

Design and analysis of 2-coil wireless power transfer (WPT) using magnetic coupling technique

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ABSTRACT

2-coil non-radiative wireless power transfer (WPT) is studied to find the coil diameter ratio to effective distance of power transfer efficiency (PTE). Single circular coil and spiral coil are designed and simulated using CST software to compare the result of coil diameter versus effective distance of PTE by using S21 value. Accordingly, the quality factor (Q) of both coils are presented as Q factor is one of the parameter that affect the performance of WPT system. The result is promising as the effective distance is more than the coil diameter with (PTE) more than 50% using spiral coil as compare to single coil design.

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1. INTRODUCTION

Wireless power systems started by Nikola Tesla basically can be divided into two categories which are radiative and nonradiative. The nonradiative are known as inductive coupling and magnetic resonance coupling when coupled with resonator coil. Both techniques basically for low-power application having near to medium field range of distance. Manipulation of wireless power system to application are growing rapidly such as in power up sensor, charging consumer electronic device, biomedical implants, electric vehicle and even now underwater applications.

Theoretical aspects of WPT are rigorously studied as the system has few limitations especially on the effective distance of power being transfer and the sizing of the coil. Bigger coil size can transfer power wirelessly through longer distance, but it will be bulky and suitable only for big application. Same aspect to the coil design as previous researcher design the coil ranges from simple circular coil to helical shape and then planarized for WPT. Both aspects are influence by parameters such as mutual inductance, coupling factor (k) and quality (Q) factor that contributed in PTE performance [1].

In order to find the best parameter, the coil design is vary where some researchers using helical, wire wound, spiral rectangular and also printed spiral coil (PSC) [1-2]. Generally, the different coil design gives different value of effective distance and PTE but still the value of k, Q and impedance matching are not discussed in depth with relation to coil design. The coil is also big in size which limits the application to be used later. Apart from the coil design, the size of transmitter and receiver coil are also varied to find the best parameter with higher PTE at higher distance of transfer. The size of transmitter can be bigger as compare to receiver or vice versa particularly to increase or maximize the distance of PTE and reducing the skin effect

when the coils are close to each other. The main consideration if bigger transmitter or vice versa, the effective distance is still less as compare to coil diameter which conclude to ineffective WPT system in term of PTE.

Therefore, in this paper, the design and analysis of 2 coil same size system is investigated. The 2-coil same size WPT single circular coil and spiral coil are investigated based on the effective distance, PTE and ratio of distance (D) to diameter of the coils (D/d_m). The aim is to target the effective distance is more than the diameter of the coil and efficiency is more than 50%. The motivation for the design is to find small and efficient coil design that give higher effective distance (more than the diameter coil) and PTE. Q-factor of the coil is also investigated to find the effect to the distance and PTE.

Basic wireless transfer operation involves the transmission of energy from a transmitter to a receiver via oscillating magnetic field. The operation starts by converting direct current (DC) supplied by a power source to high frequency alternating current (AC) using specific designed of electronic circuit built together with transmitter. The AC current excite a wire coil in the transmitter that induce a magnetic field. When a receiver coil is placed within vicinity of the magnetic field, the field can energize an alternating current in the receiver coil. Electronic circuit in the receiver converts back the AC current into DC current which turn to usable power. WPT main purpose is transferring the energy itself not the information encoded in the energy. For maximum PTE, the transmitter and the receiver coil must resonate at the same frequency.

Nowadays, WPT technologies are going through active research which focused on maximizing power transfer efficiency (PTE). Many factors affect the PTE as stated earlier but the main focused here are the design of the transmitter and receiver coil and the Q-factor. The bigger the coil, the higher the effective distance and PTE due to more magnetic fields induce in between the transmitter and receiver coil. Bigger coil will be bulky, heavy in term of weight and certainly not suitable for small application. By tuning the Q-factor of the coil, the distance and PTE is believe to improve as higher Q-factor made the coils achieved to its maximum amplitude and stayed longer at resonant frequency thus allowing maximum power transfer. Therefore, same resonant frequency exhibit at transmitter-receiver coil produce low rate of energy loss apart from other dimensional factors such as number of turn of coils and coils diameter.

Further support and relate the Q-factor effect to WPT performance is the Figure of Merit (FoM) for coil. The FoM suggest that the Q-factor for a coil should be more than 100 to be effectively operate and transfer power efficiently [9-10]. Most of the research unable to relate the FoM, Q-factor and PTE performance in detail either by theory or experimental.

2. COMPLETE SYSTEM DESIGN

Figure 1 show the basic conceptual of 2 coil WPT which consist of a transmitter and a receiver coils. The design of the coil is single circular loop to be as a reference design. Both coils are connected with source and the placement separation of the coil is the distance of transfer or effective distance. Table 1 show the single coil parameter. The wire material selection in the CST simulation is copper pure.

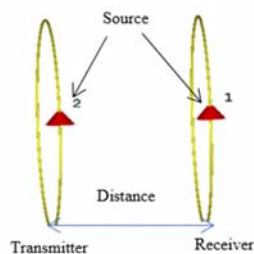


Figure 1. Basic conceptual of WPT system

Table 1. Single coil parameter

Coil Parameter (cm)	
Wire thickness	0.1
Inner radius	4.9
Outer radius	4.8

The distance is vary starting from 4 cm to maximum 7 cm and the value of S_{11} and S_{21} of the coil are measured to find the PTE according to the equation:

$$S_{21}dB = 20 \log S_{21} \quad (1)$$

$$n_{21} = S_{21}^2 \times 100\% \quad (2)$$

The value of measure S_{21} simulated is then compare with calculation using equation below:

$$|S_{21}| = \frac{k_{tx}^2 Q_{tx} Q_{rx}}{[1 + \sqrt{1 + k_{tx}^2 Q_{tx} Q_{rx}}]} \quad (3)$$

The Q-factor of the coil is taken for each distance variation to analyze the effect of the Q factor towards distance. The Q factor equation using for calculation is as below:

$$Q = \frac{2\pi fL}{R} \quad (4)$$

The coil is design with spiral shape coil with the same diameter as single 2-coil. Figure 2 show the 2-coil spiral design with the parameter as in Table 2. The value of S_{11} , S_{21} and Q-factor are taken for different distance for further analysis on the effect and comparison with the single circular 2-coil design.

Table 2. 2-coil spiral parameter

Coil parameter (cm)	
Wire radius	0.05
Coil progress (gap)	0.4
Inner Radius	0.5
Number of turns	5

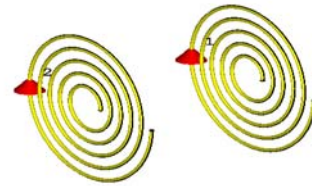


Figure 2. 2-coil spiral design

3. RESULTS AND ANALYSIS

Both coil designs are simulated at different distance starting from 4 cm to 7cm. The effective distance and PTE for both designs are compared and the result showed that the spiral coil gives better result with increase PTE over distance around 10%. Graph in Figure 3 show the overall results.

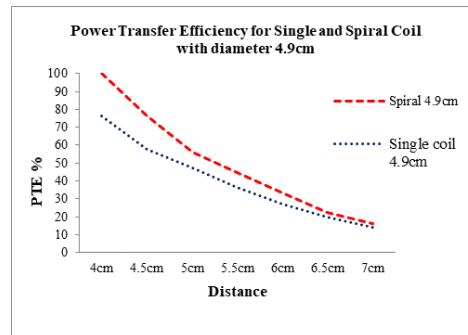


Figure 3. Power transfer efficiency for single and spiral coil with diameter 4.9cm

Table 3. Comparison with previous work

Reference	Dimension (d_{tx}, d_{rx})(cm)	Frequency	Efficiency	Distance (D (cm), D/d_m)	Coil type
Jiseong Kim, Jonghoon Kim, Sunkyu Kong, Hongseok Kim, In-Soo Suh, Nam Pyo Suh, Dong-Ho Cho, Joung-ho Kim, Senior and Seungyoung Ahn (2013)	(30,30)	30kHz	91%	(20, 0.67)	Wire wound coil
Paulo J. Abatti, Sérgio F. Pichorim, Caio M. de Miranda (2015)	(15,15)	589kHz	50%	(5, 0.33)	Helical
Zhigang Dang, Jaber A. Abu Qahouq (2014)	(11.5, 11.5)	3MHz	40%	(10, 0.87)	Helical
Yiming Zhang, and Zhengming Zhao (2014)	(28, 28)	289kHz	90%	(10, 0.357)	Helical
This work	(5, 5)	212MHz	44.53%	(5, 1.02)	Spiral

In comparison with previous work as in Table 3, most of the previous paper having large coil design which are more than 10 cm. The previous research is based on same size 2 coil conventional WPT as many other research more focusing on 3, 4 or more coils to increase the PTE versus distance [14]. The comparison is made based on the ratio of distance to the coil diameter (D/d_m). The (D/d_m) value are low comparing the efficiency to this work. Apart from the ratio, the design of the coil is also important as previous research are focusing to single, helical or wire wound coil design. Due to difficult of designing and developing the spiral coil, other design is much preferred.

The advantage of this design apart from small is that the spiral coil design is flat design making it suitable to be placed to smaller design of application or device. If the coil is resized to bigger size, the coil is still flat thus reducing the space to place it. Other type of coil design has certain variable length and width, which give effect to the thickness of the coil thus limiting to be embed to certain application or device.

Figure 4 are the results for the Q-factor for both coil. The spiral coil produce higher Q-factor as compare to single circular coil. In relation with the effective distance and PTE, proof that the Q-factor effect the WPT performance and different coil design produce different Q-factor. Further investigation on the Q-factor is recommended to extend the effective distance to higher value.

The hardware setup is done by choosing the spiral coil design. The coil is wound using the same specification as in simulation by using Litz Wire. The value of S_{11} and S_{21} are recorded by using the Vector Network Analyzer (VNA). Figure 5 simulation result by using spiral coil. In the measurement part the value of PTE are taken starting from 5 cm as below than that splitting frequency happen [4].

The hardware is design using Litz wire, wound as spiral coil without any impedance matching or capacitor. Usually capacitor is used to maintain the constant frequency at transmitter and receiver [6] coil but for this spiral design the operating frequency maintain at around 212MHz even the distance varied. The result is promising as the experimental result achieved better result as compare to simulation result. Figure 7 showed the spiral coil design using Litz wire.

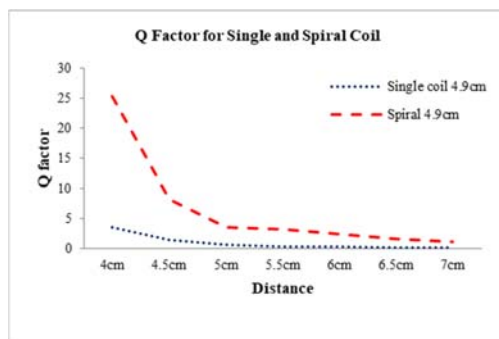


Figure 4. Q-factor for single and spiral coil

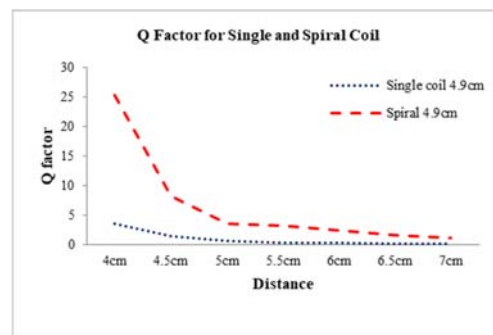


Figure 5. Comparison of experimental and simulation result

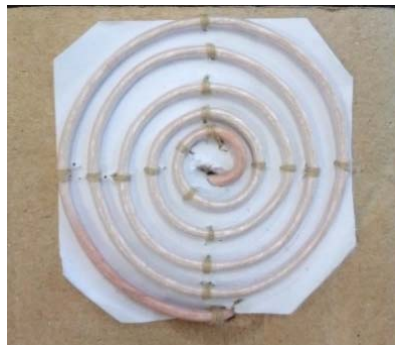


Figure 6. The spiral coil

4. CONCLUSION

The main objective of this paper is to analyze the 2-coil same size WPT using single circular and spiral coil design. The design of single circular is chosen as reference to compare with the spiral coil design interm of effective distance, PTE and also Q-factor. The spiral design is selected as the design suitable to be applied to all application ranging from small to bigger application as it is a flat coil that consume less space as compare to other design. The result of the simulated and experimental is good without even adding any tuning component to tune the frequency or increasing the Q-factor. Further investigation is needed to find the relationship between the Q-factor with the PTE. The effect of the coil parameter design such as the coil progress (gap) and wire diameter can be investigated whether its effect the Q-factor and the PTE.

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