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Design and Implementation of Material Characteristics for Capacitive Coupling Wireless Power Transfer System

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Abstract

This research work describes a design and implementation of materials characteristics for the capacitive coupling wireless power transfer system. There were two types of Wireless Power Transfer (WPT) that have widely been used and studied by researchers: Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT). Electric fields transmit by the electrostatic induction phenomena between transmitter and receiver. A capacitor is formed at the transmitter and receiver with the intervening space as the dielectric. The transmitter generates an alternating voltage that is applied on transmitter plate from primary circuit. The alternating potential is induced by the oscillating electric field on the receiver plate by electrostatic inductions which cause the alternating current to flow in the secondary circuit. In this research, two types of the materials are used as the transmitter and receiver plate; aluminum plate and a zinc plate. With the fix distance of the air gap, variable size of the plate, variable thickness of the plate and the variable thickness of the glass, the power transfer has been measured. **Improvements:** The thickness of the plates does not affect the power transfer. The conductivity of the electricity of the plates in the different thickness gives the same capability to carry electron.

Keywords: Capacitive; Thickness; Size; Plates; Electric Field;

INTRODUCTION

Wireless Power Transfer is a process of transferring electrical power from power sources to load without utilizing any physical contact between them[1]. In WPT, the electric field and the magnetic field has been studied for energy transmission, performed by the Nikola Tesla in the early 20th century shows[2]. Many types of communication systems, for example, walkie-talkies, mobile phones, and cordless phones long been utilized for the convenience of flexible movement. However, there were still devices that used the traditional electrically wired power supplies. Nowadays, there are a lot of explorations on WPT mechanism as an alternative power scheme. One of the advantages of the wireless powering method, an electronic device can be charged even if it is moving[3].

WPT techniques can be partitioned into two methods, Inductive Power Transfer, and Capacitive Power Transfer. IPT method is based on the principle of magnetic field coupling. Meanwhile, CPT method is based on the principle of electric field coupling. In WPT technology, systems mostly use IPT, but IPT needs a high free frequency to generate a magnetic field[4]. Three typical difficulties that dependably happen in the IPT are high Electro Magnetic Interference (EMI), not able to transfer the power through the metal and larger eddy current. From the other side of view, the CPT has the advantage in terms of transmitting the power through metal, reduces energy loss and has good anti-interference. These benefits make it to be widely used in either large capacitors or lower power application. An example, transmitting power and data to bio signal instrumentation system or coupling power and data between integrated circuits. In this paper, the material characteristic for capacitive coupling power transfer will be studied and analyzed as well as two materials proposed in the next chapter.

LITERATURE REVIEW

In this section, consists of reviews on capacitance power transfer, materials used for the CPT, distance of plates for power transmission, the size of the transmission and receiver and power transmission efficiency.

Reviews of Capacitive Power Transfer

According to (**Chao Liu, 2011**), the idea of contactless power transfer using an electric field (capacitive) coupling emerges from the principle of displacement current ‘flow’ in the alternating electric field in between capacitor plates. Capacitive power transfer is due to the phenomena of electric induction occurring between a transmitter and receiver plate. The electric field acts a medium for transmission of the energy in CPT. To be transformed into high-frequency AC voltage, at the power converter, a power source with the low frequency (or DC) is fed. At the output of the converter, the two primary metal plates are connecting and as two secondary plates are placed close by, the electrostatic induction occurs and displacement current will flow through the secondary plates as shown in Figure 1. The power produced at the load by the power conditioner.

The amount of power transferred depends on the size of the transmitter, the capacitance between the plates, and the area and distance of the plate. In this research, it will be fixed with a difference in a material with the plate. Capacitive coupling has only been used in low-power applications because the very high voltages on the electrodes required to transmit significant power can be hazardous. Not only has that but also caused some unpleasant side effects. The transverse or bipolar design is used in this research work. Referring to Figure 1, the plate is placed face to face.

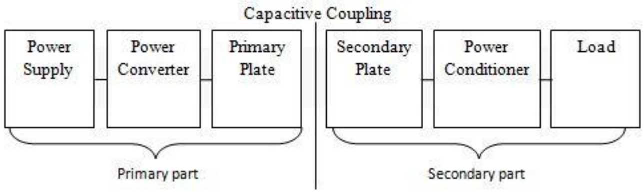

Figure 1. Block Diagram for Capacitive Power Transfer

Reviews of Materials Used for the CPT

According to (**Chao Liu, 2011**), capacitive coupling is the power transfer medium of a CPT system, which includes two or more pairs of metal plates, dielectric materials, and electric fields formed in between plates. The metal plates must have the characteristic of conducting current. Based on our research, we would like to propose two materials to be used for the metal plate at transmitter and receiver which are aluminum and zinc. Aluminum has normally been used in the previous research. Zinc is chosen because it is easy to obtain and is the low cost, besides, the conductivity order is close to the aluminum. Table 1 shows the conductive order of metals based on equal size.

Table 1. Material for capacitance power transfer

No	Conductive Order Of Metals (equally size)
1	Silver (Pure)
2	Copper (Pure)
3	Gold(Pure)
4	Aluminium
5	Zinc
6	Nickel
7	Brass
8	Bronze
9	Iron (Pure)
10	Platinum
11	Steel (Carbonized)
12	Lead (Pure)
13	Stainless Steel

There are technical factors for aluminum and zinc that have been chosen such that the Aluminum and zinc have the high strength to weight ratio and resistance to the corrosion. They have the high thermal and electrical conductivity. It is helpful in this research because it allowed the transmission of power. They are easy to handle and non-magnetic materials.

Reviews of Distance of Plates for Power Transmission

Based on (**Chenyang Xia, 2012**), for a specific system operating and load resistance, the greater the capacitance, (field area is larger, the smaller the distance), the greater the output power of the system. The proposed distance between plates for this research work is 10mm as shown in Figure 2.

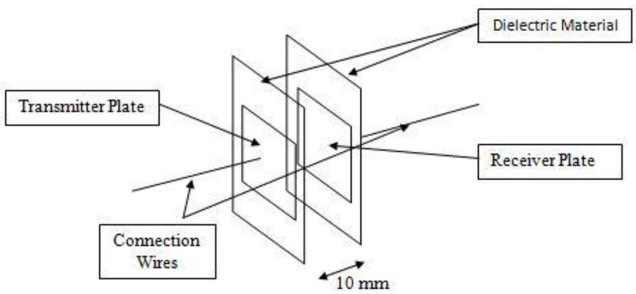

Figure 2. Schematic diagram of the distance between transmitter and receiver.

In [1], the power transfer distance that is achievable is 0.1cm. The electric field will decrease as the distance of medium of transmission increases. In [2], they successfully achieved the long distance with the value of 200mm and high-efficiency power transfer which is 90 %.

Reviews of size of the Transmitter and Receiver

According to (**Chenyang Xia, 2012**), the area of the plate also affects the power transmission because it will produce higher capacitance. The size of the plates shown in Figure 3.

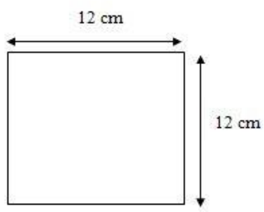

Figure 3. The size of the metal plate.

Referring to the previous works, they used various plate size. In[1], the plate size used is 12 cm x 12 cm. Besides, in [2] the plate size that they use is 110 mm x 480 mm. For this research, there were three sizes proposed for the metal plate: 9 cm x 9 cm, 11 cm x 11cm, and 13 cm x 13 cm. The proposed plate size is suitable for handling the power transmission.

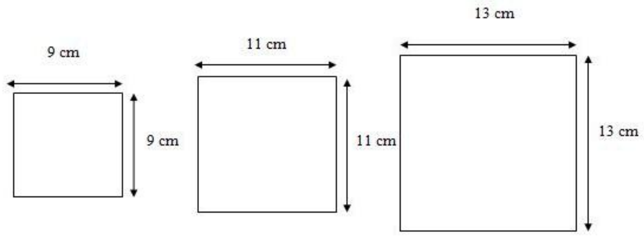

Figure 4. Various size of the metal plates for WPT

Reviews of Power Transmission Efficiency

The electric field will decrease with the increase of the distance. High frequency is needed to be injected in the primary plate to be able to observe a higher power transfer. In this research work, the study and analysis will be made based on the power transfer amount made by both materials. Power transfer amount will be measured based on the three factors associated with the condition of the materials.

According to (**Kamaruddin, 2015**), the prototype of the CPT system was successfully achieved which was capable of transmitting 2mW of power at a 4MHz frequency, with 90.7 efficiencies. In [2], they succeeded 0.3W power transfer experiment. They discovered that WPT using electric field has an advantage of WPT that uses electric field is of misalignment characteristic of one direction.

Power transmission analysis and optimization of CPT done by the Chenyang Xia, Yuejin Zhou, Juan Zhang and Chaowei Li. In [4], the power system output can be obtained as in

$$P_{CPT} = \frac{V_o{}^2}{R_L} = \frac{R_L}{(R_{C_S} + R_L)^2} V_P{}^2 = \frac{R_L}{(\frac{\tan\delta}{\omega C_S} + R_L)^2} V_P{}^2$$

where, R_L is equivalent load resistance, $V_P$is a voltage source, R_{C_S} is capacitance equivalent resistance, Cs is equivalent capacitance, δ is a dielectric loss, and ω is angular frequency.

The power transmission equation will be as the reference to produce the simulation and as well as the experiment. The modeling will develop based on the power transmission equation and the factors will be studied.

MODELING OF RESEARCH WORKS AND EXPERIMENT SETUP

In this section, it is described modeling of the project work and experimental setup.

Modeling of Research Works

In this research, the study and analysis will be done on materials used for the plates on transmitter and receiver. In producing the capacitance interface, the plates, dielectric materials, and the air are needed as shown in Figure 5. The concept of the CPT system as shown in Figure 6.

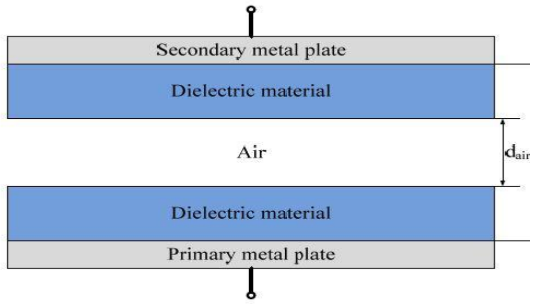

Figure 5. Schematic diagram of coupling with dielectric and air gap

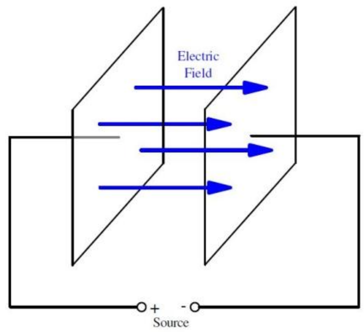

Figure 6. Schematic diagram of electric field coupling between two parallel plates

The general capacitive structure used in this work is as given by

$$C = \frac{A\varepsilon_o\varepsilon_r}{d}$$

where, A is the effective coupling area (cm^2), d is the coupling distance (cm), ε_o is the permittivity in a vacuum (8.85x10^-12), and ε_r is the permittivity of dielectric materials. This formula is the general capacitive structure for this research work. The permittivity in the small gap vacuum is considered to calculate the capacitances value.

Experiment Setup

The experiment is conducted to investigate the relationship between the power transfer and the four factors of the equipments.

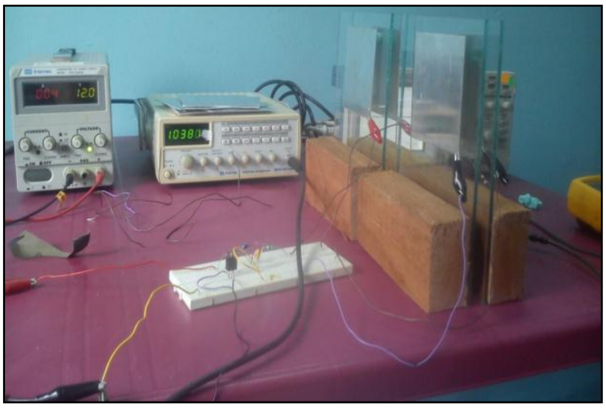

Figure 7. Experimental Setup

The equipments are DC Supply, Function Generator, and Oscilloscope which needed for the experiment as shown in the Figure 7. 12 V is the DC voltage source supplied to the circuit.

The circuit acts as Class-E Mosfet Converter, convert from DC supply to AC output at 1 MHz frequency. AC source is used for the Capacitive Power Transfer. The variable factors for the experiment is detailed in Table 3, Table 4 , Table 5 and Table 6.

Table 3. Thickness of Coupling Plates

No	Size (cm)	Thickness (mm)	Amount in RM
1	9x9	1,2,3	12
2	11x11	1,2,3	12
3	13x13	1,2,3	12

Table 4. Thickness of Glasses

No	Size (cm)	Thickness (mm)	Amount in RM
1	15 x 22	2	4
2	15 x 22	4	4
3	15x 22	6	4

Table 5. Size of the Coupling Plates

No.	Size (cm)	Amount in RM
1	9x9	12
2	11x11	12
3	13x13	12

These materials will be used as the transmitter and receiver plates or dielectrics materials (glasses). Materials will be changed per the factors of investigation requirements.

Table 6. Parameters Value

Equipment required	Value
Load Resistance (R2)	1ohm
Voltage Source	12V (DC Supply)
Inductor (L1)	33.213uH
Inductor (L2)	34.7uH
Capacitor (C1)	1.0nF
Capacitor (C4)	2.2nF

RESULT AND DISCUSSION

Table 7 shows that the voltage and current obtained at the load resistor of the circuit. The power is measured by the equation of P=V1 cos where the cos is equal to 1 due to the load: the resistor and the waveform produced at the receiver plate are the same. According to the data obtained, the result shows that the power transfer to the receiver plate is unstable for the different thickness of the plates. At thickness of plates (size= 9 cm x 9 cm) at 1 mm, 2 mm and 3 mm, the power transfer are 20.20 mW, 33mW, and 25.06 mW. The result seems the same for the size of plates of 11 cm x 11 cm and 13 cm x 13 cm. Overall it can be seen that the thickness of the plates does not affect the power transfer. The conductivity of the electricity of the plates in the different thickness gives the same capability to carry electron.

According to the Figure 18, the power transfer is unstable and the optimum power transfer level is at the thickness of 2 mm. To have a better power transferred, the thickness of the plates must be at a suitable thickness. This is because the suitable thickness does have a better electricity conduction. The distance of the transmitter plates and receiver plates is fixed at 1 cm and the thickness of the glass is at 3 mm since it is the optimum level for the glass for CPT.

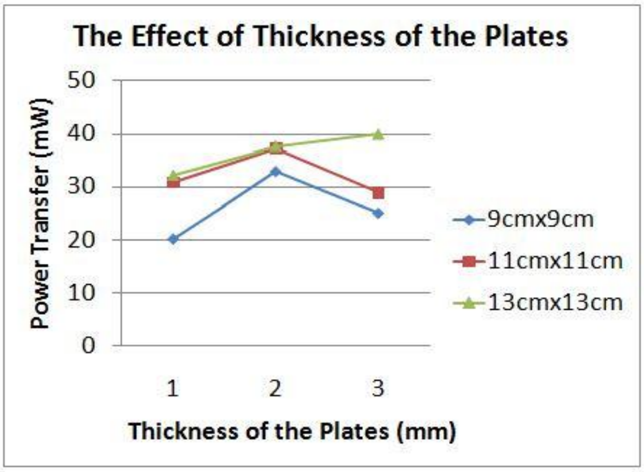

Figure 18. The graph between power transfer and thickness of the plate

Table 7. Power Transfer for the Different Thickness of the Plates

Thickness of plates: 1 mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	285.78	0.07	20.20
11x11	385.35	0.08	30.83
13x13	401.84	0.08	32.15
Thickness of plates: 2 mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	415.88	0.08	33
11x11	460.19	0.08	37.29
13x13	471.80	0.08	37.74
Thickness of plates: 3 mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	313.32	0.08	25.06
11x11	412.87	0.07	28.90
13x13	493.85	0.08	39.90

The thickness of the plates in the experiment is fixed at 3mm and the distance between plates is at 1cm. According to the result obtained in Table 8, the power transfer at the receiver plate is increase as the thickness of the glass increase. The result is same for the different size of the plates. This happened because the permittivity of the dielectric materials is increasing as the thickness of the glass increase. The increase in permittivity of dielectric materials will result in producing higher capacitance interface between the plates. The capacitor is formed by the plates and the higher capacitance results in higher in power transfer. The optimum power transfer in the experiment is at a thickness of the glass at the 6 mm for the size of the plates 13 cm x 13 cm which is when the power can be transferred is 28.01 mW, 32.79 mW, and 39.51 mW.

In Figure 19, the power transfer increases as the thickness of the glass increases. The electron attached to the dielectric materials is higher at the thicker glasses compared to the thinner glasses. This is how the thickness of the glasses affects the power transfer. However, in designing the real CPT model in any application, the suitable thickness of the glasses depends on the reliability for a particular application.

Table 8. Power Transfer for Different Thickness of the Glasses

Thickness of glasses: 2mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	374.45	0.07	26.21
11x11	388.69	0.07	27.24
13x13	380.15	0.08	28.01
Thickness of glasses: 4mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	387.35	0.08	30.98
11x11	390.62	0.08	31.25
13x13	409.92	0.08	32.79
Thickness of glasses: 6mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	375.78	0.08	30.06
11x11	412.87	0.08	33.03
13x13	498.85	0.08	39.51

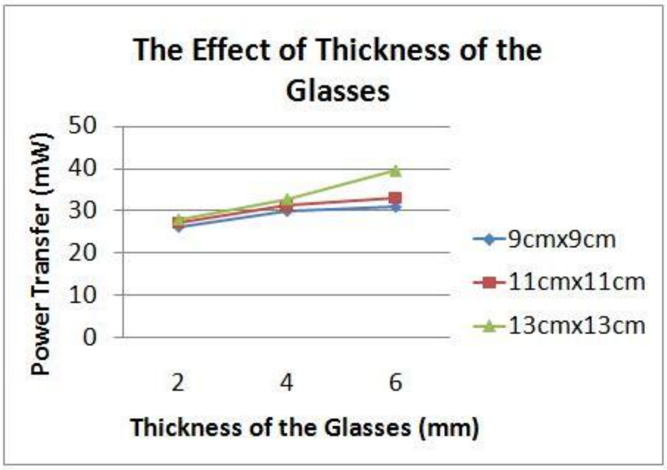

Figure 19. Power Transfer for the Different Thickness of the Glasses

Table 9. Power Transfer for the Different Size of the Coupling Plates

Thickness of plates: 1mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	285.78	0.08	17.14
11x11	385.35	0.08	30.8
13x13	401.84	0.08	32.14

In this experiment, the one thickness of the plates to demonstrate the differences in the result and it has to be compared with the zinc plates in the next point. Referring to the Table 9, the power transfer is increased as the size of the plates is increased. This is because the increase of the effective coupling area will result in higher capacitance produced for the capacitor formed at the transmitter and receiver plates. The higher the capacitance, the higher the power transfers between the plates.

Figure 20 describes that the power transfer increase as the size of the plates is increased. Power transfer at the size 9 cm x 9 cm, 11 cm x 11 cm, and 13 cm x 13 cm are 17.14 mW, 30.8 mW and 32.14 mW. In designing the application for CPT, the size of the plates is the most important part to be considered since it gives larger differences in term of the power transfer for differences of the size of the plates.

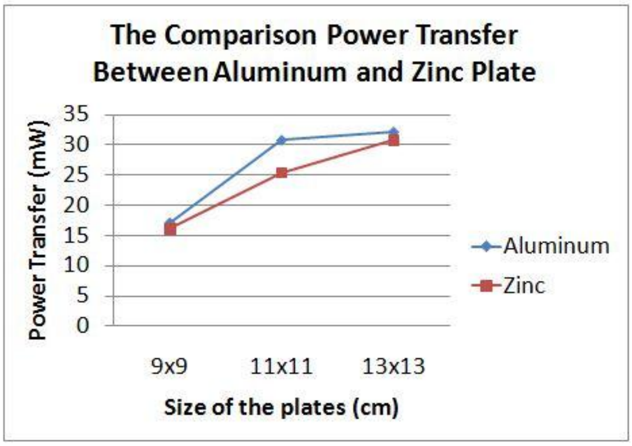

Figure 20. Graph between power transfer and for the size of the coupling plates

Table 10. Power Transfer for Zinc Plates

Thickness of plates: 1mm			
Size (cm)	Voltage (mV)	Current (A)	Power (mW)
9x9	274.83	0.06	16.08
11x11	362.87	0.07	25.4
13x13	384.69	0.08	30.77

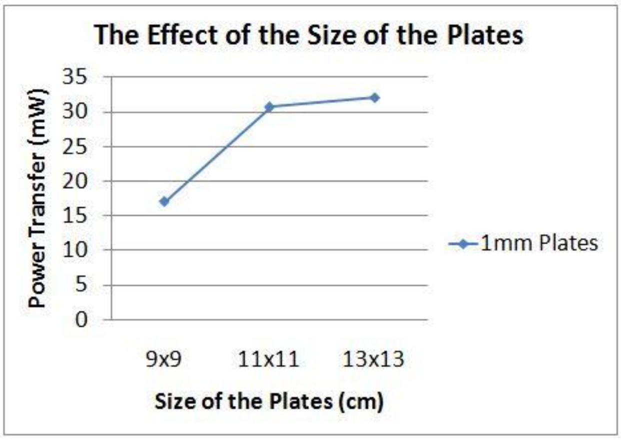

Figure 21. Power Transfer for Zinc Plates and Aluminum Plates.

The thickness of the glasses is fixed at 6 mm and the transfer distance is at 1 cm. According to the table and the figure above, the aluminum plate has the better power transfer compared to the zinc plate. It is theoretically proven as well in the wireless system. Since in the table of the conductivity of metals shows that aluminum has the better electric conductor than zinc. So, in designing the CPT application, it is important to use the better conductivity metal so that the power transfer has a better efficiency of power transmission.

CONCLUSION AND RECOMMENDATION

This research studies the material characteristics for the capacitive coupling wireless power transfer system by doing the experiment on the material used for capacitive coupling. In the experiment, there are three manipulated variables. The variables found in this studies are the size of coupling plates with power transfer, the thicknesses of the coupling plates with the power transfer and the thicknesses of the glass with the power transfer.

The conclusion that the thickness of the plates does not affect the power transfer as the general capacitive structures. Second, the thickness of the glasses affects the power transfer through the plates because of the capacitance interface formed as a capacitor as the transmitter and receiver plate affects the power transmission. The highest power transfer obtained is 39.51 mW. Third, as the size of the plates is increased, the power transfer also increased due to the effective coupling area of the plate and the permittivity of dielectric materials. Furthermore, the aluminum has better power transfer capability as compared to the zinc as the conductivity of electric of aluminum is better than zinc. All these results are very important in designing the CPT application so that the optimum power level of transfer can be obtained. Future works is to investigate factors of materials of temperature, shape and flatness and how it affects the power transfer. By investigating this factors, capacitive power transfer can be understood and the efficiency of the system can be improved.

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