Embedded Solenoid Coil to Improve Misalignment in Magnetic Resonance Power Transfer System

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***Abstract* —A embedded solenoid coil is proposed for wireless power transfer system in this paper. Measurement shows the misalignment distance convers a half of coil diameter and tilted angle covers the range of 90 degree to maintain the transfer efficiency. This proposed coil solves the misalignment between the transmitter and receiver coil in resonance wireless power transfer system.**

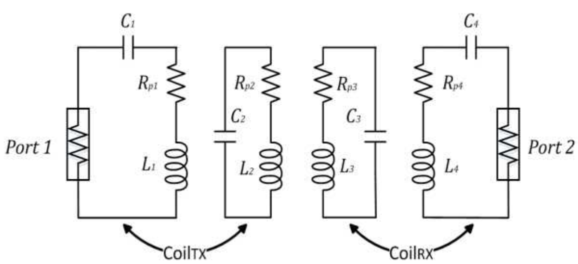


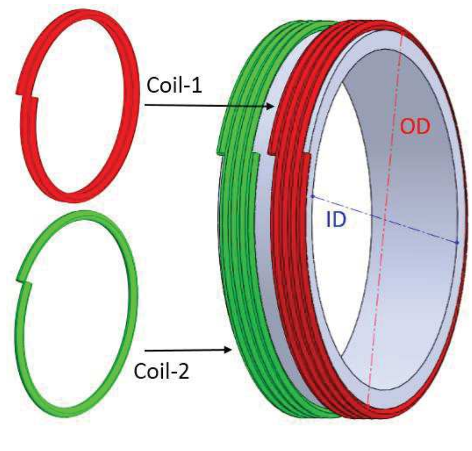
Figure.1 Equivalent circuit of four coil system.

***Index Terms* – Embedded solenoid coil, misalignment, magnetic resonance, wireless power transfer.**

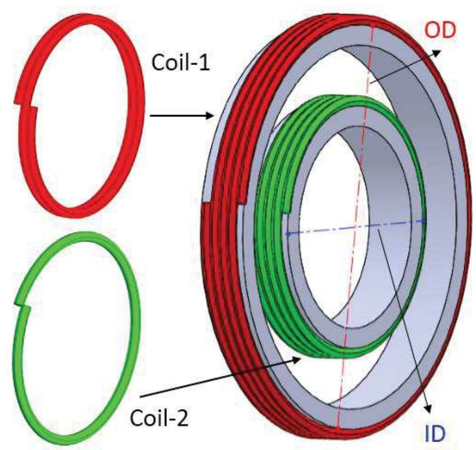
I. INTRODUCTION

The magnetic resonance is the most suitable solution among the available approaches for wireless power transfer (WPT) system. However, a conventional WPT system still suffers from efficiency degradation, due to changes in the position of the receiver. The receiver is always moving through the location, which results in transfer efficiency degradation caused by the variations in the distance, angle, and axial misalignment [1]-[2].

Reported researchers improved the WPT efficiency using ceramic filled cavity [3]. Nevertheless, the system was still not suitable under varying conditions. Hence, an WPT system to solve the misalignment must have additional methods to maintain a strong transfer efficiency under these dynamic circumstances. In previous research [4]–[15], an efficiency improvement was demonstrated, limited to a distance change with a symmetric coil WPT system. However, all the research are devoted in the efficiency improvement and the misalign between the coil is still inferior in reported literature. To solve the problem, this work presents an embedded solenoid coil to achieve the high transfer efficiency of an WPT system with variations in the relative distance, angle, and axial misalignment between asymmetric transmitting and receiving modules.



(a)



(b)

Figure.2 (a) Traditional coupling coil topology (b) Proposed embedded coil topology.

Measurement result demonstrates the proposed topology not only has wide angle performance but also improves the transfer efficiency.

II. EMBEDDED SOLENOID COIL DESIGN

The circuit of magnetic resonance coil is depicted in Fig.1. The coil includes four loops to achieve resonance power transfer in WPT system. The transmitter coil ($coil_{Tx}$) uses coil-1 and coil-2 to deliver power, the receiver coil ($coil_{Rx}$) adopts coil-3 and coil-4 to receive power. The source and load are conneted to coil-1 and coil-4, respectively. The circuit is constructed by four coils to acquire magnetic resonance behavior. The coil inductor, capacitor, and resistaor are denoted by L, C and R_p, respectively. The subscript of L, C and R_p represents the port number, respectively.

Traditional structure is the parallel topology of the four coils as depicted in Fig.2(a). The coil-1 and coil-2 are parallel to construct the coil_{Tx} , the coil-3 and coil-4 are parallel to construct the coil_{Rx}. The coil-1 and coil-2 use the green and red color, respectively. The turn number of coil-1 and coil-2 is 1 and 2, respectively. To solve the misalign between the transmitter and receiver, the proposed coil adopts the structure with the embedded topology of coil-1 and coil-2 in Fig.2(b). The coil-2 is embedded inside coil-1 to achieve a transmitter coil. Therefore, the inner dimension is different in the coil-1 and coil-2. The inner and outer dimensions are denoted as ID and OD in the Fig.2.

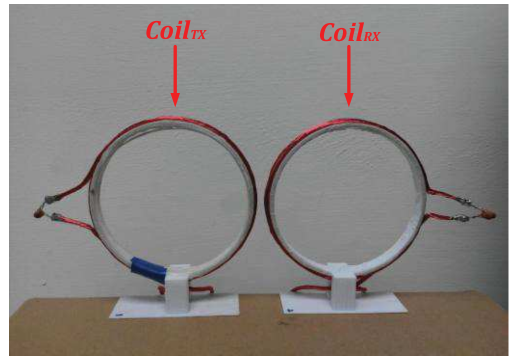
The WPT system is design to operate at 13.56MHz, the coil design parameters and geometry dimesions of the proposed and traditional topology are listed in Table I.

Table I
Device parameters and geometry dimensions of proposed and traditional topologies

	Proposed (Coil_{TX} 、Coil_{RX})	Traditional (Coil_{TX} 、Coil_{RX})
L_1, L_4	0.44 uH	0.44 uH
L_2, L_3	0.8 uH	0.9 uH
R_{p1}, R_{p4}	657.8 mΩ	516 mΩ
R_{p2}, R_{p3}	743.3 mΩ	596.6 mΩ
C_1, C_4	310 pF	308 pF
C_2, C_3	165.12 pF	145 pF
Q_1, Q_4	117.7	109
Q_2, Q_3	103	95
Outer dimension (OD)	10cm	10cm
Inner dimension (ID)	8.2cm	9.6cm
Resonance frequency (f_0)	13.56MHz	13.56MHz

To verify the proposed topology, the traditional and proposed solenoid coils are depicted in Fig.3(a) and Fig.3(b), respectively. The coupling coils use the network analyzer to measure the S-parameter. The efficiency is calculated by the square of S_{21}[16]. Figure 4 depicts the efficiency versus the separation distance of the two coils. The distance is denoted by d between coil_{Tx} and coil_{Rx}. The graph plots the efficiency in a distance range of 2cm to 5cm. The results show the proposed topology has a peak efficiency of 82% in the range of d=3~4cm. The efficiency is increase 157% in the proposed topology.

To discuss the misalignment of the vertical height (g), the separation distance is kept at d=2cm. Figure 5 shows the efficiency versus vertical height plot. The result demonstrates



(a)

(b)

Figure.3 (a), (b)Implementaion of traditional and proposed coupling coils

the proposed topology increase the efficiency 101.46%, the peak efficiency is 83% at g=4cm.

The misalignment also includes the tilted angle(θ). Figure 6 depicts the tilted angle from 0° to 90° at a fixed distance d=2cm. The results show the efficiency improves 163% in the proposed topology. The peak efficiency is 82% in the range of θ=15° to

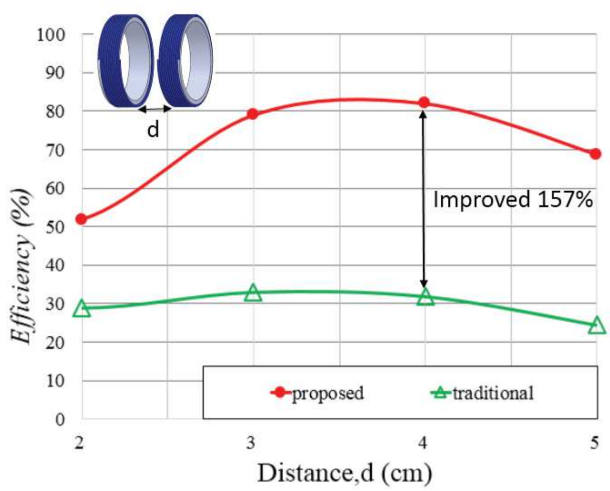


Figure.4 Measured efficiency versus separation distance. Efficiency is improved 157% at d=4cm.

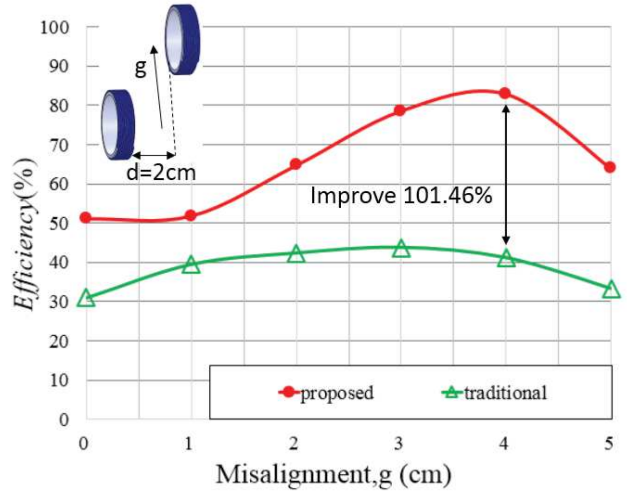


Figure.5 Measured efficiency versus misalignment distance. Efficiency is improved 101% at g=4cm.

45°. The phemoneon is a benifit result to solve the misalignment between the coils.

III. Conclusions

This paper proposed a embedded solenoid coupling coil to solve the misalignment between the transmitter and receiver coil in wireless power transfer system. The tilted angle can cover the range of 90 degree to maintain the transfer efficiency. Moreover, the misalignment distance convers a half of the coil diameter comparing the traditional counterpart. Measurement shows the optimal transfer efficiency is occurred at 4cm coupling distance. Result of this work provides a valuable refernece to design coupling coil for wireless power transfer application.

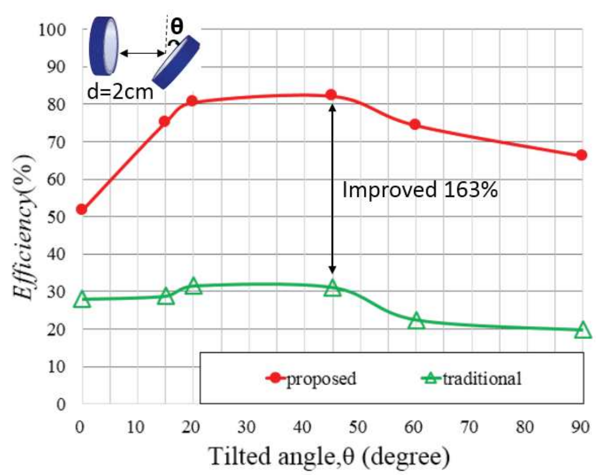


Figure.6 Measured efficiency versus tilted angle. Efficiency is improved 163% at θ=45°.

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