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Development of Wireless Power Transfer using Capacitive Method for Mouse Charging Application

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ABSTRACT

Wireless power transfer (WPT) is a non-contact power transfer within a distance. With the advantage of not-contact concept, WPT enhances the flexibility movement of the devices. Basically, there are three types of the WPT which are inductive power transfer (IPT), capacitive power transfer (CPT) and acoustic power transfer (APT). Among these, capacitive power transfer (CPT) has the advantages of confining electric field between coupled plates, metal penetration ability and also the simplicity in circuit topologies. Therefore, we focus on the capacitive method in this paper. To be specific, this paper aims to develop a wireless mouse charging system using capacitive based method. This method enables wireless power transmission from mouse pad to a wireless mouse. Hence, no battery requires to power up the mouse. In this paper, a high efficiency Class-E converter is described in details to convert the DC source to AC and the compensation circuit of resonant tank is also proposed at the transmitter side in order to improve the efficiency. In the end, a prototype is developed to prove the developed method. The performances analysis of the developed prototype is discussed and the future recommendation of this technique is also presented.

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1. INTRODUCTION

Wireless Power Transfer also known as WPT is a process of transferring power between two or more physically unconnected electric circuits or devices [1]. This innovative technology has created new possibilities to supply electronic devices with electrical energy by eliminating of wires, connectors and slip-rings. The potential application of WPT can range from a low power office or home appliances to a high power industrial systems [2]. Generally, it can be divided according to the medium used for power transmission, which are acoustic-based WPT, light-based WPT, capacitive-based WPT and the inductively coupled WPT.

The most well-known technique in the WPT technology is inductive coupling between transmitter and receiver which is widely applied to most of the applications nowadays [3]. However, the major drawback of IPT is ferromagnetic interference which is the flux cannot pass through the magnetisable material [4]. Meanwhile, the acoustic power transfer is comparatively new, which is optimizing the vibration or ultrasonic propagation wave rather than electromagnetic fields for power transmission. Although light-based systems able tosupply a great amount of power, its diffraction losses have directly influenced the efficiency over a great distance [5], [6].

As compared to popular inductive power transfer, both of the APT and CPT have the advantages over IPT. For APT, the efficiency of the power transmission is higher when the distance of the transmitter and receiver is much larger. While capacitive have the ability of metal penetration and the potential to reduce electromagnetic interference (EMI) that will overcome the problems in IPT [7]. Although the APT could overcome the metal barrier issue and the distance limitation, the difficulties of the large acoustic impedance mismatch of the transmitter and receiver with the medium could lead to a severe limit on the efficiency of power transfer. Hence, the capacitive approach is more preferable in this work.

Currently, in the market, the “Magic Charger” charger is available which utilizes the IPT method to charge up devices. But usually the “Magic Charger” comes together with a set of rechargeable battery and charger station and brings up the battery issue. Although by using the rechargeable battery would definitely reduce the battery disposal issue, but it would be great if there is no battery being implanted in the wireless mouse and yet it still can be powered up.

Therefore, in this work, a wireless computer mouse charging system is proposed. This system uses the capacitive power transfer based approach to solve the abovementioned issue. The proposed capacitive based wireless mouse charging system is able to charge the mouse while the mouse is in its use. Another saying, the mouse is still in charging mode even a user is using it as long as the mouse is in the effective area of charging (mouse pad). However, the movement of the mouse along the x-axis is preferable in due to achieve fully coupled condition to contribute a higher efficiency of power transfer.

2. OVERVIEW OF THE PROPOSED CPT METHOD

This prototype is designed in a small scale low power model up to 5V and wireless power transmission range effective is within 1cm gap. The issue that always affects the efficiency of the power transmission in CPT is the alignment of the transmitter plates and the receiver plates. Hence, in this project, both plates on the wireless computer mouse and mouse pad are to be designed in an aligned fixed position as shown in the Figure 1(a) while the Figure 1(b) shows the misalignment situation of the both plates [8]. As can be seen, when the misalignment situation occurred, there are uncoupled areas between the transmitter and receiver which will lead to the consequences in affecting the efficiency performance of the system. The plate effective area is highlighted on the mouse pad. In this prototype, a fully aligned situation is desirable.

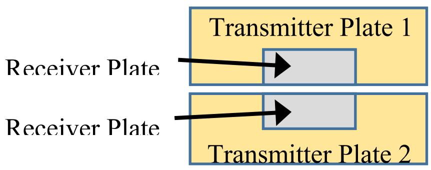

Figure 1(a). Fully Aligned and Coupled Situation

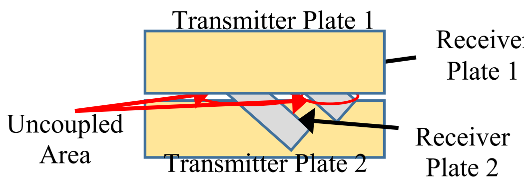

Figure 1(b). Misaligned Situation

In a CPT system, a high frequency voltage is desired to drive the electric field coupler so that the alternating current can flow through it to provide the load with the required power. Therefore, a Class-E converter is designed as the high frequency converter at the transmitter to convert DC source to AC. On the other hand, the problem of power loss during the charging process is overcome by designating capacitor compensation circuits at the transmitter and receiver part.

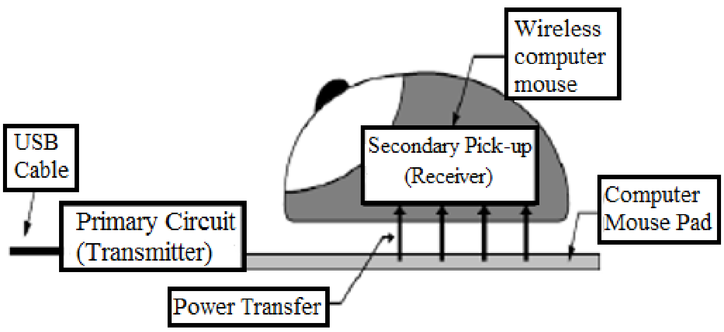

Figure 2. Conceptual Design of Wireless Mouse Charging Prototype [9]

3. DESIGN DESCRIPTION

The basic conceptual design of the prototype is shown in Figure 2. From the figure, first, a DC source from the USB port is supplied to the primary circuit which is also known as the transmitter. At the transmitter, there is a high frequency converter (Class E) that is designed to convert the DC source to a high frequency of AC voltage and then an alternating electric field is generated and pass through the capacitive coupling plate to the receiver part of the system which is the secondary pick-up (receiver plates) attached in the wireless computer mouse.

3.1. Class-E Converter

The Class-E converter is familiar implemented for the high frequency applications due to its advantage of low switching losses with high frequency output. Basically, Class-E converter can be divided into two types: Class-E Zero Voltage Switching (ZVS) converter and the Class-E Zero Current Switching (ZCS) converter [9]. Both of these converters is classified of the soft-switching converters. The basic circuit of the Class-E converter is shown in the Figure 3.

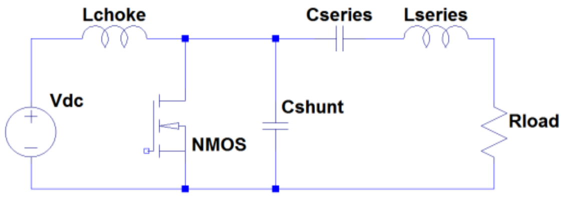

Figure 3. Class-E Converter Circuits Topology [10]

In order to design the ZVS Class-E converter, the same assumptions made in [10] is appliedFor the Class-E converter, the circuit only requires a power MOSFET as the switching device. Besides, the low input at the MOSFET gate, V_g, is also an important criterion. As the voltage at drain, V_d is three times greater than the V_g, therefore the minimum input at the gate, V_g, should be low enough to ensure the resonant tank will not be burned. In the meanwhile, USB source is used as the input source for the Class-E circuit.

In the resonant tank circuit, there are an inductor and a capacitor in series with a capacitor which is located in parallel. The value of the passive circuit elements are decided according to the equation in the previous research works [10] and [12]. By assuming load power and the voltage supply, required load resistance, R can be calculated as follows [10]:

$$R = \frac{8V_{CC}^2}{(\pi^2 + 4)P_{load}} \tag{1}$$

Besides, by assuming the operating frequency, the shunt capacitor, C_{shunt} and L_{choke} can be calculated as follows [22]:

$$C_{shunt} = \frac{2.165}{2\pi fR} \tag{2}$$

$$L_{choke} = \frac{0.4001\,R}{2\pi f} \tag{3}$$

Furthermore, by assuming the quality factor, Q, the series capacitance, C_{series} and series resonant inductor, L_{series} can be determined as follows [10]:

$$C_{series} = \frac{1}{2\pi fQR} \tag{4}$$

$$L_{series} = \frac{QR}{2\pi f} \tag{5}$$

3.2. Capacitive Plates

In the second stage of the process, the power will be delivered from the transmitter plate to the receiver plate. After designed Class-E converter and the compensation circuit, the transmitter plate 1and transmitter plate 2 are connected to the "Pin 1" and "Pin 2", respectively asis shown in the Figure 4.

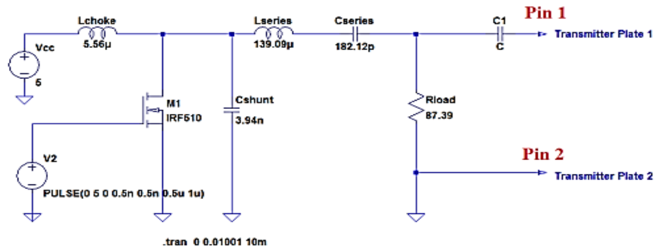

Figure 4. Connection of the Transmitter Plate 1 and Transmitter Plate 2

The position of the transmitter plates and the receiver plates. There is also a medium in between the both transmitter and receiver plates.

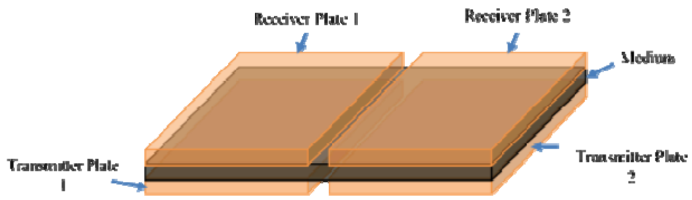

Figure 5. Position of the Transmitter Plates and the Receiver Plates

In order to analyze the different efficiency of voltage transfer, the copper plate is cut into 6 pieces, in a pair of two. Therefore, there are two pieces of 20cm x 7.5cm copper plate to form the transmitter plates while two pieces of 3cm x 3cm copper plate to form the receiver plate and also two pieces of 7cm x 7.5cm copper plate to form another bigger area of the receiver plate. These three sizes of the transmitter plates and receiver plates are shown in the Figure 7.

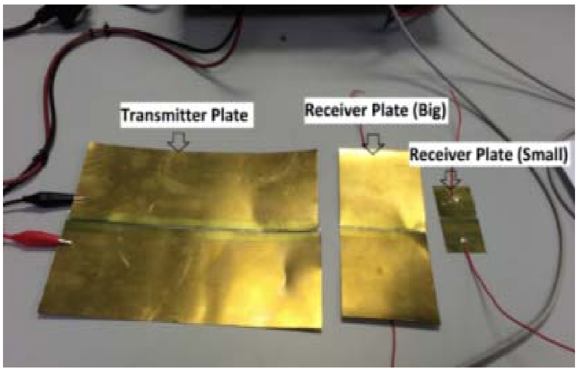

Figure 6. Sizes of the Capacitive Plate

As discussed earlier, there is a medium placed between the transmitter and receiver plates. Therefore, there are two medium are used in this experiment which are the paper and the mouse pad. Those mediums are different in their thickness. In according to that, analysis based on the medium and for each size of the receiver plates is carried out. Equation (6) will be used to calculate the transmission efficiency between the transmitter plates and receiver plate.

$$\text{Efficiency} = \frac{\text{Vr}}{\text{Vt}} \times 100\% \quad (6)$$

where V_r is voltage at receiver and v_t is voltage at transmitter.

4. ANALYSIS OF CIRCUIT PERFORMANCE

In this section, each decision which has been chosen for this research is explained in details. The results of every experiment are also presented in tables and followed by graphs plotted. Besides, the experiments performed are also according to desired characteristic as explained in following sub-sections.

4.1. Analysis of Class-E Converter

First of all, based on the desired output of the Class-E converter circuit, the value of the component in resonant circuit is decided using the Equation (1) to (5) by using the values that are given in Table 1 and therefore we have all the values which have been tabulated in Table 2.

Table 1. Desired Parameters for the Class-E Converter

Parameters	Values
Operating Frequency	1MHz
Rated Power	165mW
Quality Factor, Q	10
DC Voltage Supply	5V

Table 2. Class-E Converter Parameters

Parameters	Values
RF Choke Inductor, L_{choke}	5.56µH
Shunt Capacitor, C_{shunt}	3.94nF
Series Capacitor, C_{series}	182.12pF
Series inductance, L_{series}	139.09µH
R_{load}	87.39Ω

In this Class-E converter, a N-channel IRF 510 is chosen due to its low Static Drain-to-Source On-Resistance, $R_{(DS)}$. PIC is used to generate square wave pulse and also a driver circuit is used to boost the square wave pulse in order to achieve the minimum current and voltage required by the MOSFET. Other than that, ZVS condition is very importance in Class-E converter in order to produce a very high efficiency of the converter. Particularly, if the components in the resonant circuit are chosen properly, the switch (MOSFET) will turn on at zero voltage.

From Figure 7, the designed Class-E converter circuit is successfully achieved the ZVS condition in the simulation. When the voltage at the V(g) drops to zero, the voltage at the V(d) is achieving the value of 13.2V which means there is a flow of voltage while the MOFSET acts as open-circuited ("off" state).

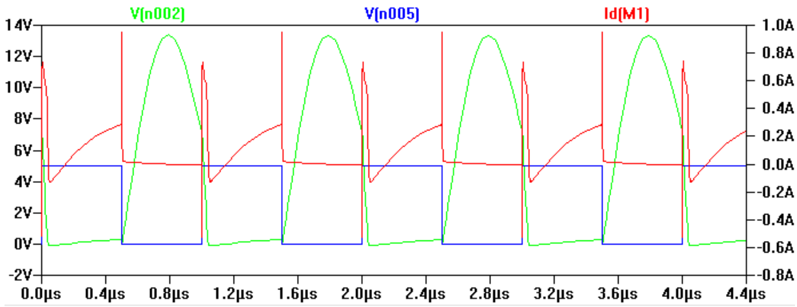

Figure 7. ZVS Condition for the Class-E Converter

For the experimental result, with the 5V dc supply and the 1MHz square wave pulse, the output waveform of the gate and drain achieved the ZVS condition is as shown in Figure 9. Due to the absence of current probe, the current waveform cannot be measured practically. Therefore, only the voltage at V(g) and V(d) can be shown. As shown in Figure 8(a), the ZVS condition is successfully achieved although there is some distortion during the "on" and "off" state of the gate. But, this distortion is not affect much on the performance on the voltage obtained as compared with the simulation result.

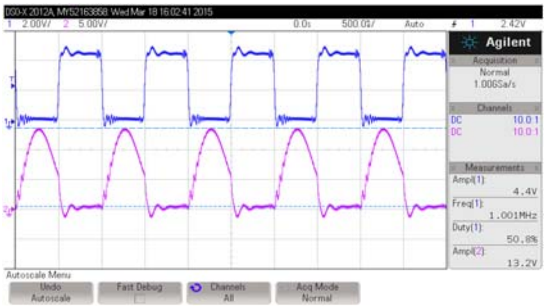

Figure 8(a). ZVS from the Oscilloscope

Figure 8(b). Drain Voltage versus Output Voltage at Load using Oscilloscope

For the Figure 8(b), the purple line is the output voltage at the load or the Class-E converter circuit, V(r). In Table 3, the value of output voltage is calculated in its average value and the output voltage, V(r), will connect to the transmitter plate in transferring the voltage to the receiver plate which will be discussed in the next section. Also, all the calculation in the next part will use the average value of this output voltage.

Table 3. Average Output Voltage, V_r, at the Transmitter Plate

Number of time taken for the Output Value	1	2	3	4	5	Average Voltage (V)
Output Voltage (V)	9.4	8.6	9.3	8.4	8.7	8.88

4.2. Analysis of Capacitive Plates

a) Small Plate at Receiver Part

From Figure 10, the measurement of the received voltage from the receiver plates is taken in different alignment from Position 1 to Position 3 at different Zone, respectively. For medium part, paper and mouse pad are tested for each of the different alignment. The results are tabulated in Table 4 and Table 5.

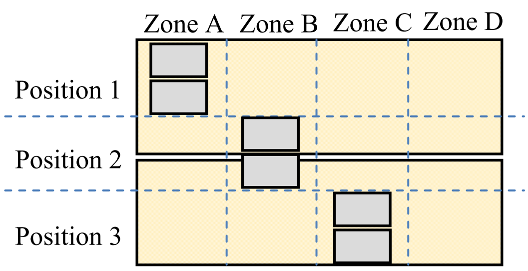

Figure 10. Different Alignment of the Receiver Plate on the Different Zone

Table 4. Received Voltage at The Receiver Plate Using Paper as a Medium

	Zone A	Zone B	Zone C	Zone D	Average	Efficiency (%)
Position 1	4.9 V	4.7 V	4.5 V	5.1 V	4.8 V	54.05
Position 2	5.2 V	5.5 V	5.3 V	5.3 V	5.33 V	60.02
Position 3	2.89 V	1.28 V	1.21 V	1.08 V	1.62 V	18.24

Table 5. Received Voltage at The Receiver Plate Using Mouse Pad as a Medium

	Zone A	Zone B	Zone C	Zone D	Average	Efficiency (%)
Position 1	1.8 V	1.8 V	2.1 V	2.2 V	1.98 V	22.23
Position 2	2.2 V	1.8 V	2.3 V	2.3 V	2.15 V	24.21
Position 3	0.6 V	0.7 V	0.7 V	0.6 V	0.65 V	7.32

Furthermore, the comparison of the performance for the paper and mouse pad as the medium of the transmission power is depicted in Figure 12.

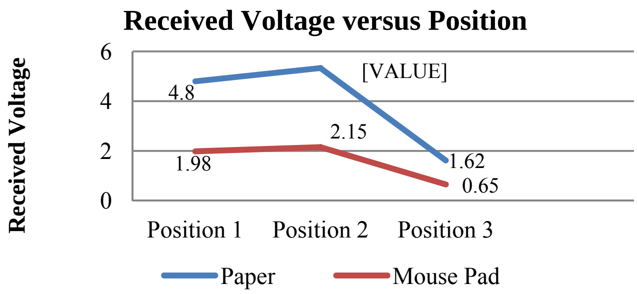

Figure 11. Graph of the Received Voltage in Different Position with Different Medium

From Figure 11, apparently, the voltage received at the receiver plate for paper is greater than using mouse pad as the medium. The received voltage at Position 2 is the highest among three fixed position on the plates. This high voltage gained is due the fully alignment of the receiver plates on the transmitter plate as well as the coupled area become greater. Therefore, the performance of the transmission voltage for paper is better than using mouse pad as the medium part. This is due the thickness of these two medium and give a direct influence to the performance of the transmission. The smaller the gap which is also the shorter the distance can higher up the capacitance of the capacitive plates. With the strong capacitance, the capacitive plates can confined a stronger electric field and therefore the voltage flow to receiver plate will be more efficient. Other than that, another experiment of a 45^{o} slant alignment of the receiver plates on the Position 2 in different Zone is also carried out. The alignment of this experiment is shown in Figure 12.

From the Table 6 and Table 7, the efficiency for the paper medium seems to be greater than mouse pad but yet the efficiency for the paper only up to 57.60%. This is consider the losses in transmission is still very high. As shown in Figure 12, there is some uncoupled area for the receiver plates when the plates is in the misaligned position which will directly decrease the voltage to be received at the receiver part.

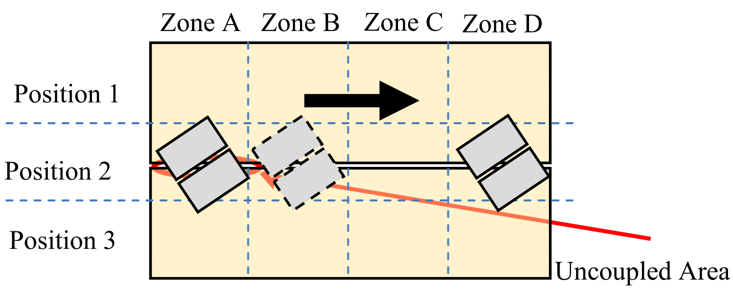

Figure 12. 45^{o} Slant Alignment of the Receiver Plate

Table 6. Received Voltage at the 45^0 Slant Receiver Plate Using Paper as a Medium

	Zone A	Zone B	Zone C	Zone D	Average	Efficiency (%)
Position 2	5.05 V	4.92 V	5.27 V	5.35 V	5.15 V	57.60

Table 7. Received Voltage at the 45^0 Slant Receiver Plate Using Mouse Pad as a Medium

	Zone A	Zone B	Zone C	Zone D	Average	Efficiency (%)
Position 2	2.19 V	2.17 V	2.33V	2.05 V	2.19 V	23.09

b) Big Plate at Receiver Part

Similarly, this experiment is carried out as the same with the first experiment. Hence the details are omitted here. By changing the small receiver plates with a bigger receiver plates (7cm x 7.5cm), the steps of collecting data is also the same. But, the position of the receiver plate is only placed in aligned position and moving from Zone A to Zone C which is illustrated in Figure 13. The value collected is then recorded in the Table 8 and Table 9 for paper and mouse pad as the medium, respectively.

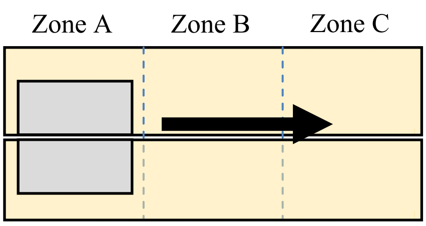

Figure 13. Alignment of the Receiver Plate on Different Zones

Table 8. Received Voltage at the Receiver Plate Using Paper as a Medium

Zone A	Zone B	Zone C	Average	Efficiency (%)
5.5 V	4.9 V	6.4 V	5.6 V	63.06

Table 9. Received Voltage at the Receiver Plate Using Mouse Pad as a Medium

Zone A	Zone B	Zone C	Average	Efficiency (%)
3.4 V	3.5 V	3.6 V	3.5 V	39.41

As shown in the Table 8 and Table 9, the efficiency of the transmission for the paper is greater than the mouse pad. While, the voltage for these three zones is not much different since the position of the receiver plates is fully aligned to the transmitter plates. Besides, the value of the voltage collected is plotted in the graph form as shown in Figure 14,

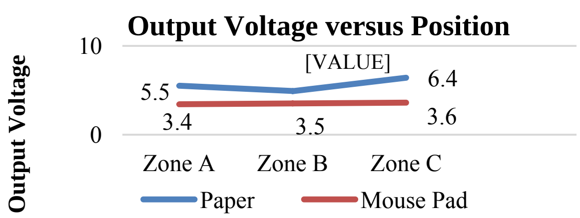

Figure 14. Graph of the Received Voltage in Different Zone with Different Medium

Other than the fully align situation, 45^o of the slant position is also tested in the medium of paper and mouse pad. the results are recorded as in Table 10 and Table 11, respectively.

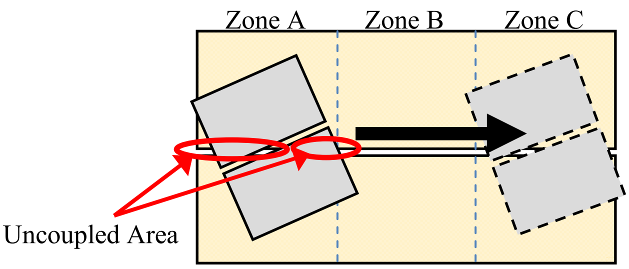

Figure 15. 45^{o} Slant Alignment of the Receiver Plate

Table 10. Received Voltage at The 45^{0} Slant Receiver Plate Using Paper as a Medium

Zone A	Zone B	Zone C	Average	Efficiency (%)
3.6 V	3.9 V	4.3 V	3.93 V	44.26

Table 11. Received Voltage at The 45^{0} Slant Receiver Plate Using Mouse Pad as a Medium

Zone A	Zone B	Zone C	Average	Efficiency (%)
3.6 V	3.7 V	3.7 V	3.7 V	41.67

By comparing these experiments result, the position and the size of the receiver plates play an important role in power transmission which is related to the efficiency in transmission. As the receiver plate is moving from one position to another position, the received voltage fluctuates. In this condition, the best position is determined which is aligned position. In other words, bigger the plates, bigger the effective area which is giving the stronger electric field confined between the transmitter and receiver plates. In addition to that, the uncoupled are is an undesired condition too. When the uncoupled are exists during the power transmission, the effective area of the receiver plate will be reduced and that will cause the losses and efficiency drop. Furthermore, by using the paper as medium, the efficiency obtained is higher than using mouse pad as the medium. Obviously, the thickness of the medium (distance between the transmitter and receiver plate) affects the performance efficiency too. Therefore, the thickness of mouse pad should be as thin as possible. In other words, a thin mouse pad is highly recommended act as the medium for this project.

4.3. Rectifier Circuit

After the voltage is transmitted, the AC voltage is then supplied into the full bridge rectifying circuit to convert to DC voltage. The circuit used as shown as in Figure 16. In this work, the wireless mouse needs 10mA, 1.5V to be powered up. Although the voltage achieved the required 1.5V after being rectified, the wireless mouse still unable to power up. This is due to the current supplied is lower than the minimum current required to power up the wireless mouse. Because of this very low current supply, therefore, a LED is used to test at the output terminal whether the power still able to light up the LED.

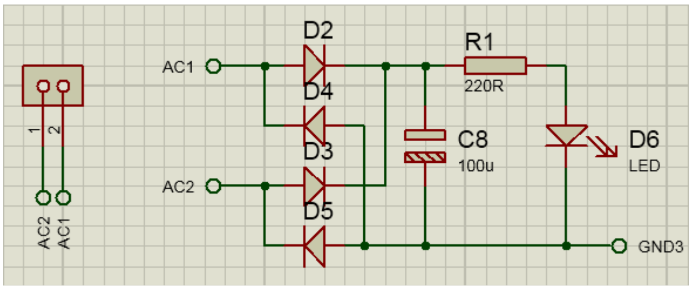

Figure 16. Rectifier Circuit in the Simulation before Fabricating

When the small receiver plate is used at the receiving part, the rectified signal could not light up the LED while the big receiver plate still able light up LED. Although the light is very weak, this shows that the big size receiver plate have a better efficiency in receiving the transmitter signal. As well as for the different type of medium being used, for the paper medium, the rectified voltage is able to light up the LED while the mouse pad could not do so.

For example, the Figure 17(a) and Figure 17(b) are taken from the oscilloscope for paper medium of the small receiver plate and big receiver plate, respectively. Although the rectified waveform is still in sinusoidal waveform but the voltage is a DC voltage. In this work, a voltage regulator is not implemented for the receiver end. This is because the signal after rectified is too low to be regulated. If there is still a voltage regulator to regulate the ripple rectified voltage, the output voltage from the voltage regulator is definitely low and could not light up the LED. Finally, the rectified signal able to light up LED but could not power up the wireless mouse.

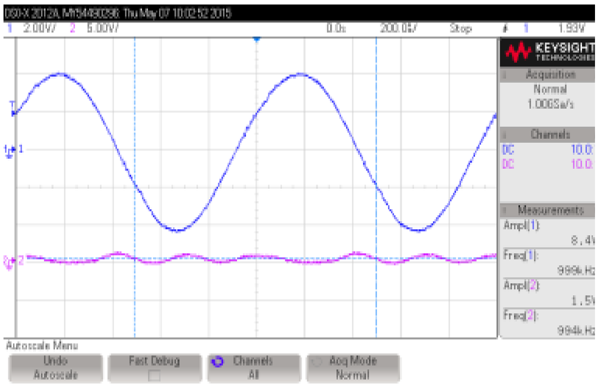

Figure 17(a). Received Voltage from the Small Receiver Plate versus Rectified Voltage (Paper)

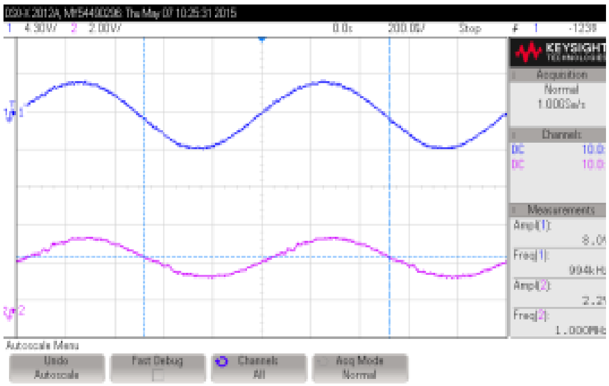

Figure 17(b). Output Voltage from the Big Receiver Plate versus Rectified Voltage (Paper)

4.4. Final Prototype

After completing the analysis part, a final prototype was developed and it is shown in Figure 18. The LED is light up successfully during the power transmission. By supplying $5V_{DC}$ to the transmitter part, the Class-E converter converts the DC source to AC source. Then, an alternating electric field is generated and passes through the capacitive coupling plate to the receiver part. By placing the receiver plates within the effective area of charging, the LED is able to light up. When the receiver plate is moving to the ineffective area of charging, the LED is not light up.

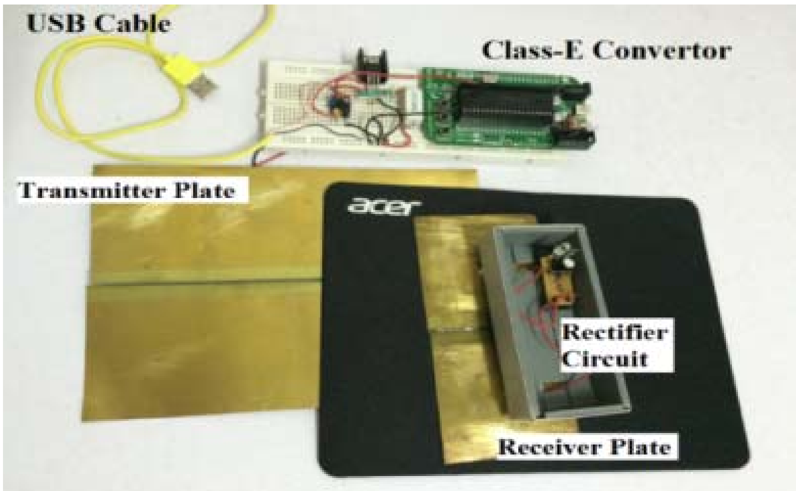

Figure 18. Final Prototype

5. CONCLUSION

In conclusion, in this project, capacitive power transfer approach can be implemented in the wireless mouse charging application. By using the capacitive coupling plate at the transmitter part and receiver part, the power is successfully transmit. Although the transmitted power is unable to power up the wireless mouse but it able to light up a LED which shows that the capacitive power transfer concept is proven in this project. Secondly, a compensation circuit is developed to improve the efficiency of the system. In the Class-E converter, a resonant tank is successfully calculated and designed based on the requirements. This resonant tank is able to resonate the frequency to match with the operating frequency and produce a great efficiency of this Class-E circuit. Therefore, in this project, the loss in the Class-E converter circuit is low. The future works are; 1. The current amplifier circuit must be designed to boost the current of the system, and 2. The auto tuning circuit needs to be introduced to ensure the effectiveness of the proposed system although at misalignment condition.

ACKNOWLEDGEMENTS

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