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A Computational Study on the Magnetic Resonance Coupling Technique for Wireless Power Transfer

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Abstract. Non-radiative wireless power transfer (WPT) system using magnetic resonance coupling (MRC) technique has recently been a topic of discussion among researchers. This technique discussed more scenarios in mid-range field of wireless power transmission reflected to the distance and efficiency. The WPT system efficiency varies when the coupling distance between two coils involved changes. This could lead to a decisive issue of high efficient power transfer. This paper presents case studies on the relationship of operating range with the efficiency of the MRC technique. Demonstrative WPT system operates at two different frequencies are projected in order to verify performance. The resonance frequencies used are less than 100MHz within range of 10cm to 20cm.

1 Introduction

Nowadays, there are a lot of technologies applied in order to enhance our daily life such as transferring energy wirelessly which has been a recent topic of discussion. Wireless energy transfer has drawing more and more attention among researchers and in this sense a question on how the energies being transferred take place. Surveys found that there are a lot of methods for wireless energy transfer that exists either by using acoustic, electromagnetic, capacitive or inductive technique. These techniques are then classified into three, whether it is near field, mid-range field or far field depending on the distance between the transmitter and receiver [1].

An investigation to develop wireless power transfer system for wireless power charging application has attracted researchers, due to the need of more convenient way of power charging system [2]. The power requirement of each application to be recharged depends on the typical range from few microwatts to tens of milliwatts based on the battery power consumption [3].

In this paper, a case study of wireless non-radiative mid-range within 10cm-20cm power transfer using magnetic resonance coupling (MRC) method is proposed. The study is in between the transfer distance with the transmission efficiency. Based on this technique, the transmitter and receiver resonator are designed by following the Wheeler's formula parameter. In case study 1, resonance frequency of 73MHz is used. While in case study 2, the resonance frequency is 32MHz. It has been reported that in Tesla's work, the operating frequency for mid-range WPT ranging from 10kHz to almost 200MHz [4].

2 Related Theory

2.1. Magnetic Induction

It has been over 180 years since Michael Faraday figured out that power can be exchanged by magnetic induction through the air [5]. In 1914, Tesla first reported about the wireless power and transferring of data based on the magnetic coupling of two loops. The principle of mutual induction between two coils can be utilized in energy transfer for the exchange of electrical power which does not include any physical contact in between [6]. Transformer is the simplest example of how the mutual induction works. There is no physical contact between both primary and the secondary coils.

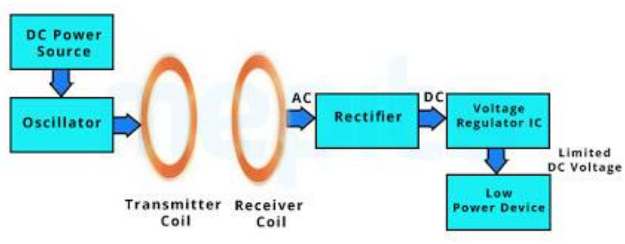

Fig. 1. Block diagram of inductive coupling

Fig. 1 shows the overview of inductive coupling where the technique of mutual induction is used to transfer power to the battery of any low power devices. The power transmission occurs when the transmitter coil transmit power to the receiver coil. In inductive power

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transfer system, it has been common to adopt Tesla's principles which state that [4]

1) By using near-field which is non-radiative for magnetic coupling gives out magneto-inductive effects.
2) Resonances technique is applied for both transmitter and receiver designs.

However, inductive coupling can transfer power with high efficiency only in the range of a few centimeters (short-distance) [7]. Therefore, any devices used are required to get very close with the induction coil of transmitter so that charging process could take place.

2.1. Magnetic Resonance Coupling

Magnetic resonance coupling technique is a near-field magnetic inductive coupling methods considering the same resonance frequency at both transmitter and receiver which then known as the mid-range MRC.

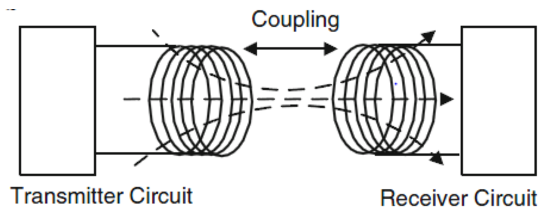

Fig. 2. Wireless charging system[6].

Fig. 2 shows the diagram of wireless charging system along with MRC. The transmission occurs due to the electromagnetic coupling between both coils without any change in the frequency used. Magnetic resonant coupling can transfer a huge amount of energy over an air gap at high efficiency [8]. The resonance frequency can be defined by using the given formula

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Where, L and C are the inductance and capacitance of the coil respectively.

The coupling between two basic LC circuits with a certain distance is fragile. However, if both transmitter and receiver coils have the same natural resonance frequency, when they operate at the resonant frequency the two coils could generate resonance and produce strong coupling [6].

3 Coil Design

The coil designed in Fig. 3 is used in both case study 1 and case study 2 with different diameter sizes and compared with the same range of distances. The aim of these case studies is to prove that the relationship between distances and efficiencies are significant.

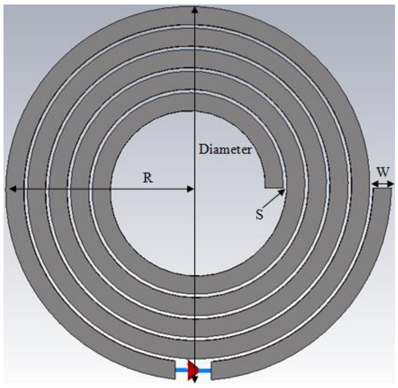

Fig. 3. Coil design parameter.

All the coil design and simulation is carried out in CST Studio Suite. While the parameter value involved is calculated by using classic Wheeler's formula for spiral coil given as [9][10]

$$L = \frac{(NR)^2}{2.54(8R + 11W)} \tag{2}$$

where,
L is inductance in micro-Henries
N is number of turns of wire
W is width of coil in cm
R is radius of coil in cm

3.1. Case Study 1

In case study 1, the size of coil used is 10cm x 10cm x 0.05cm with resonance frequency of 73MHz. All the transmitter and receiver coils parameters are listed in Table 1. Both coils use the same size and parameter values. The number of turns, N is 5, with radius 5cm and width of each turn of coil is 0.5cm.The height is 0.05cm while the spacing between coil's turn is fixed by 0.1 cm.

Table 1. Transmitting and receiving coil specification.

Parameters	**Transmitter**	**Receiver**
N (turns)	5	5
Radius (cm)	5	5
Width (cm)	0.5	0.5
Height (cm)	0.05	0.05
Spacing (cm)	0.1	0.1
Resonce frequency (MHz)	73	73

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3.2. Case Study 2

In case study 2, the size of coil used is 20cm x 20cm x 0.05cm. All the parameter values involved are recorded in the Table 2. Both transmitter and receiver coil use the same parameter value. 5 turns of coil is designed with radius of 10cm and width of 0.5cm for each turn. The height is fixed likewise in case study 1 which is 0.05cm while gap between each turn is increased to 0.3cm.

Table 2. Transmitting and receiving coil specification.

Parameters	**Transmitter**	**Receiver**
N (turns)	5	5
Radius (cm)	10	10
Width (cm)	0.5	0.5
Height (cm)	0.05	0.05
Spacing (cm)	0.3	0.3
Resonance frequency (MHz)	32	32

4 Simulation Result

Simulation of coil design in CST studio suite gives out result of S_{11}(dB) and S_{21}(dB). Each graph S_{11} shows the transmission coefficient at a simulated resonance frequency of magnetic resonance coupling system. Graph S_{21} shows the efficiency of the system which is calculated by using formula

$$\text{Efficiency} = (S_{21})^2 \times 100\% \qquad (3)$$

Where, S_{21} value from graph is first converted from dB into numerical.

4.1 Discussion case Study 1

Fig. 4 shows that at a closed distance of 5cm, there are two resonance frequencies. This is due to the splitting frequency phenomenon between both coils where both coil are tightly coupled. The transmission coefficient S_{11} at 67.27MHz is -4.876dB with efficiency of 21.74%. While at 81.2MHz, the transmission coefficient is -6.572dB with efficiency of 35.56%.

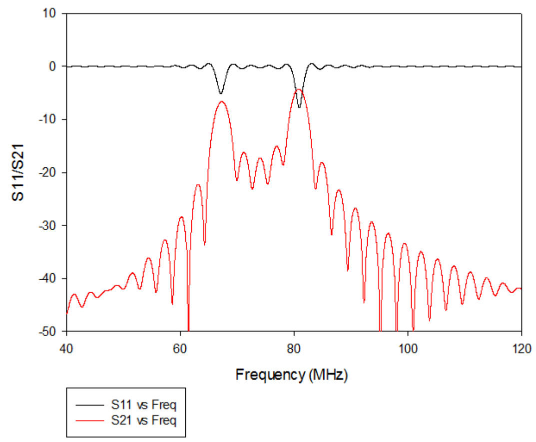

Fig. 4. Simulation result at 5cm

At a distance of 10cm, Fig. 5 shows the two resonance frequencies approach each other and become one at 73MHz. The transmission coefficient S11 is -5.2907dB with efficiency of 48.44%.

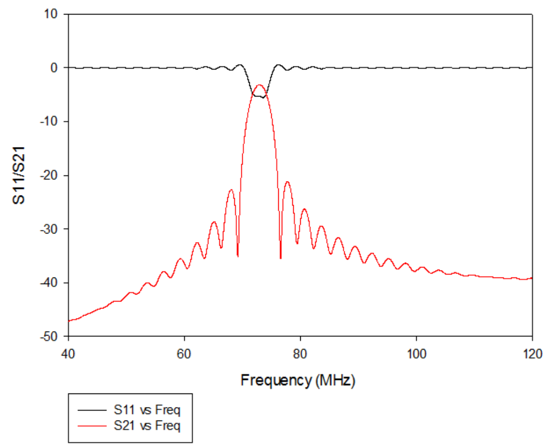

Fig. 5. Simulation result at 10cm.

As the distance becomes larger to 15cm, it can be observed that the transmission coefficient is drop to -21.07dB at 73MHz and the efficiency is 14.26% as in Fig. 6.

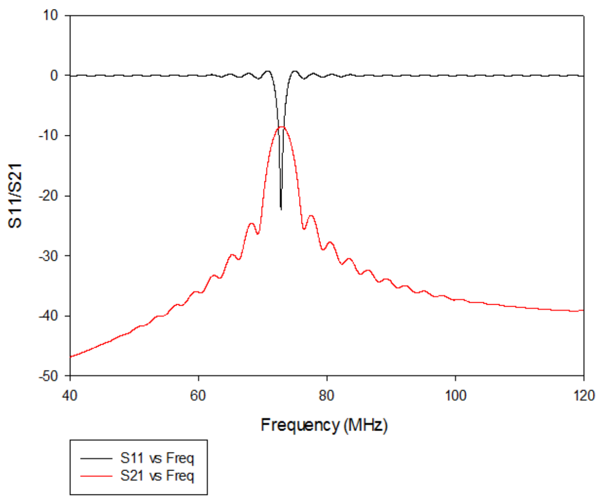

Fig. 6. Simulation result at 15cm.

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When the distance is 20cm, Fig. 7 shows the transmission coefficient at 73MHz drop to -25.016dB and the efficiency is 0.172%.

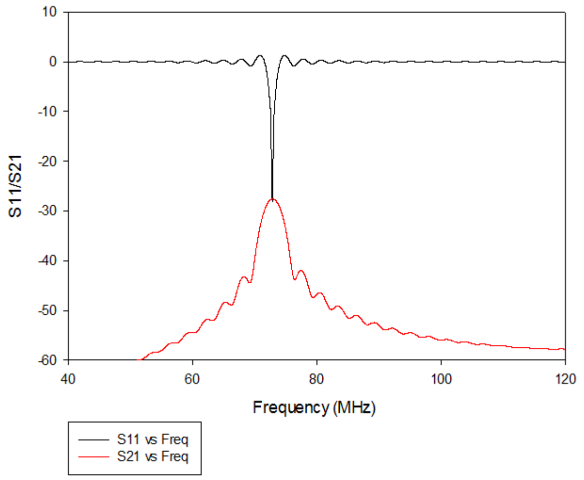

Fig. 7. Simulation result at 20cm.

4.2 Discussion case Study 2

In case study 2, the same observation likewise in the case study 1 is taken. In this case study, the observation is focused on the resonance frequency of 32MHz. At the distance of 5 cm, there are two resonance frequencies as shown in Fig. 8. At 29.1MHz, the transmission coefficient S_{11} is -2.5806dB with 6.34% efficiency. At 36.67MHz, the S11 is -4.359dB with 14.76% of efficiency.

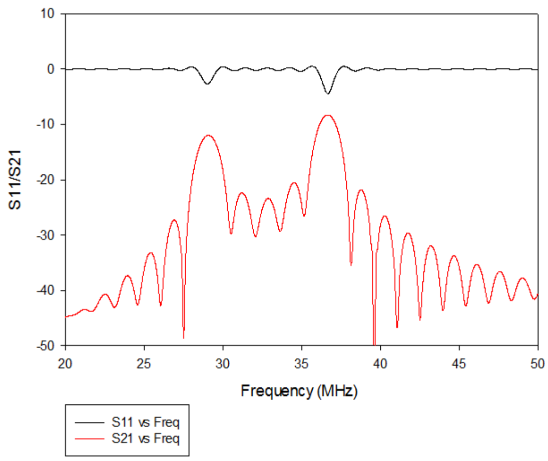

Fig. 8. Simulation result at 5cm.

When the distance is 10cm, there are also two resonance frequencies. Both frequencies become more close to each other. Fig. 9 shows the S_{11} is -3.089dB at 30.6MHz with 7.74% efficiency. At 34MHz, the value of S_{11} is -3.75dB with 10.83% efficiency.

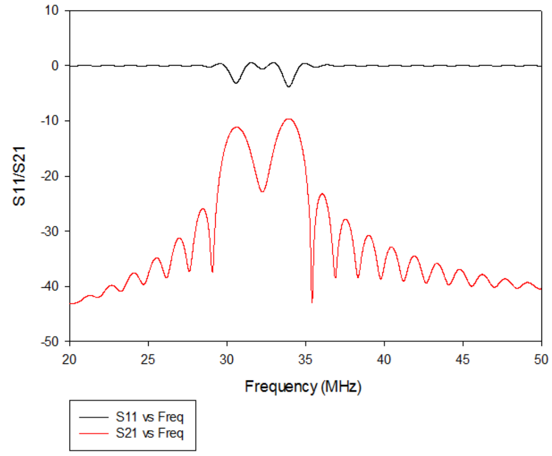

Fig. 9. Simulation result at 10cm.

The same observation is taken for a distance of 15cm. There are still two resonance frequencies at 31.2MHz with -3.43dB and 6.77%efficiency, and also at 33.05MHz with -3.7465dB and 8.35% efficiency as shown in Fig. 10.

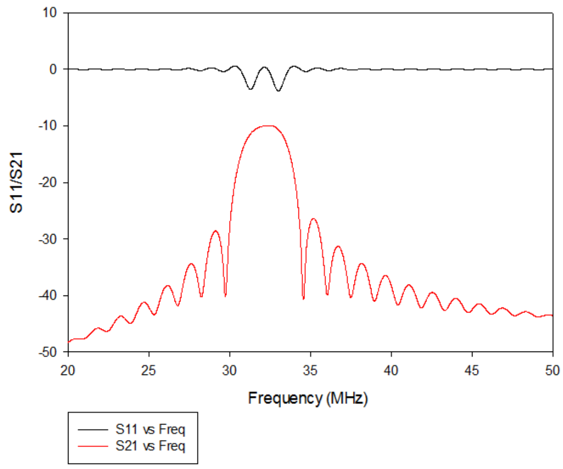

Fig. 10. Simulation result at 15cm.

Only when the distance is 20cm, the two resonance frequencies reach each other and become one at 32.33MHz with -3dB transmission coefficient and 17.72% efficiency as shown in Fig. 11.

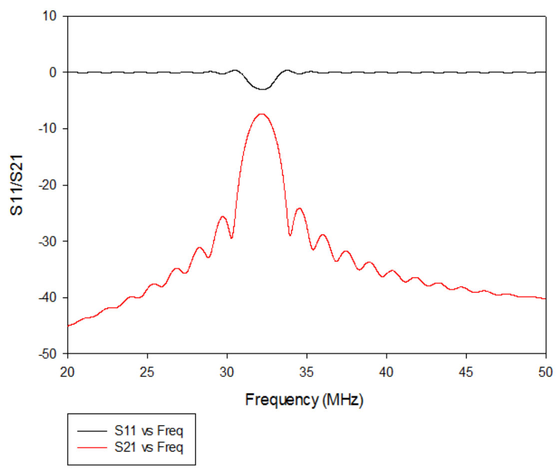

Fig. 11. Simulation result at 20cm.

5 Conclusion

From the discussion in case study 1 and case study 2, it is confirmed that the distance and the efficiency are related to each other. It can be concluded that the farther the distance, the lower the efficiency of the power transmission. Besides, the coil size and the gap between each turn also play a role in the change of resonance frequency. It seems like when the size of coil becomes larger, the resonance frequency becomes smaller. In this paper, simulation results verify the relationship between the distance and efficiency. Hence, it would be easier for further research to gain high efficiency with other design parameter.

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