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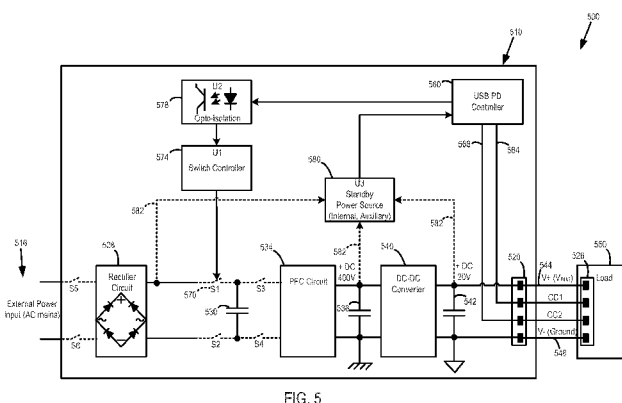
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(54) Title: REDUCING IDLE-TIME ENERGY CONSUMPTION IN UNIVERSAL SERIAL BUS POWER DELIVERY CIRCUITRY OF POWER ADAPTERS



(S7) Abstract: A Universal Serial Bus (USB) Power Delivery (PD) power adapter includes circuitry to control an electrical connection to a source of power—such as, for example, an external mains power source—based on detecting presence or absence of an electrical load of a power-consumer device. Presence is sensed using a USB Configuration Channel (CC) responsible for serial data communications between the USB PD power adapter and the power-consumer device. Accordingly, the USB communication signal lines are used to sense whether the power-consumer device is connected to the USB PD power adapter so that it may switchably disrupt the source of input power flowing from the source, through power converting and regulating circuitry, and to USB power signal lines (USB V_{BUS} and USB Ground) accompanying the USB communication signal lines in a USB power jack connector operatively connectable to the power-consumer device.

REDUCING IDLE-TIME ENERGY CONSUMPTION IN UNIVERSAL SERIAL BUS POWER DELIVERY CIRCUITRY OF POWER ADAPTERS

TECHNICAL FIELD

[0001] This disclosure relates generally to Universal Serial Bus (USB) Power Delivery (USB PD) circuitry for supplying direct current (DC) power, and, more specifically, to techniques by which circuitry of a USB PD power adapter supplying DC power to a USB PD-compliant device may switchably disconnect a source of input power (e.g., an alternating current (AC) mains electrical supply) when the device is electrically disconnected from the USB PD power adapter or an electrical load of the device is otherwise no longer requesting power.

BACKGROUND INFORMATION

[0002] FIG. 1 shows a collection of different AC adapters 100, which are also referred to as plug packs, plug-in adapters, adapter blocks, domestic mains adapters, line power adapters, wall warts, power bricks, power adapters, AC/DC adapters, or AC/DC converters. AC adapters 100 are each a type of external power supply including a case 110 that houses power converter circuitry—and sometimes also serves as an AC plug 120—used for supplying power to electrical devices that do not contain internal components capable of converting an external source of power to a usable form of electricity. AC adapters 100 that supply power to charge batteries of battery-powered devices are also referred to as chargers (or rechargers), and may be used for charging while concurrently powering other electronics of the battery-powered devices.

[0003] Some AC adapters 100, such as AC adapters 130, are generally designed for compliance with aspects of USB specifications defining standards for common USB electrical connectors 140, USB cabling 150, and USB voltage levels suitable for use in relatively low-power AC adapters 130 compatible with various portable electronic devices. More specifically, in addition to serial digital data exchange, the USB specifications provide for supplying DC power of up to 0.5 amps (A), or 900 milliamperes in USB 3.0 systems, at 5.0 volts (V).

[0004] For higher-power applications, a related specification titled “Universal Serial Bus Power Delivery Specification” (revision 2.0, version 1.1 of May 7, 2015) articulates, among other things, standards for using USB Type-A, -B, and -C connectors, cables, and associated electrical circuitry to deliver power to USB PD-

compliant USB devices having increased power demands, e.g., more than 7.5 watts (W). Accordingly, the specification defines a protocol concerning how devices communicate over USB to signal through a certified so-called PD-aware USB cable connected between a power sink and a power source. Sink may also refer to a role of a USB port, typically a device's upstream facing port (UFP), consuming power from a USB power conductor (i.e., V_{BUS}). Source also refers to a role of a USB port, typically a host's or hub's downstream facing port (DFP), providing power through the V_{BUS} . Thus, USB PD-compliant devices may request higher currents (from 2A to 5A) at increased supply voltages (from 5V to 20V). USB PD is, therefore, increasingly popular for rapid charging or supplying power to electronics.

SUMMARY OF THE DISCLOSURE

[0005] The present disclosure enhances existing USB PD technology by describing systems and methods to electrically connect or disconnect a USB PD power adapter's electrical connection to its input source of power—such as, for example, an external mains power source—based on detecting presence or absence of an electrical load of a power-consumer device or by receiving a request to stop delivery of power to an electrical load of a power sink. Presence is sensed using a USB wires, such as, for example, USB communication signal lines responsible for serial data communications between the USB PD power adapter and the power-consumer device.

[0006] According to one embodiment, USB communication signal lines are used to sense whether the power-consumer device is connected to the USB PD power adapter that controls a switch to selectively disconnect the source of input power from flowing through internal power converting and regulating circuitry coupled to USB power signal lines (USB V_{BUS} and USB Ground) accompanying the USB communication signal lines in a typical USB standard power jack connector operatively connectable to the power-consumer device.

[0007] The techniques described in this disclosure reduce power loss in a USB PD power adapter when power-consumer devices are not plugged into the USB PD power adapter or are otherwise not seeking to sink power from the USB PD power adapter. Reducing power loss in each one of millions of USB PD power adapters potentially provides significant energy savings globally. Also, the likelihood of accidental fire attributable to AC adapters left plugged into an AC wall socket could be reduced, so the safety could be improved in daily usage of AC adapters by

implementing disclosed embodiments. Additional aspects and advantages will be apparent from the following detailed description of embodiments, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a photographic view of prior art consisting of multiple AC power adapters connected to an AC power strip acting as an external source of power when electronic devices are connected to their corresponding AC power adapters.

[0009] FIGS. 2, 3, and 4 are annotated block diagrams showing three examples of pairs of USB PD-capable devices, each pair showing a power provider and a power-consumer device at, respectively, the top and bottom of the diagram.

[0010] FIGS. 5 and 6 are annotated block diagrams showing high-level electrical schematics of electrical circuitry components within the USB PD-capable power providers of FIGS. 2–4 that provide DC power through USB Type-C infrastructure to a power-consumer device having an electrical load.

[0011] FIG. 7 is an annotated block diagram showing a high-level electrical schematic of USB PD circuitry of a power supply and a mobile device connected by a USB Type-C connection.

[0012] FIG. 8 is an annotated block diagram showing a high-level electrical schematic of USB PD circuitry of a USB Type-C PD system including a USB 3.0 DisplayPort.

[0013] FIG. 9 is a flow diagram of a method of controlling delivery of input power in a power provider of FIGS. 2–8.

[0014] FIG. 10 is a block diagram of a USB PD controller of a power provider of FIGS. 2–8 configured to detect an electrical load and electrically activate a switch that switchably controls an electrical connection to a source of power.

DETAILED DESCRIPTION OF EMBODIMENTS

[0015] As shown in FIG. 1, AC adapters 100 are commonly left plugged into AC sockets 160 when no electronic devices (e.g., a laptop) are connected to or otherwise drawing power from the AC adapters 100. Although there have been some improvements in terms of reducing power consumption of AC adapters left in the aforementioned idle, no-load condition (e.g., ENERGY STAR® standards specifying that less than 0.5W should be consumed in the idle condition), there is still a vast amount of energy wasted due to the aggregate number of deployed AC adapters. For example, assuming 10% of the global population maintains an AC adapter (i.e.,

713 million AC adapters) in its idle condition using 0.5W during 80% of each day, the annual electricity wasted would be about 2.498 billion kilowatt hours (kWhr), at an annual cost of about \$250 million (assuming about \$0.10 per kWhr).

[0016] Some attempts have been made to detect whether an AC adapter is plugged or unplugged by sensing its output load current. These attempts have proved to be difficult to implement because it is sometimes difficult to accurately sense a very small output current (e.g., when the load is unplugged or plugged in but the load device is at a very low-power consumption state). In contrast, this disclosure supplements existing USB PD infrastructure by adding to it electrical circuitry and methods enhancing USB PD power adapters and similar devices so as to save energy during the aforementioned idle state.

[0017] USB PD devices are characterized by compatibility with existing USB 2.0 and USB 3.0 cables and connectors supporting relatively high power (e.g., up to about 100W). Higher voltage and currents suiting the cable capabilities and conforming to international safety requirements are negotiated over the V_{BUS} (e.g., in USB Type-A/B) or over Configuration Channel (CC) serial data communication (e.g., in USB Type-C). USB PD devices may also comply with USB Battery Charging specifications (version 1.2) for lower power demands.

[0018] A power source (or simply, source) includes at least one of an external power source (e.g., AC mains electricity), power storage (e.g., an internal battery), or power derived from another port (e.g., in the case of a bus-powered hub). A power sink (or simply, sink) includes at least one of power storage, internal electrical power consumption functions, or power used for other devices attached to the device acting as the sink (e.g., in the case of a bus-powered hub). The USB PD device providing power is also known as a provider or source, and the USB PD device consuming power is known as a consumer or sink because providers are assumed to have a source and consumers are assumed to have a sink.

[0019] Generally, each embodiment of FIGS. 2–4 shows a pair of USB PD-capable devices, in which each device includes at least one port such that there is a power source port and a power sink port establishing a USB PD connection between port partners. For USB products supporting USB PD protocols, a USB DFP is initially a source port and a USB UFP is initially a sink port. In other words, DFP and UFP are used to describe the data role, whereas source and sink are used to describe the power role. USB PD specifications allow both the source and sink roles and the DFP

and UFP roles to be swapped (e.g., DFP and UFP roles are swappable on devices having USB Type-C connectors). Also, each device contains one or more of the following components: UFPs that sink power (as a consumer), optionally source power (as a consumer or provider), optionally communicate via USB, and communicate using start of packet (SOP) communications; and DFPs that source power (a provider), optionally sink power (as a provider or consumer), optionally communicate via USB, and communicate using SOP packets.

[0020] For example, FIGS. 2–4 show some examples of USB PD-capable devices (i.e., USB power adapter, device, host, and hub) arranged in typical configurations that should not be construed as limiting the possible configurations of products that may employ the techniques of this disclosure. Broken lines indicate optional components and connections.

[0021] With reference to FIG. 2, a USB power adapter 200 includes an external power input 210 to receive a source of input power 216, load-detector circuitry 224 for controlling the switching of the source of input power 216, an optional internal power storage 228 that may also provide a source of power, and a DFP 234 representing one or multiple sources of output power 238 (i.e., the arrow's directionality and slash through its shaft represent one or more outputs). A USB device 240 may then be electrically connected to DFP 234 using a USB cable 246 so that a UFP 248 of the device 240 may act as a sink 256 of power received from the USB power adapter 200. In some embodiments, the USB device 240 may optionally include its own external power input 260 to receive a source of input power 266. The USB device 240 may also optionally include an internal power storage 270, such as a battery, in which case the USB power adapter 200 serves as a USB charger.

[0022] FIG. 3 shows a similar configuration to that of FIG. 2, but whereas FIG. 2 shows the USB power adapter 200 as a power source and the USB device 240 as a power consumer, FIG. 3 shows a USB host 300 as a power source for a USB hub 310. The USB host 300 differs slightly from the USB power adapter 200 in that a DFP 312 represents one or multiple sources and sinks 316 of power. In other words, DFP 312 may be configured to output or input power (i.e., the arrow's bi-directionality and slash through its shaft represent one or more inputs or outputs). Also, the USB hub 310 differs from the USB device 240 because it also includes a DFP 312 and associated load-detector circuitry 224 because the USB hub 310 may also act as a provider of power, as shown in FIG. 4.

[0023] FIG. 5 shows an example USB PD power adapter 500 including load-detector circuitry 510 to smartly disconnect a source of power 516 while also implementing the features of the USB Power Delivery Specification, such as, for example, port-to-port communications and a power delivery system whereby a port 520 can advertise its capabilities and other ports (e.g., a port 526) can request these capabilities. In some cases, the capabilities include voltage, current, and power direction.

[0024] Voltage and current are established by converting and regulating the source of power 516. A bridge rectifier 528, for example, may first fully rectify an AC signal, which has its high frequencies filtered by a high-frequency bypass capacitor 530. A power factor correction (PFC) circuit 534 receives the filtered AC signal and converts it to a 400V DC voltage, which is used to charge a bulk storage capacitor 536. A switch-mode power supply (SMPS) DC-DC converter 540 then down-converts the 400V DC voltage to a 20V DC voltage, which is filtered by output capacitor 542. The 20V DC voltage is then delivered through two electrical conductors, USB V_{BUS} 544, and USB Ground 546 of the port 520 to the port 526.

[0025] Power direction refers to an ability to configure the port 526 of a USB PD-capable device 550 to receive power delivered by the port 520 so that the device 550 (e.g., on a notebook) may use its port 526 as a power supply for an electrical load of the device 550. Power direction, among other things, is typically implemented by a USB PD controller 560 (see, e.g., FIG. 10) operatively coupled to a data communication bus carrying USB serial communications over two electrical conductors USB CC1 564 and USB CC2 568 of the port 520.

[0026] The USB PD controller 560—such as part number TPS65982 available from Texas Instruments Inc. of Dallas, Tex.—uses a data communication bus (e.g., the CC) to detect and determine whether the USB power adapter 500 is needed to provide power to a load of the device 550 (e.g., a laptop, tablet, smartphone, mobile smartdevice, or other electronics). For example, no load is sensed under the following scenarios. A first scenario occurs when a load device is not connected to the USB power adapter 500, in which case the USB PD controller 560 cannot detect a response from the device 550, and the source of input power 516 is disconnected as explained in the following paragraph. A second scenario occurs when the device 550 may be entering a low-power consumption state (e.g., a deep sleep state, sometimes referred to as an idle state), such as when its internal battery has been

fully charged, and the device 550 signals by serial data communications carried through a communications bus (e.g., the CC) to the USB PD controller 560 to indicate that no further power is requested. In response, the USB PD power adapter 500 may then disconnect the source of input power 516.

[0027] Under the first scenario, there are various techniques that could be employed to detect when a device is attached. For example, logic circuitry has been described for USB Type-C attach and detach detection. In general, the source provides a pull-up resistor (called R_p in the USB Type-C specifications) electrically associated with a CC wire. Similarly, the sink provides a pull-down resistor (called R_d in the USB Type-C specifications) at the CC wire. When circuitry of a source detects a signal level from the pull-down resistor, that signal indicates an attachment of a sink. The source, in turn, supplies V_{BUS} , which tells the sink that a connection has been established.

[0028] Under the second scenario, the serial data communications carried through a communications bus are generally implementation-specific, and the specific message format and protocol will depend on the particular communications bus and device behavior. For example, with reference to another communication bus, USB Type-C PD communications are carried through CC wire between the source and the sink. And in terms of device behavior, the device 550 may program its control policy to decide whether and when to trigger the indicator signaling that the device 550 is no longer operating as a power sink (e.g., when it is at a low-power consumption state). For example, under the idle state, some devices may choose to send such an indicator to the USB PD adapter 500 because the devices have determined that using an internal battery for supplying an electrical load is more energy efficient than directly sinking power from the USB PD adapter 500.

[0029] Upon determining that no power should be delivered, the USB PD controller 560 initiates steps to cut off its internal circuitry from the source of power 516 and thereby remove power from V_{BUS} 544. In general, a switch (S1) 570 is provided at a location between the source 516 and V_{BUS} 544 so that the USB PD controller 560 can switchably break the electrical connection from the source 516 to V_{BUS} 544. More specifically, the switch 570 is located between the rectified AC signal of the rectifier 528 and the bypass capacitor 530, but this location is just one of many possible switch locations indicated by broken lines and annotated by references S1–S6. For this reason, the reference number 570 is used to refer generally to any of the

switches S1–S6. An example of a suitable switch that may be used for switch 570 is a power metal–oxide–semiconductor field-effect transistor (MOSFET) identified as part number IRFI820G available from Vishay Intertechnology, Inc. of Malvern, Pennsylvania. The switch 570 could also be a junction field-effect transistor (JFET), insulated gated bipolar transistor (IGBT), or other types of suitable switch devices.

[0030] According to some embodiments, the switch 570 is normally closed and remains so until it receives an open signal (i.e., off command) from a switch controller (U1) 574. When the switch 570 receives the off command from the switch controller 574, it effectively breaks the electrical connection between the AC line input and the PFC circuit 534. The switch controller 574 sends its off command in response to the USB PD controller 560 determining that no load devices are connected to the USB PD power adapter 500 or that the load devices have indicated no power is requested for the USB PD power adapter 500. The on and off commands may be a voltage level applied to a gate of the switch 570. An example of a suitable switch controller that may be used as the switch controller 574 could be one or several N-channel trench MOSFETs identified as part number 2N7002 available from NXP Semiconductors N.V. of Eindhoven, Netherlands. A function of the switch controller 574 is to form a proper logic-level control signal (high or low) to drive on or off the switch 570.

[0031] Because some power adapters isolate ground nodes of primary and secondary sides, optional opto-isolation (U2) 578 may be used to convey control commands from the USB PD controller 560 to the switch controller 574. An example opto-isolation device is part number TLP521-1 available from Toshiba Semiconductor of Tokyo, Japan.

[0032] Also, when the source of power 516 is disconnected, a standby auxiliary power source (U3) 580 is used to supply power to the USB PD controller 560 so that it may continue to monitor communication data on the USB data bus (e.g., the CC). The following Table 1 lists two examples of rechargeable coin cell batteries available in small form factors suitable for U3 580, though other options could also provide backup power. For example, when the source of power 516 is actually an internal battery (see e.g., internal power storage 228 of FIG. 2), then the internal power storage 228 may serve as the auxiliary power source and the source of power for the device 550.

Table 1

Part No.	Diameter	Height	Electrical Specs.	Note
MS621FE	6.8mm	2.1mm	5.5mAh at 3V	battery
LIR2032	20mm	3.2mm	40mAh at 3.6V	battery

[0033] With reference to the second example battery of Table 1, the LIR2032 rechargeable coin cell battery has a total energy capacity of about 144mWhr ($3.6V \times 40mAh$). The USB PD controller power consumption (while in its sleep state) is about 0.25mW (as noted in datasheets for the TPS65982 chip). Accordingly, the total sustaining time is 518.4 hours ($144mWhr \times 0.90 \div 0.25mW$, assuming 90% efficiency for DC-DC conversion), which is 21.6 days. That means the rechargeable cell battery can power the USB PD controller for about 21 days before it is depleted of energy. Before it is depleted, however, the USB PD controller 560 switches the switch 570 back on to reestablish the connection to the source of input power 516 and to allow the rechargeable cell battery to be recharged through one of pathways 582 (multiple options shown in broken lines). For example, when stored power in a supercap or battery is less than a certain threshold, the USB PD controller 560 commands, through U1 and U2, that S1 connect the source of input power 516 to allow the supercap or battery to charge. After finishing charging, the USB PD controller 560 commands S1 to again disconnect the source of input power 516 by switching S1 (or another switch) off.

[0034] In terms of return on investment, a single USB PD brick provides 3.504kWhr ($0.5W \times 24hr \times 365 \times 0.8$ —assuming 80% idle time) in annual energy savings, which is about \$0.35 at \$0.10 per kWhr. Over a five-year lifecycle of the power adapter, that equates to a cost savings of about \$1.75. The cost savings exceeds the \$0.53 fixed cost of additional components set forth in Table 2. Thus, besides energy saving, the techniques of this disclosure also provide a net cost savings after about two years' usage.

Table 2

Ref.	Notes	Part No(s).	Cost
S1	Power MOSFET (low current rating)	IRFI820G	\$0.10
U1	MOSFET and several pull-up and pull-down resistors	2N7002	\$0.05
U2	Opto-coupler and several pull-up and pull-down resistors	TLP521-1	\$0.02
U3	Battery (\$0.16) and a DC-DC converter (\$0.20)	See Table 1	\$0.36
			\$0.53

[0035] FIG. 6 shows another example USB PD power adapter 600 for a USB Type-C port 610. The adapter 600 includes a switching device 620 in the form of two transistors 630 (FETs) resistively coupled to a USB PD controller 640. The FETs 630 may be used to remove power across V_{BUS} when: (1) sink detachment is detected or (2) a hard reset and occurs so as to revert V_{BUS} to a safe operating voltage (e.g., 0V).

[0036] FIG. 7 shows another embodiment of a USB Type-C PD system 700. At least one of a CC1 or a CC2 line (i.e., wire) 710 is connected end-to-end through a USB Type-C cable 720. The USB Type-C cable 720 also includes a V_{BUS} line 722 that carries power from a power supply 724 to a mobile device 728.

[0037] A pair of partner USB PD controllers (i.e., a first USB PD controller 730 within the power supply 724 and a second USB PD controller 750 within the mobile device 728) uses the CC wire 710 as a communication channel. The CC wire 710 carries the USB PD communication (bi-phase mark coded) signaling used for establishing a USB PD contract (e.g., 20V at 3A) negotiated between the partner USB PD controllers 730 and 750.

[0038] The USB PD controller 730 then controls an SMPS 770 to satisfy the proper voltage and current level as per the USB PD contract. The USB PD controller 730 may also control a switch 774 external to the SMPS 770, or an internal switch within the SMPS 770, so as to disconnect a source of power along the lines previously described.

[0039] The USB PD controller 750 passes the USB PD contract through an Inter-Integrated Circuit (I2C) bus to a system host (also known as an embedded controller), which in turn sets an input current limit (provided through a V_{BUS}) of a battery charger 780.

[0040] The mobile device 728 also has two power-control switches: First, S_{SNK} 786 is a sink switch that passes the input power from the V_{BUS} line 722 to the battery charger 780. Accordingly, the mobile device 728 provides a power consumer port if S_{SNK} 786 closes. Second, S_{SRC} 790 is a source switch that passes a local 5V supply to the V_{BUS} line 722 so as to power a USB peripheral. The mobile device 728 provides a power provider port if S_{SRC} 790 closes.

[0041] FIG. 8 shows another system 800 including a USB PD controller 810 and associated circuitry supporting a complete communication stack employed in USB PD communication signaling. The USB PD controller 810 includes CC logic, a USB PD physical (PHY) layer, a protocol layer, and a policy engine. The CC logic includes the electrical termination of the CC pins and a dual roll port (DRP) state machine. The USB PD controller 810 communicates with a device policy manager (within the embedded controller) that handles the USB PD policy of USB ports. The USB PD controller 810 also includes an autonomous negotiation algorithm, and it controls the pass elements (Q1, Q2, Q3 and Q4).

[0042] FIG. 9 shows a method 900 of controlling a switch in a USB PD power adapter so as to cause the switch to electrically (re)connect circuitry of the USB power adapter to an AC line input or other source of power. Initially, the switch (such as the switch 570 of FIG. 5) is normally closed and therefore connecting 910 a source of power to internal circuitry of the USB PD power adapter.

[0043] The USB PD controller receives 920 signals or messages indicating whether the switch should be opened. For example, three kinds of signals are communicated as indicators for the USB PD controller to decide whether to turn off the switch. For example, the USB PD controller receives (1) information indicating the status of the energy available in the auxiliary power source (which need not be communicated through a USB data bus, but is instead directly reported to the USB PD controller from an auxiliary power source circuit), (2) information communicated through the USB communication bus indicating whether power is requested, and (3) information indicating a device is detached.

[0044] Based on the received information, the USB PD controller determines 930 whether the standby auxiliary power energy level is less than a predetermined threshold. If yes, then the USB PD controller indicates 940 that the switch should remain on or be switched closed. Similarly, if the USB PD controller determines 950 that the switch should be off in response to information from USB communications or

signals, then the USB PD controller indicates 960 that the switch should turn off or be switched open. Finally, the USB PD controller continues monitoring 970 for a change in load connection state, energy level, or device power consumption messages.

[0045] Skilled persons will recognize that the features of FIG. 9 may be performed in a sequence that is different from the one shown. In some embodiments, certain features may be performed in parallel, whereas other features may be combined or omitted.

[0046] FIG. 10 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. 10 shows a diagrammatic representation of hardware resources 1000 including one or more processors (or processor cores) Z10, one or more memory/storage devices Z20, and one or more communication resources Z30, each of which is communicatively coupled via a bus Z40.

[0047] The processors Z10 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, an application specific integrated circuit (ASIC), a microcontroller, another processor, or any suitable combination thereof) may include, for example, a processor Z12 and a processor Z14. The memory/storage devices Z20 may include main memory, flash memory, or any suitable combination thereof.

[0048] The communication resources Z30 may include interconnection and/or network interface components or other suitable devices to communicate with one or more peripheral devices Z04. For example, the communication resources Z30 may include wired communication components (e.g., for coupling via the USB CC electrical conductors).

[0049] Instructions Z50 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors Z10 to perform any one or more of the methodologies discussed herein. The instructions Z50 may reside, completely or partially, within at least one of the processors Z10 (e.g., within the processor's cache memory), the memory/storage devices Z20, or any suitable combination thereof. Furthermore, any portion of the instructions Z50 may be transferred to the hardware resources Z00 from any

combination of the peripheral devices Z04. Accordingly, the memory of processors Z10, the memory/storage devices Z20, and the peripheral devices Z04 are examples of computer-readable and machine-readable media.

[0050] Set forth below is a list of other examples. Reference throughout this specification to “an example” means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment. But appearances of the phrase “in an example” in various places throughout this specification are not necessarily limited to one specific embodiment.

[0051] Example 1. A Universal Serial Bus (USB) Power Delivery (PD) apparatus, comprising: a USB port including USB VBUS, USB Ground, and USB serial data communications electrical conductors; power supply circuitry configured to establish, from a source of electrical power, a regulated supply of electrical power for delivery to an electrical load of a USB PD-capable power-consumer device when the USB PD-capable power-consumer device is communicatively coupled to the USB port and is configured as a sink of the electrical power; a USB PD controller configured to sense electrical signals, communicated through the USB serial data communications electrical conductors, indicating presence of the electrical load of the USB PD-capable power-consumer device so as to determine whether the USB PD-capable power-consumer device is sinking the electrical power from the USB PD power adapter; and a switch switchable to suppress flow of electrical current from the source of electrical power in response to the USB PD controller determining the USB PD-capable power-consumer device is not sinking the electrical power from the USB PD power adapter.

[0052] Example 2. The apparatus of example 1, in which the switch is operatively coupled to receive alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power.

[0053] Example 3. The apparatus of example 1, further comprising: rectifier circuitry configured to establish a rectified signal from alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power; and the switch operatively coupled to receive the rectified signal so as to disconnect the rectified signal from the power supply circuitry configured to establish the regulated supply of electrical power.

[0054] Example 4. The apparatus of example 1, further comprising: rectifier circuitry configured to establish a rectified signal from alternating current (AC) mains

power in response to the AC mains power being provided as the source of electrical power; a bypass capacitor to filter high frequency components of the rectified signal and establish a filtered rectified signal; and the switch operatively coupled to receive the filtered rectified signal so as to disconnect it from the power supply circuitry configured to establish the regulated supply of electrical power.

[0055] Example 5. The apparatus of example 1, further comprising an auxiliary power source configured to provide power to the USB PD controller in response to the switch suppressing the flow of electrical current.

[0056] Example 6. The apparatus of example 1, further comprising an auxiliary power source configured to provide power to the USB PD controller when the source of electrical power is disconnected by the switch.

[0057] Example 7. The apparatus of example 6, in which the USB PD controller is configured to: determine an amount of energy available in the auxiliary power source; and in response to determining the amount of energy is low, control the switch to allow the flow of electrical current from the source of electrical power to replenish the energy available in the auxiliary power source.

[0058] Example 8. The apparatus of example 6, in which the USB PD controller is configured to: in response to the flow of electrical current being suppressed, monitor an amount of energy available in the auxiliary power source; and control the switch to allow the flow of electrical current from the source of electrical power so as to replenish the energy available in response to it falling below a threshold.

[0059] Example 9. The apparatus of example 1, further comprising a switch controller communicatively coupled to the USB PD controller and configured to provide a drive signal to control switching behavior of the switch.

[0060] Example 10. The apparatus of example 9, further comprising an opto-isolator disposed between the switch controller and the USB PD controller.

[0061] Example 11. The apparatus of example 1, in which the USB PD controller detects presence of the USB PD-capable power-consumer device by communicating with the USB PD-capable power-consumer device through a USB data bus.

[0062] Example 12. The apparatus of example 1, in which the USB PD controller determines whether the USB PD-capable power-consumer device is operating as a sink by communicating with the USB PD-capable power-consumer device through a USB data bus.

[0063] Example 13. A USB PD power adapter comprising the apparatus of any one of examples 1–12.

[0064] Example 14. A battery charger comprising the apparatus of any one of examples 1–12.

[0065] Example 15. The apparatus of any one of examples 1–12, further comprising an internal battery configured to provide the source of electrical power.

[0066] Example 16. A method, performed by a Universal Serial Bus (USB) Power Delivery (PD) apparatus having a USB port including electrical conductors for USB serial data communications and power delivery, the method comprising: establishing, from a source of electrical power, a regulated supply of electrical power for delivery to an electrical load of a USB PD-capable power-consumer device when the USB PD-capable power-consumer device is communicatively coupled to the USB port and is configured as a sink of the electrical power; receiving electrical signals, communicated through the electrical conductors of the USB port, indicating presence of the electrical load of the USB PD-capable power-consumer device so as to determine whether the USB PD-capable power-consumer device is sinking the electrical power from the USB PD power adapter; determining, based on the received electrical signals, that the USB PD-capable power-consumer device is not sinking the electrical power from the USB PD power adapter; and controlling a switch device to suppress flow of electrical current from the source of electrical power in response to determining that the USB PD-capable power-consumer device is not sinking the electrical power.

[0067] Example 17. The method of example 16, further comprising: receiving alternating current (AC) mains power as the source of electrical power; and providing to a transistor a gate drive signal causing the transistor to suppress flow of electrical current from the AC mains power in response to determining that the USB PD-capable power-consumer device is not sinking the electrical power.

[0068] Example 18. The method of example 16, further comprising: establishing a rectified signal from alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power; and providing a switch signal to a transistor to disconnect the rectified signal.

[0069] Example 19. The method of example 16, further comprising: establishing a filtered rectified signal by filtering high frequency components of a rectified signal; and providing a switch signal to a transistor to disconnect the filtered rectified signal.

[0070] Example 20. The method of example 16, further comprising providing power from an auxiliary power source to a USB PD controller of the USB PD apparatus when the auxiliary power source is disconnected from the source of electrical power by the controlling of the switch device.

[0071] Example 21. The method of example 16, further comprising providing power from an auxiliary power source to a USB PD controller of the USB PD apparatus when the source of electrical power is disconnected by the controlling of the switch device.

[0072] Example 22. The method of example 21, further comprising: determining an amount of energy available in the auxiliary power source; and in response to determining the amount of energy is low, controlling the switch device to allow the flow of electrical current from the source of electrical power to replenish the energy available in the auxiliary power source.

[0073] Example 23. The method of example 21, further comprising: in response to the flow of electrical current being suppressed, monitoring an amount of energy available in the auxiliary power source; and controlling the switch device to allow the flow of electrical current from the source of electrical power so as to replenish the energy available in response to it falling below a threshold.

[0074] Example 24. The method of example 16, further comprising detecting presence of the USB PD-capable power-consumer device by communicating with the USB PD-capable power-consumer device through a USB data bus.

[0075] Example 25. The method of example 16, further comprising determining whether the USB PD-capable power-consumer device is operating as a sink by communicating with the USB PD-capable power-consumer device through a USB data bus.

[0076] Example 26. A USB PD power adapter configured to perform the method of any one of examples 16–25.

[0077] Example 27. A battery charger configured to perform the method of any one of examples 16–25.

[0078] Example 28. An apparatus configured to perform the method of any one of examples 16–25, further comprising an internal battery configured to provide the source of electrical power.

[0079] Example 29. The method of any one of examples 16–25, in which the USB port is a USB Type-C port.

[0080] Example 30. A Universal Serial Bus (USB) Power Delivery (PD) controller comprising circuitry configured to: receive a first signal indicating whether a USB device is attached to a USB port controlled by the USB PD controller; receive a second signal indicating whether the USB device is requesting electrical power from a source of electrical power conveyed through a power path that is controlled by the USB PD controller; and in response to the first signal indicating that the USB device is detached or the second signal indicating the USB device is not requesting power, provide a control signal to control a switch that disconnects the source of electrical power from the power path.

[0081] Example 31. The USB PD controller of example 30, further comprising circuitry to: receive a third signal indicating an amount of energy stored in an auxiliary power source that provides power to the USB PD controller when the source of electrical power is disconnected from the power path; and in response to the third signal indicating that the amount of energy is below a desired threshold, control the switch to connect the source of electrical power to the power path.

[0082] Example 32. The USB PD controller of example 30, in which the first signal comprises a message communicated over a USB communications bus.

[0083] Example 33. The USB PD controller of example 30, in which the second signal comprises a message communicated over a USB communications bus.

[0084] Example 34. The USB PD controller of example 30, in which the second signal indicates that the USB device is in an idle state.

[0085] Example 35. The USB PD controller of example 30, further comprising circuitry to provide the control signal to activate a transistor that allows current to flow along the power path.

[0086] Example 36. A method, performed by a Universal Serial Bus (USB) Power Delivery (PD) controller, comprising: receiving a first signal indicating whether a USB device is attached to a USB port controlled by the USB PD controller; receiving a second signal indicating whether the USB device is requesting electrical power from a source of electrical power conveyed through a power path that is controlled by the USB PD controller; and in response to the first signal indicating that the USB device is detached or the second signal indicating the USB device is not requesting power, providing a control signal to control a switch that disconnects the source of electrical power from the power path.

[0087] Example 37. The method of example 36, further comprising: receiving a third signal indicating an amount of energy stored in an auxiliary power source that provides power to the USB PD controller when the source of electrical power is disconnected from the power path; and in response to the third signal indicating that the amount of energy is below a desired threshold, controlling the switch to connect the source of electrical power to the power path.

[0088] Example 38. The method of example 36, in which the first signal comprises a message communicated over a USB communications bus.

[0089] Example 39. The method of example 36, in which the second signal comprises a message communicated over a USB communications bus.

[0090] Example 40. The method of example 36, in which the second signal indicates that the USB device is in an idle state.

[0091] Example 41. The method of example 36, further comprising circuitry to provide the control signal to activate a transistor that allows current to flow along the power path.

[0092] Example 42. An apparatus comprising means to perform one or more elements of a method described in or related to any of examples 16–25 or 36–42, or any other method or process described herein.

[0093] Example 43. A non-transitory (or transitory) computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of a method described in or related to any of examples 16–25 or 36–42, or any other method or process described herein.

[0094] Embodiments and implementations of the systems and methods described herein may include various operations, which may be embodied in machine-executable instructions to be executed by a microcontroller, specific logic for performing the operations, hardware, software, firmware, or combinations thereof.

[0095] Various techniques, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as solid-state memory devices, a nontransitory computer-readable storage medium, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a microcontroller, the machine becomes an apparatus for practicing the various techniques. In the case of program code execution on programmable computers, the computing device may include a

processor, a storage medium readable by the processor (including volatile and nonvolatile memory), at least one input device, and at least one output device. The volatile and nonvolatile memory and/or storage elements may be a RAM, an EPROM, a flash drive, an optical drive, a magnetic hard drive, or other medium for storing electronic data. One or more programs that may implement or utilize the various techniques described herein may use an application programming interface (API), reusable controls, and the like. Such programs may be implemented in a high-level procedural or an object-oriented programming language to communicate with a computer system. However, the program(s) may be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language, and combined with hardware implementations.

[0096] It should be understood that many of the functional units described in this specification may be implemented as one or more components, which is a term used to more particularly emphasize their implementation independence. For example, a component may be implemented as a hardware circuit comprising custom very large scale integration (VLSI) circuits or gate arrays, or off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A component may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices, or the like.

[0097] Components may also be implemented in software for execution by various types of processors. An identified component of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, a procedure, or a function. Nevertheless, the executables of an identified component need not be physically located together, but may comprise disparate instructions stored in different locations that, when joined logically together, comprise the component and achieve the stated purpose for the component.

[0098] Indeed, a component of executable code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within components, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may

exist, at least partially, merely as electronic signals on a system or network. The components may be passive or active, including agents operable to perform desired functions.

[0099] Skilled persons will understand that many changes may be made to the details of the above-described embodiments without departing from the underlying principles of the invention. For example, the switching can be controlled by various data communication buses, including the D+ and D− communication bus under USB Type A and B, the Power Management Bus (PMbus), the I2C bus, or other data communication buses. The scope of the present invention should, therefore, be determined only by the following claims.

CLAIMS

1. A Universal Serial Bus (USB) Power Delivery (PD) apparatus, comprising:
 - a USB port including USB V_{BUS} , USB Ground, and USB serial data communications electrical conductors;
 - power supply circuitry configured to establish, from a source of electrical power, a regulated supply of electrical power for delivery to an electrical load of a USB PD-capable power-consumer device when the USB PD-capable power-consumer device is communicatively coupled to the USB port and is configured as a sink of the electrical power;
 - a USB PD controller configured to sense electrical signals, communicated through the USB serial data communications electrical conductors, indicating presence of the electrical load of the USB PD-capable power-consumer device so as to determine whether the USB PD-capable power-consumer device is sinking the electrical power from the USB PD power adapter; and
 - a switch switchable to suppress flow of electrical current from the source of electrical power in response to the USB PD controller determining the USB PD-capable power-consumer device is not sinking the electrical power from the USB PD power adapter.
2. The apparatus of claim 1, in which the switch is operatively coupled to receive alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power.
3. The apparatus of claim 1, further comprising:
 - rectifier circuitry configured to establish a rectified signal from alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power; and
 - the switch operatively coupled to receive the rectified signal so as to disconnect the rectified signal from the power supply circuitry configured to establish the regulated supply of electrical power.
4. The apparatus of claim 1, further comprising:
 - rectifier circuitry configured to establish a rectified signal from alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power;
 - a bypass capacitor to filter high-frequency components of the rectified signal and establish a filtered rectified signal; and

the switch operatively coupled to receive the filtered rectified signal so as to disconnect it from the power supply circuitry configured to establish the regulated supply of electrical power.

5. The apparatus of claim 1, further comprising an auxiliary power source configured to provide power to the USB PD controller when the source of electrical power is disconnected by the switch.

6. The apparatus of claim 5, in which the USB PD controller is configured to: determine an amount of energy available in the auxiliary power source; and in response to determining the amount of energy is low, control the switch to allow the flow of electrical current from the source of electrical power to replenish the energy available in the auxiliary power source.

7. The apparatus of claim 5, in which the USB PD controller is configured to: in response to the flow of electrical current being suppressed, monitor an amount of energy available in the auxiliary power source; and

control the switch to allow the flow of electrical current from the source of electrical power so as to replenish the energy available in response to it falling below a threshold.

8. The apparatus of claim 1, further comprising a switch controller communicatively coupled to the USB PD controller and configured to provide a drive signal to control switching behavior of the switch.

9. The apparatus of claim 1, in which the USB PD controller detects presence of the USB PD-capable power-consumer device by communicating with the USB PD-capable power-consumer device through a USB data bus.

10. A method, performed by a Universal Serial Bus (USB) Power Delivery (PD) apparatus having a USB port including electrical conductors for USB serial data communications and power delivery, the method comprising:

establishing, from a source of electrical power, a regulated supply of electrical power for delivery to an electrical load of a USB PD-capable power-consumer device when the USB PD-capable power-consumer device is communicatively coupled to the USB port and is configured as a sink of the electrical power;

receiving electrical signals, communicated through the electrical conductors of the USB port, indicating presence of the electrical load of the USB PD-capable power-consumer device so as to determine whether the USB PD-capable power-consumer device is sinking the electrical power from the USB PD power adapter;

determining, based on the received electrical signals, that the USB PD-capable power-consumer device is not sinking the electrical power from the USB PD power adapter; and

controlling a switch device to suppress flow of electrical current from the source of electrical power in response to determining that the USB PD-capable power-consumer device is not sinking the electrical power.

11. The method of claim 10, further comprising:

receiving alternating current (AC) mains power as the source of electrical power; and

providing to a transistor a gate drive signal causing the transistor to suppress flow of electrical current from the AC mains power in response to determining that the USB PD-capable power-consumer device is not sinking the electrical power.

12. The method of claim 10, further comprising:

establishing a rectified signal from alternating current (AC) mains power in response to the AC mains power being provided as the source of electrical power; and

providing a switch signal to a transistor to disconnect the rectified signal.

13. The method of claim 10, further comprising:

establishing a filtered rectified signal by filtering high-frequency components of a rectified signal; and

providing a switch signal to a transistor to disconnect the filtered rectified signal.

14. The method of claim 10, further comprising providing power from an auxiliary power source to a USB PD controller of the USB PD apparatus when the auxiliary power source is disconnected from the source of electrical power by the controlling of the switch device.

15. The method of claim 10, further comprising providing power from an auxiliary power source to a USB PD controller of the USB PD apparatus when the source of electrical power is disconnected by the controlling of the switch device.

16. The method of claim 15, further comprising:

determining an amount of energy available in the auxiliary power source; and
in response to determining the amount of energy is low, controlling the switch device to allow the flow of electrical current from the source of electrical power to replenish the energy available in the auxiliary power source.

17. The method of claim 15, further comprising:

in response to the flow of electrical current being suppressed, monitoring an amount of energy available in the auxiliary power source; and

controlling the switch device to allow the flow of electrical current from the source of electrical power so as to replenish the energy available in response to it falling below a threshold.

18. The method of claim 10, further comprising detecting presence of the USB PD-capable power-consumer device by communicating with the USB PD-capable power-consumer device through a USB data bus.

19. The method of claim 10, further comprising determining whether the USB PD-capable power-consumer device is operating as a sink by communicating with the USB PD-capable power-consumer device through a USB data bus.

20. A Universal Serial Bus (USB) Power Delivery (PD) controller comprising circuitry configured to:

receive a first signal indicating whether a USB device is attached to a USB port controlled by the USB PD controller;

receive a second signal indicating whether the USB device is requesting electrical power from a source of electrical power conveyed through a power path that is controlled by the USB PD controller; and

in response to the first signal indicating that the USB device is detached or the second signal indicating the USB device is not requesting power, provide a control signal to control a switch that disconnects the source of electrical power from the power path.

21. The USB PD controller of claim 20, further comprising circuitry to:

receive a third signal indicating an amount of energy stored in an auxiliary power source that provides power to the USB PD controller when the source of electrical power is disconnected from the power path; and

in response to the third signal indicating that the amount of energy is below a desired threshold, control the switch to connect the source of electrical power to the power path.

22. The USB PD controller of claim 20, in which the first signal comprises a message communicated over a USB communications bus.

23. The USB PD controller of claim 20, in which the second signal comprises a message communicated over a USB communications bus.

24. The USB PD controller of claim 20, in which the second signal indicates that the USB device is in an idle state.

25. The USB PD controller of claim 20, further comprising circuitry to provide the control signal to activate a transistor that allows current to flow along the power path.

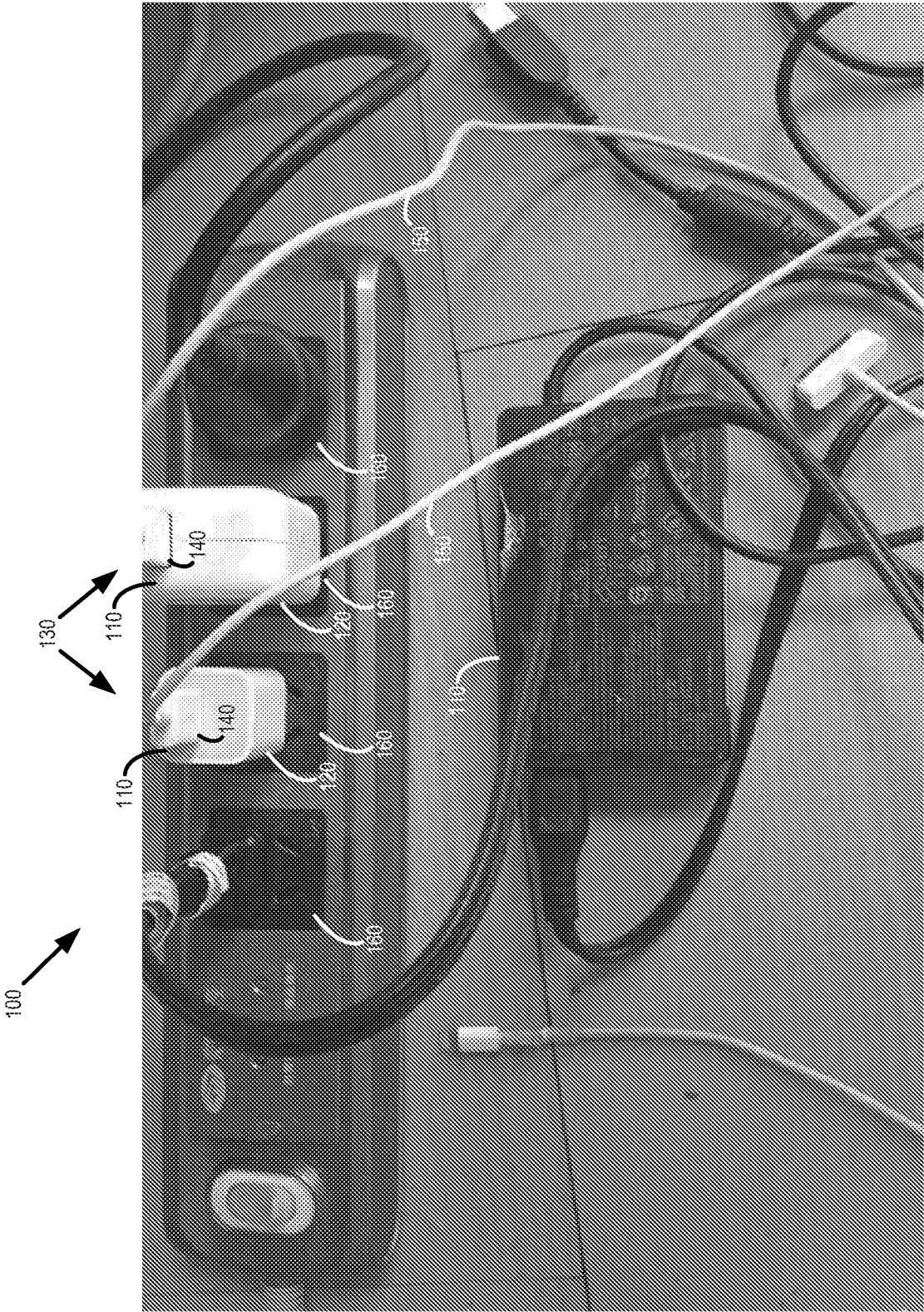


FIG. 1
(Prior Art)

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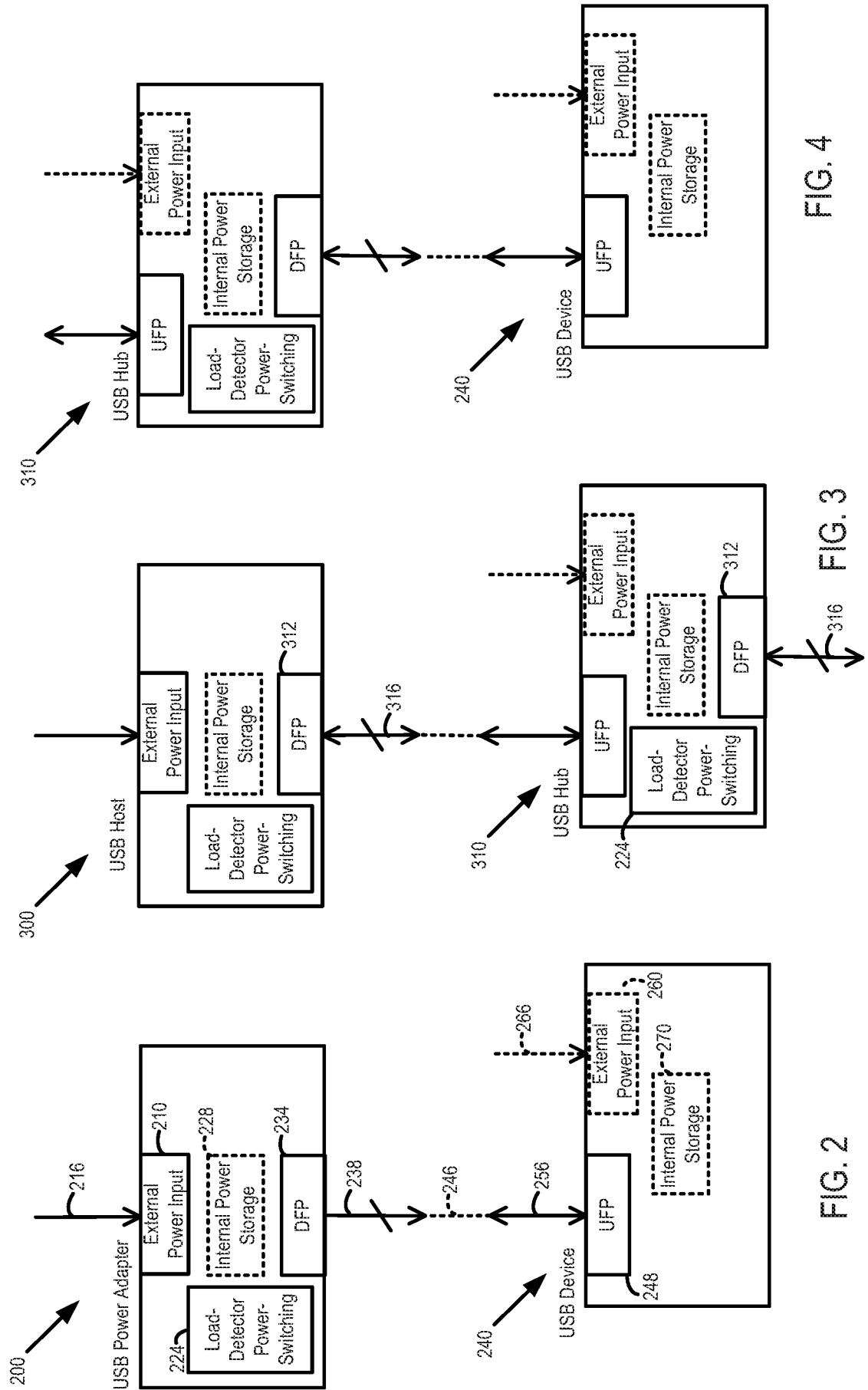


FIG. 4

FIG. 3

FIG. 2

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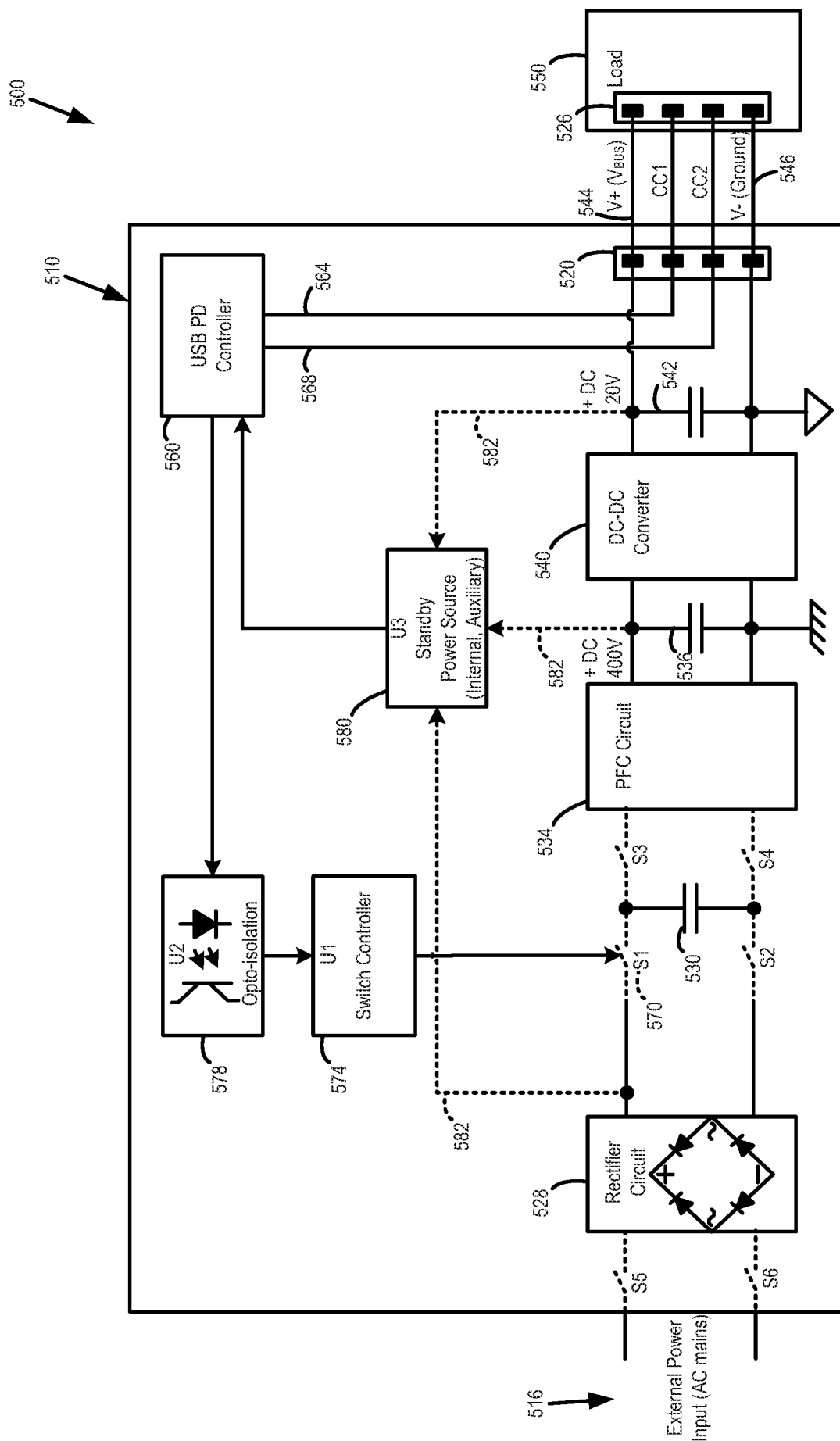
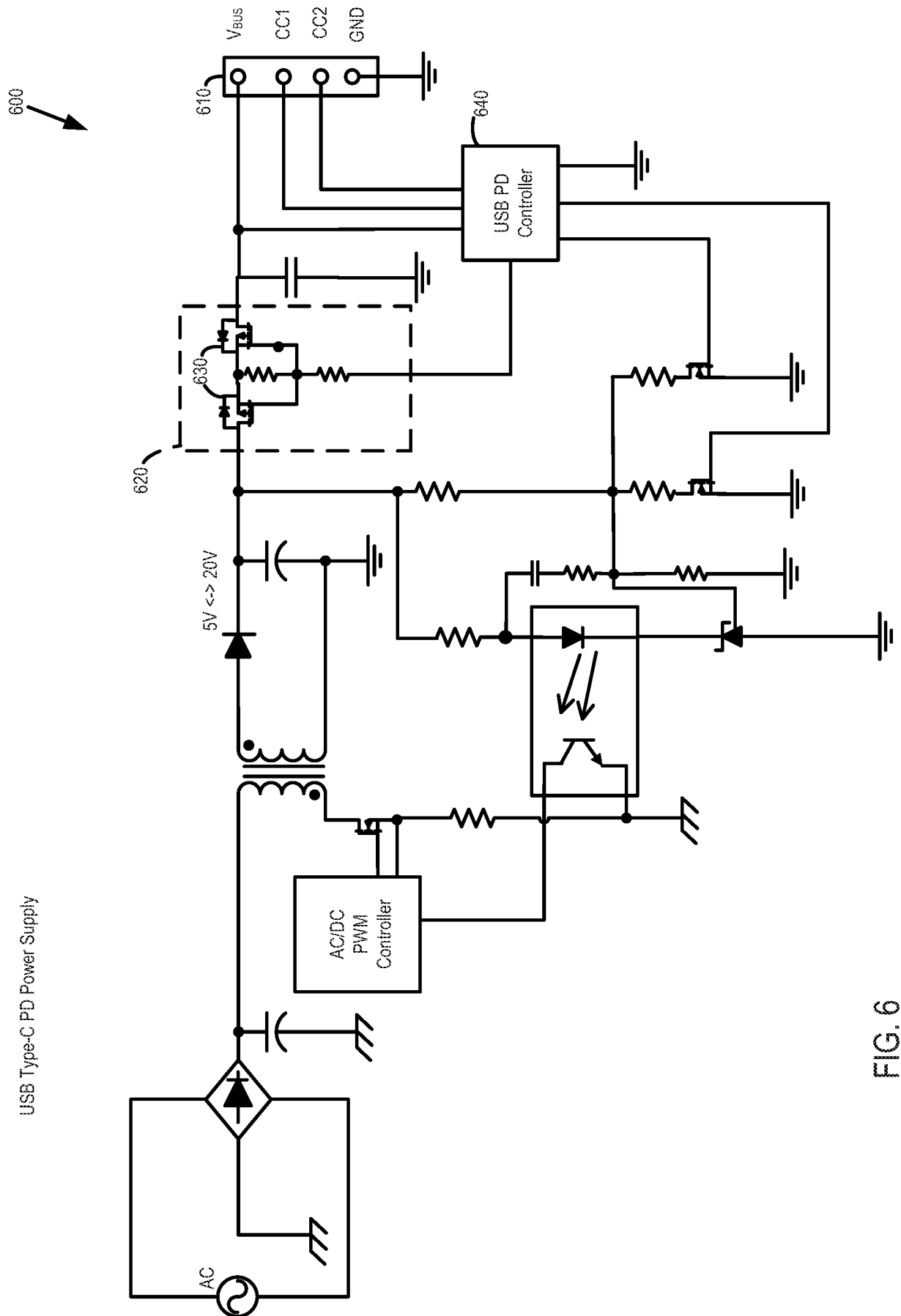
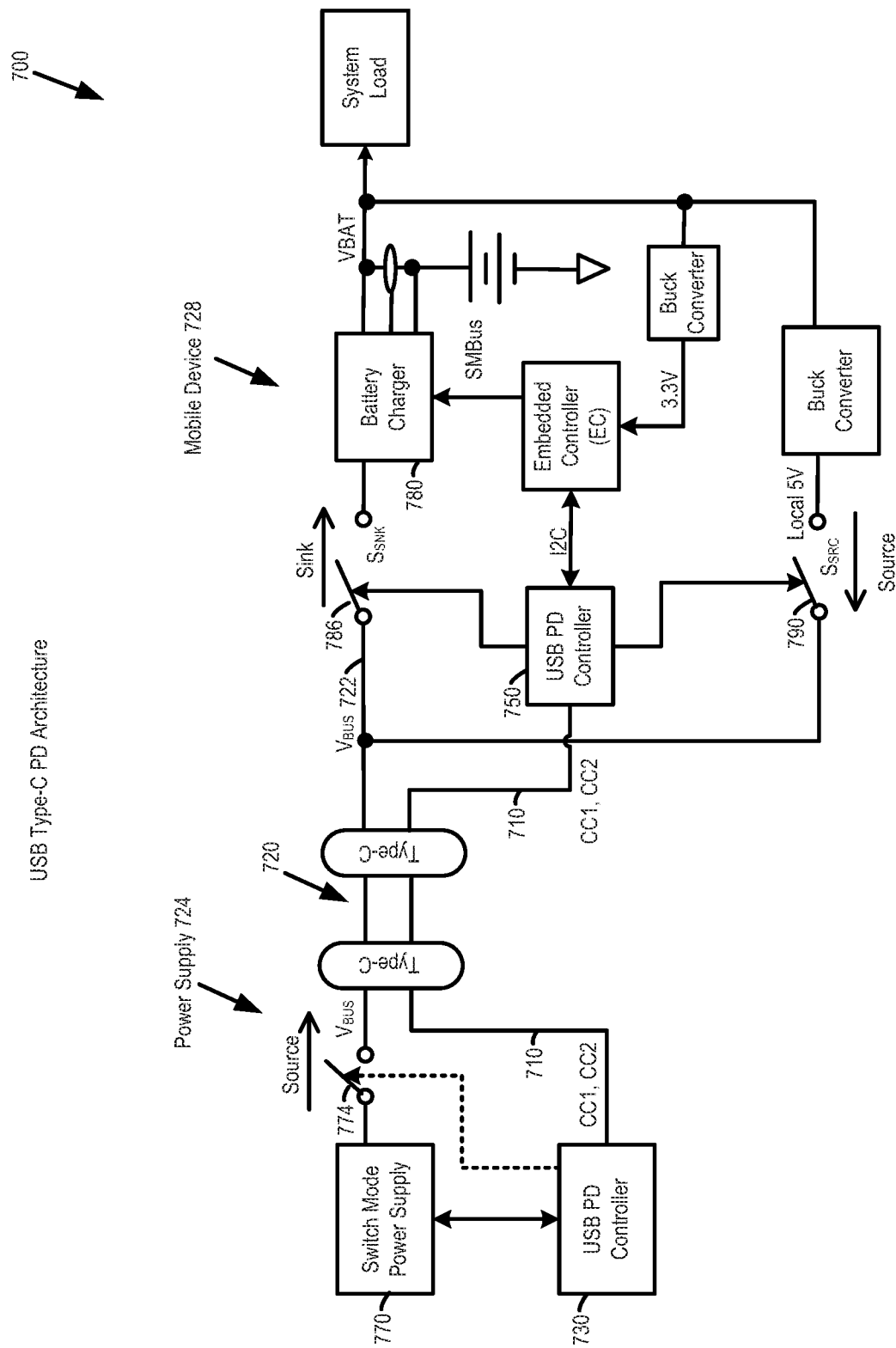
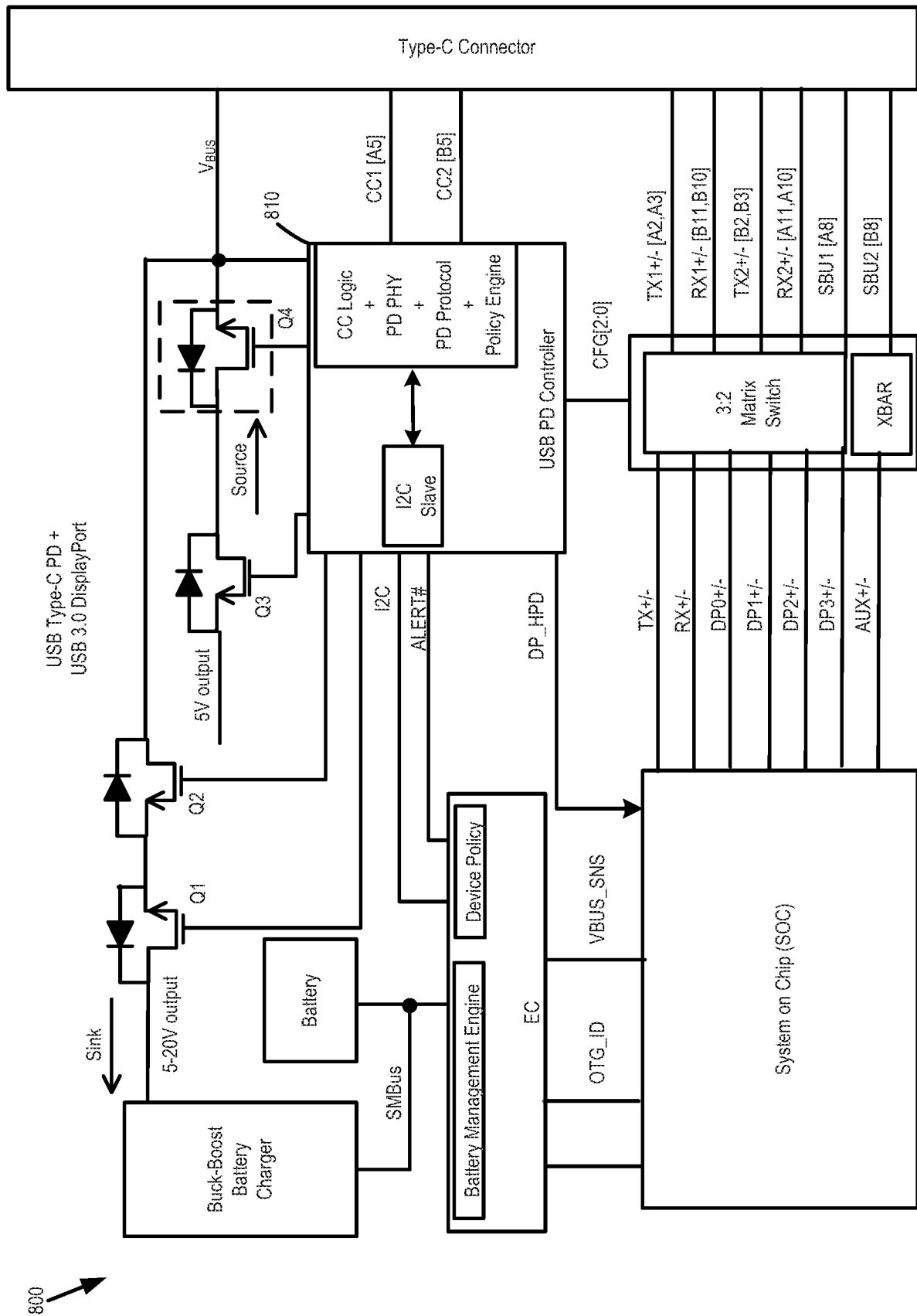


FIG. 5

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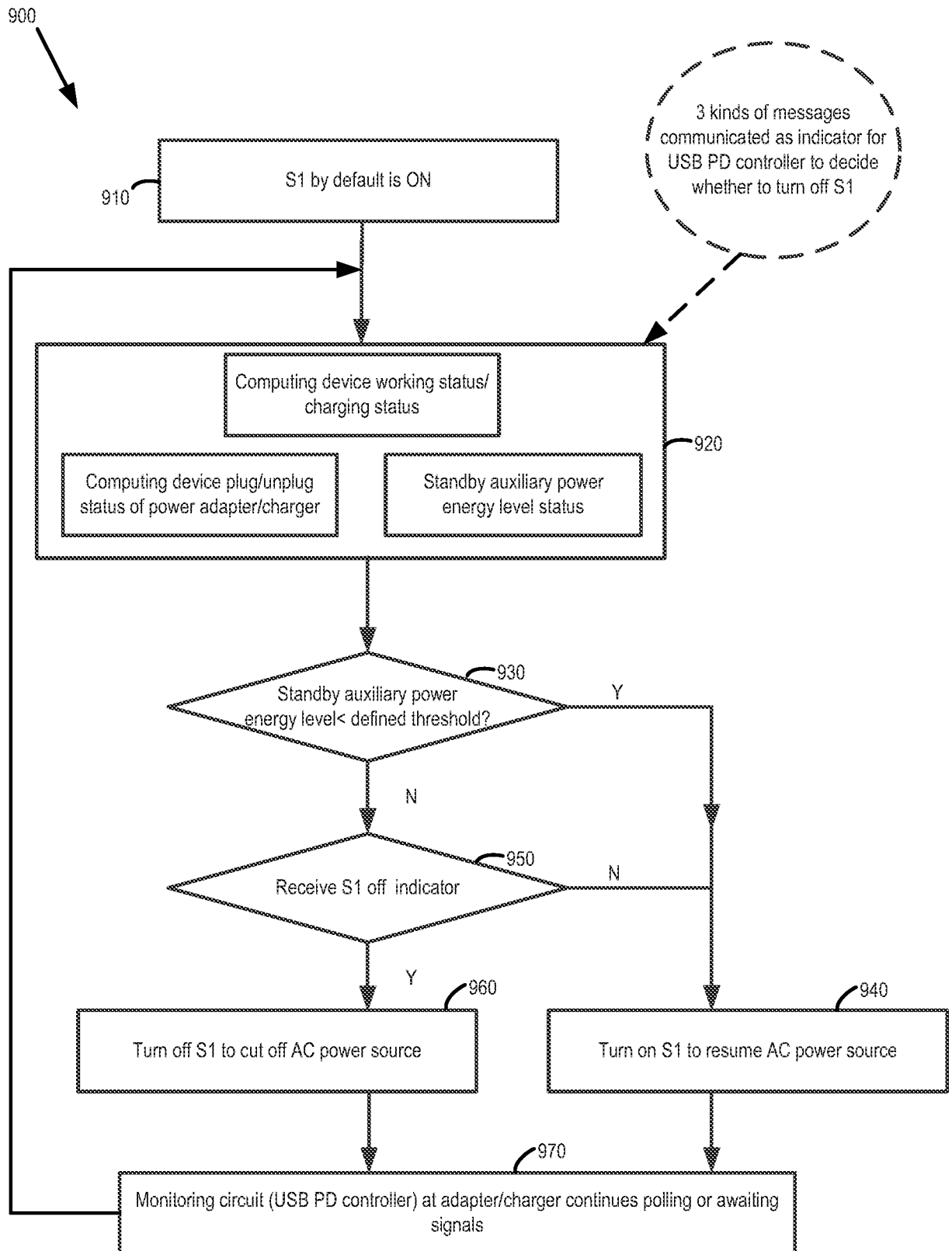


FIG. 9

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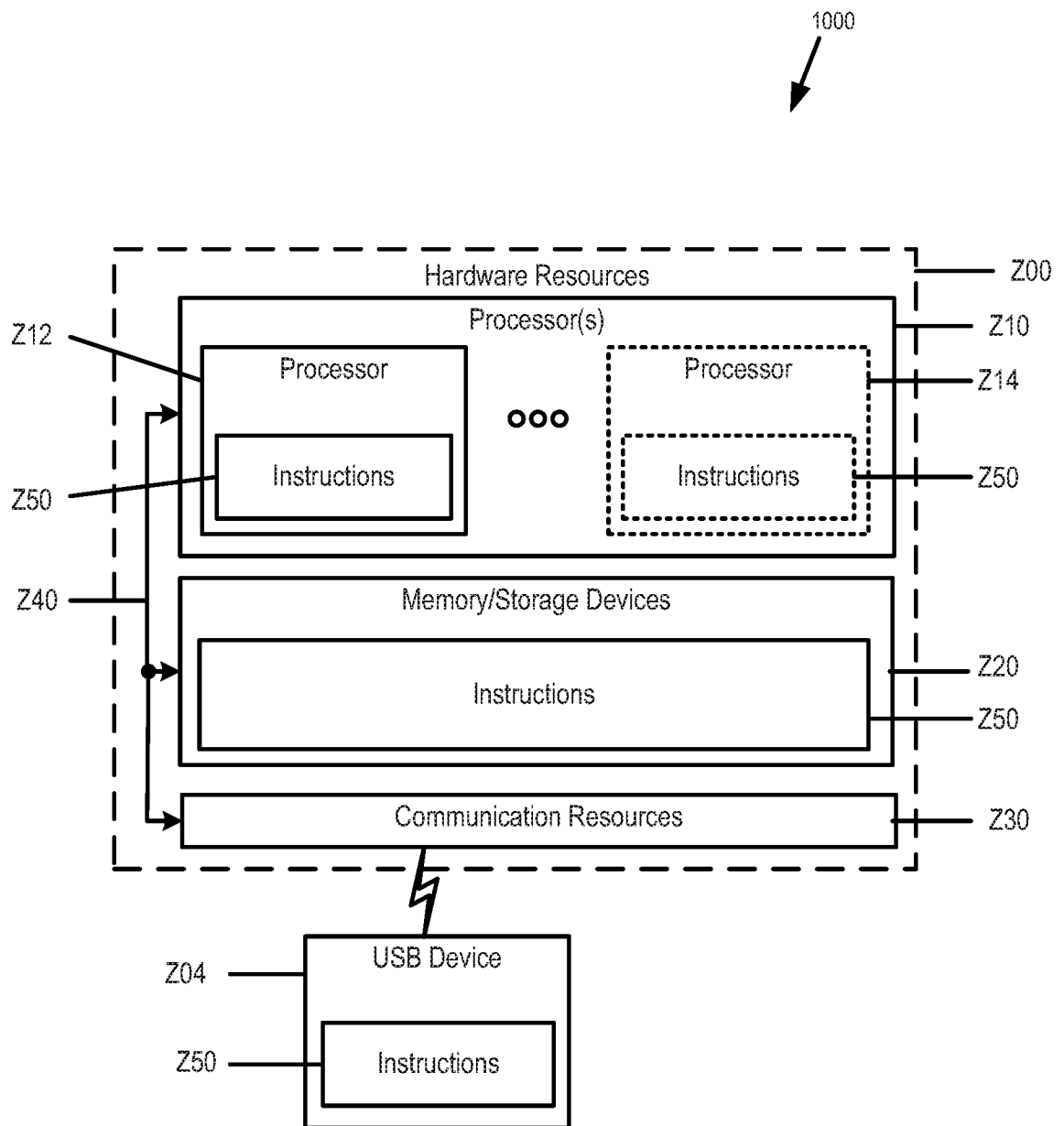


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2016/078254**A. CLASSIFICATION OF SUBJECT MATTER**

G06F 1/32(2006.01)i

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)

G06F; H02J

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)

CNPAT,WPI,EPODOC,CNKI:USB, universal, serial, bus, idle, sleep, low, power, switch, transistor, mos, fet, mosfet, relay, presence, connect

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011191616 A1 (ACTION STAR ENTPR CO LTD) 04 August 2011 (2011-08-04) description, paragraphs [0020]-[0024], [0029]-[0031] and figures 3 and 7	1-25
Y	US 2013207455 A1 (COOPER TECHNOLOGIES CO) 15 August 2013 (2013-08-15) description, paragraphs [0037]-[0052] and figure 1	1-25
A	CN 103973101 A (ZHONGSHAN DIANYING SCI & TECHNOLOGY CO) 06 August 2014 (2014-08-06) the whole document	1-25
A	CN 204304532 U (CHINA GREAT WALL COMPUTER SHENZHEN CO LT) 29 April 2015 (2015-04-29) the whole document	1-25

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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“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

20 December 2016

Date of mailing of the international search report

06 January 2017

Name and mailing address of the ISA/CN

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Telephone No. (86-10)62411797

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2016/078254

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				JP	2015502129	A	19 January 2015
				EP	2602906	A2	12 June 2013
				CN	104115360	A	22 October 2014
				KR	20140097177	A	06 August 2014
				WO	2013070595	A2	16 May 2013
				WO	2013070595	A3	10 October 2013
				IN	201403330	P4	03 July 2015
CN	103973101	A	06 August 2014	CN	103973101	B	20 April 2016
CN	204304532	U	29 April 2015	None			