). As shown in the example of FIG. 2, the peripheral modules (212-218) and the core module (210) can be connected to the four lines (202-208) in parallel. A serial connection arrangement could also be used in some implementations.

[0030] In the example of FIG. 2, VBUS 202 is a power positive line, wherein electrical current can flow in both directions through the power line. In some implementations, the voltage on VBUS can be variable and is valid for example from about 3.3V to about 5V. In some aspects, voltages higher than about 5.5V can be recognized as over-voltage and trigger an over-voltage protection (OVP) response. Voltages lower than 3.3V can lead to failure for some modules. In some embodiments, VBUS 202 is responsible for providing power to all peripheral modules and the core module. In some implementations, an external power source 220 (e.g., a 5V (or other voltage) supply from an AC adapter, USB connector, other charging connector, a power generating element or module (e.g., solar cell, kinetic charger, body heat charger, etc.), etc.) may also be connected to VBUS 202. FIG. 2 also shows a core module 210 and a plurality of peripheral modules 212-218 (e.g., EBMs) coupled to the power bus and signal bus lines. The power source 220 (e.g., solar cell, kinetic charger, body heat charger, etc.) could also be internal to its own module or integrated into another module such as an EBM or the core module.

[0031] Further to the example of FIG. 2, GND 204 is a power negative line, and can serve as the ground reference for I2C_SCL 206 (clock signal) and I2C_SDA 208 (data signal) signals. I2C_SCL 206 is the clock line of the I2C bus. In some implementations, I2C_SCL 206 can be driven solely by the core module, and the voltage can be pulled up by the core module (e.g., to provide an active low protocol). I2C_SDA 208 is the bi-directional data line of the I2C bus. It can be driven by either the core modules, or one or more of the peripheral modules. In some aspects, the voltage level of I2C_SDA 208 can also pulled up by the core module.

[0032] FIG. 3 illustrates a block diagram of example hardware modules 300 used for implementing an EBM 316. As shown in FIG. 3, an EBM 316 can include a microcontroller 306, a charging IC 308, a battery 310, a discharging switch 312, and a protection circuit 314. The microcontroller 306 handles communications between the EBM and other modules and also monitors the bus voltage level and battery voltage level (e.g., via analog to digital converters or ADCs). The charging IC 308 monitors the battery voltage level and charges the battery 310 when needed from the bus voltage and when adequate power is available from the bus and the EBM is not in discharge mode. The discharging switch 312 operates to permit the battery 310 to provide power to the power bus. The protection circuit 314 prevents reverse current flow from the bus to the battery 310 outside of the path of the charging IC 308.

[0033] In practice, the microcontroller 306 of an EBM can be connected to the I2C bus 302 to communicate with a processor (e.g., microcontroller) in the core module or in a peripheral module. The EBM microcontroller 306 can be configured to detect a voltage level of the battery 310 and report the battery voltage level to the core module (or a different peripheral module) via the communications bus and execute actions based on instructions or commands from the core module (or the different peripheral module). The EBM battery 310 level can be reported as an absolute value (e.g., battery has a voltage level of X), a relative value (e.g., battery is charged to given percentage of capacity, or a time value battery is so many minutes from being fully charged or discharged, etc.) The battery reporting can include combinations of the above. The microcontroller can also acquire analog values of VBUS 304 voltage and battery voltage etc., for example, to monitor the system status. In some implementations, the EBM microcontroller 306 can also control the charging IC 308 and discharging switch 312 to turn on or off the charging circuit and/or the discharging path. In turn, the charging IC 308 takes the voltage from the VBUS 304 and regulates and/or switches the power to charge the battery 310 and maintain a charge on the battery 310. The charging IC 308 controls the charging of the battery so as to not overcharge the battery (and possible damage the battery) or under charge the battery and not efficiently utilize the battery capacity. When the EBM is in discharge mode (i.e., supplying power to the bus), the charging IC 308 may be instructed by the EBM microcontroller to suspend charging the battery 310. Charging battery 310 from VBUS 304 can be performed when the VBUS 304 voltage is higher than the battery cell voltage and charging mode is turned on.

[0034] In some implementations, the battery 310 can be single- or multiple-cell battery pack that can be recharged. In some instances, the battery 310 is configured to terminate discharging at 3.5V (Li-ion/ Li-polymer). Other battery types and suitable corresponding voltage levels may be used.

[0035] The discharging switch 312 can be controlled by the microcontroller 306 and when the discharging switch is turned off, electrical current cannot flow in either direction between the battery 310 and the protection circuit 314.

[0036] In some aspects, the protection circuit 314 can include a fast-response and robust independent circuit configured to prevent reverse current and discharging over-current. With the protection circuit 314, little or no current can flow back into the battery 310 through the discharging path, which connects the battery to the VBUS. In instances wherein the output current is too large (e.g., exceeds a threshold value), indicating there is a short circuit or other fault, the discharging can be terminated immediately.

[0037] FIG. 4 is a block diagram of example hardware modules 400 used for implementing a core module power section 416. As illustrated, the core module power section 416 includes a core microcontroller 406, a charging IC 408, a battery 410, a converter 412 (e.g., a 3.3V buck converter) and a protection circuit 414, as shown in Fig. 4. The converter 412 can be implemented as a converter or voltage regulator, depending on a contemplated implementation.

[0038] In practice, the core microcontroller 406 is responsible for handling communications between peripheral modules and thus managing the EBMs. The microcontroller 406 can also be configured for monitoring the status of VBUS 404 and control charging and discharging instructions sent to EBMs. The charging IC 408 is controlled by the microcontroller 406 and can be used to charge the battery 410. The charging IC 408 can include a boost converter to step up the voltage from VBUS 404 to a higher level, for example, so that the charging IC 408 can charge the battery 410. In some implementations, the battery 410 is the only battery providing power to the core module. The battery 410 can also be configured for providing power to the VBUS 404 when no EBM is connected.

[0039] The converter 412 converts the battery voltage to a constant level (e.g., 3.3V). The converter 412 can be controlled by the microcontroller 406 but normally is always on. When an EBM is discharging to the VBUS 404, the voltage on the VBUS 404 can be higher than 3.3V (or other lower voltage, according to the EBM discharging terminating voltage). In some

aspects, the protection circuit 414 can prevent current from going back in a reverse direction. When the EBM terminates discharging or is detached, the VBUS voltage drops and the converter 412 outputs power to the VBUS at 3.3V, for example, to continue supplying power to one or more modules (e.g., 3.3V is lower than the minimal voltage to charge the EBM and thus will only be a supply voltage to other modules). It will be appreciated that other voltage levels can be used depending on a contemplated implementation.

[0040] The protection circuit 414 stops current flow in reverse direction from the VBUS 404 to the converter 412 when the VBUS 404 voltage is higher than 3.3V. The protection circuit 414 can also help prevent discharging over-current from the core module power section 416 to the VBUS 404.

[0041] At any time VBUS 404 should typically have at least 3.3V when the core module is alive or operational. When the core module battery (e.g., battery 410) is empty, VBUS 404 will be 0V. In turn, if EBMs are connected to the core module and a detected voltage on the VBUS is 0V, one or more of the EBMs will start discharging automatically to provide voltage to the VBUS 404 and charge the battery 410 in the core module power section 416.

[0042] If EBMs are connected to a valid VBUS which is higher than 3.3V (e.g., 5V), the default state is idle, e.g., neither charging nor discharging. By way of example, if an external 5V AC adapter (e.g., 220 shown in FIG. 2) is connected to VBUS and the core module instructs the EBM to charge the battery, the charging IC in the EBM can be activated and the EBM battery cell can be charged. The charging IC can be configured to terminate charging of the battery cell autonomously when the battery cell is full, or when termination is instructed by the core module. When the VBUS is not 5V, the Core instructs the EBMs to discharge and provide power to all the modules. The discharging terminates autonomously when the battery is empty, or when the Core instructs.

[0043] The core module can also instruct one or more EBMs individually or collectively according to various scenarios and determined conditions. For example, the core module may instruct an EBM to transition the extra battery to the charging state when the system is connected to external power. In another example, the core module may instruct an EBM to transition the extra battery to discharging state when system is not connected to power. In yet another example, the core module may instruct one or more EBMs to transition to discharging states in specific priority orders (e.g., use battery with higher charge first, before using a second

extra battery with lower charge; use batteries with faster charging rates first; use batteries with greater current discharge capability when modules requiring higher current are connected to the system; use batteries in a manner to optimize battery charge/discharge cycles, etc.).

[0044] The charging/discharging process can be performed on a single EBM at a time or multiple EBMs in parallel. Also, it will be appreciated that batteries have been used herein by way of example, but other energy storage elements could be used, such as capacitors or the like.

[0045] In some implementations, reverse current protection can include zero voltage drop to minimize power loss. An ideal diode design can be used. All power converters (boost/buck converters) can include switching types to minimize power loss.

[0046] In some implementations, when an EBM connects to the power bus, one of the below situations may occur:

[0047] Situation A- EBM battery voltage is equal to bus voltage

[0048] Situation B- EBM battery voltage is lower than bus voltage

[0049] Situation C- EBM voltage is greater than bus voltage

[0050] If the voltage of the EBM battery equals the bus voltage (e.g., Situation A), the battery can connect to the bus without any concern. If the voltage of the EBM battery is lower than the bus voltage (e.g., Situation B), for safe connection of battery to bus, the EBM must wait until the bus voltage drops to the battery voltage and after that Situation A will occur. In Situation B, the core microcontroller may communicate with the EBM to determine the EBM voltage level and command the EBM to charge the battery. The power to charge an EBM battery could come from an external power source, a harvester power generating module, etc. If the voltage of the EBM battery is greater than the bus voltage (Situation C), the EBM can be commanded by the core module microcontroller to act as a charger by discharging battery power and charge the bus until the EBM battery voltage is consumed and drops to the bus voltage and after that, again, Situation A happens.

[0051] FIG. 5 is a state diagram of an example method of controlling an EBM. An EBM starts at state (502) and transitions to state (504) offline. Once the EBM is plugged into an electronic device (e.g., a wearable device), the EBM can detect the voltage level of the VBUS.

If the VBUS voltage level is 0V (or otherwise not valid), the EBM can transition to state (506), remain offline (e.g., not in communication with a core module), and begin discharging (i.e. providing power) to the VBUS to provide power to the other modules (including the core module) until the core module battery is charged and then transition to state (508).

[0052] If the VBUS voltage level is valid (e.g., 5V), the EBM can transition to state (508) and be online (e.g., in communication with a core module) and idle (e.g., not discharging).

[0053] From state (508), the EBM can transition to online and discharging state (510) when instructed to by the core module, and transition from state (510) to state (508) when instructed by the core module or when the EBM voltage is low.

[0054] From state (508), the EBM can also transition to online and charging state (512) when instructed by the core module and VBUS is valid (e.g., 5V). The EBM can return to state (508) from state (512) when instructed by the core module or when the EBM battery is charged.

[0055] FIG. 6 is a diagram of an example EBM circuit 600 showing an EBM power section 602. The power section is coupled to ground (GND) 604 and a positive voltage supply VCC 606 (e.g., 5V). The power section 602 also includes a first analog-to-digital converter (ADC) 608, a second ADC 610, control logic 612, a battery 614, a charging section 616, a first switch 618, and a second switch 620.

[0056] In operation, the first ADC 608 can measure the voltage on 604 and 606 (e.g., VBUS) and provide a signal to the control logic 612 representing the voltage. The second ADC 610 can measure the voltage of the battery 614 and provide a signal to the control logic 612 representing the voltage level of the battery 614.

[0057] The control logic 612 can use the input from the two ADCs (608, 610) to determine how to control the charging section 616 (e.g., charging IC) and the first switch 618 and the second switch 620. The first switch 618 switches power into the EBM from the supply (604, and 606). The second switch 620 switches power out from the EBM to the VBUS. The first switch 618 would typically be closed during charging and the second switch 620 would typically be open. During discharging, the first switch 618 would be open and the second switch 620 would be closed.

[0058] The control logic 612 can include a microcontroller, a programmable logic device, an ASIC or the like. The switches (618, 620) can be any number of switching mechanisms, such as a mechanical relay. However, due to the space criteria for a module implementation related to a wearable device, regulators and DC/DC converters may be implemented. Regulators may include one or more of the following types: Linear; LDO (Low Drop Out); and/or Quasi-LDO.

[0059] In some aspects, the LDO may be preferentially implemented for battery powered systems because of the Low Drop Out voltage characteristic (i.e., a negligible difference between input and output voltage, so batteries with one cell can drive a bus).

[0060] In some implementations, one or more of the extra battery modules may give instructions that they will be the ones to discharge, instead of any other battery modules connected to the bus. The EBMs may provide these instructions based on direction from the core module or without waiting on or receiving direction or instructions from the core module. For example, one of the extra battery modules may be an energy harvester (e.g., solar, kinetic, etc.), and when it is generating power it gets the priority to discharge.

[0061] Some implementations can utilize the extra battery (or power) modules to provide power to low-power components in the core or other modules (e.g., a heart rate sensor, or time keeping module) separately, while the main battery powers the high power components like the display, main processor, etc. This can provide an advantage of a technical solution to a situation where the main battery dies. In the above example, the extra battery modules (and specifically harvester- type modules generating the energy from body heat, sunlight, motion, etc.) can keep at least the time function of the device working so that the watch, for example, will continue to tell the time even if other functions may not be available due to the low power situation.

[0062] The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. It will, however, be evident that various modifications and changes may be made thereunto without departing from the broader spirit and scope of the disclosure as set forth in the claims.

[0063] The description of the subject technology is provided to enable any person skilled in the art to practice the various embodiments described herein. While the subject technology has been particularly described with reference to the various figures and embodiments, it

should be understood that these are for illustration purposes only and should not be taken as limiting the scope of the subject technology.

[0064] There may be many other ways to implement the subject technology. Various functions and elements described herein may be partitioned differently from those shown without departing from the scope of the subject technology. Various modifications to these embodiments will be readily apparent to those skilled in the art, and generic principles defined herein may be applied to other embodiments. Thus, many changes and modifications may be made to the subject technology, by one having ordinary skill in the art, without departing from the scope of the subject technology.

[0065] A reference to an element in the singular is not intended to mean “one and only one” unless specifically stated, but rather “one or more.” The term “some” refers to one or more. Underlined and/or italicized headings and subheadings are used for convenience only, do not limit the subject technology, and are not referred to in connection with the interpretation of the description of the subject technology. All structural and functional equivalents to the elements of the various embodiments described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and intended to be encompassed by the subject technology. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the above description.

[0066] It is understood that any specific order or hierarchy of steps in the processes disclosed is an illustration of example approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged, or that only a portion of the illustrated steps be performed. Some of the steps may be performed simultaneously. For example, in certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single hardware and/or software product or packaged into multiple hardware and/or software products.

[0067] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown

herein, but are to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.”

[0068] A phrase such as an “aspect” does not imply that such aspect is essential to the subject technology or that such aspect applies to all configurations of the subject technology. A disclosure relating to an aspect may apply to all configurations, or one or more configurations. A phrase such as an aspect may refer to one or more aspects and vice versa. A phrase such as a “configuration” does not imply that such configuration is essential to the subject technology or that such configuration applies to all configurations of the subject technology. A disclosure relating to a configuration may apply to all configurations, or one or more configurations. A phrase such as a configuration may refer to one or more configurations and vice versa.

CLAIMS

What is claimed is:

1. A system comprising:

a core module having a power section, the core module including:

a core module controller;

a core module charging section having a control line connected to the core module controller;

a core module battery connected to the core module charging section;

a core module converter connected to the core module battery; and

a core module protection circuit connected to the core module battery and a power bus;

and

one or more additional battery modules coupled to the core module via a communication bus and coupled to the power bus, each additional battery module including:

an additional battery module controller;

an additional battery module charging switch connected to the additional battery module controller;

an additional battery module charging section connected to the additional battery module controller, the additional battery module charging switch and the power bus;

an additional battery module battery connected to the additional battery module charging section of the additional battery module;

an additional battery module discharging switch connected to the additional battery module controller, the additional battery module battery, and the power bus; and

an additional battery module protection circuit connected to the additional battery module discharging switch and the power bus.

2. The system of claim 1, wherein the one or more additional battery modules include a first analog to digital converter connected to the power bus and to the additional battery module controller, and a second analog to digital converter connected to the additional battery module battery of the additional battery module and the additional battery module controller.

3. The system of claim 1, wherein the core module converter includes a buck converter.

4. The system of claim 1, wherein the core module controller includes a microcontroller.
5. The system of claim 1, wherein the additional battery module controller includes a microcontroller.
6. The system of claim 1, wherein the one or more additional battery modules are configured to supply power to the power bus when voltage on the power bus falls below a threshold value.
7. The system of claim 1, wherein the additional battery module controller is configured to perform operations including:
 - initializing to an offline state upon being connected to the power bus;
 - detecting a voltage level of the power bus;
 - when the voltage level of the power bus is below a threshold, transitioning to an offline discharging state;
 - when the voltage level of the power bus is at or above the threshold, transitioning to an online idle state;
 - receiving a command from the core module to transition from the online idle state to an online discharging state, and in response, transitioning from the online idle state to an online discharging state when instructed by the core module;
 - transitioning from the online discharging state to the online idle state when instructed by the core module or when a low voltage in the additional battery module battery of the additional battery module is detected;
 - transitioning from the online idle state to the online charging state when the voltage level on the power bus is at a threshold and when instructed by the core module; and
 - transitioning from the online charging state to the online idle state when the additional battery module battery of the additional battery module is charged or when instructed by the core module.
8. A system comprising:
 - one or more additional battery modules, each including:
 - an additional battery module controller;
 - an additional battery module charging switch connected to the additional battery module controller;

an additional battery module charging section connected to the additional battery module controller, the additional battery module charging switch and a power bus;

an additional battery module battery connected to the additional battery module charging section;

an additional battery module discharging switch connected to the additional battery module controller, the additional battery module battery, and the power bus; and

an additional battery module protection circuit connected to the additional battery module discharging switch and the power bus.

9. The system of claim 8, wherein the one or more additional battery modules includes a first analog to digital converter connected to the power bus and to the additional battery module controller, and a second analog to digital converter connected to the additional battery module battery and the additional battery module controller.

10. The system of claim 8, wherein the additional battery module controller includes a microcontroller.

11. The system of claim 8, wherein the one or more additional battery modules are configured to supply power to the power bus when voltage on the power bus falls below a threshold value.

12. The system of claim 8, wherein the additional battery module controller is configured to perform operations including:

initializing to an offline state upon being connected to a power bus;

detecting a voltage level of the power bus;

when the voltage level of the power bus is below a threshold, transitioning to an offline discharging state;

when the voltage level of the power bus is at or above the threshold, transitioning to an online idle state;

transitioning from the online idle state to an online discharging state when instructed by a core module;

transitioning from the online discharging state to the online idle state when instructed by the core module or when a low voltage in the additional battery module battery of the additional battery module is detected;

transitioning from the online idle state to the online charging state when the voltage level on the power bus is at a threshold and when instructed by the core module; and

transitioning from the online charging state to the online idle state when the additional battery module battery of the additional battery module is charged or when instructed by the core module.

13. The system of claim 8, further comprising:

a core module having a core module power section, the core module coupled to the one or more additional battery modules, the core module including:

a core module controller;

a core module charging section having a control line connected to the core module controller;

a core module battery connected to the core module charging section;

a core module converter connected to the core module battery; and

a core module protection circuit connected to the core module battery and a power bus,

wherein the core module is configured to perform operations including:

transmitting, to the one or more additional battery modules, an instruction that causes the one or more additional battery modules to perform one or more of:

transitioning from an online idle state to an online discharging state;

transitioning from the online discharging state to the online idle state;

transitioning from the online idle state to an online charging state; and

transitioning from the online charging state to the online idle state.

14. A wearable computing system comprising:

a core module having a power section including:

a core module controller;

a core module charging section having a control line connected to the core module controller;

a core module battery connected to the core module charging section;

a core module converter connected to the core module battery; and

a core module protection circuit connected to the core module battery and a power bus.

15. The system of claim 14, wherein the core module converter includes a buck converter.
16. The system of claim 14, wherein the core module controller includes a microcontroller.
17. The wearable computing system of claim 14, further comprising:
one or more additional battery modules, each including:
an additional battery module controller;
an additional battery module charging switch connected to the additional battery module controller;
an additional battery module charging section connected to the additional battery module controller, the additional battery module charging switch and the power bus;
an additional battery module battery connected to the additional battery module charging section;
an additional battery module discharging switch connected to the additional battery module controller, the additional battery module battery, and the power bus; and
an additional battery module protection circuit connected to the additional battery module discharging switch and the power bus.
18. The wearable computing system of claim 17, wherein the one or more additional battery modules includes a first analog to digital converter connected to the power bus and to the additional battery module controller, and a second analog to digital converter connected to the additional battery module battery and the additional battery module controller.
19. The system of claim 17, wherein the one or more additional battery modules are configured to supply power to the power bus when voltage on the power bus falls below a threshold value.
20. The system of claim 17, wherein the additional battery module is configured to perform operations including:
initializing to an offline state upon being connected to a power bus;
detecting a voltage level of the power bus;
when the voltage level of the power bus is below a threshold, transitioning to an offline discharging state;

when the voltage level of the power bus is at or above the threshold, transitioning to an online idle state;

transitioning from the online idle state to an online discharging state when instructed by the core module;

transitioning from the online discharging state to the online idle state when instructed by the core module or when a low voltage in the additional battery module battery of the additional battery module is detected;

transitioning from the online idle state to the online charging state when the voltage level on the power bus is at a threshold and when instructed by the core module; and

transitioning from the online charging state to the online idle state when the additional battery module battery of the additional battery module is charged or when instructed by the core module.

100

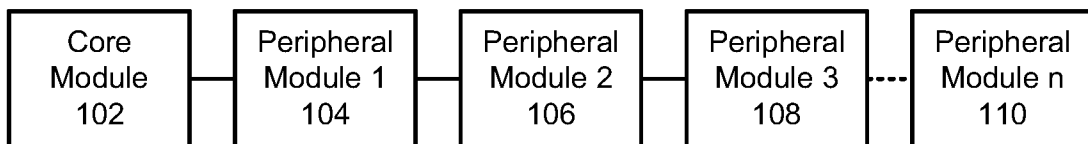


FIG. 1

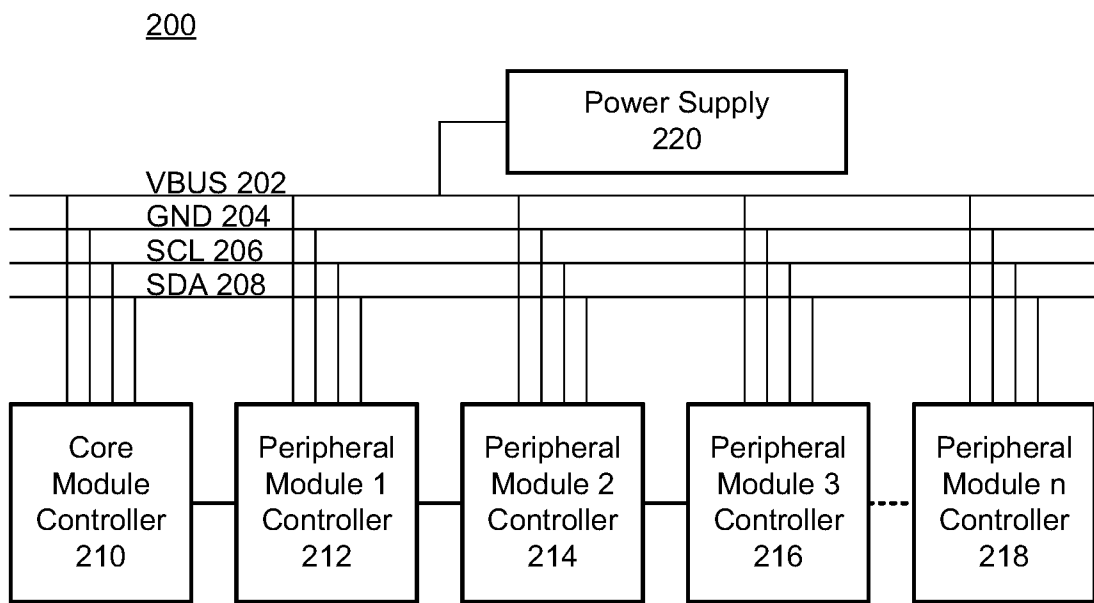


FIG. 2

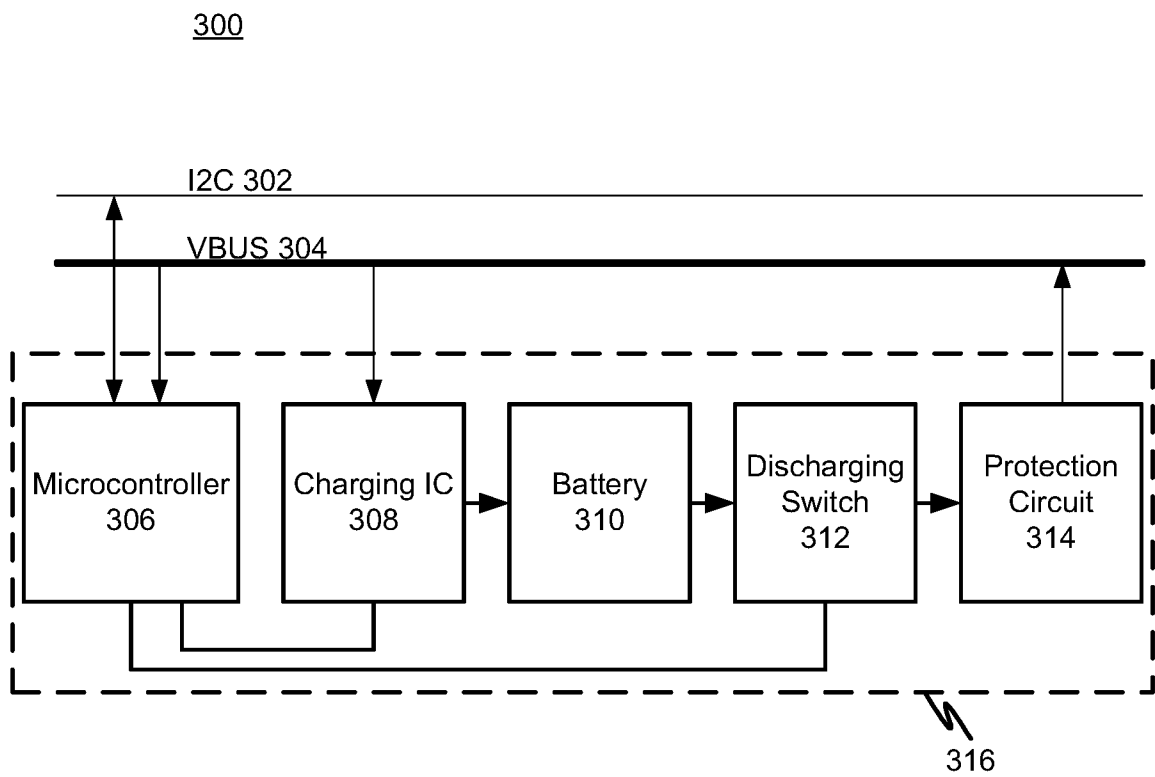


FIG. 3

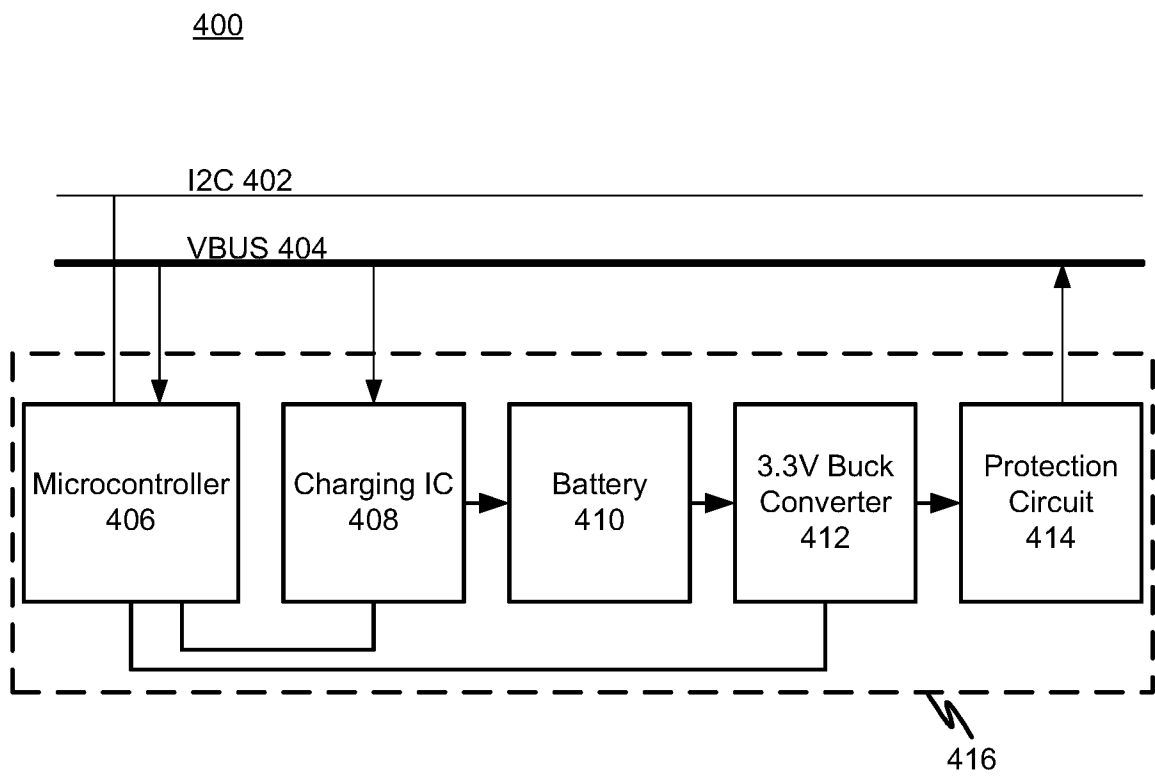


FIG. 4

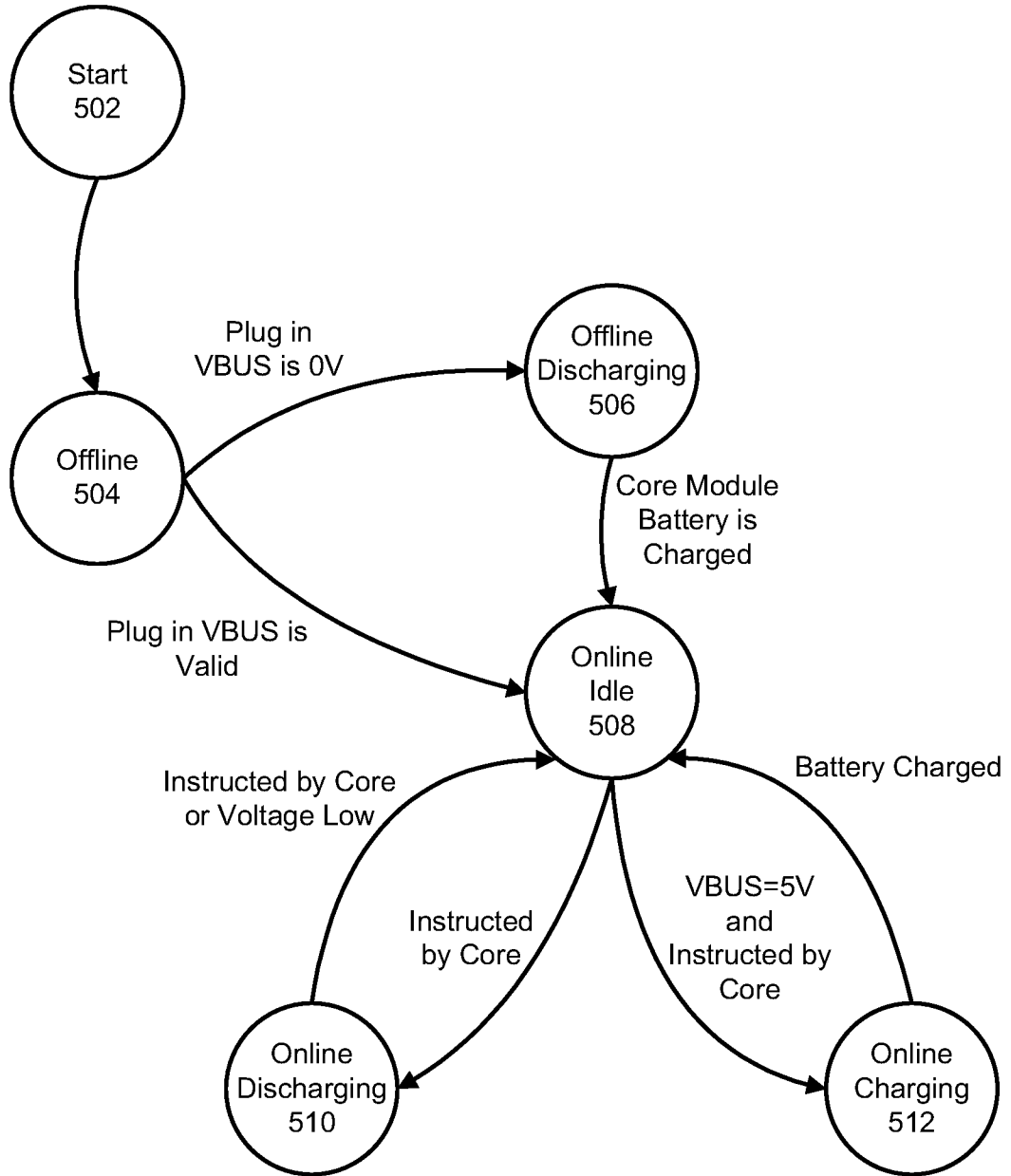


FIG. 5

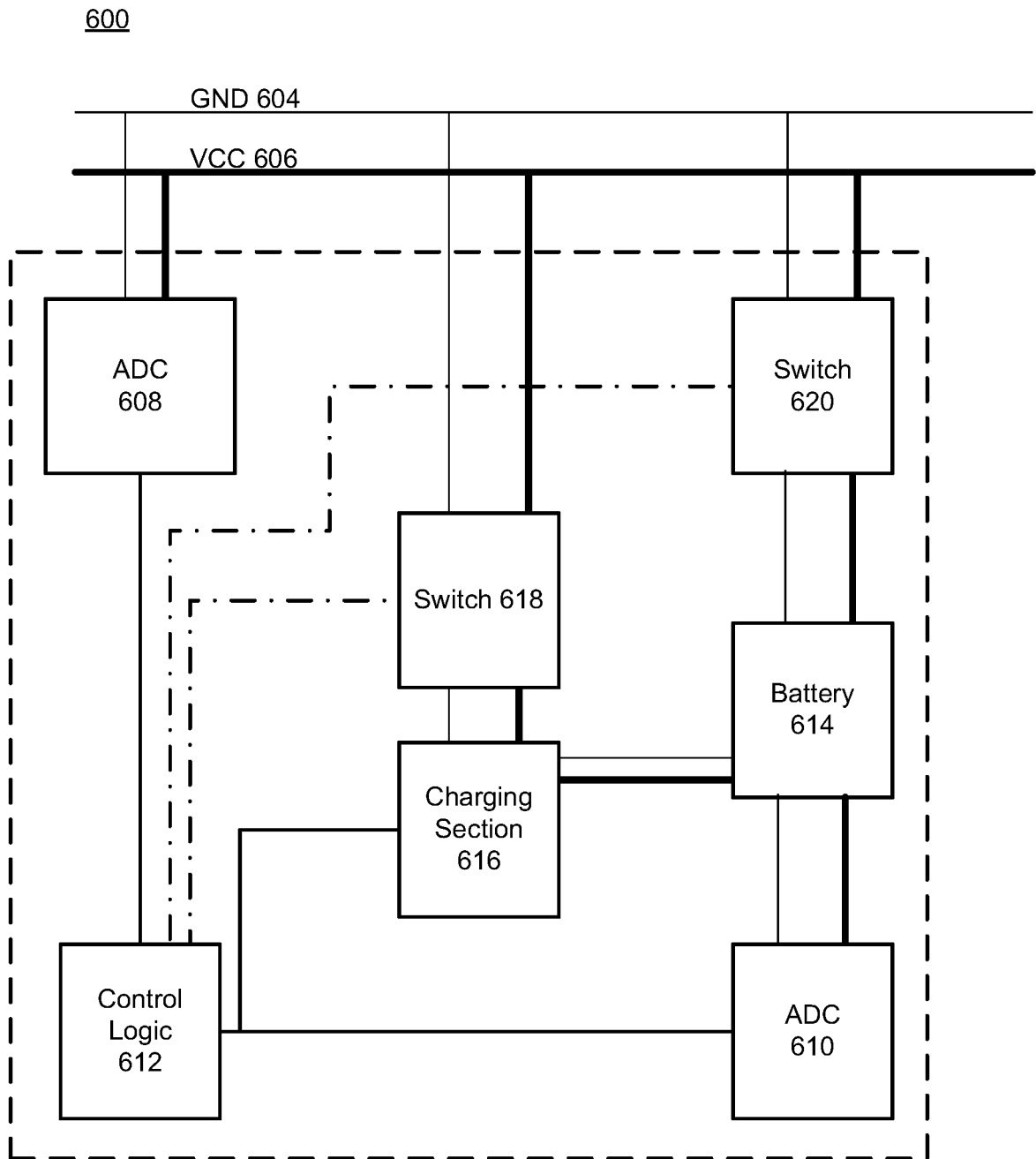


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/069232

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H02J1/12 H02J7/00 H02J9/00 G06F1/26
 ADD.
 According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
 Minimum documentation searched (classification system followed by classification symbols)
 H02J G06F

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/079960 A1 (YUN HAN-SEOK [KR]) 20 March 2014 (2014-03-20)	1-3,7-9, 12-15, 17,18,20
Y	paragraph [0038]; figure 1 paragraph [0084] - paragraph [0104]; figures 5, 6	4-6,10, 11,16,19
Y	----- US 5 422 558 A (STEWART NEAL G [HK]) 6 June 1995 (1995-06-06) column 5, line 3 - line 14	4,5,10, 16
Y	----- US 2015/280466 A1 (OWEN ROBERT BRYDON THOMAS [CA] ET AL) 1 October 2015 (2015-10-01) paragraph [0067] - paragraph [0069] ----- -/--	6,11,19

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 17 March 2017	Date of mailing of the international search report 24/03/2017
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Gatzert, C
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/069232

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/069232

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		CN 103683374 A	26-03-2014
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