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Research Article

Wireless Power Transfer System for Biomedical Devices by using Magnetic Resonance Coupling Technique

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Abstract: Aim of this work is to study the energy transfer wirelessly using a pair of transmitter and receiver coil. The system aims to generate magnetic coupling resonance between two coils. Wireless power transfer system can eliminate wire connection during energy transmission. Many researchers show great interest on wireless power transfer technique for biomedical devices. This technique is important to be applied and integrated into biomedical devices such as pacemakers, defibrillators, Left Ventricular Assist Devices (LVAD) to ease the transfer system. Basically, there are two ways to power up the biomedical devices such as external power cord and batteries. However, batteries had its limited capacity and external power cord limit patient's freedom and might lead to infection. Therefore in this study, two coil wireless transfer system was designed in order to solve the problem. Two 30 cm diameter coils transmitter and receiver pairs had been designed to provide 72.7% of efficiency up to 37 cm of transmission distance. It can be concluded that this system is suitable for long range power transmission with good efficiency.

Keywords: Contactless wireless power transfer, long range energy transfer, magnetic resonance coupling, wireless charging, wireless power transfer

INTRODUCTION

Nowadays,there wasa huge increase in the development and usage of biomedical devices for examples pacemakers, defibrillators, Left Ventricular Assist Devices (LVAD) and artificial hearts to cochlear implants, neuromuscular stimulators, analog sensors and so on (Sanni*et al*., 2012). These implantable devices or low-power biosensors can be served as the devices for identification, monitoring and treatment of patients (Zhu *et al*., 2011). Besides that, it can also perform therapeutic, prosthetic and diagnostic function. Moreover, these biomedical devices had similar weaknesses which they cannot power up themselves and need to power up with batteries or using power supplies in order to function.

This means that most of the patients highly rely on those power supply or batteries to withstand their life. The capacity of the batteries becomes another concern for the patients, which how long can the batteries last. Normally, battery had the disadvantage of limited energy storage and had to be replaced once the battery is finished.

Another option can be made which a transcutaneous power cord has to be made out from the patient's skin in order to charge the devices. There are patients who get infected due to this opening and required re-hospitalization. We should put more concern to patients who have to face the risk of death during the infections occur. Therefore a continuous supply of energy is very important in order to make the devices to continue functioning.

Basically there are three types of wireless energy transfer technique that are widely used and research by the researcher today, which is induced coupling, magnetic resonance coupling and radiative transfer (Meng*et al*., 2013). However this study will focus on magnetic resonance coupling technique (Hui*et al*., 2013).

In 2007, MIT researcher Kurs*et al*. (2007) and Li *et al*. (2012) had used a new method of wireless charging by applying the strongly magnetic resonant coupling. This concept is based on Coupled Mode Theory (CMT) and result efficiency of 40-50% at a distance of 2.74 m by using a transmitter and a receiver coil size at 60cm. Their experiment successfully light up a 60 W bulb wirelessly from 2 m away with resonant frequency of 10 MHz.

In another study wireless energy transfer system using the concept of witricity was set up. They tested their system using 1500-Ohm resistor as the load and measure the output voltage at the load. The efficiency is

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40.2% at a distance of 20 cm. They also stated that if using the normal inductive coupling, the same efficiency can only be achieve at a distance of shorter than 4 cm (Liu *et al*., 2009).

A recent workLi *et al*. (2012) and RamRakhyani*et al*. (2011) had used resonant circuit theory to analyze the magnetic resonating system. The coupling coilused was wounded using litz wire, the diameters of transmitter coils and receiver coils are 64 mm and 22 mm respectively. The energy transfer efficiency of 82% is achieved at the distance of 20 mm.

During the year 2012, Free-Range Resonant Electrical Energy Delivery (FREE-D) system (Waters *et al*., 2012, 2013) was conducted as a WPT technique. In this study, the drive resonator and receiver vest resonator diameter used were 31 and 28 cm, respectively in the aid of transmitter resonator and a receiver resonator (59 cm diameter coil size) in order to achieve better performance. The efficiency achieved approximate 56% at the resonant frequency of 13.56 MHz. Although the resonators help to improve the efficiency of the system, but the distance between the resonator became another concern and always had to be adjusted to get better performance.

In another study Zhang *et al*. (2012), a WPT technique is presented by analysis and simulation using the coupled mode theory. Two types of thin-film resonators are designed and prototyped for the construction of wireless Body Sensor Networks. The resonator designed as length 20.5 cm, width 20 cm and thickness 0.35 mm. The coil inductor consists of 6 turns of copper strips and the bottom layer is formed with 8 vertical copper strips. Q value (quality factor) as 40 had been measured using a vector network analyzer. The efficiency obtained about 80% at a 20 cm separation of transmitter and receiver.

Therefore, two coils WPT technique was chosen to be further discuss. The objective of this study is to develop a wireless power transmission system which is suitable in charging batteries of the biomedical devices using magnetic resonance technique. An experiment was demonstrated without any aid of resonators as mention in FREE-D system. Pair of round shape coils transmitter and receiver with diameter or 30cm were made using 1.5mm thickness copper coil and Quality factor (Q) of the coils were measured. The final resultsof this system was measured and recorded.

METHODOLOGY

Figure 1 show is the schematic diagram for the 2 coils WPT system design for this experiment. The first step of WPT system is to design the transmitter and a receiver coil pair. The coils had been designed and the quality factor (Q) was measured. Three turns of 1.5mm thickness of copper coil with round shape were chosen to be the transmitter and receiver pair for this experiment. Three turns of round shape coil shows the highest quality factor, Q = 190 as compare from the other turns number (two turns up to twelve turns). The capacitance and inductance of the transmitter and receiver pairs were measured calculated. After that, the resonant frequency for the experiment was calculated using formula:$f = 1/2\pi\sqrt{LC}$. The two coil WPT transfer system can be optimized when operate during its resonant frequency of overall system.

Source impedance,R_S was measured to be 3Ω and load impedance,R_L used in the experiment was 10Ω respectively. In order to maintain the maximum power transfer, a step up transformer was added in the transmitter part and a step down transformer was added in the receiver part for the impedance matching purpose. The gain of the step up transformer,$n_1$and step down transformer, $n_2$were calculated. Then, two transformers were made with gain $n_1 = 24.8$ and $n_2 = 19.6$. Figure 2 shows the steps when recorded the results. Power supply and frequency generator had been connected to the transmitter tank with aid of 30cm diameter transmitter coil and a LCR meter was connected to the load at the receiver part. The result was measured every cm from 3 cm up to 65 cm. The resonant frequency for the system during

Table 1: Parameters used in simulation

Parameter	Value
L_1, L_2	8.41μH
Q_1, Q_2	190
R_1, R_2	7.9KΩ
Coil radius	15cm
C_1, C_2	5.1nF
Frequency	768.5 kHz
n_1	25.56
n_2	19.8
R_S	3Ω
R_L	10Ω

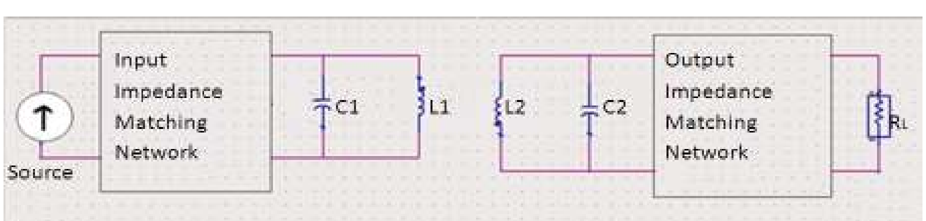

Fig. 1: Schematic diagram for the 2 coils WPT system

Fig. 2: Results recorded during the experiment

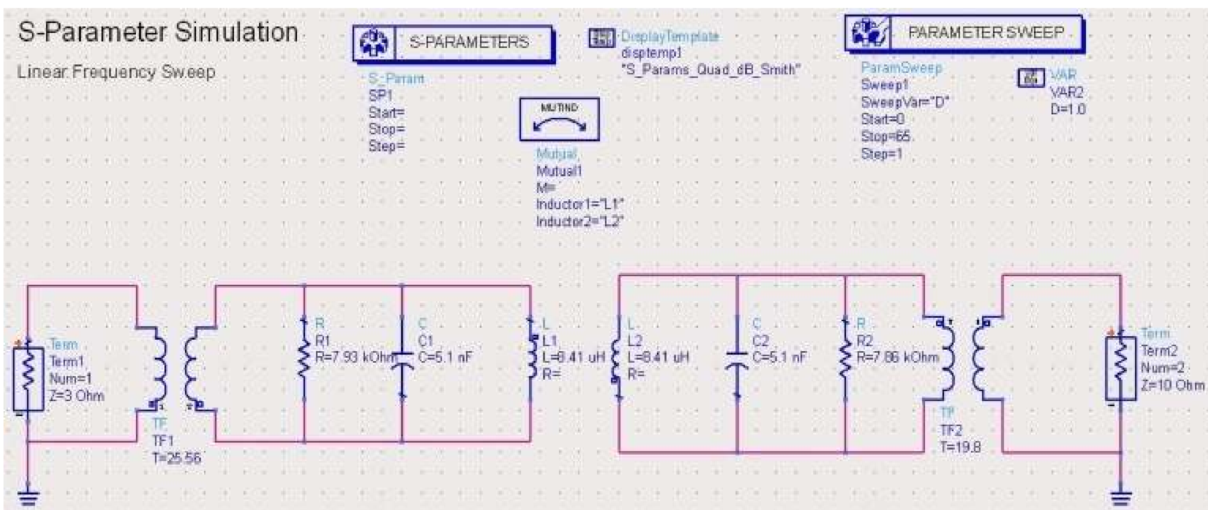

Fig. 3: Schematic diagram for S-parameter simulation using ADS

the experiment was set as 783 kHz. The result was then recorded and compare with the simulation result for further discuss.

Agilent Advanced Design System (ADS) was used during the simulation in order to verify the experimental result. ADS are the electronic design automation software for RF, microwave and high speed digital applications. Table 1 show the parameters used during the ADS simulation. Figure 3 shows the schematic diagram for overall system use for S-parameter simulation by using ADS. Result of S_{21} simulation was then measured and recorded.

RESULTS AND DISCUSSION

The experiment was carried out and the efficiency of the system which ratio of the output power to the input power was measured. The equation used to calculate the efficiency of the system was $S_{21} = 2\frac{V_L}{V_S}(\frac{R_S}{R_L})^{\frac{1}{2}}$.

Figure 4 shows the comparison of the experimental result and the simulation result using Agilent ADS. From the figure above, we can see that by magnetic coupling of two resonant coils of 30 cm diameter can achieved the energy transfer up to 46cm (from simulation result)which is approximately 1.5 time then the coil diameter. However, itmeans that this wireless transfer system can only maintain its high efficiency at limited distances. As comparison from Fig. 4, the simulation result shows the highest efficiency of 73% at the distance of 46cm and the experiment result shows the highest efficiency of 72.7% at the distance of 37 cm. The performances of this system gradually decrease after distance of 43 cm as increase in distance within transmitter coil and receiver coil.

Table 2: Comparison with previous work

Ref.	Dimension (d_p,d_s)(cm)	Freq. (MHz)	Efficiency	Distance (D(cm), D/d_m)
Li *et al*. (2012)	(3.4, 1.4)	0.742	85%	(1.5, 0.625)
Zhang *et al*. (2012)	(35, 20)	7	80%	(20, 0.727)
RamRakhyani*et al*.(2011)	(6.4, 2.2)	0.7	72%	(3.2, 0.744)
Liu *et al*.(2009)	(35.2, 16.26)	7.04	40.2%	(20, 0.777)
Waters *et al*.(2012)	(31, 28) With two 59cm resonators	13.56	56%	(100, 1.13)
This work	(30, 30)	0.783	72.7%	(37, 1.23)

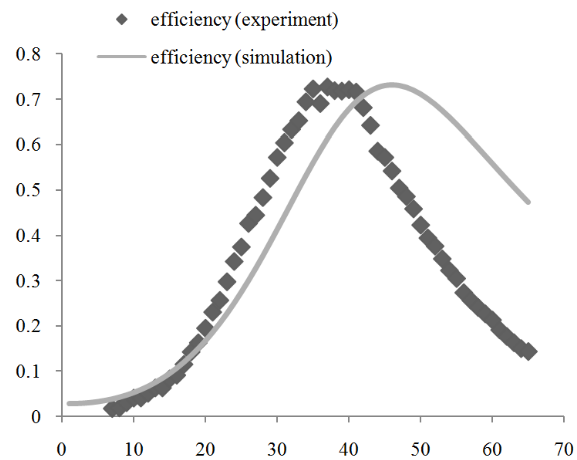

Fig. 4: Comparison of experimental result and simulation result

There are few reasons which lead to the difference between the simulation result and experiment result. First, it was because the step up and step down transformers with gain,$n_1 =$ 24.8 and $n_2 =$ 19.6, respectively were designed manually. Therefore its gain will be slightly different with the calculated gain value $n_1 =$ 25.56and n_1 =19.8.The difference in the gain causes the impedance of the system slightly unmatched. This has also resulted a difference between the experimental result and simulation result. Therefore, the transformers which were manually designed cannot achieve ideal state as in simulation. Second reason was the power losses from the transformer which during the experiment the temperature of transformers were increased. This is the result of the power losses through the system which turn into heat and increase the temperature of the transformer. Another factor which leads the difference was the resonant frequency use in the experiment was 783 kHz which was not exactly same as the calculated resonant frequency (768.5 kHz).

From the result we can see that two coils WPT technique can deliver energy wirelessly. It can replace the batteries and power cord to power up the biomedical devices and this system does not depend on any resonators as discuss in previous FREE-D system. This means that two coil WPT systems does provide a more simple design then other wireless power transfer system which have to rely on resonator to increase its transmission range. However, the efficiency of two coil WPT system canstill studied and improved in a future experiment by increase the quality factor of the resonant coil and implementing the impedance matching system.

Table 2 shows the comparison between this study and previous work done by other researchers. Whered_p and d_s are the diameter of primary and secondary coils. $d_m$is the geometric mean of d_p and d_s. From Table 2, the comparison shows that this study uses a lower resonant frequency to achieve longer transfer distance without aids of any resonators. From another point of view, this study able to achieve relatively higher efficiency in the condition of transmission distance more than$d_p$andd_s.For the Free-D system (Waters *et al*., 2012), there are extra two resonator with 59cm diameter were added in the system. Moreover, the resonant frequency used by Waters *et al*. (2012) is 13.56MHz which approximately 17 times higher than this study.

CONCLUSION

The purpose of this experiment is to prove that two coil wireless transfer system can successfully transfer the energy wirelessly with the aid of 30 cm transmitter and receiver coils. The two coil WPT system achieved 72.6% of efficiency at the resonant frequency of 783 kHz with transmission range of 37cm. The transmission range of this system is up to approximately 1.2 times of the transmitter coil diameter. This system is suitable use for mid-range charging application such as human implant medical devices. Further research on this wireless energy transfer is important and require effort from several professionals and researchers in areas of powers and biomedical in order to implement the biomedical devices which can greatly advantage to human. This two coils wireless energy transfer technique will provide more freedom, mobility and conveniences to the patients.

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