# DESIGN AND DEVELOPMENT OF CAPACITIVE POWER TRANSFER SYSTEM

ERNISHA SYUHADA BINTI FAIZUL AZMI

This report is submitted in partial fulfillment of the requirements for the award of
Bachelor of Electronic Engineering (Industrial Electronic)

Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka

JUNE 2014

" I hereby declare that this report is the result of my own work except for quotes as cited in the references."

Signature :

Author : ERNISHA SYUHADA BINTI FAIZUL AZMI

Date : 6th JUNE 2014

"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of the scope and quality for the award of Bachelor of Electronic Engineering (Industrial Electronic) with honours."

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| Signature | : | |
| Supervisor's Name | : | PN. YUSMARNITA BINTI YUSOP |
| Date | : | 6 JUNE 2014 |

Special Dedication towards my beloved family,

Supervisor and friends

## ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Powerful and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this final year project and thesis. I would like take this opportunity to express my grateful who help me and give their courage to me to finish my final year project and thesis as it is partial fulfillment or requirements for the degree of Bachelor in Electronic Engineering (Industrial Electronic).

Special appreciation goes to my supervisor, Pn. Yusmarnita Binti Yusop, for her supervision and constant support. Her invaluable help of constructive comments and suggestions throughout along one year of duration for final year project have contributed to the success of this project.

Sincere thanks to all my friends for give me motivation and boost my effort to finish this project. Thanks for the friendship and memories.

Last but not least, my deepest gratitude goes to my beloved parents; Faizul Azmi Bin Hashim and Mariani Binti Musa for their endless love, prayers and encouragement. To those who indirectly contributed in this project, your kindness means a lot to me.

Thank you very much

## ABSTRACT

The project is about Capacitive Power Transfer System (CPT) which is the Wireless Power Transfer (WPT) that transfer electric field. WPT is the process of transferring power from one circuit onto another without passing through any manmade conductive elements interconnecting them. The simplicity and low cost of capacitive power transfer makes them very interesting for wireless charging stations and galvanically isolated power supplies. Major benefits include low electromagnetic radiation, simple structure of couplings, lightweight, low cost, position flexibility and high frequency applicability. Primary part for this project contains the application of Microcontroller, High Speed Current Driver and Single Phase Class E MOSFET Converter Circuit. PWM technique is used to generate switching control signal for Class E MOSFET Converter Circuit. Then, power will transfer from primary plate to secondary plate by using capacitive plate. Next, power will receive to secondary part which contains of Rectifier and Darlington Circuit for USB specification such as charging handphone. The performance of the system will be testing by measuring efficiency of power transfer and the relationship between output voltage and distance between primary plate and secondary plate.

# ABSTRAK

Projek ini adalah kira-kira Sistem Pemindahan kapasitif Kuasa (CPT ) yang merupakan Kuasa Pemindahan Wireless (WPT ) yang medan elektrik pemindahan. WPT adalah proses memindahkan kuasa dari satu litar ke satu lagi tanpa melalui mana-mana elemen konduktif buatan manusia bersambung mereka. Kesederhanaan dan kos rendah pemindahan kuasa kapasitif menjadikan mereka sangat menarik untuk stesen pengecasan tanpa wayar dan bekalan kuasa galvanically terpencil. Faedah utama termasuk radiasi rendah elektromagnet, struktur yang mudah gandingan , ringan , kos rendah, kedudukan fleksibiliti dan frekuensi tinggi kebolehgunaan . Sebahagian utama projek ini mengandungi aplikasi mikro , Kelajuan Tinggi Pemandu Semasa dan Fasa Tunggal Kelas E MOSFET Penukar Sepang. Teknik PWM digunakan untuk menjana beralih isyarat kawalan untuk Kelas E MOSFET Penukar Sepang. Kemudian , kuasa akan memindahkan dari plat utama untuk plat menengah dengan menggunakan plat kapasitif. Seterusnya , kuasa akan menerima dengan bahagian kedua yang mengandungi daripada Penerus dan Darlington Litar untuk spesifikasi USB seperti mengecas telefon bimbit . Prestasi sistem yang akan menguji dengan mengukur kecekapan pemindahan kuasa dan hubungan antara voltan dan jarak antara plat utama dan plat menengah.

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# CHAPTER I

# INTRODUCTION

## 1.1 Introduction.

The process of transferring power from one circuit onto another circuit without passing through any manmade conductive elements interconnecting them is the definition for Wireless Power Transfer (WPT). There are several types of wireless power transfer exist such as a microwave, laser, inductive power transfer and capacitive power transfer. For this project is more focuses on capacitive power transfer because due to many advantages.

Inductive power transfer (IPT) with inductive coupling is currently the most popular way to realize wireless electric power distribution as shown in Figure 1.1. While IPT is successful method to transfer large power without metal contact, it has some disadvantages, such as power decrease by inexact connection, radiation of unexpected radio wave and unexpected heating of alien metal substance. The capacitive power transfer (CPT) with capacitive coupling as shown in Figure 1.2. CPT is however investigated recently to utilize the advantages in CPT, such as simple structure of couplings, lightweight, low cost, position flexibility and high frequency applicability

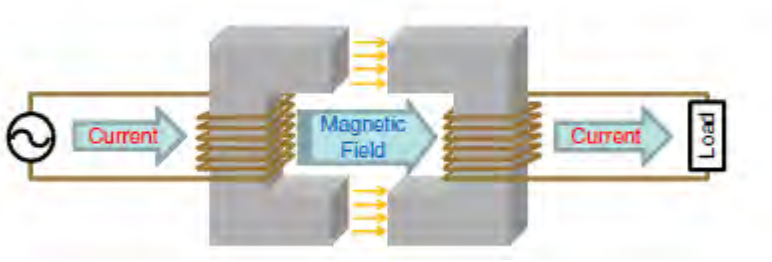



**Figure 1.1: Basic Diagram of Inductive Power Transfer**

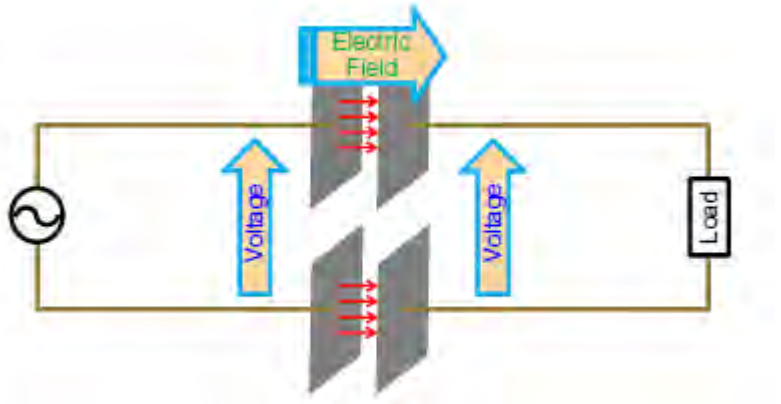



**Figure 1.2: Basic Diagram of Capacitive Power Transfer**

IPT is using coil that will produce magnetic field to transfer power while CPT is using capacitive plate that will produce electric field to transfer power. High frequency is needed to generate a magnetic field, usually in 10 kHz to 10MHz in IPT system. This can cause a large electromagnetic interference and magnetic field coupling technology required will depend on easily covered by some metal conductors with small resistance rate. Eddy current losses greater can also be formed, therefore, the IPT technology based on magnetic coupling used in a metal environment is very limited.

CPT technology has certain advantages which can overcome the shortcomings of the magnetic energy in the environment cannot be transmit in the metal shielding environment because the CPT using the electric field that does not affect the metal environment. The other advantage of CPT technology is not can only transmit through the metal body; it also reduces energy loss and also has good anti-interference capability of the magnetic field. Tough anti interference makes the device be able to function in

saturated magnetic fields environment, and capable to decrease electromagnetic interference and energy loss.

This project of design and development of CPT system is planned which involves low values of power transfer in interface capacitance, with lesser power factor than current topologies, and leads to the low power application. In the capacitive interface the field is confined between conductive plates, alleviating the need for magnetic flux guiding and shielding components that add bulk and cost to conductive solution [1].

Capacitive power transfer interfaces makes them very attractive for wireless charging stations and galvanically isolated power supplies because it simplicity and low cost compared to inductive power transfer method. However, conventional capacitive power transfer solutions are widely used either larger capacitors or lower power applications, such as coupling of power and data between integrated circuits or transmitting power and data to biosignal instrumentation systems. This project also, by introducing a self-tuning Class E MOSFET amplifier power converter.

## 1.2 Objectives of the Project

The objectives of this project are:-

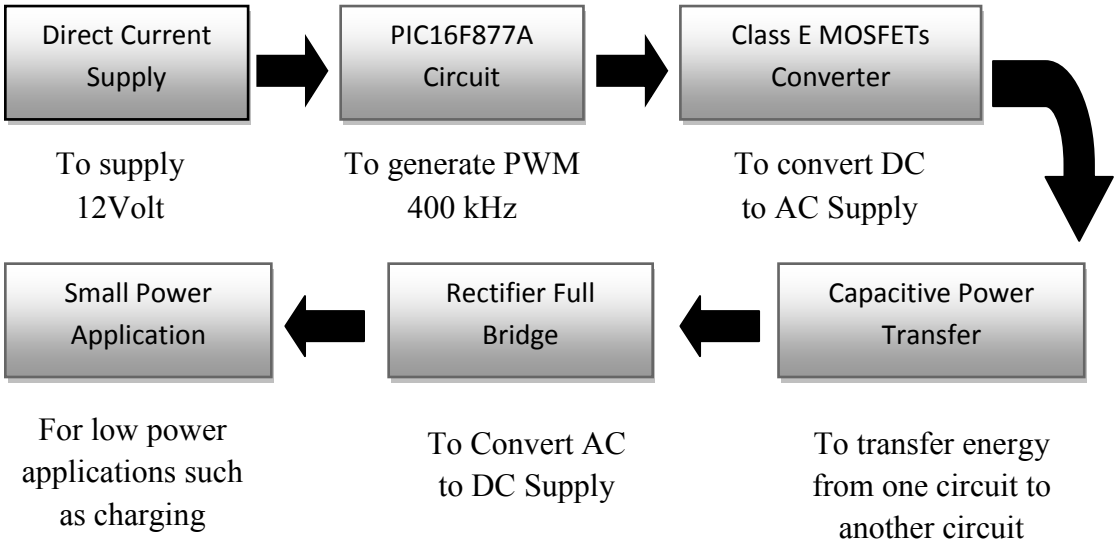
i. To design high efficiency resonant class E inverter.
ii. To generate switching control signal for class E circuit by using PWM technique.
iii. To analyze the performance of capacitive power transfer in terms of efficiency and output voltage versus distance between primary plate and secondary plate.

## 1.3 Problem Statement

A traditional approach of wireless power transfer, the IPT is commonly used. The main drawback of IPT is a very high common mode source impedance to overcome high power factor of current topology that may cause eddy current losses and difficult to penetrate the metal. A priority project is to study how to design a capacitive power transfer system with lower power factor. This involves the low power transmission at the interface capacitance and lead to the low power applications. All weaknesses of IPT can be improved and enhanced using the CPT system.

## 1.4 Scope of Project

The scope of the project is divided into small sections to ensure the project runs smoothly and to achieve the stated objectives. First stage is the development of simulation using PSPICE and Multisim for analysis the outcome of the expected result. Then, program the coding of the PWM signal to drive MOSFET Class E circuit using CCS Compiler software to get 400 kHz and 50% duty cycle. Next stage is development of hardware which contains the application of PIC16F877A circuit, high speed current driver circuit and class E circuit. For the secondary part is deliver power in 2.88 Watt to the load by capacitive power transfer that suitable for USB specification for charging application. This project will concentrate on the low voltage applications. The analysis of the system will be done by measure the output voltage versus distance between primary plate and secondary plate and also the efficiency of the system. The scope of work can be summarized as follow:-




## 1.5 Project Significant

There are some significant of this project such as this project is very attractive to contactless charging and galvanically isolated power supply and get the spotlight because of the power control and charging device mobile devices including cameras and smart phones. For electromagnetic radiation has less radiation and amenability combined power and data deliver on the same interface. It is also suitable for biomedical device. Maximum efficiency is achieved for a given number of capacitance pairs and used to find the optimal circuit.

## 1.6 Report Structure

This thesis is a documented report of the ideas generated, the theories and concepts applied, the activities performed and the final product of this project produced. The thesis consists of five chapter is described as follow:-

For Chapter 1 will briefly clarify the environment and background of this project. Preliminary with the introduction of this project, that is why this project is important and chosen. Next, this chapter will also explain about the problem statement that generate to the idea to recognize this project. Then, will also explain more about the objectives of the project, scope of work, and also the report structure.

For Chapter 2 will briefly explained about the present theory and concept related to the project. This chapter also discuss about the basic theory of capacitive power transfer system, generate PWM using PIC16F877A and Class E MOSFET converter circuit.

For Chapter 3 will briefly clarify the method to design and develop of the project. This is including the prototype and software design using CCS Compiler, Proteus, Pspice and also Multisim. The hardware development is focus on the designing circuit such as high speed current driver circuit, class E MOSFET converter circuit and microcontroller circuit. The software design focuses on the development of microcontroller instructions coding using CCS Compiler for PIC16f877A.

For Chapter 4 will briefly explain the result for testing method. The construction of capacitive Power Transfer (CPT) will be analysis by measure the output voltage versus distance between primary plate and secondary plate and also the efficiency of the system. Next, the result will be analyze and discuss to get better understanding about the result.

For the last chapter, chapter 5 will conclude the finding in this project. In addition, this chapter also included the several aspect involve in overall project such as the project achievements and the learning outcomes. Also will be discussed in this chapter is the future recommendation for future study and prototype development.

# CHAPTER II

# LITERATURE REVIEW

In this chapter, the source like journal, thesis and article had been analyzed to come out the comparison to use in this project. This chapter discussed about PWM technique, Class E MOSFET Converter circuit and Capacitive Power Transfer system

## 2.1 Introduction of Wireless Power Transfer

This part places the current study into the context of previous which is related research to the "Capacitive Power Transfer System". Wireless power transfer is also known as electric power transmission through the air without connecting conductors from a power source to an electrical load. This can offer advantages to lead-free environment and increase both the size and can be used for electronic devices. In the case of a dangerous, complicated wire connections or even impossible, wireless transmission technique is very useful. The system works in a high frequency band has attracted much attention in wireless power transfer (WPT). Especially to users of mobile devices such as PDAs, mobile phones and laptops are also justified the need WPT. Because the existing electrical-wire grid carries energy almost everywhere, even a WPT operating at the close range would be quite useful for these devices [1].

### 2.1.1 The Inductive Power Transfer Method

The journal entitled "A Ring Inductive Power Transfer System" was written by Udaya K. Madawala and Duleepa J. Thrimawithana. These journals discuss the design and development of inductive power transfer. The contactless inductive power transfer systems are currently used in many industrial domains, for example elevators, crane and traffic systems. Inductive Power Transfer (IPT) is the technology, which is now recognized as a technique that is efficient and acceptable of contactless power transfer across an air gap through magnetic coupling [2]. IPT system is using magnetic coupling across the air gap without physical contact to transfer power from one system to another system. Tracks leading to the current frequency are high and IPT systems are loosely coupled to magnetic and other systems, also known as the pickup in which power is transferred across the air gap. The magnitudes of the current track directly control. The amount of power that can be transferred across the air gap, and thus plays a major role in the design of any IPT system [2]. A system using high power is better when the track becomes high enough, but unfortunately a semiconductor device at this time is not suitable.

### 2.1.2 The Capacitive Power Transfer Method

The journal entitled "Coupling Study of a Rotary Capacitive Power Transfer System" was written by Chao Liu, Aiguo Patrick Hu and Nimal-Kumar C Nair. This journal discuss about the design of power transfer using capacitive method. Figure 2.1 shows the block diagram of a typical CPT system. A high frequency ac voltage is converted from power supply voltage which is then supplied to two primary metal plates, being function as charging pads, plug sockets and robot joints. When two copper plates (installed on plugs, mobile phones or robot arms) are placed close together, alternating electric field is formed between the plates then the displacement current can 'flow' through and the power can be deliver to a load without direct electrical contact. To obtain sufficient amount of power as well as provide electrical insulation between the

primary and secondary sides, a tuning inductor either series or parallel connection is also usually used to dielectric materials are covered on the surfaces of the plates and recompense the equivalent coupling capacitance.

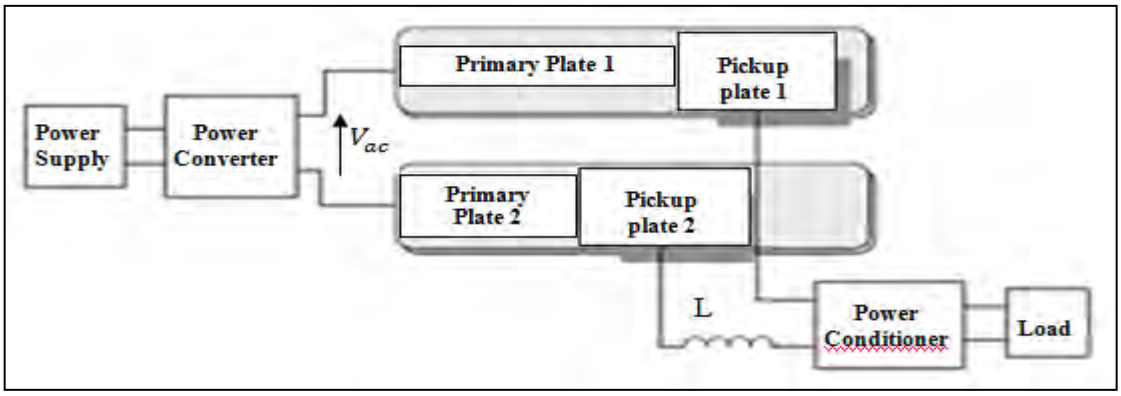



**Figure 2.1: Block Diagram of the CPT System**

### 2.1.2.1 Coupling Configuration

The configuration of the CPT system shows in Figure 2.2. A high frequency AC voltage is converted from the power source which is then supplied to two primary metal plates. Electric fields are formed between them and the displacement current is produced when two secondary plates are placed close. Finally, the power can be transferred without direct electrical contacts. It also allows for some freedom of movement between the primary and secondary plates and supply to the load. A rectifier and capacitor filter can be used, if it is a DC load.

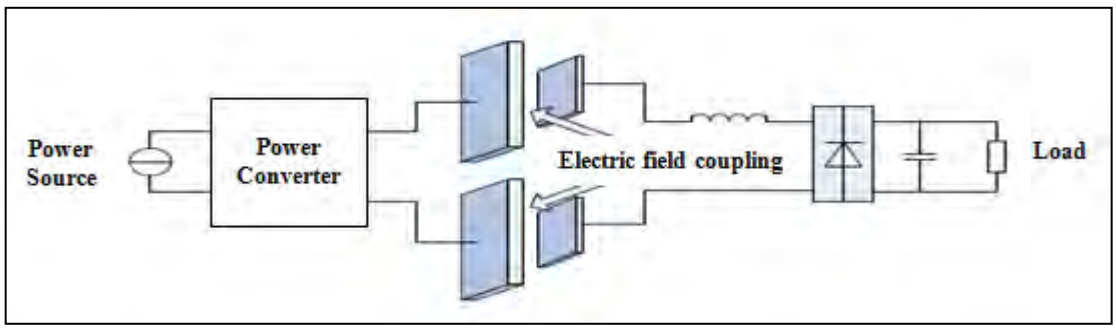



**Figure 2.2: Configuration of the CPT System**

Capacitive Power Transfer has many features compared to Inductive Power Transfer:

i. The circuit size may be compact because there is no require using bulky and costly coils and magnetic materials.

ii. The coupling preserve be considered as two capacitors connected in series so power can still pass through, if there is a metal barrier between a pair of coupling plates,. Meaning that CPT has the capability to convey power through metal barriers

iii. Capacitive Power Transfer is using capacitive plate and produce the electric field coupling, and high frequency from kHz to MHz. AC voltage should be functional to the coupling plates

iv. The radiated EMI and the power losses can be significantly compact compared to an IPT system since most electric fields are limited within the volume enclosed in the coupling plates

v. At least two pairs of coupling plates are needed to supply a complete current loop between the power source and the pickup for the complete CPT system.

The formula of equivalent capacitance of each pair of the coupling plates are shown below:

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

$\mathrm{A} =$ The effective coupling area

$d =$ The coupling distance

$\varepsilon_0 = (8.85 \times 10 - 12) =$ The permittivity in vacuum

$\varepsilon_\mathrm{r} =$ The relative permittivity of the dielectric material between the coupling plates

### 2.1.2.2 Coupling Structure

The two coupling structures are planned for the necessary rotary application. Consists of two pairs of metal plates in each structure where the coupling distance of each pair is 1mm. Figure 2.3 shows a disk type structure where two disks form one pair of coupling plates and two rings form another. The higher part is rotary and connected to the output load, while the lower part is fixed and connected to the input power source. Next, an extra structure planned is a cylinder type exposed in Figure 2.4 where the cylinders 1 and 2 coupling plate form of one pair and 3 and 4 form another. Two inner ones are rotary and connected to the output load while two outer cylinders are fixed and connected to the input power source.

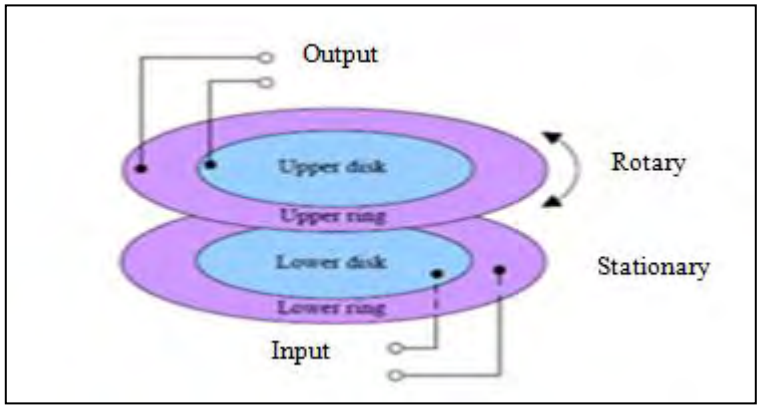



**Figure 2.3: The Structure of Disk Type Cylindrical**

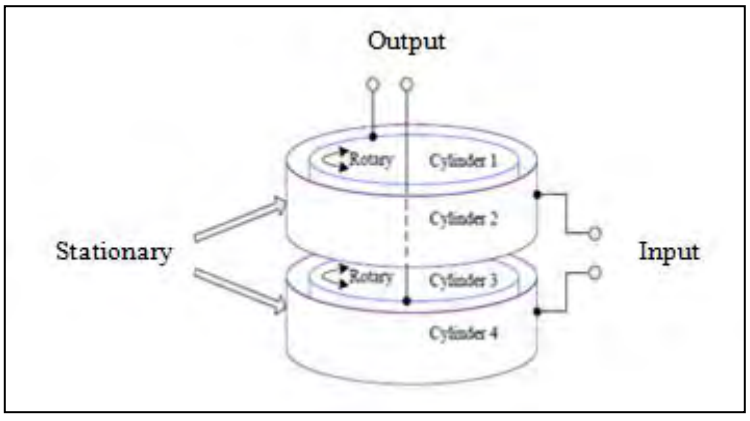



**Figure 2.4: The Structure of Coupling**