Faculty of Electrical Technology and Engineering

DEVELOPMENT OF 6.78MHz SHIELDED COUPLER FOR CAPACITIVE WIRELESS POWER TRANSFER

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Bachelor of Electrical Engineering Technology with Honours

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DEVELOPMENT OF 6.78MHz SHIELDED COUPLER FOR CAPACITIVE WIRELESS POWER TRANSFER

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A project report submitted
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DEDICATION

To my beloved mother, Siti Sapurah binti Paralan, and father, Aris bin Tik, and my siblings always support me to achieve my dream and thank you for always being with me through this journey.

ABSTRACT

Wireless power transfer (WPT) has emerged as a promising technology, offering the convenience of charging electronic devices without physical connections. Capacitive wireless power transfer, in particular, eliminates the need for cables or connectors, enabling power transfer without direct contact. This approach facilitates charging in diverse settings such as vehicles, public spaces, and locations where conventional power outlets are challenging to access. The primary goal of this study is to design a shielded coupler specifically tailored for 6.78MHz capacitive wireless power transfer. This targeted frequency addresses concerns related to bulk and health risks associated with lower frequencies. The aim is to create a lightweight shielded coupler capable of efficient and secure wireless power transfer, ultimately reducing dependence on wired charging for various applications. To achieve the objectives, a four-plate configuration is proposed, incorporating two shielding plates operating at 6.78 MHz. Additionally, the project involves the development of a copper plate coupler structure for 6.78 MHz capacitive wireless power transfer (CWPT). The analysis of the coupler structure is conducted using an LT Spice simulation circuit for the charging system. The performance evaluation of the created coupler structure is carried out through an experimental setup. The study focuses on the practical implementation of capacitive wireless power transmission for charging systems, utilizing a model developed with the LT Spice program. The proposed four-plate configuration, including shielding plates at 6.78 MHz, aims to address concerns related to bulk and health risks. The performance of the copper plate coupler structure is assessed through both simulation and experimental setups. This research underscores the potential of capacitive wireless power transfer at 6.78 MHz, offering a solution to issues associated with lower frequencies. The designed shielded coupler demonstrates efficiency and safety in wireless power transfer, presenting a viable alternative to traditional wired charging methods. The findings contribute to the advancement of capacitive interfaces for wireless charging stations, emphasizing their cost-effectiveness and user-friendly nature in various applications.

ABSTRAK

Pemindahan kuasa tanpa wayar (WPT) telah muncul sebagai teknologi yang menjanjikan, menawarkan kemudahan mengecas peranti elektronik tanpa sambungan fizikal. Pemindahan kuasa wayarles kapasitif, khususnya, menghapuskan keperluan untuk kabel atau penyambung, membolehkan pemindahan kuasa tanpa sentuhan langsung. Pendekatan ini memudahkan pengecasan dalam tetapan yang pelbagai seperti kenderaan, ruang awam dan lokasi di mana alur keluar kuasa konvensional mencabar untuk diakses. Matlamat utama kajian ini adalah untuk mereka bentuk pengganding terlindung yang disesuaikan khusus untuk pemindahan kuasa tanpa wayar kapasitif 6.78MHz. Kekerapan sasaran ini menangani kebimbangan yang berkaitan dengan risiko pukal dan kesihatan yang berkaitan dengan frekuensi yang lebih rendah. Matlamatnya adalah untuk mencipta pengganding terlindung ringan yang mampu memindahkan kuasa wayarles yang cekap dan selamat, akhirnya mengurangkan pergantungan pada pengecasan berwayar untuk pelbagai aplikasi. Untuk mencapai objektif, konfigurasi empat plat dicadangkan, menggabungkan dua plat pelindung yang beroperasi pada 6.78 MHz. Selain itu, projek itu melibatkan pembangunan struktur pengganding plat kuprum untuk pemindahan kuasa wayarles kapasitif (CWPT) 6.78 MHz. Analisis struktur pengganding dijalankan menggunakan litar simulasi LT Spice untuk sistem pengecasan. Penilaian prestasi struktur pengganding yang dicipta dijalankan melalui persediaan eksperimen. Kajian ini memberi tumpuan kepada pelaksanaan praktikal penghantaran kuasa wayarles kapasitif untuk sistem pengecasan, menggunakan model yang dibangunkan dengan program LT Spice. Cadangan konfigurasi empat plat, termasuk plat pelindung pada 6.78 MHz, bertujuan untuk menangani kebimbangan yang berkaitan dengan risiko pukal dan kesihatan. Prestasi struktur pengganding plat kuprum dinilai melalui kedua-dua simulasi dan tetapan eksperimen. Penyelidikan ini menggariskan potensi pemindahan kuasa wayarles kapasitif pada 6.78 MHz, menawarkan penyelesaian kepada isu yang berkaitan dengan frekuensi yang lebih rendah. Pengganding terlindung yang direka bentuk menunjukkan kecekapan dan keselamatan dalam pemindahan kuasa tanpa wayar, memberikan alternatif yang berdaya maju kepada kaedah pengecasan berwayar tradisional. Penemuan ini menyumbang kepada kemajuan antara muka kapasitif untuk stesen pengecasan wayarles, menekankan keberkesanan kos dan sifat mesra pengguna mereka dalam pelbagai aplikasi.

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LIST OF SYMBOLS

Cc	-	Coupling Capacitance
$C1, C2, C3, C4$	-	Parasitic Shield Capacitance
RL	-	Load Resistance
L	-	Inductance
Eo	-	Dielectric Constant in Vaccum
K	-	Relative Dielectric Constant used between plates
A	-	Surface area of the plates
D	-	The air gap distance between plates
f	-	Frequency
%	-	Percentage
W	-	Watt
V	-	Voltage
I	-	Current
j	-	Joule
ω	-	Angular Frequency
s	-	Complex Frequency
$I1$, $I2, I3$	-	Current in each loop

LIST OF ABBREVIATIONS

WPT	-	Wireless Power Transfer
IPT	-	Inductive Power Transfer
$HWPT$	-	Hybrid Wireless Power Transfer
CPT	-	Capacitive Power Transfer
$CWPT$	-	Capacitive Wireless Power Transfer
$S-CPT$	-	Shielded Capacitive Power Transfer
EOL	-	End of Line
EMI	-	Electromagnetic Interference
MHz	-	Mega Hertz
RF	-	Frequency Range
AC	-	Alternating Current
DC	-	Direct Current
EMF	-	Electromotive Force
AUV	-	Autonomous Underwater Vehicles
EFR	-	Electric Field Resonant
EOL	-	End of Life
Vi	-	Voltage Input
Vo	-	Voltage Output
CP	-	Capacitance at Primary
CS	-	Capacitance at Secondary
LP	-	Inductance at Primary
LS	-	Inductance at Secondary
PCB	-	Printed Circuit Board

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CHAPTER 1

INTRODUCTION

1.1 Background

The convenience of wireless power transfer (WPT) technology and its capacity to do away with physical connections have made it more and more popular. Capacitive wireless power transfer (CWPT) is one type of wireless power transfer (WPT) that depends on electric field shielded coupling [1]. Shielded couplers are used in CWPT to improve performance and reduce interference.

The objective of the project is to design a shielded coupler for a CWPT system operating at 6.78MHz. The coupler should maximize power transfer efficiency while minimizing electric field leakage between the transmitter and receiver electrodes [2], [3]. Long-distance transfer and user convenience are just two of the benefits of the method. The system has not been put on the market, though, because of electromagnetic interference (EMI), activity by humans, and some compelled principles [4], [5].

Finally, the shielded coupler will be designed and optimized by electromagnetic simulation software using analytical and numerical techniques. A copper plate and a printed circuit board will be used to create a prototype. A 6.78MHz CWPT system will be used to test the shielded coupler's performance, and the results will be compared to theoretical forecasts to confirm the design. The project may find use in consumer electronics, medical implants, and electric car wireless charging.

1.2 Societal and Global Issue on Shielded Coupler for CPT

Capacitive power transfer (CPT) using shielded coupler technology has numerous environmental benefits. These couplers eliminate the need for physical connectors and cables, thereby reducing the demand for their manufacture and disposal. Lowering electronic waste production and conserving non-renewable resources, helps to make power transfer a more environmentally friendly process. Shielded couplers also promote energy efficiency by reducing energy losses during wireless power transfer, which lowers overall energy use and associated greenhouse gas emissions[6] These couplers facilitate using energy that is clean, such as renewable energy, for wireless charging, aiding in the transition to a low-carbon economy and the fight against climate change. Because of their favorable effects on the environment, shielded couplers offer a more durable and environmentally friendly solution for wireless power transfer systems[7].

1.3 Problem Statement

It is more convenient when there is no need for physical connectors, especially in applications where frequent connections and disconnections are necessary. The total weight of CWPT is known to be heavy with a bulk size at lower frequencies, while lower frequencies are known to produce bulk and heavy power transfer. To make the coupler lighter, a higher frequency is used in comparison at 6.78MHz to a frequency of 1MHz[8], [9].

Due to the potential for hazardous electric fields created by capacitive wireless power transfer, a shield plate is necessary for security and safety [10]. In addition, a shield plate for safety and protection should be included in the solution to minimize any possible health dangers associated with capacitive wireless power transfer while yet retaining a lightweight and portable design. However, shield plates could add weight to the coupler.

Although induction wireless power transfer is a challenge to execute in some applications due to its bulkiness, it is an alternative to capacitive wireless power transfer [11]. Create a reliable and effective Electromagnetic Inductive (EMI) Power Transfer system that tackles issues such as heat generation, power loss, and a restricted transfer distance to allow wireless charging of electronic gadgets. It will be easier for consumers and lessen their dependency on conventional cable charging ways to create a system that uses less energy, transfers power more efficiently, and is compatible with a range of devices. Thus, by developing a thin, shielded coupler for 6.78MHz capacitive wireless power transmission, these issues can be overcome and secure wireless power transfer made possible for a range of applications.

1.4 Project Objective

The project is to aim to investigate the parameters for capacitive wireless power transfer at 6.78 MHz using a mathematical model and to develop a coupler plate for the charging system in simulation and experimental setup. Specifically, the objectives are as follows:

a) To compute the parameters of the capacitive wireless power transfer for 6.78 MHz using the algebraic method.
b) To develop the 6.78MHz shielded coupler for capacitive wireless power transfer using single-sided copper board.
c) To analyze the performance of a 6.78MHz shielded coupler for capacitive wireless power transfer using simulation and hardware setup.

1.5 Scope of Project

Due to some limitations and constraints, the project's scope is outlined below to eliminate any uncertainty:

a) This project is restricted to the modeling and simulation of the S-CPT model at a frequency of 6.78MHz, utilizing LTSpice software.

b) This project is solely on the modeling and simulation of the S-CPT model coupler structure, and it is limited to the use of LTSpice Software.

c) The performance of the designed circuit is simulated and examined using LTSpice software. Through LTSpice simulations, the circuit's effectiveness and functionality are confirmed. Using the results of the simulation to optimize the circuit's components and parameters.

d) This project was limited to implementing the designed circuit in a practical hardware setup. Selecting appropriate components such as capacitors, inductors, and power management modules for the hardware implementation. Ensuring proper hardware setup using NanoVNA saver, benchwork experimental, and Class-E inverter for efficient power transfer.

1.6 Justification of Project

For capacitive wireless power transfer, the development of a shielded coupler operating at 6.78 MHz is justified for a variety of reasons. By maximizing power transmission and minimizing losses, it aims to make wireless power transfer systems more effective. No later than incorporating shielding techniques into the coupler design, the project also addresses safety concerns. This ensures a secure and dependable power transfer environment while minimizing interference with neighboring devices and human exposure to electromagnetic radiation.

Due to its compatibility with current wireless power transfer standards, the 6.78MHz frequency choice can be widely used. The development of a shielded coupler enables reliable and efficient power transfer in numerous applications, promoting adaptability[12]. By looking into new techniques and materials to improve the effectiveness and accessibility of wireless power transfer systems, the project also aids in research and development efforts. Last but not least, by reducing reliance on traditional wired charging methods, the project helps achieve sustainability goals by lowering electronic waste and promoting a greener future.

CHAPTER 2

REVIEW ON WIRELESS POWER TRANSFER

2.1 Introduction

The need for effective and sustainable energy sources is greater than ever in today's modern society. With rising fuel prices, fiercer competition in the market, more stringent regulations, and ongoing climate change [13], it is imperative that new technologies be created that can deal with these problems. Technology that uses wireless power transmission might be a solution in this case. Due to its simplicity and capacity to eliminate physical connections, wireless power transfer (WPT) technology has grown increasingly common. Capacitive wireless power transfer (CWPT) is one type of wireless power transfer (WPT) that depends on electric field shielded coupling. Shielded couplers are used in CWPT to improve performance and reduce interference.

The project's goal is to develop a shielded coupler for a 6.78MHz CWPT system. The design, effectiveness, and performance characteristics of the system are all thoroughly examined in this study. Additionally, it is looked into how the system will affect the decline in transmission losses, which is essential for ensuring an energy-efficient distribution network [14], [15]. By carefully analyzing these elements, this study intends to offer a comprehensive picture of the evolution of this technology for wireless power transfer and its potential to advance environmentally friendly energy technologies [8], [10].

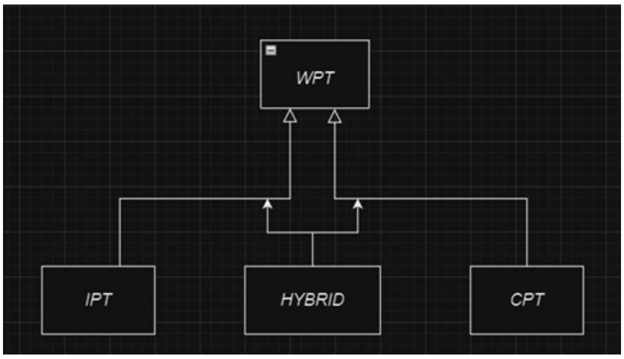


Figure 2.1Wireless Power Transfer (WPT)

Based on Figure 2.1, Wireless Power Transfer (WPT) includes Inductive Power Transfer (IPT), which uses magnetic fields; Capacitive Power Transfer (CPT), which uses electric fields; and Hybrid approaches that combine the two. By doing away with the requirement for physical connectors, these technologies enable effective and convenient energy transmission across a range of applications.

2.2 Global and Current Issue on WPT

Materials both hazardous and non-hazardous are found in electronic waste. The annual global production of electronic waste is estimated to be between 20 and 50 million tonnes. It accounts for 1% to 3% of the 1636 million tonnes of municipal waste generated annually around the world. Large amounts of EOL and obsolete electrical and electronic equipment have contributed to a rapidly expanding waste stream, which is growing at a rate of 3 to 5% per year in terms of municipal waste globally. Electronic waste contains organic toxic and dangerous substances, setting it apart from regular municipal waste. To raise awareness of the detrimental effects of treating electronic waste in an unregulated manner and to prevent human beings and the environment from being contaminated by these pollutants[16], it is important to study the characteristics of various hazardous materials found in electronic waste.

2.3 Inductive Power Transfer (IPT)

Inductive power transfer technologies used for battery charging, such as low-power consumer gadgets, are becoming more and more prevalent. With the help of magnetic induction, inductive power transfer (IPT), a wireless technology, transmits energy from a transmitter to a receiver without needing to make actual physical contact. In IPT, a primary coil in the signaling device and another coil in the receiving end exchange energy. When an alternating current (AC) is sent through the primary coil, a magnetic field is created everywhere around it. The secondary coil generates an alternating voltage as a result of this magnetic field, which may be rectified and utilized to power a load [17]. A variety of applications where wireless power transfer is desired can benefit from the potential of inductive power transfer, a promising technology.

Two coils are typically used in inductive power transfers, a primary coil that is permanent and a secondary coil that is portable or moveable. The magnetic field on the initial coil is created when it is receiving an alternating current causing the secondary coil, as shown in Figure 2.2 [18], to also receive an alternating current. The load or portable gadget can therefore receive electricity wirelessly. Coil distance, frequency, and design are just a few of the factors that affect the coil's size, shape, and capacity to transfer power. IPT systems are used to power electric cars, recharge portable electronics and power medical implants. Even though IPT has advantages like safety, convenience, and adaptability, it also has drawbacks like range and efficiency, which ongoing research is trying to overcome [19].

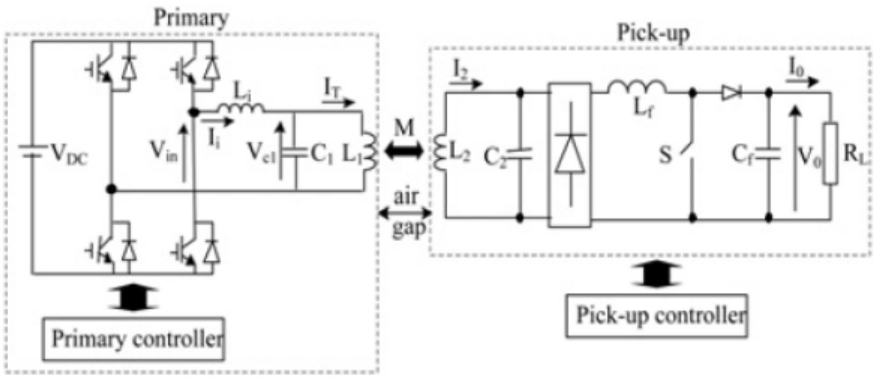


Figure 2.2 Inductive Power Transfer System [18]

Based on the Inductive Power Transfer system in Figure 2.2 [18], [20] Inductive reasoning transmission of energy is a form of wireless power transfer, also known as magnetic induction, which uses electromagnetic fields to transfer energy between two coils, an inductor (transmitter) and a receiver coil. The system begins with a power source that provides electrical energy, such as an AC power grid or a DC power supply. Then, this power is converted and conditioned to produce an appropriate AC or high-frequency AC waveform using rectifiers, inverters, and converters. The primary coil, a substantial wire coil on the transmitter side as in Figure 2.3, is excited by the generated waveform, creating a magnetic field.

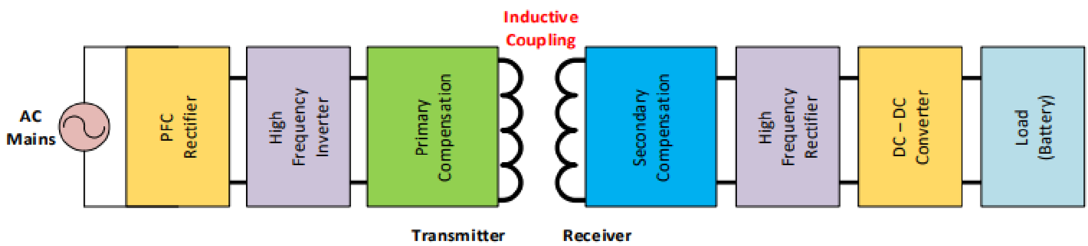


Figure 2.3 Block Diagram of IPT [20]

Because of the inductive connection between the transmitter and receiver coils, which promotes effective energy transfer, the IPT system shows excellent power transfer efficiency in Figure 2.3. The design places a high priority on user and environmental safety, to reduce the possibility of radiation exposure or electric shock brought on by the magnetic field generated during energy transmission.

The IPT system also has a lot of user-friendly capabilities, like the ability to charge small electrical items like cellphones and electric toothbrushes without the transmitter and receiver having to come into direct touch with each other. Its adaptability makes it possible to integrate it into a variety of surfaces, improving usage in many contexts. These benefits are tempered by a few drawbacks, including a limited power transmission range, sensitivity to metallic objects that reduce efficiency, and the requirement for exact coil alignment, which in certain situations might make use more difficult[21].

In addition, the IPT systems could not be as economical as conventional wired power transfer arrangements, particularly for applications that need higher power transfer or longer-range capabilities[22]. Despite these drawbacks, IPT systems' resilience to elements like temperature fluctuations, humidity, and vibrations makes them appropriate for harsh situations like industrial settings or outdoor applications. Not to mention setting up IPT systems can be more expensive than setting up traditional wired power transfer systems, particularly for applications requiring high power transfer or longer-range power transfer[23].

2.4 Hybrid Power Transfer

A hybrid power transfer system combines two or more energy sources, like petrol and electricity, to run a car or power a device. The hybrid power system maximizes efficiency and reduces emissions by choosing the best power source for a specific situation [24]. For instance, in hybrid electric vehicles, the electric motor is used for low-speed driving while the petrol engine provides power for high-speed driving or charging the battery. Some hybrid power systems as in Figure 2.4 have the capability of regenerative braking, which recovers energy that would otherwise be lost during braking and uses it to recharge the battery. This kind of resource use increases its sustainability and effectiveness.

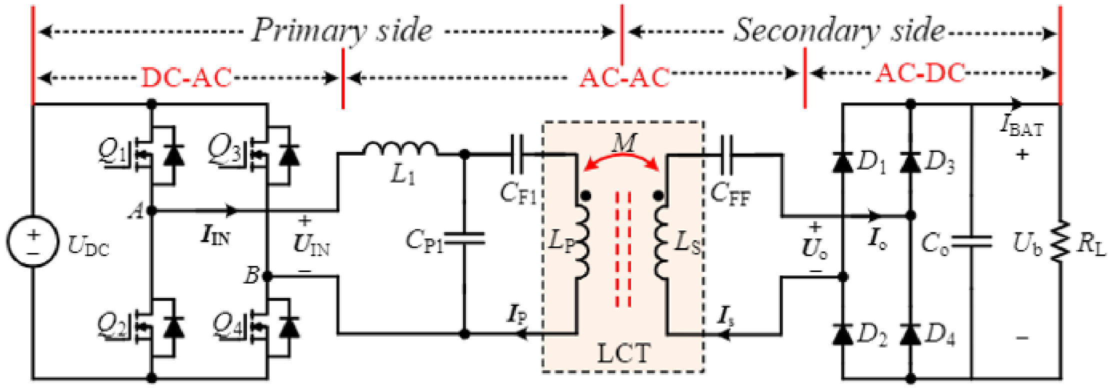


Figure 2.4 Hybrid wireless power transfer system circuit[24]

By referring to Figure 2.4, a basic hybrid wireless energy transmission system uses radio waves to send electrical energy from a power source to a device that integrates two or more wireless power transfer methods. The system may employ inductive coupling, magnetic resonance, or radio frequency energy transfer for wireless power delivery[25], [26]. These technologies can be used standalone or in combination to create a more effective and efficient system. A hybrid system can also employ a physical connection to deliver power, such as in the form of a battery or a generator if wireless power transmission is impracticable.

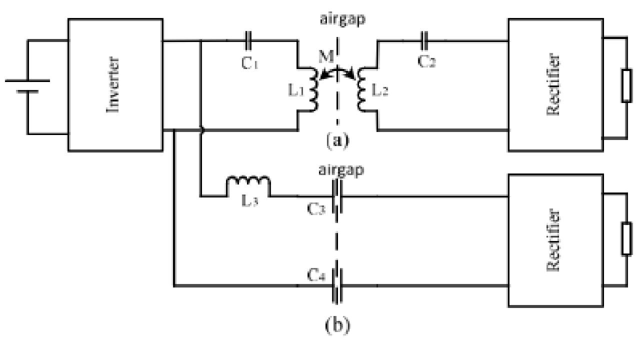


Figure 2.5 Hybrid wireless power transfer (HWPT) system
(a) IPT branch (b) CPT branch [25]

In this hybrid power transfer system, as illustrated in Figure 2.5, the efficacy and range of wireless power transmission are increased by combining the ideas of inductive and capacitive power transfer. Electrical energy is provided by a starting power source for the system, such as an AC power grid or a DC power supply [27]. This power is then converted and conditioned using rectifiers, inverters, and converters to produce a suitable AC or high-frequency AC waveform[24].

A wireless power transfer system's transmitter side is made up of a capacitive plate and an inductive coil. The capacitive plate stores electrical energy as an electric field, while the inductive coil produces a magnetic field when powered by a high-frequency AC waveform. Efficient magnetic coupling is facilitated on the receiving end by a capacitive receiver and a secondary coil, which generates an electromotive force (EMF) that is converted into electrical power. The range of the system is increased and power transmission efficiency is improved by the interaction of the electric fields of capacitive plates[28].

Hybrid wireless power transfer systems combine multiple technologies, offering advantages over single-technology systems. Increased range is a notable benefit, allowing devices to be wirelessly charged over greater distances[26]. The efficiency of hybrid systems is higher due to reduced energy loss from the coupling of multiple technologies, leading to cost savings. Additionally, these systems accommodate a wider range of devices and power requirements, enhancing their versatility [26]. However, the increased complexity, cost, and potential interference among technologies are drawbacks. Object detection is a safety feature in some hybrid systems, contributing to their popularity in wireless power transfer applications [29].

Despite their overall benefits, the complexity and cost of hybrid systems pose challenges, and compatibility issues may arise with certain devices or charging standards. The use of various technologies may limit the number of devices that can be wirelessly charged[30].

2.5 Capacitive Power Transfer (CPT)

Capacitive power transfer (CPT), a wireless power transfer technology, employs electric fields to transfer energy between two objects. In CPT, from a supply to the core, power is sent through a capacitor that stores it in an electric field [31]. CPT can be used for wirelessly charging electronic devices as well as power transfer in automotive and industrial settings compared to inductive power transmission, it has the upper hand of having the potential to transmit energy across a greater range. The upper hand of CPT includes the requirement for precise alignment between the power source and receiver as well as the potential for interference from other electric fields. A circuit diagram with the parasitic component as in Figure 2.6 [32].

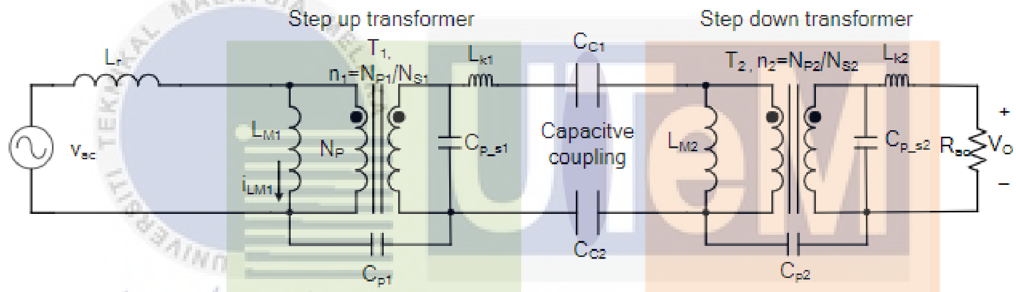


Figure 2.6 Circuit diagram with the parasitic component [32]

The circuit diagram with the parasitic component depicted in Figure 2.6 is a more recent substitute for inductive power transfer that has received more attention is capacitive wireless power (CWPT). Figure 2.7[33] depicts the CWPT system as a schematic block diagram. A power source and a receiver make up the two major parts of a standard Capacitive Power Transfer (CPT) system. When an electrode set is exposed to an AC voltage generated by the power source, an electric field is created. In the receiver, several electrodes are designed to resonate with the electric field generated by the power source[11], [32]. The capacitive coupling between the electrodes of the power source and receiver, which occurs when the receiving device is positioned within the electric field, allows energy to be transmitted. The energy that is delivered can be utilized to refuel batteries or power electrical gadgets. Just like the prototype in Figure 2.8 [34], several factors, including the range between the power source and receiver, the size and shape of the electrodes, and the system resonance frequency, influence how effective the CPT system is.

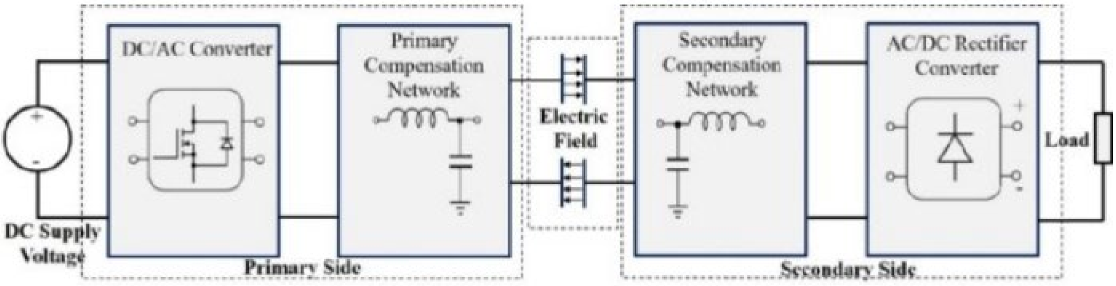


Figure 2.7 Block Diagram of Capacitive Wireless Power Transfer [33]

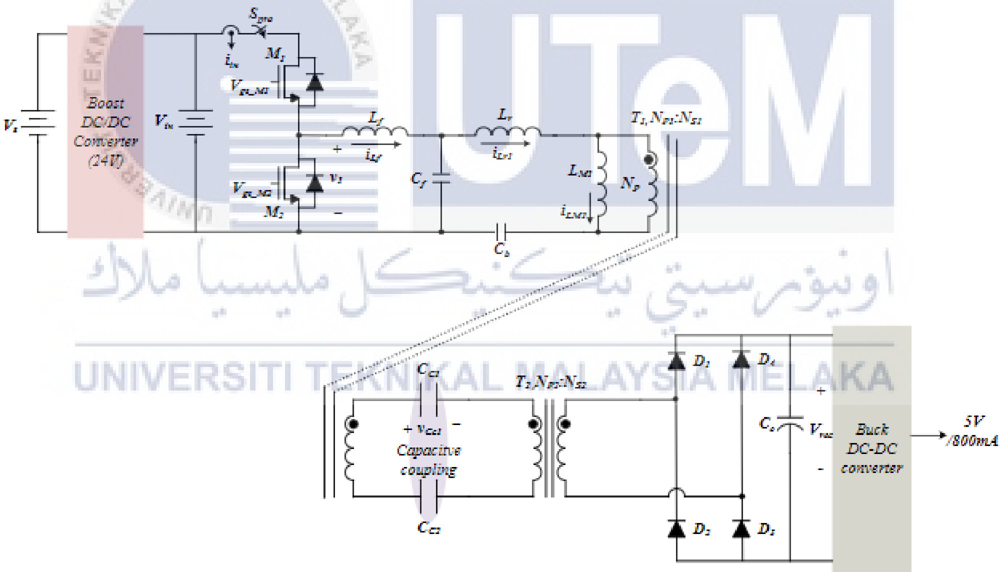


Figure 2.8 Prototype of Capacitive Power Transfer [34].

In essence, capacitive power transfer transmits energy through electric fields. The transmitter has a capacitive plate that generates an electric field and stores electrical energy. The electric field is captured by a capacitive receiver in the receiver, which converts it into usable power. The power source's electrical energy is transformed and purified. Electric fields enable power transmission, making it possible for the device that transmits to successfully send wireless energy to the receiving device[35].

Capacitive power transfer (CPT) technologies have revolutionized electrical power transmission by providing a wireless option to conventional cable systems. These systems function by transmitting power through an electric field, doing away with the necessity of physical cables and connectors. CPT systems are excellent at delivering power over short to medium distances because they are tuned for efficiency in the radio frequency spectrum. Because of their efficient energy conversion and low power losses, they can perform on par with traditional wired systems even with less physical infrastructure[35].

CPT systems prioritize safety by eliminating direct electrical contact in power transfer. Transmission occurs through an electric field between the signaling device and receiver, minimizing the risk of shock and eliminating the need for physical isolation[35], [36]. CPT systems are scalable, adaptable to diverse power requirements, and can handle higher power levels by adjusting capacitive plates or frequency[38]. Unlike inductive coupling methods, CPT systems offer enhanced alignment tolerance for spatial separation, reducing waste from physical connectors and cables and positively impacting the environment. The variation between a simple layer aluminum plate and a combined shielding design using a double-layer aluminum plate is demonstrated by one of the simulations performed in Figure 2.9 [39].

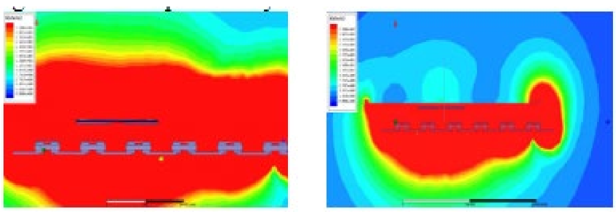


Figure 2.9 (a) Simple layer aluminum shielding. (b) Two-layer aluminum plate shielding [39]

Despite being well-known for their benefits in wireless power transmission, capacitive power transfer (CPT) devices have certain drawbacks and difficulties. The impartial analysis of these problems in this paper gives readers a thorough grasp of the problems and possible fixes related to capacitive power transfer devices[40].

The limited operational range of CPT systems is one of its main drawbacks. Because capacitive coupling operates best at short to medium distances, power transmission efficiency decreases as the distance between the sender and receiver grows[41]. Another issue with CPT systems operating at high frequencies is the possibility of electromagnetic interference (EMI), which could harm adjacent electronic equipment. Impedance matching, operating frequency, and capacitance values must all be carefully considered to maintain good power transfer efficiency and system stability[42].

Additionally, capacitive power transfer systems operate at high voltages, raising safety concerns despite implemented precautions. To mitigate electrical risks, proper insulation, grounding, and protective measures are crucial. In conclusion, while capacitive power transfer devices excel in wireless power transmission, addressing challenges such as limited operating range, sensitivity to environmental factors, potential EMI, system complexity, and safety risks from high voltage is essential for improving their durability and effectiveness[43].

2.6 Shielded Capacitive Power Transfer System

The Shielded Capacitive Power Transfer circuit can be configured into both symmetrical and asymmetrical setups. The symmetrical configuration as in Figure 2.10 offers stability in handling load changes, while the asymmetrical setup is advantageous for its lightweight nature on the receiver side[44]. For optimal performance, both symmetrical and asymmetrical S-CPT systems need to be designed with resonance and matching conditions as key considerations. In resonance, the S-CPT system exhibits a total impedance consisting of a resistive part with zero reactance, and in matching conditions, the total admittance is set to 0.01 to facilitate the transfer of maximum power[40].

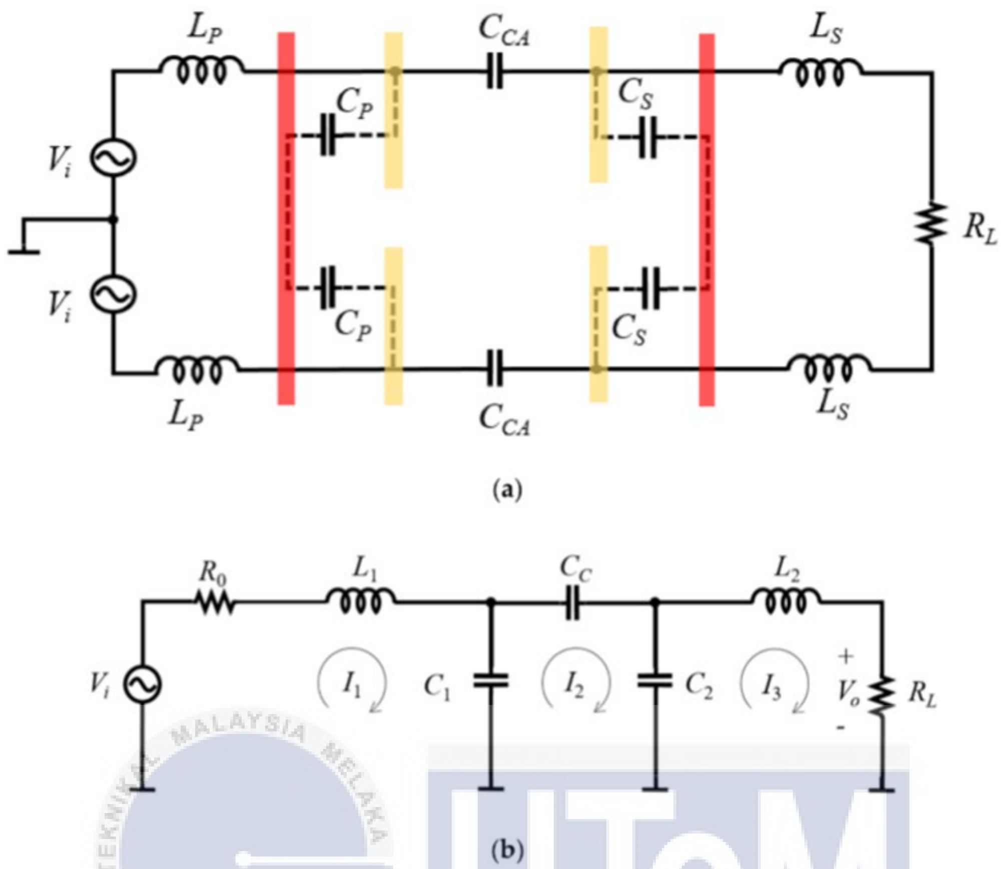


Figure 2.10 Diagram of S-CPT. (a) Configuration of Symmetrical S-CPT Circuit. (b) The equivalent circuit represents the symmetrical S-CPT circuit.

The component arrangement in the S-CPT system is shown in Figure 2.10(a). It shows a voltage input (Vi), a load resistance (RL), and a capacitive structure with six coupler plates[45]. The capacitance model only takes into account the parasitic capacitance between the coupler and shielding plate, as well as the primary coupler to the secondary coupler. It leaves out other parasitic features such as edge side-to-side capacitance and cross-coupling capacitance[44], [45]. Here, the capacitance between the primary and secondary coupler plates is indicated by the symbol Cc. While the coupler and shielding plate are involved in the parasitic capacitance at the secondary (CS), they are also involved in the parasitic capacitance at the primary (CP). On the primary side is the inductor (LP), and on the secondary side is the load (RL).

The symmetrical configuration shown in Figure 2.10(a) is represented by the equivalent circuit of S-CPT in Figure 2.10(b). In this case, R0 stands for the power source's internal characteristic. The S-CPT coupler structure, which consists of two shield plates and four coupler plates, is shown in Figure 2.11(a). The coupler's equivalent circuit is then shown in Figure 2.11(b), where capacitance C1 represents the total series capacitance CP on the primary side.

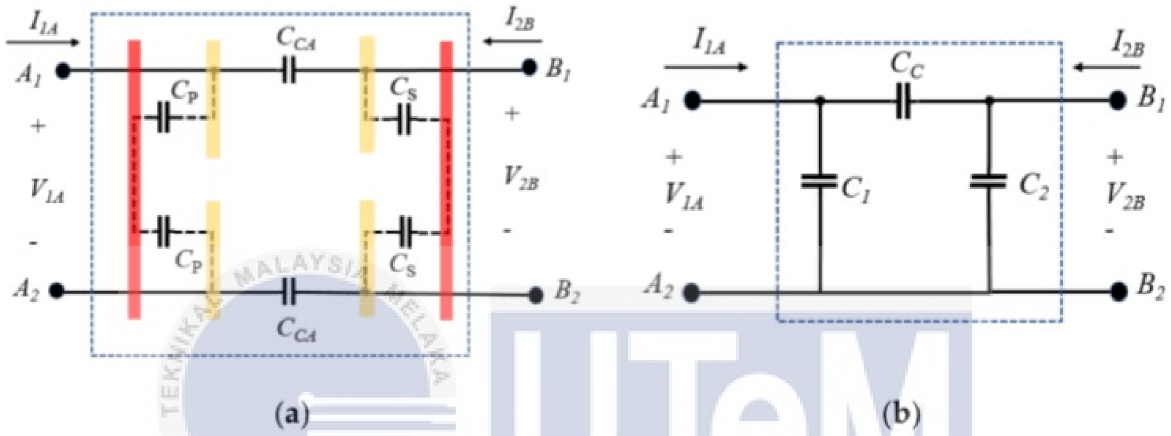


Figure 2.11 S-CPT coupler: (a) Coupler incorporating the capacitance model. (b) Equivalent circuit representing the coupler.

The secondary capacitance, denoted as C2, is equivalent to the overall series of the inductor CS. To determine the capacitance parameters illustrated in Figure 2.11(b), the two-port network method is employed. It is assumed that both circuits in Figure 2.11(a) and Figure 2.11(b) share the same ABCD transmission parameter matrix, as expressed in Equation (2.1) with s =j*ω, where ω is the angular frequency. Solving both circuits in Figure 2.11 through a MATLAB simulation with identical ABCD matrix parameters implies that Equation (2.2) yields the coupling capacitance Cc, while Equations (2.3) and (2.4) provide the primary and secondary capacitances, respectively.

$$\begin{bmatrix} V_{1A} \\ I_{1A} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_{2B} \\ I_{2B} \end{bmatrix} \tag{2.1}$$

$$C_C = \frac{C_{CA}}{2} \tag{2.2}$$

$$C_1 = \frac{C_P}{2} \tag{2.3}$$

$$C_2 = \frac{C_S}{2} \tag{2.4}$$

When the inductor L1 is introduced into the primary circuit, as depicted in Figure 2.10(b), the inductor in Figure 2.10(a) becomes half of L1 due to the equivalence of total inductance in both circuits[44]. In simplified terms, LP is expressed as 0.5 times L1, and LS is represented as 0.5 times L2. On the secondary side, the secondary capacitance C2 and secondary inductor L2 are characterized by the total series capacitance C2 and twice the value of the secondary inductor LS. Consequently, the equivalent circuit in Figure 2.10(b) is derived from Figure 2.10(a) based on these parameter relationships[44].

The ratio of the secondary capacitor C2 to the primary capacitor C1 is expressed as r=C2/C1, and the relationship between the coupling capacitance and the shield coupler is given by a = 1 + C/Cc + 1/r. The operating frequency is denoted by f, and the angular frequency is ω = 2πf. The value C is equivalent to the primary capacitance, C = C1.

In the symmetrical configuration, the primary inductor L1 is equivalent to the secondary inductor L2, and the capacitance of the shield plate at both the primary and secondary sections is identical, denoted as C=C1[45]. The ratio of the primary capacitance to the secondary capacitance is represented by r = 1. Consequently, the calculated inductor value, determined using Equation (2.2) under resonance conditions, is derived in Equation (2.5). The computation process was carried out using a MATLAB simulation[44].

$$L_1 = L_2 \frac{(C + C_C}{(C^2 + 2C_C C)\omega^2} \tag{2.5}$$

Equation (2.5) illustrates the connection between the inductor and other parameters, highlighting that the symmetrical circuit can yield three potential inductor values, forming three symmetrical S-CPT topologies[44], [45]. According to Equation (2.5), one of the S-CPT systems exhibits no correlation between the RL load and the inductor value, while the other two systems display such a relationship. Building upon the analysis of symmetrical S-CPT, these topologies can be transformed into asymmetrical configurations[44], as depicted in Figure 2.12.

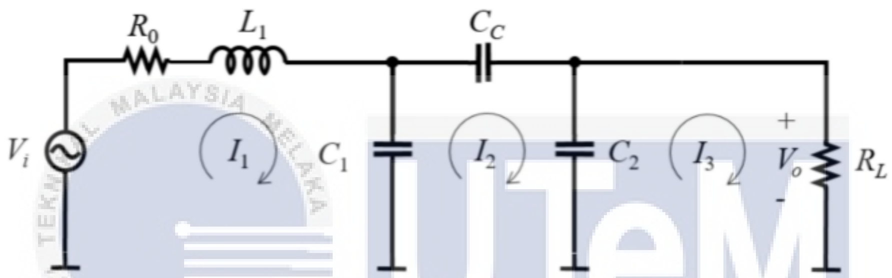


Figure 2.12 An equivalent of asymmetrical S-CPT.

Figure 2.12 illustrates an asymmetrical S-CPT configuration where the primary inductor L1 is coupled with shield plate capacitance C1 and C2, along with coupling capacitance CC, without any inductance on the secondary side.

2.7 Comparison of IPT, Hybrid and CPT

Table 2.1 Comparison of IPT, Hybrid, and CPT

Item	IPT	Hybrid	CPT
Cost	High Cost [23]	Low cost [29]	lower cost than IPT and hybrid [46]
Size and weight	320 × 450 mm [41] Heavyweight [41]	500 × 500 mm [29] Light-weight [29]	170 ×100 mm [42] light weigh [36]
Power and Efficiency	10W, 85% [41] 300W, 85% [41]	4.3W, 50%[25] 200W, 89% [29] 1.1kW, 91.9% [29]	160W, 88.2% [36] 330W, 90% [36] 1kW, 90% [36] 2.57kW, 89.3% [36]

2.8 Various applications on CPT

Table 2.2 Example Application on CPT

Application	Year	Frequency	Power	Efficiency	Citation
Charging Smart Phone Receiver	2018	6.78MHz	5W	68~80%	[3]
Electric Vehicle	2017	40kHz	3.6kW	91%	[15]
Electric Vehicle	2017	79kHz	7.6kW	96%	[15]
Electric Vehicle	2017	1MHz	2.4kW	90.8%	[15]
Electric Vehicle	2017	1MHz	2.2kW	85.87%	[15]
Electric Vehicle	2017	250kHz	1kW	94%	[15]
Electric Vehicle	2017	1MHz	3kW	94.45%	[15]

Autonomous underwater vehicles (AUVs)	2021	500kHz	226.9W	91.3%	[42]
Battery Charger	2017	6.78MHz	2.68W	91.4%	[47]
Drone	2017	2.3GHz	5W	72%	[48]
Drone	2020	85kHz	450W	±80%	[49]
Drones	2017	6.78MHz	12W	+50%	[48]
Electric Vehicle	2020	85kHz	11kW	90.8%	[50]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will go over the procedures and approaches used in the creation of a shielded coupler operating at 6.78 MHz for wireless energy transfer through capacitance. The main focus of this discussion will be on using a shielded coupler at a frequency of 6.78MHz to achieve high efficiency in wireless power transfer. High efficiency and dependable wireless power transfer at the desired frequency can be achieved by combining design analysis, simulation, prototyping, testing, and software integration. The LTspice software will be used in this project, which will be suitable to guarantee its success.

3.2 Justification for sustainable development on CPT

Shielded couplers for capacitive wireless power transfer offer significant environmental benefits, which support their continued development. According to Figure 3.1 of the Sustainable Development Goals, the project supported Goal No. 7 because electric vehicles use clean energy. Not only that, but CPT also backed Goal 12 of the Sustainable Development Goals because it would decrease electronic waste. By eliminating the need to make and dispose of physical connectors and cables, these couplers offer a more environmentally friendly alternative by reducing resource consumption and the generation of electronic waste. Conventional connectors and cables harm the environment throughout their lifetime because they demand the extraction of non-renewable resources. Shielded couplers assist in minimizing these environmental effects by eliminating the need for these physical components. Furthermore, the environmental advantages of shielded couplers are strengthened by their promotion of clean energy sources and energy efficiency. Due to their ability to reduce energy losses during wireless power transfer, these couplers maximize energy use while also reducing greenhouse gas emissions. In addition, by aiding the transition to a future with less polluted, more environmentally friendly electricity, enabling wireless charging through the use of renewable energy contributes to sustainable development objectives. Due to these positive effects on the environment, the creation of shielded couplers for capacitive wireless power transmission serves as an illustration of how to use green technologies to promote resource conservation, waste reduction, and climate change mitigation.

Figure 3.1 Sustainable Development Goals

3.3 Methodology

The General block diagram of the capacitive wireless power transmission for the charging system is presented in Figure 3.3, showcasing the fundamental components and connections within the system. Moving forward, Figure 3.4 provides a detailed block diagram specifically focused on the experimental setup for S-CPT (Capacitive Power Transfer) as observed on NanoVNA (Vector Network Analyzer).

Expanding our view into the Benchwork environment, Figure 3.5 elucidates the Block diagram of the S-CPT experimental setup, offering insights into the practical implementation and configuration of the system. Further, in Figure 3.6, the Block diagram of the Class-E Inverter for the experimental setup is illustrated, providing a comprehensive overview of the inverter component within the larger framework.

The creation and testing of each model were undertaken independently, emphasizing a meticulous approach to ensure the accuracy and reliability of the results. The design process for each model adhered to a systematic flowchart, as depicted in Figure 3.2, guiding the researchers through a step-by-step procedure.

Upon the confirmation of the primary model's results, a crucial phase ensued where all individual components were seamlessly integrated into a cohesive subsystem. This integration allowed for a holistic evaluation of the entire system's performance. The simulation of this consolidated subsystem was conducted using LTSpice, a powerful tool for circuit simulation, and the output data were thoroughly examined to validate the effectiveness of the design.

It is imperative to note that the project encompasses both software and hardware research, underscoring a multidimensional approach. The software aspect involves the utilization of simulation tools like LTSpice, while the hardware research involves the practical implementation and testing of the capacitive wireless power transmission system. This dual-focus strategy ensures a comprehensive understanding and validation of the proposed system across different domains, contributing to the robustness and reliability of the overall research endeavor.

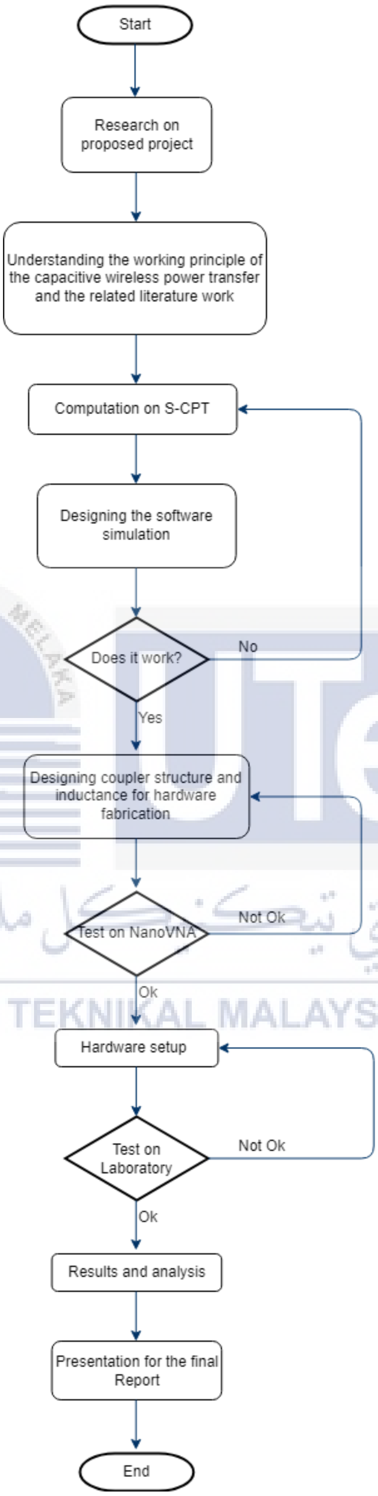


Figure 3.2 Flow chart of the capacitive wireless power transfer project.

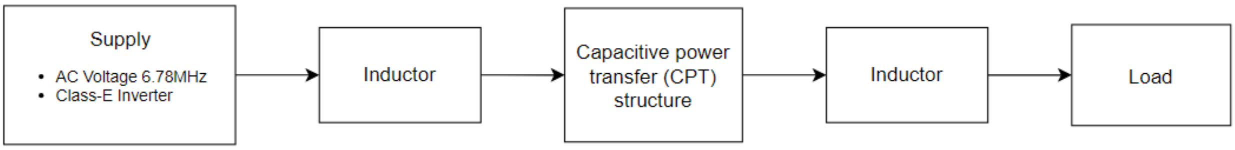


Figure 3.3 General block diagram for the experimental setup.

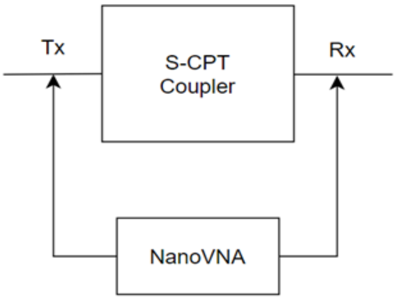


Figure 3.4 Block diagram of S-CPT experimental setup on NanoVNA

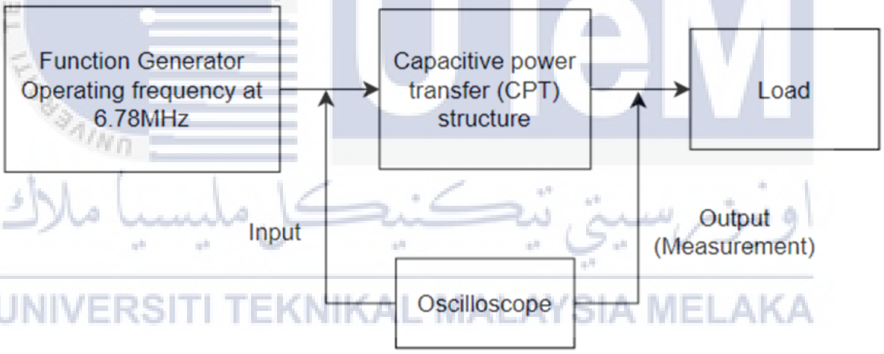


Figure 3.5 Block diagram of S-CPT experimental setup in Benchwork

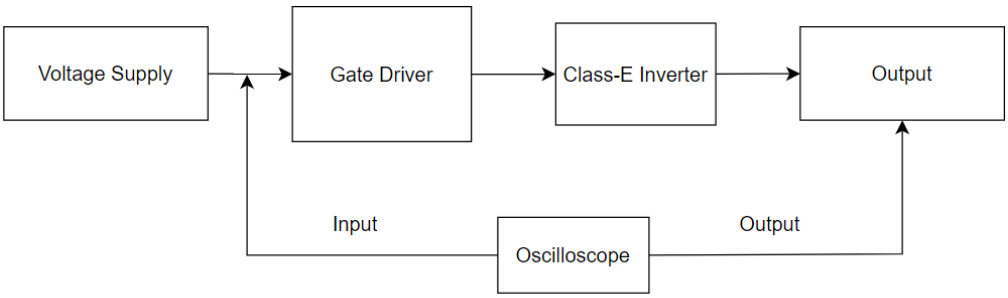


Figure 3.6 Block diagram of Class-E Inverter for experimental setup

3.4 Computation on S-CPT

Circuit modeling is the process of constructing a mathematical representation of an electrical circuit to understand its behavior and assess its performance. It makes it possible for scientists and engineers to model circuit behavior. Without actually building the circuit, this report evaluates various design options using circuit modeling.

3.4.1 Shielded Capacitive Power Transfer

The size of the object that needs to be charged is a limiting factor in the shielded CPT design. As can be seen in Fig. 3.7, four pairs of coupling plates are mainly used to construct shielded CPT, which acts as an interface for power transmission throughout the receiver and the transmitter. An extra plate is positioned behind the couplers as a shield to reduce on electromagnetic emission of the CPT system. A simplified shielded CPT model will be used for the simulation.

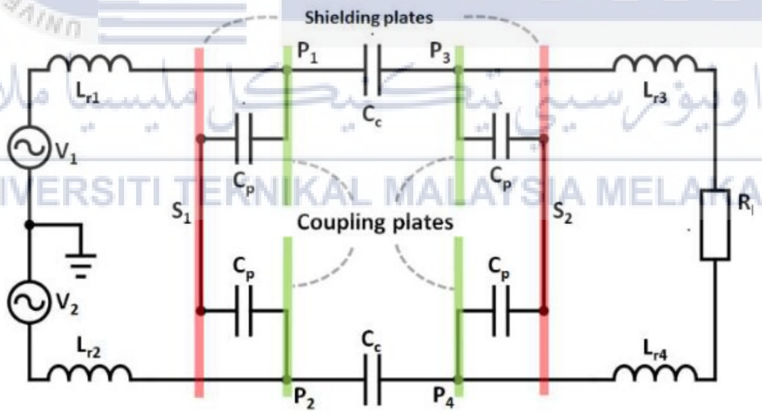


Figure 3.7 Structure model of shielded-CPT

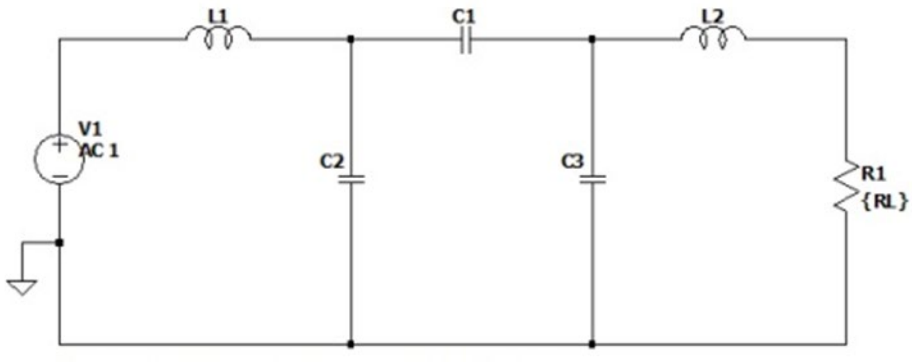


Figure 3.8 Simplified model of shielded-CPT coupling structure

The project can now proceed with the calculation for the coupling capacitance (CC) and parasitic shield capacitance (C2 and C3) based on Figure 3.8 thanks to the overlapped surface area of the plate that has been researched. Theoretically, the capacitance (Cx, which stands for CC and C1) between two plates can be calculated as

$$Cx = \frac{K(Eo)(A)}{D} \tag{3.1}$$

Cx: Capacitance, in farad (F)

Eo: 1

K: dielectric constant (8.854x10-12 F/m)

A: Area, mm²

D: The vertical gap distance between the plates, mm

Where the relative dielectric constant of the material utilized between the plates is 1, and Eo and K stand for the vacuum dielectric constant (8.854x10-12 F/m), respectively. A and D, respectively, stand for the overlapping surface area of the plates (mm^2) and the vertical gap distance between the plates.

Table 3.1 Parameters of the coupling saiz

Load	Parameter		
	Length (mm)	Width (mm)	Overlapping surface area of the plates (mm^2)
Drone 1	90	80	7200
Drone 2	110	110	12100
Phone	160	70	11200
RC Car	80	70	5600

3.4.2 Resonant Inductance

Assumedly, the size and placement of the coupling structure are symmetrical. Additionally, the parasitic capacitance C1 and C2 values provided by the coupling plate and shield plate are nearly identical. This system makes use of a L network with series inductance. Inductors are also added to two locations, to put the L onto the connection plate, placing one on the side that transmits and the other on the receiving side. Modeling of the simplified shielded-CPT coupling structure is shown in Fig. 3.6. Matching network L's inductance can be thought of as

$$L = \frac{(C + Cc)}{(C^2 + 2Cc \times C)w^2} \quad (3.2)$$

L: Inductnce, in hertz (H)

C: Parasitic shield capacitance

CC: Coupling capacitance

ω: $2\pi f$, where f = 6.78 MHz

When w is 2f, f is resonance frequency, C is the equivalent parasitic shield capacitance, coupling capacitance, and Cc is for coupling capacitance. For the inductance of matching network L in the secondary side, shielded-CPT can be used with the same equation or equivalent with the inductance in the primary side shielded-CPT.

3.5 Development of the S-CPT model in the software stage

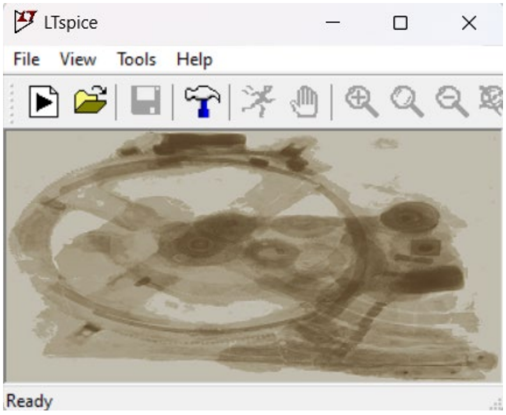


Figure 3.9Ltspice Illustration [51]

To simulate electronic circuits, such as those depicted in Figure 3.9, a program called LTspice from Linear Technology is frequently used. Engineers and electronics enthusiasts can simulate and analyze the behavior of electronic circuits before building physical prototypes. LTspice supports circuit designs for analog, digital, and mixed-signal applications. Users can create and edit circuit schematics using a graphical user interface or by writing netlists. Just a few of the many components that are available in the software include transistors, operational amplifiers, inductors, resistors, capacitors, operational amplifiers, and digital logic gates. In the electronics industry, the software is frequently used for circuit design and verification, component value selection, examining the behavior of circuits under various conditions, and circuit troubleshooting [51].

It is an effective tool that gives engineers of all levels a practical and affordable way to iterate and improve circuit designs. Figure 3.10 shows the circuit simulation for hardware fabrication using LT Spice. Meanwhile, Figure 3.11 shows the simplified circuit that has been proposed for the simulation.

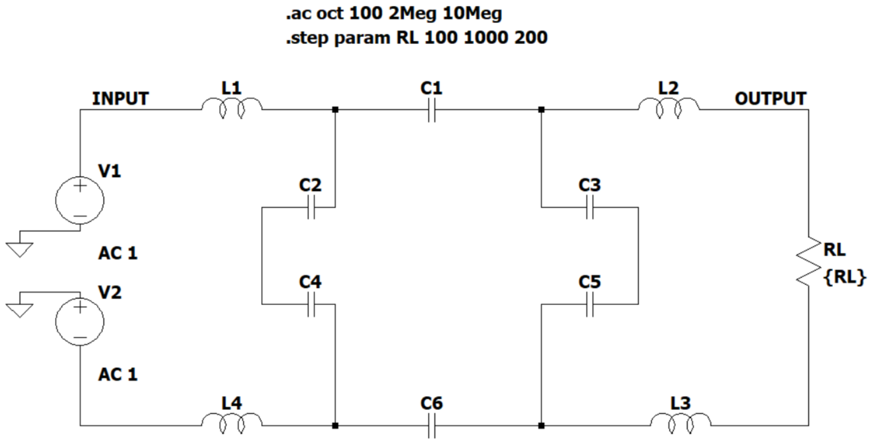


Figure 3.10 The proposed capacitive wireless power transfer model for hardware fabrication.

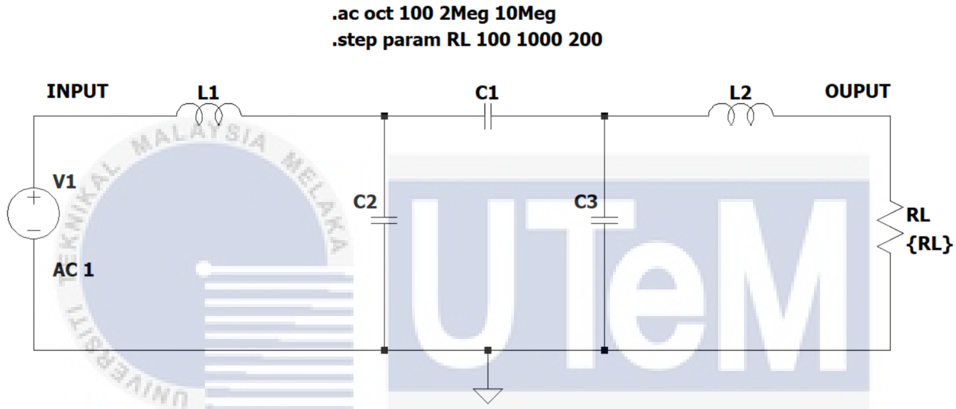


Figure 3.11 The proposed capacitive wireless power transfer model for software requirement.

All the relevant parameters are listed in Table 3.1, and Equations 3.1 and 3.2 are applied to determine the values of the capacitor and inductor in the circuit simulation indicated in Figure 3.10 and Figure 3.11. Because the circuit components are precisely configured thanks to this algebraic method, the simulation results are more accurate and reliable. The simulation process is made more defined and methodical by methodically calculating the values based on the given equations and consulting the detailed parameter table. This enables well-informed decision-making in the circuit's design and analysis as well as a deeper understanding of the behavior of the circuit.

3.6 Development of the S-CPT model in the hardware stage

The suggested shielded CPT structure is built with two additional plates behind each side, resembling a typical CPT coupling-plate interface. The coupling structure creates a six-plate CPT system made up of a shielding component and a power transfer component. In this setup, the circuit parameter as shown in Table 3.2 is tuned to the necessary power and efficiency, and the coupling's size and distance are taken into account about the air breakdown voltage safety level and the EF stray. Through field simulation and hardware experiments, the EF-emission characteristic was observed by introducing the extra plates. When compared to the four-plate systems in these investigations, the six-plate CPT system demonstrates, as in Figure 3.12, a significant decrease in EF emission. From the four simulations that have been made, only one has been chosen for the hardware implementation.

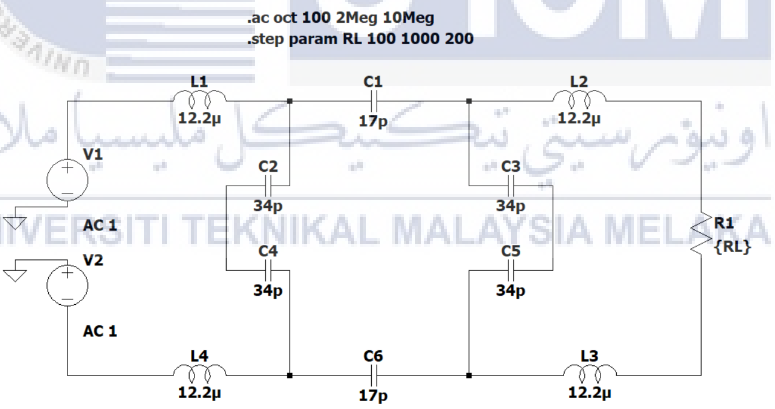


Figure 3.12 LT Spice circuit schematics of 6.78 MHz capacitive wireless power transfer prototypes.

Table 3.2 Parameter for experiment specification

Symbol	Description	Value	Unit
$C1$, C6	Coupling capacitance	17	pF
$C2$, C3, C4, C5	Parasitic shield capacitance	34	pF
L	Inductance	12.2	μH
f	Switching frequency	6.78	MHz
A	Area	11000	mm^2
s	Separation distance	5	mm

3.6.1 Power Source DC Voltage

A variety of electronic devices and DC motors are powered by direct current voltage, also known as DC voltage Source just like in Figure 3.13. This dependable and unidirectional electrical voltage is also known as DC voltage. Unlike Alternating Current (AC) voltage, which occasionally changes direction, DC voltage provides a steady and reliable flow of electrical energy in one direction. Applications requiring a constant voltage source, such as battery charging, electronic circuits, and motor control, are ideal for their dependability and steadiness.

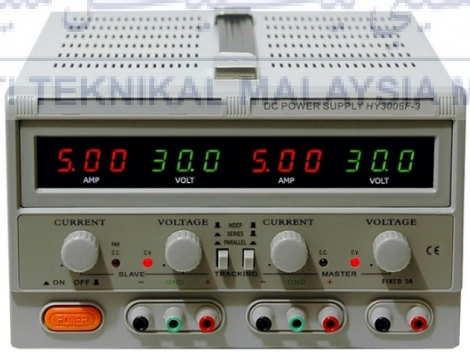


Figure 3.13 DC Voltage Source

3.6.2 Copper Plate

One of the conducting plates used to create a parallel plate capacitor, as shown in Fig. 3.14, is a copper plate. The capacitor functions as a surface for charge accumulation when a potential difference is applied across it. An increase in negative charge results from the flow of electrons onto the copper plate when a voltage is applied. The capacitor may store electrical energy because the charges build up and create an electric field between the copper plate and the other plate. Copper is frequently used to facilitate efficient charge transfer because of its excellent electrical conductivity. Additionally, copper's high thermal conductivity helps with heat dissipation.

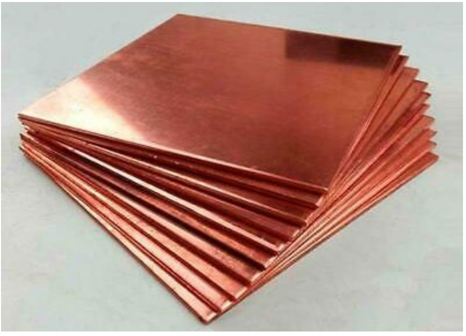


Figure 3.14 Copper Plate

3.6.3 Oscillator

An electronic circuit or device is referred to as an oscillator if it generates a repeating waveform without the assistance of an external input, as shown in Figure 3.15. To produce a periodic output signal that can be used in electronic systems for timing, communication, or sound generation, it combines several components. Oscillators are crucial for generating accurate and dependable oscillating signals in many electronic devices and applications.

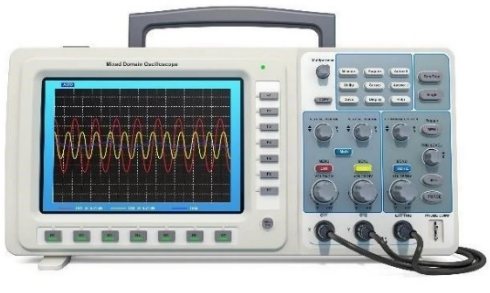


Figure 3.15 One of an Oscilloscope Device

3.6.4 Resistor

An electronic component called a resistor in Figure 3.16 regulates how much current can flow through a circuit. How much current it blocks is determined by the specific resistance value, which is expressed in ohms. Resistors are devices used in electronic circuits to divide voltage, restrict current flow, and control signal levels. They are necessary for various devices to ensure proper circuit operation and component protection.

Figure 3.16 An example of a Resistor

3.6.5 Inductor

A magnetic field is used to store energy in an electronic component known as an inductor, similar to that shown in Figure 3.18. A wire coil is wrapped around a material as the core of the device. When current passes through the coil, it creates a magnetic field that stores energy. Circuits use inductors for impedance matching, energy storage, and filtering. They are essential for many different electronic devices' performance and functionality.

Figure 3.17 A small example of an inductor

3.6.6 Coupler Structure

One crucial component that has a big impact on the effectiveness and general performance of wireless power transmission in the shielded-CPT (Capacitive Power Transfer) system is the Coupler Structure implementation as in Figure 3.19. Effective coupling of electromagnetic fields is made possible by the energy transfer between the transmitter and receiver coils, which is made possible in large part by the Coupler Structure. With a detailed plan in place and resources at hand, the project is set into motion. This phase involves the practical application of skills, knowledge, and tools to produce the desired outcome. Figure 3.18 shows the process of making a shielded CPT system. Once all components are in place and the project meets the established criteria, the final version is prepared.

Figure 3.18 The process of making a shielded-CPT system.

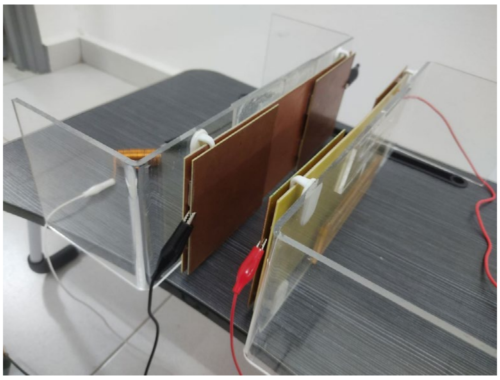


Figure 3.19 Coupler Structure implementation of the shielded-CPT system.

3.7 Experimental on S-CPT

In this experimental study on S-CPT, we systematically characterized the system's performance using a NanoVNA and experimented at benchwork, analyzing factors such as operation frequency amplitude approaching to 6.78MHz at the peak, power transfer efficiency, and voltage transferred from transmitter to receiver.

3.7.1 Experiment using NanoVNA Server

A cross-platform application called the NanoVNA saver as illustrated in Figure 3.20 enables you to store Touchstone files from the NanoVNA, sweep frequency spans in segments to gather more than 101 data points, and then view and evaluate the information that has been gathered. This program creates a connection to a NanoVNA to extract data for computer display and storage as Touchstone files. Figure 3.21 shows the setup connection of S-CPT with NanoVNA.

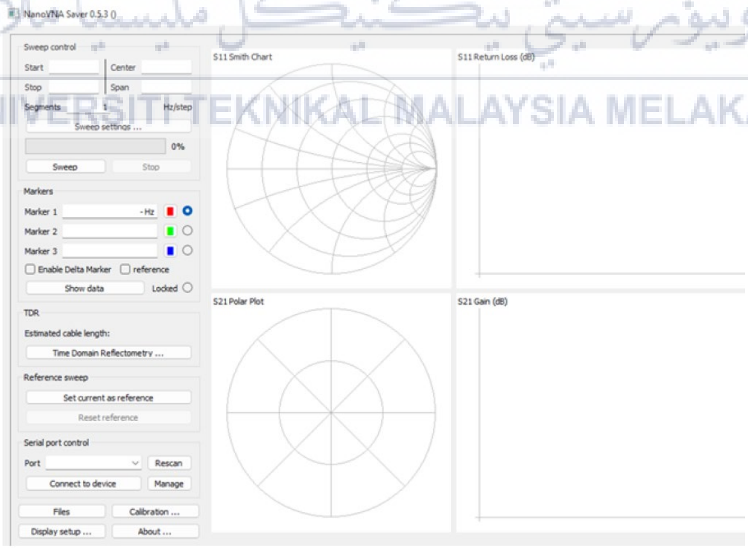


Figure 3.20 NanoVNA Saver

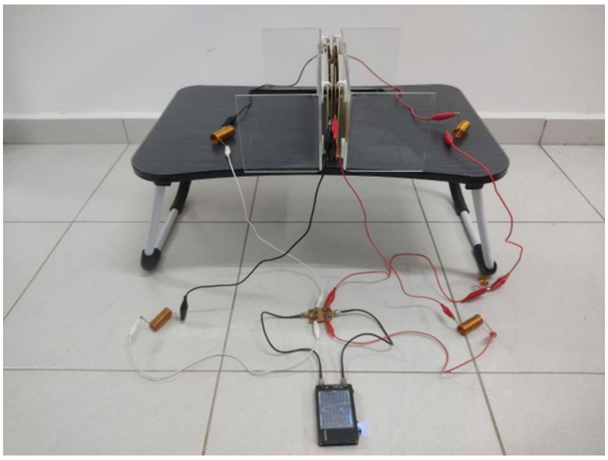


Figure 3.21 The setup connection for NanoVNA

Figure 3.21 depicts the connection made to the NanoVNA from the parallel plate to generate the required output graph, based on the block diagram in Figure 3.4. The parallel plate needs to be linked to the inductor with a crocodile clip before it can be secured to the frame. To deliver the output from the capacitive power transfer structure, the NanoVNA is linked to an SMA connection on the experimental board.

3.7.2 Benchwork Experiment

The goal of capacitive wireless power transfer experiments is to transfer electrical energy between systems in an efficient manner without the need for physical connectors. Energy transfer is made possible by electric fields between the transmitter and receiver plates via capacitive coupling. A resonant tank circuit, a high-frequency AC source, and a receiving module with a rectifier and load are all part of the setup.

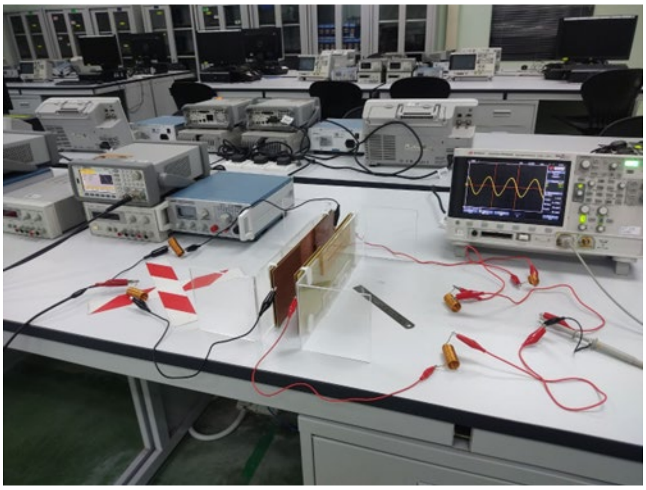


Figure 3.22 Complete circuit of 6.78MHz Shielded Coupler for Capacitive Wireless Power Transfer without inverter

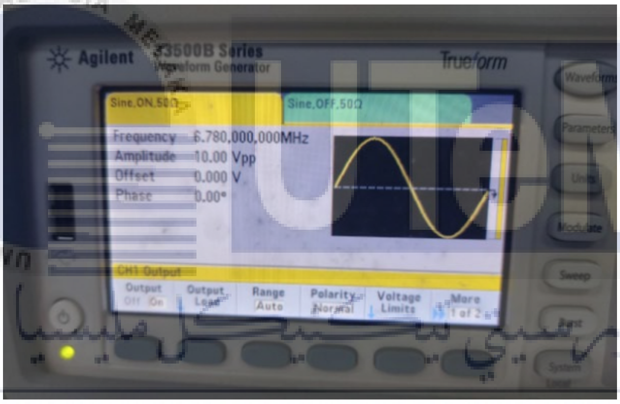


Figure 3.23 RF Signal Generator set to 10Vpp

The hardware experimental setup connection using an oscilloscope and RF Signal Generator is shown in Figure 3.22 and is followed by the block diagram in Figure 3.2. The capacitive power transfer structure has been connected from an RF Signal Generator set to 10 Vpp as in Figure 3.23. The oscilloscope's input will be connected to the input function generator, and its output will be connected to the CPT structure to obtain the desired output waveform.

3.8 Class-E Inverter as the supply

A suitable topology, component selection, control circuit design, efficiency optimization, taking safety precautions into account, PCB design, simulation, testing, iterative refinement, and documentation are all necessary when designing an inverter for capacitive power transfer (CPT). It is crucial to take into account the needs of the system, such as output power, frequency, and efficiency. A successful and optimized design requires knowledge of power electronics and circuit design. It is recommended to ask for advice and consult pertinent resources, for that reason, figure 3.24 is designed using Sofware Class-E.

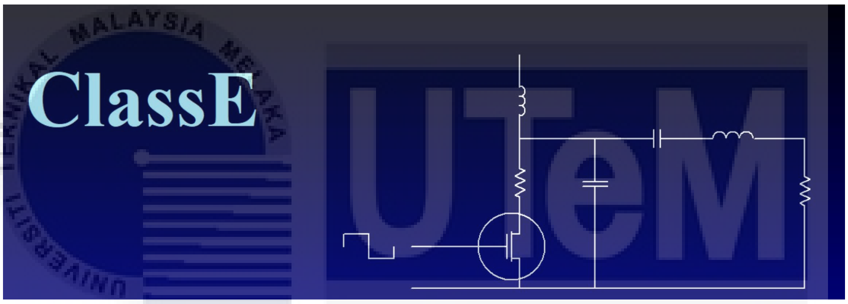


Figure 3.24 Class-E Illustration

3.8.1 Simulation for Inverter

In the simulation setup for the Class-E inverter experiment, we configured the circuit parameters, including Mosfet, capacitance, inductance, resistance, and other components. The simulation was conducted using Class-E Inverter software. The simulation as in Figure 3.25 and Figure 3.26 aimed to assess the inverter's performance under varying load conditions. Additionally, S-CPT (Shielded Capacitive Power Transfer) was incorporated into the simulation to explore potential enhancements in efficiency and performance. Comprehensive data logging was implemented to capture key parameters such as voltage, and power across the circuit components.

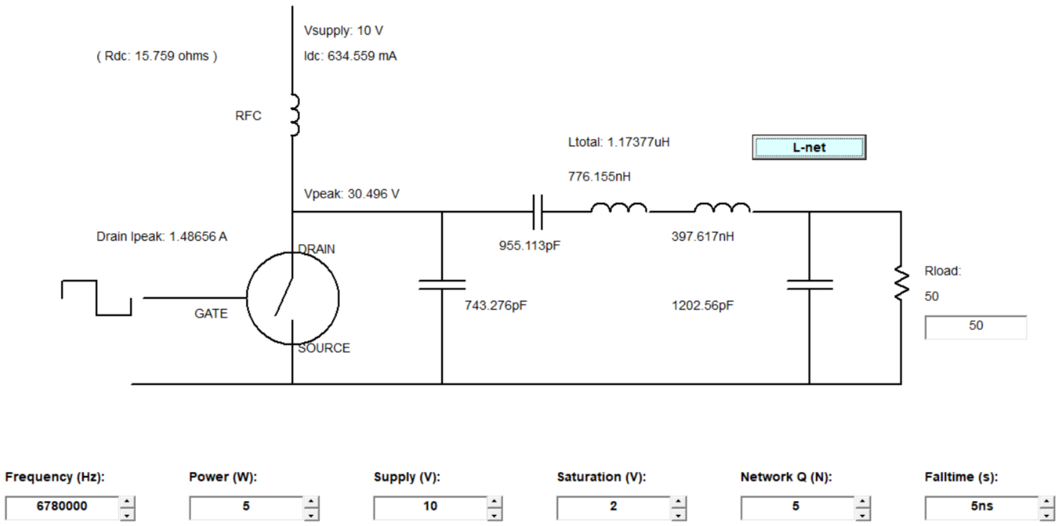


Figure 3.25 Designed Circuit for Inverter using Class-E

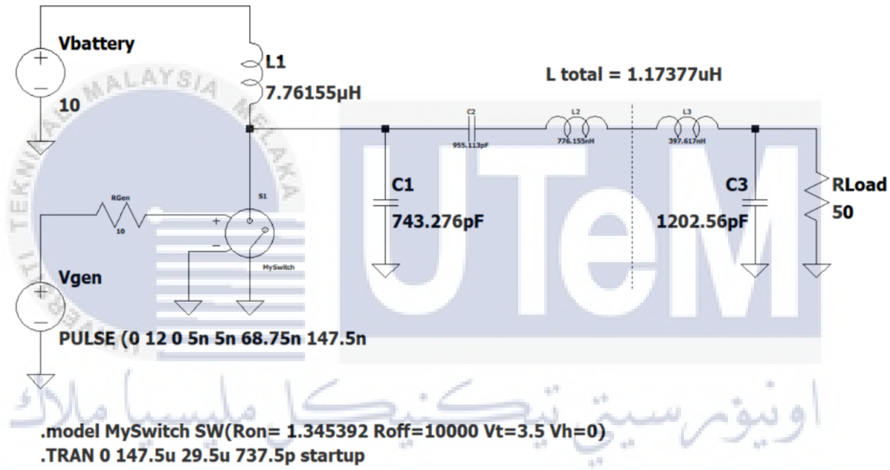


Figure 3.26 Designed Circuit for Inverter transferred to LT Spice

Due to a lack of detailed measurement capabilities within the Class-E software, we opted to transfer the circuit from the Class-E inverter circuit as in Figure 3.25 to LT Spice as in Figure 3.26. This decision was driven by the desire to take advantage of LT Spice's advanced functionality, particularly its robust simulation capabilities and comprehensive analysis tools. By utilizing LT Spice, we aimed to obtain more precise measurements and a deeper understanding of the circuit's behavior, facilitating a more thorough and accurate analysis.

3.8.2 Hardware setup for Inverter

The precise and controlled switching of power semiconductor devices at specific frequencies is achieved through the use of a gate driver in an experimental setup similar to that shown in Figure 3.27, which focuses on frequency requirements. It is essential for devices like inverters, motor drives, and frequency converters that power switches, such as MOSFETs or IGBTs, turn on and off at the appropriate frequency. The gate driver makes sure of this cause existence of MOSFET that will be used.

The hardware experimental setup with an oscilloscope and function generator for gate driver connection is shown in Figure 3.28. To function as shown in Figure 3.29, the gate driver needs a 5V input source. The oscilloscope's output will be connected to the Gate Driver structure, and its input will be connected to the input function generator in order to obtain the desired output waveform.

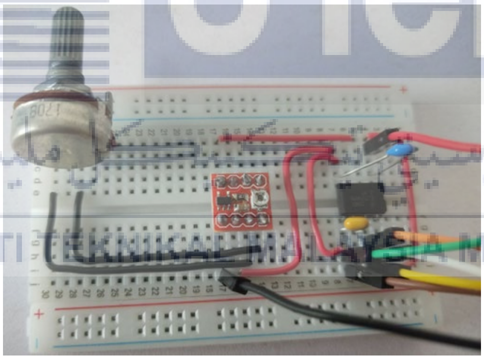


Figure 3.27 Gate Driver Circuit Design

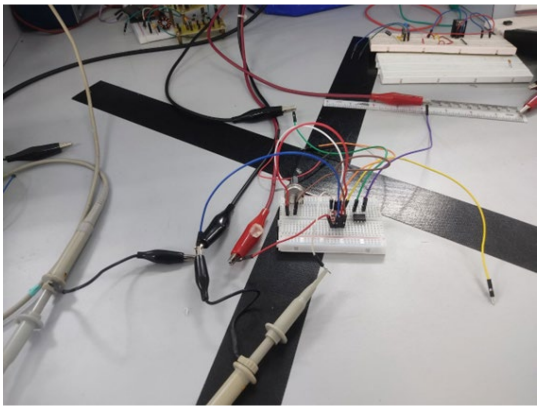


Figure 3.28 Gate Driver Circuit Design

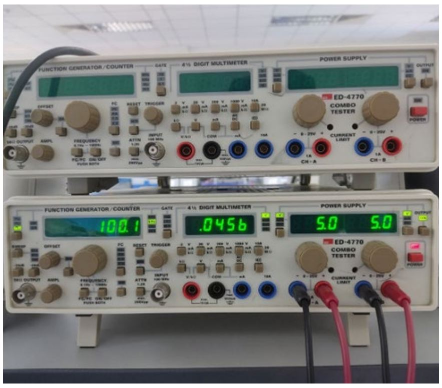


Figure 3.29 Supply for gate driver

To validate the simulations, a power converter experimental circuit has been realized. A picture of the experimental setup. An enlargement of the breadboard is shown in Figure 3.30, while the equivalent electrical schematic is shown in Figure 3.25. A 10V input source is required for the Inverter to operate as depicted in figure 3.31. To obtain the desired output waveform, the oscilloscope's input and output will be connected to the input function generator and the Inverter structure, respectively.

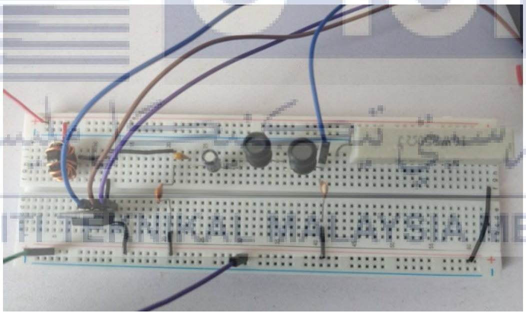


Figure 3.30 Electrical circuit connection of the inverter

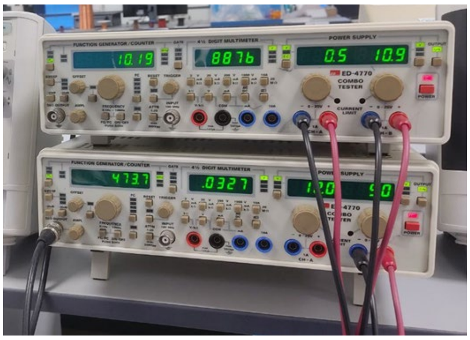


Figure 3.31 Supply for Inverter

3.9 Gantt Chart

Project handlers utilize Gantt charts to help stakeholders communicate more easily and to visually represent the project timeline, task dependencies, progress tracking, resource allocation, and planning adjustments. It gives a concise and clear summary of the project's timeline, aids in monitoring progress, identifies dependencies, and facilitates efficient resource management. Clarity is improved, decision-making is made easier, and stakeholder engagement is increased when a Gantt chart is included in a project report. Overall, a Gantt chart is used for presenting the project's schedule and timeline to ensure that the consistency and organization of the project's development will improve as the develops. Appendix A demonstrates the Gantt chart throughout the entire PSM1 and PSM2 progress.

3.10 Summary

This chapter outlines the suggested methods for the 6.78MHz shielded coupler for capacitive wireless power transfer. It involves methodically designing and evaluating the coupler's performance at the target frequency. To begin, one must be knowledgeable of the design requirements and standards, including the coupling distance and power transfer performance. The appropriate components, such as capacitive plates, shielding materials, and circuitry, are chosen to construct the shielded coupler. Testing and prototyping are carried out to make sure the design functions as intended, to evaluate the efficiency of the power transfer, and to evaluate how well it performs in various scenarios. Analysis of the experimental data is done for design optimization and improved coupler efficiency. The method aims to achieve a reliable and efficient wireless power transfer at 6.78MHz by capacitive coupling while taking into account factors like interference reduction, safety, and practicality.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The results and discussion presented in this section focus on the evaluation and analysis of a 6.78MHz shielded coupler specifically designed for capacitive wireless power transfer. The performance characteristics of the coupler have been carefully examined through experimental investigations and measurements. The results obtained give important information about the specified frequency.

4.2 Calculation Results for S-CPT

Table 4.1 shows the value of the coupling capacitance (Cc), parasitic shield capacitance (C1 and C2), and inductance (L) that have been calculated using the formula in 3.1 and 3.2 and load resistance (RL) that been used because of the selection had been made using LTSpice during the circuit design.

Table 4.1 Analysis of test parameters of the S-CPT system

Load	Parameter			
	Cc (pF)	C1 and C2 (pF)	L (µH)	RL (Ω)
Drone 1	6.37	15.9	26.9	900
Drone 2	10.7	21.4	19.3	900
Phone	9.92	24.48	17.3	900
RC Car	8.26	16.5	25	900

4.3 Simulation using LTSpice

Tables 4.2, 4.3, 4.4, and 4.5 show the preliminary result based on Ltspice showing the calculated CPT system can be used in drones, phones, and RC cars by the matching impedance amplitude approaching 6.78MHz at the peak.

Table 4.2 Drone 1's result for CPT at 6.78MHz

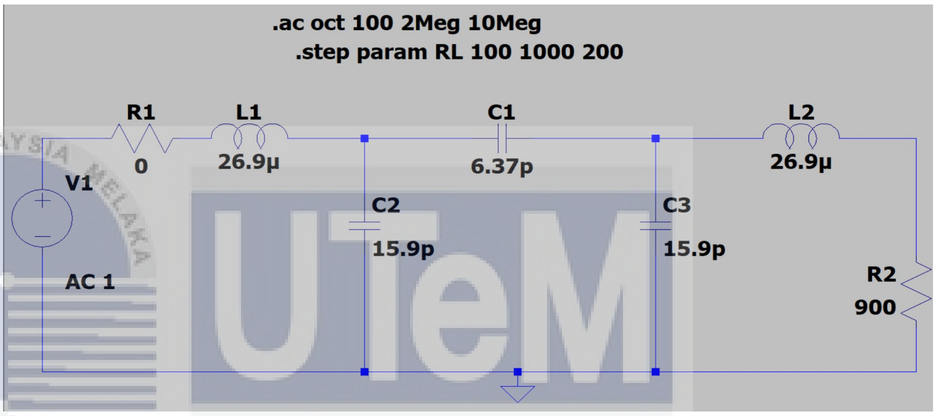
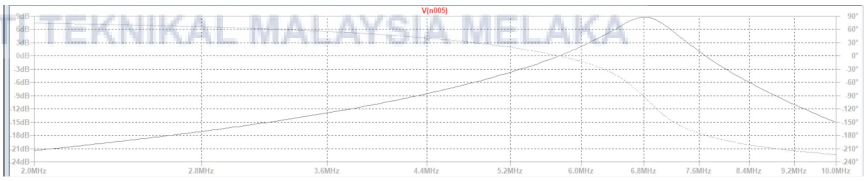
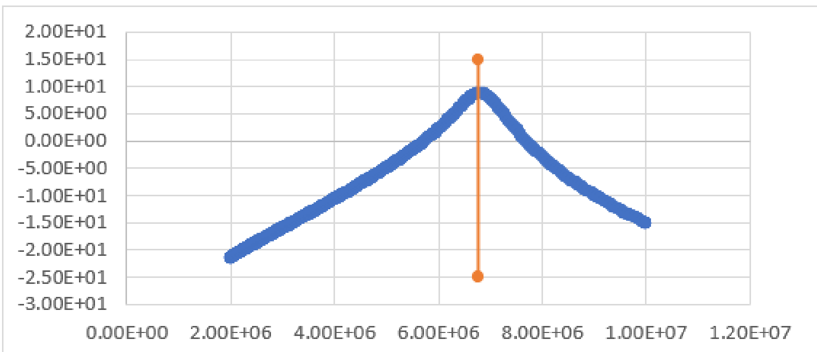
RESULTS	
DRONE 1	
Circuit Diagram	 Figure 4.1 Circuit diagram for charging drone 1 using LTspice
LT Spice simulation: Frequency response	 Figure 4.2 Results from the circuit diagram
Analysis finding: Operation frequency amplitude approaching to 6.78MHz	 Figure 4.3 Operation frequency amplitude approaching to 6.78MHz at the peak

Table 4.3 Drone 2's result for CPT at 6.78MHz

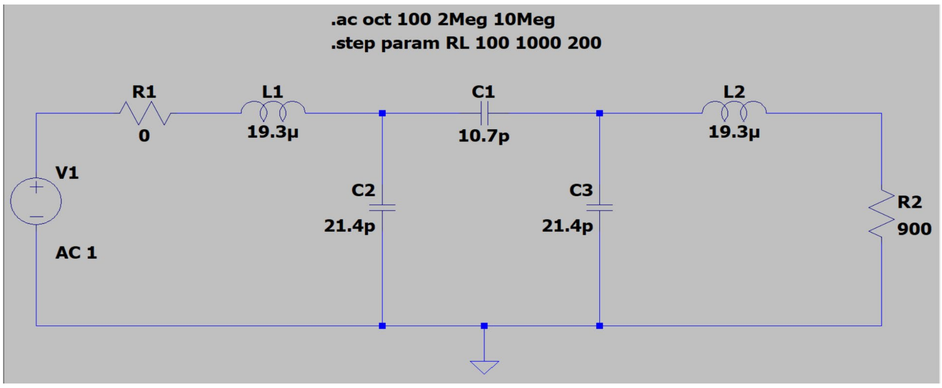
<table>
<tr><td colspan="2">DRONE 2</td></tr>
<tr><td>Circuit
Diagram</td><td>

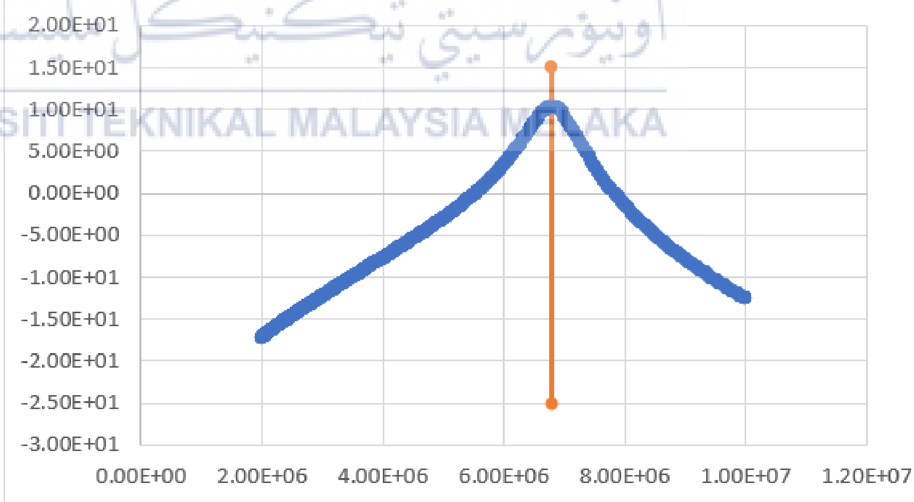
Figure 4.4 Circuit diagram for charging drone 2 using LTspice</td></tr>
<tr><td>LT Spice simulation:
Frequency response</td><td>
Figure 4.5 Results from the circuit diagram</td></tr>
<tr><td>Analysis finding:
Operation frequency amplitude approaching to 6.78MHz</td><td>

Figure 4.6 Operation frequency amplitude approaching to 6.78MHz at the peak</td></tr>
</table>

Table 4.4 Phone's result for CPT at 6.78MHz

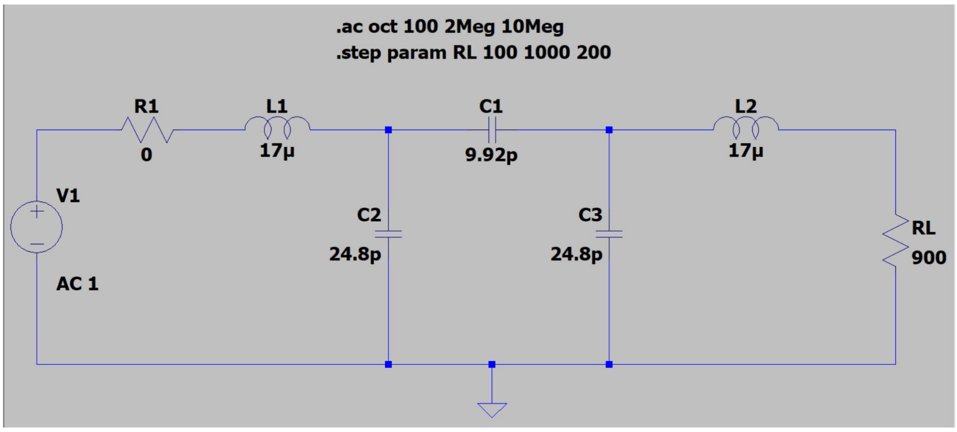
<table>
<tr><th colspan="2">PHONE</th></tr>
<tr><td>Circuit
Diagram</td><td>


Figure 4.7 Circuit diagram for charging the phone using LTspice
</td></tr>
<tr><td>LT Spice simulation:
Frequency response</td><td>

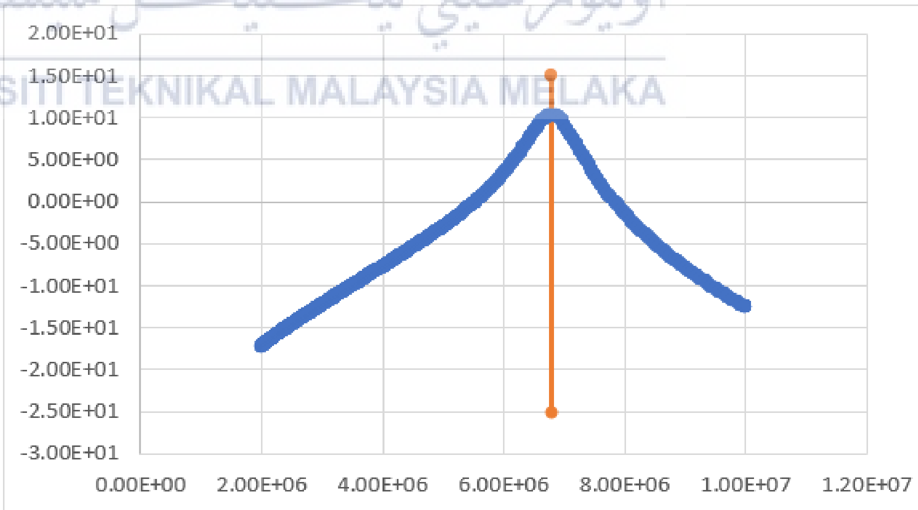

Figure 4.8 Results from the circuit diagram
</td></tr>
<tr><td>Analysis finding:
Operation frequency amplitude approaching to 6.78MHz</td><td>


Figure 4.9 Operation frequency amplitude approaching to 6.78MHz at the peak
</td></tr>
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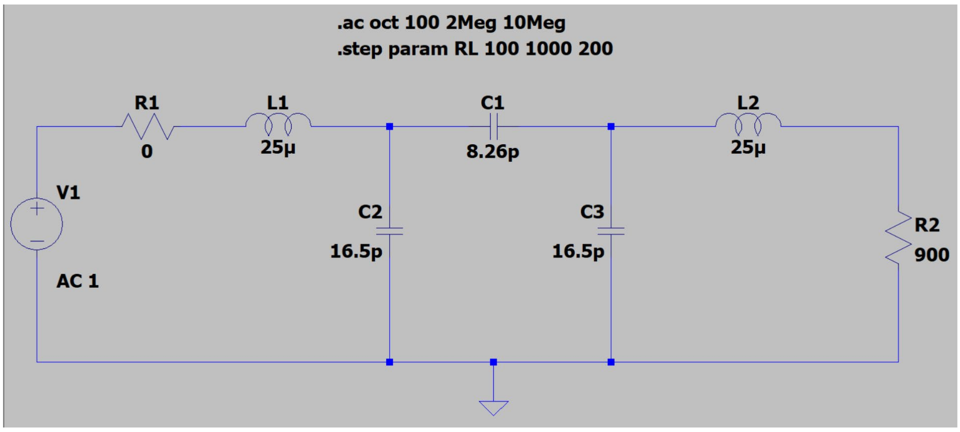
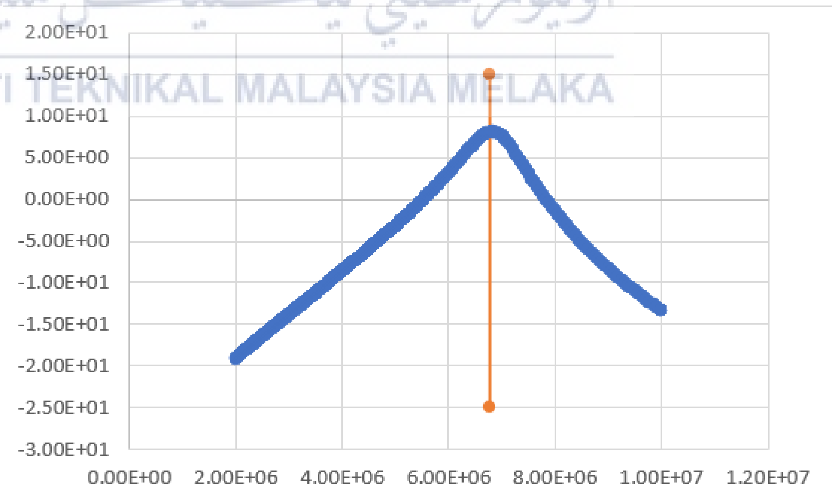
Table 4.5 RC Car's result for CPT at 6.78MHz

RC Car	
Circuit Diagram	 Figure 4.10 Circuit diagram for charging RC Car using LTspice
LT Spice simulation: Frequency response	 Figure 4.11 Results from the circuit diagram
Analysis finding: Operation frequency amplitude approaching to 6.78MHz	 Figure 4.12 Operation frequency amplitude approaching to 6.78MHz at the peak

4.4 Hardware

The validation of theoretical models and simulations is aided by hardware results. Although simulations can shed light on how well a capacitive wireless power transfer system works, real hardware tests are required to verify the accuracy of these models. Hardware results allow for the evaluation of the actual performance of a capacitive wireless power transfer system in real-world conditions. This includes efficiency, power transfer capability, and other relevant parameters. This type of design is made possible by hardware testing, allowing for adjustments and enhancements based on real performance data.

4.4.1 Results from NanoVNA

In this experiment, the analysis using the NanoVNA, aimed to achieve an Output waveform in magnitude and phase, leveraging its capabilities to measure that reaches 6.78MHz. The NanoVNA results unveiled an Output waveform in magnitude and phase achieved 6.78MHz in the CPT system based on Figure 4.13.

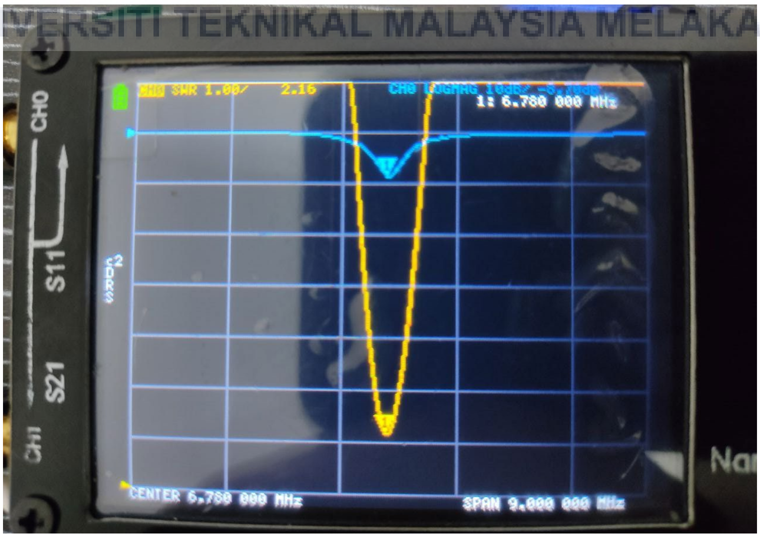


Figure 4.13 Output waveform in magnitude and phase from NanoVNA.

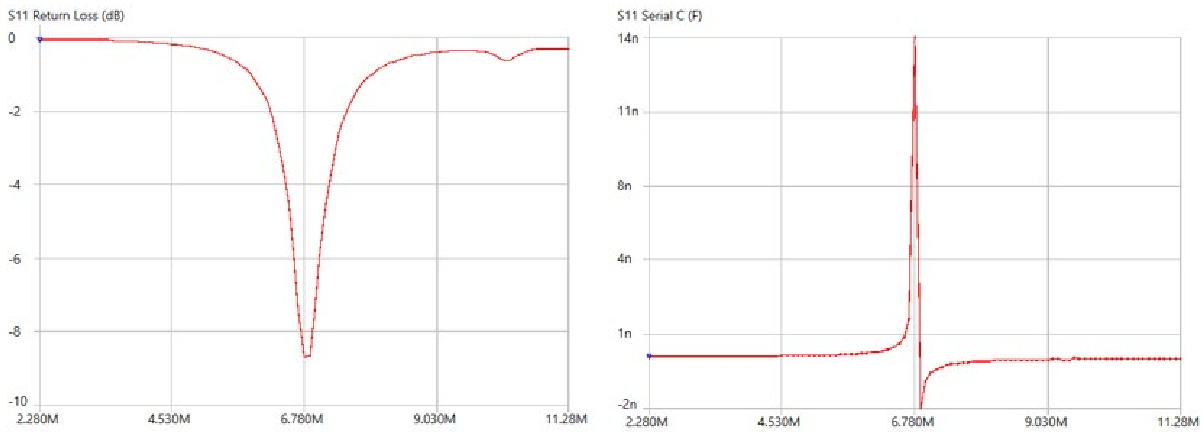


Figure 4.14 Output waveform for matching impedance and measurement of capacitor for hardware design

The matching impedance or return loss waveform, and the measurement of capacitor or Serial C, are both shown in Figure 4.14. The matching impedance and measurement of the capacitor in the S-CPT situation are 1 and 1, respectively, as is well known. But in this instance, it demonstrates that the hardware has a -8.2 matching impedance or return loss and 14nF measurement of the capacitor. It completely results in an imperfect situation, which may be caused by the hardware fabrication process's minor imprecision such as the value of the inductor may be different because it is self-rolled. Besides, it may be caused by the distance of the plate because the capacitance at the plate plays a very important role as well but the frequency that is achieved is perfect which is to be exact 6.78MHz.

4.4.2 Results from Benchwork

The experiment aimed to evaluate the voltage transfer characteristics of capacitance between the primary and secondary coupler plates. Table 4.5 presents the voltage transfer results under three different load conditions, no load, 250Ω, and 10kΩ Figure 4.15 shows graph results of voltage transferred. The voltage transfer values are measured in volts (V), and the experiments were conducted at different distances between primary and secondary coupler plates.

Table 4.6 Results of Voltage transferred

Voltage Transferred			
Distance (mm)	Load Resistor		
	No Load (V)	250Ω (V)	10kΩ (V)
5	16.7	20.7	16.5
10	7.8	12.2	7.6
15	4.5	5.23	4.78
20	3.3	3.22	3.4
25	2.49	2.31	2.63
30	1.93	1.79	2.13
35	1.59	1.51	1.83
40	1.35	1.31	1.63
45	1.07	1.13	1.45
50	920m	1.03	1.32
60	780m	940m	1.23
70	-	780m	1.17
80	-	-	1.09
90	-	-	1.03
100	-	-	920m

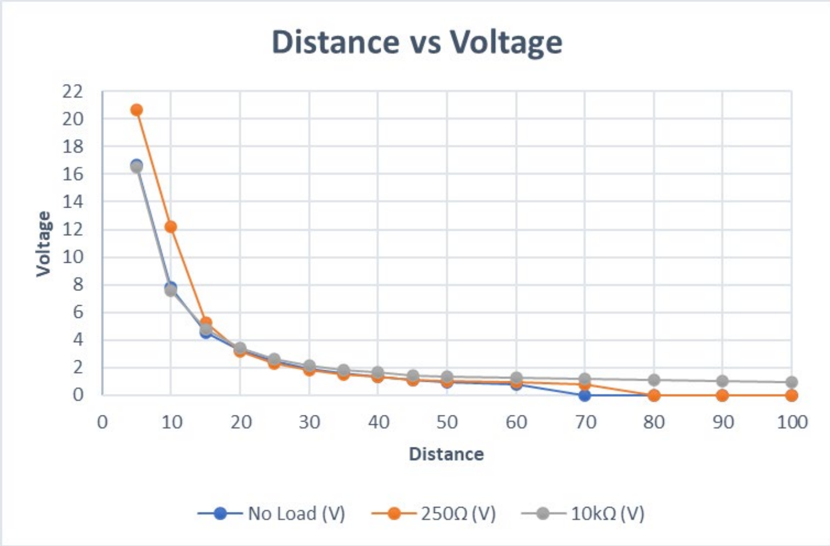


Figure 4.15 Graph Results of Voltage Transferred

Variations in voltage transfer across the various load circumstances were shown by the graph's results in Figure 4.15. For all load circumstances, voltage transfer diminishes with increasing distance. The largest voltage transfer is when there is no load, which is followed by 250Ω load and 10kΩ load. With larger loads, the effect of distance on voltage transfer is increasingly noticeable. As the distance grows, the voltage transfer drops from 16.7 V to 1.07 V when there is no load. A similar trend is observed with the 250Ω load, although with greater beginning voltages. A more gradual fall in voltage transfer is seen for a 10kΩ load, highlighting the device's resistance to drops caused by distance.

The three load circumstances' voltage transfer at different distances differs significantly, according to a statistical study. The power transmission efficiency is directly impacted by the resistance of the loads. The consequences of load resistance become increasingly noticeable as distance rises. The results are consistent with the hypothesis that lower voltage transfer, particularly over longer distances, would be produced by greater loads. Real-world fluctuations in load conditions are not taken into account, and the experiment assumes constant load resistances. at short-range applications, there may be no appropriate load circumstances, but at longer ranges, there may be improved voltage transmission with 10kΩ load conditions.

4.5 Class-E Inverter

The purpose of the experiment is to investigate of the Class-E inverter's performance, data analysis revealed a noteworthy enhancement in switching frequency unfortunately the data analysis of the Class-E inverter in conjunction with S-CPT did not exhibit a meaningful performance improvement. This unexpected result challenges the hypothesis that S-CPT would enhance the Class-E inverter's capabilities.

4.5.1 Gate Driver for Inverter

The experiment's goal was to evaluate the 6.78 MHz switching frequency. After testing, the gate driver runs reliably at 6.78 MHz at both the Mosfet driver and Oscillator as in Figure 4.16 and Figure 4.17 with a high degree of accuracy, deviating from the target frequency by no more than 0.1%. Excellent stability is demonstrated by the gate driver under a variety of working situations, such as changes in input voltage and temperature. The gate driver's stability is demonstrated by the switching frequency staying within an acceptable range.

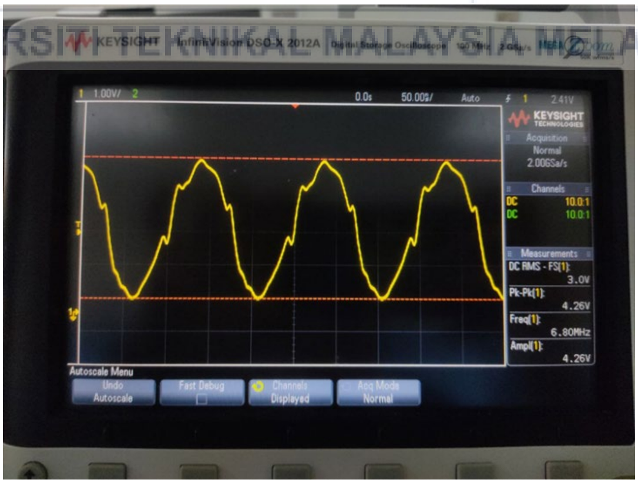


Figure 4.16 Output waveform at Mosfet Driver, EL7104

Figure 4.17 Output waveform at Oscillator, LTC1799

4.5.2 Inverter

The purpose of the experiment was to assess the output waveform for 4 different outputs, output voltage between C2 and L2 (Point A), Output voltage between L2 and L3 (Point B), Output Voltage on Gate to source Mosfet (Point 1), and Output Voltage on Drain to source Mosfet (Point 2) as in Figure 4.18 between simulation and Hardware.

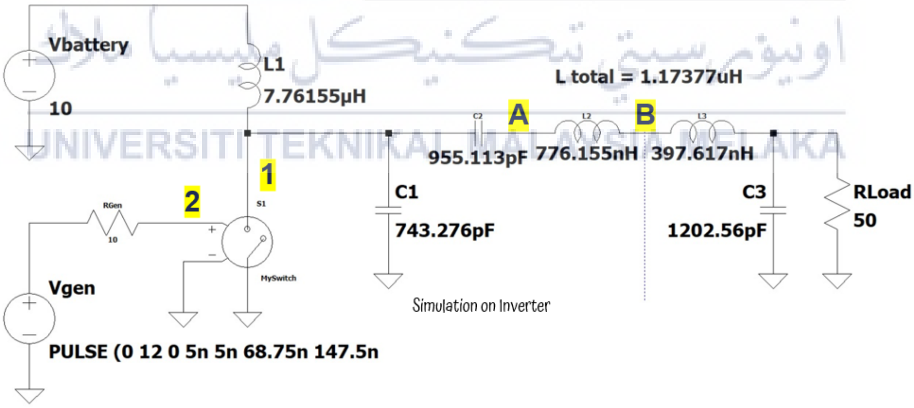


Figure 4.18 Demonstration of Output Source

Table 4.7 Results for Inverter at Output

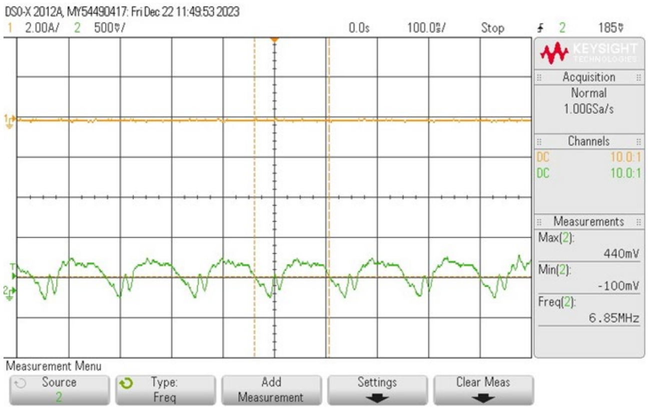
<table>
<tr><th colspan="2">Voltage Output Waveform</th></tr>
<tr><td>Output voltage between C2 and L2 for Hardware</td><td>


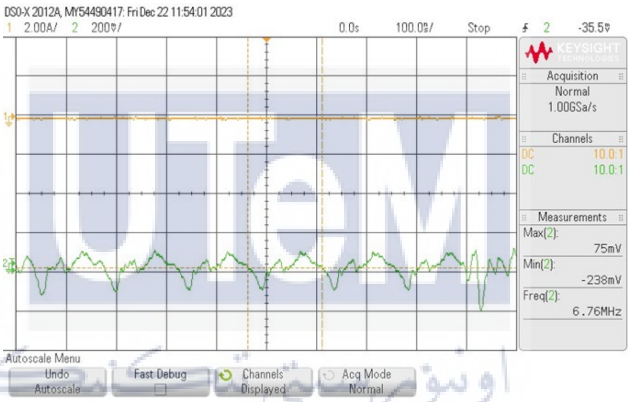
Figure 4.19 Output at Point A (Hardware)
</td></tr>
<tr><td>Output voltage between L2 and L3 for Hardware</td><td>


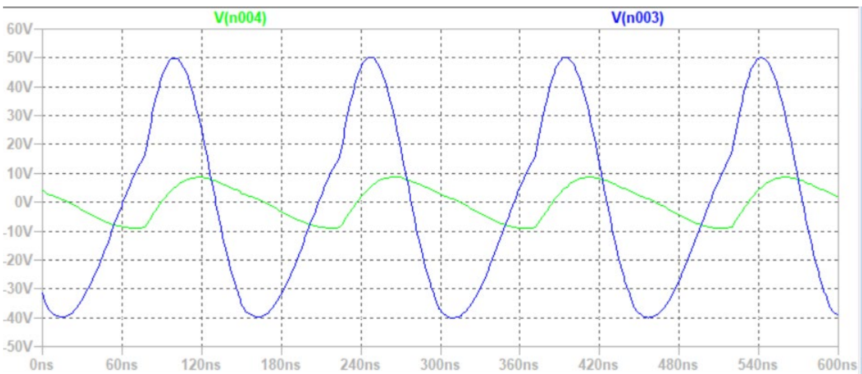
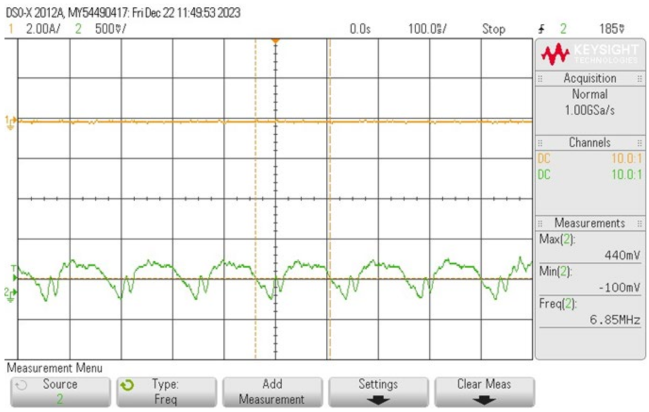
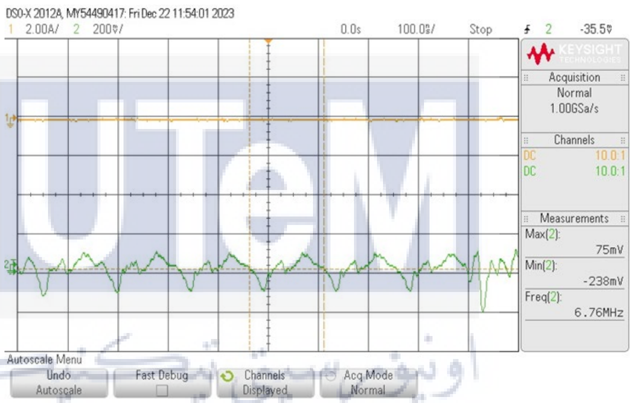
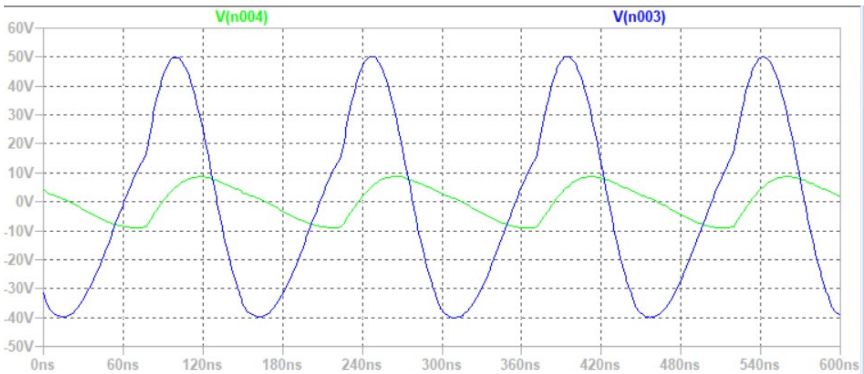
Figure 4.20 Output at Point B (Hardware)
</td></tr>
<tr><td>Output voltage between C2 and L2 (Green Wavefrom), Output voltage between L2 and L3 (Blue Waveform) for Simulation</td><td>


Figure 4.21 Output at Point A (Green Waveform) and Output at Point B (Blue Waveform) (Simulation)
</td></tr>
</table>

Table 4.8 Results for Inverter at Mosfet

	Voltage Output Waveform
Output Voltage on Gate to source Mosfet for Hardware	 Figure 4.22 Output at Point 1 (Hardware)
Output Voltage on Drain to source Mosfet for Hardware	 Figure 4.23 Output at Point 2 (Hardware)
Output Voltage on Gate to source Mosfet (Green Wavefrom), Output Voltage on Drain to source Mosfet (Blue Waveform) on Simulation	 Figure 4.24 Output at Point 1 (Green Waveform) and Output at Point 2 (Blue Waveform) (Simulation)

4.5.3 Simulation for a complete circuit of S-CPT and Inverter

In this comprehensive experimental study on Shielded Capacitive Power Transfer (S-CPT), our primary objective was to systematically characterize the system's performance. The simulation aimed to assess the output voltage and power from the combined circuit of S-CPT and the Inverter in Figure 4.25. Remarkably, our findings revealed an output power of 8.2 watts and a voltage of 45 volts based on Figure 4.26 and Figure 4.27, providing valuable insights into the capabilities and efficiency of the integrated S-CPT and Inverter system.

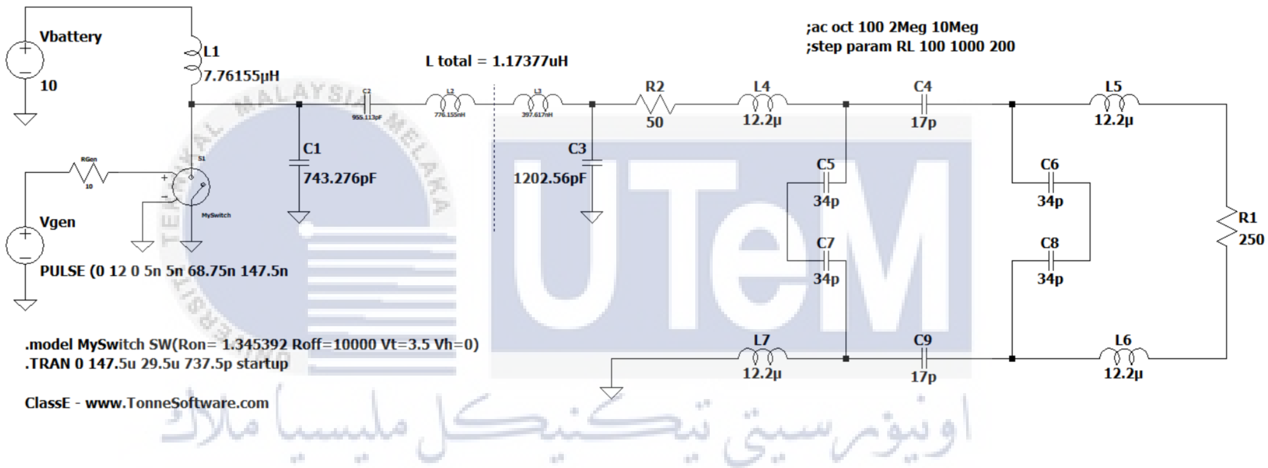


Figure 4.25 Circuit simulation on S-CPT and Inverter

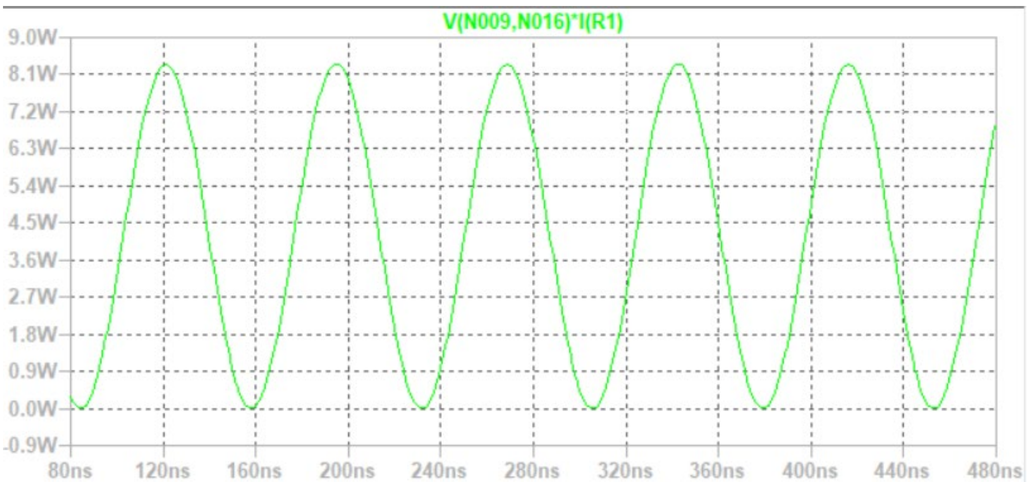


Figure 4.26 Output waveform in power from LTSpice

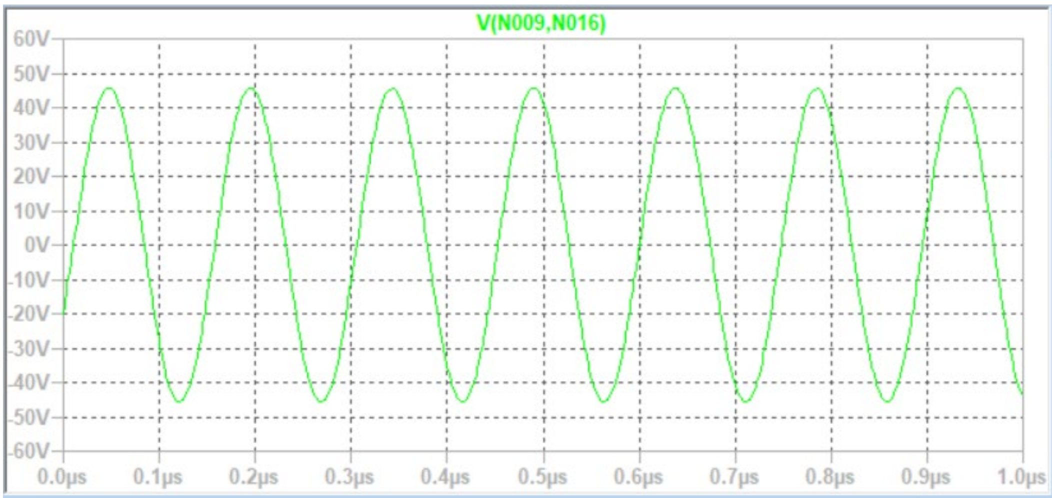


Figure 4.27 Output waveform in voltage from LTSpice

4.6 Summary

In a nutshell, this chapter depicts the results of circuit simulations that achieve the desired result. It was tested to see how well a shielded coupler for capacitive wireless power transfer would work at a frequency amplitude close to 6.78 MHz. For the best performance, careful design considerations like materials and dimensions were crucial. The coupler showed potential uses in capacitive coupling-based wireless power transfer systems.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This chapter will conclude the overall function achievement results obtained for this project, as well as the recommendations for this project. The issues that will be encountered when completing this project are the most crucial aspects of this chapter. We may select how to improve and overcome challenges based on the problems we experience. This chapter also discusses ways to make this project better in the future.

The design and implementation of the Class-E Inverter employ a dual-pronged approach that takes into account both software and hardware factors in addition to the circuit modeling. An important contribution to the creation of a capacitive wireless power transfer coupler for charging system models was made by the well-known circuit modeling program LT Spice. A more thorough depiction of the behavior of the circuit was made possible by the addition of mathematical equations to the modeling process.

Using a variety of hardware instruments, such as NanoVNA and NanoVNA Saver, exact data measurements were taken to verify and improve the suggested designs. Before each component was integrated into the overall subsystem, it needed to meet the prescribed criteria. This was accomplished through a thorough data collection process. The combination of hardware-based measurements and software-driven simulations offered a comprehensive testing process that ensured the Class-E Inverter's operation and dependability.

Once the data supplied from the hardware measurements and simulation software was combined, the designs were carefully verified and modified as needed. This iterative method demonstrated that the project was successful in accomplishing its predetermined goals in addition to aiding in the improvement of the Class-E Inverter. After all of this work, a highly efficient capacitive wireless power transfer system for charging applications was realized, proving how well hardware and software could work together during the development and validation phases.

5.2 Potential for Commercialization

The project involving the shielded coupler for capacitive wireless power transfer has a great deal of potential for commercialization due to the rising need for practical and effective power delivery in a variety of industries[52]. The market for wireless power transfer is expanding quickly as businesses look for ways to do without physical cables and connectors.

New markets and applications are emerging due to the wireless power transfer technology's constant evolution. This offers a chance for the project to stay at the cutting edge of innovation while examining underserved niche markets and extending its commercial footprint. The project can take advantage of these developing markets and establish itself as a major player in the wireless power transfer sector by staying ahead of the curve and adjusting to the changing industry[53].

Another way to achieve commercial success is through alliances with well-established businesses in related industries. The integration of the shielded coupler into their goods or systems can be made easier by working together with electronics producers, automakers, or IoT solution providers. This strategic partnership approach enables the project to make use of existing customer and distribution networks, accelerating market penetration and increasing commercial viability.

In conclusion, the shielded coupler for the capacitive wireless power transfer project is ready for successful commercialization. The project has the potential to transform power delivery and spur economic growth across a range of industries with careful execution and ongoing innovation.

5.3 Future Works

For future improvements, the accuracy of the TL estimation results could be enhanced as follows:

i) Specify the shielded coupler's performance objectives and requirements in detail. This includes elements like operating frequency range, coupling coefficient, maximum power transfer capability, and power transfer efficiency.

ii) Examine various shielding strategies to reduce electromagnetic interference (EMI) and boost the effectiveness of power transfer.

iii) Learn about the benefits, drawbacks, and potential advancements of the coupler designs and technologies currently in use.

iv) Create shielded coupler physical prototypes based on the improved design. Conduct thorough testing to validate the simulation results and evaluate the performance in comparison to the stated goals.

v) The implementation of a functional inverter within the context of S-CPT will be explored, aiming to optimize energy transfer efficiency and system performance.

REFERENCES

[1] Institute of Electrical and Electronics Engineers, IEEE Microwave Theory and Techniques Society, Wireless Power Consortium, Q. IEEE PELS Workshop on Emerging Technologies: Wireless Power (2018 : Montréal, and Q. Wireless Power Congress (2018 : Montréal, *2018 IEEE Wireless Power Transfer Conference (WPTC) : WPTC, IEEE MTT-S Wireless Power Transfer Conference ; WoW, IEEE PELS Workshop on Emerging Technologies: Wireless Power ; WPC, Wireless Power Consortium : June 3-7, 2018, Montreal, Quebec, Canada.*

[2] C. Lecluyse, B. Minnaert, and M. Kleemann, "A review of the current state of technology of capacitive wireless power transfer," *Energies*, vol. 14, no. 18. MDPI, Sep. 01, 2021. doi: 10.3390/en14185862.

[3] J. Feng, Q. Li, F. C. Lee, M. Manteghi, V. A. Centeno, and S. C. Southward, "6.78MHz Omnidirectional Wireless Power Transfer System for Portable Devices Application."

[4] Z. Zhang, H. Pang, A. Georgiadis, and C. Cecati, "Wireless Power Transfer - An Overview," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 2. Institute of Electrical and Electronics Engineers Inc., pp. 1044–1058, Feb. 01, 2019. doi: 10.1109/TIE.2018.2835378.

[5] X. Wei, Z. Wang, and H. Dai, "A critical review of wireless power transfer via strongly coupled magnetic resonances," *Energies*, vol. 7, no. 7. pp. 4316–4341, 2014. doi: 10.3390/en7074316.

[6] R. I. Pramana, Institute of Electrical and Electronics Engineers. Indonesia Section, Lembaga Ilmu Pengetahuan Indonesia, and Institute of Electrical and Electronics Engineers, *Proceedings, 2019 International Conference on Sustainable Energy*

Engineering and Application (ICSEEA) : "Innovative technology toward energy resilience" : 23-24 October 2019, International Convention Exhibition (ICE), BSD City, Tangerang, Banten Province - Indonesia.

[7] International Islamic University Malaysia. Kulliyyah of Engineering, IEEE Instrumentation and Measurement Society. Malaysia Chapter, and Institute of Electrical and Electronics Engineers, *7th International Conference on Computer and Communication Engineering (ICCCE 2018) : 19-20 September 2018, Kuala Lumpur, Malaysia*.

[8] W. Xu, X. Li, and Y. Peng, "Review and New Developments of Adaptive Tunning Technologies for Wireless Power Transfer," in *Proceedings of the 9th International Conference on Power Electronics Systems and Applications, PESA 2022*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/PESA55501.2022.10038437.

[9] Z. Zhang, H. Pang, A. Georgiadis, and C. Cecati, "Wireless Power Transfer - An Overview," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 2. Institute of Electrical and Electronics Engineers Inc., pp. 1044–1058, Feb. 01, 2019. doi: 10.1109/TIE.2018.2835378.

[10] M. A. Houran, X. Yang, W. Chen, and M. Samizadeh, "Wireless Power Transfer: Critical Review of Related Standards."

[11] K. W. Lao, W. Deng, J. Sheng, and N. Dai, "PQ-Coupling Strategy for Droop Control in Grid-Connected Capacitive-Coupled Inverter," *IEEE Access*, vol. 7, pp. 31663–31671, 2019, doi: 10.1109/ACCESS.2019.2902314.

[12] S. Sinha, A. Kumar, B. Regensburger, and K. K. Afridi, "Design of High-Efficiency Matching Networks for Capacitive Wireless Power Transfer Systems," *IEEE J*

Emerg Sel Top Power Electron, vol. 10, no. 1, pp. 104–127, Feb. 2022, doi: 10.1109/JESTPE.2020.3023121.

[13] IEEE Microwave Theory and Techniques Society, IEEE Power Electronics Society, London. Imperial College, Technische Hogeschool Eindhoven., Institute of Electrical and Electronics Engineers, and E. IEEE PELS Workshop on Emerging Technologies: Wireless Power (2019 : London, *2019 IEEE Wireless Power Transfer Conference (WPTC).*

[14] Institute of Electrical and Electronics Engineers, IEEE Microwave Theory and Techniques Society, Wireless Power Consortium, Q. IEEE PELS Workshop on Emerging Technologies: Wireless Power (2018 : Montréal, and Q. Wireless Power Congress (2018 : Montréal, *2018 IEEE Wireless Power Transfer Conference (WPTC) : WPTC, IEEE MTT-S Wireless Power Transfer Conference ; WoW, IEEE PELS Workshop on Emerging Technologies: Wireless Power ; WPC, Wireless Power Consortium : June 3-7, 2018, Montreal, Quebec, Canada.*

[15] IEEE Staff, *2017 IEEE Transportation Electrification Conference and Expo (ITEC).* IEEE, 2017.

[16] M. C. Vats, S. K. Singh, and M. C. Vats, "E-Waste Characteristic and Its Disposal," 2019. [Online]. Available: http://www.aascit.org/journal/ijesee

[17] Y. Wang *et al.*, "A Double-T-Type Compensation Network and Its Tuning Method for IPT System," *IEEE Trans Ind Appl*, vol. 53, no. 5, pp. 4757–4767, Sep. 2017, doi: 10.1109/TIA.2017.2715005.

[18] M. Asri, Z. Abidin, W. I. Ibrahim, and M. S. Jadin, "DESIGN OF INDUCTIVE POWER TRANSFER (IPT) FOR LOW-POWER APPLICATION," vol. 10, no. 21, 2015, [Online]. Available: www.arpnjournals.com

[19] Institute of Electrical and Electronics Engineers, *IEEE ENERGYCON'20 : 6th IEEE International Energy Conference : 28th September-1st October, 2020, hybrid (virtual-physical) conference, Tunisia*.

[20] N. Korakianitis, G. A. Vokas, and G. Ioannides, "Review of wireless power transfer (WPT) on electric vehicles (EVs) charging," in *AIP Conference Proceedings*, American Institute of Physics Inc., Dec. 2019. doi: 10.1063/1.5138558.

[21] W. Cao, J. Wang, and S. Wang, "Simulation Analysis of Inductive Coupling and Capacitive Coupling between Cables," in *2021 4th International Conference on Energy, Electrical and Power Engineering, CEEPE 2021*, Institute of Electrical and Electronics Engineers Inc., Apr. 2021, pp. 330–333. doi: 10.1109/CEEPE51765.2021.9475676.

[22] S. Sinha, S. Maji, and K. K. Afridi, "Comparison of large air-gap inductive and capacitive wireless power transfer systems," in *Conference Proceedings - IEEE Applied Power Electronics Conference and Exposition - APEC*, Institute of Electrical and Electronics Engineers Inc., Jun. 2021, pp. 1604–1609. doi: 10.1109/APEC42165.2021.9487431.

[23] M. F. C. Jorgetto, G. D. A. E Melo, and C. A. Canesin, "Wireless inductive power transfer, oriented modeling and design," in *2015 IEEE 13th Brazilian Power Electronics Conference and 1st Southern Power Electronics Conference, COBEP/SPEC 2016*, Institute of Electrical and Electronics Engineers Inc., 2015. doi: 10.1109/COBEP.2015.7420257.

[24] G. Li and D. H. Kim, "A wireless power transfer charger with hybrid compensation topology for constant current/voltage onboard charging," *Applied Sciences (Switzerland)*, vol. 11, no. 16, Aug. 2021, doi: 10.3390/app11167569.

[25] X. Chen, S. Yu, and X. Yang, "Hybrid Wireless Power Transfer."

[26] R. Shadid and S. Noghanian, "Hybrid power transfer and wireless antenna system design for biomedical implanted devices," in *2018 International Applied Computational Electromagnetics Society Symposium in Denver, ACES-Denver 2018*, Institute of Electrical and Electronics Engineers Inc., May 2018. doi: 10.23919/ROPACES.2018.8364247.

[27] G. A. Covic and J. T. Boys, "Modern trends in inductive power transfer for transportation applications," *IEEE J Emerg Sel Top Power Electron*, vol. 1, no. 1, pp. 28–41, 2013, doi: 10.1109/JESTPE.2013.2264473.

[28] E. Abramov and M. M. Peretz, "Multi-Loop Control for Power Transfer Regulation in Capacitive Wireless Systems by Means of Variable Matching Networks," *IEEE J Emerg Sel Top Power Electron*, vol. 8, no. 3, pp. 2095–2110, Sep. 2020, doi: 10.1109/JESTPE.2019.2935631.

[29] B. Luo, T. Long, R. Mai, R. Dai, Z. He, and W. Li, "Analysis and design of hybrid inductive and capacitive wireless power transfer for highpower applications," *IET Power Electronics*, vol. 11, no. 14, pp. 2263–2270, Nov. 2018, doi: 10.1049/iet-pel.2018.5279.

[30] X. Wang, A. Kosuge, Y. Hayashi, M. Hamada, and T. Kuroda, "A 7 Gb/s Micro Rotatable Transmission Line Coupler with Deep Proximity Coupling Mode and Ground Shielding Vias," in *ICECS 2022 - 29th IEEE International Conference on Electronics, Circuits and Systems, Proceedings*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/ICECS202256217.2022.9970894.

[31] B. Minnaert and N. Stevens, "Design of a Capacitive Wireless Power Transfer Link with Minimal Receiver Circuitry," in *2018 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer, Wow 2018*, Institute of Electrical and Electronics Engineers Inc., Aug. 2018. doi: 10.1109/WoW.2018.8450659.

[32] K. H. Yi, “6.78MHz capacitive coupling wireless power transfer system,” *Journal of Power Electronics*, vol. 15, no. 4, pp. 987–993, Jul. 2015, doi: 10.6113/JPE.2015.15.4.987.

[33] M. Zeino and G. Monich, “A new directional coupler to measure the performances of noncontact devices used for the reduction of the shielding current on cables,” *IEEE Trans Electromagn Compat*, vol. 53, no. 2, pp. 372–379, May 2011, doi: 10.1109/TEMC.2011.2107036.

[34] S. Sinha, A. Kumar, and K. K. Afridi, “Optimized Design of High-Efficiency Immittance Matching Networks for Capacitive Wireless Power Transfer Systems,” in *2021 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer, WoW 2021*, Institute of Electrical and Electronics Engineers Inc., Jun. 2021. doi: 10.1109/WoW51332.2021.9462883.

[35] T. M. Mostafa, A. Muharam, and R. Hattori, “Wireless battery charging system for drones via capacitive power transfer,” in *2017 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer, WoW 2017*, Institute of Electrical and Electronics Engineers Inc., Jun. 2017. doi: 10.1109/WoW.2017.7959357.

[36] J. Dean, M. Coultis, and C. Van Neste, “Wireless Sensor Node Powered by Unipolar Resonant Capacitive Power Transfer,” in *2021 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer, WoW 2021*, Institute of Electrical and Electronics Engineers Inc., Jun. 2021. doi: 10.1109/WoW51332.2021.9462877.

[37] Z. Wang, Y. Zhang, X. He, B. Luo, and R. Mai, “Research and Application of Capacitive Power Transfer System: A Review,” *Electronics (Switzerland)*, vol. 11, no. 7. MDPI, Apr. 01, 2022. doi: 10.3390/electronics11071158.

[38] A. Muharam, S. Ahmad, R. Hattori, and A. Hapid, "13.56 MHz scalable shielded-capacitive power transfer for electric vehicle wireless charging," in *2020 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer, WoW 2020*, Institute of Electrical and Electronics Engineers Inc., Nov. 2020, pp. 298–303. doi: 10.1109/WoW47795.2020.9291299.

[39] IEEE Industry Applications Society and Institute of Electrical and Electronics Engineers, *2019 22nd International Conference on Electrical Machines and Systems (ICEMS)*.

[40] B. H. Lee, "Wireless power transfer via magnetic resonance coupling (MRC) with reduced standby power consumption," *Journal of Power Electronics*, vol. 19, no. 3, pp. 637–644, May 2019, doi: 10.6113/JPE.2019.19.3.637.

[41] H. Zhao *et al.*, "Comprehensive Investigation on the Influence of Magnetic Materials on the Weight and Performance of Onboard WPT Systems," in *IEEE Transactions on Industry Applications*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 6842–6851. doi: 10.1109/TIA.2022.3188611.

[42] L. Yang *et al.*, "Analysis and Design of Four-Plate Capacitive Wireless Power Transfer System for Undersea Applications," *CES Transactions on Electrical Machines and Systems*, vol. 5, no. 3, pp. 202–211, Sep. 2021, doi: 10.30941/CESTEMS.2021.00024.

[43] S. Ahmad, A. Muharam, R. Hattori, A. Uezu, and T. M. Mostafa, "Shielded capacitive power transfer (S-cpt) without secondary side inductors," *Energies (Basel)*, vol. 14, no. 15, Aug. 2021, doi: 10.3390/en14154590.

[44] S. Ahmad, R. Hattori, and A. Muharam, "Generalized circuit model of shielded capacitive power transfer," *Energies (Basel)*, vol. 14, no. 10, May 2021, doi: 10.3390/en14102826.

[45] S. Ahmad, A. Muharam, R. Hattori, A. Uezu, and T. M. Mostafa, "Shielded capacitive power transfer (S-cpt) without secondary side inductors," *Energies (Basel)*, vol. 14, no. 15, Aug. 2021, doi: 10.3390/en14154590.

[46] B. Minnaert *et al.*, "Constant Capacitive Wireless Power Transfer at Variable Coupling."

[47] M. Liu, C. Zhao, J. Song, and C. Ma, "Battery Charging Profile-Based Parameter Design of a 6.78-MHz Class E^2 Wireless Charging System," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 8, pp. 6169–6178, Aug. 2017, doi: 10.1109/TIE.2017.2682017.

[48] X. He, J. Bito, and M. M. Tentzeris, "A Drone-Based Wireless Power Transfer and Communications Platform."

[49] Institute of Electrical and Electronics Engineers, IEEE Power Electronics Society, IEEE Microwave Theory and Techniques Society, and Wireless Power Week (2020 : Online), *2020 IEEE Wireless Power Transfer Conference (WPTC) : Nov 15-19, 2020, Seoul, Korea*.

[50] Institute of Electrical and Electronics Engineers, IEEE Power Electronics Society, IEEE Microwave Theory and Techniques Society, and Wireless Power Week (2020 : Online), *2020 IEEE Wireless Power Transfer Conference (WPTC) : Nov 15-19, 2020, Seoul, Korea*.

[51] F. Irsyadi, M. Ramdhani, E. Ali, D. Darlis, and R. A. Priramadhi, "Implementation of Learning Together Method with Ltspice Simulation to Enhance Student's Comprehension in Electric Circuits Course," 2019.

[52] London. Imperial College *et al.*, *Wireless Power Week : WPW 2019 : IEEE MTT-S Wireless Power Transfer Conference (WPTC) & IEEE PELS Workshop on*

Emerging Technologies: Wireless Power Transfer (WoW) : 17-21 June 2019, London.

[53] S. Shin *et al.*, "Wireless Power Transfer System for High Power Application and a Method of Segmentation."

APPENDICES

Appendix A Gantt Chart

NO.	Task	PSM1														PSM2													
	Weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	BDP 1 Briefing by JK PSM, FTKEE	■																											
2	Discussion with Supervisor	■	■																										
3	Project Title Confirmation and Registeration		■																										
4	Study the Project Background			■																									
5	Drafting Chapter 1: Introduction			■	■																								
6	Drafting Chapter 2: Literature Review					■	■																						
7	Table of Summary Literature Review						■																						
8	Task progress evalution 1						■																						
9	Drafting Chapter 3: Methodology							■																					
10	Work on the Software/ Hardware							■	■	■						■	■	■											
11	Drafting Chapter 4: Analyse Data and Results										■						■	■											
12	First Draft submission to Supervisor										■						■	■											
13	Data Analyse and Result										■	■	■						■	■									
14	Record Result											■	■						■	■	■								
15	Task progress evalution 2												■									■							
16	Drafting Chapter 5: Conclusion and Recommendation													■									■						
17	Submission Report to the Panel													■														■	
18	Presentation of BDP1														■														
19	Compiling Chapter 4 and Chapter 5																							■	■	■			
20	Submit Latest Report to Supervisor																										■		
21	Finalize the Report																											■	
22	Presentation of BDP2																												■