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Motorized Wireless-Charging Pad that Uses Magnetic Field Detection

Abstract:

This publication describes a motorized wireless power transfer (WPT) system (*e.g.*, motorized Qi charger) that utilizes tunnel magnetoresistance (TMR) to automatically laterally and vertically align the transmitter (Tx) of the WPT system to the receiver (Rx) of a user equipment (UE), such as a smartphone, earphones, a smartwatch, and so forth. The WPT system has TMR sensors that utilize magnetic tunnel junction (MTJ) elements that exhibit low magnetic hysteresis and high magnetoresistance sensitivity to a change in the magnetic field. An array of TMR sensors can be used to reliably detect the magnetic field distribution and can detect the lateral, vertical alignment, and/or misalignment between the Tx of the WPT system and the Rx of the UE. The exact number and spatial arrangements of the TMR sensors may differ depending on the shape and size of the charging pad of the WPT system. The WPT system may have one, two, three, and so forth, transmitters sitting on top of one, two, three, and so forth, motorized arms that enable the WPT system to automatically laterally and/or vertically align to and charge one, two, three, and so forth, UE at the same time. The described WPT system can support different-size UE, can wirelessly charge multiple UE at the same time, increases the coupling coefficient, increases the transferred-power efficiency, decreases power loss, decreases charging time, may mitigate damages to the UE and the WPT system caused by thermal energy, enhances user experience, and enables a user to use electric energy more efficiently.

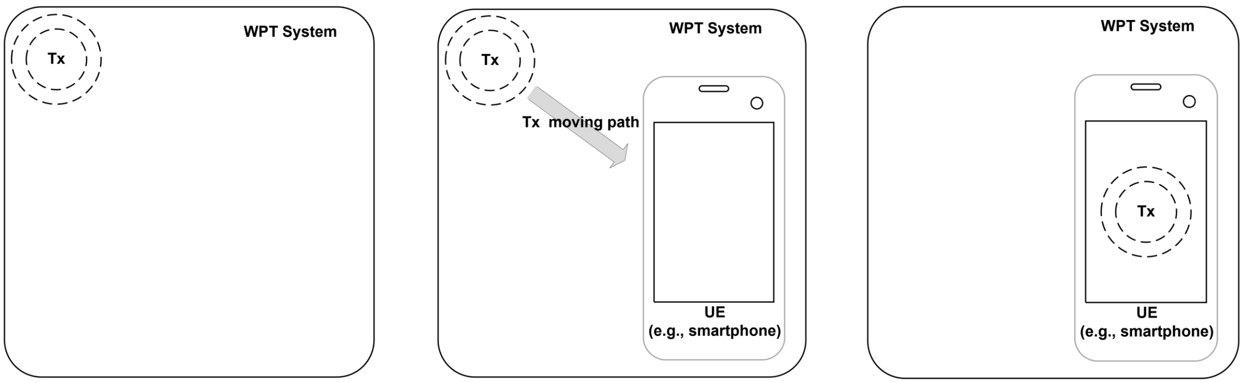
Keywords:

Wireless-charging pad, wireless power transfer, WPT, motorized wireless-charging pad, wireless charger, inductive charging, motorized WPT, tunnel magnetoresistance, TMR, magnetic tunnel junction, MTJ, inductive charger, Qi charger, motorized Qi charger, user equipment charger, smartphone charger, smartwatch charger, transmitter, Tx, receiver, Rx.

Background:

A user may often utilize a wireless power-transfer (WPT) system (*e.g.*, wireless-charging pad, Qi charger) to charge user equipment (UE), such as a smartphone, earphones, a smartwatch, and the like. WPT systems use inductive coupling to wirelessly charge the UE. Designing an effective and efficient WPT system has some challenges. One challenge is minimizing the lateral-coil misalignment between the transceiver (Tx) of the WPT system and the receiver (Rx) of the UE. The lateral-coil misalignment causes a decrease in the transferred-power efficiency between the Tx and Rx coils. The decrease in the transferred-power efficiency is due to power loss, which often manifests itself as thermal energy (heat). The user may often notice that the UE may get warm when using the WPT system to charge their UE and may not understand that some of the generated heat is due to the lateral misalignment between the Tx of the WPT system and the Rx of the UE.

Original design manufacturers (ODMs) of WPT systems, using various designs (*e.g.*, using a transparent pad surface, using a semi-transparent pad surface, using light-emitting diodes, designing a target location on the pad surface) can indicate the location of the Tx of the WPT system and guide the user where to place their UE to increase the transferred-power efficiency. Even in such cases, the user may not know exactly where the Rx of the UE is located and may still struggle to optimally laterally align the Rx of the UE to the Tx of the WPT system. To help improve the lateral alignment between the Tx of the WPT system and the Rx of the UE, some ODMs of WPT systems may automatically align the Tx of the WPT to the Rx of the UE, as is illustrated in Figure 1.



1A) WPT System **1B) WPT System and UE** **1C) Automatic Lateral Alignment of the Tx and Rx**

Figure 1

The WPT system illustrated in Figure 1 incorporates a printed circuit board (PCB) coil (not illustrated) on top of the Tx of the WPT System. It is worth noting that the dashed line means that the Tx is located below the pad surface of the WPT system; refer to Figure 1A. Assume the user places their UE on the right side of the pad surface of the WPT system, as is illustrated in Figure 1B. Once the PCB coil that sits on top of the Tx of the WPT system senses the Rx coil (not illustrated) of the UE, the WPT system uses a motor to move and laterally align the Tx of the WPT system to the Rx of the UE, as is illustrated in Figure 1B and Figure 1C. Thus, the WPT system illustrated in Figure 1 automatically performs a lateral alignment between the Tx and the Rx and increases the transferred-power efficiency without needing the user to manually make such alignment.

The example in Figure 1 illustrates how a WPT system can automatically laterally align the Tx to the Rx of a large-size UE, such as a smartphone, but using a PCB coil to detect the Rx of a small-size UE, such as earphones, is challenging. In addition, the user of the smartphone in Figure 1 may also use a thick smartphone case, which increases the vertical distance of the Tx to the Rx. Generally, especially for distances greater than three millimeters (mm), an increase in the vertical distance between the Tx and Rx decreases the coupling coefficient, which leads to a decrease in the transferred-power efficiency, an increase in power loss, an increase in thermal energy, and wasted energy.

Therefore, it is desirable to have a technological solution that can automatically laterally and vertically align the Tx of the WPT system to the Rx of the UE. Also, it is desirable to have a technological solution that can increase the transferred-power efficiency regardless of the size of Rx, and that can charge more than one UE at a time (*e.g.*, a smartphone and earphones). Such technological solutions can improve the user experience, may mitigate damages to the UE and the WPT system caused by thermal energy, can decrease charging time, and enable the user to use electric energy more efficiently.

Description:

This publication describes a motorized wireless power transfer (WPT) system (*e.g.*, motorized Qi charger) that utilizes tunnel magnetoresistance (TMR) to laterally and vertically align the transmitter (Tx) of the WPT system to the receiver (Rx) of a user equipment (UE), such as a smartphone, earphones, a smartwatch, and so forth. TMR is a magnetoresistive effect that occurs in a magnetic tunnel junction (MTJ) element, which is a component consisting of two ferromagnets separated by a thin insulator (a tunnel barrier), as is illustrated in Figure 2.

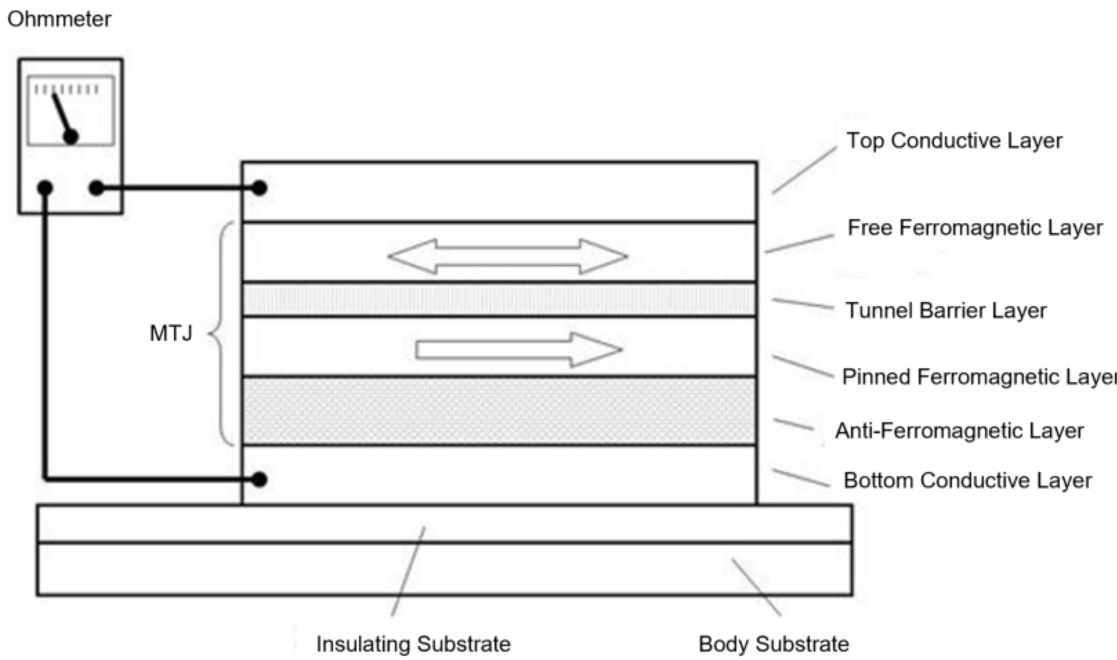


Figure 2

Figure 2 illustrates a schematic cross-section diagram of the MTJ element structure. The MTJ element has a pinned ferromagnetic layer, a tunnel barrier layer, a free ferromagnetic layer, and an anti-ferromagnetic layer, as is illustrated in Figure 2. A bottom conducting layer is electrically coupled to the anti-ferromagnetic layer, and a top conducting layer is electrically coupled to the free ferromagnetic layer; refer to Figure 2. The anti-ferromagnetic layer helps to couple the magnetic behavior of the free ferromagnetic layer and the pinned electromagnetic layer. The magnetization direction of the pinned ferromagnetic layer is fixed, while the magnetization direction of the free ferromagnetic layer can easily rotate. A change in the magnetizing direction leads to a change in magnetoresistance that can be quantified by measuring the resistance between the top conductive layer and the bottom conductive layer, as is illustrated in Figure 2.

Preferably, in an MTJ element, the response curve of the magnetoresistance (R) versus (vs.) the magnetic field (H) is perfectly linear. The R vs. H curve, however, exhibits magnetic hysteresis, as is illustrated in Figure 3.

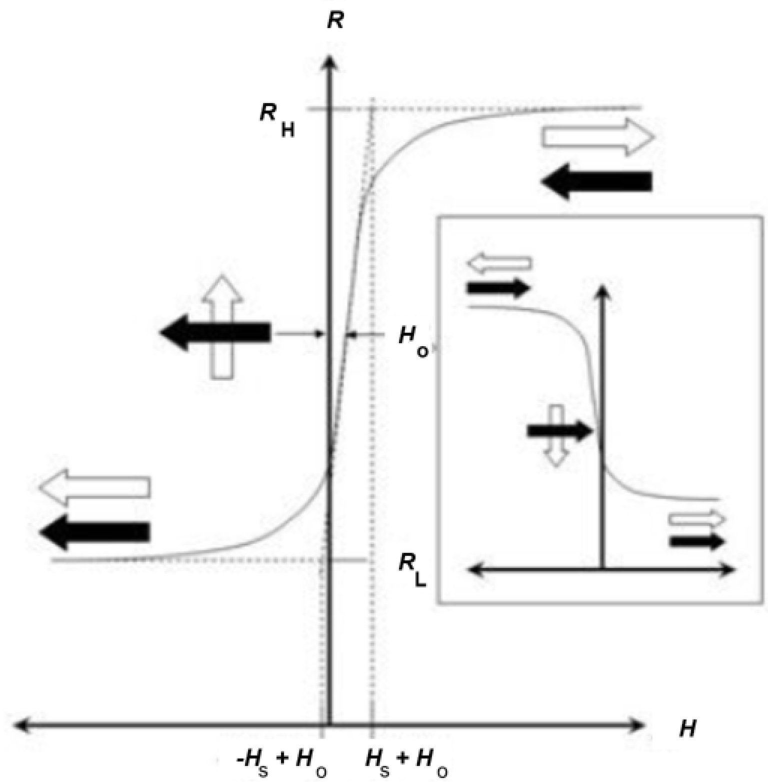


Figure 3

Figure 3 illustrates the R vs. H curve, which describes the resistance change as a function of the angle between the magnetization directions of the free ferromagnetic layer and the pinned ferromagnetic layer. In Figure 3, H_s refers to the saturation region of H, and H_o refers to the offset region of H. The white arrows represent the direction of the free ferromagnetic layer magnetization, while the black arrows represent the direction of the pinned ferromagnetic layer magnetization. When the free ferromagnetic layer magnetization is antiparallel (180-degrees angle) to the pinned ferromagnetic layer magnetization, the resistance has a maximum value, R_H; refer to Figure 3. When the free ferromagnetic layer magnetization is parallel (zero-degrees angle) to the pinned ferromagnetic layer magnetization, the resistance has a minimum value, R_L; refer to Figure 3. When the magnetizations of the free and pinned ferromagnetic layers are at a perpendicular (90 degrees) angle, the resistance is the median of R_H and R_L, the MTJ element has low hysteresis, and the magnetoresistance is highly sensitive to a change in the magnetic field because the R vs. H cure is nearly linear; refer to Figure 3. Therefore, an original device manufacturer (ODM) can mitigate hysteresis by using TMR sensors with MTJ elements that exhibit low magnetic hysteresis and high magnetoresistance sensitivity to a change in the magnetic field.

Lateral Alignment

The TMR sensor reliably detects the magnetic field distribution and can be used to detect the lateral alignment and/or misalignment between the Tx of the WPT system and the Rx of the UE, as is illustrated in Figure 4 (Figure 4A, Figure 4B, Figure 4C, and Figure 4D).

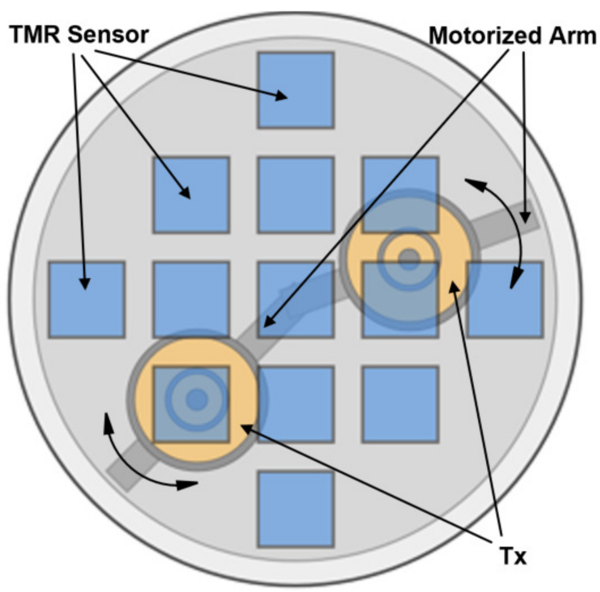


Figure 4A

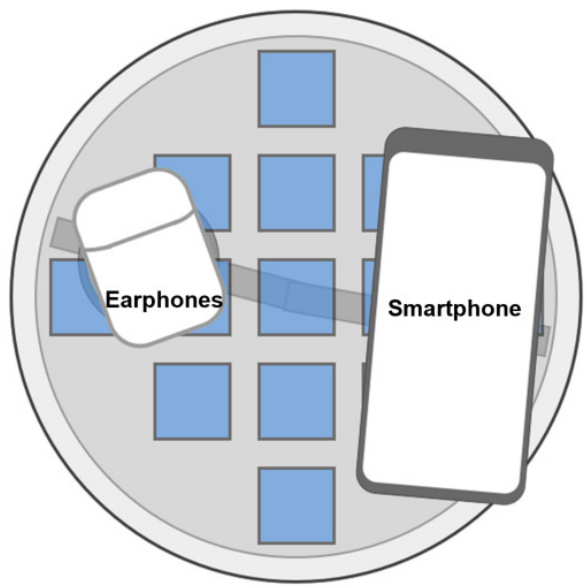


Figure 4B

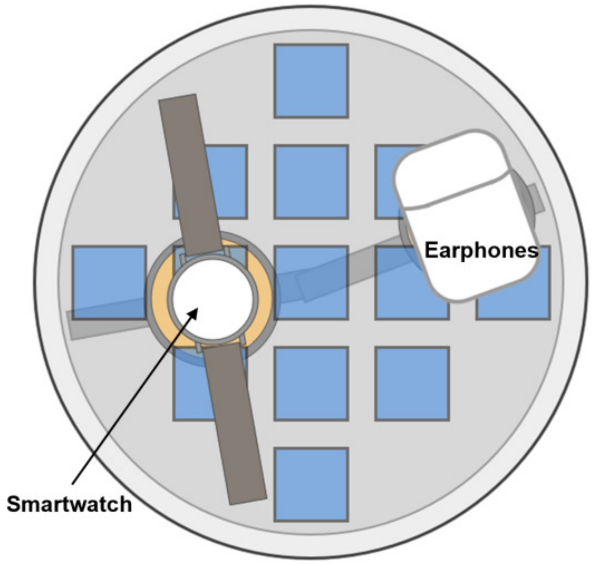


Figure 4C

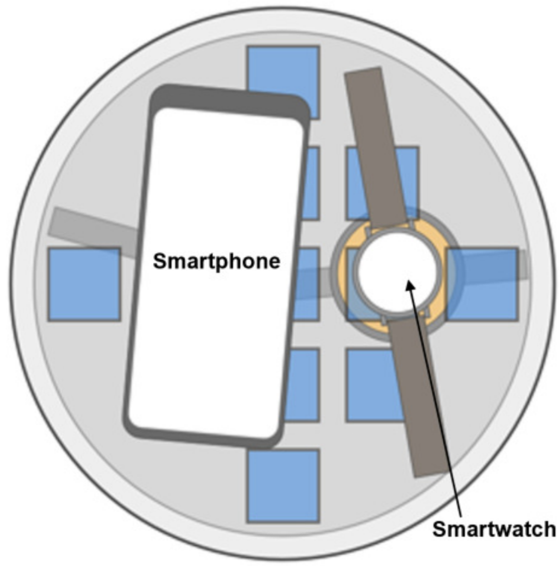


Figure 4D

Figure 4

Figure 4A illustrates a WPT system that utilizes TMR sensors (the blue squares). The TMR sensors are arranged in a three-by-three (3x3) matrix in the center of a circular charging pad with an additional four (4) squares to cover more area—making up a total of thirteen (13) TMR sensors. The exact number and spatial arrangement of the TMR sensors may differ depending on the shape and size of the charging pad. The WPT system has two (2) transmitters (the yellow circles) sitting on top of two (2) motorized arms (the grey rectangles), as is illustrated in Figure 4A. The motorized arms are physically arranged similar to the minute and the hour hands of an analog watch—one on top of the other. Each motorized arm can rotate 360 degrees clockwise or counterclockwise relative to a center. The first Tx sits on top of the first motorized arm, and the second Tx sits on top of the second motorized arm. Also, each Tx can move from the center to the edge of the circular pad by utilizing the respective motorized arm. Essentially, the two transmitters can move to any location of the circular pad. The WPT system provides current to the Tx using a constant current source. Consequently, the magnetic field induced by the Tx is constant.

Therefore, the TMR sensor can only detect a change in the magnetic field that is induced by the presence or the misalignment of the Rx of the UE.

Figure 4B illustrates the presence of two UE, a smartphone and a case holding a pair of wireless earphones. The TMR sensors detect the presence of the receivers of both UE. An analog-to-digital (ADC) converter of the WPT system samples and processes the output of the TMR sensors and feeds that data to a microcontroller, which can determine the position of each Rx based on the symmetry of the variable magnetic field distribution. The WPT system then uses direct-current (DC) motors to move and laterally align the first Tx to the smartphone and the second Tx to the earphones, as is illustrated in Figure 4B. Similarly, the WPT system can charge a smartwatch and the earphones (Figure 4C), the smartphone and the smartwatch (Figure 4D), and any combination of two UE, as is illustrated in Figure 4B, Figure 4C, and Figure 4D.

Although not illustrated in Figure 4, an ODM can use derivative designs to incorporate more than two transmitters and more than two motorized arms. Revisiting the analogy of the design in Figure 4 to an analog watch, the ODM can add a third motorized arm that helps move a third Tx, similar to the second hand in the analog watch. Therefore, theoretically, the ODM can integrate one, two, three, and so forth, transmitters and/or motorized arms. In addition, the number of transmitters does not have to equal the number of motorized arms. For example, the ODM can place two transmitters in one motorized arm, where one transmitter can move from the beginning to the center of a motorized arm, while the other transmitter can move from the center to the edge of the motorized arm.

Vertical Alignment

As in the case of lateral alignment, the WPT system can detect a change in the magnetic field due to a change in the vertical position. Generally, especially for distances greater than three millimeters, an increase in the vertical distance between the Tx and Rx decreases the coupling coefficient, which leads to a decrease in the transferred-power efficiency, an increase in power loss, an increase in thermal energy, and wasted energy. UE, such as a smartphone, can accommodate various accessories, such as a smartphone case. If the user protects their smartphone with a smartphone case that is two or three millimeters thick, the distance between the Tx and the Rx increases by the thickness of the smartphone case. To this end, the WPT system can vertically move the Tx, up or down, to accommodate for the change in the vertical distance between the Tx of the WPT system and the Rx of the UE. In order for the WPT system to accurately adjust the height of the Tx, the microcontroller of the WPT system considers the exact location of the Rx inside the UE because there is a "sweet spot" in the vertical distance of the Tx to the Rx to achieve the highest transferred-power efficiency. This publication references a three millimeters vertical distance. Nevertheless, the exact "sweet spot" vertical distance depends on the design of the Tx and the design of the Rx. Regardless of the exact design of the Tx and the Rx, the described WPT system can adjust the vertical position of the Tx.

In addition, to align the Tx automatically laterally and vertically to the Rx, the described WPT system is advantageous regarding cost, accuracy, stability, and design versatility. TMR sensors are inexpensive to produce thus, the ODM can use an array of a considerable number of TMR sensors. The number of TMR sensors is independent of the number of transmitters and/or the number of motorized arms. As such, an ODM may use the same array layout of TMR sensors on various products. In addition, TMR sensors do not take much "real estate," enabling the ODM to increase the number of TMR sensors to provide better position data to the microcontroller of the WPT system—that is another reason why an array of TMR sensors can detect the receiver of small-size UE. Furthermore, TMR sensors produce less thermal energy (heat) compared to coils. A reduction in thermal energy increases the longevity of the WPT system and the UE, decreases operating costs, and enables the user to use electric energy more efficiently.

In conclusion, a motorized WPT system that utilizes an array of TMR sensors, motorized arm(s), and transceiver(s) that can automatically move laterally and/or vertically to optimize the distance between the transceiver(s) of the WPT system and the receiver(s) of the UE, can support different-size UE, can wirelessly charge multiple UE at the same time, increases the coupling coefficient, increases the transferred-power efficiency, decreases power loss, decreases charging time, may mitigate damages to the UE and the WPT system caused by thermal energy, enhances user experience, and enables a user to use electric energy more efficiently.

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