POWER SOURCE VOLTAGE CONTROL FOR WIRELESS CHARGING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This Patent Application claims benefit of priority to India Provisional Patent Application No. 202411058363, filed August 1, 2024, and India Provisional Patent Application No. 202411022135, filed March 22, 2024, the contents of which are incorporated by reference herein.

TECHNICAL FIELD

[0002] This disclosure relates generally to wireless power and some aspects relate to power source control in a wireless power system.

DESCRIPTION OF RELATED TECHNOLOGY

[0003] A wireless power system includes a Power Transmitter (PTx) and a Power Receiver (PRx). Inductive coupling can enable wireless power transfer between a primary coil of the Power Transmitter and a secondary coil of the Power Receiver. The primary coil of the Power Transmitter produces an electromagnetic field during a power state of the wireless power system. The electromagnetic field induces a voltage in the secondary coil of the Power Receiver when the secondary coil is present in the electromagnetic field. Thus, the Power Transmitter can wirelessly transfer power to the Power Receiver using inductive coupling between the primary coil and the secondary coil. The Power Receiver can provide the received power to operate a load. Example loads might include a motor, a heating element, electronics, or a power storage device, among other examples.

[0004] Wireless power technologies continue to evolve as manufacturers and consumers develop new capabilities. Consumers continue to adopt wireless power technology for new applications and deployment scenarios. For example, some advances in wireless power technology enable a wireless power system to increase the amount of power that can be transferred from a Power Transmitter to a Power Receiver.

BRIEF SUMMARY

[0005] The systems, methods, and apparatuses of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0006] One innovative aspect of the subject matter described in this disclosure can be implemented as a method of a Power Transmitter. The method includes the Power Transmitter

receiving power from an external power supply. The method includes the Power Transmitter performing a power negotiation with a Power Receiver. The method includes the Power Transmitter coordinating with the external power supply to adjust a power supply voltage of the power from the external power supply based, at least in part, on the power negotiation.

[0007] Another innovative aspect of the subject matter described in this disclosure can be implemented as a method of a Power Transmitter. The method includes the Power Transmitter receiving a power request from a Power Receiver. The method includes the Power Transmitter coordinating with an external power supply to adjust power from the external power supply to the Power Transmitter based, at least in part, on the power request.

[0008] Another innovative aspect of the subject matter described in this disclosure can be implemented as a Power Transmitter having a power transfer coil, an inverter, and a controller configured to implement any one of the above-referenced methods.

[0009] Details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0010] Like reference numbers and designations in the various drawings indicate like elements. Note that the relative dimensions of the figures may not be drawn to scale.

[0011] **FIG. 1** is a block diagram of an example wireless power system.

[0012] **FIG. 2A** is a simplified block diagram of an example wireless power system.

[0013] **FIG. 2B** is another simplified block diagram of an example wireless power system.

[0014] **FIG. 2C** is another simplified block diagram of an example wireless power system in which a Power Receiver supports multiple types of battery chargers.

[0015] **FIG. 3A** shows an example plot of voltage and current in a wireless power system that supports up to 15W power charging.

[0016] **FIG. 3B** shows an example plot of power versus voltage in a wireless power system that supports up to 25W power charging.

[0017] **FIG. 4** shows a first example protocol for voltage and power modification.

[0018] **FIG. 5A** shows additional options for the first example protocol of FIG. 4.

[0019] **FIG. 5B** shows further options in which a power renegotiation can occur after an initial instance of the first example protocol of FIG. 4.

[0020] **FIG. 6A** shows a second example protocol for voltage and power modification, continued in FIG. 6B.

[0021] **FIG. 6B** shows the continuation of the second example protocol from FIG. 6A.

[0022] **FIG. 7A** shows the second example protocol for voltage and power modification, continued to FIG. 7B, in which the power supply has insufficient power reserve to satisfy a power increase requested by the Power Transmitter.

[0023] **FIG. 7B** shows the continuation of the second example protocol from FIG. 6A.

[0024] **FIG. 8** shows several PRx architectures for use in a wireless power system.

[0025] **FIG. 9** illustrates several power delivery profiles including universal serial bus (USB) power delivery (PD), USB PD standard power range (SPR), and USB PD extended power range (EPR).

[0026] **FIG. 10** shows an example procedure for establishing an explicit contract in USB PD.

[0027] **FIG. 11** shows an example Power Transmitter in accordance with aspects of this disclosure.

[0028] **FIG. 12** shows graphs of example Power Transmitter voltage transitions.

[0029] **FIG. 13A** shows another example protocol for voltage and power modification.

[0030] **FIG. 13B** shows the continuation of the example protocol from FIG. 13A.

[0031] **FIG. 14** illustrates a block diagram of an example apparatus for use in a wireless power system.

DETAILED DESCRIPTION

[0032] The following description is directed to certain implementations for the purpose of describing innovative aspects of this disclosure. However, a person having ordinary skill in the art will readily recognize that the teachings herein can be applied in a multitude of different ways. The described implementations can be implemented in any means, apparatus, system, or method for transmitting or receiving wireless power.

[0033] As described previously, a wireless power system includes a Power Transmitter (PTx) and a Power Receiver (PRx). A Power Transmitter also may be referred to as a wireless power transmission apparatus. A Power Receiver also may be referred to as a wireless power reception apparatus. A Power Receiver includes a secondary coil configured to wirelessly receive power via inductive coupling with a primary coil of the Power Transmitter. A wireless power standard can support different power levels (such as 5 Watts (5W), 15W, 25W, etc.) using different operating parameters. For example, a first wireless power mode (referred to

as baseline power profile (BPP) mode) can support up to 5W wireless power transfer using an operating frequency in the range of 110 kilohertz (kHz) to 205 kHz (typically BPP mode in a MPP transmitter is operated at 128 kHz). A second wireless power transfer mode (referred to as magnetic power profile (MPP) mode) can operate at higher frequencies (such as 360 kHz) and can support higher power levels (such as 15W). For example, an MPP mode can be used when a Power Receiver and a Power Transmitter both have magnets that can improve the alignment and coupling of the two devices. MPP mode currently supports up to 15W and may continue to increase as the MPP mode is further developed. It is desirable to support 25W or higher using MPP mode.

[0034] A Power Transmitter can include a direct current (DC)-DC converter, an inverter (to converter DC to AC) and other components. A power source supplies power to the inverter of the Power Transmitter. The power source (sometimes also referred to as a power supply) can include a power adapter. The terms power source, power adapter, and power supply might be used interchangeably in the examples of this disclosure. In some implementations, the power adapter is external from the Power Transceiver. For example, the power adapter can be electrically coupled to the Power Transmitter using a universal serial bus (USB) cable. As an example, a USB Type C (also referred to as "USB-C") can support different power delivery from an external power adapter to the Power transmitter. There exists a need for a Power Transmitter to coordinate with a power adapter to control the voltage and power delivered via an electrical connection (such as a USB-C cable). Some Power Transmitters are configured to supply power to wearables in the less than 5 watts (W) range. Those same Power Transmitters might also supply power to higher Power Receivers (such as 15W, 15W, 50W, etc.). Single supply voltage of transmitter to cater to high and low Power Receiver can result in high currents when operating at higher powers and hence high losses, higher electromagnetic interference (EMI) and lower efficiency. Hence the Power Transmitter needs to readjust its voltage based on the power request coming from the Power Receiver. This document discloses example protocols for the Power Transmitter and the Power Receiver to adjust the voltage levels based on the power transfer requirements and the voltage/current control at the power adapter. Some existing systems enable the variation of supply voltage. Furthermore, power transfer and interoperability protocols exist individually for PTx-PRx pair and supply power-Load pair. However, existing protocols fail so describe coordination among multiple components that include the power supply (e.g., power adapter), the PTx and the PRx based on a variety of power levels.

[0035] This disclosure provides systems, methods and apparatuses for power control in a wireless power apparatus. In some aspects, the disclosed techniques enable standardization

of the supply voltage by a Power Transmitter based on a power request received from a Power Receiver. Some techniques include communication between a Power Transmitter and the power supply to adjust the value of the voltage based on the power request received during negotiation. The power supply voltage adjustment can be based on the power request received by the transmitter. A Power Transmitter can communicate a request for a voltage re-adjustment based on the transmitted/received power during power transfer.

[0036] According to aspects of this disclosure, a PTx can communicate a request for a new voltage and current level to the power adapter after receiving the control error packet from the PRx after both have agreed on the new power level. Based on the voltage error packet that has come from the PRx side, the PTx can analytically decide the one or more parameters (such as input voltage (Vin), phase shift, and/or duty ratio) for the PTx inverter before the power adapter shifts to the next voltage output setting as part of a transition to a higher power level, or vice-versa. During a transition to the higher power level, after receiving the first control error packet, if the power adapter refuses to provide a higher voltage or current setting as promised before, the PTx can perform a renegotiation with the PRx to go to a power level according to the reserve available in the power adapter.

[0037] Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. A wireless power apparatus can support higher power transfer levels (such as 25W, 50W, or higher) using a common design for power supply (such as power delivery via a USB-C cable). The disclosed techniques can enable better efficiency across different manufacturers by supporting interoperability and standardization of power control protocols.

[0038] **FIG. 1** is a block diagram of an example wireless power system 100. The example wireless power system 100 includes a Power Transmitter 110 (PTx) and a Power Receiver 130 (PRx). The Power Transmitter 110 includes a power transfer coil 116 (sometimes referred to as a primary coil) and a PTx controller 120. The power transfer coil 116 may be associated with a Power Transmitter circuit 114 (sometimes also referred to as a power signal generator, or a driver circuit, or a driver). The power transfer coil 116 may be a wire coil which transmits wireless power (which also may be referred to as wireless energy). The power transfer coil 116 may transmit wireless energy using an inductive or a resonant magnetic field. The Power Transmitter circuit 114 may include components (not shown) to prepare the wireless power. For example, the Power Transmitter circuit 114 may include one or more switches, drivers, series capacitors, rectifiers, inverters, or other components. In some implementations, the Power Transmitter circuit 114 includes an inverter and a PTx resonant tank circuit (which can be referred to as a "tank circuit" for brevity). The PTx controller 120

may be implemented as a microcontroller, dedicated processor, integrated circuit, application specific integrated circuit (ASIC) or any other suitable electronic device.

[0039] A power supply 112 provides power to the power transmitter unit 118. In some implementations, the power supply 112 may convert alternating current (AC) power to direct current (DC) power. For example, the power supply 112 may include a converter that receives an AC power from an external power supply and converts the AC power to a DC power used by the Power Transmitter circuit 114. Alternatively, or additionally, a component (such as an inverter) of the Power Transmitter circuit 114 may convert the DC power to the AC power. The power supply 112 may be integrated as part of the Power Transmitter 110 or may be external to the Power Transmitter 110. In some implementations, the Power Transmitter 110 causes the power supply 112 to regulate the DC output voltage of the power supply 112. For example, the PTx controller 120 can set DC voltage of the power supply 112 based on information (such as a value indicating a requested power) received from the Power Receiver 130. The Power Transmitter 110 can receive power configuration information from the Power Receiver 130 and use the information to set a parameter (such as the DC output voltage of the power supply 112). In some implementations, the Power Transmitter 110 includes a DC-DC converter (not shown) between the power supply 112 and the Power Transmitter circuit 114 to control the variable DC output voltage.

[0040] The PTx controller 120 is connected to a communication interface 122. The communication interface 122 is connected to a first communication coil 124. In some implementations, the communication interface 122 and the first communication coil 124 may be collectively referred to as a first communication unit. In some implementations, the first communication unit may support short-range radio frequency communication, such as Near-Field Communication (NFC) or Bluetooth (BT). NFC is a technology by which data transfer occurs on a carrier frequency of 13.56 Megahertz (MHz). The first communication unit also may support any suitable communication protocol. The first communication unit may contain modulation and demodulation circuits to wirelessly communicate via the first communication coil 124. Alternatively, or additionally, the PTx controller 120 may use frequency, amplitude, current, or voltage modulation of a wireless power signal to communicate via an in-band communication link (not shown) that includes the power transfer coil 116.

[0041] In the example of FIG. 1, an example apparatus 160 includes a Power Receiver 130 and other components, such as a converter 142, an energy storage unit (e.g., battery 144), a load 162, a load controller 164, and/or a user interface 166. The Power Receiver 130 includes a power transfer coil 132 (sometimes referred to as a "secondary coil" to distinguish from the primary coil of a Power Transmitter), a PRx tank circuit 136 (or "tank circuit"), a bridge

circuit 140, a PRx controller 146, and a communication interface 148. The converter 142 can operate as a buck or boost converter to alter the voltage of electricity being supplied to the battery 144 (when the Power Receiver 130 is being operated in a power reception mode) or being drawn from the battery 144 (when the Power Receiver 130 is being operated in a power transmission mode). Examples of a battery 144 include an energy storage unit, a battery pack, a capacitance, or any type of device capable of storing energy. For brevity, the terms "energy storage unit" and "battery" can be used interchangeably in this disclosure.

[0042] In some implementations, the apparatus 160 also includes a load controller 164 and a user interface 166 (such as a button, switch, touchpad, indicator, touch screen, or wireless local area network interface). The bridge circuit 140 can be a rectifier. In some implementations, the bridge circuit 140 is capable of operating as a rectifier or an inverter, as shown in FIG. 12 and may be implemented as an active bridge. The PRx tank circuit 136 can include a capacitor or other components to enable the second power transfer coil 132 to receive the wireless power 168 during the power state. Although not shown, a small capacitor can be used before the bridge circuit 140 and a load capacitance can be used after the bridge circuit 140 to match impedance and to filter a high frequency component of the rectifier voltage. In accordance with aspects of this disclosure, the PRx tank circuit 136 includes a capacitance component that can alter the capacitance of the PRx tank circuit 136 depending on different power levels, power transmission or reception modes, or power profile, among other examples.

[0043] Although shown as different components, some components may be packaged or implemented in the same hardware. For example, in some implementations, the PRx controller 146 and the load controller 164 may be implemented as a single controller. The PRx controller 146, the load controller 164, the communication interface 148, or any combination thereof, may be implemented as a microcontroller, dedicated processor, integrated circuit, application specific integrated circuit (ASIC) or any other suitable electronic device. The communication interface 148 and the second communication coil 150 can be collectively referred to as a second communication unit. The second communication unit might also include a power harvester (not shown) that can harvest energy from the communication signals and provide harvested bias power to the PRx controller 146 or the load controller 164.

[0044] The PTx controller 120 may detect the presence or proximity of a Power Receiver 130. This detection may happen during a periodic pinging process of the communication interface 122. During the pinging process, the communication interface 122 supplies power to the communication interface 148 via communication signals 170 when the Power Receiver

130 is in proximity to the Power Transmitter 110. The communication interface 148 can send a reply signal back to the communication interface 122 to confirm that it is a Power Receiver. Prior to power transfer, a handshaking process may take place during which the PTx controller 120 may receive identification and configuration data, among other information, from the Power Receiver 130. The PTx controller 120 may control characteristics of wireless power it provides to the Power Receiver 130 based on the configuration data.

[0045] A PRx controller 146 may be operationally coupled to the bridge circuit 140 and the communication interface 148. The communication interface 148 may contain modulation and demodulation circuits to wirelessly communicate via the second communication coil 150. Thus, the PRx controller 146 may wirelessly communicate feedback information to the PTx controller 120 via the communication interface 148 to the communication interface 122 using short-range radio frequency communication, such as NFC. Alternatively, or additionally, the PRx controller 146 may use load modulation to communicate via an in-band communication link (not shown) that includes the power transfer coil 132.

[0046] A load controller 164 may be operationally coupled to the load 162 and the PRx controller 146 (or to the communication interface 148, coupling not shown in Fig. 2). The load controller 164 may detect changes to load states. The load controller 164 also may determine a load voltage reference and/or a power requirement of the load. The load controller 164 also may send load voltage references, load current, load power requirement and any other suitable information to the PRx controller 146 or the communication interface 148 for communication to the Power Transmitter 110. During a power state, the PRx controller 146 may additionally determine and provide one or more feedback information indicating a measured load voltage, load current, load power requirement, and power available to the load 162. In some feedback messages, the feedback information may include a reference voltage indicating a required voltage for the load 162. In some feedback messages, the feedback information may indicate an error in the output voltage of the load 162. In some feedback messages, the feedback information may include the required power for the load. Although the PRx controller 146 and load controller 164 are shown separately, they may be included in the same component of the Power Receiver 130.

[0047] Some appliances are equipped with safety features, such as a disconnect switch 134, that are operated in conjunction with the operating states. For example, the disconnect switch 134 might be maintained in an open position to prevent the flow of current to the load 162 when the Power Receiver 130 is in a pre-power state (such as a standby state, a discovery state, or and a connected state). In some implementations, the disconnect switch 134 is positioned between the power transfer coil 132 and the PRx tank circuit 136 (as shown in

FIG. 1). Alternatively, or additionally, the disconnect switch (sometimes referred to as a load disconnect switch) can be positioned at the battery 144 or the load 162. Before transitioning to the power state, the PRx controller 146 might cause the disconnect switch 134 to move to a closed position to enable the flow of current to the load 162. In an emergency condition (such as excessive voltage or current), the PRx controller 146 might open the disconnect switch 134 to prevent damage to the load 162 or other components of the Power Receiver 130 or the apparatus 160. After the disconnect switch 134 is closed, the PRx controller 146 can communicate a message to the PTx controller 120 to cause the wireless power system to transition to the power state. Alternatively, or additionally, the PRx controller 146 can communicate a power request to begin the transmission of the wireless power 168.

[0048] As further described with reference to FIG. 8, there are different types of the Power Receiver 130 and battery charger 174, which can be referred to as a PRx architecture. In some implementations, the Power Receiver 130 and/or the converter 142 may include a buck converter before the rectified output current of the Power Receiver 130 reaches the battery 144. In some implementations, the Power Receiver 130 and/or the converter 142 may include a switched capacitor converter (SWC) instead of the buck converter. Similarly, an implementation may include another switching process enabling at least two options to alter the current signal before reaching the battery 144. In this case, the SWC converter may be considered the high power path and the buck converter may be considered the low power path.

[0049] **FIG. 2A** is a simplified block diagram 200a of an example wireless power system. The power supply 112 includes a power adapter that supplies power to the inverter 278 of the Power Transmitter 110. The voltage to the inverter 278 is referred to as an input voltage (Vin). In some implementations, the Power Transmitter 110 also includes a DC/DC converter 276 (such as a boost converter or voltage regulator) to adjust the voltage level of the input voltage Vin. In accordance with aspects of this disclosure, the Power Transmitter 110 can coordinate with the power supply 112 to adjust the power supply voltage 280 that power supply 112 (e.g., the power adapter) provides to the Power Transmitter 110.

[0050] The Power Receiver 130 includes a rectifier (as described with reference to FIG. 1). The battery charger 174 can receive power from the Power Receiver 130 and manage charging to the battery. The battery charger 174 can communicate to the Power Receiver 130 (e.g., to a PRx controller) to include the charging level, power required, or other parameters. Based on information from the battery charger 174, the Power Receiver 130 can communicate a request to the Power Transmitter 110 to increase or decrease the wireless power. In addition to minor changes in voltage or power level, the Power Receiver 130 can also request a different power profile (such as changing from a 5W power level to a 15W or 25W power

level). In turn, the Power Transmitter 110 can coordinate with the power supply 112 to adjust the amount of power delivered from the power supply 112 to the Power Transmitter 110 to satisfy the PRx-requested power.

[0051] **FIG. 2B** is another simplified block diagram 200b of an example wireless power system. The example wireless power system includes the power supply 112, the Power Transmitter 110, the Power Receiver 130, and the battery charger 174. The Power Receiver 130 provides power to the battery charger 174 via an electrical connection 204. Meanwhile, the battery charger 174 can communicate (shown as communication 208) information to the Power Receiver 130 regarding charging state. the Power Receiver 130 can communicate (not shown) to the Power Transmitter 110 (such as via the communication signals 170 described with reference to FIG. 1). The Power Transmitter 110 receives power from the power supply 112 via an electrical connection 202. Furthermore, the Power Transmitter 110 can communicate (shown as communication 206) with the power supply 112. In some implementations, the electrical connection 202 and communication 206 can be conducted via a USB-C cable, or similar cable, which includes multiple conductors.

[0052] **FIG. 2C** is another simplified block diagram 200c of an example wireless power system in which a Power Receiver supports multiple battery chargers. The simplified block diagram 200c includes all the features of simplified block diagram 200b and shows the ability of the Power Receiver 130 to connect to more than one battery charger (such as a first charger 274A and a second charger 274B). Each battery charger 274A and 274B may have a different electrical connection (such as electrical connections 204 and 205, respectively) to the Power Receiver 130. Similarly, each battery charger 274A and 274B may communicate (shown as communication 208 and communication 207, respectively) with the Power Receiver 130. The battery chargers 274A, 274B can be connected in parallel to charge a single battery (not shown).

[0053] **FIG. 3A** shows an example plot 300a of voltage and current in a wireless power system that supports up to 15W power charging. In the example plot 300a, for wireless power transfer up to about 15W, the voltage (Vrect) varies between 12-14 V and the current (Irect) can vary up to 1.07A.

[0054] **FIG. 3B** shows an example plot 300b of power and voltage in a wireless power system that supports up to 25W power charging. The example power levels in FIG. 3B shown an example voltage variation between 12.5V to 18V for 0 to 25W wireless power transfer. Note that USB power delivery (PD) can support various voltages, including 5V, 9V, 15V, 20V. Although not shown in FIG. 3B for brevity, some power levels can use less than 12.5V.

For example, in some implementations, a USB PD connection can use (i) 5V for power delivery up to 5W, (ii) 9V for power delivery between 5W and 12W, and (iii) 15V for power delivery greater than 12W. Extended power ranges of USB PD can support higher voltages, including up to 48 V. Several combinations of these voltage ranges, along with subsequent current ranges, may be organized in accordance with USB power delivery capabilities. These power delivery capabilities include USB Type-C, USB PD standard power range (SPR), and USB PD extended power range (EPR) as further shown in FIG. 9.

[0055] **FIG. 4** shows a first example protocol 400 for voltage and power modification between a Power Supply 112, Power Transmitter 110, Power Receiver 130, and battery charger 174. Upon initial connection, the Power Supply 112 can provide 5V DC and a power source capability 402 to the Power Transmitter 110. The power source capability 402 may include information such as the power ratings, maximum data rate ratings, and other information that could be useful. In some implementations, the Power Supply 112 can communicate its power source capability 402 in accordance with the USB Implementers Forum (USB-IF) standards such as USB PD 2.0 through USB PD 3.1 specifications. The Power Transmitter 110 can use DC-DC regulation (such as a boost converter) to increase the inverter input voltage (Vin) to 11-19V. This enables the Power Transmitter 110 to transmit wireless power 404, using BPP mode up to 5W, to Power Receiver 130. After receiving wireless power 404, Power Receiver 130 can provide a power 406 to the battery charger 174. In this example the power 406 delivered to the battery charger 174 is 5W. At block 408, the battery charger 174 can use the power 406 to deliver 5W to a battery (not shown) or other load.

[0056] In the example of FIG. 4, the Power Receiver 130 may desire to receive a greater amount of power, such as due to a power requirement of the battery charger 174, a charging state, or time-lapse charging schedule. In some embodiments, the Power Receiver 130 starts a low power level (such as 5W or 15W) and then requests for a higher power level (such as 15W or 25W). The Power Receiver 130 can send a wireless power negotiation request 410 to the Power Transmitter 110 to request a new power level. For example, the wireless power negotiation request 410 might inquire whether the Power Transmitter 110 can support the new power level or whether the Power Transmitter 110 can support an increased voltage/current level. After the Power Transmitter 110 receives the wireless power negotiation request 410, the Power Transmitter 110 can determine whether the requested power can be satisfied based on the power source capability 402 of the power supply 112. If the Power Transmitter 110 can support the requested power, the Power Transmitter 110 can send an ACK 412 to the

Power Receiver 130 indicating that the Power Transmitter 110 can deliver the requested power level.

[0057] Based on the Power Receiver 130 receives the ACK 412 from the Power Transmitter 110, the Power Receiver 130 sends a control error packet (XCE) 414 to the Power Transmitter 110 asking to increase the voltage, power, or current. In the example of FIG. 4, the XCE packet 414 requests the Power Transmitter 110 to transmit the wireless power signal to deliver sufficient wireless power transfer to enable the Power Receiver 130 to provide 14V at the output of the rectifier of the Power Receiver 130. The Power Transmitter 110 may send a power adapter request 416 to the power supply 112 to negotiate new power delivery settings. For example, the power adapter request 416 can indicate a new voltage and current level (such as 9V and 3A in the example of FIG. 4). The power supply 112 can acknowledge the request by sending an ACK 418. Either before, concurrently, or after sending the ACK 418, the power supply 112 modifies the voltage/current level being sent to the Power Transmitter 110 to satisfy the request 416. The request 416 and acknowledgment 418 can also be referred to as power negotiation for a power contract (sometimes referred to as an explicit contract) between the power supply 112 and the Power Transmitter 110. In some implementations, the power negotiation might borrow aspects of a USB power delivery (PD) protocol, such as described with reference to FIG. 10.

[0058] Based on an acknowledgement 418 and power modification from the power supply 112, the Power Transmitter 110 adjusts its inverter settings (block 420) for a voltage and phase shift control based on the control error packet (such as the XCE packet 414 or a subsequent control error packet). As a result of the change in inverter settings, the Power Transmitter 110 transmits a power signal 424 to satisfy 15W power transfer. In some implementations, the Power Receiver 130 may stop the power transfer, before going to the high or low power mode, to make power control adjustments for the power signal 424. In some implementations, before transmitting the power signal 424, the Power Transmitter 110 may communicate a message (not shown) to the Power Receiver 130 to inform the Power Receiver 130 about the change in voltage or power mode. The Power Receiver 130 receives the power signal 424 and delivers power 426 to the battery charger 174. At block 428, the battery charger 174 delivers 15W of power to the battery (not shown). In some implementations, the Power Receiver 130 may cause the battery charger 174 to turn during a transition to the high power (15W) before delivering the power 426 and then cause the battery charger 174 to turn on a regulated charger as part of block 428.

[0059] Although FIG. 4 provides one example implementation, modifications to the protocol are possible. For example, in some implementations, the Power Transmitter 110 and Power

Receiver 130 may not to enter an initial 5W power transfer state in the BPP mode (shown as wireless power 404 and power 406). Instead, after a pre-power state in the BPP mode (such as a 128 kHz ping state, not shown), the Power Transmitter 110 and the Power Receiver 130 may perform a pre-power negotiation before power transfer. The pre-power negotiation may negotiate a high power mode (such as a 25W). In some implementations, the pre-power negotiation may happen prior to any power transfer, such as after the Power Transmitter 110 receives the source capability 402. Based on the pre-power negotiation being for a high power mode, the Power Transmitter 110 and the Power Receiver 130 may enter the high power mode (such as MPP) without a prior 5W power transfer 404, 406. After the pre-power negotiation (in the BPP mode at 128 kHz), the Power Transmitter 110 may transition to the MPP mode (at 360 kHz as part of the MPP power transfer procedure. For example, in FIG. 4, the power transfer 404, 406 may be omitted. The wireless power negotiation request 410 may be initially performed using 128 kHz BPP protocol as a pre-power negotiation. During the pre-power negotiation, the Power Receiver 130 can initiate a wireless power negotiation request 410 that is associated with a low power mode (e.g., 5W or less), a medium power mode (e.g., 5W to 15W), or a high power mode (e.g., greater than 15W). In some implementations, Power Receiver 130 may request and receive information from the Power Transmitter 110 regarding the available modes or power source capabilities. If the wireless power negotiation request 410 indicates a request for a high power mode, after the ACK 412, the Power Transmitter 110 may change to the high power mode (such as MPP mode at 360 kHz).

[0060] **FIG. 5A** shows additional options 500 for the first example protocol of FIG. 4. All messages and processes described with reference to FIG. 4 are the same as those having the same reference numerals in FIG. 5A. For brevity, the descriptions of those items having the same reference numerals as FIG. 4 are not duplicated in the description of FIG. 5A.

[0061] As an addition to the protocol of FIG. 4, FIG. 5A shows that the Power Transmitter 110 can check (at block 508) with the power adapter (e.g., power supply 112) before responding to a wireless power negotiation request 410 from the Power Receiver 130. For example, the Power Transmitter 110 can transmit a request for power supply capability information or other message to the power supply 112. The Power Transmitter 110 can receive a response from the power supply 112 and use the information in the response to determine whether the Power Transmitter 110 can support the wireless power negotiation request 410. If the Power Transmitter 110 can support the wireless power negotiation request 410, the Power Transmitter 110 can transmit an acknowledgement. Otherwise, the Power Transmitter 110 might transmit a NAK (not shown) or other message to inform the Power

Receiver 130 that the Power Transmitter 110 cannot satisfy the wireless power negotiation request 410.

[0062] Another example addition to the protocol of FIG. 4, as shown in FIG. 5A, is that the wireless power negotiation request 410 can include gain information (block 505) or other information to enable the Power Transmitter 110 to determine whether it can support the requested power level. For example, the gain information or other information can be an indication of PRx rectified voltage, power transfer efficiency, a degree of coupling, or any information that the Power Transmitter 110 can use to determine whether a power signal can support the voltage/current levels and power transfer efficiency to satisfy the requested power level. In some implementations, a gain measurement (not shown) is performed before the wireless power negotiation request 410. In some implementations, the gain refers to the voltage ratio of the PRx rectified voltage to PTx inverter voltage. The gain information can include a report from the Power Receiver 130 to indicate the PRx rectified voltage such that the Power Transmitter 110 can calculate the gain. Based on the gain, the Power Transmitter 110 might prepare itself for the going into a high power mode.

[0063] In addition to the power source capability 402, at block 510, the Power Transmitter 110 can consider other characteristics such as a coupling factor (k), voltage boost capability (of the Power Transmitter and/or the Power Receiver), the voltage gain between the Power Transmitter 110 and Power Receiver 130 and/or the maximum phase shift capability of the Power Transmitter to determine whether the requested power and/or voltage can be satisfied.

[0064] **FIG. 5B** shows further options 501 in which a power renegotiation can occur after an initial instance of the first example protocol of FIG. 4. All messages and processes described with reference to FIG. 4 are the same as those having the same reference numerals in FIG. 5B. For brevity, the descriptions of those items having the same reference numerals as FIG. 4 are not duplicated in the description of FIG. 5B. The items in FIG. 5B are the same as FIG. 4 up to the operations at block 420.

[0065] As shown in FIG. 5B, the Power Transmitter 110 may determine whether the received voltage and/or received power at the Power Receiver 130 is sufficient to satisfy the requested power. For example, at block 520, the Power Transmitter 110 determines whether either the rectifier voltage (Vrect) or the rectifier power (Prect) is not as required (e.g., insufficient) at the Power Receiver 130. In some implementations (shown at block 522), the Power Receiver 130 may send the Vrect or Prect information to the Power Transmitter 110. In some embodiments, the Power Receiver 130 can send the Vrect/Prect information on its own initiation or as a response to a request from the Power Transmitter 110. In some

implementations (shown at block 524), the Power Transmitter 110 does a renegotiation with the power supply 112 (such as a power renegotiation using USB PD) to adjust the power supply to a higher or lower voltage level based on the Power Receiver 130 Vrect/Prect, the original requested power (e.g., wireless power negotiation request 410), or a new power level.

[0066] **FIG. 6A** shows a second example protocol 600 for voltage and power modification, continued further in FIG. 6B. The protocol in FIG. 6A is similar to FIG. 4, with at least one difference including the battery charger 174 being replaced by two or more battery chargers (referred to as dual battery chargers 606). Initially, the one of dual battery chargers 606 can operate (block 608) as a regulated battery charger delivering 5W of power to a battery (not shown).

[0067] The Power Receiver 130 is configured to communicate a wireless power negotiation request 610 to Power Transmitter 110 which requests changing to a 25W wireless power level. Similar to FIG. 4, the Power Transmitter 110 can determine whether the Power Transmitter 110 can satisfy the wireless power negotiation request 610 based on the power source capability 402. In the example of FIG. 6A, the power supply 112 and Power Transmitter 110 can satisfy the wireless power negotiation request 610, so the Power Transmitter 110 transmits an ACK 612 to the Power Receiver 130. The Power Receiver 130 communicates a message 614 (such as a control packet or other information) to indicate a voltage target, indicating approximately 18V in the example of FIG. 6A.

[0068] In some implementations (shown at block 616), the Power Transmitter 110 can determine whether it can satisfy the power and voltage target request based on power supply 112 capability information, the coupling factor (k) between the Power Transmitter 110 and the Power Receiver 130, the voltage boost capability, maximum phase shift capability, and/or other information. In some implementations (shown at block 617), the Power Transmitter 110 assessment includes the gain between the Power Transmitter 110 and the Power Receiver 130. In the example of FIG. 6A, the Power Transmitter 110 determines that the system can satisfy the 25W power level while satisfying the voltage target of the Power Receiver 130. The Power Transmitter 110 sends an ACK 618 to the Power Receiver 130. The ACK 618 can serve as a confirmation to the Power Receiver 130. A potential technical advantage of the confirmation is that the Power Receiver 130 can use its more efficient unregulated battery charger if the Power Transmitter 110 can support both power and voltage target as requested by the power receiver.

[0069] **FIG. 6B** shows the continuation 601 of the second example protocol from FIG. 6A. After the Power Receiver 130 receives the ACK 618 (at bottom of FIG. 6A) from the Power

Transmitter 110, at block 620, the Power Receiver 130 causes the dual battery chargers 606 to turn off the regulated charger during a transition to the high power (25W) wireless power system level. The Power Receiver 130 then sends a XCE packet 622 to Power Transmitter 110 to request the voltage increase (such as to 18V).

[0070] The Power Transmitter 110 sends a negotiation request 624 to the power supply 112 asking for a new voltage and current level or a new power level. In some implementations, the Power Transmitter 110 ensures that there can be no overvoltage on the PRx side with proper adjustment of Vin and phase shift when the adapter is transitioning to higher voltage level. In some implementations, for safety reasons, Power Transmitter 110 may interrupt the power signal to the Power Receiver 130 or may enter a low power state to facilitate the adapter voltage transition. Once the Power Transmitter 110 has received a message 626 indicating an acknowledgement of a transition to a new voltage and current level from the power supply 112, the Power Transmitter 110 can adjust its inverter settings (at block 628). In some implementations, the Power Receiver 130 sends a request 630 asking the Power Transmitter 110 to send its inverter voltage value (Vinv) to check if it is safe to turn on the unregulated charger. For example, the Power Receiver 130 can communicate an inquiry to determine the inverter voltage value based on which it can estimate its own possible voltage. The Power Transmitter 110 can send its inverter voltage value 632 to Power Receiver 130 and the Power Receiver 130 can send a confirmation message 634 to the dual battery chargers 606.

[0071] Once the Power Receiver 130 confirms the voltage is at a safe value to operate an unregulated battery charger, the Power Receiver 130 can cause the dual battery chargers 606 to turn on the unregulated charger(s) (block 636). The Power Receiver 130 can continue sending XCE packets 638 to the Power Transmitter 110 with adjustments to modify voltage/current level as needed, and the Power Transmitter 110 can continue inverter control (block 640) based on the XCE packets 638.

[0072] **FIG. 7A** shows the second example protocol 700 for voltage and power modification, continued in FIG. 7B and similar to FIG. 6A and FIG. 6B. Different from FIG. 6A/6B, the example in FIG. 7A/7B show what might happen when the power supply has insufficient power reserve to satisfy a power increase requested by the Power Transmitter 110. FIG. 7A and FIG. 7B start the same as FIG. 6A and FIG. 6B, respectively. The first difference occurs in FIG. 7B.

[0073] **FIG. 7B** shows a continuation 701 of the second example protocol 600 from FIG. 7A. FIG. 7B starts the same as FIG. 6B. The first difference occurs when the power supply 112 cannot satisfy the requested new voltage/current level in the negotiation request 624 from

the Power Transmitter 110 to the power supply 112. Because the power supply 112 cannot satisfy the requested new voltage/current level, the power supply 112 communicates a NAK 740 in response to the negotiation request 624.

[0074] Based on the power adapter NAK 740, the Power Transmitter 110 communicates an ACK 742 to the power supply 112 indicating that the Power Transmitter 110 received the NAK 740. The Power Transmitter 110 also communicates a NAK 744 to the Power Receiver 130 indicating that the Power Transmitter 110 cannot satisfy a voltage increase requested by the XCE packet 622. In some implementations, the NAK 744 includes information about or from the power adapter NAK 740. The Power Transmitter 110 and the Power Receiver 130 can initiate a renegotiation. For example, the Power Transmitter 110 can transmit a power level proposal 746 to the Power Receiver 130. In some implementations, the power level proposal 746 is based on power supply capability information from the power supply 112.

[0075] After a successful renegotiation (such as based on the power level proposal 746), the Power Receiver 130 can transmit an ACK 748 to the Power Transmitter 110 and also cause (shown at arrow 750) the dual battery chargers 606 to turn on the relevant charger (block 752) based on the new power level.

[0076] **FIG. 8** illustrates several example PRx architectures for use in a wireless power system. In a first example PRx architecture 802 (sometimes referred to as a regulated charger), an apparatus can include a PRx integrated circuit (IC) 810 coupled to a power transfer coil 132. The PRx IC 810 and the power transfer coil 132 can implement features of a Power Receiver (such as the Power Receiver 130 described herein). The PRx IC 810 provides rectified power to a buck charger 830 connected in series between the PRx IC 810 and a battery 144. The buck charger 830 can be part of a battery charger (such as the converter 142 of the battery charger 174 shown in FIG. 1).

[0077] A second example PRx architecture 804 can be referred to as a PRx architecture with a nonregulated converter. The second example PRx architecture 804 includes a PRx IC 820. In some implementations, the PRx IC 820 includes a linear dropout regulator (LDO) to adjust the rectified voltage passed to the SWC 840. The battery charger is implemented as a SWC 840 (such as a 4:1 SWC) connected in series between the PRx IC 820 and the battery 144.

[0078] A third example PRx architecture 806 (sometimes referred to as a PRx hybrid architecture) combines features of the first example PRx architecture 802 and the second example PRx architecture 804. The third example PRx architecture 806 includes switches to select a high power path or a low power path. The high power path includes the SWC 840 as described with reference to the second example PRx architecture 804. The low power path

includes the buck charger 830 as described with reference to the first example PRx architecture 802. The high power path is more efficient (compared to the low power path) for high power transfer mode (e.g., 25W). The lower power path is more efficient (compared to the high power path) in lower or nominal power mode (e.g., 5W or 15W).

[0079] **FIG. 9** illustrates a diagram that includes several charging ranges in accordance with USB PD schemes. The charging ranges include USB Type-C, USB PD SPR, and USB PD EPR. USB Type-C includes current ratings from 600 mA to 3 A and a voltage rating of 5V which produces power ratings from 2.5W to 15W. USB PD SPR includes current ratings from about 3 A to about 5 A and voltage ratings from 9V to 20V which produce power ratings from 15W to 100W. USB PD EPR includes a current rating of about 5A and voltage ratings from 28V to 48V which produce power ratings from 100W to 240W.

[0080] **FIG. 10** shows an example procedure for establishing an explicit contract in USB PD. The example procedure in FIG. 10 uses terms (such as source and sink) associated with USB PD. In the context of this disclosure, the source 1004 can be an example of a power supply or power adapter (such as the power supply 112 described in the various Figures), and the sink 1006 can be an example of the Power Transmitter (such as the Power Transmitter 110 described in the various Figures).

[0081] To enter an explicit contract, the source 1004 sends its source capabilities (such as the power source capabilities 402 described in various Figures). The sink 1006 (such as a Power Transmitter 110) makes a request (such as request messages 416 and 624). The source can accept the request and send a power supply ready (PS_RDY) message. The PS_RDY message is an example of ACK messages 418 and 626.

[0082] An explicit contract can be renegotiated. For example, the source 1004 can resend its source capabilities which can trigger a new negotiation between the source 1004 and the sink 1006. Alternatively, the sink 1006 can send a new request which can trigger a new negotiation.

[0083] **FIG. 11** shows an example Power Transmitter 110 in accordance with aspects of this disclosure. The Power Transmitter 110 includes an inverter 278 which receives an input voltage (Vin) from the power supply 112 (or from a DC/DC converter 276 such as a boost converter). The output of the inverter 278 is labeled as V_{AB}. An inverter can also be referred to as a driver. In FIG. 11, the inverter 278 is implemented as a full bridge circuit with four gate-operated transistors controlled by gate signals G1, G2, G3, and G4. The inverter 278 converts a DC power from the power supply 112 (or DC/DC converter 276) into an AC signal

at the power transfer coil 116. By controlling a phase offset (or duty ratio) of the gate signals G1-G4, the Power Transmitter 110 can control the V_{AB}.

[0084] **FIG. 12** illustrates an example bridge circuit operation with associated graphs depicting DC to AC conversion at an inverter of a Power Transmitter. The graphs show gate signals G1-G4 (referring to gate signals in FIG. 11) to produce different voltages V_{AB} at the output of the inverter. For example, the left side of FIG. 12 shows (arrow 1204) a low phase shift between gate signals G1/G4 and G2/G3, resulting in a higher voltage V_{AB}. The right side of FIG. 12 shows (arrow 1206) a high phase shift between gate signals G1/G4 and G2/G3, resulting in a lower voltage V_{AB}. For example, when the V_{IN} has a lower voltage (such as 11V), the higher phase shift can deliver power for a low power mode (such as less than 15W). To achieve a high power mode, a higher input voltage V_{IN} (such as 19V) is used with a lower phase shift. The inverter control to achieve the target operating point can involve a change in the input voltage V_{IN}, phase shift control, or both based on the target voltage/power indicated by a control error packet. FIG. 12 also serves as an example of PTx voltage transitions, such as when moving from one voltage level to another. Example PTx voltage transitions are present in this disclosure, such as at block 420 of FIG. 4 and block 628 of FIG. 6B. In some implementations, the gate signals G1-G4 can also be turned on or off according to a duty cycle to manage the amount of output power based on the output voltage V_{AB} of the inverter and a target voltage/power level.

[0085] **FIG. 13A** shows another example protocol 1300 for voltage and power modification between a Power Supply 112, Power Transmitter 110, Power Receiver 130, and a battery charger 174. Upon initial connection, the Power Supply 112 can provide 5V DC and a power source capability 1302 (similar to the power source capability 402 described with reference to FIG. 4) to the Power Transmitter 110. The Power Transmitter 110 stores the power source capability information and performs a pre-power protocol (such as a wireless power negotiation) with the Power Receiver 130. The Power Transmitter 110 can send a power adapter request 1306 to the power supply 112 to request a voltage and current needed to deliver power at a level negotiated (1304) with the Power Receiver 130. The power supply 112 can modify the voltage/current level being sent to the Power Transmitter 110 based on the power adapter request 1306 and can send an ACK (such as a PS_RDY message). The messages 1306 and 1308 can be an example of an explicit contract in USB PD, as described with reference to FIG. 10.

[0086] In the example of FIG. 13A, the initial power is based on 5W power transfer. The Power Transmitter 110 receives power from the power supply 112 and transmits power 1310 to the Power Receiver 130. At the 5W power profile, the Power Transmitter 110 is said to be

in a low power mode or light power mode. At the light power mode, the Vin to the PTx inverter can be in the range of 6.5V to 18V to deliver 5W of power. The Vin might depend, for example, on the power transfer efficiency, gain, alignment, degree of electromagnetic coupling, or other factors. The Power Receiver 130 receives the power 1310 and delivers 5W of power 1312 to the battery charger 174, which in turn delivers 5W of power to the battery (not shown).

[0087] At some point, the Power Receiver 130 may request 1314 a change from the light power mode (such as 5W) to a higher power mode (such as 25W). The Power Transmitter 110 can initiate a new power negotiation (such as a renegotiation of the explicit contract) with the power supply 112. The Power Transmitter 110 communicates a power adapter request 1316 to the power supply 112 requesting a new voltage and current (or power level) based on a power profile of the high power mode. The power supply 112 communicates an ACK 1318 (such as a PS_RDY message) if the power supply 112 can satisfy the requested new voltage/current. Otherwise, the power supply 112 can communicate a NAK denying the request if the power supply 112 does not have enough resources to satisfy the requested new voltage/current. Based on the ACK 1318, the Power Transmitter 110 can communicate an ACK 1320 to the Power Receiver 130. The example protocol continues on FIG. 13B.

[0088] **FIG. 13B** shows the continuation 1301 of the example protocol from FIG. 13A. After the Power Receiver 130 receives the ACK 1320 from the Power Transmitter 110, the Power Receiver 130 prepares (shown at bracket 1322) for a transition to the high power mode. As a preparation 1322 to enter the high power mode, the Power Receiver 130 can request 1324 a low/no power mode from the Power Transmitter 110. The low/no power mode is intended to prevent voltage on the PRx side as a result of spurious voltage modifications at the power supply 112 and the Power Transmitter 110. The Power Transmitter 110 adjusts the phase shift and Vin in such a way that no or very low power transfer is happening from the Power Transmitter 110 to Power Receiver 130. The Power Transmitter 110 acknowledges 1326 the action to the Power Receiver 130. At this point, the Power Receiver 130 can make load transitions on its end and send the control error packet (XCE) 1328 to the Power Transmitter 110. Upon receiving the first control error packet, the Power Transmitter 110 can request 1330 the power supply 112 for the voltage/current modification. The power supply 112 modifies its power settings to provide the requested voltage/current (or power) to the Power Transmitter 110 and send an acknowledgement 1332 (such as a PS_RDY message). In some implementations, the Power Transmitter 110 also initiates control changes on a boost converter or voltage regulator and phase shifts to adjust the Vin based on the XCE. At that point, the Power Transmitter 110 can transmit power 1334 to the Power Receiver 130 using a

high power mode (such as 25W). In the high power mode, the Power Transmitter 110 may operate using an input voltage Vin between 10V and 20V. The Power Receiver 130 receives the wireless power using the high power mode and delivers the power 1338 to the battery charger 174, which in turn delivers 25W to the battery (not shown).

[0089] **FIG. 14** illustrates a block diagram of an example apparatus 1400 for use in a wireless power system. In some implementations, the example apparatus 1400 may be a wireless power apparatus (such as any of the Power Transmitter, Power Receiver, or Power Transceiver described herein. The apparatus 1400 can include a processor 1402 (possibly including multiple processors, multiple cores, multiple nodes, or implementing multi-threading, etc.). The apparatus 1400 also can include a memory 1404. The memory 1404 may be system memory or any one or more of the possible realizations of computer-readable media described herein. The apparatus 1400 also can include a bus 1406 (such as PCI, ISA, PCI-Express, HyperTransport®, InfiniBand®, NuBus®, AHB, AXI, etc.).

[0090] The apparatus 1400 may include one or more controllers 1408 (such as a PTx controller). In some implementations, the controller 1408 can be distributed within the processor 1402, the memory 1404, and the bus 1406. The controller 1408 may perform some or all of the operations described herein. For example, the controller 1408 may implement the processes described with reference to any one of FIG. 1 through FIG. 14, or any combination thereof.

[0091] The memory 1404 can include computer instructions executable by the processor 1402 to implement the functionality of the implementations described herein. Any one of these functionalities may be partially (or entirely) implemented in hardware or on the processor 1402. For example, the functionality may be implemented with an application specific integrated circuit, in logic implemented in the processor 1402, in a co-processor on a peripheral device or card, etc. Further, realizations may include fewer or additional components not illustrated in FIG. 14. The processor 1402, the memory 1404, and the controller 1408 may be coupled to the bus 1406. Although illustrated as being coupled to the bus 1406, the memory 1404 may be coupled to the processor 1402 or the controller 1408.

[0092] The apparatus 1400 also includes a power supply controller 1410. The power supply controller 1410 is controlled by the controller 1408. For example, the power supply controller 1410 can be in a power supply (e.g., a power adapter) that is communicatively coupled to the controller 1408 of the Power Transmitter.

[0093] This disclosure describes several communications/messages between a Power Transmitter and a power supply and between the Power Transmitter and the Power Receiver.

The described communications can be implemented as data packets or signals. Typically, when a communication/message includes information, a request, ACK, or NAK, among other example, those communications/messages are communicated as data packets. For example, referring to FIGs. 4-7B, 13A, and 13B, any or all of the communications 410, 412, 414, 416, 418, 508, 522, 524, 610, 612, 614, 618, 622, 624, 626, 630, 632, 634, 638, 740, 742, 744, 746, 748, 1302, 1304, 1306, 1308, 1314, 1316, 1318, 1320, 1324, 1326, 1328, 1330, and 1332 can be communicated as data packets.

[0094] The foregoing disclosure provides illustration and description but is not intended to be exhaustive or to limit the aspects to the precise form disclosed. Modifications and variations may be made in light of the above disclosure or may be acquired from practice of the aspects. While the aspects of the disclosure have been described in terms of various examples, any combination of aspects from any of the examples is also within the scope of the disclosure. The examples in this disclosure are provided for pedagogical purposes. Alternatively, or in addition to the other examples described herein, examples include any combination of the following enumerated example implementation options (referred to as clauses for clarity).

[0095] Clause 1: A method of a Power Transmitter, comprising: receiving power from an external power supply; performing a power negotiation with a Power Receiver; and coordinating with the external power supply to adjust a power supply voltage of the power from the external power supply based, at least in part, on the power negotiation.

[0096] Clause 2: The method of clause 1, wherein coordinating with the external power supply includes: communicating a message to the external power supply to request the power supply voltage; and receiving an acknowledgement (ACK) from the external power supply that the external power supply can provide the power supply voltage.

[0097] Clause 3: The method of clause 1 or 2, further comprising: receiving power source capability information from the external power supply or a cable that connects the Power Transmitter to the external power supply.

[0098] Clause 4: The method of any one of clauses 1 to 3, wherein performing the power negotiation includes one of: receiving a first power request for a first power mode; or receiving a second power request for a second power mode that supports more power than the first power mode; and wherein the power supply voltage is based on the first power mode or the second power mode.

[0099] Clause 5: The method of clause 4, further comprising: controlling an inverter of the Power Transmitter based, at least in part, on the first power mode or the second power mode.

[0100] Clause 6: The method of clause 4 or 5, further comprising: initially operating in the first power mode; and transitioning to the second power mode based on the power negotiation.

[0101] Clause 7: The method of clause 6, further comprising: as part of a transition from the first power mode to the second power mode, transitioning to a low or no power mode before transitioning to the second power mode.

[0102] Clause 8: The method of any one of clauses 4 to 7, wherein the first power mode is associated with 5 watts (5W) or 15W wireless power transfer, and the second power mode is associated with 25W wireless power transfer.

[0103] Clause 9: The method of any one of clauses 1 to 8, wherein the power negotiation includes the Power Transmitter receiving power request information indicating a requested power or a requested voltage, the method further comprising: determining the power supply voltage based, at least in part, on the requested power or the requested voltage.

[0104] Clause 10: The method of any one of clauses 1 to 9, further comprising: receiving a first control error packet from the Power Receiver; determining that the Power Transmitter requires a higher power supply voltage from the external power supply; and requesting the higher power supply voltage from the external power supply.

[0105] Clause 11: The method of any one of clauses 1 to 10, further comprising: receiving a power request from the Power Receiver; and determining whether the Power Transmitter can satisfy the power request based on one or more parameters including: power source capability information that indicates supported power source voltages or power levels of the external power supply, coupling factor (k) between the Power Transmitter and the Power Receiver, voltage boost capability of the Power Transmitter, maximum phase shift capability of the Power Transmitter, or any combination thereof.

[0106] Clause 12: The method of any one of clauses 1 to 11, wherein coordinating with the external power supply includes communicating with the external power supply in accordance with a universal serial bus (USB) power delivery (PD) protocol.

[0107] Clause 13: The method of any one of clauses 1 to 12, wherein performing the power negotiation with the Power Receiver includes: receiving, from the Power Receiver, a request for a 25 watt (25W) power mode; and communicating, to the Power Receiver, acknowledgement for the 25W power mode; and wherein coordinating with the external power supply includes performing a power adapter negotiation with the external power supply to set the power supply voltage to 15 volt (15V) and the power supply current to 3 amps (3A) based on the 25W power mode.

[0108] Clause 14: The method of any one of clauses 1 to 13, wherein performing the power negotiation includes a pre-power negotiation before power transfer.

[0109] Clause 15: The method of any one of clauses 1 to 14, wherein performing the power negotiation includes: initially operating in a first power mode associated with a 128 kHz operating frequency; receiving, from the Power Receiver, a request for a second power mode associated with a 360 kHz operating frequency; and communicating a request to the external power supply to increase the power supply voltage based on the second power mode.

[0110] Clause 16: A Power Transmitter, comprising: a power transfer coil; an inverter; and a controller configured to perform a method according to any one of clauses 1 to 15.

[0111] Clause 17: A method of a Power Transmitter, comprising: receiving a power request from a Power Receiver; and coordinating with an external power supply to adjust power from the external power supply to the Power Transmitter based, at least in part, on the power request.

[0112] Clause 18: The method of clause 17, further comprising: initially transferring power to the Power Receiver using a power profile that supports up to 5 watts (W), wherein the power request indicates a power level more than 5W.

[0113] Clause 19: The method of clause 1 or 4, further comprising: determining a power supply voltage and current level for the Power Transmitter to receive from the external power supply based, at least in part, on power request information from the Power Receiver, wherein the power request information includes a requested power and/or a requested voltage.

[0114] Clause 20: The method of clause 19, further comprising: communicating a message to the external power supply to indicate the power supply voltage and current level; and receiving an acknowledgement (ACK) or non-acknowledgement (NAK) from the external power supply, wherein the ACK indicates that the external power supply can provide the power supply voltage and current level, and wherein the NAK indicates that the external power supply cannot provide the power supply voltage and current level.

[0115] Clause 21: The method of clause 2 or 9, further comprising: controlling an inverter of the Power Transmitter based, at least in part, on the power supply voltage and current level.

[0116] Clause 22: The method of any one of clauses 1-2, 4-5 or 9, further comprising: determining whether the Power Transmitter can satisfy the power request based, at least in part, on power source capability information.

[0117] Clause 23: The method of any one of clauses 1-2, 4-5 or 9, further comprising: determining whether the Power Transmitter can satisfy the power request based on one or more parameters including: power source capability information, coupling factor (k) between

the Power Transmitter and the Power Receiver, voltage boost capability of the Power Transmitter, maximum phase shift capability of the Power Transmitter, or any combination thereof.

[0118] Clause 24: The method of any one of clauses 1-2, 4-5, 9 or 11, further comprising: receiving power source capability information from the external power supply or a cable that connects the Power Transmitter to the external power supply, wherein the power source capability information indicates supported voltage and/or power levels that the Power Transmitter can receive from the external power supply.

[0119] Clause 25: The method of any one of clauses 1-5, 9 or 11, wherein coordinating with the external power supply includes communicating a request and receiving an acknowledgement (ACK) in accordance with a universal serial bus (USB) power delivery (PD) protocol.

[0120] Clause 26: The method of any one of clauses 1-5, 9 or 11-12, further comprising: receiving a first control error packet from the Power Receiver as part of a process to change power; and requesting a new voltage or current level from the external power supply based on the first control error packet.

[0121] Clause 27: The method of any one of clauses 1-5 or 9-12, further comprising: initially operating in a first power mode for power delivery from the Power Transmitter to the Power Receiver; as part of a transition from the first power mode to a second power mode, transitioning to a low or no power mode; and transitioning to the second power mode after the low or no power mode.

[0122] Clause 28: The method of clause 27, wherein the first power mode is associated with 5 watts (5W) wireless power transfer and the second power mode is associated with 25W wireless power transfer.

[0123] Clause 29: A Power Transmitter, comprising: a power transfer coil; an inverter; and a controller configured to: receive a power request from a Power Receiver; and coordinate with an external power supply to adjust power from the external power supply to the Power Transmitter based, at least in part, on the power request.

[0124] Clause 30: The Power Transmitter of clause 29, wherein the controller is further configured to: initially transfer power to the Power Receiver using a power profile that supports up to 5 watts (W), wherein the power request indicates a power level more than 5W.

[0125] Clause 31: The Power Transmitter of clause 16, wherein the controller is further configured to: determine a power supply voltage and current level for the Power Transmitter to receive from the external power supply based, at least in part, on power request information

from the Power Receiver, wherein the power request information includes a requested power and/or a requested voltage.

[0126] Clause 32: The Power Transmitter of clause 16, wherein the controller is further configured to: communicate a message to the external power supply to indicate the power supply voltage and current level; and receive an acknowledgement (ACK) or non-acknowledgement (NAK) from the external power supply, wherein the ACK indicates that the external power supply can provide the power supply voltage and current level, and wherein the NAK indicates that the external power supply cannot provide the power supply voltage and current level.

[0127] Clause 33: The Power Transmitter of clause 15 or 16, wherein the controller is further configured to: control the inverter of the Power Transmitter based, at least in part, on the power supply voltage and current level.

[0128] Clause 34: The Power Transmitter of clause 16, wherein the controller is further configured to: determine whether the Power Transmitter can satisfy the power request based on one or more parameters including: power source capability information, couple factor (k) between the Power Transmitter and the Power Receiver, voltage gain between the Power Transmitter and the Power Receiver, voltage boost capability of the Power Transmitter, maximum phase shift capability of the Power Transmitter, or any combination thereof.

[0129] Clause 35: The Power Transmitter of clause 16, wherein the controller is further configured to: receive power source capability information from the external power supply or a cable that connects the Power Transmitter to the external power supply, wherein the power source capability information indicates supported voltage and/or power levels that the Power Transmitter can receive from the external power supply.

[0130] Clause 36: The Power Transmitter of clause 16, wherein coordinating with the external power supply includes communicating a request and receiving an acknowledgement (ACK) in accordance with a universal serial bus (USB) power delivery (PD) protocol.

[0131] Another innovative aspect of the subject matter described in this disclosure can be implemented as a computer-readable medium having stored therein instructions which, when executed by a processor, causes the processor to perform any one of the above-mentioned functionalities.

[0132] Another innovative aspect of the subject matter described in this disclosure can be implemented as a system having means for implementing any one of the above-mentioned functionalities.

[0133] Another innovative aspect of the subject matter described in this disclosure can be implemented as an apparatus having one or more processors configured to perform one or more operations from any one of the above-mentioned functionalities.

[0134] Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which this specification belongs. The terms "first," "second," and the like, as used herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. The use of terms "including," "comprising" or "having" and variations thereof herein are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. The terms "connected" and "coupled" are not restricted to physical or mechanical connections or couplings and can include electrical connections or couplings, whether direct or indirect. Furthermore, terms "circuit" and "circuitry" and "control unit" may include either a single component or a plurality of components, which are either active and/or passive and are connected or otherwise coupled together to provide the described function. In addition, the term operationally coupled as used herein includes wired coupling, wireless coupling, electrical coupling, magnetic coupling, radio communication, software based communication, or combinations thereof.

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[0136] Some or all of the foregoing or the following implementations can be jointly combined or formed to be a new or another one implementation. The foregoing or the following techniques can be used to solve at least (but not limited to) the issue(s) or scenario(s) mentioned in this disclosure. Any two or more than two of the foregoing or the

following paragraphs, (sub)-bullets, points, actions, or claims described in each method/technique/implementation may be combined logically, reasonably, and properly to form a specific method. Any sentence, paragraph, (sub)-bullet, point, action, or claim described in each of the foregoing or the following technique(s)/implementation(s)/concept(s) may be implemented independently and separately to form a specific method. Dependency, such as "based on," "more specifically," "where" or etc., in technique(s)/implementation(s)/concept(s) mentioned in this disclosure is just one possible implementation which would not restrict the specific method.

[0137] Certain techniques are described in this disclosure as including logic or a number of components or modules. Modules can be software modules (*e.g.*, code, or machine-readable instructions stored on non-transitory machine-readable medium) or hardware modules. A hardware module is a tangible unit capable of performing certain operations and may be configured or arranged in a certain manner. A hardware module can comprise dedicated circuitry or logic that is permanently configured (*e.g.*, as a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC), a digital signal processor (DSP), etc.) to perform certain operations. A hardware module may also comprise programmable logic or circuitry (*e.g.*, as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software to perform certain operations. The decision to implement a hardware module in dedicated and permanently configured circuitry, or in temporarily configured circuitry (*e.g.*, configured by software) may be driven by cost and time considerations.

[0138] When implemented in software, the techniques can be provided as part of the operating system, a library used by multiple applications, a particular software application, etc. The software can be executed by one or more general-purpose processors or one or more special-purpose processors.

[0139] As used herein, the terms "component" and "module" are intended to be broadly construed as hardware, firmware, or a combination of hardware and software. As used herein, a processor is implemented in hardware, firmware, or a combination of hardware and software. As used herein, the phrase "based on" is intended to be broadly construed to mean "based at least in part on."

[0140] As used herein, a phrase referring to a list of items separated by "or" refers to any combination of those items, including single members. For example, "a, b, or c" is intended to cover the possibilities of: a only, b only, c only, a combination of a and b, a combination of a and c, a combination of b and c, and a combination of a and b and c.

[0141] In this disclosure, an expression of "X/Y" may include meaning of any of the following: "X or Y" or "X and Y" or "X and/or Y." An expression of "(A) B" or "B (A)" may include concept of "only B." An expression of "(A) B" or "B (A)" may include the concept of "A+B" or "B+A."

[0142] Some aspects are described herein in connection with thresholds. As used herein, satisfying a threshold may refer to a value being greater than the threshold, greater than or equal to the threshold, less than the threshold, less than or equal to the threshold, equal to the threshold, not equal to the threshold, or the like.

[0143] The various illustrative components, logic, logical blocks, modules, circuits, operations and algorithm processes described in connection with the implementations disclosed herein may be implemented as electronic hardware, firmware, software, or combinations of hardware, firmware or software, including the structures disclosed in this specification and the structural equivalents thereof. The interchangeability of hardware, firmware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and processes described above. Whether such functionality is implemented in hardware, firmware or software depends upon the particular application and design constraints imposed on the overall system.

[0144] As described above, some aspects of the subject matter described in this specification can be implemented as software. For example, various functions of components disclosed herein, or various blocks or steps of a method, operation, process or algorithm disclosed herein can be implemented as one or more modules of one or more computer programs. Such computer programs can include non-transitory processor-executable or computer-executable instructions encoded on one or more tangible processor-readable or computer-readable storage media for execution by, or to control the operation of, a data processing apparatus including the components of the devices described herein. By way of example, and not limitation, such storage media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store program code in the form of instructions or data structures. Combinations of the above should also be included within the scope of storage media.

[0145] Various modifications to the implementations described in this disclosure may be readily apparent to persons having ordinary skill in the art, and the generic principles defined herein may be applied to other implementations without departing from the scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown

herein but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein.

[0146] Additionally, various features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. As such, although features may be described above as acting in particular combinations, and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0147] The drawings may schematically depict one or more example processes in the form of a flowchart or flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In some circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

CLAIMS

What is claimed is:

1. A method of a Power Transmitter, comprising:

receiving power from an external power supply;

performing a power negotiation with a Power Receiver; and

coordinating with the external power supply to adjust a power supply voltage of the power from the external power supply based, at least in part, on the power negotiation.

2. The method of claim 1, wherein coordinating with the external power supply includes:

communicating a message to the external power supply to request the power supply voltage; and

receiving an acknowledgement (ACK) from the external power supply that the external power supply can provide the power supply voltage.

3. The method of claim 1 or 2, further comprising:

receiving power source capability information from the external power supply or a cable that connects the Power Transmitter to the external power supply.

4. The method of any one of claims 1 to 3,

wherein performing the power negotiation includes one of:

receiving a first power request for a first power mode; or

receiving a second power request for a second power mode that supports more power than the first power mode; and

wherein the power supply voltage is based on the first power mode or the second power mode.

5. The method of claim 4, further comprising:

controlling an inverter of the Power Transmitter based, at least in part, on the first power mode or the second power mode.

6. The method of claim 4 or 5, further comprising:

initially operating in the first power mode; and

transitioning to the second power mode based on the power negotiation.

7. The method of claim 6, further comprising:

as part of a transition from the first power mode to the second power mode, transitioning to a low or no power mode before transitioning to the second power mode.

8. The method of any one of claims 4 to 7, wherein

the first power mode is associated with 5 watts (5W) or 15W wireless power transfer, and

the second power mode is associated with 25W wireless power transfer.

9. The method of any one of claims 1 to 8, wherein the power negotiation includes the Power Transmitter receiving power request information indicating a requested power or a requested voltage, the method further comprising:

determining the power supply voltage based, at least in part, on the requested power or the requested voltage.

10. The method of any one of claims 1 to 9, further comprising:

receiving a first control error packet from the Power Receiver;

determining that the Power Transmitter requires a higher power supply voltage from the external power supply; and

requesting the higher power supply voltage from the external power supply.

11. The method of any one of claims 1 to 10, further comprising:

receiving a power request from the Power Receiver; and

determining whether the Power Transmitter can satisfy the power request based on one or more parameters including:

power source capability information that indicates supported power source voltages or power levels of the external power supply,

coupling factor (k) between the Power Transmitter and the Power Receiver,

voltage boost capability of the Power Transmitter,

maximum phase shift capability of the Power Transmitter, or

any combination thereof.

12. The method of any one of claims 1 to 11, wherein coordinating with the external power supply includes communicating with the external power supply in accordance with a universal serial bus (USB) power delivery (PD) protocol.

13. The method of any one of claims 1 to 12,

wherein performing the power negotiation with the Power Receiver includes:

receiving, from the Power Receiver, a request for a 25 watt (25W) power mode; and

communicating, to the Power Receiver, acknowledgement for the 25W power mode; and

wherein coordinating with the external power supply includes performing a power adapter negotiation with the external power supply to set the power supply voltage to 15 volt (15V) and the power supply current to 3 amps (3A) based on the 25W power mode.

14. The method of any one of claims 1 to 13, wherein performing the power negotiation includes a pre-power negotiation before power transfer.

15. The method of any one of claims 1 to 14,

wherein performing the power negotiation includes:

initially operating in a first power mode associated with a 128 kHz operating frequency;

receiving, from the Power Receiver, a request for a second power mode associated with a 360 kHz operating frequency; and

communicating a request to the external power supply to increase the power supply voltage based on the second power mode.

16. A Power Transmitter, comprising:

a power transfer coil;

an inverter; and

a controller configured to perform a method according to any one of claims 1 to 15.