



WIRELESS POWER TRANSFER VIA MAGNETIC RESONANCE COUPLING

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ABSTRACT

The study demonstrates efficient wireless power transfer between two resonators. This paper compares self-resonator coils with LC resonator, which exhibits higher efficiency than typical self-resonator device. The effects of the following on power transmission efficiency and the resonant frequency are numerically investigated in revealing the effect of external capacitor. The numerical results show that a power transmission efficiency of nearly 76% can be achieved at 70 cm distance.

Keywords: magnetic resonance coupling, LC resonator, self-resonator.

INTRODUCTION

The development of the revolutionary technology involving the transfer of electricity without the use of wires or Wireless Power Transfer (WPT) has recently become a significant area of interest among researchers in the field. By definition, WPT, also known as Wireless Electricity (WiTricity) refers to the transmission of electricity from a power source to an electrical load without using any wires. The technology which has removed the dependency on wires has in turn lead to the increasing demand on batteries among consumers such as seen in the application of wireless internet, mobile phones and blue tooth among others. Wireless Power Transfer (WPT) was first discovered around the turn of the 19th century by Nicola Tesla who put forward the concept of WPT through ionised air [1]. Wireless charging tools, namely electric toothbrushes, cell phones, laptops and electrical vehicles commonly apply a renowned WPT method known as inductive coupling. Its range of operation is restricted to short distances of below a centimetre as the magnetic coupling between two close coils forms the basis of this technique [2-3].

A plausible discovery was made by MIT's Karalis [3] involving a midrange wireless energy transfer as a result of an innovative scheme based on strongly coupled magnetic resonances, which is grounded on the basic notion that resonant objects switch energy effectively, whereas non-resonant objects demonstrate the opposite. A power transfer of 60 W and RF-to-RF coupling efficiency of 40% for 2 m, a distance of more than three times the coil's diameter was employed in the scheme's transmission.

By utilising the evanescent-wave coupling between two resonant coils, it is possible that the magnetic resonance coupling method to stretch out the operating range to lengthier distances, between tens of centimetres to a few meters [4-7]. Self-resonator and LC resonator are

two commonly applied variations of resonance coils in WPT [7]. While self-resonators resonance is made up with self-inductance coil and parasitic capacitance between turns, the LC type comprises of added lumped capacitor on the outside. The benefit of self-resonators lies in their low level of loss. However, the typical parasitic capacitance is exceedingly minimal due to the difficulty in realizing it at low frequency. As for LC type, it is more controllable during the design process. This paper highlights the comparison between the self-resonator and LC resonator and investigates the effect of the capacitor's existence. The magnetic field overpowers as the electric fields are mostly restricted within capacitors as stated in [6].

Section 2 establishes an overview system of the magnetic resonance coupling WPT system, while Section 3 provides the description of the proposed self-resonator and LC resonator. In the last section, Section 4, the simulation results of the proposed WPT system are presented.

WIRELESS POWER TRANSFER SYSTEM



Figure-1. Wireless power transfer system.

Figure-1 displays the overall wireless power system which is made up of the followings: RF power supply, matching network, resonator, rectifier and load. To facilitate and ensure maximum effectiveness of the WPT system, the parameters mentioned above are essential.



Along this line, this paper for the most part elaborates on magnetic resonance.

MODELLING AND ANALYSIS

The coupling coefficient is imperative in ensuring the increased capability of WPT as each of the quality factor Q in transmitter and receiver is minimal where magnetic induction method is concerned. Nevertheless, the application of magnetic induction for an extended distance is inappropriate since the coupling coefficient (k) is inversely proportional to the distance between the transmitter and receiver. On the contrary, a tunnel between transmitter and receiver is formed when the magnetic resonance make use of the resonance effect to secure a greater energy transfer rate even in the case of extended distances. The resonance phenomena between L and C can significantly increase each quality factor Q in both the transmitter and receiver, despite the lower coupling coefficient, r . This is shown in the equation below:

$$Q = \frac{\omega_o L}{R} = \frac{1}{R} \sqrt{\frac{L_{self}}{C_{self}}} \quad (1)$$

Where R , L and C are the self-resistance, self-inductance and self-capacitance of the coil. The most important parameters in the WPT system is the resonant frequencies of the transmitting element and the receiving element, considering that resonant coupling occurs when two objects with same-frequency resonant are inclined to pair up as they ineffectually relate with other off-resonant environmental objects. In order to fine-tune the resonant frequencies of both the transmitting and receiving elements, they have to be identified beforehand so that these frequencies can be linked. A full-wave electromagnetic field simulation was carried out parallel to those performed in an analysis of the characteristics of an antenna and is explained in this section.

A schematic model of proposed WPT system is shown in Figure-1 Figure-1 (a) shows the self-resonator whereas Figure-1 (b) illustrates LC resonator. The external capacitor is included as a lumped element for the LC resonator. The following equation encapsulates this:

$$f = \frac{1}{2\pi\sqrt{L(C_{self} + C_{ext})}} \quad (2)$$

As shown in Figure-2, a simulation was carried out on wireless energy transmission resonators containing the same size of transmitting and receiving inductive coils, by changing the number of turns (n) at the transmission distance of 50cm, 70cm and 1m, whereby 290pF was set as the external capacitance and the shape of transmitting and receiving inductive coils were square. In this case, the transmitting and receiving inductive coils' inner diameters (d_{in}), outer diameters (d_{out}), width (w) and turn spacing (s) were 19.5cm, 50cm, 1cm and 0.5cm. The number of turn is determined to be 4. Computer Simulation

Technology Microwave Studio (CST MWS) application was employed to conduct the simulation.

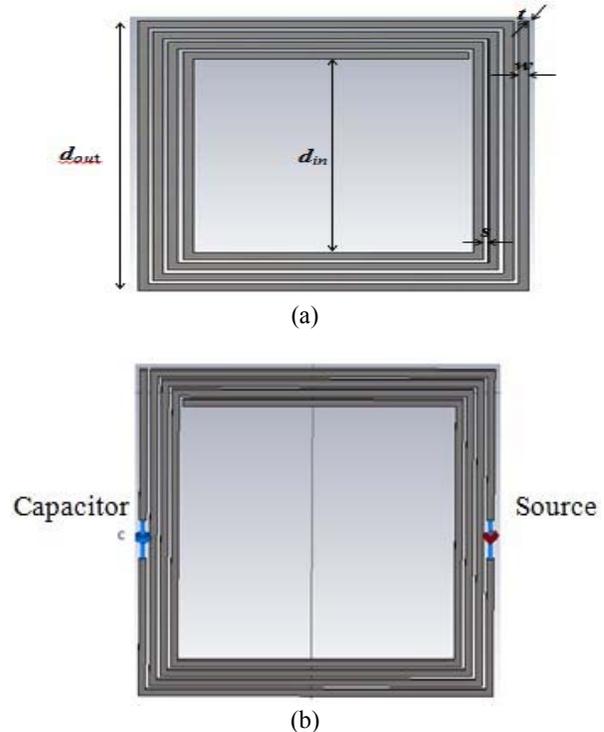


Figure-2. Layout for square inductor (a) self-resonator (b) LC resonator.

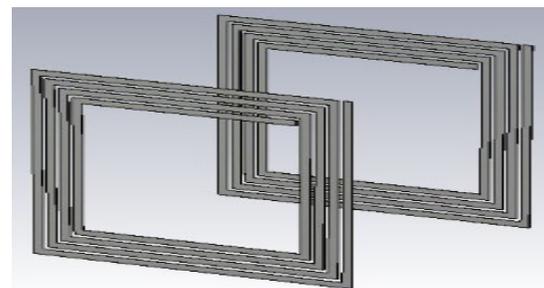


Figure-3. The number of turns (n) of transmitting and receiving coils

Figure-3 shows the simulation outcome of WPT's frequency versus efficiency at multiple distances. The power output was sourced from Port 1 which flowed from the transmitting coils across an air gap to the receiving coils. It then entered into transmitting power target which is Port 2. The efficiency is represented by η_{21} , whereas η_{11} is the ratio of power reflection.

$$S_{11} (dB) = 20 \log S_{11} \quad (3)$$

$$S_{21} (dB) = 20 \log S_{21} \quad (4)$$



$$\eta_{11} = |s_{11}|^2 \times 100\% \tag{5}$$

$$\eta_{12} = |s_{21}|^2 \times 100\% \tag{6}$$

Where s_{11} is the reflection coefficient of port 1 and s_{21} is the transmission coefficient from port 2 to 1 with port 2 is terminated in a perfect match.

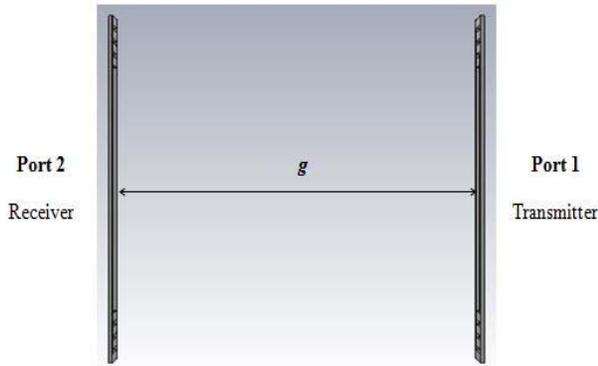
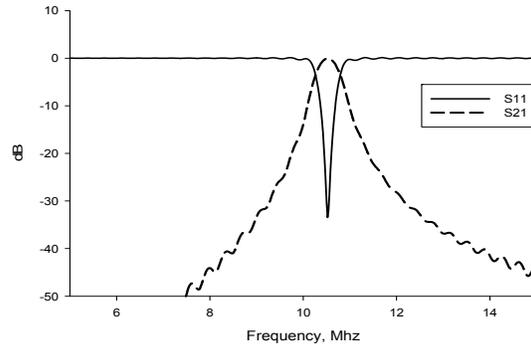


Figure-4. The various distances.

RESULT

Figure-4 (a) and (b) shows s_{11} and s_{21} of self-resonator and LC resonator at the distance of 50 cm. It was found that that -10 db was obtained at 36 MHz for self-resonator, while for LC resonator the resonance was recorded at 11.35MHz. On the other hand, the efficiency of power transfer was minimal for self-resonator too low, which is approximately lower than 1%. Meanwhile, LC resonators achieved 98% efficiency as shown in Figure-5 (). This phenomenon was triggered by the confinement of the electrical field due to the existence of the external capacitor. The power transfer efficiency therefore improved as a result of the sole dominance of the magnetic field.



(b)

Figure-5. Simulated S Parameters and (a) self-resonator (b) LC resonator.

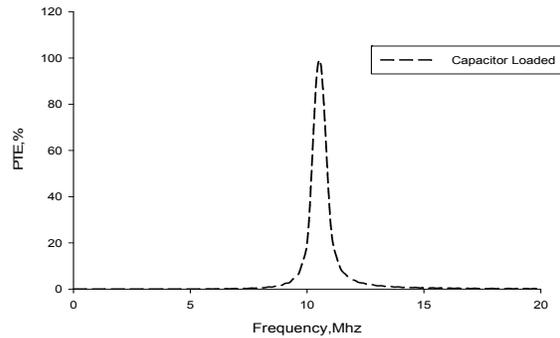
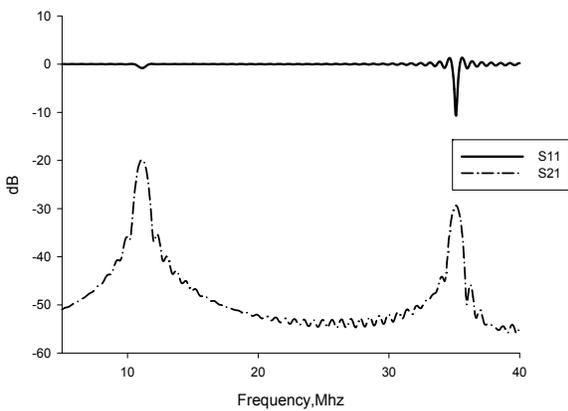


Figure-6. Power transfer efficiency for LC resonator.

Figure-6 shows the simulated parameters of s_{11} and s_{21} for LC resonators versus the frequency at the wireless energy transmission distance of 70 cm of. The figure reveals that the mutual coupling coefficient, and the power transfer efficiency (shown in Figure-7), are at -1.73 dB, as well as 76% at the distance of 70cm, respectively.



(a)

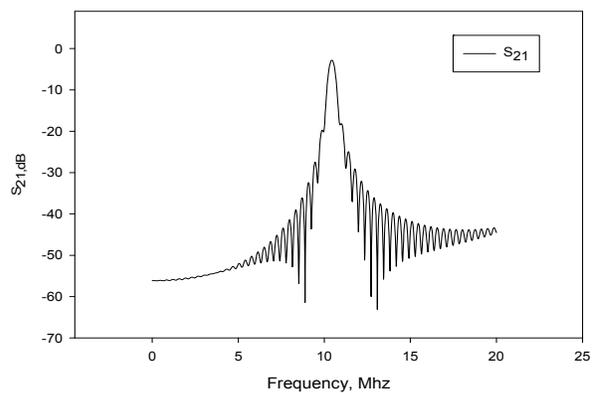


Figure-7. At 70cm.

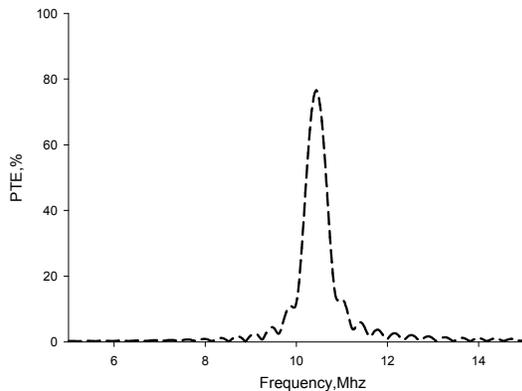


Figure-8. Power transfer efficiency at 70 cm.

Meanwhile, the maximum transfer efficiency against the distance simulation is shown in Figure-8 which reveals that the transfer efficiency declined a little at a distance that exceeded 70 cm. These results indicate that the best distance can lead to the best possible power transfer efficiency.

CONCLUSIONS

Two types of magnetic resonance coupling were studied in this paper to identify the effect of the presence of external capacitor in enhancing the performance of a WPT system. The analysis revealed that the electric field is well confined inside the capacitor hence the fields in the air become primarily magnetic dominance that allowed maximum power transmission.

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