Development of Wireless Charging for Mobile Application using PV Module

by

Yee Kang Yung

17215

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical and Electronic)

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CERTIFICATION OF APPROVAL

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Approved by,

_____

(Dr. Nor Zaihar B Yahaya)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

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 source or persons.

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YEE KANG YUNG

ABSTRACT

In this paper, a wireless power transmission (WPT) using resonant magnetic coupling for mobile phone charger is presented. Solar energy was used as the energy source to address the scarcity of non-renewable energy sources and tackles the constraints of wired charging technology such as lack of universal electrical standard, untidiness and inconvenience of wires and wires' wear and tear. The system includes PV panels and battery, oscillator, transmitting coil and receiving coil and rectifier. Proteus 8.1 was used to simulate before implementing in the hardware. The resonant magnetic coupling resonated at 800 kHz $\pm$ 10 kHz. The maximum distance to charge a mobile phone was 4 cm at 3.7 V. All the objectives are achieved within the limited time frame. The significance of the project can help to eradicate the use of wires and the need of power plugs. The future research includes the study of efficiency, coil design, system with multiple loads.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION

AC   -   Alternating Current

d -   Distance

DC   -   Direct Current

f -   Resonant Frequency

I_{out} -   Output Current

ISM   -   Industrial, Scientific and Medical

PV   -   Photovoltaic

PWM   -   Pulse Width Modulation

Rx   -   Receiver

Tx   -   Transmitter

V_{out} -   Output Voltage

WPT   -   Wireless Power Transmission

η -   Efficiency

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Palm, an American mobile phone company, first presented its smart phone with wireless charging features in the year 2009 that precedes to an opening of a new breadth in the mobile world [1]. The ripple effect of Palm's wireless charging devices has engrossed the competitors in the smart phone arena. As a result, its competitors such as Nokia's Lumia, Google's Nexus, Samsung's Galaxy and Motorola have offered an optional wireless charging in their mobile phone package. Besides that, the famous coffee franchises, Starbucks and The Coffee Bean & Tea Leaf have provided public wireless charging stations in their shop as a tryout. Thus, coffee lovers can charge their compatible mobile phones at ease just by putting it on the table or countertop. [2, 3].

The concept of wireless charging materialized from the idea of Wireless Power Transmission (WPT) which started in the early 20th century, when a visionary Serbian electrical engineer, Nikola Tesla invented a resonant transformer – Tesla Coil. The Tesla coil is a device that could power the electrical devices around wirelessly. While it is used in a minor scale of experiments, a bigger version of the Tesla coil – the Wardenclyffe Tower, also known as Tesla Tower, was built. It was believed to transmit energy to a much greater distance, from city to city. However, due to the low feasibility of the project and the fear of safety hazards, the project investors decided to discontinue its funding. In the end, the project was not accomplished. However, that was not the end of the WPT. Companies started using the concept of the WPT to produce numerous creation ranging from, electric toothbrush, surgically implanted devices, electric vehicle, and now mobile phone charger [4-7].

The general principle of the WPT is when an alternating current (AC) passes through a closed loop coil, magnetic fields will be generated around the coil. This

phenomenon is known as Ampere's Law [8]. On the other hand, the magnetic field generated by the transmitter will induces a voltage in the receiver coil. This incident is recognized as Faraday's Magnetic Induction Law [8].

While wireless charging method in the market, called inductive coupling, operates at a near distance, in Massachusetts Institute of Technology (MIT), Professor Marin Soljačić and his team developed a prototype that transmits power wirelessly at a middle range distance, ($d > 1$ meters). Their objectives are to increase the distance of transmitting and the efficiency. The working principle of their prototype is to utilize a resonant coupled coil in magnetic induction, or called resonant coupling [9].

This magnetic resonant coupling technique operates at the resonant frequency by both transmitter and receiver coils. When two coils are tuned to the same resonant frequency, the efficiency and the range of the transmitted energy are enhanced. Besides that, energy could be transferred while the coils are not aligned. This is called Non-Radiative Energy Transfer. The resonant frequency (*f*) is generated using *LC* tuned circuit where the inductance is from the excitation or receiving coil and a capacitor [9].

In our modern world in which technologies are ubiquitous in everyday life, we need additional electrical energy to turn on our appliances or gadgets. While conventional energy sources like gas, coal, natural gas are limited and emit polluted air to the atmosphere, the renewable energy emerges as the solution to reduce the dependency on traditional energy sources and scale down the pollution level [10]. One of the many choices of renewable energy, solar power, has been a viable option because of it is economical, pollution-free and readily available [10]. This project uses solar photovoltaic panels to convert solar energy into electricity, which then charges mobile devices wirelessly using a magnetic resonance coupling technique [9, 11].

1.2. PROBLEM STATEMENTS

With the newest technology materializing everyday to improve people's standard of living, there is higher demand for more electricity. However, many weaknesses in the conventional energy sources have compelled energy producer to consider alternative

energy or renewable energy. Solar energy is considered to be one of the viable solutions due to its superiority over the conventional energy in terms of environmental cause and availability [10].

People rely on electrical devices and electronic gadgets to improve the way they perform daily activities. Most of the electrical devices powered by wire technology, but its limitation has become nuisances to the users. Several notable current issues of wire technology are clarified in the next section.

1.2.1. No Universal Power Standard and Plug

Numerous power standards have established by a certain country since the early invention of electrical equipments around the world. Three significant parameters in power standards are the voltage level, frequency and plug head. The Fig. 1 shows the variation of electrical standards which are ranging from 100 - 130 V and 60 Hz (North America and Eastern South America), 100 - 130 V and 50 Hz (Northern Japan) and the rest of the world uses 220 - 240 V and 50 Hz. The Fig. 2 displays the variation of power plug standards and the variety of plug head ranges from Type A-Type M.
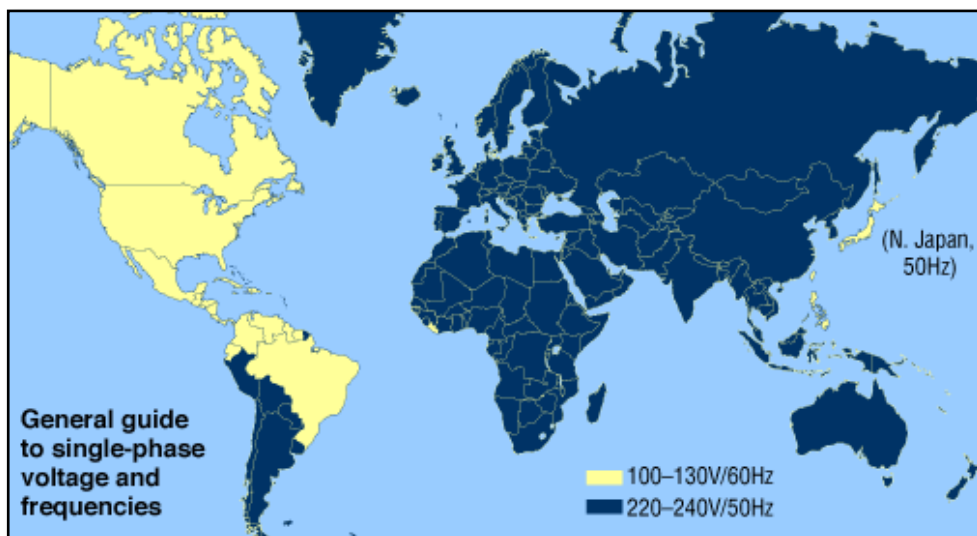
FIGURE 1.   The Variation of Voltage and Frequency Standards in the World [12]
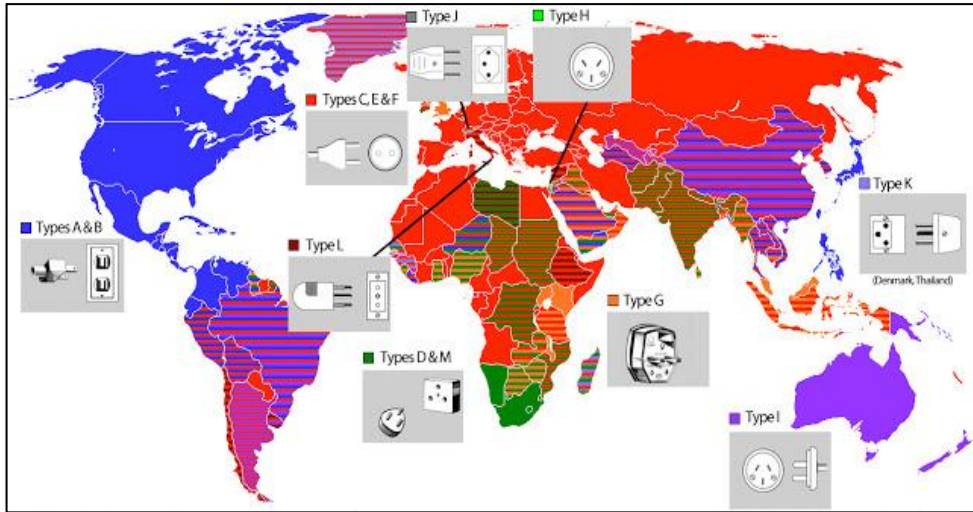
FIGURE 2.   The Variation of Power Plug Standards in the World [13]

1.2.2. Inconvenience and Untidiness

Now, electronic gadgets and electrical equipments are extremely reasonable cost due to the ever-growing technologies and global competitions. Thus, consumers could afford many different gadgets and workstations to solve variety of problems. As a result, due to many wires interconnected with each equipment, the wires are cluttered behind the desk as shown in Fig. 3.
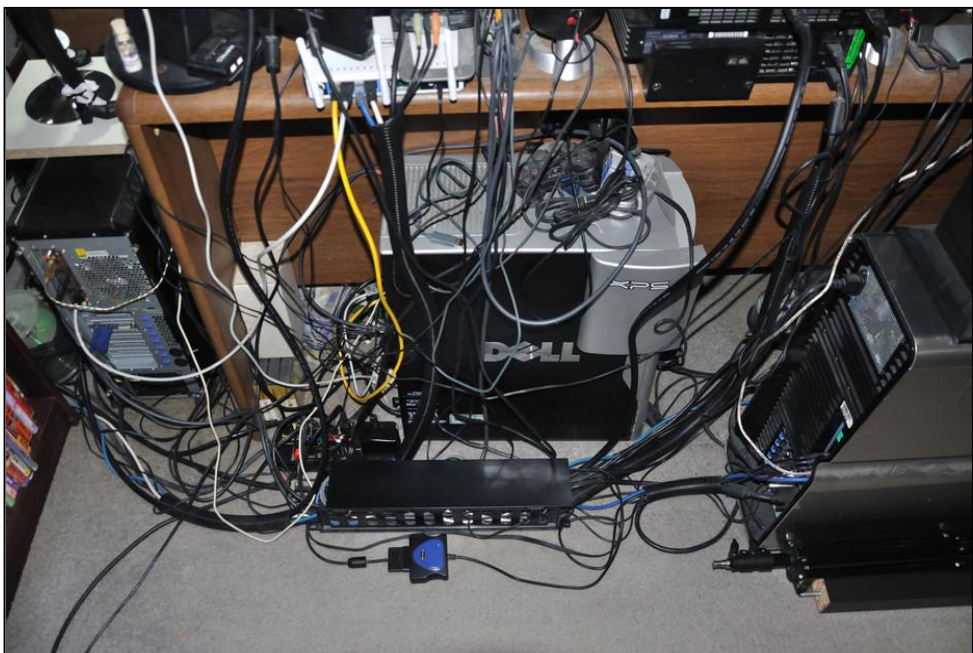
FIGURE 3.   Untidiness of Wires at a Workstation [14]

1.2.3. Wires' Wear and Tear

The wire's wear and tear are one of the most imperative problem in the wire technology. The wear and tear of the wire are imminent due to the extensive use and improper handling of the wires. Thus, the wires require maintenance every certain period of time to retain its capability of transmission and preserve the efficiency of the transmission.

Aside from the three current issues, previous works from other researcher have showed several limitations [6, 9, 15-18]. Thus, this paper proposed an improvise solution of research [18]. This paper proposed a solar based non-radiative magnetic resonance coupling wireless mobile charger.

From the current issues, the problem statements in regards to the limitations of wire charging can be simplified into a block diagram as shown in Fig. 4.
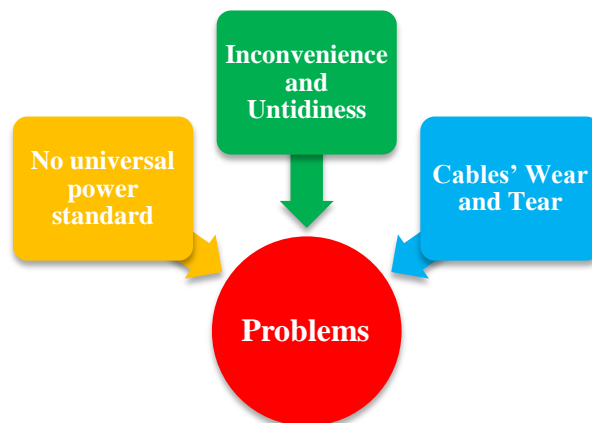
FIGURE 4. Limitations of Wire Technology

1.3. OBJECTIVES

This dissertation aims to develop a workable prototype and achieve three objectives that have been identified based on the problem statements. The project's objectives are as followings:

- To understand the concept of wireless power transmission
- To design a system for the generation of wireless power transmission in order to charge a mobile application

- To analyze the results for reliability and efficiency of the wireless power transmission

1.4. SCOPES OF STUDY

The scopes of this project reflects the objectives of this project. The project's scope of studies consists of:

- To study the principles of wireless power transmission and resonant coupling
- To develop a wireless charging device that uses solar energy as input
- To test the efficiency and the reliability of the wireless power transfer system

1.5. SIGNIFICANCES OF THE PROJECT

The key prospects of this project are to study and comprehend the operation and the principle of the magnetic resonance coupling technique. As electricity is a commodity in the modern world we are living in, the energy transmission medium serves as a link between the power plant and the consumers or power plug to electronic gadgets.

At present, the concept of the WPT has been proven and it is used as part of the advance mobile phone charging technology in the mobile phone market. However, not much research has been done in this area, i.e. solar based wireless power transfer system. The advantages of having solar based wireless power transfer system are:

- The amount of wires used are reduced
- Universal power standards could achieved because no plug is necessary
- Users are not restricted to an area while charging an electronic device

The targeted application of this project is a mobile phone. However, the project's application can extend to any mobile application such as tablets, laptops, cameras, etc. Furthermore, it can also apply to home appliances such as televisions, printers,

cook top, etc, where a larger scale system is required. In future application, this can be a system for electric vehicle (EV) charging station where the cost of electricity for the EV can be reduced.

Hence, it is crucial to acknowledge the potential of wireless power transmission using solar energy as a source. Many areas of research can be conducted especially in medium and high power applications, the efficiency of power transfer, coil design etc.

1.6. FEASIBILITY OF THE PROJECT

This project needs to be accomplished within a given time frame. The feasibility of this research is charted in the Scope of Studies and Gantt Chart. This project is limited to one device which is achievable within the time frame and it is because it is crucial to first determine best parameters to transfer power effectively before designing the system for multiple load. Hence, this makes the project feasible and achievable within the duration of the Final Year Project (FYP).

CHAPTER 2

LITERATURE REVIEW AND THEORY

The research on wireless power transmission and the theory behind this system that includes magnetic resonance coupling is described in details.

2.1. AMPERE'S LAW

The Ampere's Law discovered by André-Marie Ampère in 1826 defined that "an electric current-carrying conductor produces a magnetic field proportional to the current."

$$\oint H \bullet dL = I_{enc} \tag{1}$$

The Eq. (1) concluded that any path that enclose the wire, the sum of the magnetic field at each point along the path is equal to the amount of current that flowing in the wire. In a given wire, the magnetic field, H can be calculated using Eq. (2) where R, is the radius of the loop [8]. Figure 5 shows the magnetic field generated by electric current flowing in the conductor.

$$H = \frac{I_{enc}}{2R} \tag{2}$$
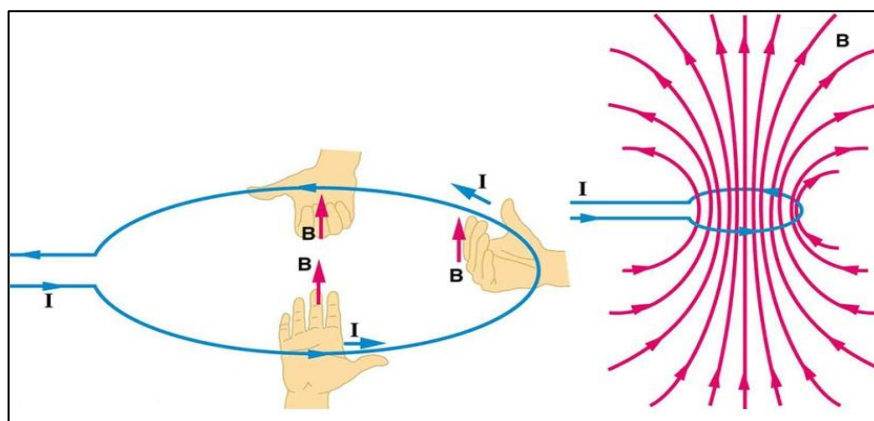
FIGURE 5. Ampere Law [19]

2.2. FARADAY'S LAW OF MAGNETIC INDUCTION

Faraday's Law of Magnetic Induction stated that "the time-varying electromagnetic field will induce an electromotive force (*emf*) in a closed circuit." The direction of the *emf* is explained in Lenz Law -- "the current in the loop is always in such a direction as to oppose the change of magnetic flux that produced it" [8]. The equation of Faraday's Law of Magnetic Induction is expressed as follows:

$$emf = -N\frac{d\phi}{dt} \tag{3}$$

The Eq. (3) shows that the *emf* is proportional to the change in flux, $d\phi$. The *emf* is inversely proportional to the change in time, dt when the *emf* is highest when dt is smallest. The number of turns, N is proportional to the *emf* as the higher the turns in the coil, the greater the *emf* is produced. The minus sign is based on Lenz's Law as it states that "the current and the magnetic field is opposed to the change in flux, $d\phi$" [8].

Figure 6 shows the operation of electromagnetic induction. The generated current from the battery flows into the first coil and produces electromagnetic fields. When a second closed circuit coil is near the electromagnetic field, the load will be energized, and in this case, the bulb will light.
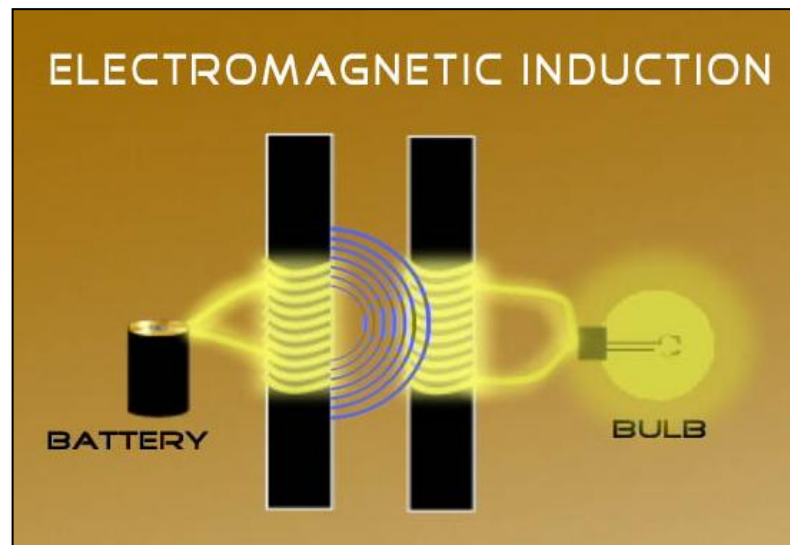
FIGURE 6.   Electromagnetic Induction [20]

9

2.3. RESONANT FREQUENCY

Resonance is a phenomenon in which a system or an object vibrates at its natural frequency at maximum amplitude. When a system oscillates or vibrates at a frequency that matches with its natural frequency, it is said that the system is oscillating at the resonant frequency. Resonance can be used to transfer energy when two objects vibrate at the same frequency.

2.4. MAGNETIC RESONANCE COUPLING

Magnetic resonance coupling uses the concept of resonant frequency and magnetic induction. The magnetic resonance coupling method increases the power transmission efficiency and the distance of the transmission [9],[15]. The transmitter produces Alternating Current (AC) that oscillates at the resonant frequency of the transmitter coil where the coil is tuned to the same frequency. On the other hand, the receiver coil then captures the magnetic field where the coil is also tuned at the same resonant frequency as the transmitter that is connected to the load. When the coils are tuned to the same frequency, the position of the secondary coil and objects between the coils would not affect the transmission provided the secondary coil is within the magnetic field of the primary coil. This phenomenon is called non-radiative energy transfer. The Eq. (4) demonstrates the resonant frequency is dependent to the inductance and capacitance.

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (4)$$

in which: f = Resonant Frequency, L = Inductance and C = Capacitance

Figure 7 shows the resonant inductor and resonant capacitor in the orange boxes are responsible to create the resonance for both of the sides. This is called the *LC* tuned circuit. The resistor, RA and RB represent the resistance for the resonator [21].
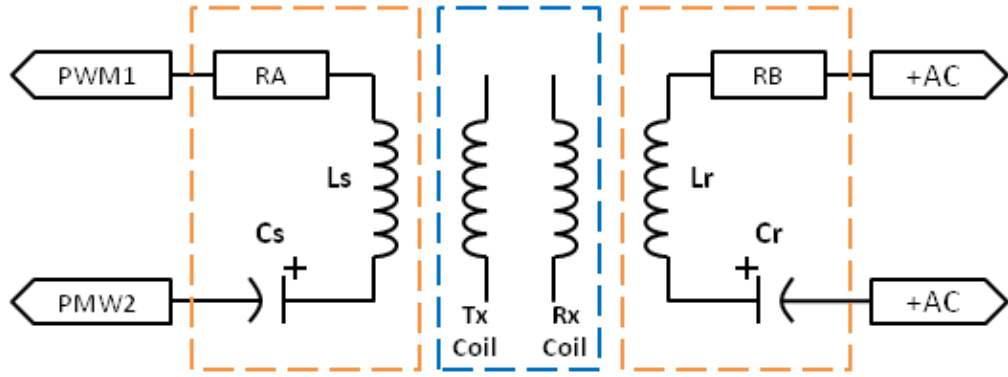
FIGURE 7.   Schematic Diagram of the Magnetic Resonant Coupling

The coil, Tx coil and Rx coil are a very crucial component in a whole system. The coils can be manipulated by the following parameters: the shape of the coil, the number of turns, the size and diameter of the coil, the diameter and the type of the wire.

The function of the resonant capacitor, Cs and Cr in the LC tuned circuit is to generate a resonant frequency of the transmitter coil and the receiver coil. The value of the capacitor must be consistent with the resonant inductance to produce the accurate resonant frequency. The *LC* tuned circuit needs to be precise and almost as identical to the frequency generated by the timer to achieve the magnetic resonant coupling effect. The Eq. (5) shows value of the capacitor is derived from the Eq. (4):

$$C = \frac{1}{(2\pi f)^2 L} \tag{5}$$

2.5. ADVANTAGES AND DISADVANTAGES OF WIRELESS POWER TRANSMISSION

Wireless power transmission may help to eliminate the role of transmission line in any kind of electrical conveniences. For example, in power grid network, the WPT reduces the usage of interconnected transmission cables that cover the entire nation. Therefore, the cost of the electrical system is reduced radically as procurement and maintenance of the cables are nonexistent. As a result, the cost of electrical energy for consumers may also decrease. Furthermore, power failures due to failure of copper cables, short circuits or external disturbances and maintenances could be

prevented. Besides that, in a smaller scale, the WPT helps the user to charge their electrical devices conveniently. In addition, it will reduce the space consumption for wires and cables.

However, the negative side of the WPT is that it is a new and exciting field where the currently low number of experts is available to bring WPT into succession. Moreover, the feasibility of the WPT at present is not economical where the efficiency is still not up to expectation. Besides that, the cost of implementing WPT is high in current market [22].

2.6. RECENT WORK AND ITS APPLICATION

From [9], the team led by Professor Marin Soljačić and his team at Massachusetts Institute of Technology (MIT), first demonstrated magnetic resonance coupling wireless power transmission. Their technique was able to light up a 60 W light bulb over a distance of 2 m with 40 % efficiency. In their research, they have pointed out that a traditional non-resonance approach is inefficient for midrange applications. Through their findings, it is believed that the geometry of the coil is an important aspect to improve the wireless power transmission system.

In University of Tokyo, a team led by Professor Yoichi Hori used the same technique as the team at MIT had carried out [9],[17]. However, this team in Japan explored their method by using the impedance matching circuit to improve their overall efficiency of the system. The impedance matching circuit involves an LC circuit to reduce the power reflection ration to the power source of the WPT system. However, the team resorted to Industrial, Scientific and Medical (ISM) frequency for their WPT system to resonate. ISM band frequency is a reserved radio frequency for industrial, scientific and medical purposes.

From [23], the researchers developed a wireless charging pad that could accommodate various mobile devices. The efficiency of the wireless power transmission system ranged from 42 % to 51 %. The researchers proposed a high efficient transmitter to improve the conversion of power from wall power outlet to transmitter circuit. Their resonance frequency was at 6.78 MHz.

In [16], the team in Croatia used a restricted ISM band as their resonance frequency which was at 16.64 MHz. This frequency is different than the ISM band in Japan [17]. The author in Croatia agreed that the resonant frequency should be in the high frequency (MHz) region because the coil size is suitable for mobile devices. However, the usage of higher frequency has its limitations as skin effect of the conductor degrades the performance of the system. The WPT system achieved 16.44 % efficiency with 0.1 A and 0.5 W at a distance of 2.5 cm.

TABLE I.   Review of Past Works

Reference Number	Description of the Work	Technique Used	Measured Parameters	Advantages	Disadvantages
[9]	Strong Coupled, self-resonant coils power transfer over 2 *m*; light up a 60 *W* blub	Magnetic Resonance Coupling	d η	Mid range, d $\approx$ 2 *m*	Low Efficiency
[16]	Wireless charging pad for multiple load devices	Magnetic Resonance Coupling with power amplifier and power tracking	d η	Improves η Multiple load	Short Distance
[17]	Wireless phone charger with 0.5 *W* power output	Inductive Coupling and Impedance Matching	d η	Sufficiently to charge a mobile phone	Low Efficiency Short Range
[23]	It uses IM technique to achieve maximum power transfer efficiency	Magnetic Resonance Coupling with Impedance Matching	d η	Increased efficiency when coils are tuned to resonant frequency IM circuit	Short Distance

CHAPTER 3

METHODOLOGY

3.1. RESEARCH METHODOLOGY

One of the objectives of this project is to design and develop a prototype which could charge a mobile phone using the wirelessly transmitted energy with the use of solar energy as the input. The wireless transmission obeys the magnetic resonance coupling principle. The project specifications and design are discussed in the next section.

3.2. PROJECT DESIGN

The proposed prototype specification for this solar based wireless charger is listed in Table II. From Table II, the system was able to provide output current of 200 mA, within the maximum rating of 1 A for mobile phone. Besides that, the output voltage and output impedance to charge a mobile phone was listed as the output voltage and output impedance. As a result, power consumption of 1 W was achieved and the system's resonant frequency was resonating at 800 kHz with a tolerance of 1.25 %.

TABLE II.   Proposed Prototype Specification

Output Current, mA	200
Output Voltage, V	5
Output Impedance, Ω	1
Power Consumption, W	1
Resonant Frequency, kHz	800 ± 10

The block diagram of the solar wireless charging system is shown in Fig. 8. Details will be discussed in the following sections for each of the components in the block diagram.
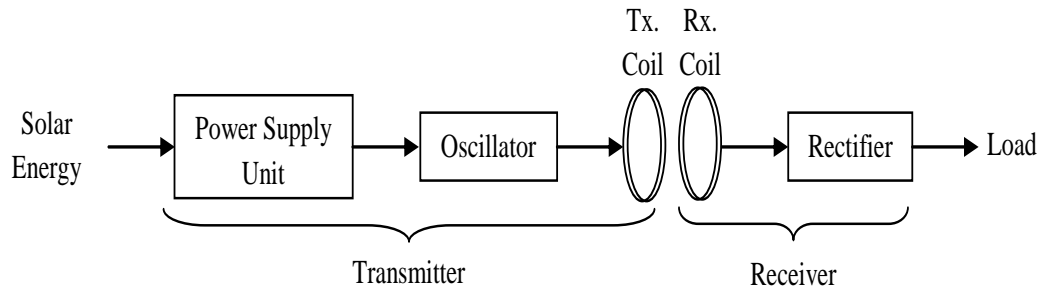
FIGURE 8.   The Block Diagram of Solar Wireless Charging System

3.2.1. Power Supply Unit

The solar energy is used as the input energy in this system. The solar energy has converted into electrical energy by a solar PV panel. Detailed description of the solar PV module was stated in Table III. From Table III, a total of 8 W was listed as the power rating of the solar PV module. Besides that, a voltage of 17.5 V and a current of 0.46 A were rated as the maximum output voltage and the output current of the PV module respectively.

The battery is used to store electrical energy and provide power whenever there are no solar energy available. From Table IV, a voltage of 12 V and the ampere-hour of 1.2 Ah were rated as the output voltage and the output current respectively. In other words, the battery can supply up to 1.2 A per hour or 2.4 A per half an hour.

TABLE III.   Specifications of the Photovoltaic Panel

Type	Polycrystalline
Rated Power, W	8
Rated Voltage, V	17.5
Rated Current, A	0.46

TABLE IV.   Specifications of the Battery

Rated Voltage, V	12
Rated Current, Ah	1.2
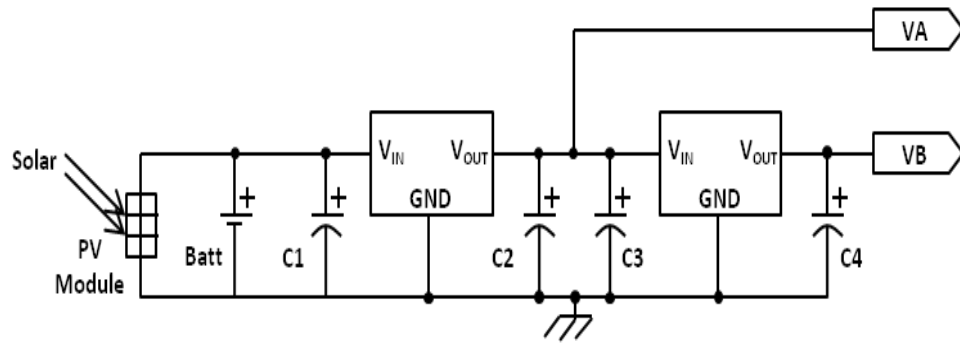
FIGURE 9.   Circuit Diagram of Power Supply Unit

The Fig. 9 shows the power supply unit. The solar energy was converted into electrical energy by a PV module. The converted electrical energy was stored in the battery and it is used when the system is turned on. The DC voltage level is converted into VA and VB by two voltage regulators. The voltage levels, VA and VB are necessary for the subsequent operation. These voltage regulators are able to sustain the current up to 1 A. The capacitors, C1 - C4 are used to stabilize the ripples of the voltage. The capacitor value of 0.33 μF was used for C1 and C3 and the capacitor value of 0.1 μF was used for C2 and C4, according to datasheet in appendix I.

3.2.2. Oscillator

A precision timer, TLC555, and half-H Driver, L293d were part of the oscillator as shown in Fig. 10. The operation of the TLC555 timer was operated in astable mode. In other words, the timer will produce a series of High and Low square pulses with a certain frequency. The transmitter coil, L1 was driven by the half-H driver, L293d where the TTL input was amplified into a higher voltage output depending on the voltage level supplied into pin 8. The capacitor, C8 is the resonant capacitor that produces resonant frequency. The capacitance value of 10 nF was used because the capacitor is widely available. The capacitors C5 and C6 in the timer were used in accordance to the datasheets in appendix II. Thus, the capacitance value of 0.1 μF was set for capacitors C5 and C6. The value of the capacitor is set to 0.1 μF as well to smoothen the ripple or a sudden input voltage spike. The value of capacitor, VC1 was set to 10 nF which will ease in achieving the resonant frequency of 800 kHz. The resonant frequency of 800 kHz was selected at the maximum capability of the

timer. It is because higher frequency can increase the distance of transmission [9]. Thus, the value of R1 and VR1 were designed at 3.6 Ω and 88.2 Ω.
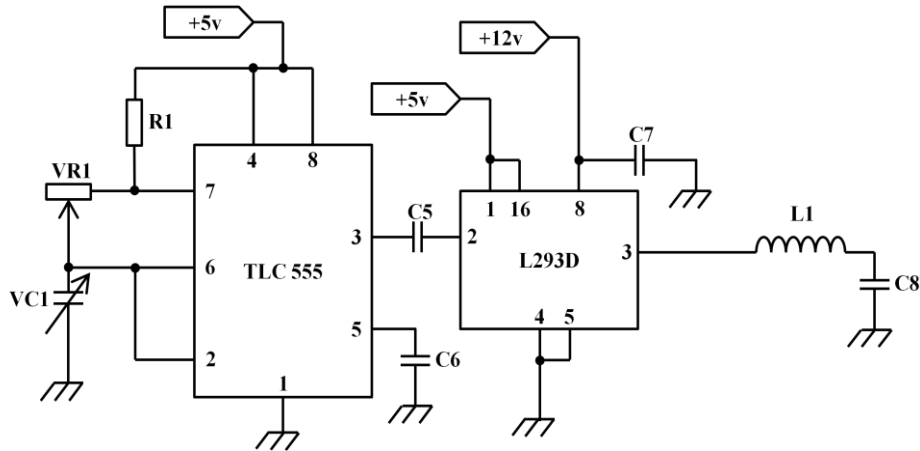
FIGURE 10. The Circuit Diagram of the Transmitter

3.2.3. Coils

The transmitter coil and receiver coil are explained in the previous chapter under chapter 2.4. where the equivalent circuit for coils and resonator are shown in Fig. 7. The structures of transmitter and receiver coils are as Table V. The parameters of these coils are based on the construction of previous project [24]. However, due to the unavailability of 0.9 mm of enameled copper wire, the coil used in this project was replaced by 1 mm of enameled copper wire. The enameled copper wire was hand wound into circular shape with the diameter of 70 mm.

TABLE V. Structures of the Transmitter and Receiver Coils

Material	Enameled Copper Wire
Number of Turns for Each Coils, *N*	5
Diameter of Turns, mm	70
Diameter of Coil, mm	1
Shape of Turns	Circular

3.2.4. Rectifier

Figure 11 shows the circuit diagram for the rectifier. AC signal to DC signal conversion was completed by bridge rectifier, BR. The voltage was regulated by 5 *V* positive voltage regulator. The load, R_{LOAD} was driven by the voltage regulator. The voltage ripples were stabilized by the capacitors C9 and C10 where the values are 0.33μF and 0.1 μF according to the datasheet of voltage regulator in appendix I.
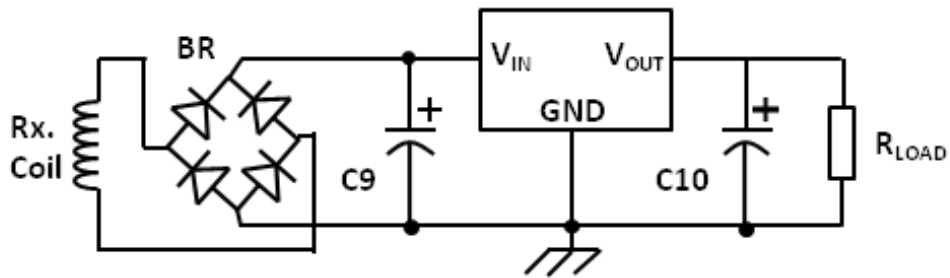
FIGURE 11. Circuit Diagram of Rectifier

3.3. THEORETICAL CALCULATION AND EQUATION

3.3.1. Resonant Frequency

The resonant frequency of this system was chosen at 800 kHz. As previously mentioned in the oscillator section, the values for R1, VR1 and VC1 were selected at 3.6 Ω, 88.2 Ω and 10 nF. To calculate that the values selected to achieve the required frequency, the Eq. (6) was used where the equation was obtained from the datasheet of 555 timer at appendix II.

$$f = \frac{1.44}{(R1 + 2 \times VR1)VC1} \tag{6}$$

$$f = \frac{1.44}{(3.6 + 2 \times 88.2)10 \times 10^{-9}}$$

$$f = 800kHz$$

$$t = \frac{1}{f} = 1.25 \times 10^{-6} \sec s \tag{7}$$

The resonant frequency was calculated using Eq. (6) and the total period of a cycle of the frequency was calculated in Eq. (7) where the resonant frequency is the inversely proportional to the total period per cycle.

The duty cycle, D was calculated by Eq. (8). After applying the value of VR1 and R1 into Eq. (8), the 51% of the duty cycle was calculated. However, the duty cycle does not affect the performance of the system.

$$D = \frac{R1 + VR1}{R1 + 2 \times VR1} \tag{8}$$

$$D = \frac{3.6 + 88.2}{3.6 + 2 \times 88.2} \times 100 = 51\%$$

3.3.2. Coil Parameters

The circular shaped coil was used in this project. The design of the coil was based on Neumann's equation [25]. The inductance required of the coils was calculated from Eq. (9):

$$L1 = N^2 R \mu_0 \left[\ln\left(\frac{8R}{a}\right) - 2 \right] \tag{9}$$

where; N is the number of turns, R is the radius of the coil, μ_0 is the permeability constant and a is the radius of the conductor. Thus,

$$L1 = 5^2 (0.035) 4\pi e^{-7} \left[\ln\left(\frac{8(0.035)}{0.001}\right) - 2 \right]$$

$$L1 = 3.99 \times 10^{-6} H$$

$$C8 = 9.9 \times 10^{-9} F$$

Based on the calculated value of the L1 and selected value of C8, the resonant frequency of this project is calculated using Eq. (4) is 800 kHz, which then fulfilled the magnetic resonant coupling's principle.

3.4. TOOLS

- **Proteus Simulator Version 8.1**

  The simulation was done by using Proteus circuit simulator.

- **CadSoft EAGLE PCB Design Software**

  Printed Circuit board layout is generated by CadSoft Eagle PCB Design software.

- **Digital Multimeter**

  Voltage, resistor's value, capacitor's value and current is measured by digital multimeter.

- **TekTronix TDS 1002 Digital Oscilloscope**

  Frequency and AC and DC voltage levels are measured by TekTronix TDS 1002 Digital Oscilloscope.

- **Fluke Automatic RCL Meter**

  The inductance of the charging coils is measured and verified by RCL meter.

- **GW Instek Laboratory DC Power Supply**

  DC voltage supplied by GW Instek Laboratory DC Power Supply to represent the battery.

- **Microsoft Excel 2007**

  Calculation, graphing, tabulation is prepared using Microsoft Excel 2007.

- **Microsoft PowerPoint 2007**

  The presentation was completed using Microsoft PowerPoint 2007.

- **Microsoft Word 2007**

  Documentation was completed using Microsoft Word 2007.

3.5. PROJECT ACTIVITY

This section of the report described the project's key milestone, flow charts and Gantt Chart.

3.5.1. Key Milestones

This project has several achievable key milestones throughout Final Year Project as shown in Fig. 12. The key milestones started with project confirmation in May 2014 to Literature Review and Initial Design in June and July 2014. In August 2014, final design and procure material is conducted. Testing, troubleshooting and analysis are started from September 2014 and completed in October 2014. In November 2014, the focus will be on prototype design.
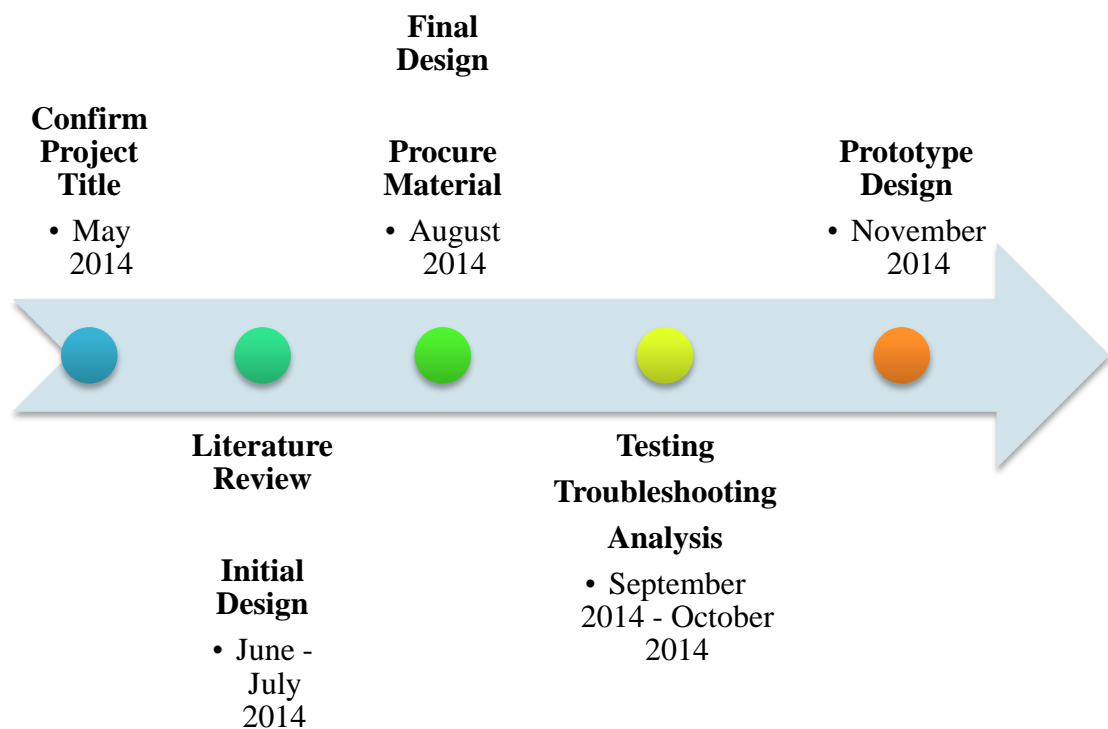
FIGURE 12. Key Milestones of Final Year Project

3.5.2. Project Flow Chart For Final Year Project 1

```
                    ┌──────────────┐
                    │    Start     │
                    └──────────────┘
                            │
                            ▼
                    ┌──────────────┐
                    │ Confirmation of │
                    │  Title Project  │
                    └──────────────┘
                            │
                            ▼
                    ┌──────────────┐
                    │  Research &   │
                    │ Literature Review │
                    └──────────────┘
                            │
                            ▼
                    ┌──────────────┐
                    │  Theoretical  │◄──────┐
                    │ Development   │       │
                    └──────────────┘       │
                            │              │
                            ▼          NO  │
                        ◇─────────◇        │
                        │  Meet   │────────┘
                        │Requirement?│
                        ◇─────────◇
                            │
                          YES
                            ▼
                    ┌──────────────┐
                    │Purchase Materials│
                    └──────────────┘
                            │
                            ▼
                    ┌──────────────┐
                    │   Circuit    │
                    │ Development  │
                    └──────────────┘
                            │
                            ▼
                    ┌──────────────┐
                    │Preliminary Result│
                    │  and Analysis │
                    └──────────────┘
                            │
                            ▼
                    ┌──────────────┐
                    │      A       │
                    └──────────────┘
```

3.5.3. Project Flow Chart For Final Year Project 2

```
        ┌──────────────────┐
        │        A         │
        └──────────────────┘
                 │
                 ▼
        ┌──────────────────┐
        │  Optimization of │
        │    Methodology   │
        └──────────────────┘
                 │
                 ▼
        ┌──────────────────┐
        │   Model Testing  │
        └──────────────────┘
                 │
                 ▼
        ┌──────────────────┐
        │    Prototype     │◄──────────┐
        │   Development    │           │
        └──────────────────┘           │
                 │                      │
                 ▼                      │
            ◇ Prototype Meet ◇    NO    │
            ◇   Objective?   ◇──────────┘
                 │
               YES
                 ▼
        ┌──────────────────┐
        │ Getting Result and│
        │     Analysis     │
        └──────────────────┘
                 │
                 ▼
        ┌──────────────────┐
        │       End        │
        └──────────────────┘
```
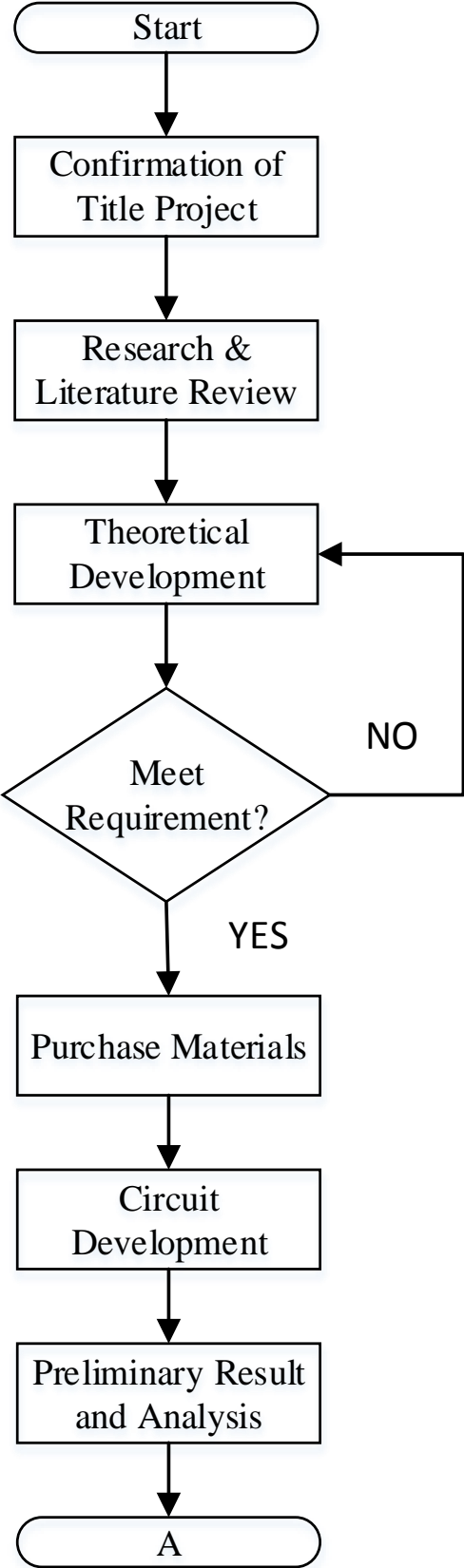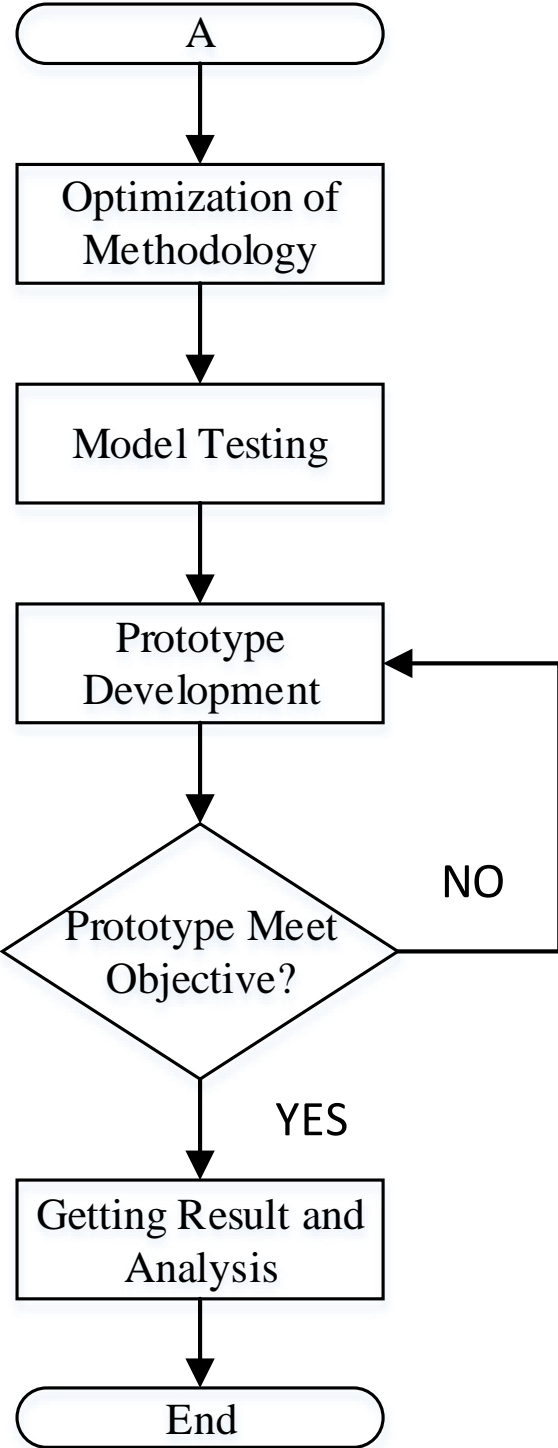
3.5.4. Gantt Chart

The overall plan for Final Year Project 1 as shown in TABLE VI.

TABLE VI.   Gantt Chart of Final Year Project 1

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	🟩	🟩												
2	Preliminary Research Work		🟩	🟩	🟩	🟩									
3	Attend FYP Talk	🟩	🟩	🟩	🟩	🟩									
4	Submission of Extended Proposal						⭐								
5	Purchase Materials						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
6	Simulation and Prototype						🟩	🟩	🟩	🟩	🟩	🟩	🟩		
7	Circuit Improvement						🟩	🟩	🟩	🟩	🟩	🟩	🟩		
8	Proposal Defense								🟩	🟩					
9	Hardware Testing								🟩	🟩	🟩	🟩	🟩		
10	Interim Report Preparation								🟩	🟩	🟩	🟩	🟩		
11	Submission of Interim Draft Report													⭐	
12	Submission of Interim Report														⭐

Legend: 🟩 Progress   ⭐ Milestone

The overall plan for Final Year Project 1 as shown in TABLE VII.

TABLE VII. Gantt Chart of Final Year Project 2

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues	�	▢	▢	▢	▢	▢	▢								
2	Submission of Progress Report								★							
3	Project Work Improvement								▢	▢	▢					
4	Prototyping								▢	▢	▢					
4	Pre-SEDEX										★					
5	Submission of Draft Final Report											★				
6	Submission of Dissertation (SoftBound)												★			
7	Submission of Technical Paper												★			
8	Viva													★		
9	Submission of Dissertation (HardBound)															★

Legends : ▢ Progress ★ Milestone

CHAPTER 4

RESULT & DISCUSSION

4.1. OVERVIEW

This section demonstrates the result for each segment of the prototype including:

1. Transmitter circuit
2. Coil design
3. Testing and result

The theoretical calculation and computer simulation to determine the values for the components and then used to confirm the actual results tested from the circuit board. The theoretical and actual result is compared for each of the segments.

4.2. TRANSMITTER CIRCUIT

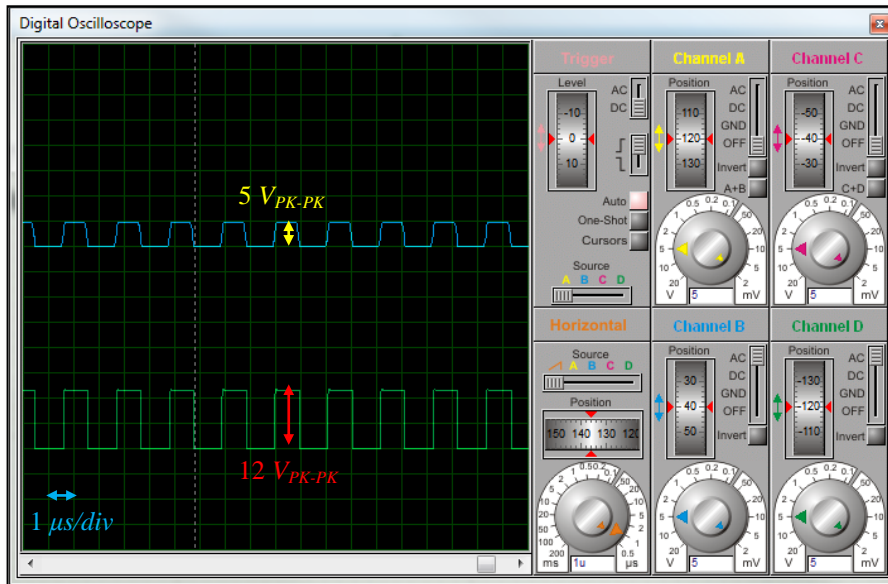### 4.2.1. Simulation Prototype

The simulation result was based on the design of Fig. 13. It was simulated using Proteus simulation software. In this setup, the oscillator was designed to give 800 kHz. The square wave was generated by the oscillator is then amplified through the half-H driver which then transmitted using an inductor, L1 which is a representation of the transmitter coil.

The Fig. 14 obtained from the oscilloscope where the blue coloured square wave in showed the Pulse Width Modulation (PWM) generated by the timer, 555 at 800 kHz. On the other hand, the green coloured square wave showed the amplified signal produced by the half-H driver, L293d. The amplified signal was ranged from +12 V to 0 V. With that, the condition for WPT with oscillator and half-H driver were verified by simulation and proceeded with practical application.
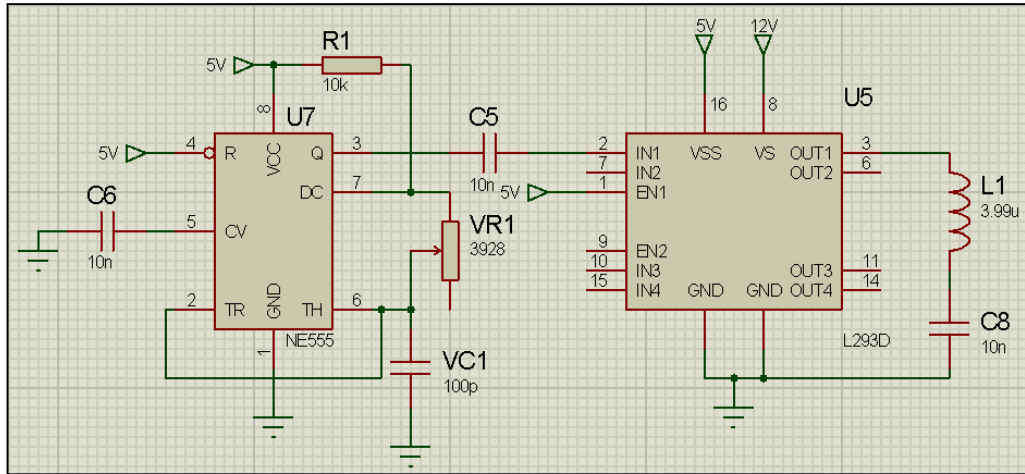
**FIGURE 13.** Proteus Simulation of the Transmitter Circuit

**FIGURE 14.** Oscilloscope Result of the 555 Timer Output and L293d Output

4.2.2. Practical Prototype

The circuit shown in Fig. 15 was assembled based on Fig. 13. The component for simulation and practical application may be slightly different. The NE 555 oscillator was replaced by the TLC 555 oscillator which performed better at higher frequencies as NE 555 was limited to 100 kHz. The reason was that the frequency rating of TLC 555 timer was up to 1 MHz. Heat sinks were attached to the voltage regulator, 7812A and 7805A to prevent overheat as seen in Fig. 15. At this stage, the circuit was supplied using DC supply where the input voltage emulated the solar PV output voltage rating as shown in Table III. The Fig. 16 shows the oscillator output at
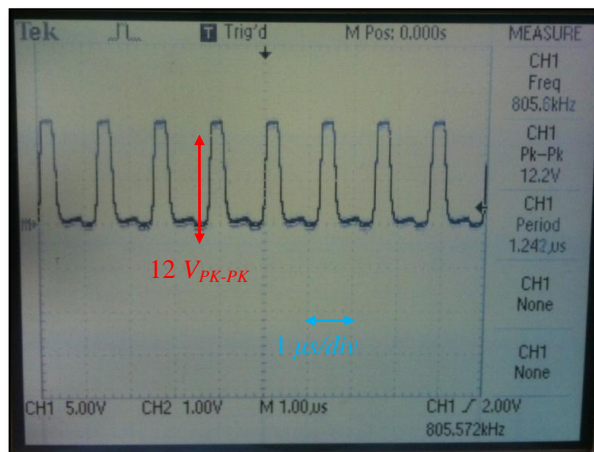
805.272 kHz at 0-5 Vpk-to-pk. Besides that, Fig. 17 shows the amplified voltage using L293d and transmitted using Tx. Coil shown in Fig. 17. This shows the transmitter circuit performed as expected.
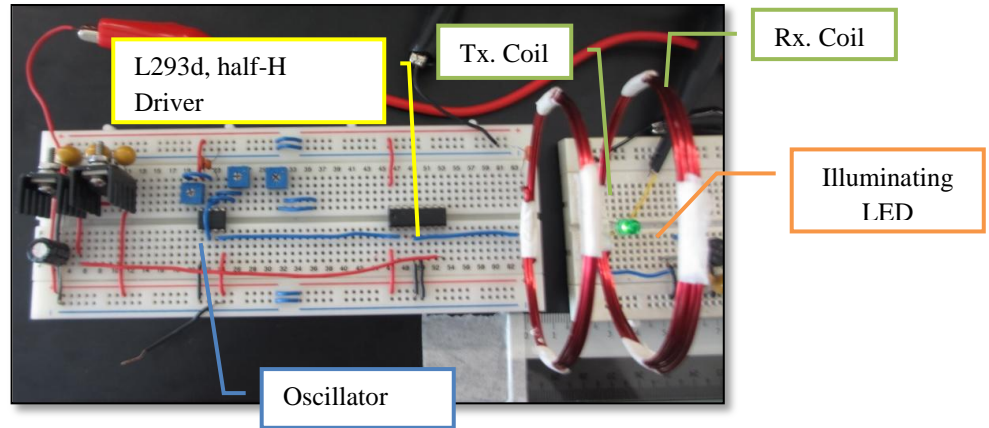
FIGURE 15. Hardware Prototype
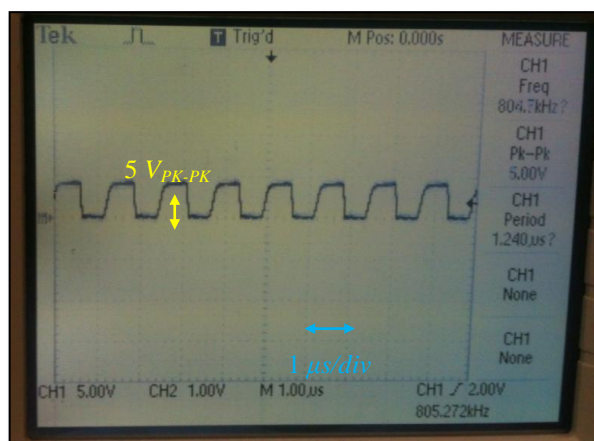
FIGURE 16. The Oscillator Output with 805.27 kHz

FIGURE 17. The L293d Output with Amplified Voltage of 12 V

4.3. COIL DESIGN

The coil specification is listed in Table V and the inductance of the coil setup was calculated in Eq. (17). In practice, the coil was hand wound due to unavailable winding machine. The coils' characteristics were measured using the FLUKE Automatic RCL Meter including the inductance, resistance and Q-factor of the coils. The outcome is tabulated in Table VIII.

TABLE VIII. Measured Coil Specification

Details		Inductance, µH	Resistance, Ω	Q-Factor
Measured	**Tx.**	3.9	0.05	0.487
	Rx.	3.9	0.05	0.487

From Table VIII, the value of inductance deviated by 2.3% from the calculated inductance of 3.99 µH. The resistance of the coil is 0.05 Ω to be to avoid any significant effect on the performance of the WPT. The Q-factor is subjected to the size and shape of the coil because it is related to resistance and inductance of the coil.

4.4. TESTING AND EXPERIMENTAL RESULT

4.4.1. Testing

The testing method of this system included voltage and current measurement in the receiver side against distance. The starting distance between transmitter and receiver coil is 0 cm which both of the coils are touching. Whereas the maximum distance between transmitter and receiver coil is 6 cm as it would be suffice for performance testing. Each incremental step is 1 cm.

4.4.2. Experimental Result

Table IX shows the experimental results of voltage and current measured against distance. The measurements were collected at the receiver. The Fig. 18 and Fig. 19 show the graph of voltage & current and power against distance based on Table IX.

TABLE IX. Results of Voltage (V) and Current (A) based on Distance (cm)

Distance (cm)	Voltage (V_{P-P})	Voltage (V_{DC})	Current (A)
0	10.0	5.0	0.194
1	8.0	5.0	0.046
2	7.0	5.0	0.03
3	6.4	4.5	0.019
4	5.9	3.7	0.013
5	3.7	1.7	0.009
6	2.6	0.6	0.007
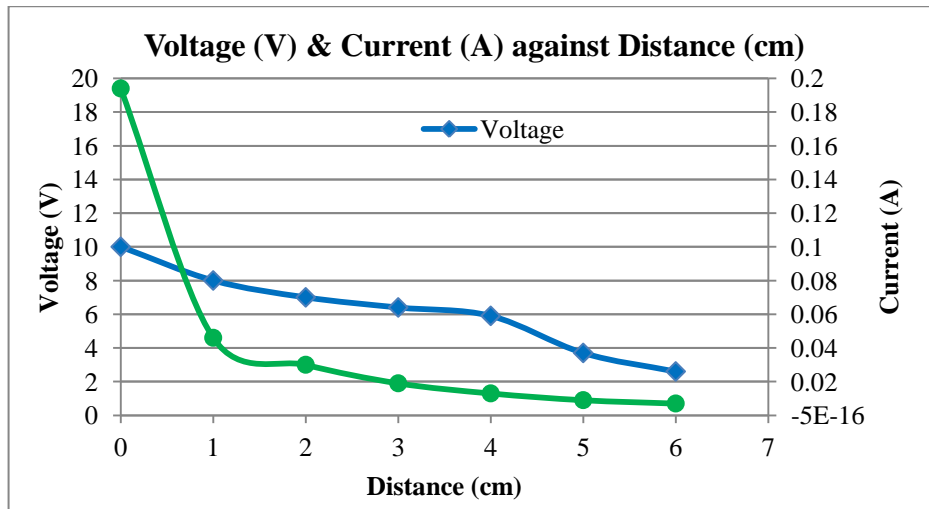
FIGURE 18. Graph of Voltage (V) & Current (mA) against Distance (cm)
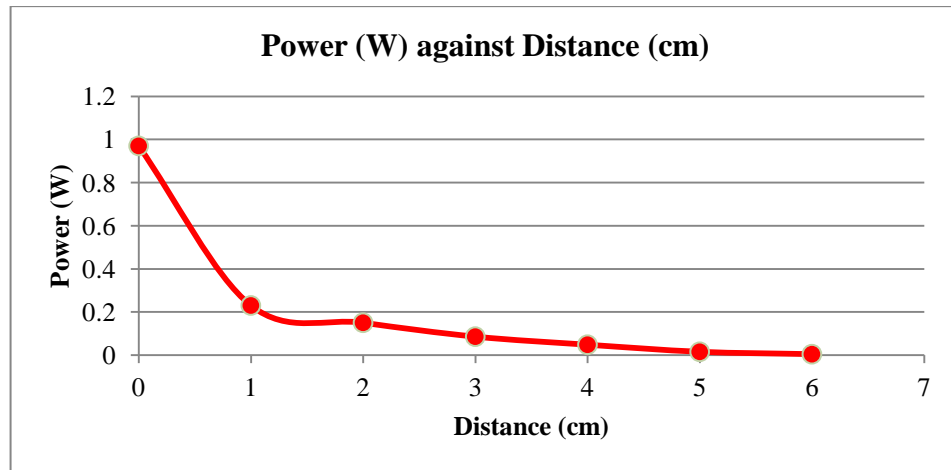
FIGURE 19. Graph of Power (W) against Distance (cm)

4.5. DISCUSSION

From the Fig. 18, the WPT system appears to be working satisfactorily at distances less than 4 cm where it achieved the minimum DC voltage of 3.7 V to charge a mobile application. However, the voltage decays exponentially as the distance increased because the magnetic field strength decreased as the distance increased. The current decays exponentially when the distance increased. This is also correlated to the magnetic field strength. The power measured highest, 0.97 W at 0 cm, where the current is highest. The power continues to decrease as the distance increase. This is due to low current supplied from the source. This limits the distance of the WPT system. This is because to generate a strong and wide magnetic field, a greater current is needed because magnetic field is proportional to current as seen in Eq. (2).

Several improvements can be made to improve the performance of the system. First, increase the input power can improve the power received by receiver side and the distance as current is correlated with magnetic field. Besides that, a current amplifier could increases the performance at the receiver side. In addition, a redesign coil can amplify the electromagnetic force at the receiver side, according to Faraday's Law of Magnetic Induction.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1. CONCLUSION

The objective of understanding the principle behind the wireless power transmission using the magnetic resonance coupling technique is achieved. A comprehensive literature review has been revised to analyze the previous works of magnetic resonance coupling theory and technique.

Furthermore, to develop a working prototype of magnetic resonance coupled wireless power transmission using solar energy as input was also accomplished. The prototype has successfully charged a mobile phone using solar energy at 4 cm. In addition, analysis and testing has been conducted on the magnetic resonance coupling based on two parameters: efficiency and distance.

In conclusion, this research on wireless power transmission using PV module has been investigated and interpreted comprehensively through prototype demonstration and experimentation. The theoretical study and experiment result have proved the energy transmission is viable using resonance magnetic coupling and will excite more applications in the future.

5.2. RECOMMENDATION OF FUTURE WORKS

The integration of these two fields, wireless power transmission and solar energy, is still underdeveloped which is part of the motivation of this objective. There are ample of spaces for further enhancement. For future study, study on charging multiple load devices can improve the usability of the system. Besides that, research on power efficiency, critical coupling can be conducted to improve the system's practicality and reduce the power losses. Furthermore, coil design for better efficiency can be one of the research areas.

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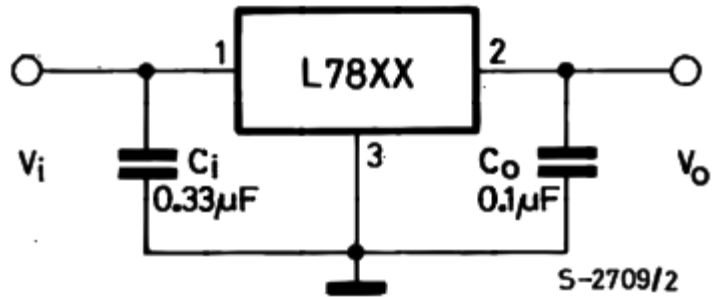
APPENDICES

APPENDIX I: Partial datasheet of L7800 Series Voltage Regulator

APPENDIX II: Partial datasheet of TLC 555 Timer

APPENDIX I: Partial datasheet of L7800 Series Voltage Regulator

URL: https://cdn.shopify.com/s/files/1/0243/7593/files/l7805.pdf

(pg. 4, figure 5: DC Parameter)

APPENDIX II: Partial datasheet of TLC 555 Timer

URL: http://www.ti.com/lit/ds/symlink/tlc555-q1.pdf

(pg. 9, figure 4: Astable Operation)