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THE EFFECT OF ELECTROMAGNETIC COUPLING VIA PLANAR SPIRAL INDUCTOR FOR WIRELESS POWER TRANSFER

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ABSTRACT
Wireless power transfer based on electromagnetic coupling is a popular technique that is used in cases where the connection between wires are troublesome or inconvenient. Recently, it has drawn a lot of attention due to increased usage of mobile devices which needed wireless charging. In this paper, a method using circular planar spiral inductor structure to wirelessly transfer energy is proposed. It represents the characteristic of two parallel air core inductor mutually coupled in the free space for wireless power transfer system. Coupled inductance theory is used to compute the resonant frequency and power transfer efficiency. Simulations show that the change of air gap distance is found to be affecting the power transfer efficiency and is described in this paper.
Keywords: Wireless power transfer, Magnetic resonance coupling, Planar spiral inductor, Tranfer Coefficient, Distance, Antenna.

1. INTRODUCTION
In recent years, wireless power transfer has been the focus of many research and development. The invention of wireless power transfer no longer requires us to use troublesome cable and is used in a variety of applications for charging electronic device [1] such as mobile phones, robot vacuum cleaner, tablet PC and so on Jang, et al. [2]. Furthermore, when the wireless techniques provide constant power transfer to the device, it will help reduce battery size as well. Therefore, it will also serve to increase the portability and reduce the product price. Wireless power transfer can be categorized into near field and far field [3]. The far field is not recommended for user application due to the radioactive nature of the field and required large antenna size. But the near field has low frequency and suitable for magnetic coupling such as to power and recharge implantable medical devices [4].

For example, cardiac pacemakers can be recharged with limited distance without replacing the battery when the end of battery lifetime. The working principle of this technology is two circular planar spiral inductor with separation distance between them forms a resonant system. Energy is exchanged in both spiral inductors in an efficient and also low frequency magnetic coupling. Therefore, a magnetic field is used as medium of energy transfer in this technology. Lately, mid-range wireless power transfer technology has been proposed by Kurs [5]. It can transmit the power in high efficiency. However, the technology is using large of transmitting and receiving coil and it has not been use to wirelessly charge the small size electronic devices.

In this paper, different distance between the two circular spiral inductor with small structures is presented. The parameters of the planar spiral inductor are computed using finite element method (FEM) and analytical method. The design of the planar circular spiral inductor model is used to evaluate the distance effect on power transmission. The research provides the reader with information about the architecture, the modelling and the evaluation of the planar circular spiral inductor base on difference coupling distance.

2. MATERIALS AND METHODS

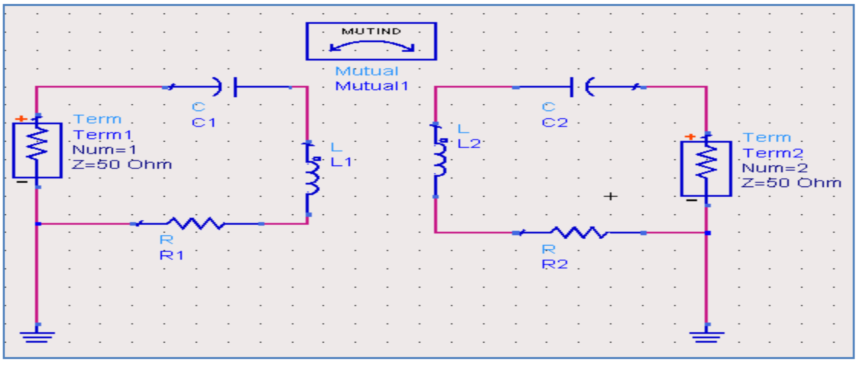
2.1. Material

This section presents the material and design method of using a circular planar spiral inductor that was used to generate an electromagnetic field. The printed circuit board used in this design is Duroid 4003 from Roger corps with the dielectric constant $\varepsilon_r = 3.38$, loss tangent of 0.0027, thickness of the ground layer is 0.035mm. Thereafter, the designs were modelled using Agilent Advanced Design Software (ADS) software so as to better characterize them The input was excited by 50 ohm microstrip feeder.

2.2. Method of Coupled Magnetic Resonance

LC resonance represents the fundamental theory of magnetic resonant coupling [6] . Thus, equivalent circuit of power transfer system using magnetic coupling as in Figure 1 will be discussed.

Fig-1. Magnetic resonant coupling circuit



Mutual 1 in this circuit represents the mutual inductance between transmitting and receiving spiral inductor. Z_0 source represents the impedance and Z_L is the load impedance. In this system, the input and output port is set at default 50 ohm. The equivalent impedance is

$$Z = R_1 + \frac{kw^2 L_1 L_2}{R_z + Z_L} \quad (1)$$

In Figure 1, C_1 and C_2 represent series capacitors in resonance circuit, their value are,

$$C_1 = \frac{1}{(2\pi f)^2 L_1} \quad (1)$$

$$C_1 = \frac{1}{(2\pi f)^2 L_2} \quad (2)$$

The circular planar spiral inductor is used in this resonance system. The amount of magnetic energy storage is represented by an inductance [7].

$$L = \frac{\mu_0 n^2 d_{avg} C_1}{2}\left(\ln\left(\frac{C^2}{\rho}\right) + C_3\rho + C_4\rho^2\right) \quad (3)$$

If the inductance L and capacitor C in resonant circuit is determined, the resonant frequency of the wireless power transfer system can be determined by using the formula below [8].

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (4)$$

Magnetic coupling is generated between transmit and receive spiral inductor in vertically oriented direction as Figure 3.

Fig-2. Two parallel spiral inductor at distance 1mm

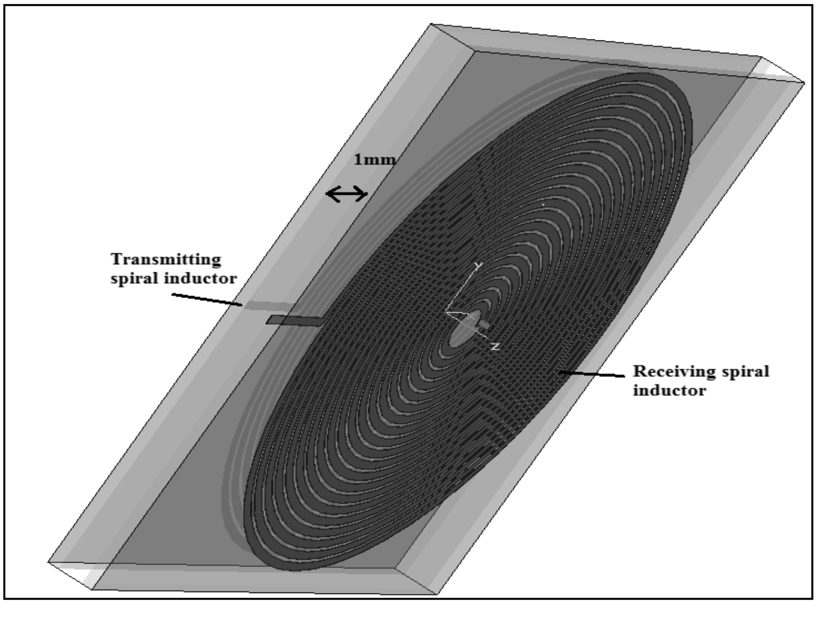
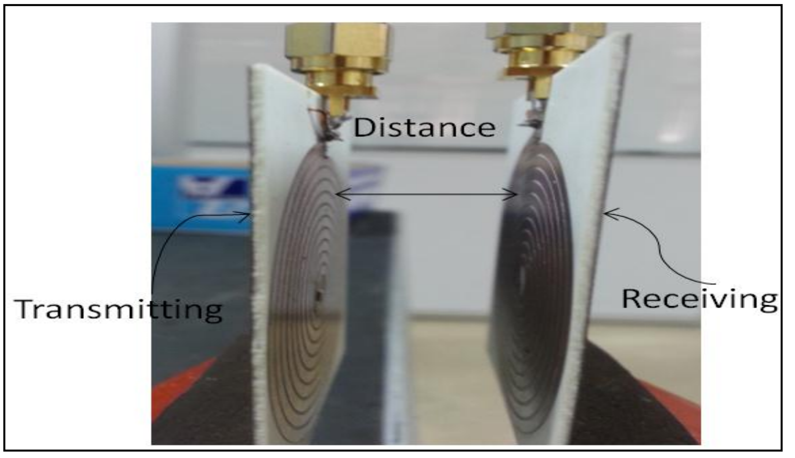


Fig-3. Two parallel spiral inductor

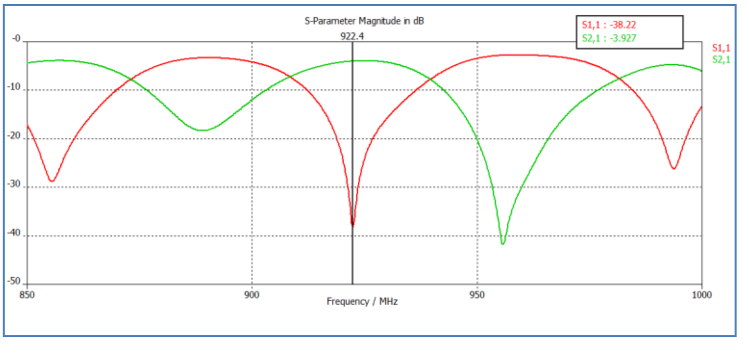


The system also closely related to factors such as different distance between transmitting and receiving spiral inductor. When the distance between them is close to each other, the electromagnetic at the surface of the inductor will have better coupling effect.As the distance changes, the electromagnetic coupling between the two spiral inductor surface is becoming weak. This is because according to the matching distance, the maximum value of the expected S_{21} decreases due to the degradation of the mutual inductance [9].

3. RESULTS

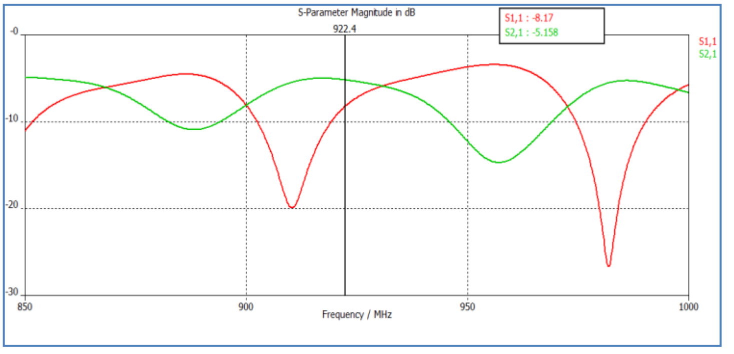
S-parameter is important to evaluate the circuit characteristic in MHz frequency ranges. The transfer coefficient between a pair of antenna are dependent on the distance which can be measured by the network analyzer. When the signal is applied through the transmitting circular spiral inductor, it will create a sinusoidally varying magnetic field, which induces a voltage across the receiving spiral inductor, thus transfer the power to the load. The transfer coefficient (S_{21}) is measured under condition of several different distances. Figure 3 shows the set up of two parallel spiral inductor. It can be observed that when separation of distance is 1mm, the transfer coefficient S_{21} at 922.4MHz is -3.93dB as in figure 4.

Fig-4. Transfer Coefficient (S_{21}) when the distance separation is 1mm



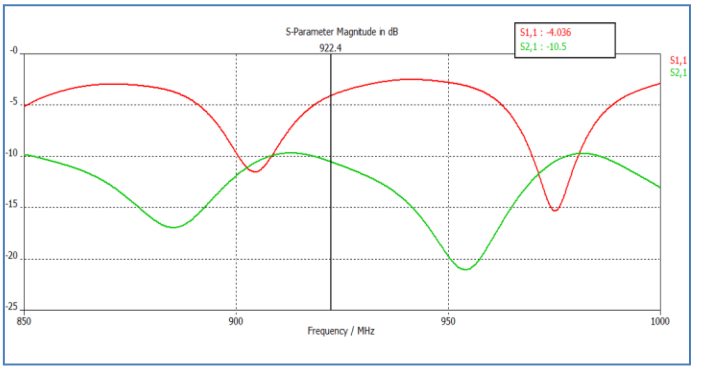
When the distance separation between transmitting and receiving spiral inductor is at 1.3mm but the turn of the spiral remains unchanged, it can be observed that S_{21} at 922.4MHz is drop to -5.16dB as given in Figure 5.

Fig-5. Transfer Coefficient (S_{21}) when the distance separation is 1.3mm



The transfer coefficient has dropped around 1.2dB when the distance is increased. Next, the distance is further increase until 1.9mm and S_{21} is observed as in Figure 6 below.

Fig-6. Transfer Coefficient (S_{21}) when the distance separation is 1.9mm



S_{21} at 922.4MHz is read on -10.5dB and has dropped around 6.57dB from the distance of 1.3mm. It it confirmed that transfer coefficient S_{21} is changed according to the distance. When the distance is increased, the transfer coefficient is decreasing. This is due to when the separation of distance between the transmitting and receiving spiral inductor is becoming bigger, the electromagnetic field is not coupled properly to the receiving spiral inductor.

4. CONCLUSION

In this paper, magnetic resonance coupling of wireless power transfer system base on multi turn circular spiral inductor on printed circuit board is presented. The power transfer efficiency is evaluated based on the equivalent circuit system and electromagnetic analysis. We conclude that when the distances change, the transfer efficiency will be changed accordingly. In all, there is a good agreement between the simulated, modelled and measured results. Further research, such as using new material for improving inductor design will extensively carry out to enhance the energy transfer based on electromagnetic resonance coupling theory.

5. ACKNOWLEDGMENTS

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