An Investigation of Wireless Electricity for Small Battery Charger

by

AMMAR KAMARUL BIN BAHATIM

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2013

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.

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Ammar Kamarul Bahatim

ABSTRACT

In this paper, the author investigates the fundamental of wireless electricity. One of the known way to transfer power wirelessly is through electromagnetic induction between two coils. Electromagnetic induction is the process of inducing electrical current in a closed loop in the presence of changing magnetic field. By introducing resonant frequency to the changing magnetic field, it is believe that the distance between the two coil to transfer power wirelessly can be increase. Modern world has seen the uses of mobile electronic peripherals such as laptops and cellphones, it is known that such peripherals run on battery and need to be recharged on routine basis. The user usually find very inconvenient to charge their peripheral when there are many power cables messing around the power socket. Thus, the objective of this project is investigate the resonant inductive power coupling in wireless electricity. The proposed methodolgy then used to develop a prototype of wireless cellphone charger. Prior to prototype development, several design parameters is investigated in determining optimum prototype design. From the result gained, it is proven that resonant inductive power coupling method can transfer power wirelessly over short distance. The prototype developed is proven to be able to charge the cellphone battery. This project serves as the fundamental works on this topic thus further studies need to be carry out so in the future, we might be able to enjoy the novel wireless power distribution system .

ACKNOWLEDGEMENTS

'In the name of God, the most Gracious and the most Merciful'

First and foremost, my deepest gratitude to God, for He had given me strength and guidance in completing this Final Year Project.

My sincerest appreciation goes to my Project Supervisor, Dr. Zuhairi Baharudin for giving me a chance to be part of this project. Your guidance and shared knowledge throughout this project is appreciated.

Not to forget, I would like to take this opportunity to express my gratitude to my family for their warm support from the beginning till the completion of this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background Study

Wireless electricity is a technology first experimented by the Croatian-American scientist, Nikola Tesla back in 1899 [1]. Unfortunately, Tesla was unable to finish his work when he died in 1943. In 2007, a group of Massachusetts Institute of Technology (MIT) researchers led by Prof. Marin Soljacic able to demonstate the wireless electricity experiment on basis of resonant magnetic power coupling principle. In this experiment, the researchers able to light up a 60W light bulb attached to the receiver separated by nothing but air about two meters away from the transmitter [2]. This experiment had started a new field of studies that believed to change the way the power being distributed in the future.

In today electrical power transfer, scientists and engineers have known that transferring electric power does require wires to be in physical contact all the way. For years since the invention of alternating currents that enable the electricity to be transmitted to far places, copper cables had been stretched all over the globe.

However, with the discovery of electromagnetic induction, the believe that electricity can be transferred without any medium come into perspective. Electromagnetic induction principle is applied in operation of induction motors and power transformers. Briefly, for induction motor, the supply power from the stator are transferred to the rotor wirelessly at air gap region between these two parts. Similarly, supply power from the primary windings in converted to output power at secondary winding by means of induction, since both windings are not electrically connected [3].

As researchers and engineers are researching on the novel wireless power transmission and distribution, the trend of getting rid from wires become popular recently among the electronics gadgets. The mobile phone companies started to introduce wireless charger into their products. This trend is very important as a basement for this technology to revolve and somewhere in the future we can imagine having a fully wireless system for our power transmission and distribution.

1.2 Problem Statement

Today world comprises a lot of electronic peripherals. These peripherals run on battery and need to charge up on routine basis. It is inconvenient to bring along the charger and power banks when the person is on the go and need to recharge their cellphone. Besides, as manufacturers usually introducing unique power cord for their products, users usually find inconvenient to charge their peripheral when there are many power cables messing around the power socket.

1.3 Project Objectives

- To investigate the resonant inductive power coupling in wireless electricity.
- To investigate the design parameters of the wireless charger prototype.
- To develop a wireless charger prototype for cellphone.

1.4 Scope of Study

This project acquires the knowledge and application of electrical and electronics field of study especially in electrical power system as this project aims to gain much knowledge and data about the application of electromagnetic induction to transfer the electrical power without the conventional medium. In order to gain such knowledge, the student need to do researches on past works related to this topic. After that, the student should be able to decide the design of the coils and overall system. At the end of this project, with all the information gained, the student is expected to develop a working wireless charger prototype to charge cellphone battery.

1.5 Relevancy of the Project

This project is relevant because eliminating wires for gadgets becoming a trend recently among the electronic gadget manufacturers. As we manage to have a wireless system for data exchange, Wi-Fi few years back, wireless electricity can be said as everybody dream today. This technology promises a very bright prospect to be widely implemented in the future. Past experiment conducted resulted in a low efficient or short range system but that's why continuous works need to be carry out from time to time so in the future, the system efficiency can be raised as good as the conventional wired system.

1.6 Feasibility of the Project

The project will be conducted in two semesters which include three major phases; literature review, designing and testing of the wireless charger prototype. For Final Year Project I (FYP1), only cover literature review and methodology selection will be covered. Then, for Final Year Project II (FYP2), the project will proceed with experiments to have optimum design of the system and developing a wireless charger prototype. At the end, testing on charger prototype will be conducted. Overall, this project is feasible as the materials used such as enamelled copper wire to make the coils and other electronic components to make the system circuits can be obtained within Malaysia's market with reasonable price.

CHAPTER 2
LITERATURE REVIEW

2.1 Electromagnetic Induction

The relationship between electricity and magnetism first discovered by Hans Christian Oersted, a Danish physicist who discovered that a wire carrying electrical current produces magnetic field around it [3].

Later, Michael Faraday, an English scientist discovered that presence of magnetic field can produce an electric current in a closed loop, but only if the magnetic field is changing with time [4]. Faraday's law of induction states that if a flux passes through a coil of wire, a voltage will be induced in the coil which is directly proportional to the rate of change in the flux with respect to time [3][4]. The voltage induced can be summerize as equation below,

$$e_{\text{ind}} = - d\Phi / dt \qquad (1)$$

If the coil consist of several number of turns, denoted as N, with the same flux passing through, the induced voltage in the coil with N turns is given by,

$$e_{\text{ind}} = - \text{N}\, d\Phi / dt \qquad (2)$$

Summarizing this theory, it is known that;

- A current carrying wire produces magnetic field around it.
- Time-varying magnetic field can induces a voltage in a coil.
- Magnitude of voltage induced depends on the rate of changes of magnetic field and number of turns of the coil.

Power transformers and induction motors are working based on this electromagnetic induction principle [3]. However, this principle only enable electrical power to be transmitted wirelessly over very small air gap. In case of induction motors, the air gap between the stator and rotor usually spans a few milimeters [3].

Jun Zhao *et al* in a conference paper entitled “A Contrastive Studies between Magnetic Coupling Resonance and Electromagnetic Induction in Wireless Energy Transmission” discovered that the efficiency of the resonant magnetic coupling is much higher compared to traditional electromagnetic induction energy transmission devices [5][6]. In [5-6], they investigate the difference in output voltage received by the receiver when each principle is tested in identical configuration. Figure 1 below shown the result of the output voltage with variation in distance for both principle.

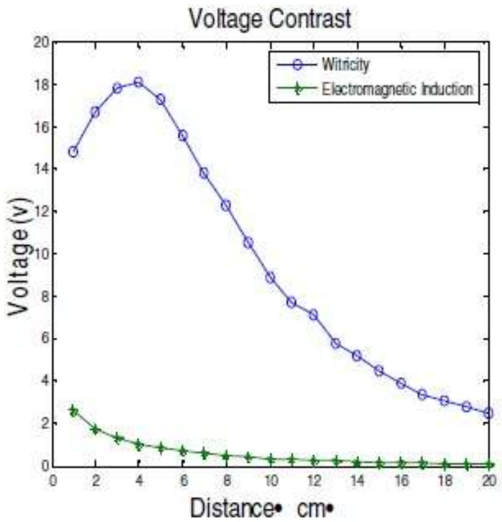

Figure 1 : Output voltage contrast of the two principles [5]

From [5], the author figure out that Witricity used higher frequency to transmit the energy further, in range of 1MHz. Thus, there are need to increase the frequency of the system in order to have greater air gap between coils. One of possible way to do this is to have an oscillator to oscillate the current flowing into the transmitter coil.

2.1.1 Time-varying Magnetic Field

As previously discovered, for electromagnetic induction to happen, the magnetic field produced by the primary coil need to change with time. Changing magnetic field can happen if the current flowing in the coil also changes with time, in other word the current passing the primary coil is an alternating current [3][4].

2.1.2 Relationship between Magnetic Field Intensity and Magnetic Flux Density

The maximum distance between the coils to induce voltage is determine by the magnetic field intensity, **H** produced by the transmitting coil. However, the rate of power transfer between coil is depending on the magnetic flux linkage between them. We can increase the magnetic flux linkage between coil by increasing the magnetic flux density, **B** of the coil. Basically, the denser the flux density, the higher the chance for the flux lines to link between coil. The relationship between magnetic field intensity and the resulting magnetic flux density is given by;

$$\mathbf{B} = \mu\mathbf{H} \qquad (3)$$

However, as this project based on the theory of air core transformer, the μ value will be the permeability of free space (air), $\mu_o = 4\pi \times 10^{-7}$ H/m (0.000001256 H/m).

As the μ parameter is fixed, the only way to increase the flux density is by increasing the magnitude of magnetic field intensity.

2.2 Colpitts Oscillator

Colpitts oscillator is a type of LC oscillator designed for generation of high frequency sinusoidal oscillation ranging between 10kHz to 100MHz [7]. This oscillator is choose to drive the transmitter because unlike other type of oscillators, Colpitts oscillator is a current oscillator. This type of oscillator produces changing current in the circuit thus generating changing magnetic field around the transmitter coil. Futhermore, Colpitts oscillator is much easier to construct. Figure 2 stated below shows the design of the Colpitts oscillator used.

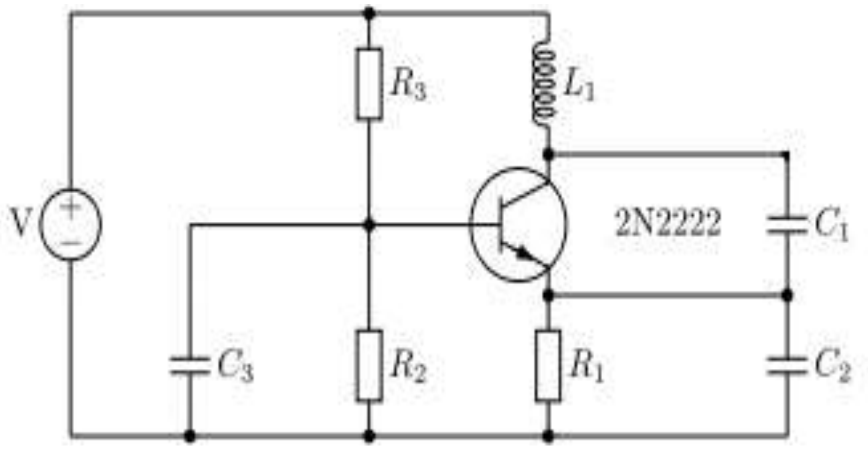

Figure 2 : Colpitts Oscillator configuration

From the figure above, it is known that to construct the Colpitts oscillator, the main component is 2N2222 NPN switching transistor. Besides, a pair of capacitors is used to tuned the frequency of the transmiter. The value of the capacitor used will determine the frequency of the system it is important to have same capacitance value at both transmitter and receiver so that both system at resonate at same frequency.

2.3 Resonance Frequency

Resonance is the tendency of the system to resonate at higher amplitude given certain range of frequencies. This theory is an important finding in determining the oscillation frequency produced by the oscillator and the need of having the receiver resonate at the same frequency. The resonance frequency of the systam can be calculated by using formula below,

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

It is very important to keep the frequency of the system high enough so that the waves can propagate further. The frequency of the system is determine by the rate of charging and discharging of the capacitors in the circuit with presence of inductance element in the circuit. The circuit consisting of these two element usually referred as LC circuit. In LC circuit, when the capacitor is initially charged, both current and charge in the circuit oscillates from maximum positive to maximum negative values [8]. During charging, the energy is stored in the capacitor's electric field, therefore no energy stored in inductor magnetic field. However, as the capacitor discharging, the energy now starts to store in the inductor magnetic field and this process keeps repeating, determine the frequency. At point where the energy is stored in the inductor magnetic field is where the energy can be propagate and coupled by the nearby inductor [8]. For instance, it is very important to determine the optimum proportion between inductance and capacitance element in the circuit, so more energy can be propagated.

Y. Hori *et al* in a conference paper entitled "Wireless Power Transfer System via Magnetic Resonant Coupling at Restricted Frequency Range" emphasized on the important of having the same capacitance and inductance value in both coils, referred as impedance matching [9] to the resonance frequency. In [9], the result shown that the efficiency of the wireless power transfer in improved when impedance matching is done [9].

2.4 Resonant Inductive Power Coupling

Based on the theory of electromagnetic induction and resonance frequency, the author decided to implement resonant inductive power coupling in developing the wireless cellphone charger. Resonant inductive coupling is a short range wireless power transfer between two coils that are tuned to resonate at the same frequency. As non-resonant electromagnetic induction used in power transformers and induction motors is inefficient over greater distance, the author believed this principle is the most suitable method considering the air gap distance and the efficiency concerned in developing a prototype of wireless cellphone charger. However, past reseaches done shown there are limitation in term of efficiency of the system and rates of power transfer of this system. Waffenschmidt *et al* [10] indicates that the efficiency of the system by using this method ranges between 30% - 40% [10].

CHAPTER 3
METHODOLOGY

3.1 Detailed Project Activities

This project methodology can be divided into 3 main phases, which are;

3.1.1 Phase 1 – Literature Review

At the start of the new semester, students have to discuss with all the lecturers and researchers on the project they are currently working on and decide to join in any project they are interested. For the author case, the author chose to join project on wireless electricity. Thus, some researches on wireless electricity topic are carry out to gain a clear pictures on the fundamental theories and concepts behind this wireless electricity technology.

The comparative study to choose which method is suitable and achievable to gain a result is conducted and after the evaluation carry out, the most suitable method is chosen to proceed. As for assurance, further discussion on the method chosen is conducted for a several time to ensure that the method is achievable, safe for use and yield an outcome with reasonable efficiency.

3.1.2 Phase 2 – Project Commission and Testing

As Phase 1 of this project completed, the project progresses to Phase 2. This phase starts with material acquisition. While most of the material needed are available in the department store, several are not. So these material need to be acquired from the outside store first. Once all the materials are ready, only then the circuitry can be developed. First, all the components are assemble on the breadboard to enable any changes be easily made to the circuit. Once the most efficient design is achieved, a prototype is fixed and ready for testing.

3.1.3 Phase 3 – Documentation

The project documentation not only done at the end of the project. However, as the project progresses, the author need to submit several reports prior to Final Report. These intermediate reports include Extended Proposal, Interim Report and Progress Report. At the end of the project, the author also need to complete a Technical Paper regarding this project.

3.2 Project Flowchart for Final Year Project 1

For the first semester, the project will only covers the theoretical part only. The activities for this semester include the title selection, literature review and methodology proposal. For instance, the Figure 3 attached below outlined the flowchart of this project for Final Year Project 1 duration.

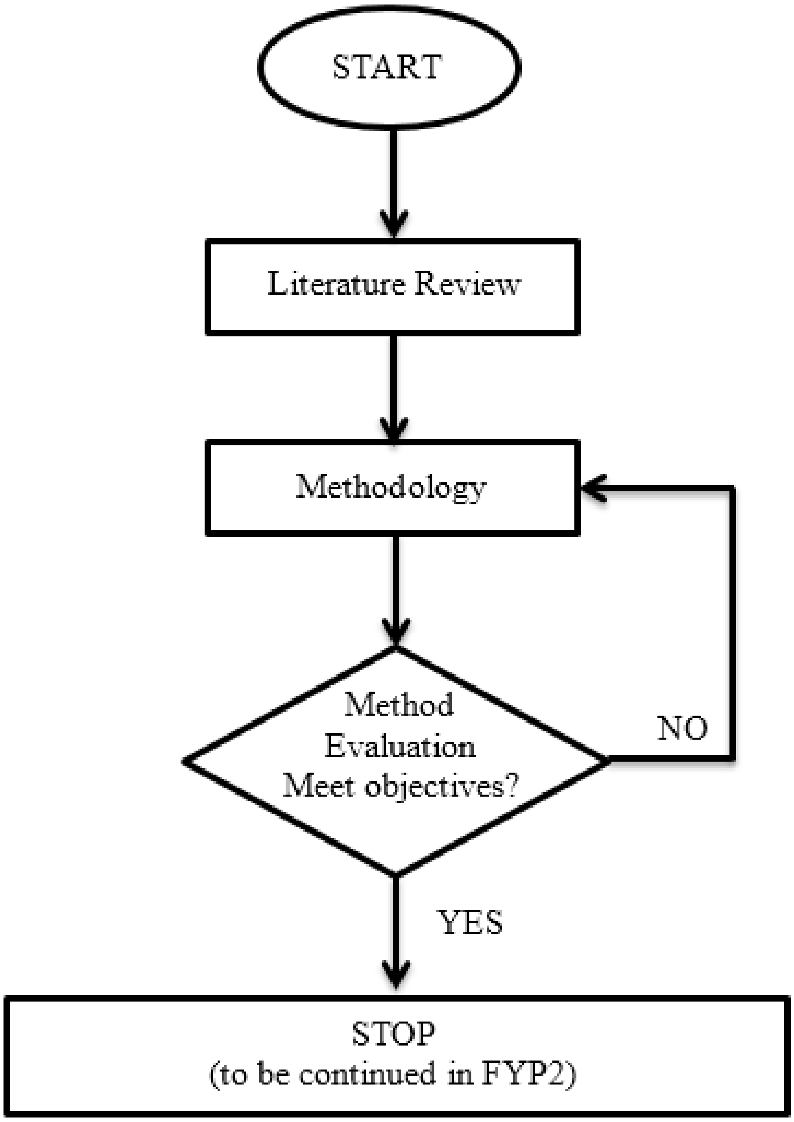

Figure 3 : Project flowchart for Final Year Project 1

3.3 Project Flowchart for Final Year Project 2

For Final Year Project 2, the flowchart for the activities to be carry out on the second semester is illustrated as in Figure 4 below;

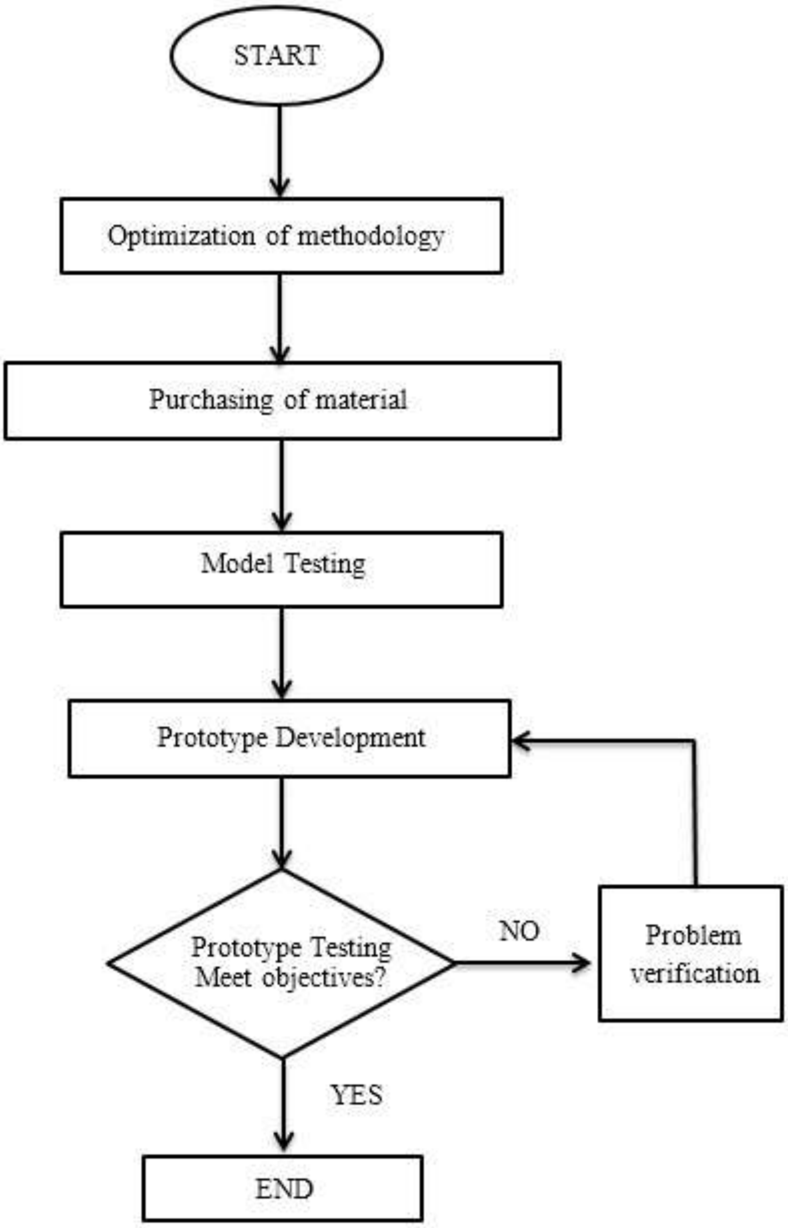

Figure 4 : Project flowchart for Final Year Project 2

3.4 Project Gantt Chart for Final Year Project 1

Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Project Title Selection	■													
Prelim Research		■	■	■										
Detailed Literature Review				■	■	■	■	■	■	■	■			
Methodology							■	■	■	■	■	■		
Method Evaluation									■	■	■	■	■	
Interim Report Writing							■	■	■	■	■	■	■	■

3.5 Project Gantt Chart for Final Year Project 2

Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Methodology Re-evaluation	■	■												
Methodology Optimization		■	■	■										
Material Purchase			■	■	■	■								
Model Development and Testing				■	■	■	■	■	■					
Prototype Development						■	■	■	■	■	■			
Progress Report Writing						■	■	■						
Final Report and Technical Paper Writing								■	■	■	■	■	■	■

3.6 Project Key Milestones

Milestone	FYP1					FYP2				Remarks
	J	F	M	A	M	J	J	A	S	
FYP Title Selection	✔									Completion of title selection
Submission of Extended Proposal	✔									Completion of Extended Proposal
Submission of Draft Interim Report		✔								Completion of Draft Interim Report
Submission of Interim Report				✔						Completion of Interim Report
Development of wireless charger system					✔					Completion of wireless charger system
Testing of wireless charger						✔				Completion of wireless charger testing
Submission of Progress Report							✔			Completion of Progress Report
SEDEX							✔			Completion of SEDEX
Submission of Draft Final Report							✔			Completion of Draft Final Report
Submission of Technical Paper								✔		Completion of Technical Paper
Submission of Final Report									✔	Completion of Final Report

3.7 System Block Diagram

From the literature review done on the inductive power coupling, the author designed the system. The system consists of transmitter and receiver. The complete system illustration is as shown in Figure 5 below however both transmitter and receiver part will be discussed separately afterward.

Figure 5 : The block diagram of the wireless system

3.8 Tools and Equipments

The list of tools and equipments used to construct the preliminary design for developing the prototype purposes is listed as below;

- enammelled copper wire (various size and length)
- 100 nF capacitor
- 4 x 150 nF capacitors
- 100Ω resistor
- 2 x 10kΩ resistors
- 2N2222 NPN Bipolar Junction Transistor
- AC-DC rectifier
- 240V AC to 12V DC adaptor
- 3.7V battery (load)

3.8.1 Enamelled Copper Wire

Enamelled copper wire, usually called as “magnet wire” is a copper wire coated with a very thin layer of insulation. This coating layer is essential to ensure the wire when turns into coil is not short circuited. This type of copper wire usually used in contructing induction motor windings and inductors. For this project, enamelled copper wire will be used to construct the transmitter and receiver coils.

Figure 6 : Enamelled copper wire

3.8.2 Capacitor

Capacitor is an electrical component which can store energy in its electric field. For this project, among the capacitor used is Polyester Poly Film capacitor type and it is used as coupling capacitor which determine the resonant frequency between coils.

Figure 7 : 2A154J 150nF Polyester Poly Film capacitor

3.8.3 2N2222A NPN Bipolar Junction Transistor

2N2222A NPN bipolar junction transistor is type of transistor commonly used for switching purposes. It is designed for low to medium current, low power, medium voltage, and can operate at moderately high speeds. This features make it suitable to be used as oscillator for the transmitter.

Figure 8 : 2N2222A NPN bipolar junction transistor

3.8.4 AC-DC Rectifier

AC-DC rectifier is used to rectify the alternating current input into direct current output in the circuit. For this project, this component will be used at the receiver since charging process requires DC supply. The rectifier used for prototype is RS101 Silicon Bridge Rectifier.

Figure 9 : RS101 Silicon Bridge Rectifier

CHAPTER 4
RESULT AND DISCUSSION

4.1 Simulation Result

The author figure out (up to the time when this report is written) there are no application available in the campus to simulate the wireless power transfer of static coils in changing magnetic field around it.

However, the author simulates proposed design of the transmitter by using Multisim 12 to determine the frequency generated by the transmitter. The simulation circuit of the transmitter is illustrated as Figure 10 below,

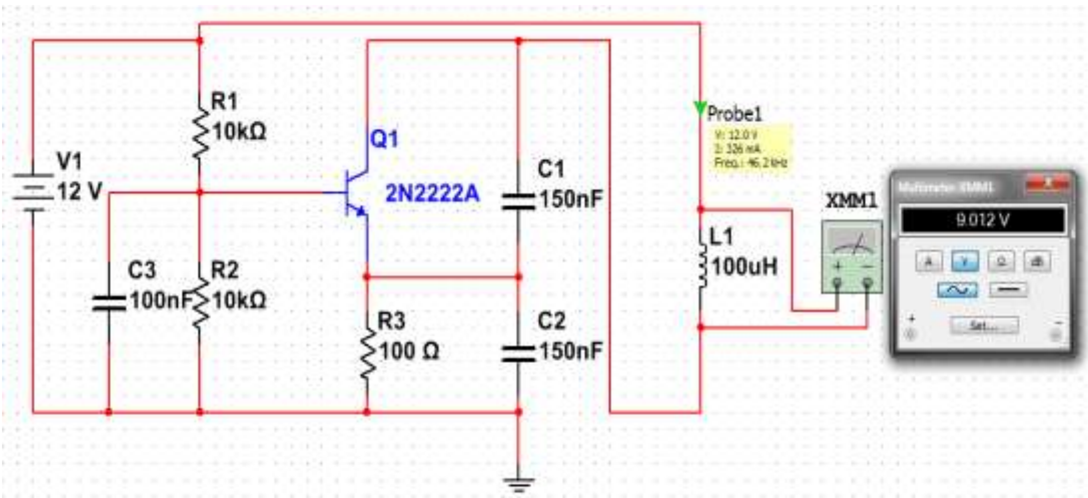

Figure 10 : Transmitter circuit simulates using Multisim

By using this simulation schematic, test on the effect of capacitance and inductance element in the circuit to the frequency of the system is carry out. Table 1 below summarized the result of the test.

Table 1 : Simulation result on frequency of the transmitter

No.	Supply voltage (V)	Capacitance (nF)	Inductance (uH)	Frequency (kHz)
1	12	100	50	82.0
2	12	100	75	74.6
3	12	100	100	60.9
4	12	150	50	59.1
5	12	150	75	52.4
6	12	150	100	46.3

From the result obtained, we can see a trending where lesser value of capacitance and inductance element inside the circuit produces higher frequency. As for prototype development, the capacitors walue will be fixed at 150 nF, however the inductance value may varies depending on the handmade transmitter coil. Thus from this simulation, the frequency of the prototype is expected to be lies between 40kHz to 80kHz depending on the inductance value of the coil.

Comparative to the theoretical frequency of the system by calculation, $f = \frac{1}{2\pi\sqrt{LC}}$ as listed in Table 2 below, the frequency of the simulation circuit are a bit higher than its theoretical value. This happened maybe due to presence of resistive element in the circuit which turns the circuit to be RCL circuit instead of LC circuit.

Table 2 : Theoretical frequency of the system

No.	Capacitance (nF)	Inductance (uH)	Theoretical Frequency (kHz)
1	100	50	71.18
2	100	75	58.11
3	100	100	50.33
4	150	50	58.11
5	150	75	47.45
6	150	100	41.10

4.2 Circuit Designs

Actual circuit is developed on the breadboard to ensure the circuit is working in real life. Where other component values are similar to the simulation, the author compromised on the inductance value of the coil. This is due to the absence of reliable measuring device in the campus to measure the inductance value of the handmade coil. For information, the inductance value of the coil will change even with slight changes in the turns position. The mathematical formula to calculate the inductance value of the solenoid only applicable to single layer winding only. On the other hand, the author cannot have a single layer winding for the prototype to minimize the overall size of the coils. The testing model of both transmitter and receiver can be referred at Figure 11 below,

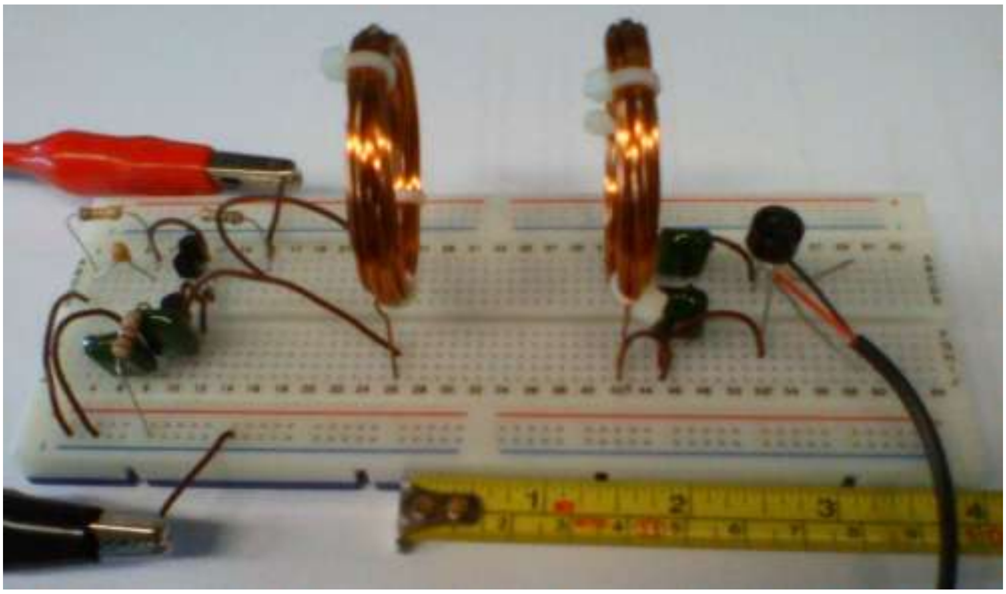

Figure 11 : The actual circuit developed on the breadboard

By using this test model, the author carry out several tests to investigate the effect of several parameters to the performance of the system. The parameters that need to be investigated are;

- The position of the coil, θ
- The size of the enamelled copper wire used as coil, s
- The distance between the transmitter coil and the receiver coil, d
- The radius of the coil, r
- The number of turns of the coil, N

4.2.1 The effect of coil position

This experiment is conducted to determine the optimum position of the coil in inducing the voltage at the receiver coil. In this experiment, the author decided to vary the position of the receiver coil in three different position, $\theta_1 = 0^o$ (receiver coil is facing transmitter coil) , $\theta_2 = 45^o$ (receiver coil is 45^o away from the transmitter coil) , and $\theta_3 = 90^o$ (receiver coil is 90^o away from the transmitter coil).

Through out this experiment, the coils used is identical single layer coils and the supply voltage is fixed at 12V.

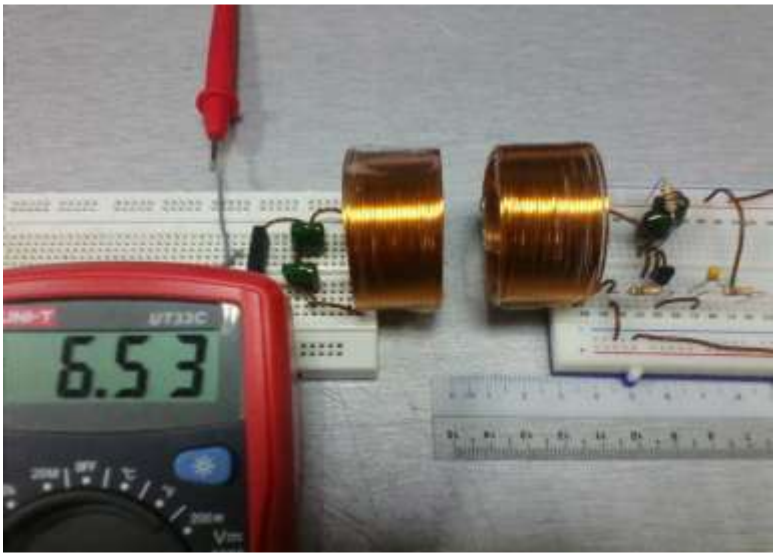

Figure 12 : The wireless electricity experiment for receiver position $\theta_1 = 0^o$

Figure 13 : The wireless electricity experiment for receiver position $\theta_2 = 45^o$

Figure 14 : The wireless electricity experiment for receiver position θ_3= 90^o

The summary of result obtained from this experiment can be refer in the Table 3 below;

Table 3 : The experimental results from from varying receiver coil position

No.	Supply voltage (V)	Capacitance (nF)	Receiver coil position (θ)	Receiver Output Voltage (V)
1	12	150	0^o	6.53
2	12	150	45^o	3.28
3	12	150	90^o	0.64

From the result obtained, it shown that the output voltage measured at the receiver is at maximum when the receiver coil is facing the transmitter coil, $\theta_{1.}$ Thus, in the next experiments and for prototype development, the position of the receiver coil will be facing the transmitter coil for better performance.

4.2.2 The effect of copper wire size

This experiment is conducted to determine the effect of copper wire size used as the coil to the magnitude of induced voltage at the receiver. The author conducted this experiment by using 3 different wire sizes, s_1=0.22mmø (32AWG), s_2=0.75mmø (21AWG) and s_3=1.12mmø (17AWG). Throught out this experiment, other parameters which kept constant are;

- The distance between coils is set at 20mm.
- The number of turn is set at 30 turns.
- The radius of the coil is set at 20mm.

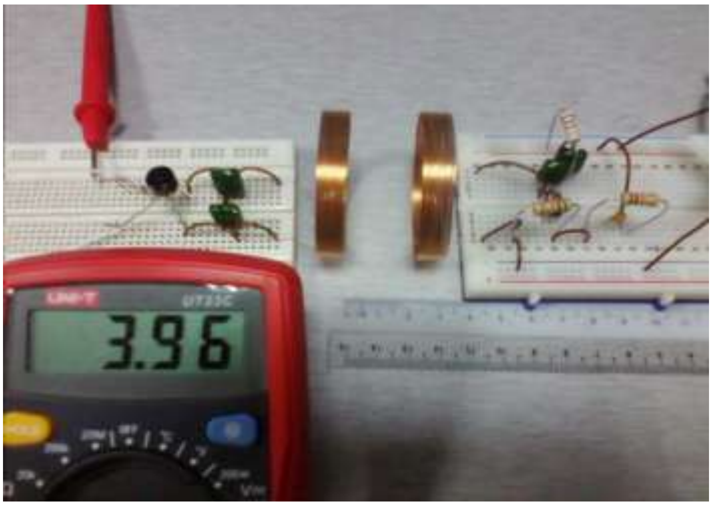

Figure 15 : The wireless electricity experiment for wire size of s_1=0.22mm.

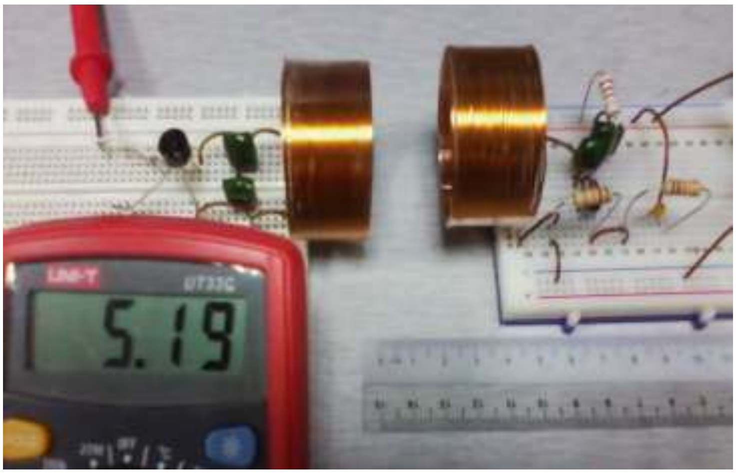

Figure 16 : The wireless electricity experiment for wire size of s_2=0.75mm.

Figure 17 : The wireless electricity experiment for wire size of s_3=1.12mm.

The summary of result obtained from this experiment can be refer in the Table 4 below;

Table 4 : The experimental results from varying wire size

No.	Supply voltage (V)	Capacitance (nF)	Coil wire size (mm)	Receiver Output Voltage (V)
1	12	150	0.22	3.96
2	12	150	0.75	5.19
3	12	150	1.12	6.01

From the result obtained, it is shown that the output voltage measured at the receiver increases when bigger wire size is used. Thus, for prototype development purposes, bigger wire size is considered.

4.2.3 The effect of distance between the coils

Another parameter that may affect the performance of the system is the distance between the coils. The author's hypothesis on this matter is the longer the distance separates the two coils, the lesser the capability of the receiver to induce voltage. This experiment is to investigate this hypothesis, and the author decided to carry this experiment with three different air gap distance, d_1=10mm, d_2=20mm and d_3=30mm. For this experiment, the parameters that kept constant are;

- The wire size is set at 0.75mmø (21AWG).
- The number of turns is set at 30 turns.
- The radius of the coil is set at 20mm.

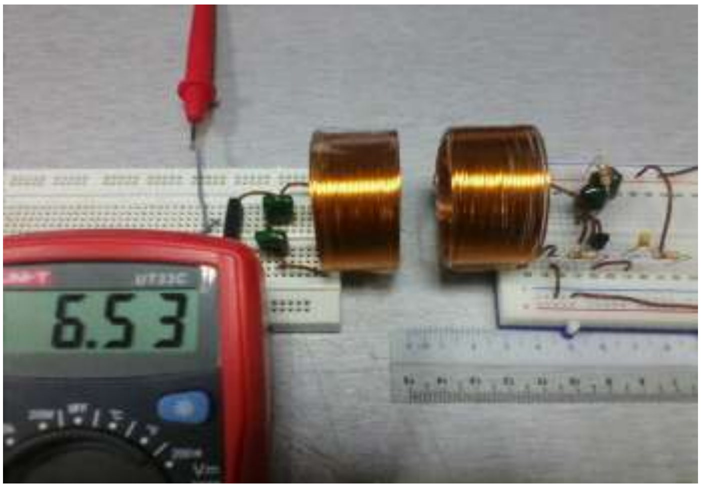

Figure 18 : The wireless electricity experiment for distance between coil, d_1=10mm.

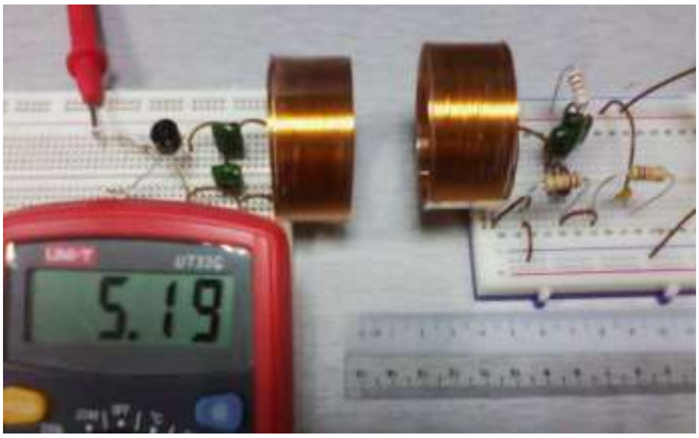

Figure 19 : The wireless electricity experiment for distance between coil, d_2=20mm.

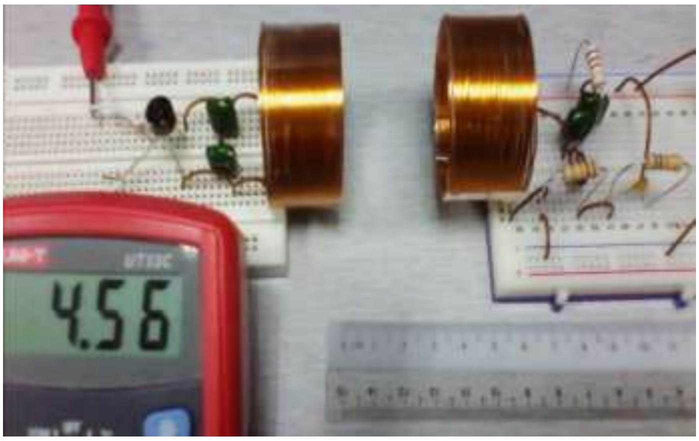

Figure 20 : The wireless electricity experiment for distance between coil, d_3=30mm.

The summary of the result obtained is listed in Table 5 below;

Table 5 : The experimental results obtained from varying distance between the coils.

No.	Supply voltage (V)	Capacitance (nF)	Distance between coils (mm)	Receiver Output Voltage (V)
1	12	150	10	6.53
2	12	150	20	5.19
3	12	150	30	4.56

From the result obtained, it is shown that the output voltage measured at the receiver increases when both coils are placed nearer. Thus, for prototype development purposes, nearer air gap distance between the coils is taken into consideration.

4.2.4 The effect of radius of the coil

This experiment is conducted to investigate the effect of coil radius to the magnitude of the induced voltage at the receiver. For this experiment, the author decided to vary the radius into three different radius, r_1=20mm, r_2=25mm and r_3=30mm. For this experiment, the parameters kept constant are;

- The wire size is set at 0.22mmø (32AWG).
- The number of turns is set at 30 turns.
- The distance between the coils is set at 20mm.

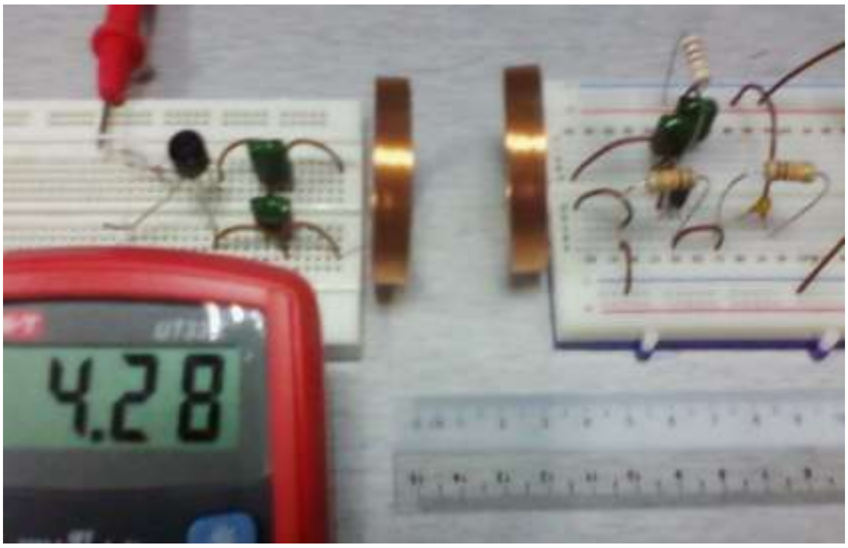

Figure 21 : The wireless electricity experiment for coil radius, r_1=20mm.

Figure 22 : The wireless electricity experiment for coil radius, r_2=25mm.

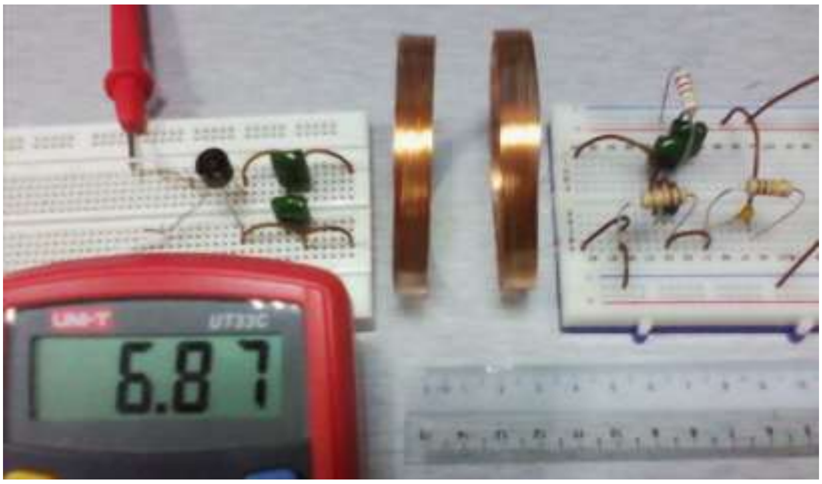

Figure 23 : The wireless electricity experiment for coil radius, r_3=30mm.

The summary of the result obtained from this experiment in summarized in Table 6 below;

Table 6 : The experimental results obtained from varying radius of the coils.

No.	Supply voltage (V)	Capacitance (nF)	Coil radius (mm)	Receiver Output Voltage (V)
1	12	150	20	4.28
2	12	150	25	5.11
3	12	150	30	6.87

From the result obtained, it is shown that the output voltage measured at the receiver increases as the coil with bigger radius is used. Thus, for prototype development purposes, bigger coil radius is taken into consideration.

4.2.5 The effect of number of turns of the coil

This experiment is to investigate the effect of number of turns of the coil to the magnitude of the induced voltage at the receiver. The author decided to carry this experiment with three set of different number of turns, which are N_1=30 turns, N_2=40 turns and N_3=50 turns. Other parameters which kept constant for this experiment are;

- The wire size is set at 0.75mmø (21AWG).
- The distance between coils is set at 20mm.
- The radius of the coil is set at 20mm.

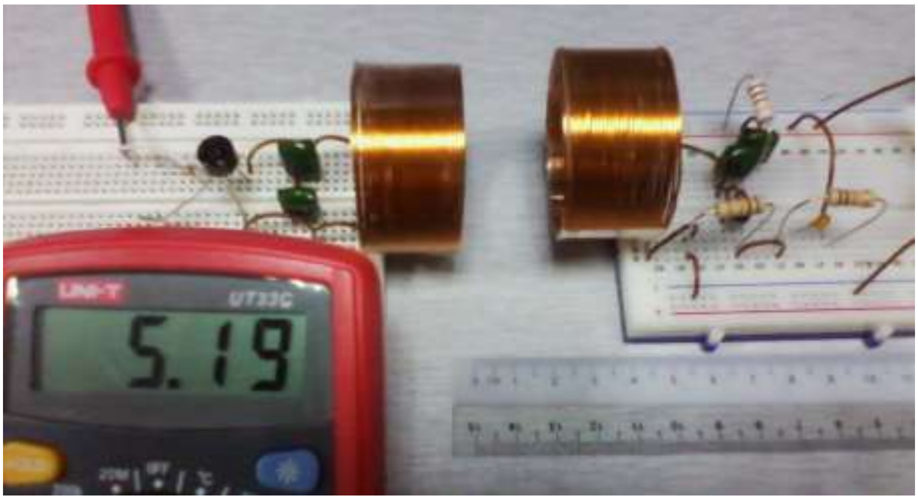

Figure 24 : The wireless electricity experiment for coil number of turns, N_1=30 turns.

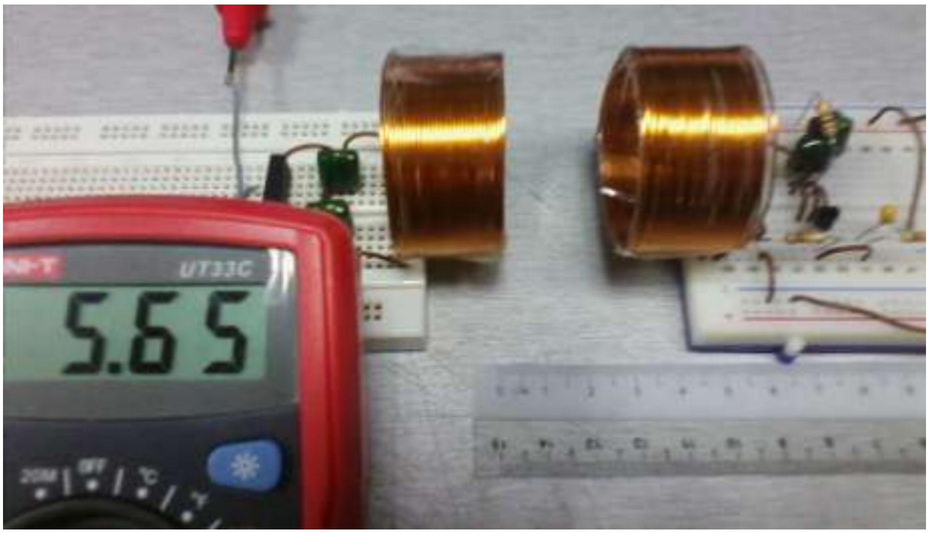

Figure 25 : The wireless electricity experiment for coil number of turns, N_2=40 turns.

Figure 26 : The wireless electricity experiment for coil number of turns, N_3=50 turns.

The summary of the result obtained from this experiment in summarized in Table 7 below;

Table 7 : The experimental results obtained from varying coil number of turns.

No.	Supply voltage (V)	Capacitance (nF)	Number of turns (N)	Receiver Output Voltage (V)
1	12	150	30	5.19
2	12	150	40	5.65
3	12	150	50	6.31

From the result obtained, it shown that the output voltage measured at the receiver increases with the increase in the number of turns of the coil. Thus, for prototype development purposes, more number of turns of the coil is taken into consideration.

4.3 Prototype Development

Result obtained from the experiments conducted is essential in determining the design of the prototype to be developed. From the experiment results, the author finalized the design parameters for prototype as listed in Table 8 below;

Table 8 : Finalized prototype design parameters.

Parameters	Value
Supply voltage (V)	12
Capacitance (nF)	150
Number of turns (N)	50
Coil wire size (mm)	0.75
Coil radius (mm)	20

4.3.1 Transmitter Prototype Design

For the transmitter prototype design, the author set the input voltage at 12V as from the experiment coducted, it is proven to be effective in maintaining at least 5V as the charging voltage at the receiver. As the cellphone battery used in this project rated at 3.7V, it is important to maintain 5V at the receiver in order to recharge the battery.

The transmitter coil is contructed by using 0.75mm wire size. The author used this size even though experiment result shown that this wire size induced less voltage compared to 1.22mm. The justification for this matter is 0.75mm wire size still able to induce at least 5V at the receiver with respect to lesser air gap distance. Besides, it is easier to work with this wire size since 1.1.2mm cannot be directly soldered onto veraboard.

For the number of turn, it is proven more turns will induce moe voltage at the receiver, thus the author decided to have 50 turns. For the coil radius, the author used 20mm radius because this radius fits average cellphone width. As both tranmitter and receiver need to have equal value of inductance and capacitance in order to resonate at resonant frequency, it is important to consider the cellphone width since the receiver will be attached at the back of the cellphone.

The capacitor used is arbitrarily set at 150nF as the proposed coil design will produce resonant frequency between 40kHz to 80kHz with this capacitance value. It is important to keep the frequency at this range considering the oscillator used. The prototype design of the transmitter is illustrated in Figure 27 below;

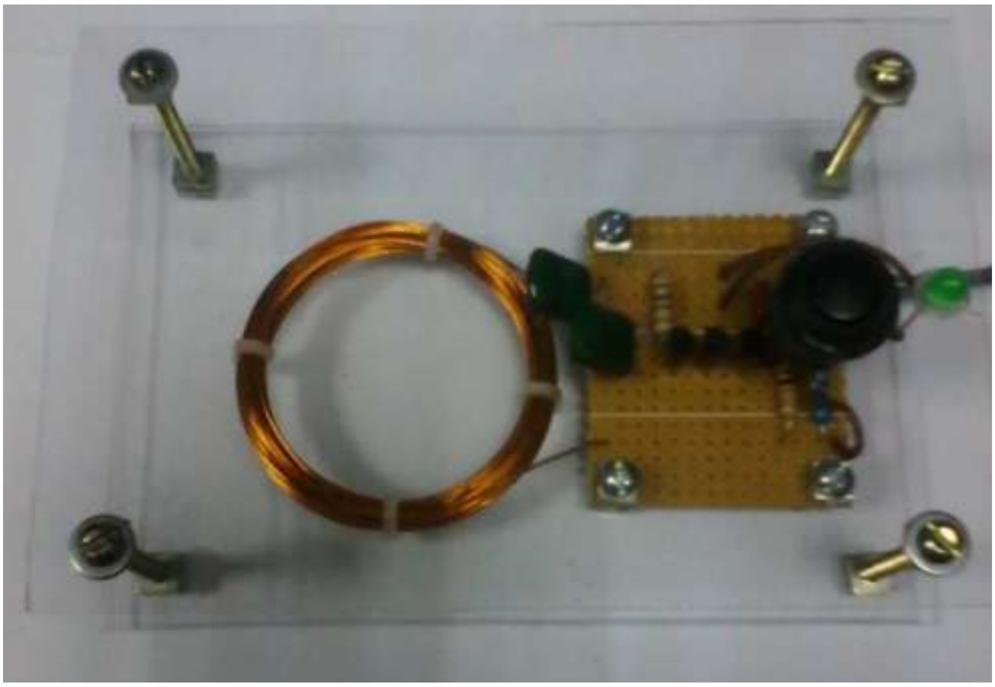

Figure 27 : The prototype design of the transmitter

4.3.2 Receiver Prototype Design

For the receiver prototype design, the idea is very simple. The receiver is consisting of receiving coil, which is identical to the transmitter coil, a pair of capacitors with exact value as the capacitor used at transmitter, and the full wave bridge rectifier to rectify the received AC voltage into DC voltage to charge the battery.

For the receiver prototype, Figure 28 below shows that the receiver having the same coil design and identical 150nF coupling capacitors as used in transmitter and bridge rectifier. While in Figure 29, it is shown that receiver part is attached to the cellphone which complete the receiving part.

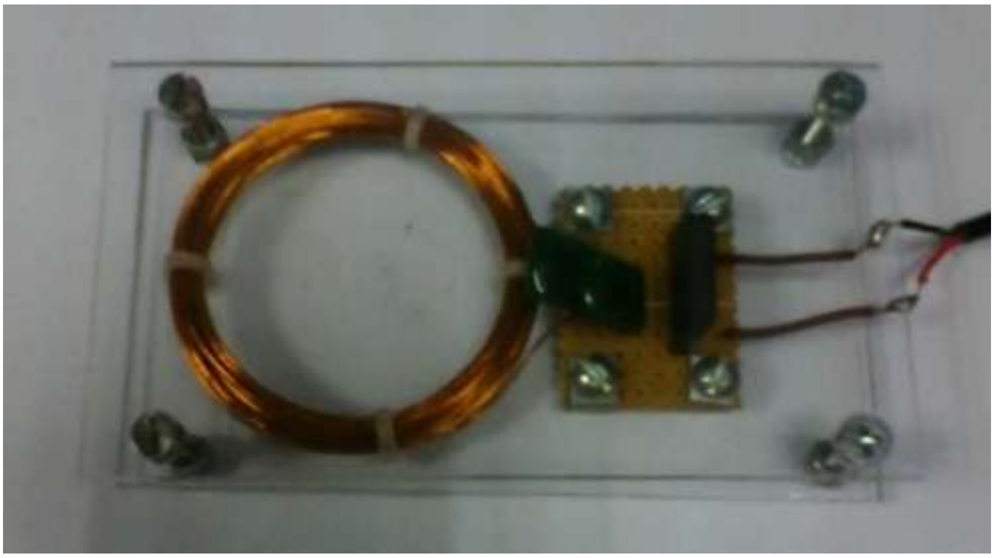

Figure 28 : The prototype design of the receiver

Figure 29 : The receiver prototype connected to cellphone with 3.7V Li-ion battery.

4.3.3 Overall Prototype Developed

For overall design, the author placed the receiver coil 30mm from the transmitter. With transmitter supply of 12V and the design of the coil, it is believed that the receiver induced voltage will be at least 5V with this air gap range and able to charge the cellphone battery.

Figure 30 : Overall prototype developed

4.4 Prototype Testing Result

4.4.1 Operability Testing

After the prototype development completed, the prototype is tested for its charging capability. Operability testing is conducted to determine whether the prototype developed really can charge the cellphone. Figure 31 below shows that the prototype developed is proven to be able to transfer electrical power wirelessly and able to recharge cellphone.

In Figure 32, the author measured the voltage induced at the receiver. As mentioned before, it is important to have at least 5V at receiver in order to recharge the battery. Figure 32 shows that the measured charging voltage of the prototype developed is 6.65V which is within range of charging voltage for 3.7V battery.

Figure 31 : The prototype is used to charge the cellphone.

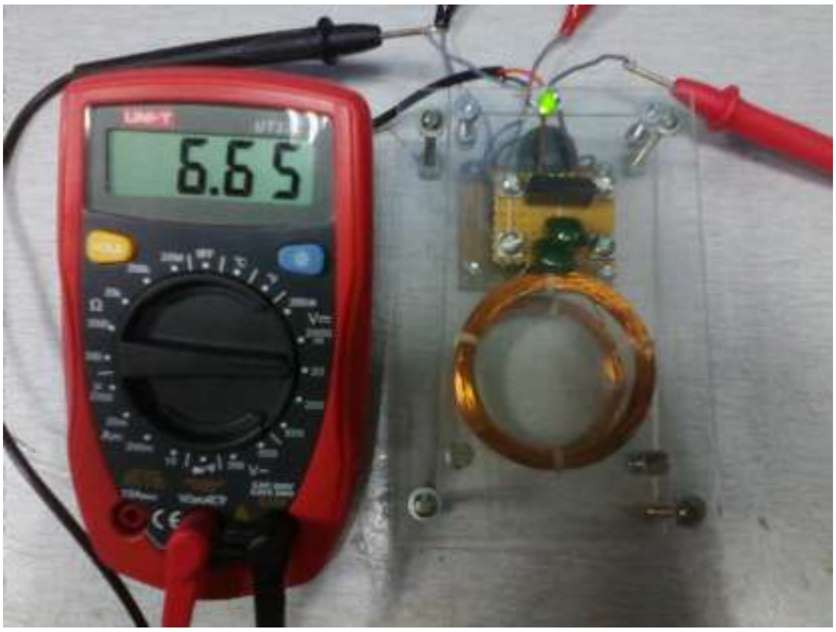

Figure 32 : Charging voltage measured at the receiver terminal

4.4.2 Prototype Resonant Frequency

As previous testing proved that developed prototype is working, the author decided to determine the resonant frequency of the system. The resonant frequency of the system can be determine by using oscilloscope. Figure 33 below shows that when the receiver is placed far (around 10 cm) from the transmitter, there are no frequency detected at the receiver coil. At this time, there are no voltage induced at the receiver coil.

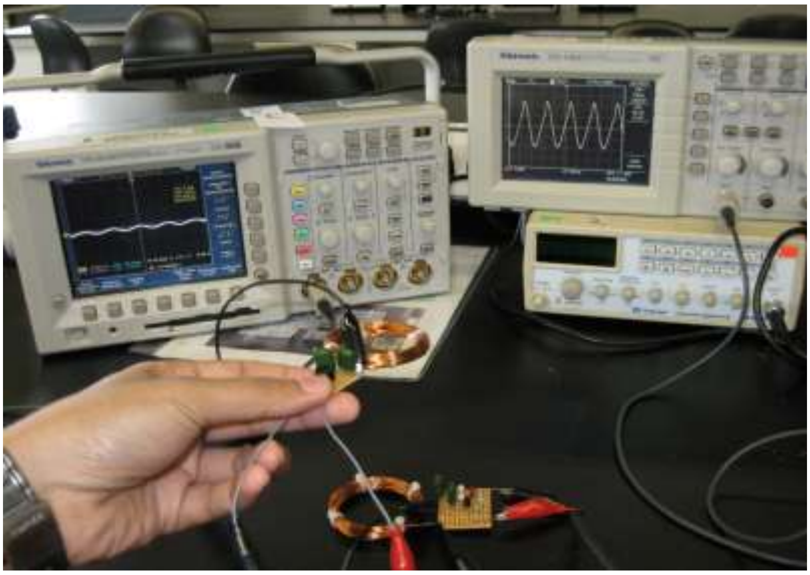

Figure 33 : At air gap of 10 cm, the system is not coupled at resonant frequency.

While in Figure 34, as the author placed the receiver near (3 cm as proposed for prototype) to the transmitter, in the region of the transmitter changing magnetic field is present, the receiver coil simultaneously having the same frequency as the transmitter frequency and inducing voltage in its coil.

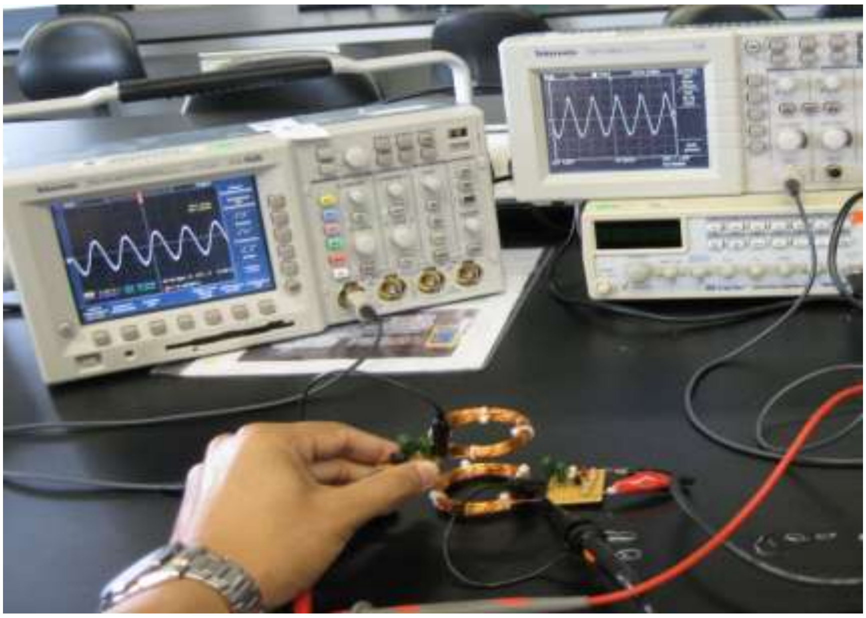

Figure 34 : The system is coupled at resonant frequency of 49.57kHz.

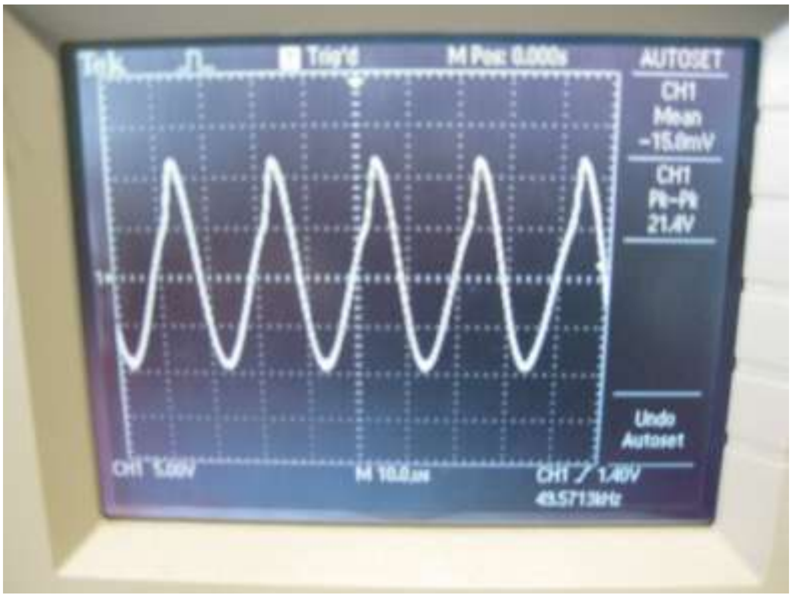

Figure 35 : The frequency reading from the transmitter.

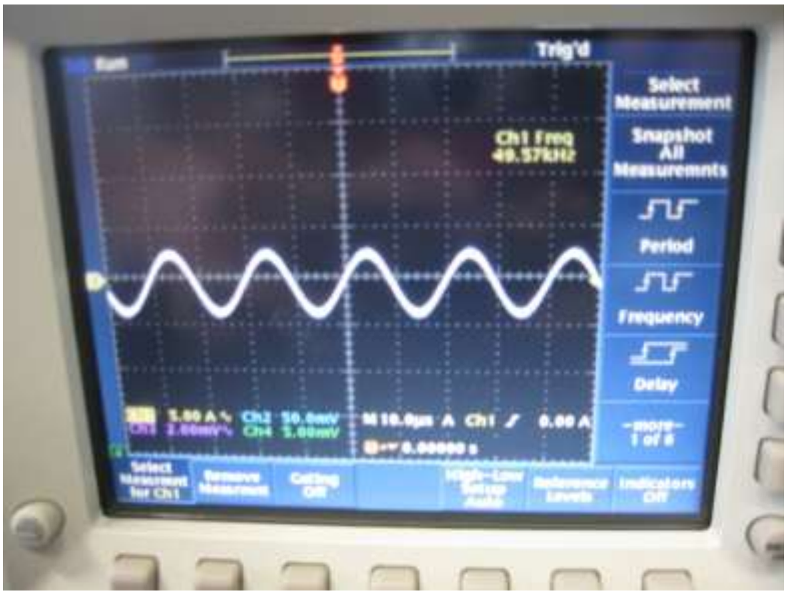

Figure 36 : The frequency of the receiver.

The transmitter and receiver is said to be coupled at resonant frequency of 49.57kHz. From this frequency value, we can determine the inductance value of the handmade coils. Theoretically, for this prototyple, the inductance value is calculated as 65.55 mH. At 30mm air gap distance, the voltage induced at the receiver coil is measured at 6.65V. Thus, it is sufficient to be used to recharge the cellphone battery.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project is an important steps taken in understanding how how wireless electricity can be made possible.

From the methodology proposed, it is proven that resonant inductive power coupling between two coil can transfer electrical power wirelessly in range of several centimeters. Thus, this finding concluded that the first objective of this project is achieved.

The application of resonant inductive power coupling in wireless electricity then apllied in developing a prototype of wireless cellphone charger. Prior to the development of the prototype, several parameters of the design is investigated which are the effect of coil positioning, coil radius, number of coil turns, the size of copper wire used as coil and the distance between the coils. The experiment conducted yield breakthrough results and considered in prototype development process. Thus, the second objective of this project can be concluded as achieved.

Based from the experiment result obtained before, the wireless cellphone charger prototype is developed. The prototype is proven to be able to charge cellphone battery. This achievement concluded that the third objective of this project which is to develop a wireless cellphone charger is achieved.

Through out this project, the author gained much knowledge about the wireless electricity technology. At the end of this project, he author managed to write a thesis, a technical paper and develop a prototype.

5.2 Recommendations

For future works, the author recommends several changes to the system which in turn can be very beneficial if further analyzed. Among the changes can be made are;

- Use of another type of oscillator which can produce higher frequency.
- Use of another type of wire as coil.
- Use of another type of load such as small DC motor.
- Use of another capacitor value.

This changes to the system is important to gain further understanding of this wireless electricity technology. However, to complete all these analysis, a lot of time required. Thus the author recommends extension of literature review of past works done by other researchers to be done first to avoid any unnecessary analysis as the analysis might be done before, thus can reduce the time consumption on the analysis.

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