UNIVERSITI TEKNOLOGI PETRONAS

MODELLING AND INVESTIGATION OF WIRELESS POWER TRANSFER FOR SMALL GAP APPLICATIONS

by

Amirulnaaim Bin Ali

16113

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical and Electronic)

JAN 2016

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Modelling and Investigation of Wireless Power Transfer for Small Gap Applications

by

Amirulnaaim Bin Ali

16113

A project dissertation submitted to the

Electrical and Electronic Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

Bachelor of Engineering (Hons)

(Electrical and Electronic)

Approved by,

____

(DR RAMANI KANNAN)

JAN 2016

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

(AMIRULNAAIM BIN ALI)

ABSTRACT

Wireless Power Transfer (WPT) is a process of transferring power to any load without using wires. WPT technology has help public in term of their devices portability and conveniences. There are two types of wireless power transfer which are Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT). This project investigate IPT for small gap applications, focusing on coil parameters in affecting efficiency of WPT. Coils with different number of turns is implemented to determine the maximum power and distances in power transfer.

There are experiments done to investigate IPT for small gap applications. First, relationship between frequency tuning and output voltage of receiver coil. In first experiment, the distance between transmitter and receiver coil, and number of turns of transmitter coil is fixed. Second, relationship between number of turns of transmitter coil and output voltage of receiver coil. In second experiment, frequency, distance between transmitter and receiver coil, and number of turns of receiver coil is fixed. Third, relationship between distance between transmitter and receiver coil and output voltage of receiver coil with different number of turns. And in third experiment, frequency and number of turns of transmitter and receiver coil is fixed. Fourth experiment, relationship between operating frequency and output voltage of receiver coil with different distances between transmitter and receiver coil. In fourth experiment, only number of turns of transmitter and receiver coils is fixed.

The outcome of the experiments are, between the ranges of 10kHz to 100kHz, the suitable frequency to operate the wireless power transfer is 45kHz when the receiver coil is fixed at 5 turns and diameter of the coil is 4.5cm. As the number of turns increases, the output voltage also increases, with 40 turns, the output voltage 2.7V. The transfer distance also increased when number of turns increases, due to magnetic field strength increased.

ACKNOWLEDGEMENT

First and foremost, I would like to thank my supervisor Dr Ramani Kannan for his supervision and experienced guidance. His continuous support and encouragements gave me more confidence in my work and abilities and led me to complete my project successfully. I would like also to thank my co supervisor Dr Mohd Fakhizan Romlie for his valuable discussions, cooperation and support.

This journey would not have been pleasant without my friends and fellow student of Universiti Teknologi PETRONAS, especially Mohd Naaim, Wan Mohd Farid, Natthawin Vetsandonphong and my roommate Jackson Jacob.

I owe every part of this work, my education and every step forward in my life to my parents. I would like to thank them for their love, support and encouragement.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

Ampere's Law and Faraday's Law of Induction are the two main principles of Wireless Power Transfer (WPT). Ampere's Law states that "an electric current-carrying conductor produces a magnetic field proportional to the current." Ampere's Law has been discovered by Andre-Marie Ampere in 1826. And Faraday's Law states that "the time-varying electromagnetic field will induce an electromotive force (emf) in a closed circuit." The direction of the emf can be determined by applying Lenz's Law which stated that "the current in the loop is always in such a direction as to oppose the change of magnetic flux that produced it.

In 1891, the first public WPT demonstration was by Nikola Tesla. He demonstrated WPT by using capacitive coupling technique to transfer power for tube lighting [1 and 2]. WPT has been applied to various applications such as mobile phone charging, electric vehicle charging also in wireless sensor network. WPT technology has increased electronic devices portability and convenience to the public. Though it has been applied to many application and give advantages to the society, this technology still has more to improve in term of its efficiency in transferring power.

The general principle of WPT is when alternating current (AC) passes through a closed loop coil, magnetic field will be produced around the coil. This phenomenon is based on Ampere's Law which defined as "an electric current-carrying conductor produces a magnetic field proportional to the current". The magnetic field produced will induced voltage at receiver coil which is based on Faraday's Magnetic Induction Law which stating that electromagnetic force is induced in a coil when it is linked with the flux produced by another coil.

WPT techniques can be divided into two methods, which are Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT). IPT method is based on the principle of magnetic field coupling. Magnetic field coupling also can be known as inductive coupling occurs when energy is coupled from transmitter circuit to receiver circuit through magnetic field under condition when the circuit impedance is low. While CPT method is based on the principle of electric field coupling [2, 3 and 7]. Electric field coupling or capacitive coupling occurs when energy is coupled from transmitter circuit to receiver circuit through electric field when the circuit impedance is high.

Between these two methods, IPT is the most popular among the researchers and have received many achievement. By understanding methods of manipulating magnetic flux, IPT method can be apply to many power levels and gap distances of applications [2 - 6]. The demerits of IPT, which are this method is unable to penetrate metal to transfer electrical power also produces high eddy current loses.

To overcome this problem, another method is approached, which is CPT method. Research on CPT is still at early stage. Most of CPT research are more focusing on its stability and function and lack of study on its power transmission characteristics [3 and 5]. Although CPT method can only be apply to applications with small gap, CPT is able to transfer power for kilowatt power level applications [2]. This project focus on IPT and investigation of factors that affecting the efficiency in power transfer. In this project, modelling and hardware of IPT is develop in order to understand and investigate the working principle of IPT and factors affecting efficiency of IPT which are frequency and number of turns, for mobile phone charging application.

1.2 Problem Statements

1. Power transfer efficiency decreases when transfer distances between transmitter and receiver increases.

   Wireless power transfer efficiency still has low efficiency when transferring power to greater distance. Most of the researchers have done lot of research in improving the efficiency especially by applying magnetic resonance coupling which tuning the transmitter coil frequency to be same with receiver coil frequency in order to maximize power transfer.

2. Untidiness of cables.

    These kind of situation can be obviously seen at the behind of personal computer's desk with many cables from different parts of computer, desktop, CPU, printer and speaker. These cables are cluttered behind the desk cause uncomfortable view and can cause difficulties in maintenance.

3. Cables damage.

    Cables damage is one of serious problems due to human improper handling. Cables damage not just can cause short circuit, it also can cause dangerous to human if been touched.

1.3 Objectives of the Project

The objectives of the project can be summarized as follow:

1. To understand the principle of Wireless Power Transfer (WPT).
2. To identify suitable modelling of Inductive Power Transfer (IPT).
3. To analyze factors affecting WPT which are frequency and number of turns.

1.4 Scope of study

The project's scope of studies consists of

1. To understand the working principle of IPT.
2. To do modelling of IPT.
3. To investigate the factors affecting the efficiency of IPT which are frequency and number of turns.

1.5 Significances of the Project

1. The key prospect of this project is to study and understand the concept of WPT, specifically IPT and to improve the efficiency of WPT by manipulating frequency and number of turns of transmitter coil.

2. The concept of WPT has been proven and has been applied to various application such as mobile phone wireless charger.

3. Wireless power transfer can bring advantages by reducing the amount of wires used, universal power standards also can be achieved because there is no plug needed and users also not restricted in an area while charging their devices.

4. This project focused on mobile phone and can be extend to other applications such as tablets, laptops, camera or any other mobile application.

5. This technology can be applied to larger scale system which can be used to home appliances, such as television, printers, and etc.

6. It is important to acknowledge the importance of WPT by doing more research on many areas in order to improve the WPT technology.

1.6 Feasibility of the project

1. This project need to be completed within a given time frame of 28 weeks.
2. The feasibility of the project is charted in the scope of study and gantt chart.
3. This project is investigate frequency and number of turns which is achievable within the time frame.
4. It is important to identify suitable parameter to transfer power effectively.
5. This project is feasible and achievable within the duration.

CHAPTER 2

LITERATURE REVIEW

2.1 History of Wireless Power Transfer

The idea of WPT starts with Nikola Tesla in 19^{th} century. His main idea was to use air as medium to transfer power to everywhere in the earth. In 1900s, at Colorado, he created a resonant transformer which can transfer to 50km from the source. Input power of the transformer was 300kW and frequency of 150 kHz. But it was not stated the amount of power received only a statement of "thousands of discharge". Tesla also constructed Wardenclyffe tower on Long island. This transmitter had a height of 154 feet. After few years, US government demolished this tower due to his debts and the government claimed that the tower act as spy transmitter.

In 1964, William C. Brown invented a cordless helicopter. The power microwave transmitter continuously transmit 400W to the receiver on the helicopter which can received up to 100W. In 1973, RFID was developed which tags used induction coupling to power up. And in 2007, a research group called "witricity" able to light up 60W bulb at distance of 2 meter. This achievement has become the starting point of rapid development of wireless power transfer until now [1].

2.2 Resonant Frequency

When a system is vibrating at its natural frequency at maximum amplitude, it produced resonance. Resonant frequency is the frequency when a system is vibrating at a frequency that same with its natural frequency. Resonance can be used to transfer energy between two systems that vibrating at resonant frequency.

2.3 Magnetic Resonance Coupling

Magnetic resonant coupling uses resonance to increase the transfer distance for energy between transmitter and receiver coils to exchange energy. Resonance is a condition when natural frequency of transmitter coil and receiver coil are approximately the same. The resonant frequency of the coil is affected by the coil design, including the size, shape and material of the coil. There are two types of resonance which are series and parallel resonance. These two type have the same principal in obtaining maximum energy but have different methods. Magnetic resonant coupling can increase the efficiency of power transfer and power transfer distance. In WPT system, magnetic resonance coupling is applied by tuning transmitter and receiver coil to the same frequency by using oscillator at transmitter coil and capacitor at receiver coil [1 and 14].

2.4 Recent Works and its Applications

Jiejian Dai and Daniel C. Ludois done a survey on WPT and done a critical comparison between inductive coupling and capacitive coupling for small gap applications. In this paper, they provide comparison of IPT and CPT wherein the theoretical and limitation of each approach are established. They collects data from previous research which using IPT and CPT technology to compare their approaches in power level, gap distance, operational frequency and efficiency. They found out that limitation of IPT and CPT lies on that power density is restricted to gap sizes. They also present guideline on selecting IPT and CPT in small gap systems [2].

Yuejin Zhou, Juan Zhang and Chaowei Li done a comparison between IPT and CPT for their power transfer characteristics. They have obtained IPT and CPT maximum power transfer transmission capacity and analyzed these two structures. Then, mutual inductance of 4 typical IPT systems was optimized to achieve maximum power transfer and justified by simulation and experiment [3].

Pooja Sharma, Jayshree Pande and Archana Singh made a comparison and analysis of IPT and CPT and data transfer in USB. This paper found out that inductive power transfer gives less efficiency because power is wasted due to magnetic field. And a capacitive power and data transfer circuitry that delivers both power and data on the same channel. They also designed a prototype which can transfer 1.25W of power and has efficiency of 53% [4].

Kamarudin. Kh, Shakir Saat, Y. Yusmarnita and Norezmi Jamal presents an analysis and design of CPT. They uses class E converter in their design. Class E converter able to produce zero voltage switching which can improve efficiency of CPT system. They developed a prototype which was capable to transmit 2mW of power at 4MHz with efficiency of 90.7% through a plate of size 12cm x 12cm [5].

S. Y. R. Hui, Wenxing Zhong and C. K. Lee studied on WPT with the transmission distance greater than the transmitter coil dimension. They summarizes the operating principle of a range of wireless power research into maximum power transfer and maximum energy efficiency principles. They found out that two coil system suitable for short range applications, the use of the maximum power transfer in the four coil systems is good for maximizing the transmission distance [6].

Xuezhe Wei, Zhenshi Wang and Haifeng Dai present current developments and research progress in the Strongly Coupled Magnetic Resonances (SCMR). They analyzed the advantages of SCMR by comparing it with other WPT technologies. They found out SCMR can transfer power with high efficiency over long distances by applying high operating frequencies and high quality factors [7].

Basharat Nizam proposed a project of an innovative application of Faraday's laws of electromagnetic induction. This paper provides details of IPT including working principle, inductive charging technique which are near field, induction and electro dynamic induction. This paper also includes advantages and disadvantages of WPT [8].

From [10], Weidong Peng and Guozhu Zhao demonstrated WPT by using magnetic resonant technique. This technique applied in a simple and effective circuit structure with a source coil and receiver coil. In their research, they found out that voltage at receiving coil is related to transfer distance and driving frequency. Their results show that the load receive maximum voltage and maximum power which is 42% from input power at 22KHz with 4mm of distance between coils. They also designed a wireless mobile charger that can charge a mobile phone with charging current of 380Ma and charging voltage of 4V.

In [11], L.Olvitz, D.Vinko and T.Svedek, they discuss on the theory of WPT and design a functional wireless charger device. In their research, they states that coil design with highest Q factor affect the performance of power transfer. The wireless charger designed has an operating distance up to 2.5cm with transfer power 0.5W.

From [12], Syed Khalid Rahman, Omar Ahmed, Md Saiful Islam, A.H.M. Rafiul Awal and Md. Shariful Islam, they design and implement a WPT system by magnetic resonant coupling. They tried to transfer power wirelessly by placing intermediate coil between transmitter coil and receiver coil. Their results shows that, with intermediate coil, less power can be transferred to the receiver coil. In their circuit, they used capacitor at the receiver coil to match the resonant frequency for the coils.

In [13], Zhuo Yan, Yang Li, Chao Zang and Qinxin Yang, they analyzed factors influences the efficiency of WPT via coupled magnetic resonance. In their research, they came out with three conclusions. First, if the material parameters of the coil is fixed, the transfer efficiency will be affected by resonant frequency and mutual inductance. Second, if the resonant frequency is fixed, the transfer efficiency will be affected by characteristics changes of transmitter and receiver coils. Lastly, efficiency can be increase when applying frequency tuning instead of using fixed frequency.

WPT is not a new concept. There are many research have been done in order to understand deeper in this concept. Most of this research, their main objectives is to increase efficiency of the system by increasing output power of receiver side. IPT has been received most attentions from the researchers in many areas and applied into various applications from mobile phone charging to electric vehicle charging.

CHAPTER 3

CONCEPT OF WIRELESS POWER TRANSFER

3.1 Introduction

Wireless Power Transfer (WPT) is the process of transferring power from power sources to load without the use of wires. There are many ways in transferring power wirelessly by using different type of field such as electric, magnetic or electromagnetic field. In WPT, transmitter circuit which is connected to power source will transmit field energy through spaces between transmitter and receiver, to the receiver circuit to be converted back to electrical current then transferred to the load. WPT is useful when someone have to do wire connection in hazardous or impossible area.

There are two types of WPT which are Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT). IPT uses magnetic field to transfer power by using magnetic inductive coupling between transmitter and receiver coil. There are many applications that uses IPT especially for charging purposes such as electric toothbrush charger or current focus is mobile phone charger for charging mobile phone wirelessly. While CPT uses electric field to transfer power by using capacitive coupling between two metal electrodes. Both IPT and CPT can transfer power wirelessly but must be aimed to the receiver.

IPT and CPT fall under near field technique which have distance limitation where their efficiency decreases as transfer distances increases. There are many researchers done research on IPT and CPT for different approaches such as power level, gap distances, material characteristics and comparison between IPT and CPT.

3.2 Capacitive Power Transfer

In this section, details of CPT is discussed. It includes the operation of CPT, block diagram, material characteristics, and drawbacks of CPT.

3.2.1 Operation of Capacitive Power Transfer

In CPT, electric energy is transferred by electric field between electrodes such as metal plates. Transmitter and receiver electrodes act as capacitor with the distances between them as the dielectric. Transmitter generate alternating voltage to the transmitter plate and the oscillating electric field will transmit to the receiver and induces alternating potential by electrostatic induction causes alternating current flow to receiver circuit to the load.

3.2.2 Block Diagram of Capacitive Power Transfer

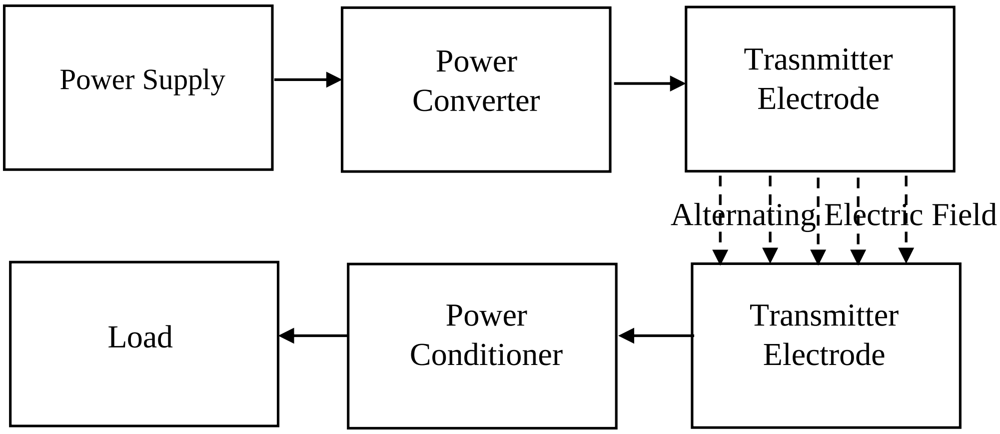

Figure 1 Block Diagram of a typical CPT system

Based on Figure 1, voltage from power supply is converted by inverter to high frequency AC voltage before transferred to the transmitter. When transmitter electrode is placed close with receiver electrode, alternating electric field will formed between the plate causes current to flow through the receiver and power can be transferred to the load.

3.2.3 Material Characteristic of Capacitive Power Transfer

Transmitter and receiver plates are usually coated with dielectric materials. Dielectric materials is an insulator so that when voltage is applied to the material, no current will flow through but the material will be polarized. Polarization is when negatively charged nucleus move towards positively charged nucleus between a close distances. It is important for the transmitter and receiver plate to have a good dielectric material coated on it. A good dielectric material is material that easy to polarize. Amount of electrical field energy stored is affected by the amount of polarization occur on the material.

More polarization occur means more electrical field energy can be stored and more power can be transferred. Figure 2 and Figure 3 shows relationship between material and its dielectric constant.

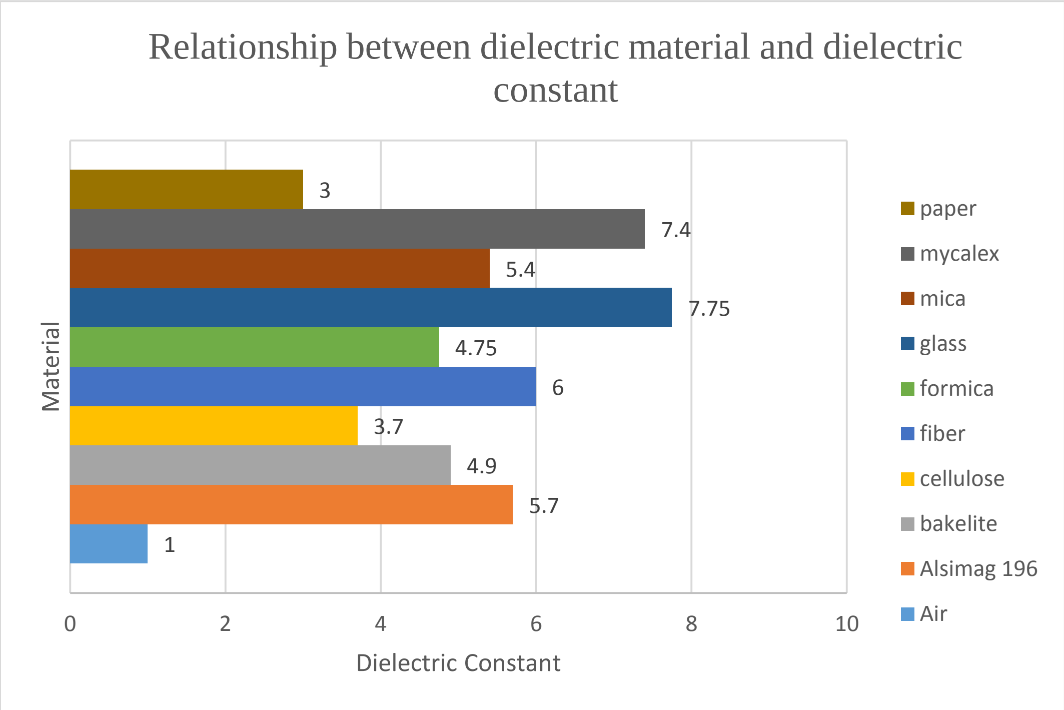

Figure 2 Relationship between dielectric material and dielectric constant

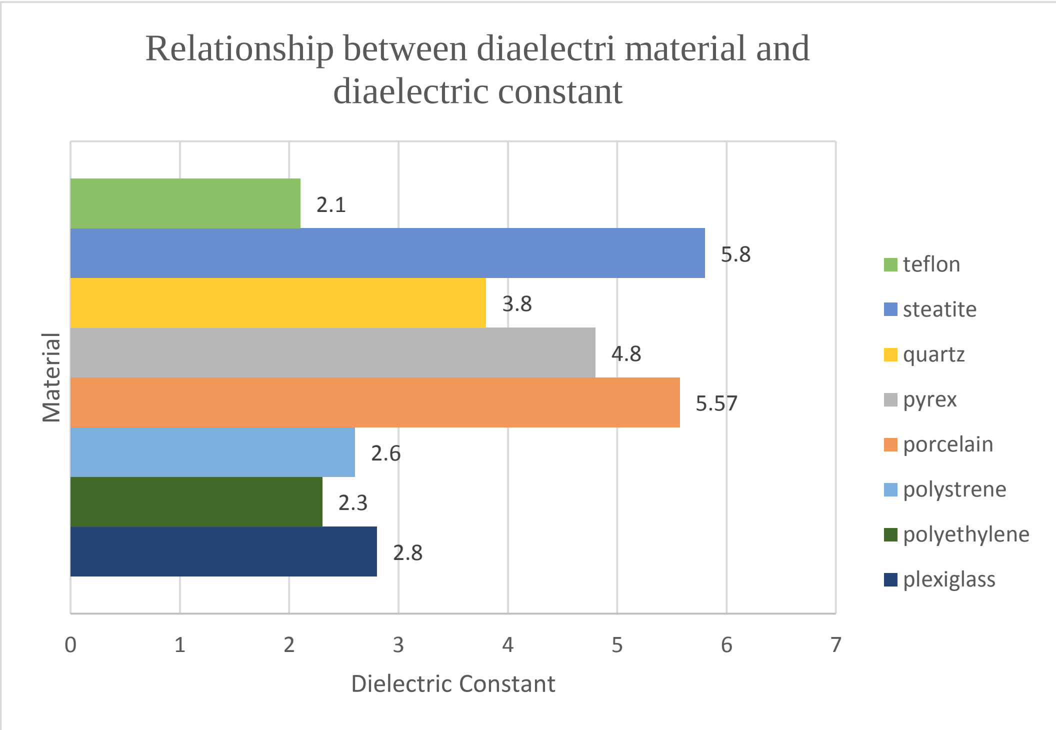

Figure 3 Relationship between dielectric material and dielectric constant

3.2.4 Drawbacks of Capacitive Power Transfer

CPT has only been applied on low power level applications. CPT is incapable to be applied to high power level due to its limited power delivery and has low efficiency. This causes researcher to focus more on IPT. Besides that, CPT when applied on higher power level, the higher voltage on the plate can be hazardous or can harm the environment through ozone depletion. Electric field also react strongly with almost materials including human skin. This is due to dielectric polarization. So, any materials disturb the polarization will absorb the energy from the process as example humans will expose to excessive electromagnetic field which will cause their health.

3.3 Inductive Power Transfer

In this section, details of IPT is discussed. It includes the operation of IPT, block diagram, material characteristics, and drawbacks of IPT.

3.3.1 Operation of Inductive Power Transfer

In IPT, power are transferred by magnetic field from transmitter coil of wire to receiver coil of wire. Transmitter and receiver coils is acting like a transformer. An Alternating Current (AC) that passes through the transmitter coil will create oscillating magnetic field by Ampere's Law and induces voltage at receiver coil by Faraday's Law of induction which create an AC current in the receiver circuit then transferred to the load. There are many application using IPT for charging purposes such as electric toothbrush stand. This toothbrush stand works under 50 or 60 Hz means that AC is supplied directly to the transmitter coil but most of the application nowadays has its own electronic oscillator to convert fundamental frequency to higher frequency of AC because the efficiency will increase as the frequency increases.

3.3.2 Block Diagram of Inductive Power Transfer

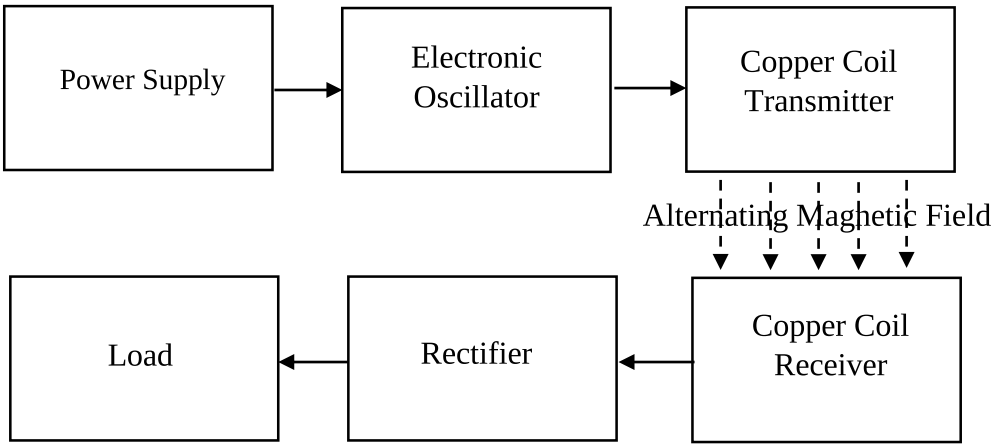

Figure 4 Block Diagram of a typical IPT system

Figure 4 explains the basics of wireless power involves the transmission of energy from a transmitter to a receiver via an oscillating magnetic field. To achieve this, Alternating Current (AC) supplied by a power source, is converted into high frequency by electronics oscillator built into the transmitter. AC energizes a transmitter coil, which generates a magnetic field. Once receiver coil is placed within magnetic field, the field can induce an alternating current in the receiver coil. Rectifier then converts the alternating current back into direct current transfer to the load.

3.3.3 Material Characteristics of Inductive Power Transfer

In IPT, copper is a standard material used transmitter and receiver coil. In electrical conductivity table, copper stands number 2 after silver. Copper chose because of cost and abundance factor. Copper has structure of crystal. It is yellowish red in colour and can be bright metallic colour after polished. Copper has been used in many applications such as power transmission lines, spark plugs, high conductivity wires, electrodes and etc. Figure 5 shows relationship between metal and its electrical conductivity.

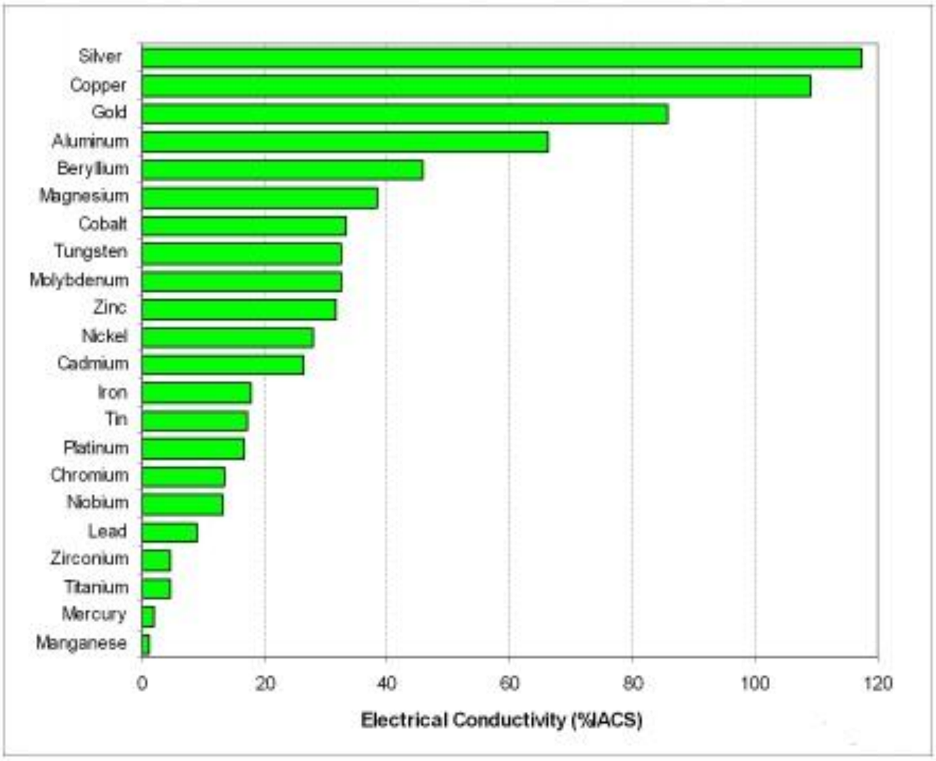

Figure 5 Relationship between metal and its electrical conductivity

3.3.4 Modelling of Inductive Power Transfer

In this project, two factors that affecting the efficiency of WPT will be investigated.

i. Number of turns of coils

Different number of turns of transmitter coil will be investigated to see how it affecting the voltage at the receiving coil.

ii. Frequency tuning and Resonant frequency

For frequency tuning, an oscillator is construct by using 555 timer to vary frequency from 10kHz to 100kHz. And resonant frequency is affected by number of turn at receiver coil with capacitor connected parallel with the coil.

In modelling of IPT, this project is focusing on coil design. There are 2 important components need to be determined because the component will be take part in experimenting the circuit. These components are manipulated, changes with different number of turns of coil. These 2 components are:

1. Inductance of coils
2. Resonant frequency at receiver coil

Mathematical formulae are applied with the coil parameters in order to investigate how the two factors can affect the efficiency of WPT. Table 1 shows the coil parameters for both transmitter and receiver coil.

L_1 = Inductance at Transmitter coil

L_2 = Inductance at Receiver coil

Table 1 Transmitter and Receiver Coil Parameter

Diameter of the coil, mm	45
Diameter of conductor section, mm	0.71

By applying the Equation 3.1, the inductance for different number of turn of receiving coil can be calculated. Figure 6 shows result after applying Equation 3.1. Inductance of the coil increases when number of turns increases. Moreover, inductances of the coils can also be increased by increasing the diameter of the coil but in this project the diameter is fixed.

$$L = n^2 R \mu_0 [\ln\left(\frac{8R}{a}\right) - 1.75] \qquad (3.1)$$

Where,

n − Coil turn

$\mu_0 = 4\pi * 10^{-7}$ − Permeability of vacuum ($\frac{H}{m}$)

R − Radius of coil (m)

a − Radius of conductor section (m)

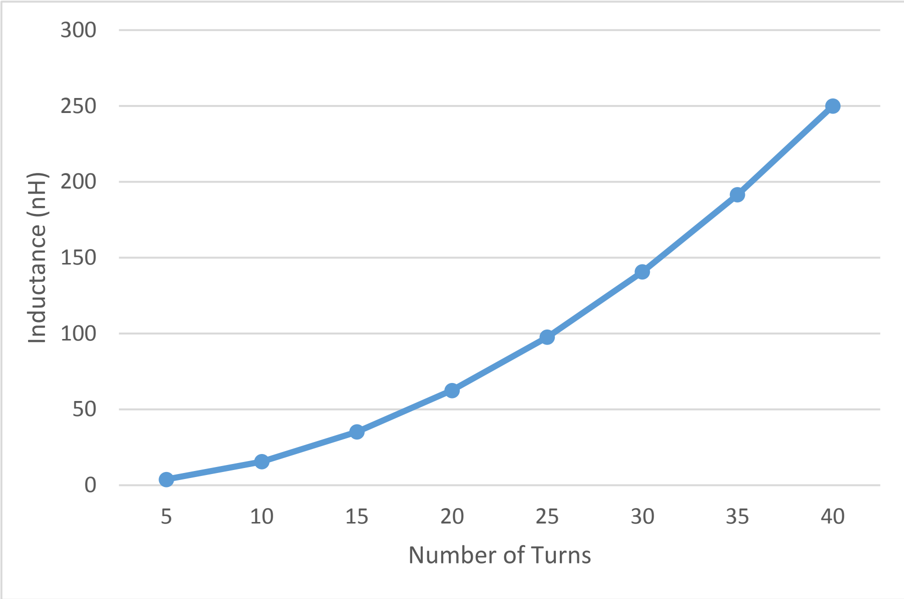

Figure 6 Relationship between number of turns and its inductance

From Equation 3.1, it is shown as the number of turn increases, the value of inductance will also increase. Resonant frequency is affected by number of turn at receiver coil and capacitor connected parallel to the coil. This can be shown by applying this formula:

$$f = \frac{1}{2\pi\sqrt{L_2 C}} \tag{3.2}$$

Where,

$\mathrm{f} = \text{Resonant frequency, Hz}$

$\mathrm{L_2} = \text{Inductance at Receiver coil, H}$

$\mathrm{C} = \text{Capacitor value at receiver coil, F}$

Besides affecting the resonant frequency, number of turns also affecting the voltage at receiving coil. It can be approved by formula below.

$$\mathrm{V} = -\mathrm{N}\frac{\mathrm{d}\emptyset}{\mathrm{dt}} \qquad \emptyset = \text{flux} = \mathrm{B_1} * \mathrm{A_2} \tag{3.3}$$

Where,

$\mathrm{B_1} = \text{Magnetic fields from transmitter coil}$

$\mathrm{A_2} = \text{Area of receiver coil}$

It is shown that as the number of turns increases, the voltage receive at receiving coil will also increases. Based on Equation 3.4, emf induced on the coil is directly proportional to the self inductance of the coil and rate at which the current changing. When inductances increases, the emf induced also increased.

$$\varepsilon = -L\frac{dI}{dt} \tag{3.4}$$

Mutual inductance of the system can determined by Equation 3.5 where $L_1$the inductance of transmitter coil is and L_2 is the inductance of receiver coil. Figure 7 shows the result of mutual inductance.

$$M = k\sqrt{L_1 L_2} \tag{3.5}$$

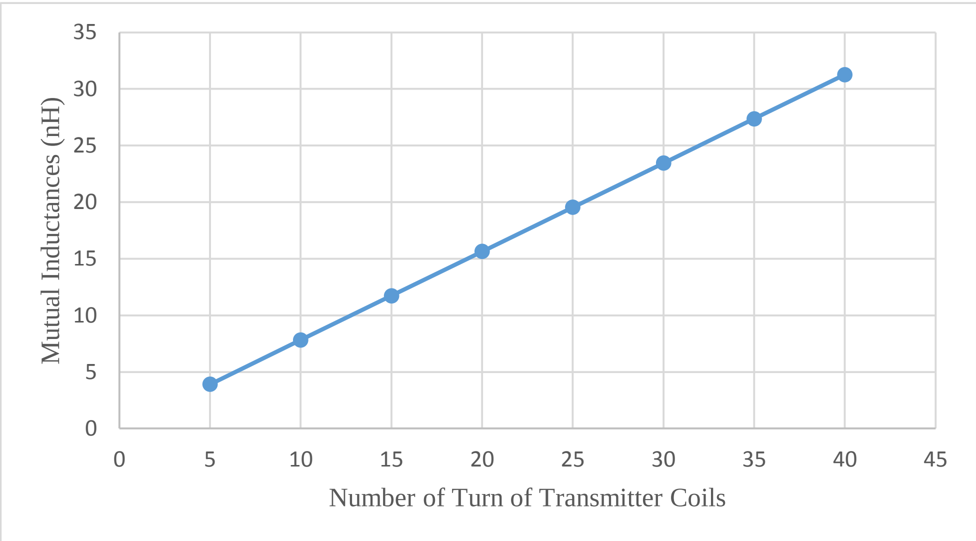

Figure 7 Relationship between number of turns and mutual inductance

Output power of the system can be defined in Equation 3.6, where $V_1$is the input voltage, ω is the operating frequency, and R_L is the load resistance. R_1 is the transmitter resistance. R_2 is the receiver resistance and M is the mutual inductance.

$$P_{out} = \frac{V_1\omega^2M^2R_L}{(R_1(R_2+R_L)+\omega^2M^2)^2} \tag{3.6}$$

3.3.5 Limitations of Inductive Power Transfer

IPT is only is feasible for general power applications only if transmitter and receiver coil are closed with each other. IPT has limitation in transfer distance. As transfer distances, efficiency will decreases. So, it is no feasible for larger space due to its low efficiency. IPT efficiency is affected by magnetic field strength, and in order to have high efficiency receiver coil must be as near as it can be to the source to have maximum power transfer.

3.4 Experimental Setup

3.4.1 Introduction

In this project, investigation will be done on three aspects, relationship between frequency tuning and voltage receive at receiver coil when the distance between transmitter and receiver coil and number of turn of receiver coil is fixed. Second, relationship between number of turns of transmitter coil and voltage receive at receiver coil when frequency, distance between transmitter and receiver coil, and number of turn at receiver coil is fixed. Third, relationship between distance between transmitter and receiver coil and voltage receive at receiver coil when frequency and number of turn of transmitter and receiver coil is fixed.

3.4.2 Block Diagram of Experiment Setup

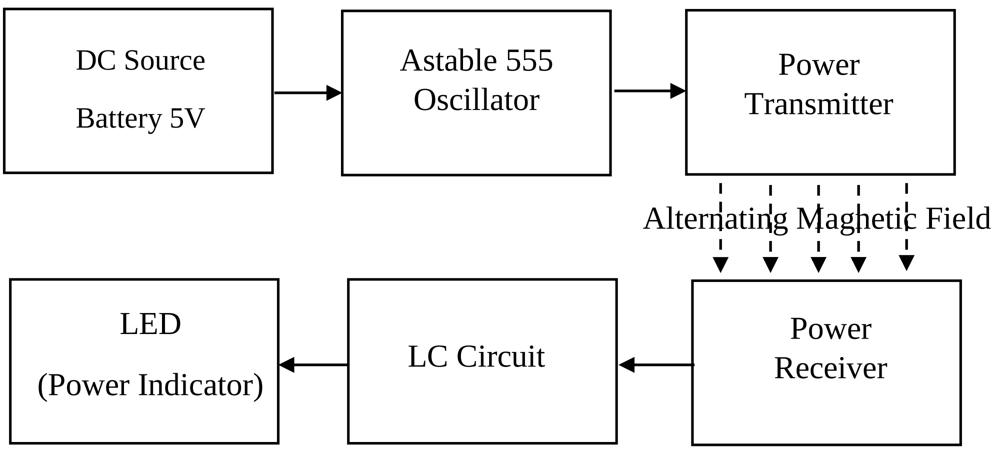

Figure 8 Block Diagram of IPT experimental setup

Power from battery 5V is converted to high frequency alternating current from 10 kHz to 100 kHz by using astable 555 oscillator then transfer to transmitter coil which is in circular shaped. Alternating current that flow through the transmitter coil will generate an oscillating magnetic field which then induce alternating voltage at receiver coil. LC circuit will smoothen the voltage before to the LED which will light up as power indicator. Figure 9 shows transmitter and receiver experiment setup. .

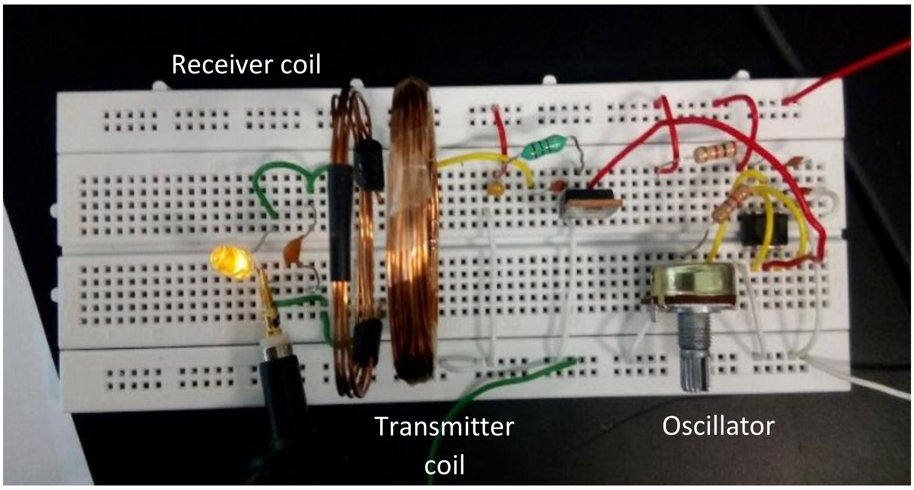

Figure 9 Experimental setup

3.4.3 Components Requirement

Table 2 show the list of components used in this project that will be used in experiment. These component can be borrow from UTP Electrical and Electronic department (EE) store. Total cost of the components also listed in the table. It is shown that the total cost of this project is under allocated FYP budget of RM500.

Table 2 Project component list and Project cost

No	Components	Quantity	Cost (RM)
1.	LM555CN	1	1.50
2.	Resistor 2k Ohm	1	0.20
3.	Resistor 4.7k Ohm	1	0.20
4.	Capacitor 101	1	1.20
5.	Capacitor 102	1	1.20
6.	Capacitor 103	1	1.20
7.	Capacitor 104	1	1.20
8.	Capacitor B471K	1	1.20
9.	Variable Resistor 100k Ohm	1	8.00
10.	Inductor	1	1.30
11.	IRF620	1	4.20
12.	Yellow LED	1	0.60
13.	Breadboard	1	14.00
Total Cost			36.00

3.4.4 Output of the Experiments

There are 4 experiment will be conducted. Experiment 1 is to determine range of frequency which is suitable and maximum output voltage at receiver coil before conduct the next experiment. In experiment 1, distance between coil and number of turns of the coil will be fixed at 5mm and 5 turns, only the frequency will be varied from 10kHz to 100kHz. Experiment 2 is to investigate the relationship between number of turns and output voltage at receiver coil. In experiment 2, the distance between transmitter and receiver coil will be fixed at 5mm, frequency is fixed at value from experiment 1, and number of turns will be varied from 5 to 40 turns.

Experiment 3 is to investigate relationship different number of turns with output voltage at receiver coil with increasing distance between transmitter and receiver coil. In experiment 3, the frequency also fixed at the value from result from experiment 1. Experiment 4 is to investigate the relationship between frequency and voltage received at receiver coil and distance between transmitter and receiver coil. In experiment 4, only number of turns will be fixed for 5 turns.

These 4 experiments are done to investigate factors affecting IPT by measuring output voltage at receiver coil. Receiver side especially receiver coil is fixed from the first experiment until the last experiment due to adapt to real life situation where mobile phone is small means that there are limitation for number of turns for receiver coils.

CHAPTER 4

PROJECT ACTIVITIES

4.1 Tools Used in Completing Project

There are tools and software used in order to complete this project. This tools is important in order to make sure project can be completed on time and data collected can be analyzed in form of table and graph.

1. Digital Multimeter
   Digital Multimeter is used to measure voltage and resistor value, especially the voltage value at resistor coil.

2. TekTronik TDS 1002 Digital Oscilloscope
   TekTronik TDS 1002 Digital Oscilloscope is used to measure frequency and DC and AC voltage level.

3. GW Instek Laboratory DC Power Supply
   GW Instek Laboratory DC Power Supply is used to supply input power for this project.

4. Microsof Excel 2013
   Tabulation and graph of data is analyzed by Microsoft Excel 2013.

5. Microsoft Power Point 2013
   Presentation slides is done by Microsoft Power Point 2013.

6. Microsoft Word 2013
   Documentation is done by Microsoft Word 2013.

4.2 Flow Chart

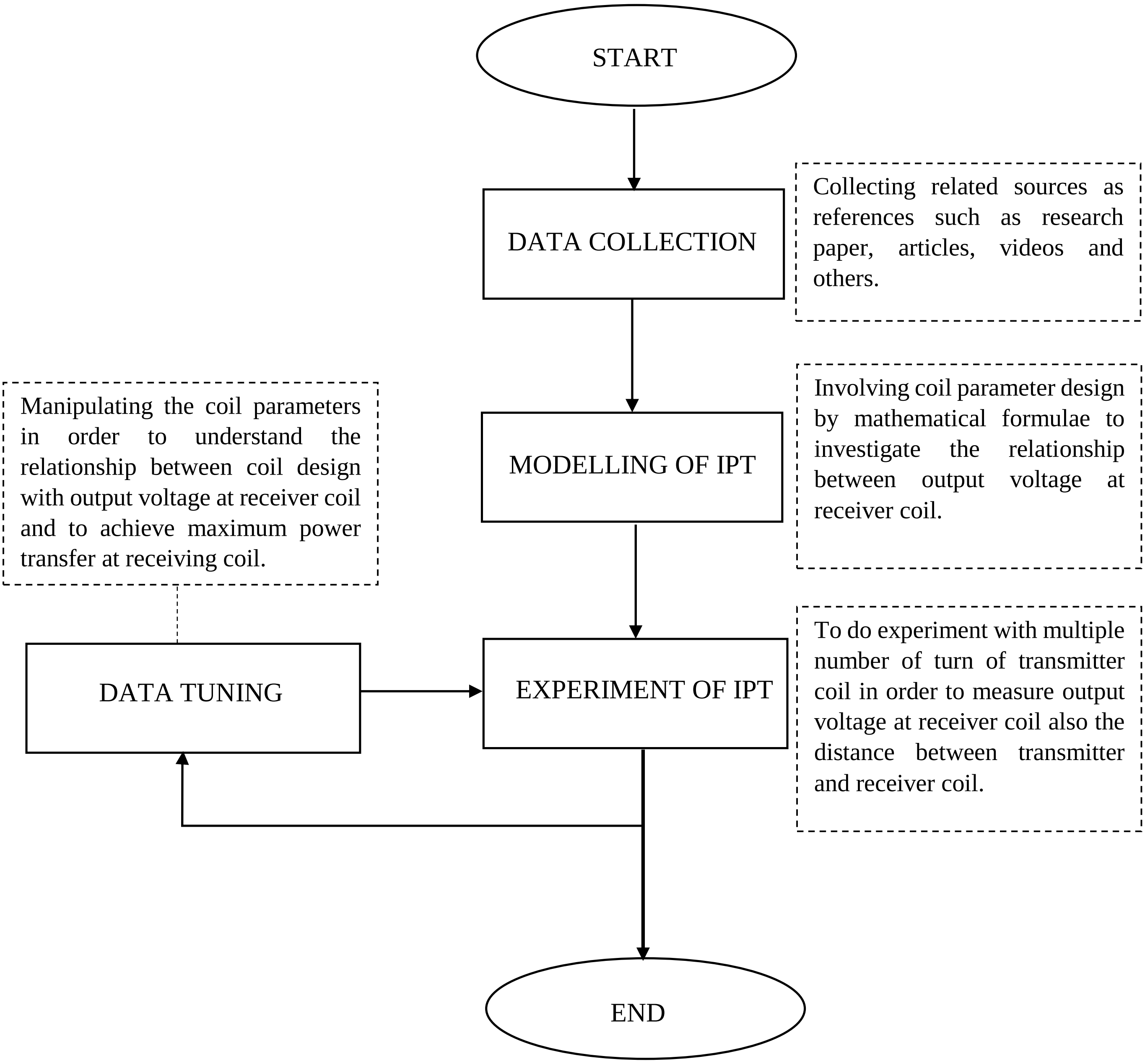

Figure 10 Flow Chart of the project

4.3 Key Milestones

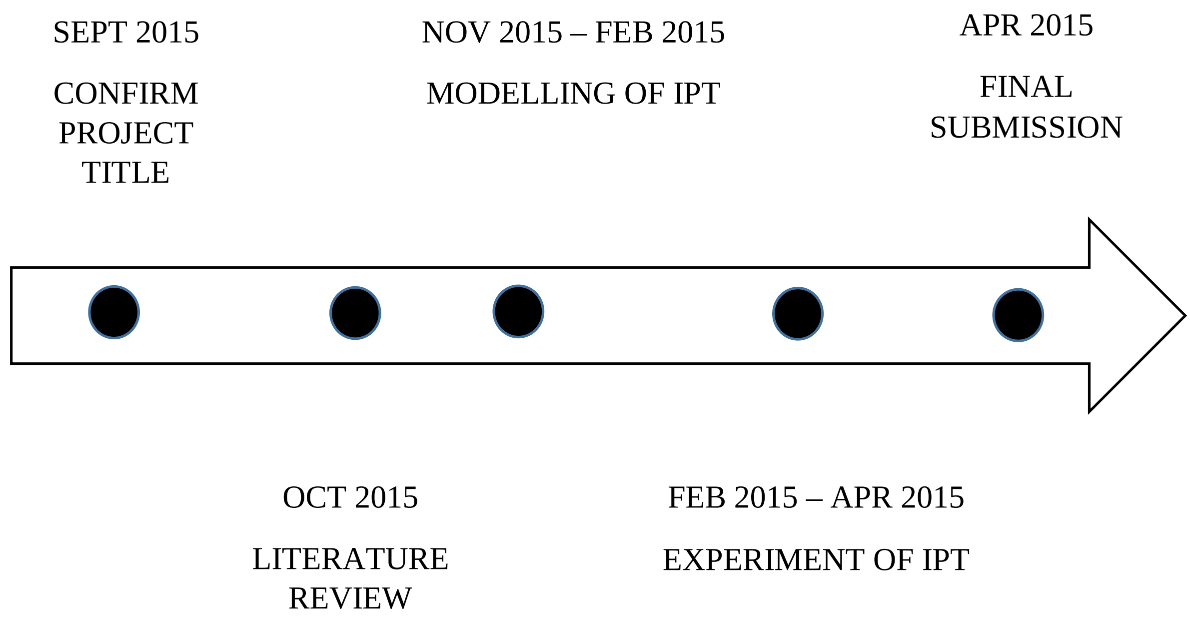

Figure 11 Key Milestones of the project

Figure 11 shows several key milestones needed to achieve for this final year project. In September 2015, key milestones start with confirmation of project title with supervisor and final year project coordinator. Continue with literature review in Oct ober2015, involving collection of data involving past related research paper, related articles and related videos as references. In November until February 2015, next key milestone is modelling of IPT, this step need a longer time due to its importance and also the main focus for this project. This step need to be taken seriously because it can affect the next step result which is the hardware implementation. Hardware implementation is done in February 2015 until April 2015. This project is complete in April 2015.

4.4 Gantt Chart

Table 3 Gantt Chart of Final Year Project 1

Activities Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Titles Selection/Proposal														
Data collections and Literature review														
Extended proposal														
Modelling of IPT														
Proposal defence and Progress evaluation														
Draft report														
Final report														

Table 4 Gantt Chart of Final Year Project 2

Activities Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project work continues														
Progress report														
Project work improvement														
Pre-Sedex														
Draft report submission														
Dissertation submission (soft bound)														
Technical paper submission														
Viva														
Dissertation submission (Hard bound)														

CHAPTER 5

RESULTS AND DISCUSSIONS

Experimental result of output voltage at receiver coil against operating frequency of the oscillator is shown in Table 5. Figure 12 shows the graph of receiver coil against frequency based on Table 5. Measurement were taken by using oscilloscope. Distance between transmitter and receiver coil is fixed at 5mm with input voltage of 5V and number of turn of transmitter coil is 5. Based on Table 5 and Figure 12, it is shown voltage at receiver coil is highest when the frequency of the oscillator is 45 to 55 kHz. In theory, when frequency is nearing the resonance, the magnetic field produced is strongest thus more voltage on the receiver coil.

Table 5 Relationship between frequency and output voltage of receiver coil

Frequency (kHz)	Output Voltage (V)
10	0.6
15	0.7
20	0.8
25	0.8
30	0.8
35	0.8
40	0.8
45	1.0
50	1.0
55	1.0
60	0.8
65	0.7
70	0.7
75	0.7
80	0.7
85	0.6
90	0.5
95	0.5
100	0.4

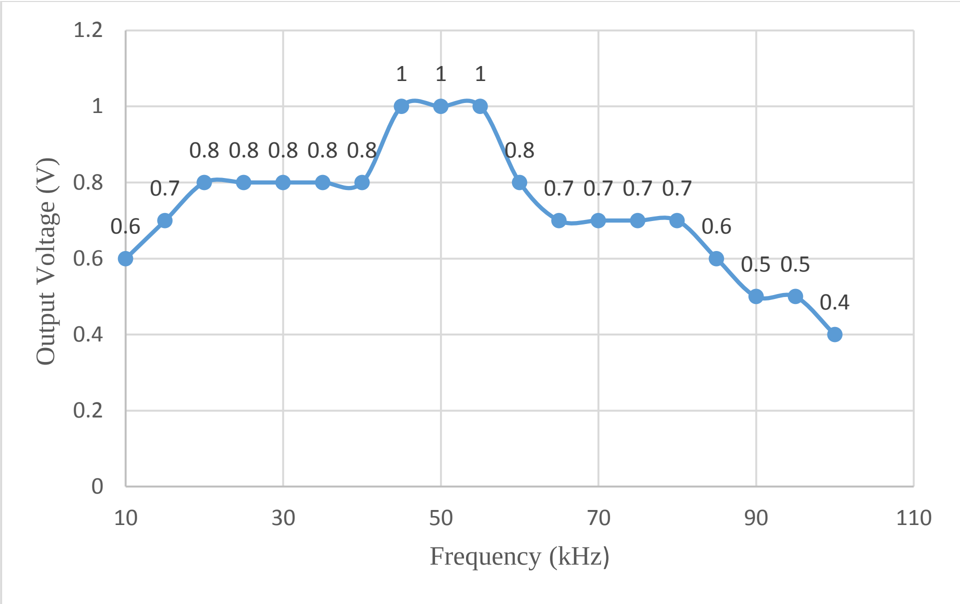

Figure 12 Relationship between frequency and output voltage at receiver coil

Experimental result of output voltage of receiver coil against number of turns of transmitter coil is shown in Table 6 and Figure 13. Based on table 6 and figure 7, explains that output voltage at receiver coil increase as number of turns increase with maximum voltage of 2.7V with fixed distance of 5mm and frequency of 45kHz. As number of turns increases, magnetic field produced also increased, more cutting magnetic flux at receiver coil thus more current induced at receiver coils cause more voltage produced.

Table 6 Relationship between output voltage of receiver coil and number of turns

Number of turns	Output voltage (V)
5	1
10	1.7
15	2.5
20	2.5
25	2.7
30	2.7
35	1.8
40	1.8

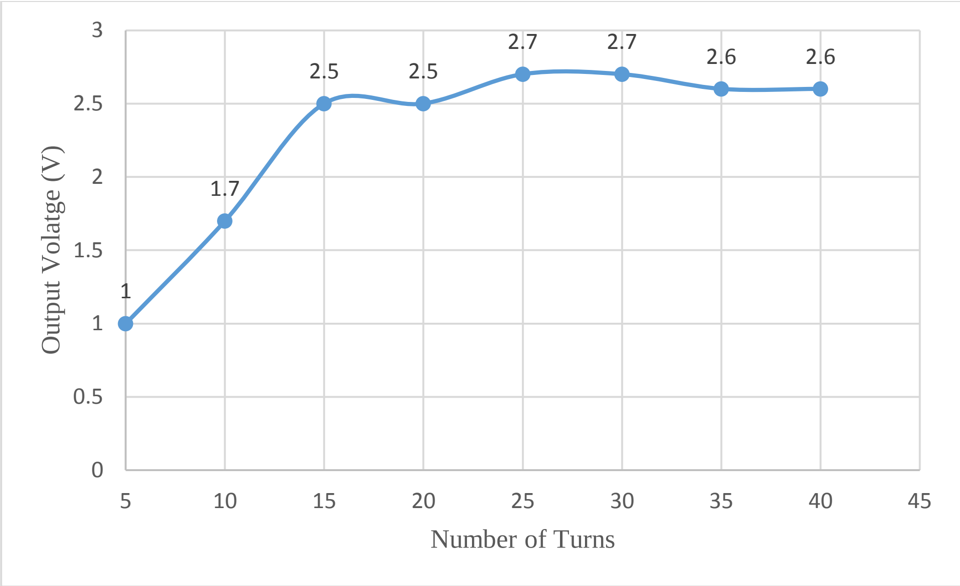

Figure 13 Relationship between voltage at receiver coil and number of turns

Experimental result of output voltage of receiver coil against distance between transmitter and receiver coil is explained in Table 7 and Figure 14. Initial distances is 1 mm and increasing by 1mm until 1cm. Figure 14 shows that output voltage of receiver coil decreases as the distances increases. This is because as the distances increases, the magnetic field strength also decreases. The voltage measured highest, 1.8V at 2mm with number of turn of transmitter coil of 5.

Table 7 Relationship between output voltage of receiver coil and distances between transmitter and receiver coils

Distance between coils (mm)	Output voltage (V)
1	1.7
2	1.8
3	1.6
4	1.5
5	1.5
6	1.3
7	1.1
8	1.1
9	1
10	1

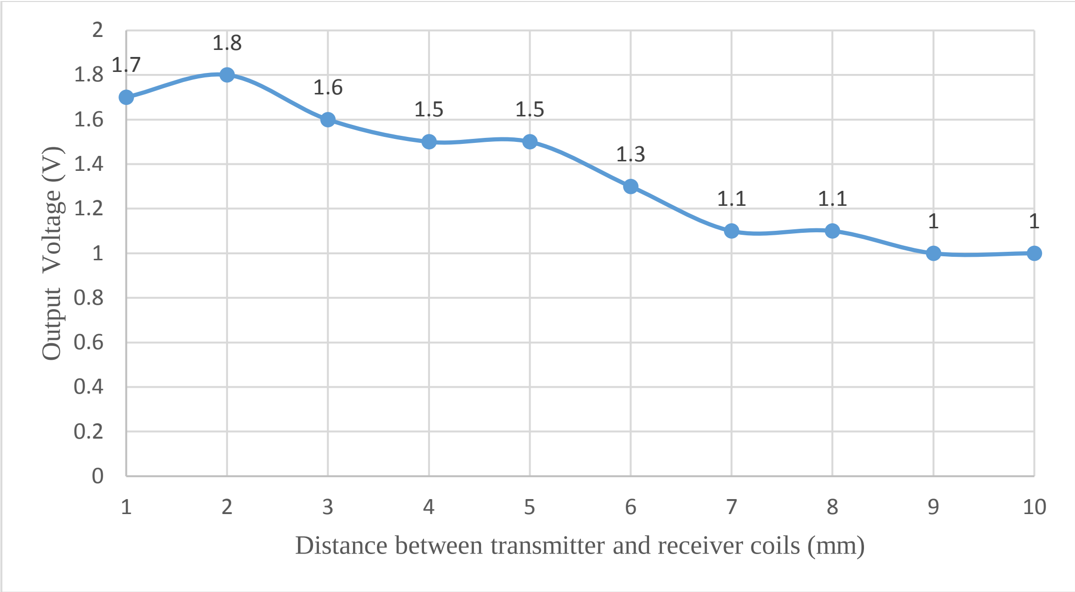

Figure 14 Relationship between output voltage of receiver coil and distances between transmitter and receiver coils

Different number of turns affect the output voltage of receiver coil and the transfer distance between the transmitter and receiver coils is shown in Figure 15. As number of turns increase, output voltage at receiver coil increase, transfer distance between transmitter and receiver coil also increased. This is due to magnetic field strength which increases as number of turns increases.

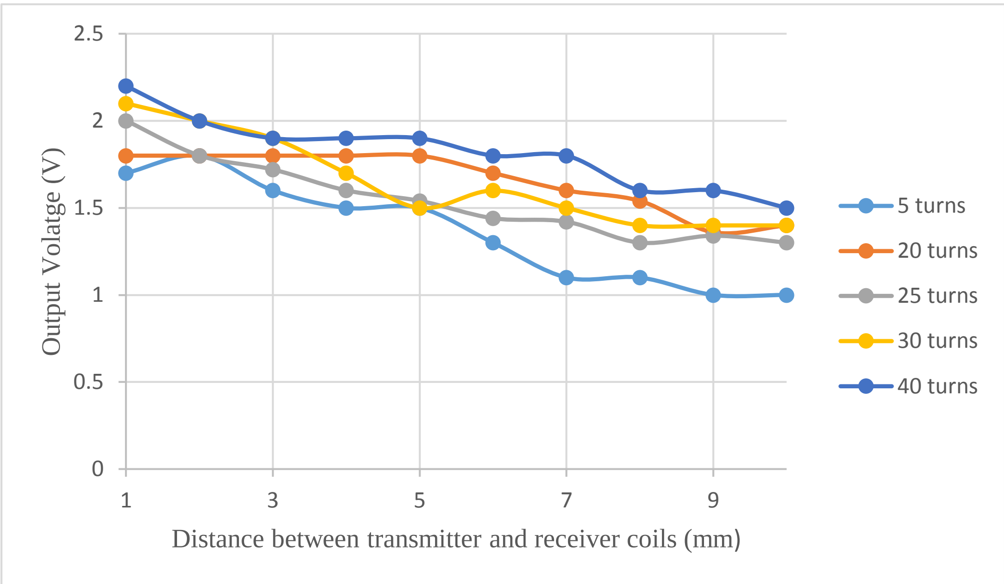

Figure 15 Relationship between output voltage of receiver coil and distances between transmitter and receiver coils with different number of turns

Figure 16 and 17 explains that between 10kHz to 100kHz, 45kHz is suitable frequency to perform induction power transfer with coil parameters. Operating frequency is affected by receiver coil parameters. Since receiver coil number of turns is fixed, this frequency is fixed for other experiments.

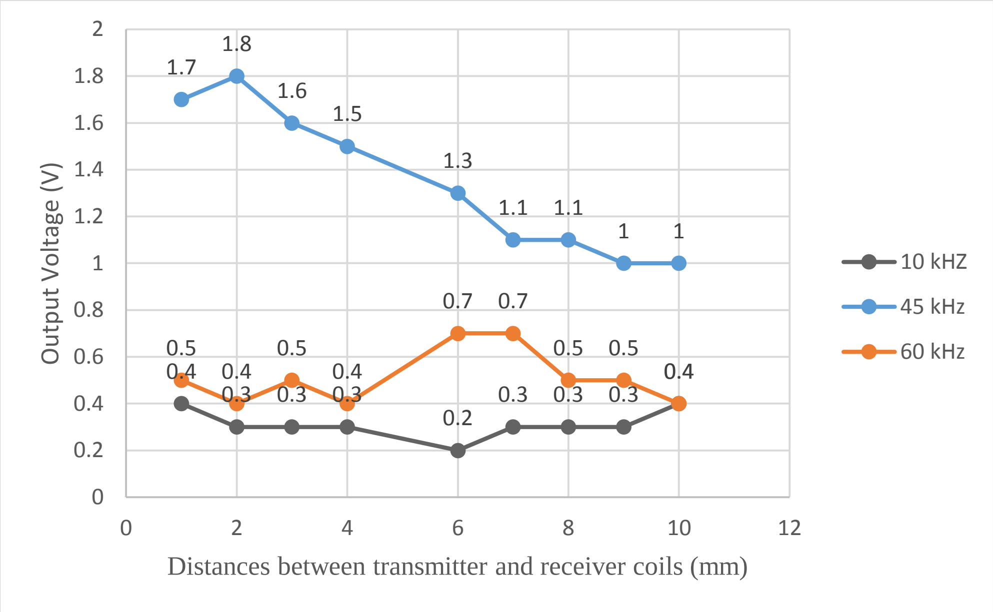

Figure 16 Relationship between output voltage of receiver coil and distances between transmitter and receiver coils with different frequency

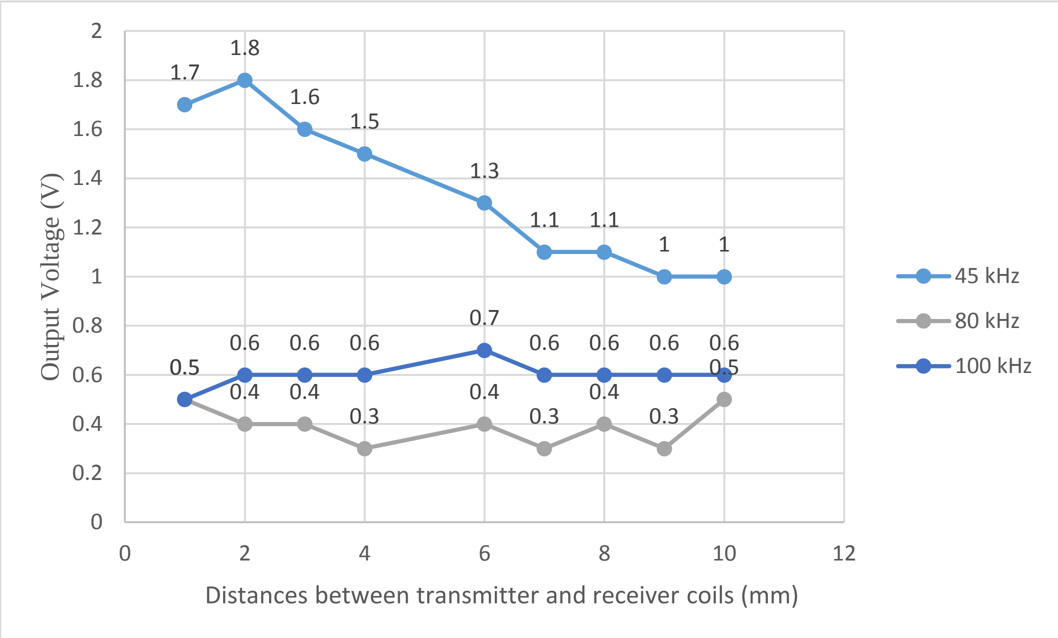

Figure 17 Relationship between output voltage of receiver coil and distances between transmitter and receiver coils with different frequency

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project investigate the factors affecting efficiency wireless power transfer by modelling and experimentation on hardware implementation. The objectives of this project are to understand the principle of WPT, to identify the suitable modelling of IPT and to investigate factors affect the efficiency of IPT.

Coil parameters are manipulated in order to achieve maximum power to transfer to receiver coil. In experiment, there are four aspects will be investigated. First, relationship between operating frequency with output voltage at receiver coil. Second, relationship between number of turns of transmitter coil with output voltage at receiver coil. Third, relationship between distance between transmitter and receiver coil with output voltage at receiver coil. Fourth experiment, relationship between operating frequency and output voltage of receiver coil with different distances between transmitter and receiver coil.

The outcome of the experiments are, between the ranges of 10kHz to 100kHz. The suitable frequency to operate the wireless power transfer is 45kHz when the receiver coil is fixed at 5 turns and diameter of the coil is 4.5cm. As the number of turn increases, the voltage received also increases, with 40 turns, the voltage received 2.7V. The transfer distance also increased when number of turns increases, due magnetic field strength increased.

As recommendations, for future research, to investigate the relationship different shapes of transmitter coils in affecting output power of receiver coil. There are many shapes of transmitter coils can be investigates such as circle, rectangle, triangle, pentagon or hexagon and others. Next, to investigate between single and multiple transmitter coils in affecting output power of receiver coil. By investigating these factors, inductive power transfer can be understand more deep and efficiency of the system can be improved.

REFERENCES

[1] Vladislav Khayrudinov (2015), Wireless Power Transfer System Development and Implementation. Retrieved from https://www.researchgate.net/profile/Vladislav_Khayrudinov/publications

[2] Jiejian Dai; Ludois, D.C., "A Survey of Wireless Power Transfer and a Critical Comparison of Inductive and Capacitive Coupling for Small Gap Applications," in *Power Electronics, IEEE Transactions on* , vol.30, no.11, pp.6017-6029,Nov.2015

[3] Xia, C., Zhou, Y., Zhang, J., Li, C.. Comparison of Power Transfer Characteristics between CPT and IPT System and Mutual Inductance Optimization for IPT System. Journal of Computers, North America, 7, nov. 2012.

[4] Sharma, P., Pande, J., & Singh, A. (2015). Comparative Implication and Analysis of Inductive & Capacitive Wireless Power and Data Transfer in USB.

[5] Kamarudin.Kh, ShakirSaat, Y.Yusmarnita, Norezmi Jamal. Analysis and Design of Wireless Power Transfer: A Capacitive Based Method for Low Power Applications. WSEAS Transactions on Circuits and Systems, Vol.14, 2015.

[6] Hui, S.Y.R.; Wenxing Zhong; Lee, C.K., "A Critical Review of Recent Progress in Mid-Range Wireless Power Transfer," in *Power Electronics, IEEE Transactions on* , vol.29,no.9,pp.4500-4511,Sept.2014

[7] Wei, X., Wang, Z., & Dai, H. (2014). A critical review of wireless power transfer via strongly coupled magnetic resonances. *Energies*, *7*(7), 4316-4341.

[8] Nizam, B. (2013). Inductive Charging Technique. International Journal of Engineering Trends and Technology (IJETT), vol.4, pp.1054-1059, Apr. 2013

[9] Kurs, A., Karalis, A., Moffatt, R., Joannopoulos, J. D., Fisher, P., & Soljačić, M. (2007). Wireless power transfer via strongly coupled magnetic resonances.*science*, *317*(5834), 83-86.

[10]Weidong Peng; Guozhu Zhao, "Experimental Analysis on Wireless Power Transmission Based on Magnetic Resonant Coupling," in Remote Sensing, Environment and Transportation Engineering (RSETE), 2012 2nd International Conference on , vol., no., pp.1-4, 1-3 June 2012

[11]Olvitz, L.; Vinko, D.; Svedek, T., "Wireless power transfer for mobile phone charging device," in MIPRO, 2012 Proceedings of the 35th International Convention , vol., no., pp.141-145, 21-25 May 2012

[12]Syed Khalid Rahman, Omar Ahmed, Md. Saiful Islam, A. H. M. Rafiul Awal, Md. Shariful Islam. Design and Construction of Wireless Power Transfer System Using Magnetic Resonant Coupling. American Journal of Electromagnetics and Applications. Vol. 2, No. 2, 2014, pp. 11-15

[13] Zhuo Yan; Yang Li; Chao Zhang; Qingxin Yang, "Influence Factors Analysis and Improvement Method on Efficiency of Wireless Power Transfer Via Coupled Magnetic Resonance," in Magnetics, IEEE Transactions on , vol.50, no.4, pp.1-4, April 2014

[14] Burali, Y.N., & Patil, C. B. (2012). Wireless electricity transmission based on electromagnetic and resonance magnetic coupling. Int. J. of Computational Engr. Res, 3(7), 48-51