

Implementation of Intermediate Passive Loop Coils to Extend the Range of Qi Wireless Charging

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Abstract—Wireless power transfer (WPT) based system such as Qi charging technology can not operate with a separation between transmitter and receiver coils. In this paper, a novel passive wireless loop made with magnetic wire is proposed to extend the range between the transmitter and receiver coil. One end of the proposed loop coil is placed on the Qi transmitter while the other end is placed on the Qi receiver. Experimental results are presented for coils with different number of turns and diameter, where Qi transmitter and receiver were separated by a distance of 10 inches. The proposed setup was able to reasonably provide similar performance as the traditional setup of coil positions, while increasing the range of Qi charging.

Index Terms—wireless power transfer, Qi charging, passive loop coil, efficiency

I. INTRODUCTION

Wireless power transfer (WPT) system is a way to transfer power from transmitter (Tx) to receiver (Rx) without using any wire. WPT is proved to be advantageous where using the wired connection is not feasible and inconvenient. Several technological options for WPT are, inductive coupling (ICp), magnetic coupling (MCp), microwave, and laser radiation. All of these techniques have different power level, frequency, transfer distance, size and forming factors that are preferred by a certain specific application over the others. Using far field, microwave and laser radiation can transfer power over meters or hundreds of meters, but the power level is relatively small in order to avoid hazardous radiation [1] - [2]. On the contrary, the ICp and MCp use near field. Although the transfer distance is usually limited to a range of centimeters, while the transferred power can reach to a level of tens of kilowatts. The inductive coupling systems working in kilohertz band are also usually tuned to resonance by using external capacitors [3] - [4]. As the ICp technique uses low frequency non-radiative near field, it is suitable to use in devices placed near human. As a result, this technique is advantageous to wearable devices. The ICp based WPT system has gained popularity in different body-worn sensors and devices and as well as, medically implanted devices [5] - [7]. Moreover, wireless charging for smartphones is already available commercially. For instance, Qi charging based solution is now available which provides the way to charge smartphones wirelessly [8]. Also, power transfer for electric vehicle using WPT is being investigated

to remove the need of already available wired charging system [9].

In many cases, the WPT system uses planar spiral coil (PSC) based design for Tx and Rx side coils. Because of the spiral structure, the magnetic flux is concentrated on the center of the structure. To minimize the effect of leakage flux, the Rx coil is placed coaxially with respect to the Tx coil. The amount of magnetic flux is reduced by the cube of the distance as the coils are separated further. Also, the power transfer decreases by the square of 60 dB per decade. Hence, the Tx and Rx coils are placed less than 1 inch distance. In some applications such as, implanted deep brain stimulator, we might need the Tx and Rx to be placed further away. Many groups have been conducting investigations to resolve the limitations associated with shorter distance by using multiple coils with larger coil size or using ferromagnetic materials [10].

In this paper, a novel method for increasing the range of Qi charging is proposed by implementing wireless passive loop coils. Two coils were connected in series. One end of the loop coil is placed on the Qi tx and the other end of the series connected loop coil is placed on top of the Qi Rx coil. The proposed coil has been investigated with different coil diameter (22, 26 and 28 gauge) and number of turns (7, 9 and 11 turns). The efficiency of the proposed technique is also presented to show the feasibility of this novel technique. Although this work used the Qi charging based solution, the proposed concept is not limited to Qi.

II. METHODOLOGY

In this section, the theoretical concept for the proposed technique is discussed. Also, the experimental setup showing different components of the proposed method is presented.

A. Theory

In traditional WPT system, the Tx coil is placed on top of the Rx coil with no separation between them. In our proposed technique, 2 passive coils connected in series are laced in between the Qi Tx and Rx coil. Fig. 1 shows the setup for wireless charging for 2 different cases: usual setup for WPT based charging (Fig. 1a) and the proposed technique with wireless passive coil (Fig. 1b). The output current in the receiving side can be expressed as follows, where, B_{Tx} and

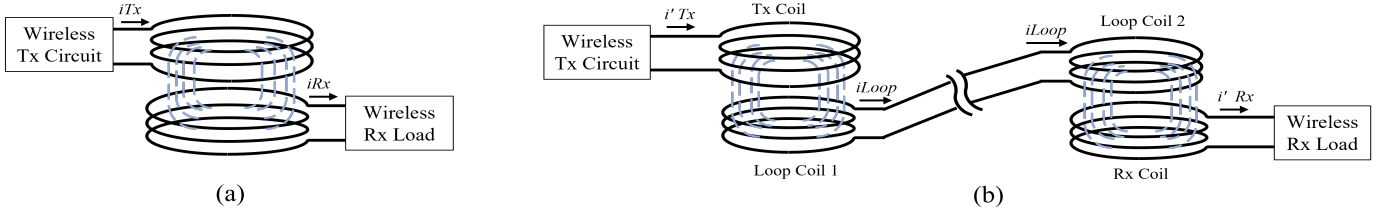


Fig. 1. (a) traditional WPT system where Tx and Rx coil are placed on top of each other, (b) proposed WPT range extension method where passive wireless loop coils, composed of Loop Coil 1 (LC1) and Loop Coil 2 (LC2), is used between Tx and Rx coil.

B_{LC2} are magnetic flux density of Qi Tx and LC2, i_{Tx} , i_{Rx} , i_{Loop} are current through Tx, Rx of the proposed setup, i'_{Tx} , i'_{Rx} are current through Tx, Rx of proposed setup, ϕ_{Rx} , ϕ_{LC1} are magnetic flux in Rx and LC1, L_{Rx} , L_{C1} are inductance of Rx and LC1, N_{Rx} , N_{LC1} are number of turns for Rx and LC1, respectively.

$$B_{Tx} \propto i_{Tx}$$

$$\phi_{Rx} = \int (B_{Tx}) dS$$

$$i_{Rx} = N_{Rx} * \phi_{Rx} / L_{Rx}$$

$$\propto N_{Rx} * \int (i_{Tx}) dS / L_{Rx}$$

Coupling equation for proposed loop coils:

$$B_{Tx} \propto i'_{Tx}$$

$$\phi_{LC1} = \int (B_{Tx}) dS$$

$$i_{Loop} = N_{LC1} * \phi_{LC1} / L_{LC1}$$

$$B_{LC2} \propto i_{Loop}$$

$$\phi_{Rx} = \int (B_{LC2}) dS$$

$$i'_{Rx} = N_{Rx} * \phi_{Rx} / L_{Rx}$$

$$i'_{Rx} = N_{Rx} * \int (B_{LC2}) dS / L_{Rx}$$

$$\propto N_{Rx} * \int ((N_{LC1} * \int (i'_{Tx}) dS) / L_{LC1}) dS / L_{Rx}$$

The overall efficiency of the proposed method is, $\eta' = \eta_{LC1} * \eta_{LC2}$, where, η_{LC1} and η_{LC2} are efficiency for LC1 and LC2 respectively. This equation suggests that the expected efficiency on the Rx side for proposed setup will be somewhat less than the traditional setup.

B. Experimental Setup

The proposed system uses commercial Qi charging system from GeekFun (Model: EK1854). The wireless passive loop coil uses interconnecting wires of any length. The experimental setup for the proposed technique is shown in Fig. 2. LC1 is placed on top of the Tx coil and LC2 is placed on top of the Rx coil. A breadboard setup was used to put the Rx load. In the Rx side, the nominal load resistor is connected in series with shunt resistor, where, the shunt resistor is always kept 1% of the nominal load resistance. The voltage across both of these resistance is observed using a Keysight oscilloscope (Model: KT-DSOX1204G-InfiniiVision 1000 X-Series Oscilloscope). To calculate the current through the Rx side, the voltage across the shunt resistor is taken into account. To calculate the efficiency, the power from the Tx side is compared with the power achieved at the Rx side. 2 different setup has been used to collect data. Setup A consists of the traditional Qi charging setup where, Tx and Rx coils are placed on top of each other. Setup B reflects the proposed technique with 2 passive coils in series placed on Qi Tx and Rx. In setup B,

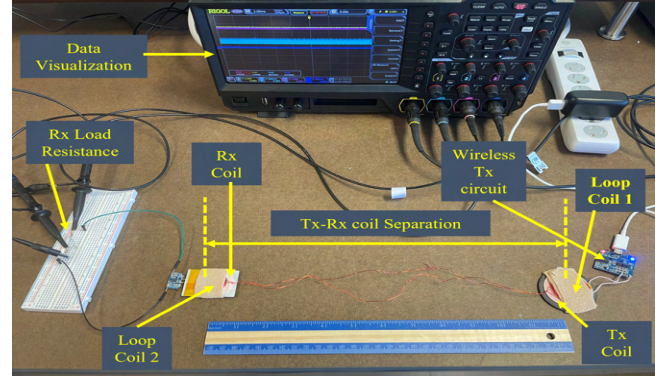


Fig. 2. Experimental setup of proposed wireless loop coils implemented with Qi Tx and Rx coil.

Tx and Rx coils are separated horizontally by approximately 10 inches distance. For setup B, coil diameter and number of turn were changed to different values.

III. EXPERIMENTAL RESULTS

Fig. 3 shows output voltage and current achieved for traditional and proposed setup. In traditional setup, the GeekFun Tx is placed over the Rx. In proposed setup, the passive loop coils have been placed between Tx and Rx coil with a separation of approximately 10 inches between them. The load resistance was varied from 100 Ω to 47 k Ω . Fig. 3 represents the setup with 22 gauge loop coil with 11 turns for both of the loop coils. Same experiments have been done for 22, 26 and 28 gauge coils with 11, 9 and 7 turns. Also, the loop coils shape were similar to the Qi Tx and Rx coil. As depicted in the figure, pattern of output voltage and current values are almost identical even if the Tx and Rx coils are separated by a distance of 10 inches using the passive loop coils.

Fig. 4 shows the performance of the proposed setup with different coil size and number of turns. The magnetic coil sizes used in the proposed setup were 22, 26 and 28 American wire gauge (AWG). For each of the different coil diameters, the number of turns were varied for 7, 9 and 11 turn respectively. The efficiency is better with lower load resistances compared to higher ones. As depicted in the figure, the overall performance of the efficiency is better when number of turn is increased to 11. Also, better efficiency is observed for greater coil diameter (22 AWG) compared to lower ones in case of 1 k Ω to 47 k Ω load resistances.

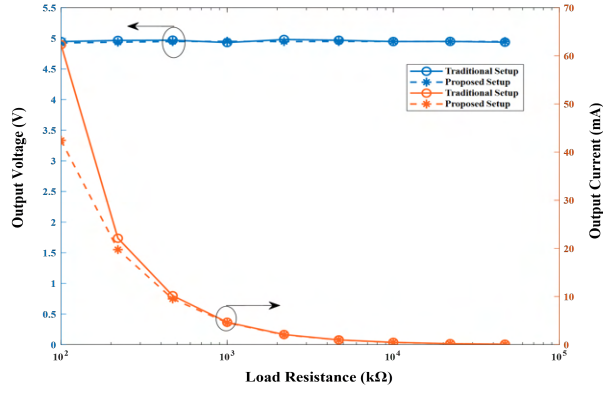


Fig. 3. Output Voltage and Current for different load resistance: (A) for traditional setup (GeekFun Tx over Rx), (B) for proposed setup (Tx and Rx coils separated by a distance of 10 inches by two loop coils).

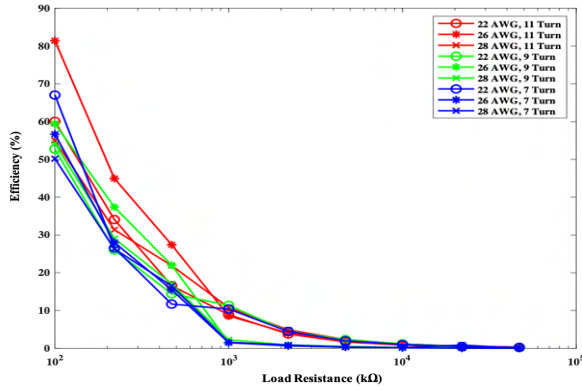


Fig. 4. Performance of the proposed setup in terms of efficiency for different coil diameters and number of turns.

Table I presents the performance comparison between Tx-Rx and proposed setup for different load resistances. The Tx-Rx setup implements the GeekFun Tx and Rx traditionally placed on top of each other. The Tx-Rx setup offers greater efficiency, however the range is limited. The proposed setup offers longer range power transfer with reasonable efficiency compared to Tx-Rx setup when the load resistances are lower.

IV. CONCLUSION

A new method to increase the range of WPT system by implementing wireless passive loop coil is proposed in this paper. The proposed method for specific coil diameter and number of turns, can offer reasonably identical output voltage and current as like as traditional setup. By using the proposed method the distance between Qi Tx and Rx can be extended to at least 10 inches. The work demonstrated 2 coil implementation in series. However, it is not limited to 2 coils. The work can further be improved by considering the resonant configuration for the loop coils. Using tuning capacitor can improve the power efficiency, which can be investigated further. The proposed method can be useful in

TABLE I
PERFORMANCE COMPARISON BETWEEN TX-RX AND PROPOSED SETUP
FOR DIFFERENT LOAD RESISTANCES

AWG, Turns	Efficiency (%)								
	Load resistance (kΩ)								
	0.1	0.22	0.47	1	2.2	4.7	10	22	47
22,11	60.1	34.1	16.6	8.9	3.8	1.7	0.9	0.4	0.3
26,11	81.4	45.0	27.4	8.6	4.1	1.9	0.9	0.4	0.3
28,11	55.1	31.4	21.9	10.8	4.9	2.3	1.2	0.5	0.4
22,9	52.7	26.1	14.4	11.4	4.7	2.3	1.2	0.5	0.2
26,9	59.5	37.4	22.0	0.2	0.8	0.3	0.2	0.1	0.1
28,9	54.2	29.1	17.1	2.3	0.9	0.5	0.2	0.1	0.1
22,7	67.1	26.6	11.7	10.4	4.5	2.1	1.1	0.5	0.3
26,7	56.7	28.0	15.5	1.5	0.7	0.3	0.1	0.1	0.1
28,7	50.2	26.3	16.5	1.6	0.9	0.4	0.1	0.9	0.1
Tx-Rx setup	63.9	47.9	32.5	48.6	31.3	18.7	13.9	5.4	3.1

power transfer for wearable, consumer electronic products, physical implant or for autonomous electric vehicles.

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