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(54) Title: POWER SUPPLY ARCHITECTURE WITH BIDIRECTIONAL BATTERY IDEALIZATION

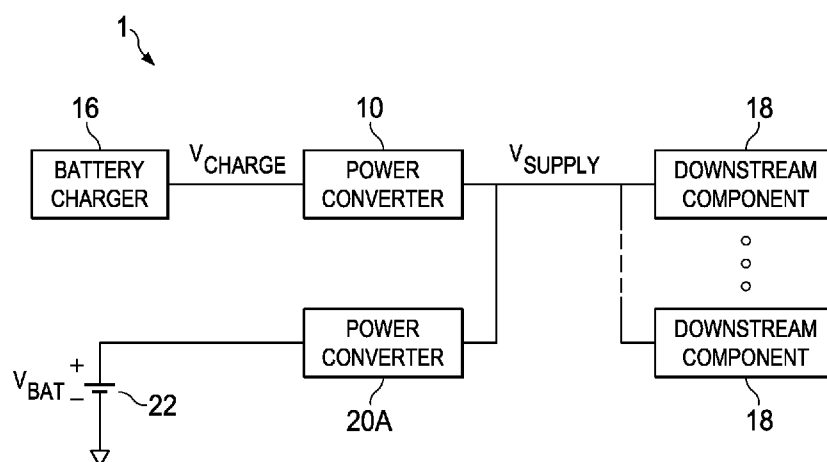


FIG. 2

(57) Abstract: A power management system (1) for use in a device comprising a battery (22) and one or more components (18) configured to draw electrical energy from the battery may include a first power converter (10) configured to electrically couple between charging circuitry (16) configured to provide electrical energy for charging the battery (22) and the one or more downstream components (18) and a bidirectional power converter (20A) configured to electrically couple between the charging circuitry and the battery, wherein the bidirectional power converter is configured to transfer charge from the battery or transfer charge from the battery based on a power requirement of the one or more components and a power available from the first power converter.



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KM, ML, MR, NE, SN, TD, TG).

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**POWER SUPPLY ARCHITECTURE WITH BIDIRECTIONAL BATTERY
IDEALIZATION**

RELATED APPLICATION

5 The present disclosure claims priority to United States Provisional Patent Application Serial No. 63/065,759, filed August 14, 2020, and United States Provisional Patent Application Serial No. 63/148,352, filed February 11, 2021, both of which are incorporated by reference herein in their entirety.

10 FIELD OF DISCLOSURE

 The present disclosure relates in general to circuits for electronic devices, including without limitation personal audio devices such as wireless telephones and media players, and more specifically, a power supply architecture with bidirectional battery idealization.

BACKGROUND

Portable electronic devices, including wireless telephones, such as mobile/cellular telephones, tablets, cordless telephones, mp3 players, smart watches, health monitors, and other consumer devices, are in widespread use. Such a portable electronic device may include circuitry for implementing a boost converter for converting a battery voltage (e.g., provided by a lithium-ion battery) into a supply voltage delivered to one or more components of the portable electronic device. The power delivery network may also regulate such supply voltage, and isolate the downstream loads of these one or more devices from fluctuation in an output voltage of the battery over the course of operation.

SUMMARY

In accordance with the teachings of the present disclosure, one or more disadvantages and problems associated with existing approaches to power supply architectures may be reduced or eliminated.

5 In accordance with embodiments of the present disclosure, a power management system for use in a device comprising a battery and one or more components configured to draw electrical energy from the battery may include a first power converter configured to electrically couple between charging circuitry configured to provide electrical energy for charging the battery and the one or more downstream components, and a bidirectional
10 power converter configured to electrically couple between the charging circuitry and the battery, wherein the bidirectional power converter is configured to transfer charge from the battery or transfer charge from the battery based on a power requirement of the one or more components and a power available from the first power converter.

In accordance with these and other embodiments of the present disclosure, a method
15 may include, in a device comprising a battery and one or more components configured to draw electrical energy from the battery receiving electrical energy from charging circuitry configured to provide electrical energy for charging the battery at a first power converter configured to electrically couple between the charging circuitry and the one or more downstream components. The method may also include transferring charge from the
20 battery or transferring charge from the battery, by a bidirectional power converter configured to electrically couple between the charging circuitry and the battery, based on a power requirement of the one or more components and a power available from the first power converter.

In accordance with these and other embodiments of the present disclosure, a method
25 may include, a device may include a battery, one or more components configured to draw electrical energy from the battery, and a power management system. The power management system may include a first power converter configured to electrically couple between charging circuitry configured to provide electrical energy for charging the battery and the one or more downstream components, and a bidirectional power converter
30 configured to electrically couple between the charging circuitry and the battery, wherein the bidirectional power converter is configured to transfer charge from the battery or

transfer charge from the battery based on a power requirement of the one or more components and a power available from the first power converter.

Technical advantages of the present disclosure may be readily apparent to one skilled in the art from the figures, description and claims included herein. The objects and
5 advantages of the embodiments will be realized and achieved at least by the elements, features, and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are examples and explanatory and are not restrictive of the claims set forth in this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present embodiments and advantages thereof may be acquired by referring to the following description taken in conjunction with the accompanying drawings, in which like reference numbers indicate like features, and
5 wherein:

FIGURE 1 illustrates an example portable electronic device, in accordance with embodiments of the present disclosure;

FIGURE 2 illustrates a block diagram of selected components internal to a portable electronic device, in accordance with embodiments of the present disclosure;

10 FIGURE 3 illustrates a block diagram of selected components of an example power converter, in accordance with embodiments of the present disclosure;

FIGURE 4 illustrates a block diagram of selected components internal to a portable electronic device in an alternate embodiment of a portable electronic device, in accordance with embodiments of the present disclosure; and

15 FIGURE 5 illustrates a block diagram of selected components of another example power converter, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

FIGURE 1 illustrates an example portable electronic device 1, in accordance with embodiments of the present disclosure. FIGURE 1 depicts portable electronic device 1 coupled to a headset 3 in the form of a pair of earbud speakers 8A and 8B. Headset 3 depicted in FIGURE 1 is merely an example, and it is understood that portable electronic device 1 may be used in connection with a variety of audio transducers, including without limitation, headphones, earbuds, in-ear earphones, and external speakers. A plug 4 may provide for connection of headset 3 to an electrical terminal of portable electronic device 1. Portable electronic device 1 may provide a display to a user and receive user input using a touch screen 2, or alternatively, a standard liquid crystal display (LCD) may be combined with various buttons, sliders, and/or dials disposed on the face and/or sides of portable electronic device 1.

FIGURE 2 illustrates a block diagram of selected components integral to portable electronic device 1, in accordance with embodiments of the present disclosure. As shown in FIGURE 2, portable electronic device 1 may include a battery charger 16, a power converter 10, a battery 22, a power converter 20A, and one or more downstream components 18.

Battery charger 16 may include any system, device, or apparatus configured to charge a battery, for example by delivering electrical energy to a battery in order that such battery converts the electrical energy to chemical energy that is stored in such battery. In some embodiments, battery charger 16 may include a wired charger configured to draw electrical energy from an electrical power outlet or from a power bank. In other embodiments, battery charger 16 may include a wireless charger configured to draw electrical energy via inductive coupling from a wireless charging pad or similar device. In some embodiments, a portable electronic device 1 may include both a wired charger and a wireless charger.

Power converter 10 may include any system, device, or apparatus configured to receive a charger voltage V_{CHARGE} (e.g., 5 volts, 9 volts, 20 volts) output by battery charger convert such charger voltage V_{CHARGE} into a supply voltage V_{SUPPLY} (e.g., 5 volts). In some embodiments, power converter 10 may comprise a buck converter that may convert charger voltage V_{CHARGE} into supply voltage V_{SUPPLY} equal to or less than charger voltage V_{CHARGE} .

In these and other embodiments, power converter 10 may comprise a capacitive power converter or “charge pump.” In other embodiments, power converter 10 may comprise an inductor-based power converter.

Battery 22 may include any system, device, or apparatus configured to convert chemical energy stored within battery 22 to electrical energy for powering downstream components 18 of portable electronic device 1. Further, battery 22 may also be configured to recharge, in which it may convert electrical energy received by battery 22 into chemical energy to be stored for later conversion back into electrical energy. For example, in some embodiments, battery 22 may comprise a lithium-ion battery.

Power converter 20A may include any system, device, or apparatus configured to operate in a boost mode to receive battery voltage V_{BAT} generated by battery 22 and convert such battery voltage V_{BAT} into supply voltage V_{SUPPLY} greater than or equal to battery voltage V_{BAT} . In addition, as described in greater detail below, power converter 20A may also operate bidirectionally, including a buck mode in which power converter 20A may convert supply voltage V_{SUPPLY} into battery voltage V_{BAT} lesser than or equal to supply voltage V_{SUPPLY} in order to recharge battery 22.

Downstream components 18 of portable electronic device 1 may include any suitable functional circuits or devices of portable electronic device 1, including without limitation processors, audio coder/decoders, amplifiers, display devices, etc. As shown in FIGURE 2, downstream components 18 may be powered from supply voltage V_{SUPPLY} generated by either or both of power converter 10 and power converter 20A.

FIGURE 3 illustrates a block diagram of selected components of an example power converter 20A, in accordance with embodiments of the present disclosure. Power converter 20A may be used to implement power converter 20A depicted in FIGURE 2.

As shown in FIGURE 3, power converter 20A may include a plurality of inductive phases 24 (e.g., phases 24A and 24B). As shown in FIGURE 3, each inductive phase 24 may include a power inductor 32, a first switch 34, and a second switch 36. Although FIGURE 3 depicts only two inductive phases 24 for the purposes of clarity and exposition, in some embodiments, power converter 20A may have a single inductive phase 24 or may have more than two inductive phases 24.

In operation in a boost mode, control circuitry 30 may periodically commutate first switches 34 (e.g., during a charging state of an inductive phase 24) and second switches 36 (e.g., during a transfer state of an inductive phase 24) of an inductive phase 24 by generating appropriate control signals P_1 , P_1 , P_2 , and P_2 , to boost battery voltage V_{BAT} to a higher supply voltage V_{SUPPLY} at output capacitor 38 in order to regulate supply voltage V_{SUPPLY} at a desired voltage level.

In addition, in operation in a buck mode, control circuitry 30 may periodically commutate second switches 36 (e.g., during a charging state of an inductive phase 24) and first switches 34 (e.g., during a transfer state of an inductive phase 24) of an inductive phase 24 by generating appropriate control signals P_1 , P_1 , P_2 , and P_2 , to buck supply voltage V_{SUPPLY} to a lower battery voltage V_{BAT} in order to charge a battery (e.g. battery 22) regulate supply voltage V_{SUPPLY} at a desired voltage level.

Accordingly, control circuitry 30 may sense charger voltage V_{CHARGE} , battery voltage V_{BAT} , supply voltage V_{SUPPLY} , and/or another suitable parameter associated with portable electronic device 1 and based thereon, determine in which mode it is to operate, and then operate in such mode. For example, when power available from battery charger 16 and power converter 10 is in excess of a power demanded by downstream components 18, control circuitry 30 may operate power converter 20A in the buck mode to deliver such excess power to battery 22. As another example, when power available from battery charger 16 and power converter 10 is insufficient to supply the power demanded by downstream components 18, control circuitry 30 may operate power converter 20A in the boost mode to draw power from battery 22.

Using such a power supply architecture such as that described above, in which an output of a charger path (e.g., battery charger 16 and power converter 10) is coupled to supply voltage V_{SUPPLY} , power converter 20A may boost to downstream components 18 during discharge of battery 22 and buck to battery 22 during charging of battery 22. The flexibility of placing bidirectional power converter 20A between the electrical nodes for supply voltage V_{SUPPLY} and battery voltage V_{BAT} as described above is that it may provide an ideal fixed voltage of supply voltage V_{SUPPLY} for both downstream components 18 and for the charger path (e.g., battery charger 16 and power converter 10), thus presenting an idealized version of battery behavior to both downstream components 18 and the charger

path. Because power converter 20A may idealize battery 22 both during charging and discharge, power converter 20A may be able to handle power distribution in complex scenarios such as that which may occur when power demanded by downstream components 18 exceeds that available from the charger path.

5 FIGURE 4 illustrates a block diagram of selected components internal to portable electronic device 1 in an alternate embodiment 1B of portable electronic device 1, in accordance with embodiments of the present disclosure. In alternate embodiment 1B, instead of power converter 10 directly generating supply voltage V_{SUPPLY} , power converter 10 may generate intermediate supply voltage $V_{\text{SUPPLY}'}$, which may be received by power
10 converter 20B as an input. Also as shown in FIGURE 4, power converter 20B may be used in lieu of power converter 20A.

FIGURE 5 illustrates a block diagram of selected components of example power converter 20B, in accordance with embodiments of the present disclosure. Power converter 20B may be similar in many respects to power converter 20A, except that in power
15 converter 20B, the node for intermediate supply voltage $V_{\text{SUPPLY}'}$ may be coupled to the boost output of at least one inductive phase 24A, the node for supply voltage V_{SUPPLY} may be coupled to the boost output of at least one inductive phase 24B, and a bypass switch 40 may be interfaced between the nodes for intermediate supply voltage $V_{\text{SUPPLY}'}$ and supply voltage V_{SUPPLY} .

20 In the embodiments represented by FIGURES 4 and 5, when battery 22 has insufficient state of charge, it may not be possible to boost from battery 22 at a high enough voltage to match intermediate supply voltage $V_{\text{SUPPLY}'}$ generated by power converter 10. Thus, in the case of portable electronic device 1 in which the output of power converter 10 is coupled to the boost output of power converter 20A, the resultant difference in voltages
25 generated by power converter 10 and power converter 20A may cause an uncontrolled current to flow from the charger path (e.g., battery charger 16 and power converter 10).

To overcome this problem, control circuitry 30 may control bypass switch 40 in either a bypass mode or split mode of power converter 20B. In the bypass mode, power converter 20B may operate as a single multiphase buck or boost converter (e.g., in either
30 of the boost mode or buck mode as described above with respect to power converter 20A). In the split mode, which may be activated when battery 22 is low on state of charge, power

converter 20B may be effectively split into two separate converters to allow bucking down from intermediate supply voltage V_{SUPPLY}' to battery voltage V_{BAT} (in order to charge battery 22) and then boosting battery voltage V_{BAT} up to at least a minimum voltage level for supply voltage V_{SUPPLY} . Thus, power converter 20B may be able to operate in the boost mode in situations in which state of charge of battery 22 is insufficient to support boosting to higher voltages. Operating supply voltage V_{SUPPLY} at a lower voltage may reduce current demands by downstream components 18.

As used herein, when two or more elements are referred to as “coupled” to one another, such term indicates that such two or more elements are in electronic communication or mechanical communication, as applicable, whether connected indirectly or directly, with or without intervening elements.

This disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Similarly, where appropriate, the appended claims encompass all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, or component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Accordingly, modifications, additions, or omissions may be made to the systems, apparatuses, and methods described herein without departing from the scope of the disclosure. For example, the components of the systems and apparatuses may be integrated or separated. Moreover, the operations of the systems and apparatuses disclosed herein may be performed by more, fewer, or other components and the methods described may include more, fewer, or other steps. Additionally, steps may be performed in any suitable order. As used in this document, “each” refers to each member of a set or each member of a subset of a set.

Although exemplary embodiments are illustrated in the figures and described below, the principles of the present disclosure may be implemented using any number of

techniques, whether currently known or not. The present disclosure should in no way be limited to the exemplary implementations and techniques illustrated in the drawings and described above.

Unless otherwise specifically noted, articles depicted in the drawings are not
5 necessarily drawn to scale.

All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the disclosure and the concepts contributed by the inventor to furthering the art, and are construed as being without limitation to such specifically recited examples and conditions. Although embodiments of the present
10 disclosure have been described in detail, it should be understood that various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the disclosure.

Although specific advantages have been enumerated above, various embodiments may include some, none, or all of the enumerated advantages. Additionally, other technical
15 advantages may become readily apparent to one of ordinary skill in the art after review of the foregoing figures and description.

To aid the Patent Office and any readers of any patent issued on this application in interpreting the claims appended hereto, applicants wish to note that they do not intend any of the appended claims or claim elements to invoke 35 U.S.C. § 112(f) unless the words
20 “means for” or “step for” are explicitly used in the particular claim.

WHAT IS CLAIMED IS:

1. A power management system for use in a device comprising a battery and one or more components configured to draw electrical energy from the battery, the power management system comprising:

a first power converter configured to electrically couple between charging circuitry configured to provide electrical energy for charging the battery and the one or more components; and

a bidirectional power converter configured to electrically couple between the charging circuitry and the battery, wherein the bidirectional power converter is configured to transfer charge from the battery or transfer charge from the battery based on a power requirement of the one or more components and a power available from the first power converter.

2. The power management system of Claim 1, wherein the bidirectional power converter is configured to:

operate in a first mode to transfer charge to the battery when the power requirement is lesser than the power available from the first power converter; and

operate in a second mode to transfer charge from the battery when the power requirement is greater than the power available from the first power converter.

3. The power management system of Claim 2, wherein the bidirectional power converter is configured to:

operate as a buck converter in the first mode; and

operate as a boost converter in the second mode.

4. The power management system of Claim 1, wherein the bidirectional power converter is configured to operate in a plurality of modes including:

a bypass mode, in which the bidirectional power converter operates as a single multiphase power converter; and

5 a split mode, in which the bidirectional power converter operates as two separate power converters.

5. The power management system of Claim 4, wherein the two separate power converters comprise a buck converter and a boost converter.

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6. The power management system of Claim 5, wherein:

the buck converter converts a charging voltage generated by the charging circuitry to battery voltage for charging the battery; and

15 the boost converter converts the battery voltage to a supply voltage for powering the one or more components.

7. A method comprising, in a device comprising a battery and one or more components configured to draw electrical energy from the battery:

receiving electrical energy from charging circuitry configured to provide electrical energy for charging the battery at a first power converter configured to electrically couple
5 between the charging circuitry and the one or more components; and

transferring charge from the battery or transferring charge from the battery, by a bidirectional power converter configured to electrically couple between the charging circuitry and the battery, based on a power requirement of the one or more components and a power available from the first power converter.

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8. The method of Claim 7, further comprising:

operating the bidirectional power converter in a first mode to transfer charge to the battery when the power requirement is lesser than the power available from the first power converter; and

15

operating the bidirectional power converter in a second mode to transfer charge from the battery when the power requirement is greater than the power available from the first power converter.

9. The method of Claim 8, further comprising:

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operating the bidirectional power converter as a buck converter in the first mode; and

operating the bidirectional power converter as a boost converter in the second mode.

10. The method of Claim 7, further comprising operating the bidirectional power converter in a plurality of modes including:

25

a bypass mode, in which the bidirectional power converter operates as a single multiphase power converter; and

a split mode, in which the bidirectional power converter operates as two separate power converters.

30

11. The method of Claim 10, wherein the two separate power converters comprise a buck converter and a boost converter.

12. The method of Claim 11, wherein:
- the buck converter converts a charging voltage generated by the charging circuitry to battery voltage for charging the battery; and
- 5 the boost converter converts the battery voltage to a supply voltage for powering the one or more components.

13. A device comprising
a battery;
one or more components configured to draw electrical energy from the battery; and
a power management system comprising:

5 a first power converter configured to electrically couple between charging
circuitry configured to provide electrical energy for charging the battery and the one
or more components; and

a bidirectional power converter configured to electrically couple between
the charging circuitry and the battery, wherein the bidirectional power converter is
10 configured to transfer charge from the battery or transfer charge from the battery
based on a power requirement of the one or more components and a power available
from the first power converter.

14. The device of Claim 13, wherein the bidirectional power converter is
15 configured to:

operate in a first mode to transfer charge to the battery when the power requirement
is lesser than the power available from the first power converter; and

operate in a second mode to transfer charge from the battery when the power
requirement is greater than the power available from the first power converter.

20 15. The device of Claim 14, wherein the bidirectional power converter is
configured to:

operate as a buck converter in the first mode; and

operate as a boost converter in the second mode.

25 16. The device of Claim 13, wherein the bidirectional power converter is
configured to operate in a plurality of modes including:

a bypass mode, in which the bidirectional power converter operates as a single
multiphase power converter; and

30 a split mode, in which the bidirectional power converter operates as two separate
power converters.

17. The device of Claim 16, wherein the two separate power converters comprise a buck converter and a boost converter.

18. The device of Claim 17, wherein:

5 the buck converter converts a charging voltage generated by the charging circuitry to battery voltage for charging the battery; and

the boost converter converts the battery voltage to a supply voltage for powering the one or more components.

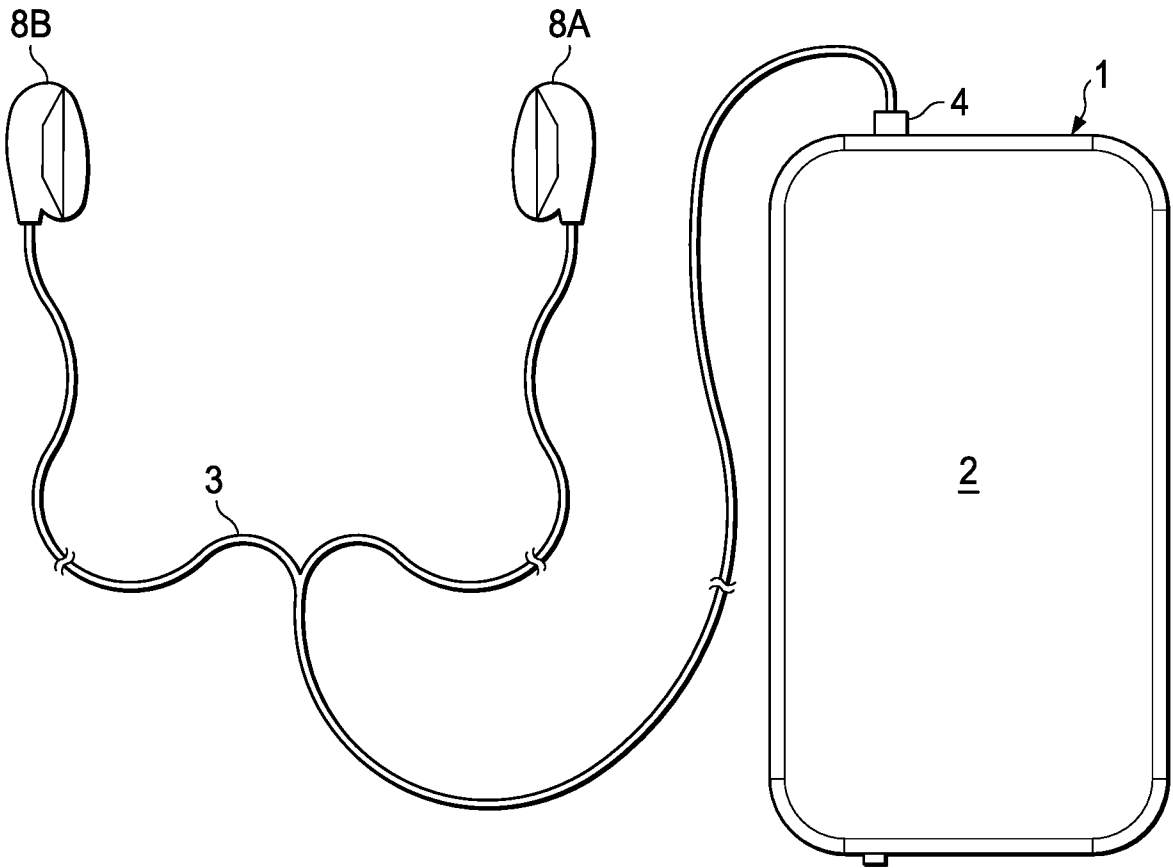


FIG. 1

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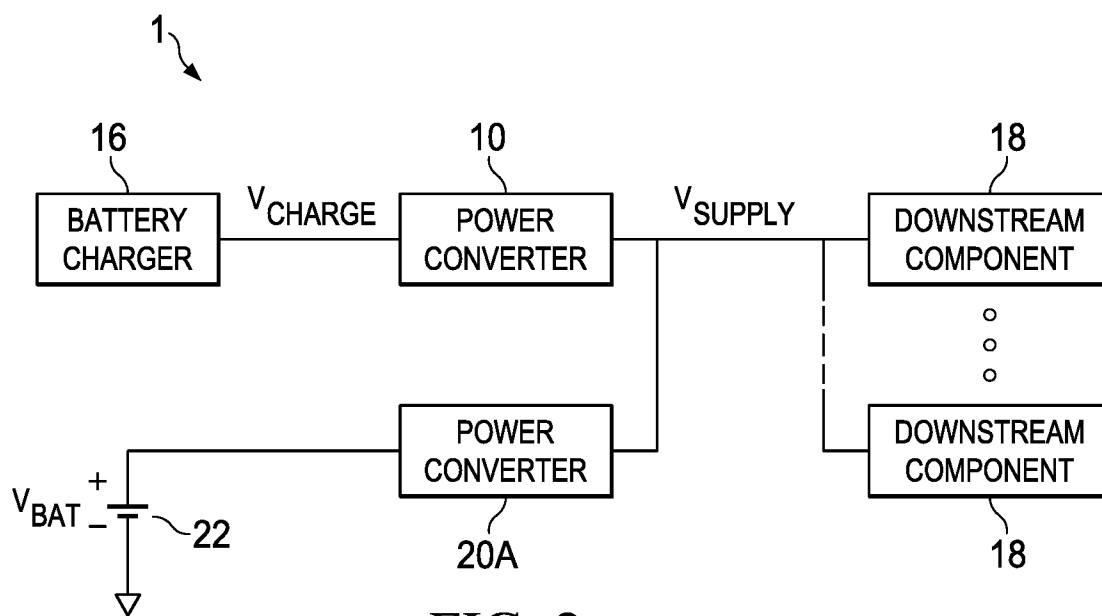


FIG. 2

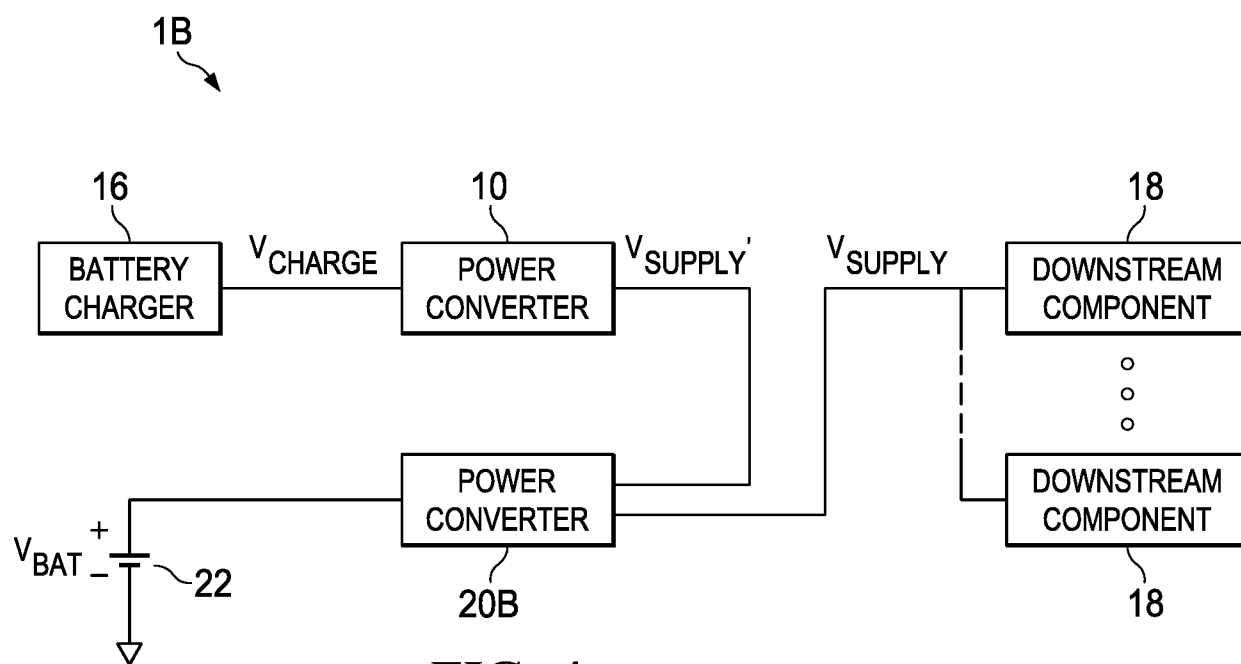
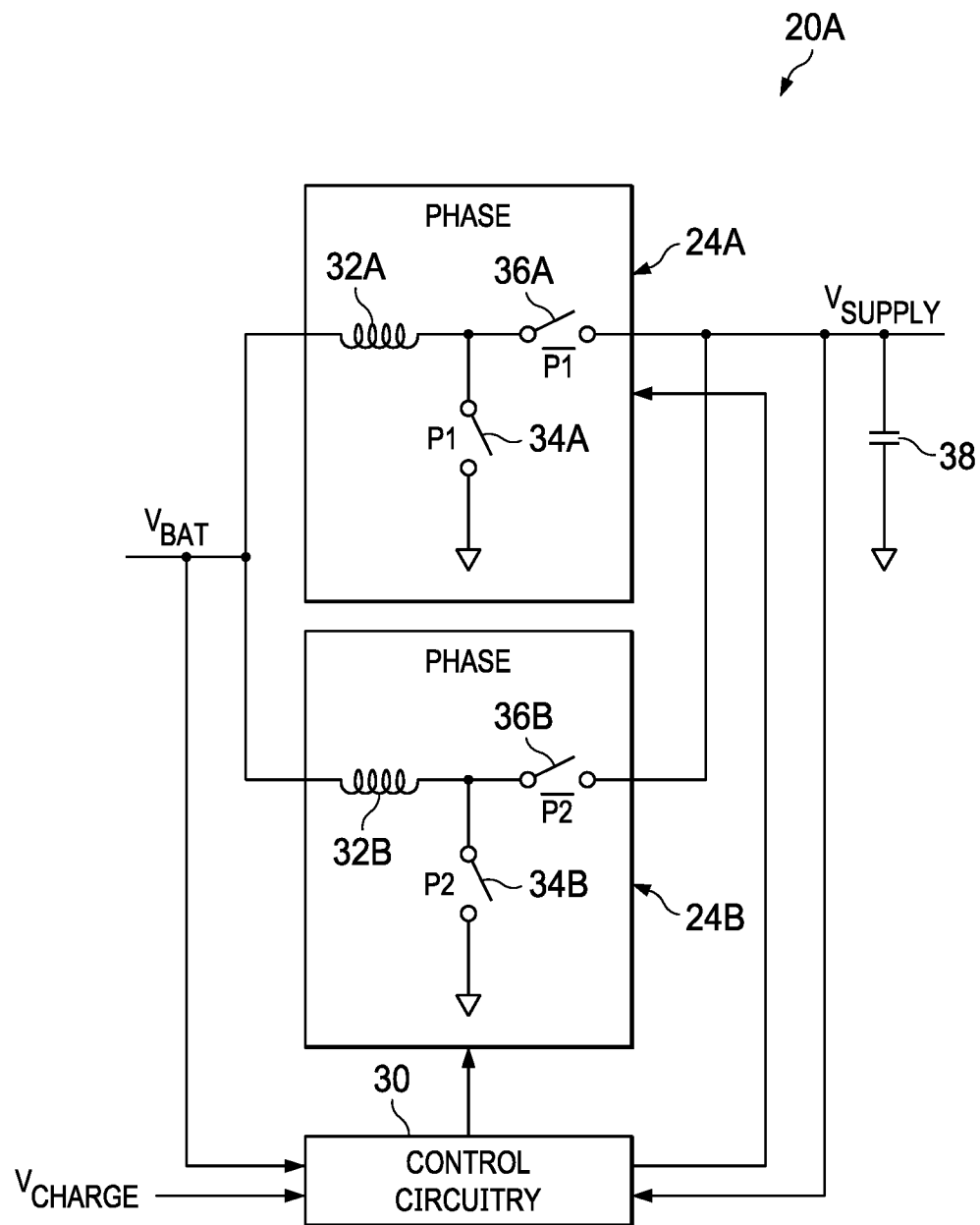


FIG. 4

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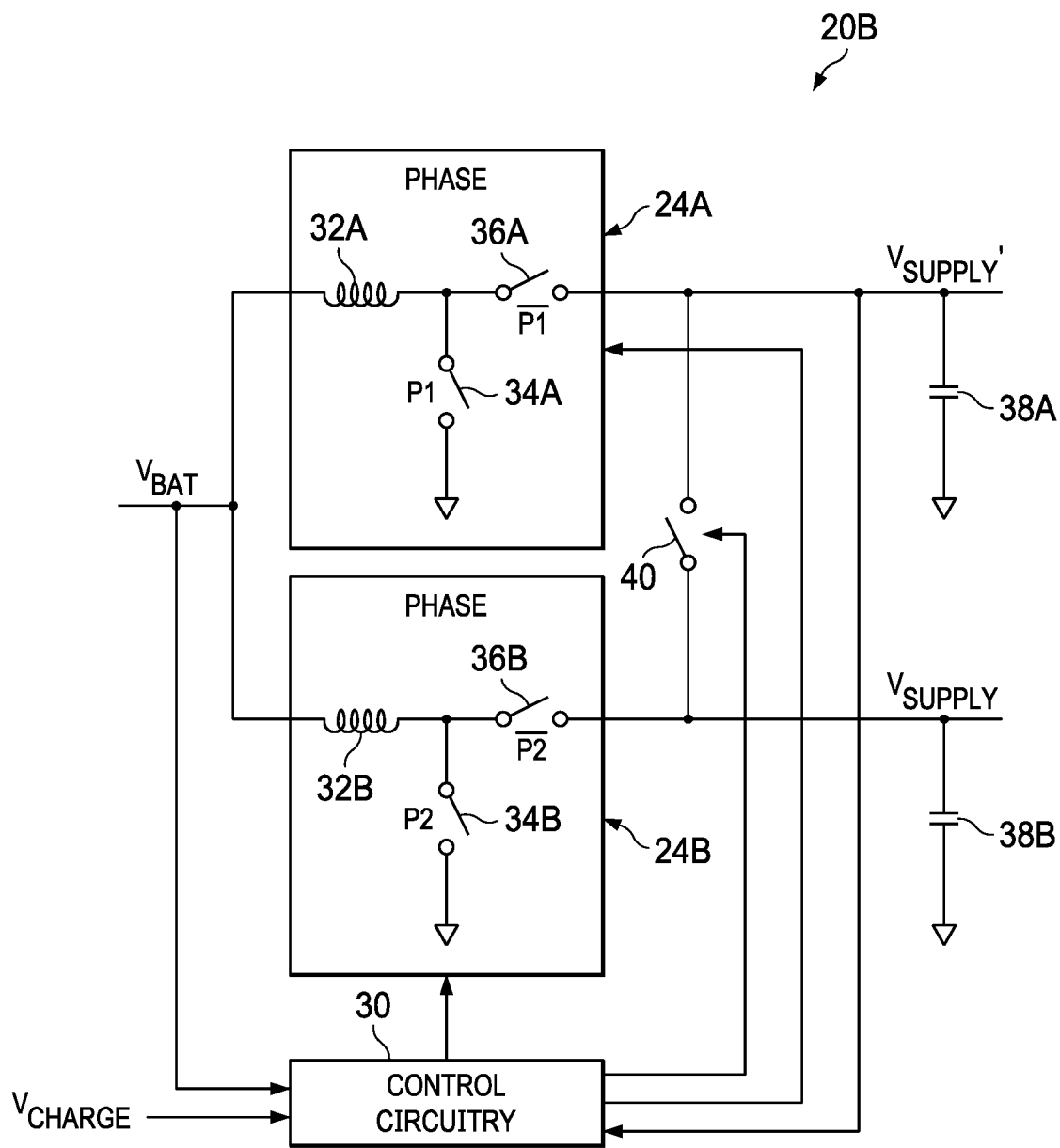


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2021/041918

A. CLASSIFICATION OF SUBJECT MATTER INV. H02J7/00 H02J7/34 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	EP 1 919 058 A2 (O2MICRO INC [US]) 7 May 2008 (2008-05-07)	1-3,7-9, 13-15
Y	abstract; figure 3 paragraphs [0020] - [0029]; claims 1,20; figure 3	4-6, 10-12, 16-18
Y	----- US 2016/064986 A1 (LANGLINAIS JAMIE [US] ET AL) 3 March 2016 (2016-03-03) abstract paragraphs [0063] - [0098]; figure 4A	4-6, 10-12, 16-18
X	----- US 2011/121653 A1 (HARTULAR ALEXANDRU [US] ET AL) 26 May 2011 (2011-05-26) abstract paragraphs [0023] - [0038], [0075] - [0086]; figures 1A,7A ----- -/--	1-3,7-9, 13-15
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "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) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "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 "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 "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 "&" document member of the same patent family		
Date of the actual completion of the international search 1 November 2021		Date of mailing of the international search report 10/11/2021
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 Lorenzo Feijoo, S

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Information on patent family members

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