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Implementing Transmitter Current Limit During Wireless Charging

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Abstract:

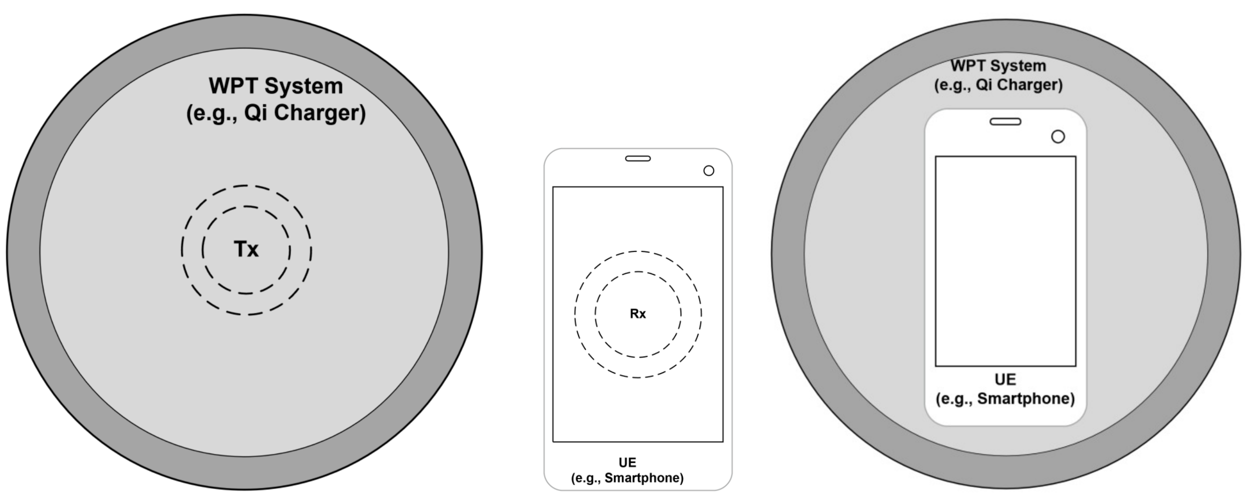
This publication describes Qi-based wireless-charging protocols that enable and protect user equipment (UE) (*e.g.*, smartphones) that can act as power transmitter (Tx) or receivers (Rx). The UE acting as a Tx, herein referred to as "Tx UE," and a UE acting as an Rx, herein referred to as "Rx UE," can safely enter and maintain a power-transfer phase without causing wireless-charging disconnection due to power limitations of the Tx UE or other system errors, such as out of target output rectified voltage (V_{RECT}), output voltage (V_{OUT}), or control error packet (CEP). The described Qi-based wireless-charging protocols can accomplish the power-transfer phase using two methods—utilizing a bi-directional communication between the Tx UE and the Rx UE or without communication from the Tx UE to Rx UE. Power transferring using bi-directional communication requires that both the Tx UE and the Rx UE support the required firmware and/or software to enable power transferring without wireless-charging disconnection. On the other hand, power transferring without Tx-to-Rx bi-directional communication does *not* require that both the Tx UE and the Rx UE support the required firmware and/or software to enable power transferring without wireless-charging disconnection, as long as the Rx UE supports firmware and/or software that can monitor the parameters V_{RECT}, V_{OUT}, and/or CEP, and adjust (lower) the current (Amperes) demand until it reaches a charging current that matches the current being supplied by the Tx UE.

Keywords:

Wireless charging, wireless power transfer, WPT, Qi, Qi charging, Qi charger, cordless charger, inductive charger, charging current, transmitter current, receiver current, transmitter current, receiver current, control error packet, CEP, bi-directional communication, transmitter to receiver, Tx, Rx, PTx.

Background:

A user may often utilize a wireless power-transfer (WPT) system (*e.g.*, wireless-charging pad, Qi charger) to wirelessly charge user equipment (UE), such as a smartphone, earphones, a smartwatch, and the like. Qi is an open interface standard that defines wireless power transfer using inductive coupling. Using electromagnetic induction coupling between two coils, WPT systems can transfer power from a transmitter (Tx) of the WPT system to a receiver (Rx) of the UE, as is illustrated in Figure 1.



1A 1B 1C

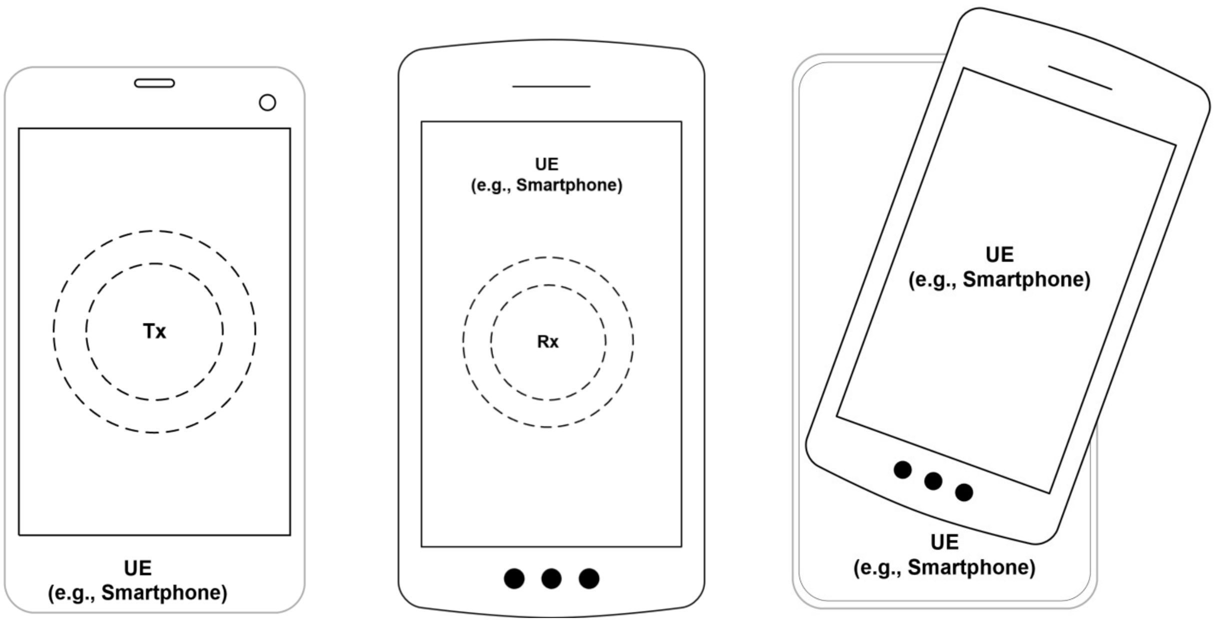
Figure 1

Figure 1A illustrates a Qi charger and the Tx of the Qi charger, herein referred to as a "conventional transmitter." In Figure 1A, the dashed line means that the Tx (not to scale) is located below the pad surface (the mat) of the Qi charger. The Qi charger in Figure 1B receives alternating power (AC) power from a single-phase voltage outlet (not illustrated), which differs from country-to-country (*e.g.*, 120 Volts (V), 60 Hertz (Hz)), through a power adapter (not illustrated) that enables the Qi charger to output a rectified voltage (V_{RECT}). Figure 1B illustrates a UE (*e.g.*, a smartphone) and the Rx of the UE. In Figure 1B, the dashed line means that the Rx is embedded inside the smartphone. Figure 1C illustrates a user placing their smartphone on top of the Qi charger mat to charge their smartphone utilizing electromagnetic inductive coupling between the Tx of the Qi charger and the Rx of the UE.

In a conventional Qi-based wireless-charging protocol, the Qi charger and the UE agree on a maximum power-transfer level (*e.g.*, 5 Watts) before entering a power-transfer phase between the Tx of the Qi charger and the Rx of the UE. It is worth noting that, in many instances, the transmitting Qi (Tx Qi) charger can deliver as much power as is requested from the receiving user equipment (Rx UE) depending on the power needs of the receiving UE, herein is referred to as "Rx UE."

The maximum agreed-upon power level does not change during the power-transfer phase, but the Rx UE may change its charging current for several reasons, such as a detection in increased thermal power. It is also worth noting that an original device manufacturer (ODM) often designs the conventional Tx Qi charger to be bulky enough to endure any possible thermal heat that is generated during normal operation. Differently stated, in the conventional Qi-based wireless-charging protocol, the Rx UE is the master and controls the amount of charging current—this is done, in part, to protect the UE during the power-transfer phase.

The example illustrated in Figure 1 and the conventional Qi-based wireless-charging protocol works well because the conventional Tx Qi charger can handle any possible thermal heat that is generated during normal operation. Nevertheless, modern UE can also function as Qi chargers, as is illustrated in Figure 2.



2A **2B** **2C**

Figure 2

Figure 2A illustrates a UE (*e.g.*, a smartphone) that also functions as a power transmitter, herein referred to as a "Tx UE." In Figure 2A, the dashed lines mean that the Tx (not to scale) is embedded inside the UE. Figure 2B illustrates a UE (*e.g.*, a smartphone) and the Rx of the UE, recall that herein is referred to as "Rx UE." In Figure 2B, the dashed lines mean that the Rx is embedded inside the smartphone. Figure 2C illustrates a user placing the back of Rx UE on top of the back of Tx UE, to charge their smartphone utilizing electromagnetic inductive coupling between the Tx UE and the Rx UE. Although not illustrated, the user can also place the back of Tx UE on top of the back of Rx UE.

Unlike the conventional Tx Qi charger example illustrated in Figure 1A, the Tx UE illustrated in Figure 2A does not have a bulky design that can endure an increase in thermal energy during the power-transfer phase. During the power-transfer phase, the Tx UE can reduce its transfer power or temporarily shuts down due to an increased thermal energy in the Tx UE. The Rx UE (the smartphone acting as a receiver), however, is not notified that the Tx UE (the smartphone acting as a transmitter) has reduced the power-transfer level or has temporarily shut down. This causes a high control error packet (CEP) because the Rx UE expects to draw up to the agreed-upon power level and results in a wireless-charging disconnection. Unlike the case of the conventional Qi-based wireless-charging protocol, where the Rx UE is the master and controls the amount of charging current to protect the Rx UE during the power-transfer phase, it is desirable to have a technological solution that takes into consideration the power-transferring ability of the Tx UE.

Description:

This publication describes Qi-based wireless-charging protocols that enable and protect user equipment (*e.g.*, smartphones) that can act as power transmitter (Tx) or receivers (Rx). The UE acting as a Tx, herein referred to as "Tx UE," and a UE acting as an Rx, herein referred to as "Rx UE," can safely enter and maintain a power-transfer phase without causing wireless-charging disconnection due to power limitations of the Tx UE or other system errors, such as out of target output rectified voltage (V_{RECT}), output voltage (V_{OUT}), or control error packet (CEP). The described Qi-based wireless-charging protocols can accomplish the power-transfer phase using two methods—utilizing a bi-directional communication between the Tx UE and the Rx UE or without communication from the Tx UE to Rx UE.

Power Transferring Using Bi-Directional Communication

Unlike the conventional Qi-based wireless-charging protocol, the described bi-directional communication between the Tx UE and the Rx UE enables both UE to re-negotiate the power level even after entering the power-transferring phase with a previously-agreed-upon power level, as is illustrated in Figure 3.

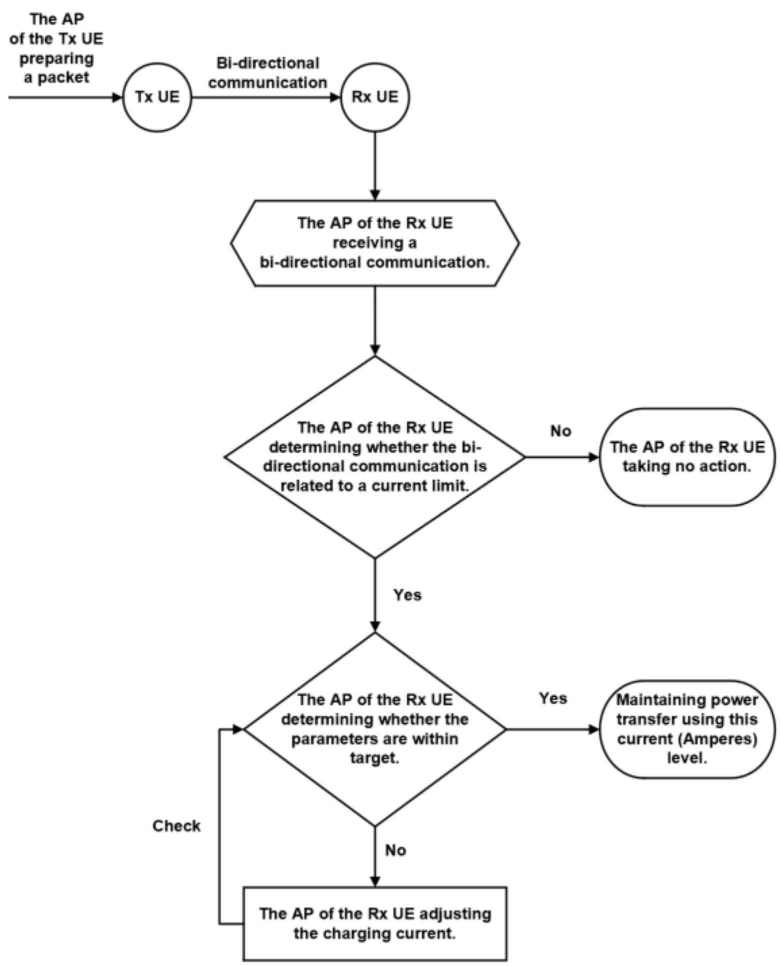


Figure 3

Figure 3 illustrates the bi-directional communication between the Tx UE and the Rx UE that enables the power-transfer phase. If the Tx UE senses that it cannot supply a previously-agreed-upon power level, the application processor (AP) of the Tx UE prepares a communication packet to be shared with the Rx UE using bi-directional communication. Then, the Tx UE sends the communication packet to the Rx UE using bi-directional communication. The AP of the Rx UE receives the communication packet and determines whether the communication is related to a current limit. Note that when the Tx UE lowers the transfer power, it does so by lowering the charging current (Amperes). If the AP of the Rx UE determines that the notification is not related a current limit, the AP of the Rx UE takes no action. If the AP of the Rx UE determines and decodes that the received notification is related to a current limit and is due to at least of the parameters V_{RECT}, V_{OUT}, and/or CEP, the AP of the Rx UE adjusts (lowers) the current demand until it reaches a charging current that matches the current being supplied by the Tx UE.

Unlike the example illustrated in Figure 1, where the Rx UE acts as a master and the Tx of the conventional Qi charger continues to supply a previously-agreed-upon power level until the Rx UE decides to lower the charging current due to the Rx UE being overheated, in the example illustrated in Figure 3, the Tx UE acts like a master, and the Rx UE responds to the power-transfer ability/inability of the Tx UE. Power transferring using bi-directional communication requires that both the Tx UE and the Rx UE support the required firmware and/or software to enable power transferring without wireless-charging disconnection.

Power Transferring Without Tx-to-Rx Communication

Again, unlike the conventional Qi-based wireless-charging protocol, the described power transferring without Tx-to-Rx communication enables the AP of the Rx UE to decode the reason why the Tx UE reduces the supplied power below a previously-agreed-upon power level, as is illustrated in Figure 4.

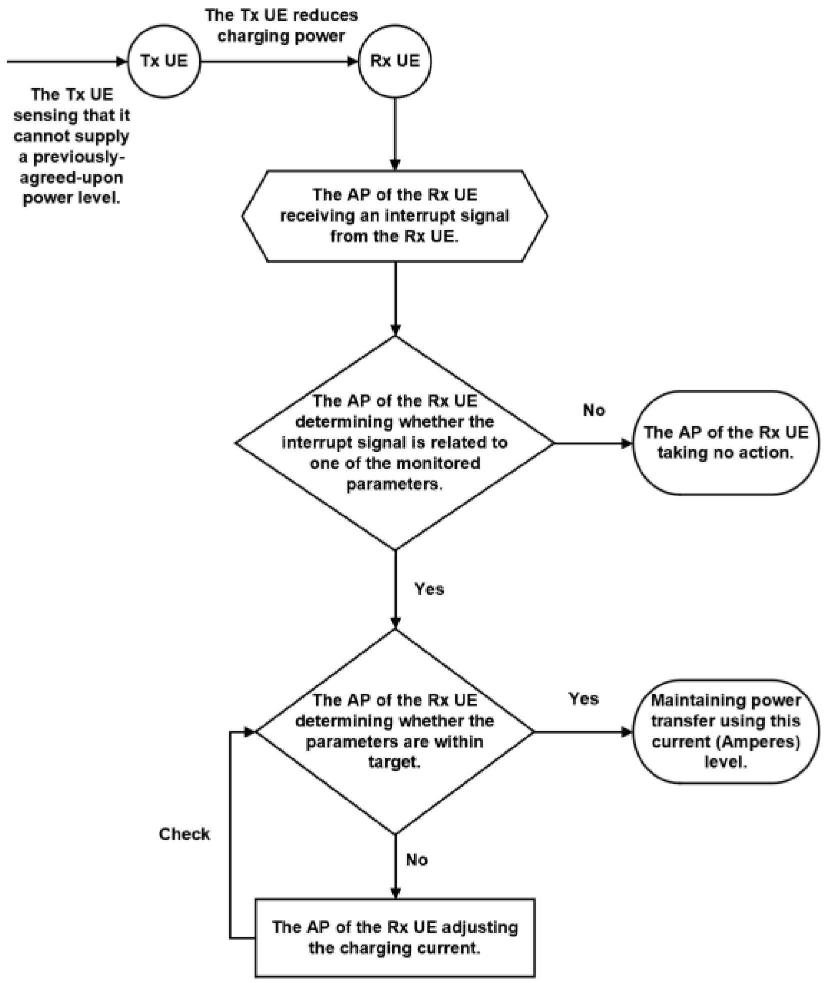


Figure 4

Figure 4 illustrates the power-transfer phase between the Tx UE and the Rx UE without using bi-directional communication. If the Tx UE senses that it cannot supply a previously-agreed-upon power level, the Tx UE reduces the charging power by lowering the charging current. Unlike power transferring using bi-directional communication illustrated in Figure 3, the Tx UE illustrated in Figure 4 does not send a notification to the Rx UE. The AP of the Rx UE receives an interrupt signal from the Rx UE, and the AP of the Rx UE determines whether the interrupt signal is due to at least one of the monitored parameters V_{RECT}, V_{OUT}, and/or CEP. If the AP of the Rx UE determines that the notification is not related to the monitored parameters V_{RECT}, V_{OUT}, and/or CEP, the AP of the Rx UE takes no action. If the AP of the Rx UE determines and decodes that the received interrupt signal is due to at least of the parameters V_{RECT}, V_{OUT}, and/or CEP, the AP of the Rx UE adjusts (lowers) the current (Amperes) demand until it reaches a charging current that matches the current being supplied by the Tx UE.

Unlike the example illustrated in Figure 1, where Tx of the conventional Qi charger continues to supply a previously-agreed-upon power level until the Rx UE decides to lower the charging current, the Tx UE in Figure 4 lowers the charging current if the Tx UE starts to reach a pre-determined safe level thermal limit. Differently stated, the Tx UE in Figure 4 can lower the charging current when it senses an unsafe thermal energy limit. In addition, unlike the example illustrated in Figure 3, where the Tx UE acts as a master, the Tx UE illustrated in Figure 4 simply reduces the charging power with no control over the Rx UE. The Rx UE illustrated in Figure 4 responds to the power-transfer ability/inability of the Tx UE with no control of the Tx UE either. Differently stated, the power transferring illustrated in Figure 4 enables both UE to reduce the charging power when the respective UE senses an increase in thermal energy. Power transferring without Tx-to-Rx bi-directional communication does *not* require that both the Tx UE and the Rx UE support the required firmware and/or software to enable power transferring without wireless-charging disconnection, as long as the Rx UE supports firmware and/or software that can monitor the parameters V_{RECT}, V_{OUT}, and/or CEP, and adjust (lower) the current (Amperes) demand until it reaches a charging current that matches the current being supplied by the Tx UE. The Rx UE does not need to decipher the reason why the Tx UE does not supply the previously-agreed-upon power level—the Rx UE simply adjust its current demand and avoids a wireless-charging disconnection.

In conclusion, two user equipment (*e.g.*, smartphones), can safely enter and maintain a power-transfer phase without causing wireless-charging disconnection.

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