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Performance comparison of capacitive power transfer between matching resonant circuit π1a and π1b at 13.56 MHz operating frequency

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ABSTRACT

This paper proposes current technique for wireless power transfer (WPT), which is capacitive power transfer (CPT). To date, inductive power transfer (IPT) remains the most popular technique for this technology. However, CPT has several benefits which make the development of this technique is growing up faster in industry and able to compete the IPT technology. A low number of components usage, simple topology, enhanced EMI performance, robustness to surrounding metallic elements are the benefits of CPT. In this work, the system is designed using class E power amplifier with the presence of impedance matching circuit. It assists the system to attain maximum power transfer. Two types of impedance matching are selected and compared in this work in order to understand the advantage and disadvantage of each in the framework of CPT system. MATLAB/Simulink software is used in this work to design and simulate the CPT system. This proposed system ables to generate 0.83W output power through a combined interface capacitance of 0.024nF at an operating frequency of 13.56 MHz, with 99.2% efficiency for both matching resonant circuits π1a and π1b. In the case for biomedical implantable device application, π1b is the superior matching resonant circuit since it requires smaller capacitance value and smaller size of receiver unit.

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1. INTRODUCTION

Recently, wireless power transfer (WPT) has been gaining a high market demands due to easy to use and an effective way in delivering energy to the device without the cable usage. From that, metal-to-metal contact method is directly cut out. Heretofore, inductive power transfer (IPT) has attained great performance in WPT technology. However, this technique has several limitations which magnetic field is unable to penetrate through metal shielding environment since IPT used magnetic field as transfer interface. Thus, this technique is not applicable in situation when metal barriers exist between power sources and the loads. Besides, since the magnetic field is functioning as transfer interface, it may cause electromagnetic interference (EMI) problems. EMI surfeit amount may interfere with peripheral circuits and cause health concerns [1]. Hence, to overcome the disabilities of IPT, the capacitive power transfer (CPT) technique is introduced. On the other hand, CPT has capability to transfer the energy through metal shielding environment. This is because of CPT used electric field as energy carrying medium [1], [2]. In addition, CPT has potential in minimizing the EMI [2], [3].

Power amplifier is one of the most vital elements for transmitter unit in CPT system. This is due to its function which determining the overall system performance [4]. This paper proposes a CPT system with class E power amplifier. The class E power amplifier is chosen since it has simple topology and good performance in term of efficiency, which able to attain 100% switch condition known as zero-voltage-switching (ZVS) [5]-[7]. Thus, it is the most preferable power amplifier for WPT system. The overlapping throughout the switching time intervals between switch current and voltage waveform have to be overcome. Consequently, it will produce a good efficiency in the system due to switching losses are almost zero and the components values are selected perfectly [8].

Impedance matching is a term to show that the source and load are effectively equal [9]. Generally, it is a technique used to match a load resistance to a source resistance in order to attain maximum power transfer [9]. It is usually applied in power transfer system to enhance the system efficiency [10] and maximize the capability of power transfer to the load [11]-[16]. By utilizing this technique in the system, high and maximum efficiency can be achieved [10], [12]. Impedance matching has several types which consist of matching resonant circuit $\pi 1a$, $\pi 1b$, $\pi 2a$ and $\pi 2b$. In this work, matching resonant circuit $\pi 1a$ and $\pi 1b$ are chosen since the technique used is capacitive approach; meanwhile the matching resonant circuit $\pi 2a$ and $\pi 2b$ are preferable for inductive technique. Due to the fact that every matching resonant circuit has their own strength and weaknesses, different topologies will produce different output power and efficiency of power transfer [16].

Generally, matching resonant circuit $\pi 1a$ and $\pi 1b$ both are good in term of power transfer efficiency and output power. However, in considering the application for biomedical implantable devices, such as pacemaker, this work confirms that matching resonant circuit $\pi 1b$ is more superior since the size of receiver unit is smaller compare to the matching resonant circuit $\pi 1a$. This is due to the consideration for human friendly and safety which need the smallest device size to put inside the human body. In terms of device production, diminishing size and weight is a strong trend to produce devices in order to make them compatible with normal human activities and enhance comfort for the host [17]. Besides, the capacitance value needed for matching resonant circuit $\pi 1b$ is smaller than matching resonant circuit $\pi 1a$. In section 2.3, the matching resonant circuits will be illustrate and explained in detail.

Contributions from this work can be summarised as follows: i) This work highlights on CPT system design which based on class E power amplifier. This system is powered with 8.93V dc input supply at 13.56 MHz operating frequency in producing an idle sinusoidal signal across the loads. The obtained efficiency for $\pi 1a$ and $\pi 1b$ impedance matching circuits are 99.2% for both; ii) Over 95% efficiency is maintained by developing both impedance matching circuits, $\pi 1a$ and $\pi 1b$ in the CPT system; and iii) In this work, comparison and analysis of output power performance for CPT system between $\pi 1a$ and $\pi 1b$ impedance matching circuits are shown in detail.

This paper is organized as follows: section 2 briefly shows the design of CPT system, meanwhile section 3 presents the simulation results and analysis for both circuit simulations, which are matching resonant circuit $\pi 1a$ and $\pi 1b$ and finally section 4, which conclude this work.

2. CAPACITIVE POWER TRANSFER (CPT) SYSTEM

Basically, CPT system is consisting of 2 major parts, which are transmitting unit and receiving unit. Both of these major units are separated by a medium, for instance air, skin, paper, plastic, etc. The proposed CPT system is illustrated as in Figure 1. In transmitting unit, the conversion process occur which transform the standard frequency dc power supply to a high frequency ac voltage. This shows the role of transmitting unit as a high frequency voltage source inverter. Then, the high frequency ac voltage is transferred to the transmitting coupling plates. When 2 receiving coupling plates are placed close to transmitting coupling plates, an alternating electric field is formed between these 2 plates and consequently, the displacement current can flow through it. During the CPT operation, the electric field coupler functions as two capacitors which connected in series. As a consequent, although without direct electrical contact, the power can be transferred to the loads in receiver unit.

2.1. Class E power amplifier

Power amplifier is an important part in transmitting unit of CPT system. It determines the overall system performance. Generally, class E ZVS power amplifier is the most efficient amplifier rather than other classes [8], [18]-[21]. This is due to the current and voltage waveforms of the switch are displaced with respect to time and resulting very low power dissipation in transistor. When the switch current and voltage waveforms do not overlap during the switching time intervals, switching losses are almost zero, thus high efficiency is attained.

Figure 2 depicts the circuit of class E power amplifier. It consists of power MOSFET, L-C-R series-resonant circuit, shunt capacitor C1 and choke inductor Lf. The power MOSFET is functioning as a switch. At the operating frequency f = ω/2π, the switch will turn on and off which determined by a driver. The choke inductor, Lf is chosen with sufficient inductance to force a dc input current [4], [21]. When the switch is on, the resonant circuit consists of L, C and R. This is due to the short-circuited occur to C1 by the switch. Meanwhile, when the switch is off, the resonant circuit consists of C1, L, C and R and all the components connected in series. The components value in Figure 2 are calculated by all these following equations for optimum operation at D=0.5. The equations are based on [22].

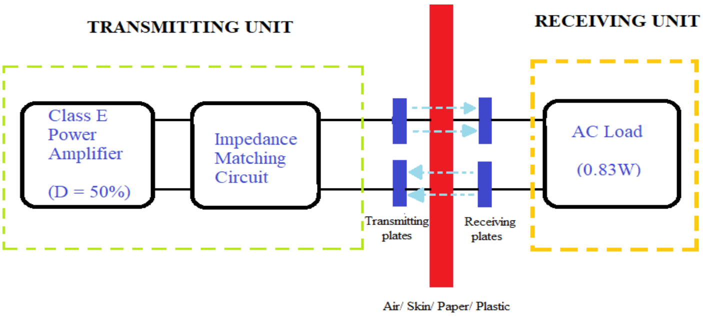


Figure 1. Block diagram of capacitive power transfer system

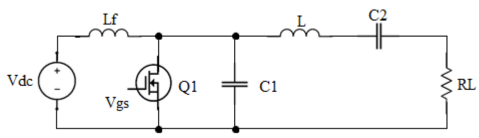


Figure 2. Class E power amplifier circuit

The full – load resistance is given by:

$$R = Rs = \frac{8}{\pi^2+4}\frac{Vi^2}{Po} \approx 0.5768\frac{Vi^2}{Po} \tag{1}$$

besides, the reactance of shunt capacitor can be obtained as:

$$X_{C1} = \frac{1}{\omega C1} = \frac{\pi(\pi^2+4)R}{8} \approx 5.4466R \tag{3}$$

The reactance of the resonance inductor is then:

$$X_L = \omega L = Q_L R \tag{3}$$

next, the reactance of resonance capacitor can be calculated as:

$$X_C = \frac{1}{\omega C} = \left[Q_L - \frac{\pi(\pi^2-4)}{16}\right]R \approx (Q_L - 1.1525)R \tag{4}$$

to note here that Figure 2 shows the basic resonant circuit without impedance matching capability. The load resistance, *R* have to be of the value determined by (1) in order to transfer a specified amount of power, *Po* at a specified dc voltage, *Vin*. Consequently, an impedance matching circuit is required to match any impedance to the desired load resistance.

2.2. Impedance matching resonant circuits

The aim of the impedance matching circuit is to transform the load resistance or impedance into the impedance needed in producing the desired output power, *Po* at the specific supply voltage, *Vin* with operating frequency *f*. The major reasons to have an impedance matching resonant circuit in CPT system are to attain higher power efficiency, maximum in power transfer and function as device protection [21].

Impedance matching resonant circuits have several types, which are matching resonant circuit π1a, π1b, π2a and π2b. Matching resonant circuit π1a and π1b are impedance transformation by tapping the resonant capacitor, *C* meanwhile matching resonant circuit π2a and π2b are impedance transformation by tapping the resonant inductance, *L*. Therefore, the comparison between matching resonant circuit π1a and π1b are selected since the method used for this work is capacitive approach (CPT), which utilized the resonant capacitor as the coupling plates for transmitter and receiver parts.

In general, the performances for both of the matching resonant circuits are good in term of power transfer efficiency and output power. However, there are several advantages and disadvantages for both of the types. For biomedical implantable devices application such as pacemaker, it needs the smallest device size [23] due to the concern of safety and human friendly for body. In this case, matching resonant circuit π1b is superior and more preferable due to the smaller size of receiver part and smaller capacitance value needed compare to matching resonant circuit π1a. Figure 3(a) and Figure 3(b) show the comparison in term of receiver units for both of the matching resonant circuits.

Figure 3(a) shows the size of receiver part (matching resonant circuit π1a, which has bigger size of receiver part than the receiver part in Figure 3(b) (matching resonant circuit π1b. This is due to the presence of capacitor, C3 in receiver part of Figure 3(a), meanwhile in Figure 3(b), all of the capacitors are allocated in transmitter part. From the size comparison of receiver part for both matching resonant circuit π1a and π1b, it proven that matching resonant circuit π1b is more superior compare to matching resonant circuit π1a.

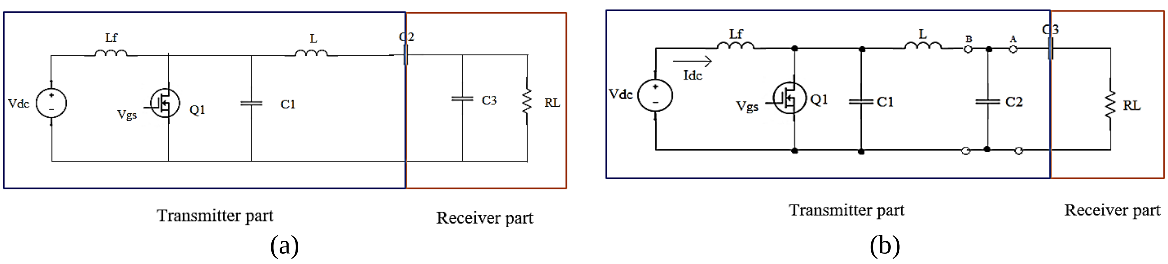


Figure 3. Transmitter and receiver parts: (a) matching resonant circuit π1a and (b) matching resonant circuit π1b

2.2.1. Matching resonant circuit π1a

As stated in (1), dependent quantities are supply voltage, *Vin*, output power, *Po* and load resistance, *R*. The load resistance is usually given in a lot of applications and it is different from that given in (1). Hence, an impedance matching resonant circuit is required which provides impedance transformation downwards and/or upwards. Figure 4(a) and Figure 4(b) show the tapped capacitor impedance matching resonant circuit π1a that provide downward impedance transformation. Figure 4(a) presents the circuit of matching resonant π1a meanwhile Figure 4(b) expresses the equivalent circuit for resonant circuit π1a.

Figure 4. Tapped capacitor impedance matching resonant circuit π1a providing downward impedance transformation: (a) matching circuit π1a and (b) equivalent circuit of matching circuit π1a

Then based on Figure 4, R_L-C_3 and Rs-Cs equivalent single-port network reactance factor can be calculated as:

$$q = \frac{R_L}{X_{Cs}} = \frac{X_{Cs}}{R_s} \quad (5)$$

resistances Rs and R_L as well as the reactances Xc_s and Xc_3 are related by (6).

$$Rs = R = \frac{R_L}{1+q^2} = \frac{R_L}{1+\left(\frac{R_L}{X_{Cs}}\right)^2} \tag{6}$$

While,

$$X_{Cs} = \frac{X_{Cs}}{1+\frac{1}{q^2}} = \frac{X_{Cs}}{1+\left(\frac{X_{Cs}}{R_L}\right)^2} \tag{7}$$

reorder (6), one arrives at:

$$q = \sqrt{\frac{R_L}{R_S} - 1} \tag{8}$$

Substitution of (5) into (8), then we have:

$$X_{Cs} = qR_S = R_S\sqrt{\frac{R_L}{R_S} - 1} \tag{9}$$

This provides the reactance Xc_2 design equation as:

$$X_{C2} = \frac{1}{\omega C_2} = X_C - X_{Cs} = \left[Q_L - \frac{\pi(\pi^2-4)}{16}\right]R_S - qR_S \ = R_S\left[Q_L - \frac{\pi(\pi^2-4)}{16} - \sqrt{\frac{R_L}{R_S} - 1}\right] \tag{10}$$

Meanwhile, the reactance of the capacitor C_3 design equation is given by:

$$X_{Cs} = \frac{1}{\omega C_3} = \frac{R_L}{q} = \frac{R_L}{\sqrt{\frac{R_L}{R_S}-1}} \tag{11}$$

From (11), the circuit shown in Figure 4(a) can match the resistances that satisfy the following inequality:

$$R_S < R_L \tag{12}$$

Suboptimum operation is then obtained for:

$$0 \leq R_{S(sub)} < R_S \tag{13}$$

Which corresponds to:

$$R_L < R_{(sub)} < \infty \tag{15}$$

2.2.2. Matching resonant circuit π1b

According to (1), supply voltage, *Vin*, output power, *Po* and load resistance, *R* are dependent quantities. The load resistance given in many applications is different from that stated in (1), thus an impedance matching resonant circuit that provides impedance transformation downward and/or upwards is needed. Figure 5 shows the tapped capacitor downward impedance matching circuit π1b.

The reactance factor of the series circuit R_L-C_3 located to the right of point A in Figure 5(a) is:

$$qA = \frac{X_{C3}}{R_L} = \frac{R_P}{Xc_P} \tag{15}$$

The series circuit R_L-C_3 can be converted to the parallel circuit Rp-Cp as depicted in Figure 5(b) by applying following equations:

$$Rp = R_L(1+q_A^2) = R_L\left[1+\left(\frac{X_{C3}}{R_L}\right)^2\right] \tag{16}$$

$$X_{Cp} = X_{C3}\left(1+\frac{1}{q_A^2}\right) = X_{C3}\left[1+\left(\frac{R_L}{X_{C3}}\right)^2\right] \tag{17}$$

and

$$Cp = \frac{C_3}{1+\frac{1}{q_A^2}} \tag{18}$$

The parallel impedance R_P-X_B can be converted to the series impedance Rs-Cs as shown in Figure 5(c). The conversion equations are:

$$qB = \frac{R_P}{X_B} = \frac{X_{Cs}}{R_s} \tag{19}$$

$$Rs = R = \frac{R_P}{1+q_B^2} = \frac{R_P}{1+\left(\frac{R_P}{X_B}\right)^2} \tag{20}$$

$$X_{Cs} = Xc = \frac{X_B}{1+\frac{1}{q_B^2}} = \frac{X_B}{1+\left(\frac{X_B}{R_P}\right)^2} \tag{21}$$

Hence, the design equation for the reactance of the capacitor C_3 is:

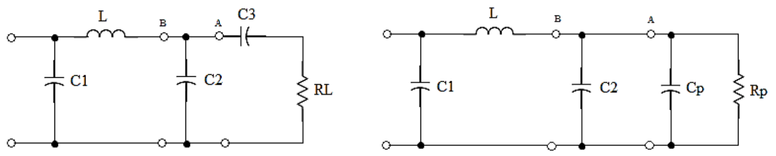
$$X_{C3} = \frac{1}{\omega C_3} = q_A R_L = R_L\sqrt{\frac{R[(Q_L-1.11525)^2+1]}{R_L}-1} \tag{22}$$

This given the design equation for the reactance Xc_2 as:

$$X_{C2} = \frac{1}{\omega C_2} = \frac{R[(Q_L-1.1525)^2+1]}{Q_L-1.1525-\sqrt{\frac{R[(Q_L-1.1525)^2+1]}{R_L}}-1} \tag{23}$$

Thus, the resistances 8that can be matched by the above-mentioned circuit are:

$$\frac{R_L}{(Q_L-1.1525)^2+1} < R_S < R_L \tag{24}$$



(a) (b) (c)

Figure 5. Tapped capacitor downward impedance matching circuit π1b (a) matching circuit π1b, (b) the series impedance R_L-C_3 is converted to parallel impedance R_P-C_P, and (c) the parallel equivalent R_P-X_B is converted to the series impedance R_S-C_S

3. RESULTS AND DISCUSSION

The design specifications were set up as follows in order to satisfy the output requirement, which are: Dc power supply, V_{dc} = 8.93 V, operating frequency, f = 13.56 MHz, Q = 10, D = 0.5, R_L = 66.46 Ω and output power, Po = 0.83 W. The circuit parameters are obtained based on the equation as stated in section 2 and also from the design specifications. The data from the calculation to satisfy the theoretical is tabulated in Table 1 and 2. Then, it is utilised as a reference value for simulation process. MATLAB/Simulink software is used for circuit simulation to run all the circuits, which are CPT system with matching resonant circuits of π1a and π1b. The circuit performances comparison can be studied and analysed for both impedance matching π1a and π1b. The matching resonant circuits are proposed to the system in order to achieve the satisfactory of circuit performance which able to generate 0.83W output power since biomedical implantable device, such as pacemaker requires only in the range of 10μW to 1mW output power [24] and maximizing the efficiency of power transfer over 95%. The comparison in term of receiver unit size is one of the most vital purposes of matching resonant circuit.

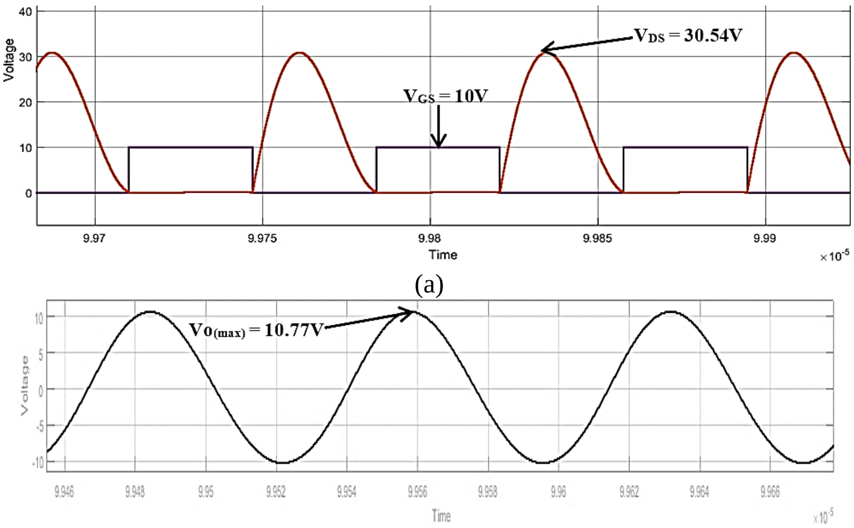
3.1. CPT system with matching Resonant circuit π1a

Table 1 shows the comparison of components values for CPT system with matching resonant circuit π1a between calculation and simulation. From Table 1, small number of differences for a few components values, which are shunt capacitor, C_1, series inductor, L and impedance matching, C_3 are shown. The components values of the simulation are slightly different from the calculation is because of the snubber circuit parameter in the MATLAB/Simulink software such as the resistance in the MOSFET and equivalent series resistance, *ESR* of capacitor which consider the circuit not as the idle circuit. Meanwhile, the theoretical for calculation results are in the idle condition circuit, which consider all the values such as such the resistance in the MOSFET and equivalent series resistance, *ESR* of capacitor are absolutely 0. Thus, the result of calculation and simulation for a few of the components are slightly different. Figures 6(a) and 6(b) show the simulation results for ZVS and the output voltage, *Vo* of the CPT system respectively.

From Figure 6(a), the voltage waveform of gate and drain MOSFET do not overlap during the switching time intervals, therefore switching losses are virtually zero. The Zero-Voltage Switching, ZVS is achieved, thus yielding high efficiency of power transfer. The ZVS condition is satisfied with the value of Voltage Drain to Source, *Vds* is 30.54V. Besides, based on Figure 6(b), the output voltage, *Vo* is 10.77 V. Then, the output power, *Po* produced for CPT system with matching resonant circuit π1a is 0.825W with 99.2% efficiency.

Table 1. The components value of CPT system with matching resonant circuit π1a

Components	Calculation	Simulation
Shunt Capacitor, C_1 (nF)	0.040	0.051
Series Inductor, L (μH)	6.5	6.8
Series Capacitor, C_2 (nF)	0.024	0.024
Load Resistor, R_L (Ω)	66.5	66.5
Choke Inductor, L_f (μH)	100	100
Impedance Matching, C_3 (nF)	0.08	0.11



(b)

Figure 6. Result of matching resonant circuit π1a: (a) switch voltage waveform and (b) output voltage waveform

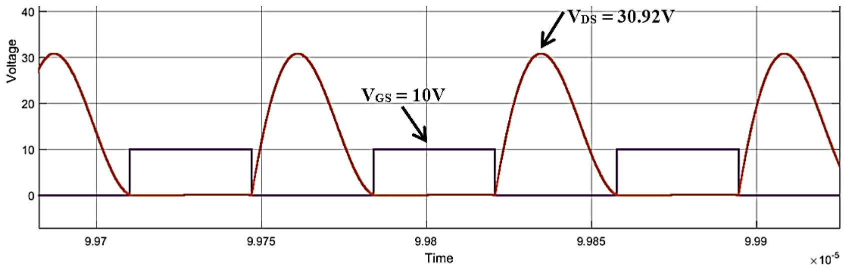
3.2. CPT system with matching resonant circuit π1b

Table 2 shows the comparison of components' values for CPT system with matching resonant circuit π1b between calculation and simulation. A few of components values for the simulation are slightly different from the calculation based on Table 2 which are shunt capacitor, C_1, series inductor, L and impedance matching, C_3. In simulation, the circuit is considered as non-idle circuit. This is due to the snubber circuit parameter in the MATLAB/Simulink software which consists of resistance in MOSFET and equivalent series resistance, *ESR* of capacitor. Consequent from the non-idle circuit, small differences in components values for simulation do not satisfy the theoretical of calculation. On the other hand, for calculation, all the values such as resistance in MOSFET and equivalent series resistance, *ESR* of capacitor are assumed as 0, which is in idle condition. Figure 7(a) and Figure 7(b) show the simulation results for ZVS and the output voltage, *Vo* of the CPT system respectively.

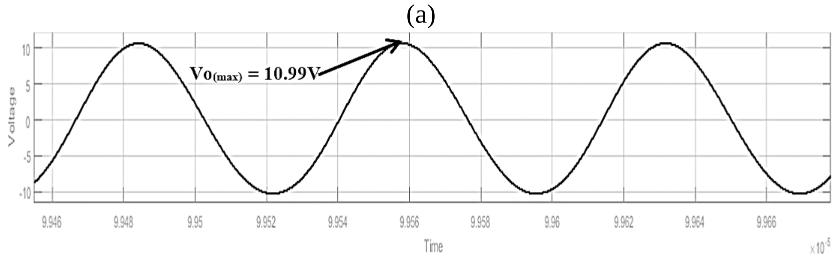
As seen from Figure 7(a), the voltage waveform of gate and drain MOSFET do not overlap during the switching time intervals, which mean zero-voltage-switching, ZVS is attained. Thus, switching losses are virtually zero and yielding high efficiency of power transfer. The ZVS condition is satisfied with the value of Voltage Drain to Source, *Vds* is 30.92 V. Meanwhile, from Figure 7(b), the output voltage, *Vo* is 10.99 V. Then, the output power, *Po* produced for CPT system with matching resonant circuit π1b is 0.829W with 99.2% efficiency.

Table 2. The components value of CPT system with matching resonant circuit π1b

Components	Calculation	Simulation
Shunt Capacitor, C_1 (nF)	0.039	0.054
Series Inductor, L (μH)	6.50	5.45
Series Capacitor, C_2 (nF)	0.024	0.024
Load Resistor, R_L (Ω)	66.5	66.5
Choke Inductor, L_f (μH)	100	100
Impedance Matching, C_3 (pF)	2.09	5.09



(a)



(b)

Figure 7. Result of matching resonant circuit π1b: (a) switch voltage waveform and (b) output voltage waveform

3.3. The comparison of circuit performance for matching resonant circuit π1a and π1b

From Table 3, the simulation results prove that the circuit performance for CPT system with matching resonant circuit is good, which the output power, *Po* for both of the matching resonant circuits π1a and π1b are 0.825W and 0.829W, respectively which attain virtually 0.83W while maintaining 99.2% efficiency of power transfer. All the parameters are almost the same for matching resonant circuit π1a and π1b except third capacitor, C_3 which act as impedance matching. It has a big amount of different between these two matching resonant circuits, which 110 pF and 5.09 pF for π1a and π1b respectively. From the comparison based on Table 3, matching resonant circuit π1b is chosen since the value needed for the third capacitor, C_3 is smaller than the value of matching resonant circuit π1a.

Besides that, matching resonant circuit π1b is selected because of the size of receiver part in the system. It provides a smaller size of receiver part compare to the matching resonant circuit π1a. The size of receiver part is one of the limitation and vital element for biomedical implantable device application. This is due to the consideration for human safety and makes the biomedical implantable devices compatible with normal human activities and increase the level of comfortable for the users. Figure 8 shows the circuit of class E CPT system for Biomedical Implantable Device application. The circuit is design same as in the simulation part and all parameters are based on the calculations part.

Table 3. Simulation results of CPT system with matching resonant circuit π1a and π1b

Data	Π1a	Π1b
Shunt Capacitor, C_1 (nF)	0.051	0.054
Series Inductor, L (µH)	6.8	5.45
Series Capacitor, C_2 (nF)	0.024	0.024
Load Resistor, R_L (Ω)	66.5	66.5
Choke Inductor, L_f (µH)	100	100
Impedance Matching, C_3 (pF)	110	5.09
Input Voltage, Vin (V)	8.93	8.93
Output Voltage, Vp-p (V)	20.95	21.00
Input Power, Pin (W)	0.832	0.836
Output Power, Pout (W)	0.825	0.829
Efficiency, η (%)	99.2	99.2

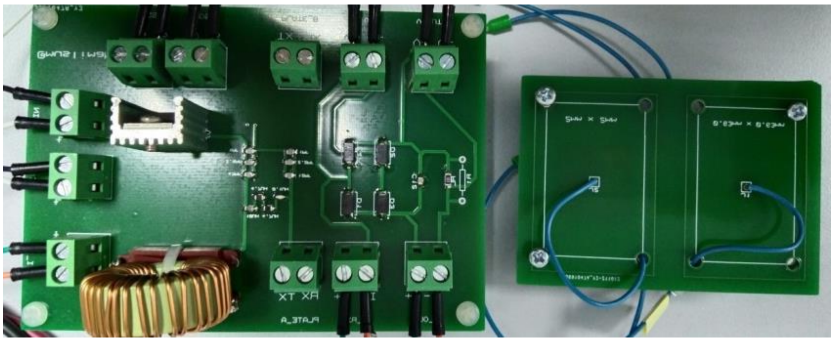


Figure 8. Full circuit of class E CPT system with impedance matching

In order to determine the best performance between matching resonant circuit π1a and π1b, the distance is set as manipulated variable, which the gap distance between two coupling plates will be adjusted from 1 mm to 10 mm. Table 4 presents the data collection from the experiment which is the comparison of circuit efficiency between matching resonant circuit π1a and π1b. Table 4 and Figure 9 show the efficiency of each circuit versus the gap distance between two (2) capacitor coupling plates. From the graph lines, overall, the class E CPT system with matching resonant circuit π1b is more efficient compared to class E CPT system with π1a. This is due to the stability measurement of power transmission efficiency for matching resonant circuit π1b as illustrated in Figure 9. At optimum distance, which is 5 mm, both of the circuits attain the best efficiency which are 98.6% for π1a matching network and 98.9% for π1b matching network. However, when the distance is changed to a different value, class E CPT system with π1a matching resonant circuit cannot maintain the efficiency of power transmission. Contrast to the class E CPT system with π1b matching resonant circuit, the efficiency of power transmission is stable even though the gap distance is changed to a different value. At 1 mm distance, the efficiency of power transmission reached a low point with 41.8%. This is due to the value of impedance for coupling plate is less than the value of load resistance. This situation is not satisfying the theory which the value of load resistance must be less than the impedance, $R_L < X_C$. Start from 2 mm distance, the value of impedance is bigger than load resistance, thus the efficiency of power transmission is consistent over than 90%.

Table 4. Experiment results of CPT system with Matching Resonant Circuit π1a and π1b

Distance (mm)	Efficiency (%)	
	Π1a	Π1b
1	18.1	41.8
2	32.6	96.9
3	63.3	98.4
4	99.3	98.5
5	98.6	98.9
6	70.6	99.3
7	32.9	97.9
8	17.9	96.8
9	11.3	94.8
10	8.0	92.5

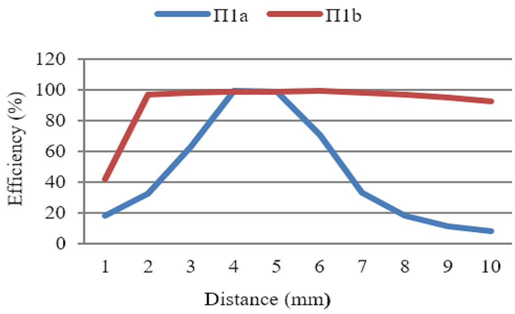


Figure 9. Graph of efficiency versus distance

4. CONCLUSION

The analyses of the performance for Capacitive Power Transfer system with matching resonant circuit π1a and π1b have been presented. The purpose of matching resonant circuit is to assist the CPT system in maximizing the power transfer. In this work, the analysis for both circuits which are CPT system with matching resonant circuit π1a and π1b have been made in term of output power, *Po*, efficiency of power transfer, third capacitor, C_3 and the size of receiver part. Although the circuit performance in term of output power, *Po* and the efficiency of power transfer for both of the matching resonant circuit are good and virtually the same for both circuits, matching resonant circuit π1b is more superior since the value needed for third capacitor, C_3 and the size of receiver part are smaller compare to the matching resonant circuit π1a. 0.829 W output power, *Po* with 99.2% of CPT system efficiency is accomplished at operated frequency of 13.56 MHz. As a nutshell, the class E CPT system with matching resonant circuit π1b is superior to class E CPT system with matching resonant circuit π1a due to their performance in stability and consistency of power transmission efficiency even though the distance is changing. For future works, CPT system with self-tuning feedback controller will be proposed in order to enhance the power transfer efficiency directly reduce the power losses.

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