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Bachelor of Electrical and Electronics Engineering Technology with Honours

2022

DEVELOPMENT OF 13.56MHz CAPACITIVE WIRELESS POWER TRANSFER WITH DIFFERENT DIELECTRIC MATERIAL FOR CHARGING SYSTEM

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2022

DECLARATION

I declare that this project report entitled " Development of 13.56MHz Capacitive Wireless Power Transfer With Different Dielectric Material For Charging System "is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours



DEDICATION

To my beloved mother, Norasikin

and father, Abdul Manaf

and honorable supervisor Dr.Suziana Ahmad



ABSTRACT

In order to perform wireless power transfer, capacitive wireless power transfer (CWPT) employs an electric field as a means of transmission (WPT). This system's low eddy current loss, easy system construction, and significant plasticity of the coupling coupler have recently attracted a great deal of attention. The CWPT system has greatly improved transfer power, system efficiency, and transfer distance as a result of continual research and discussion. Research on capacitive coupler structures and high-frequency power converters is summarised in this article, which also serves to show the basic working principle of the CWPT system. Medical equipment, consumer communications, transportation, and other modes of conveyance are all included in the application of CWPT technology. This research will focus more on the emission of electric fields because safety is a major concern in CWPT. A six-plate capacitive coupler can be used to minimise the electric field by identifying the optimal circuit parameter values for various dielectric materials. The results of the experiments will show that the recommended solution is effective.

Keywords: Wireless Power Transfer (WPT), Capacitive Wireless Power Transfer (CWPT).

ABSTRAK

Untuk melakukan pemindahan kuasa tanpa wayar, pemindahan kuasa wayarles kapasitif (CWPT) menggunakan medan elektrik sebagai alat penghantaran (WPT). Kehilangan arus pusar rendah sistem ini, pembinaan sistem yang mudah, dan keplastikan yang ketara pada pengganding baru-baru ini telah menarik perhatian ramai. Sistem CWPT telah mempertingkatkan kuasa pemindahan, kecekapan sistem dan jarak pemindahan dengan ketara hasil daripada penyelidikan dan perbincangan yang berterusan. Penyelidikan mengenai struktur pengganding kapasitif dan penukar kuasa frekuensi tinggi diringkaskan dalam artikel ini, yang juga berfungsi untuk menunjukkan prinsip kerja asas sistem CWPT. Peralatan perubatan, komunikasi pengguna, pengangkutan dan cara pengangkutan lain semuanya termasuk dalam aplikasi teknologi CWPT. Penyelidikan ini akan memberi lebih tumpuan kepada pelepasan medan elektrik kerana keselamatan adalah kebimbangan utama dalam CWPT. Pengganding kapasitif enam plat boleh digunakan untuk meminimumkan medan elektrik dengan mengenal pasti nilai parameter litar optimum untuk pelbagai bahan dielektrik. Keputusan eksperimen akan menunjukkan bahawa penyelesaian yang disyorkan adalah berkesan.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to my supervisor, Dr. Suziana for her precious guidance, words of wisdom and patient throughout this project.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) and for the financial support through Dr. Suziana which enables me to accomplish the project. Not forgetting my fellow colleagues for the willingness of sharing their thoughts and ideas regarding the project.

My highest appreciation goes to my parents and family members fortheir love and prayer during the period of my study. An honourable mention also goes to Nur Izzati for all the motivation and understanding.

Finally, I would like to thank all the staffs at the Universiti Teknikal Malaysia Melaka (UTeM), fellow colleagues and classmates, the Faculty members, as well as other individuals who are not listed here for being co-operative and helpful.

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LIST OF SYMBOLS

- δ Voltage angle
- μ Micro
- p Pico
- Ω Ohm
- ε Permittivity
- *π* Phi



LIST OF ABBREVIATIONS

V	- Voltage
А	- Ampere
WPT	- Wireless Power Transfer
CWPT	- Capacitive Wireless Power Transfer
IWPT	- Inductive Wireless Power Transfer
EV	- Electric Vehicle
EF	- Electric Field
PWM	Pulse Width Modulation
AC	- Alternating Current
DC	- Direct Current
EMI	- MElectromagnetic Interference
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CHAPTER 1

INTRODUCTION

1.1 Background

Wireless power transmission has been around for over a century. The most popular type of wireless power transfer employs magnetics (inductors or cores). Magnetic fields are used to transmit power in IPT systems. Because the magnetic fields produced have a detrimental impact on the devices in its area, insulation for the IPT system and the device in its vicinity is necessary. There are a few potential drawbacks to adopting a wirelessly inductive system [1].

Capacitive power transfer systems are therefore abbreviated as CPT. In the search for alternatives to wired power transmission, capacitive power transfer systems (CPT) are one of the options presented. In many aspects, the CPT system is comparable to the IPT system. In contrast, CPT technology has several advantages over IPT devices. In CPT systems, electric fields are utilised to transmit power, and a substantial amount of the electromagnetic field is restricted to capacitive contacts. Using an electric field as opposed to an electrical flux decreases electromagnetic interference in the system (EMI). While retaining signal separation, capacitive systems can transfer both energy and data. The majority of converters used in capacitive systems are resonant and operate in either the zero-voltage switching (ZVS) or zero-current switching (ZCS) zone, making CPT systems highly efficient [2].

In addition, the CPT system's diverse characteristics make it applicable to a vast array of applications. CPT is utilised in a variety of fields, including medicine and charging electric vehicles. CPT systems are typically employed for less than 1cm distances and low-power applications. In contrast, an IPT system can be used to transmit high power across vast air gaps.

Aside from that, as comparing to well-established IPT systems, CPT systems have various limitations and drawbacks. Understanding the coupling interfaces, which are important for power transfer from the primary to the secondary side of the system, is vital for overcoming the shortcomings of CPT systems. The electric field is well restricted between the plates, and safety precautions must be taken in certain conditions to maintain the electric field contained.

1.2 Problem Statement

Currently, electric vehicles can only be charged using a plug-in connection. The issue arises when the user must identify the charging port yet the charging cable is lost or destroyed. The objective of this research is to create a capacitive wireless power transmission system. This project's concept can be adapted to any electric vehicle, including buses, cars, and light rail. It will establish a new method for charging electric vehicle batteries that is more convenient than the current plug-in connection. When using capacitive wireless power transfer (CWPT) to charge an electric vehicle, there is no physical connection or touch between the vehicle and the power source [3].

Since the operation is fully automated, no human intervention is required to finish the billing procedure. Although the principle of wireless power transmission is well understood and has been implemented in industrial applications, its applications in the transportation industry are still in their infancy. Individuals can receive an electrical shock if the current plug-in cable system for electric vehicles is compromised. The wireless charging approach for electric vehicles can prevent this scenario from occurring because no wires or cables are required and the energy is transferred in electromagnetic form; hence, no one will feel an electrical shock during this type of energy transfer.

1.3 Project Objective

This chapter contains a detailed overview of project objectives:

- a) To apply coupler structure for 13.56 MHz capacitive wireless power transfer with different dielectric material using LTspice software simulation circuit for charging system.
- b) To implemented 13.56 MHz capacitive wireless power transfer (CWPT) coupler structure using metal plate.
- c) To evaluate the performance of 13.56 MHz capacitive wireless power transfer (CWPT) using analysis method in both hardware and software simulation experimental set up.

1.4 Scope of Project

The following are the details of the project' scope:

- a) This project considered as high-performance capacitive wireless power transfer (CWPT) system of 13.56 MHz.
- b) Fabrication of 13.56MHz capacitive wireless power transfer (CWPT) coupler with air core inductor.
- c) LT Spice was used for modelling design and simulation in this project.
- d) Experimental set up includes voltage input with frequency at 13.56Mhz that generates to the coupler to test the functionality effectiveness wirelessly to output.

1.5 Research Outline

The primary chapter goes into detail on the behaviour and properties of the CPT system's coupling interface. The second chapter of the study provides a brief literature analysis of the capacitive wireless power transfer system, the notion of coupling capacitance, as well as the many configurations

available for CPT systems and their comparison. In Chapter 3, the methodologies has been presented. All the method based on development of the project will recorded in this chapter. Chapter 4 is essentially the simulation's outcome. All the results are discussed and compared to one another.

a)



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is organized to overview the research about the previous project and gives literally a fundamental information which will contribute the large body of knowledge about the project. In addition, this chapter also present the comparison on type of power converter and type of compensation. All the information gathered is mostly based on related research paper and journal about the project.

2.2 Research, Ideology and Concept Previous Project

Past research and study on Development of 13.56MHz capacitive wireless power transfer with dielectric material for charging system.

2.2.1 Maximum Available Power of Undersea Capacitive Coupling in a Wireless Power Transfer System

To transmit power between coupling plates, a capacitive power transfer (CPT) system employs the alternating electric field idea. The CPT system is an ideal wireless power transmission system due to its simple design, low cost and weight, minimal electromagnetic interference (EMI), limited capacity to penetrate through metals, and good misalignment performance [4]. CPT has been proposed for electric car, underwater vehicle, and ship charging applications due to these intrinsic properties. An analogous model is one technique to model capacitive coupling plates (couplers). To investigate the highest feasible efficiency of a CPT system based on this model, the coupling coefficient (k), the quality factor (Q), and their extended product (kQ) are employed. The study is further broadened to include three potential solutions: one that improves efficiency, one that maximizes transmitted power, and one that achieves power matching[5].

The above solutions are investigated for a non-dissipative CPT system connected directly to a lossless dielectric. If a CPT system is immersed in saltwater to improve the coupling capacitance of the plates, the dielectric losses of the seawater must be considered. Because of the large proportion of dissolved ions, electric conductivity and water losses rise. As a result, a dissipative system analysis is necessary. For a dissipative system, the maximum possible CPT system efficiency has previously been evaluated. In the study, the conjugate-impedance approach is employed to optimize the efficiency of the CPT system immersed in saltwater. The conjugate-impedance analysis is also addressed in this paper in order to provide the highest feasible power solution for a dissipative CPT system. The coupling parameters are utilized to show the maximum load power and overall system efficiency. The derived equations were tested experimentally at separation distances ranging from 100 to 300 mm and operation frequencies ranging from 300 kHz to 1.5 MHz [4].

2.2.2 High-Performance 13.56-MHz Large Air-Gap Capacitive Wireless Power Transfer System for Electric Vehicle Charging

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In this study, a high-performance capacitive WPT system with a large air gap for charging electric vehicles is detailed. This system provides superior power transfer density and efficiency by utilising coupled-inductor capacitor lower matching networks with a high switching frequency (13.56 MHz). A 13.56-MHz capacitive WPT system with 12-cm air-gap and 150-cm2 connection plates was designed, built, and evaluated. This device transmits 884 W with 91,3% efficiency, resulting in a power transmission density of 29.5 kW/m2 [6]. When transmitting 348 W, the system reaches an efficiency of 95%. According to the authors' understanding, this is the best - established performance for a capacitive WPT system with a significant air gap for EV charging.

The design of a capacitive WPT EV charging system is depicted in Figure 2.1. Energy is then transferred from one set of conductive plates implanted in the road to another set connected to the undercarriage of the vehicle via a vast air gap. The system consists of a high-frequency converter and a network on the roadway's shoulder. This matching network (illustrated in Figure 2.1) amplifies voltage on the roadway side of the coupling plates, enabling high power transfer with low displacement currents and consequently low fringing fields.

This network serves in correcting for the coupling plates' capacitive reactance. A second matching network and a high-frequency rectifier are added to the vehicle side[6]. The remaining reactive compensation is provided by this matching network, which reduces the voltage and current to the levels required to charge the car battery. Figure 2.2 shows how the capacitive WPT concept illustrated in Figure 2.1 is implemented. Full bridge structures are employed to produce the inverter and rectifier, whilst single-stage L-section networks are used to construct the matching networks.



Figure 2.1 : A large air-gap capacitive WPT system architecture appropriate for EV charging applications. Two pairs of coupling plates, a high-frequency inverter and rectifier, and matching networks that give voltage or current gain and reactive compensation



Figure 2.2 : Implementation of the capacitive WPT system

A prototype 13.56-MHz 12-cm air-gap capacitive WPT system with coupled inductors was conceived, produced, and tested in this study. In this arrangement, which is identical to Figure 2.3, an RF resistor simulates the rectifier and battery.



The mechanism is depicted in Figure 2.4. The metal sheets in Figure 2.44 depict the road and car chassis. The inverter of the prototype system is made of 650-V 30-A GaN Systems GS66508T enhancement-mode GaN transistors.



Figure 2.4 : 13.56-MHz prototype capacitive WPT system

The prototype system's measured waveforms while transmitting 884 W are displayed in Figure 2.5. The inverter functions with zero voltage switching (ZVS), as shown in Fig. 2.5(a).



Figure 2.5 : Waveforms measured from the prototype capacitive WPT system running at 884 W: (a) inverter switch node voltages and currents, and (b) system input voltage, current, and output voltage

Figure 2.6 depicts the observed effectiveness of the 13.56-MHz coupled-inductor system as a function of output power. The prototype 13.56-MHz system has a power transmission density of 29.5 kW/m2 and an efficiency of 91.3% at 348 W and 95.0% at 884 W. Figure 2.6 depicts the efficiency of a 6.78-MHz system prototype with detached split inductors. As can be shown, the 13.56-MHz system is significantly more efficient throughout the whole of the output power range, with up to 53% fewer losses.



Figure 2.6 : Measured efficiency of the coupled-inductor 13.56-MHz system and the splitinductor 6.78-MHz system as a function of output power

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2.2.3 Analysis and Design of Coupling Capacitors for Contactless Capacitive Power Transfer Systems

The primary goal of this study is to describe the behaviour and features of the CPT system's coupling interface. The capacitive power transfer system's coupling interfaces are its beating heart. The coupling contact is activated by a high-frequency inverter. The transmitting and receiving antennas are composed of two metal plates with a suitable dielectric/insulator overlaying the coupling contact. The plates and dielectric coating resemble a loosely coupled capacitor [7]. As a result, when electricity is delivered to the primary plate of the capacitor, an electric field is formed between the primary and secondary side plates. A displacement current is flowing between the system's antennas as a by product

of the electric field, allowing power to be transmitted. For the coupling capacitors, metal plates are arranged in the shape of a loosely coupled capacitor.

The capacitive contact possesses an equivalent series resistance (ESR) and an equivalent series inductance (ESI) (ESL). As a frequency-dependent component, the capacitor's reactance lowers as the frequency increases, allowing AC impulses to travel through it. At a particular frequency, the ESL and the capacitor form a series resonant circuit, which enables maximum power flow. This is known as the self-resonant frequency of the capacitor. The self-resonant frequency of a capacitor is typically a few MHz.

To assist the capacitor in approaching resonance, inductors and capacitors are coupled in series, series-parallel, and composite networks. The energy transmission mechanism is hence naturally resonant. Resonance has the benefit of serving as a filter, allowing the fundamental component to pass while filtering out higher order harmonics. Another advantage of resonance is the natural smooth switching of the converter, which reduces switching losses and boosts converter efficiency.

There are two different types of coupling interfaces in wireless systems. The interface represented in Figures 2.7 and 2.8(b) is the most fundamental type of capacitive interface. The capacitor is formed when the primary plate of the active electrode is linked to a high-frequency inverter and the secondary plate is connected to the load (active electrodes). To accomplish resonance, a series-connected inductor is used as compensation. The passive electrodes act as a current return channel. The electric field produced by connecting two sets of asymmetric dipoles is used to transmit electricity [7].



Figure 2.7 : Unipolar interfaces

Figures 2.8(c) and 2.8(d) illustrate the bipolar interface of the second contact (d). This is the most prevalent structure in literary works. There are two coupling capacitors since the transmitter and receiver plates are duplicated. The four active interface plates aid in power transmission and completion of the return path.



Figure 2.8 : (a) Bipolar Row arrangement (b) Unipolar Compact Column Arrangement (c) Bipolar Column Arrangement (d) Matrix Arrangement

The building of the capacitor is the most significant part of the total system. The coupling structure has a direct impact on the maximum power transferred, output power, frequency, and efficiency of the systemic [8]. As a result, knowing the factors influencing the system is crucial for

overcoming its restrictions. The coupling capacitors, voltage stress across the coupling interface, operational frequency, and ambient conditions are the four most critical factors impacting the CPT system.

This study describes the CPT systems' behavioral features. The coupling capacitor is an essential component of this wireless power transmission technology. The different CPT system interfaces and settings are explored. The term "mutual capacitance" is defined. Various factors affecting the system's coupling capacitance are thoroughly examined. A guideline for the design of the capacitive interface is specified based on the study.

2.2.4 Capacitive Coupling Wireless Power Transfer with glass dielectric layers for Electric Vehicles

Inductive coupling wireless power transfer (ICWPT) and capacitive coupling wireless power transfer (CCWPT) are the two forms of WPT (CCWPT). ICWPT makes use of the magnetic field generated by the transmitter and the receiver coils. Although this technology is highly efficient and has a well-established commercialization approach, it has a number of limitations, including one-position power transfer, heat dissipation in the metal barrier, and a large coil volume. Moreover, the metal emits radiation noise and interferes with power transmission [9]. The CCWPT, on the other hand, is an alternate method for wireless power transfer that employs an electric field and a displace current. Figure 2.9 depicts the basic structure of a capacitive coupling system.



Figure 2.9 : Simple structure of the capacitive coupling wireless power

A high frequency inverter converts a direct current (DC) voltage to a high frequency alternating current (AC) voltage, which is subsequently fed to two main metal plates. The displacement current by the electric field might flow between two secondary plates that are near to each other. Finally, a rectifier can be used to obtain the dc output voltage.

This paper provides a current CCWPT method for charging electric vehicles[10]. The recommended CCWPT system contains a glass dielectric layer for the coupling capacitor as well as step-up and step-down transformers in order to obtain a low quality factor. The proposed CCWPT system leverages LLC resonant operation to reduce the switching loss of the power switch. Glass has a high relative permittivity, and the front, back, and sides of electric vehicles are largely composed of it. It generates a significant amount of coupling capacitance and output power. In the power conversion circuit, the resonant action of the LLC helps to reduce switching loss. Consequently, both the power MOSFET turn-on loss in a transmitter and the rectifier turn-off loss in a receiver can be decreased. A 1.2kW charging electric vehicle (EV) prototype is utilised to examine the operation and functionality of the proposed system.

Figure 2.10 depicts the intended CCWPT system for charging electric vehicles. In electric vehicles, the dielectric layer of the coupling capacitor is composed of glass. The AC voltage is provided by a high frequency full-bridge inverter, the coupling capacitor's impedance is reduced by a step-up transformer, a step-down transformer will be used to create an output voltage, and rectifiers produce the DC output voltage. Resonance between a resonant inductor Lr and the corresponding coupling capacitance transfers wireless power. Sometimes underestimated, the magnetic inductance of the step-up transformer is significant. The magnetic inductor of a step-down transformer functions as a magnetized inductor within an LLC resonant DC/DC converter, enabling the full-bridge inverter switches to achieve zero voltage switching (ZVS).



Figure 2.10 : Proposed CCWPT for Evs

In EVs, a large area of a good glass dielectric layer may result in a capacitance coupling value that is high. The output power of the step-up and step-down transformers is sufficient. In addition, ZVS power switches use LLC resonance operation and have extremely low electromagnetic interference (EMI). Consequently, productivity is at an all-time high.

To validate the design concept, a system prototype was developed. With a rectangular surface area of 2400cm2, the capacitance of the coupling capacitor was approximately 8nF. The glass dielectric layer is approximately 2 mm thick. The highest power output is 1.2 kW. Figure 2.11 illustrates the experimental waveforms. The fundamental waveforms mimic those of an LLC resonant DC/DC converter. It has been demonstrated that full-bridge inverter switches have ZVS capabilities. The suggested CCWPT system has an efficiency of 94% at 1.2kW. In comparison to prior efforts, the transmission power is the highest and the efficiency is the highest.



Figure 2.11 : Output waveform (1.2kW)

Presented is a novel CCWPT system for charging electric automobiles. The recommended CCWPT has no EMI noise by definition. The researched CCWPT makes use of the glass dielectric layer of EVs for high coupling capacitance, and significant output power can be attained using impedance transformations such as step-up and step-down transformers. The ZVS functionality of power switches is made possible by the LLC resonant action. In terms of power transfer and efficiency, it is unparalleled [9].

2.2.5 Role of Dielectrics in the Capacitive Wireless Power Transfer System

Previously, capacitive coupling devices were overlooked due to problems with power transfer over long distances. Capacitive power transfer is a dynamically growing field of research in wireless power transfer for low to medium power (mW-100s of watts) and small airgap (10 mm) implementations like biomedical/mobile device charging, along with high power (3 kW) and large airgap (100-200 mm) applications like electric vehicle charging [10].

Capacitive coupling uses an electric field to transport power across an air gap, avoiding significant issues such as metal object penetration and eddy current loss while being less expensive

and easier to set up than electromagnetic, inductive-based coupling. It is made up of two metal plates joined by a dielectric. When the metal plates and dielectric are activated, they produce a capacitor with loose connections. Over power transmission lengths of 10 mm and 80 mm, the authors examined the effect of diverse dielectric materials on the effective capacitance produced at the interface, as well as the breakdown electric field and breakdown voltage.

The primary and secondary sides of the capacitive coupler interface in Figure 2.12 are composed of electrostatic induction-based capacitor plates that are loosely connected. Due to charge displacement, as long as the primary side is activated, the high voltage at the main plate forms a high frequency electric field between both the primary and secondary plates. As a result, a displacement current travels from the capacitive interface's primary to secondary.



Effective coupling area, dielectric permittivity, and power transmission distance between coupling plates typically restrict coupling capacitance to around 100pF. On either side of the coupling contact, there must be at least two pairs of conductive plates that function as the primary and secondary conductors. A suitable dielectric can be utilised to protect the plates. The primary objective of this thin layer of dielectric coating is to provide galvanic isolation here between transmitter and receiver, rather than to increase mutual capacitance.

When a high frequency inverter drives the capacitor's primary plate, an electric field forms between the primary and secondary side plates as a result of the charges q1 and q2 generated on either

side via electrostatic induction [11]. A displacement current runs between them as a consequence of the electric field, allowing power to be transmitted. Figure 2.13 depicts a capacitive coupling interface with main and cross coupling capacitances (a). Figure 2.13 depicts an equivalent model with two coupling capacitances C1 and C2 (b).







Figure 2.13 : a) Six plate capacitance model of the capacitive interface with cross capacitances b) Equivalent Model

On both the primary and secondary sides of the capacitive coupler, an appropriate dielectric/insulator is applied on metal plates separated by an air gap. The capacitance between the coupling plates has a direct effect on the maximum amount of power transferred and the efficiency of the system. It is mostly governed by construction and plate spacing. Capacitive connections consist of parallel plate and non-parallel plate topologies.

As seen in Figure 2.14, parallel plate arrangements are mainly employed in rectangular/square configurations. When the separation between the plates is smaller than 1 mm and when the airgap is bigger than the dielectric thickness, the influence of the dielectric constant on the capacitance value is minor. As a result, air is the preferable dielectric for large airgap (100mm-200mm) applications.


Figure 2.14 : Parallel plate capacitive coupler with area A (a) separated by a single dielectric at a thickness d (b) separated by multiple dielectrics, at thicknesses d1, d air and d2.

Capacitive coupling-based wireless power transfer is a feasible alternative to inductive wireless systems. This study investigates the influence of employing different dielectrics to enhance the power transmission capabilities of the CPT system. According to the results of the investigation, adopting dielectrics could increase the effective coupling capacitance if the area covered by the dielectrics is more than the airgap. In addition, the usage of dielectrics leads in significantly increased breakdown voltage constraints across all power transmission channels.

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2.3 Comparison of Journals

2.3.1 Comparison between 1MHz. 6.78MHz and 13.56MHz

metallic barriers while also reducing EMI shielding requirements.

- The purpose of a high frequency three leg inverter is to switch inductive and capacitive links at 85 kHz and 1 MHz, respectively.
- These charging stations can help drones fly longer distances and for longer periods of time by acting as a transit station, allowing them to be employed in delivery services or other applications that need long distance flying. It's also beneficial for security applications that require regular flights.
- With a large separation distance and low-frequency range, the CPT system can provide an attractive wireless charging solution for

- Electromagnetic radiations can exceed the safe limits when an inductive link is operated at high frequency and power.
- Physical restrictions, grounding instability, continual change in impedance matching, and field fringing at the barrier isolation / segmentation are all challenges that limit the use of a traditional CPT system in a wide range of applications.
- If a CPT system is submerged in seawater to increase the plates' coupling capacitance, the dielectric losses of the seawater cannot be ignored. The high concentration of dissolved ions raises the electric conductivity and water losses.

coupling capacitance between two metal plates separated by an air gap.

- HPT employs a three-leg inverter topology. Inductive wireless power transfer (IPT) is utilized on two legs of the inverter, which are switched at 85 kHz, while capacitive wireless power transfer (CWPT) is used on the third leg, which is switched at 1 MHz (CPT).
- In the application, the circuit on the power receiving side, or drone side, must be small and light. A transformer and all inductors are placed on the emitting side, and the circuit on the receiving side is made up of small devices that use semiconductor elements for DC-DC converter and charge controlling IC.

electric ships and underwater vehicles.

- With the same input voltage and load situation, the "two branches with a single inverter" power transfer method achieves a greater coupling coefficient and consequently higher output power.
- One of the most effective applications of Inductive Power Transfer (IPT) is in biomedical equipment, where it delivers a lifetime of power without the risk of infection that comes with percutaneous leads.
- However, in particular applications, such as smart phones, the available area and space are usually very limited. The phone company must provide two chargers with different output voltages.

However, how the electric field interacts with tissue is yet unknown, and no extensive electric field distribution analysis is performed to

address safety concerns.

- The conjugate image technique was used to drive the greatest possible power in a dissipative capacitive power transfer (CPT) device submerged in seawater. As a function of capacitive coupling settings, the highest available load power and the corresponding efficiency have been expressed.
- With a single DC power supply and inverter, power is transported from the primary to secondary side via magnetic and electric fields at the same time.
- To better understand the effect of body tissue on the power transmission

			mechanism, create a finite element model of a capacitive power transfer system.
6.78 MHz [15] [16]	 By enabling autonomous charging in applications ranging from electric cars (EVs) to portable devices, WPT can eliminate the requirement for energy storage and improve user convenience. An active variable reactance (AVR) rectifier is used to correct for coupling fluctuations in inductive and capacitive WPT systems. While operating at a fixed frequency and preserving soft switching, the AVR rectifier provides a continually varying reactance. 	 Using banks of switchable capacitors or changeable inductors to maintain the resonance frequency in coupling fluctuations has substantial drawbacks, including increased size, weight, and losses, especially in high-power WPT systems. This method necessitates many high-voltage and high-current switches in high-power WPT systems, which makes it costly. Furthermore, because multiple switchable compensating inductors, which are larger and more lossy than capacitors, this approach is less suitable to capacitive WPT systems. 	 The variable compensation inverter (VCI) consists of numerous high-frequency inverters feeding a lossless resonant network, with configurable voltages at the inverters' inputs. The AVR rectifier has a power-splitting resonant network and operates at a fixed frequency. The AVR rectifier adjusts for severe misalignments and distance fluctuations between couplers by regulating the ratio of split powers in its branches, while ensuring full power transfer. To determine the appropriate number of matching network stages, as well

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- Because capacitive WPT systems do not require ferrites, they can be operated at high frequencies, resulting in smaller and less expensive systems and an appealing option for a range of applications, including EV charging.
- Capacitive WPT systems generate significantly less eddy-currentinduced heating and losses in surrounding metallic structures than their inductive equivalents, and they are more resistant to coupling fluctuations.
- Inductive WPT systems often require costly and delicate ferrite cores that suffer significant losses, limiting their frequency of operation and thus their size reduction potential.
- Typical ferrite cores for inductive WPT systems are heavy, expensive, and fragile, resulting in losses. Using ferrites also limits their working frequency and, as a result, their size
- reduction potential.
- The latter allows for more flexibility in power regulation, but at the cost of potentially slower system dynamics and a reduction in overall efficiency.

as the optimal gain and compensation distribution among these stages and the optimal air-gap voltage.

- The ideal number of matching network stages, as well as the optimal distribution of profits and compensations among these stages, are determined using this method.
- The new controller IC has on-the-fly high-resolution very-high-frequency tracking circuitry and an independent high-resolution digital PWM-based (HR-DPWM) current programmed
 control.
- The multi-mixed-signal controller's complicated functional linkages, as well as theoretical and practical insights into the dynamics and

•	Because	of	its	simp	olicity,
	dependabili	ity, a	ind safe	ety, it	is the
	most often	use	ed near	-field	WPT
	approach	in	comme	rcial	WPT
	application	s.	ALA	YSI.	

- The power transfer capabilities of CPT systems are successfully disengaged from any drift or changes, allowing spatial independence of the transferred energy from transmitter to receiver.
- Utilizing a unique design approach that includes the modelling and mitigation of inter-module interactions, this system achieves high power transfer at high efficiency while keeping fringing electric fields below safe limits

• By creating matching networks that enable loose coupling between the transmitting and receiving sides, the WPT system's sensitivity to changes can be reduced.

These parasitic capacitances cause unwanted intra-module and intermodule interactions, which can significantly reduce power transmission and efficiency, especially at high (multi-MHz) frequencies. implementation of a closed-loop capacitive power transfer (CPT) system.

• Near-field phased-array fieldfocusing techniques, in which nearby modules of a multi-modular system are out-phased with respect to one another, are used to lessen the fringing fields.

	using near-field phased-array field-		
	focusing techniques.		
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13.65 MHz	• Providing stationary, semi-	• The impact of parasitic and dissipative	• A prototype 13.56-MHz 12-cm airgap
	dynamic, and dynamic charging,	materials (such as asphalt) on the	500-W capacitive WPT system that
[17], [18]	which helps overcome the cost,	charging environment, which can	uses these charging pads for power
	charging time, and range restrictions	significantly reduce power transfer and	transfer supports the design with
	of electric cars (EVs), has the	efficiency.	theoretical analysis and simulations.
	potential to expand adoption of EVs.	• High costs, long charging times, and	• Gain and reactive compensation are
	• Can significantly reduce the cost of	restricted range are the primary barriers	provided via coupled-inductor based
	electric vehicles (by significantly	to widespread EV adoption.	L-section matching networks. The
	reducing on-board energy storage),	• When the IPT's coils are misaligned, it	system's efficiency and size are
	remove charging periods, and	has a vulnerability in terms of	greatly improved by the high
	provide an endless range.	supplying power. A study on	operating frequency and coupled-
	• The capacitive wireless power	electromagnetic interference (EMI)	inductor matching network design.
	transfer is used in an EV charging	and the potentially dangerous system	• Protected capacitive power transfer
	system with two pairs of coupling	caused by metal barrier disruption was	(shielded-CPT) is a scalable shielded
		also released.	capacitive power transfer (shielded-

plates and shielding plates to protect	• Tunable inductors are another means of	CPT) for micro electric vehicle (EV)
the CPT from EMI radiation.	delivering variable compensation;	wireless charging.
	however, these techniques degrade	
	system efficiency and do not scale well	
MALAYSIA	with power.	
24 M.C.		
S V	• The efficiency of a previously reported	• Co-designing the AVR rectifier with
• This design method allows large air-	system using STIF coupled inductors is	the WPT system's matching networks
gap capacitive WPT systems to	also superimposed, highlighting the	to accommodate for substantial
adapt for coupling fluctuations in a	new system's enhanced efficiency	coupling fluctuations while
dynamic EV charging environment	provided using TIF coupled inductors.	maintaining high efficiency.
while retaining a stable frequency	Most losses in this prototype system	• These matching networks also use
and soft-switching (thus, high	are conduction losses in the inductors,	 parasitic capacitances in the charging
efficiency).	according to a comprehensive loss	environment to give gain and reactive
• Capacitive WPT systems do not	breakdown.	compensation. To achieve a
require ferrites and can function at	• For most load impedance/power level	sufficiently high self-resonance
high frequencies, making them	combinations, these constraints will	frequency while minimizing losses.
lighter, more compact, and less	not be enough to confine the system,	• Two HF inverters with individually
expensive to install in the roadway.	and another constraint, such as a cost	changeable amplitude and phase are
	function, will be required.	connected and to the load via a

- Despite substantial differences in load impedance, the loading on each constituent inverter can be kept in a desired resistive/inductive area by adjusting the amplitudes and relative phase of the two constituent inverters.
- WPT can reduce battery requirements and enhance consumer convenience by enabling autonomous charging in applications ranging from electric vehicles (EVs) to biomedical systems and portable electronics.
- A galvanically-wired connection and conductive connectors can be used to transfer energy between modules. Power converters can be
- The coupling reactance changes when the couplers are misaligned or the air space between them is modified (for example, while charging a moving vehicle or charging vehicles with varied ground clearances, respectively). As a result, the system loses resonance, resulting in a significant reduction in power transfer and efficiency.
- The rate at which each module's battery is depleted will vary depending on the module's function. The robot's

lossless power combining network, implemented here as an immittance converter, in the HF variable-load inverter (HFVLI) design.

- In an AVR-rectifier-enabled capacitive WPT system, maximize the tolerated range of misalignments while satisfying efficiency requirements.
- provide a bidirectional capacitive
 wireless power transfer technique for
 balancing energy between several
 robot modules. To make the power
 transmission resilient to changes in
 robot dimensions, a modified
 CMCDE architecture is also
 provided.

added to each module to control the flow of energy.

- The capacitances in the circuit model are determined by the physical structure of the conductors as well as the spatial relationship between the conductors, and the circuit capacitances can be calculated using a field solver.
- WPT is a useful method for charging electric vehicles (EVs), since it provides the ease of self-charging, eliminates expensive, cumbersome, and wear-prone cables and connectors, and speeds up the transition to completely powered transportation.
 It is the best amplifier for the WPT
- system. As a result, it provides a

operation time will be limited to the time it takes the most power-hungry module to empty its local battery.

- The inverter and rectifier circuits are also sensitive to RF port impedance, and variations in port impedance due to spatial changes have a major impact on the wireless transfer system's overall efficiency.
- The parasitic capacitances are represented as a circuit. By separating the inductors into forward and return routes, they can be absorbed into and used as matching network capacitances

through circuit symmetry.

• An analogous circuit is used to model the capacitively coupled connection, which contains all coupling routes between the four conductors that make up the link.

- The system is first tested with a resistive load in dc to high frequency ac mode. The prototype system transfers 895 W with a 93 % efficiency in this mode. The prototype is next tested with a fullbridge passive rectifier in dc-to-dc mode.
- Because of its ability to conduct the dc-to-ac inversion efficiently, a Class-E resonant inverter with π1a impedance matching network

very	efficient system. This is since	٠	Metals prevent the	magnetic field from		was used as a high frequency ac
switc	hing losses are almost non-		penetrating. As a	result, IPT is not		power supply in this study. It aids the
existe	ent when the component values		relevant in situatio	ons where there are		CPT system in achieving the highest
are co	onveniently chosen.		metal barriers betw	veen power sources		possible power transfer.
	ALAYSIA		and loads. F	Furthermore, the		
	24		electromagnetic fi	eld serves as an		
	S X		"energy carrying ch	nannel."	-	
	AN AN					
	F				V.	
	E	•	By establishing	a local ground	•	By imposing a virtual ground, the
	9 da		reference for	all the system		balanced design neutralizes
• Two	resonators are coupled by a		capacitances, ne	eutralizing these		numerous plate capacitances. The
lump	ed element transmission line in	1	capacitances effec	tively isolates the		capacitance network connecting the
an e	equivalent circuit model of	-	system from the	earth ground. This	دروته	transmitter and receiver is reduced to
capac	citances. Matching inductors		reduces the syste	em's sensitivity to	14 M	a half-circuit equivalent.
are in	cluded in the model, and their	NI	capacitance in the e	environment.	LAK	Δ
value	es are easily derived.		a to the star that			5. J

2.3.2 Comparison between Variety of Compensation

Types of Compensation	Advantages	Disadvantages	Applications
LC [19]	Lower cost.Lower weight.	• Produce low power output efficiency compares to other.	• Charging of biomedical devices.
	 Various application either low-power or high- power application. Better misalignment performance. 	ITeM	
CL [20]	 Can produce less sensitive and robust system. Leakage electric flux is dramatically reduced by adding the CL circuit on the secondary side. UNIVERSITI TEKNIKAL 	 Unnecessary in a practical low power CWPT system design owing to the high impedance of the capacitive interfaces. High voltage stress. 	 Fuel cell vehicles. Hybrid electric vehicles. Electric vehicles.

LCLC [21] [22]	 When utilised at 2.1 kW, its efficiency is 90.7 percent. Enables great transmission efficiency under the desired operating conditions. 	• Complex build up simulation.	Vehicle charging.Battery oriented.
	• The output power increases with an approximately.		
CLLC [21]	 At 2.57 kW, it achieves an efficiency of 89.3 percent Allows for excellent transmission efficiency under specified operating conditions. 	• CLLC compensation does not behave as a current source.	• Vehicle charging.
	سي من مسين مارد	ويورسيني يت	

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2.3.3 Comparison between CPT Structure, Circuit and Model







	Model type: Mutual Capacitance.	



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2.4 Summary

This chapter provides a summary of concept and previous study of project title related. The previous study reviews different type of result demonstrated in the journal, so that comparison has been made to simplify all the knowledge gathered in the research journal.



CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides an explanation of the many methods that were utilized in the process of acquiring all of the data and doing the analyses that are essential to the project. The methodology will cover topics including using software, developing circuits, illustrating block diagrams, constructing equations, and doing calculations, among other things.

3.2 Project Methodology

Shortly before the project is released, supervisor proposed the project title selection which is development of 13.56MHz capacitive wireless power transfer with different dielectric material for charging system. In order to develop ideas and figure out the aims and solutions, the proposed project title will be studied as shown in Figure 3.1.

Next, a literature review from previous project or research related has been conducted. Journal and articles that linked to the project objectives has been previewed to gain more knowledge. It is important to do such thing as literature review will delivered in assist on theories and ideas for project development.

Apart from that, there are some calculations done. Calculation needs to be performed as its value is used to determine the dimension of the hardware. Lastly, preliminary test been conducted to identified whether there are problems in simulation. This can avoid and improves for running this project further.



Figure 3.1 : Flowchart of project methodology

3.3 Project Characteristic

The capacitive wireless power transmission (CWPT) technique transfers power wirelessly by applying the electric field coupling mechanism[26]. Electric fluxes are often formed here by a pair of metallic plates, as seen in Figure 3.2. As seen in the diagram, electric flow is unidirectional, beginning at the transmitting plate (which is positively polarised) and ending at the receiving plate's inner surface (negatively polarized). This feature is unaffected

by the distance between the two plates. In actuality, due to fringing fields, the electric field lines on the margins of the plates might become slightly deformed. The parallel plate properties here are quite similar to those of the parallel-plate capacitor [7].



The methods and techniques used in this entire project will be explained briefly in detail with the assistance of block diagram.

3.3.1



Figure 3.3 : Block diagram of CPT system

A typical CWPT system, as illustrated in Figure 3.3, consists of the following blocks: an alternating current power source, an inverter, a compensation circuit, a capacitive coupler, a compensation circuit, a rectifier, and a load. On the transmitter side, the input DC voltage is converted to high frequency AC voltage and supplied to the transmitter plate (copper plate). The electric field formed by the plates is utilised to transport electrical energy from the transmitter to the receiver [25]. The high-frequency alternating current voltage obtained at the receiver is rectified to direct current voltage, which may be used to charge a battery or power any device. The quantity of power delivered is determined by the frequency and capacitance between the plates.



Figure 3.4 : Overall Project Development

3.5 Calculation

This section explained briefly all the calculation related to the proposed model of CWPT. Value of capacitances and inductances is calculated by derivation of equation. A table of each test parameter presented in this section.

3.5.1 Test Parameter 1 (Acrylic Sheet)

	Parameter					
Symbol	Description	Simulation Value	Unit			
V1	Input voltage	20	V			
C _C	Coupling capacitance	5.3	pF			
$C_{11}, C_{21}, C_{32}, C_{42}$	Parasitic shield capacitance	10.6	pF			
$L_{r1}, L_{r2}, L_{r3}, L_{r4}$	Resonant inductance	0.515	μΗ			
F	Resonant frequency	13.56	MHz			
RL	Load resistance	500	Ohm			
AL LE	Dimension	12 x 5	cm			

 Table 1 : Value of Component

Calculation for Capacitance



Dimension of Capacitance Coupling Plate:

 $12 \text{cm} \ge 5 \text{cm} = 60 \text{cm}^2$

Distance between the two Coupling Plate:

10mm

Dielectric constant = 2 (Acrylic Sheet)

$$C_C = \frac{A\varepsilon_0}{\frac{2d_d}{\varepsilon_r} + d}$$

Capacitance = 5.3pF

Calculation for Inductance

$$L_A = \frac{C_{11} + C_C}{[C_{11}^2 + (2C_{11}C_C)]\omega^2} \text{ where, } \omega = 2\pi f$$
$$L_A = 1.03 \ x \ 10^{-6}$$

3.5.2 Test Parameter 2 (Air)

Calculation for Capacitances



Dielectric constant = 1 (Air)

$$C_C = \frac{A\varepsilon_0}{\frac{2d_d}{\varepsilon_r} + d}$$

Calculation for Inductances

$$L_A = \frac{c_{11} + c_C}{[c_{11}^2 + (2c_{11}c_C)]\omega^2} \text{ where, } \omega = 2\pi f$$
$$L_A = 9.74 \ x \ 10^{-6}$$

3.6 Simulation LTspice



Figure 3.5 : LTSpice logo



Figure 3.6 : LTSpice window interface

Analog Devices' LTspice is a high-performance circuit simulation programme that allows students to construct, explore, and analyse the performance of their circuit for free. The programme being used is not a crack kind of file. LTspice uses unique modelling methodologies for its micromodels, resulting in fast and precise simulation results. LTspice has an integrated schematic editor, waveform viewer, and complicated features that are easy to use once you learn the fundamentals.

Circuit Diagram

In order to describe the working principle of capacitive wireless power transfer (CWPT), the simulation circuit have been constructed. This circuit simulation is constructed to analysed the transfer capability of the CWPT coupler. To simplify the system analysis, simplified circuit then constructed. Both simulation circuit been designed with LTspice software.



Figure 3.7 : Full Capacitive Wireless Power Transfer Circuit

CWPT Equivalent Circuit



Figure 3.8 : Equivalent Capacitive Wireless Power Transfer Circuit

3.7 Hardware Development

This chapter contains overview of hardware requirement for this project. Each of the component will be explained their function and role into this project.

3.7.1 FR-4 PCB



The most widely used dielectric grade is FR4. Single-sided, double-sided, and multi-layered boards use this material. Single-sided FR-4 PCB was used in this project. FR4 materials have a high range of operating temperatures (50°C to 115°C) and decent mechanical capabilities to keep the board structure intact. To facilitate the transmission of power from transmitter to receiver, FR-4 PCBs are used as coupling plates.

3.7.2 Ceramic Cement Power Resistor (10W 500 ohm)



Figure 3.10 : Ceramic Cement Power Resistor

Ceramic cement power resistors are made by winding resistance wires around a non-alkaline ceramic core that contains a layer of heat and humidity resistant and noncorrosive protective material on top. After that, the wire wound resistor is sealed in a square ceramic package with a nonflammable heat-resistant cement.

3.7.3 Inductor Core



Figure 3.11 : Air core inductor

Inductors are commonly used as energy storage devices in switched-mode power devices to generate DC current. To keep the current flowing during "off" switching times, an inductor provides energy to the circuit, allowing for higher voltage outputs than input voltage.

Figure 3.12 : Crocodile Clip Wire

3.7.4 Crocodile Clip Wires

Crocodile clips are typically used to make temporary electrical connections. Clips can be used to connect two wires or to connect one lead to a device directly. They are extremely beneficial in laboratories and experimental circuits.
3.7.5 Donut Board

3.7.6



Figure 3.13 : Donut Board

The prototyping donut board provides more solid/rugged prototyping because the components are soldered to the board. This board is brown in colour, made of Paper Phenolic, and each hole or solder pad (at the bottom of the PCB) is independent.



Figure 3.14 : Multimeter

A multimeter is a type of electronic measuring instrument that combines several measurement functions into a single unit. A typical multimeter may have capabilities such as measuring voltage, current, and resistance.

3.8 Hardware Fabrication



Figure 3.16 : Function Generator

A function generator is an alternating current current power supply for alternating current circuits . A variable voltage source (or amplitude) is provided by a function generator, but it can also change depending the frequency, which is measured in Hertz or cycles per second.

3.9.2 Nano Vector Network Analyzer (VNA)



Figure 3.17 : Nano VNA

From port 1, the Nano Vector Network Analyzer sends a stimulus signal. The signal is routed to a device under test via a 50 ohm characteristic impedance coaxial cable. The stimulus signal's frequency range can be there between 10 kHz and 1500 MHz.



Figure 3.18 : Oscilloscope

Oscilloscopes (or scopes) measure and display voltage signals as waveforms, which are visual representations of voltage variation over time. The signals are plotted on a graph to demonstrate how the signal changes.

3.10 Summary

This chapter described the method used in developing the whole operation of the project entitled 'Development of 13.56MHz capacitive wireless power transfer with different dielectric material for charging system '. The construction and design circuit of the system are recorded alongside the equipment and software used for the respective function. Other than that, all the calculation related has been featured in this chapter. There is 2 calculation provided as it is been compared to 2 different materials between air and acrylic sheet. Calculation is the main important things which it is contributed in determine the value of capacitor and inductor to obtain the expected result according to the theories. The analysis of the data collected will be clearly stated in the next chapter.



CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this section, all the result is being recorded and discussed during the simulation and harware measurement process. The value of the component such as capacitor and inductor are obtained from derivation of equation and do some calculation. Basically, all the simulation circuit either full CWPT or simplified CWPT are constructed in LTSpice software. However, for the circuit that was constructed in LT Spice then be tested experimentally to prove and compare to the simulation result.

4.2 Overall Result Development



Figure 4.1 : Overall Result Developement

4.3 **Results and Analysis for Simulation**

All result from simulation for 2 condition which included calculation value and measurement value. CWPT full circuit and CWPT equivalent circuit with different dielectric material is been analyzed. As both circuit preview different parameter.

4.3.1 CWPT Full Circuit (Calculated Value) – Acrylic Sheet



Figure 4.2 : Full Capacitive Wireless Power Transfer simulation circuit with calculated value





Figure 4.3 : Equivalent Capacitive Wireless Power Transfer simulation circuit with calculated value

Symbol	Description	Value	Unit
V ₁ ,V ₂	Voltage	20	V
C _{1,3}	Coupling capacitance	10.6	pF
Cc	Coupling capacitance	5.3	pF
C _{p,s}	Parasitic shield capacitance	10.6	pF
C_2, C_4, C_5, C_6	Parasitic shield capacitance	21.2	pF
<i>L</i> _{1,} <i>L</i> ₃	Resonat inductance	1.03	μΗ
$L_{1,}L_{2,}L_{3,}L_{4}$	Resonant inductance	0.515	μΗ
f MAI	Ays/A Switching frequency	13.56	MHz
A	Area	6000	mm²
S	Separation distance	10	mm
s salar	Separation distance between	5	mm
ملاك	shield plate	المتحر سيت	
R _L	Load resistance	500	Ω
UNIVE	Dimension	120 × 50	mm ²

 Table 2 : Component Values

4.3.3 CWPT Full Circuit (Measurement Value) – Acrylic Sheet



Figure 4.4 : Full Capacitive Wireless Power Transfer simulation circuit with measurement value

4.3.4 CWPT Equivalent Circuit (Measurement Value) – Acrylic Sheet



Figure 4.5 :Equivalent Capacitive Wireless Power Transfer simulation circuit with measurement value

Symbol	Description	Value	Unit
V ₁ ,V ₂	Voltage	20	V
C _{1,3}	Coupling capacitance	106	pF
C _C	Coupling capacitance	53	pF
C _{p,s}	Parasitic shield capacitance	106	pF
C_2, C_4, C_5, C_6	Parasitic shield capacitance	212	pF
<i>L</i> _{1,} <i>L</i> ₃	Resonat inductance	1.47	μΗ
$L_{1,}L_{2,}L_{3,}L_{4}$	Resonant inductance	0.735	μΗ
f MA	Ays Switching frequency	13.56	MHz
A	Area	6000	mm²
S	Separation distance	10	mm
s stann	Separation distance between	5	mm
ملاك	shield plate	المؤمر إستاج	
R_L	Load resistance	500	Ω
UNIVE	Dimension	120 × 50	mm ²

 Table 3 : Component Values

4.3.5 CWPT Full Circuit (Measurement Value) – Air



Figure 4.6: Full Capacitive Wireless Power Transfer simulation circuit with measurement value

4.3.6 CWPT Equivalent Circuit (Measurement Value) – Air



Figure 4.7 : Equivalent Capacitive Wireless Power Transfer simulation circuit with measurement value

Symbol	Description	Value	Unit
V ₁ ,V ₂	Voltage	20	V
C _{1,3}	Coupling capacitance	144	pF
C _C	Coupling capacitance	72	pF
$C_{p,s}$	Parasitic shield capacitance	144	pF
<i>C</i> ₂ , <i>C</i> ₄ , <i>C</i> ₅ , <i>C</i> ₆	Parasitic shield capacitance	288	pF
L _{1,} L ₃	Resonat inductance	1.45	μΗ
$L_{1,}L_{2,}L_{3,}L_{4}$	Resonant inductance	0.735	μΗ
f NA	Ays Switching frequency	13.56	MHz
A	Area	12000	mm²
S	Separation distance	10	mm
S	Separation distance between	5	mm
ملاك	shield plate	المؤمر سيت	
R _L	Load resistance	500	Ω
UNIVE	Dimension	120 × 100	mm ²

Table 4 : Component Values

4.4 Simulation Result

This section previews all the gathered result based on how each circuit is respond. LTSpice software have been used to simulate all the waveform from circuit simulation either from full CWPT or equivalent CWPT circuit.

4.4.1 Test Parameter 1 (Acrylic Sheet)



Figure 4.8 : Simulation waveform for voltage input (green) and output (blue)



Figure 4.9 : Output waveform of matching impedence

4.4.2 Test Parameter 2 (Air)

.9d3

11MHz

12//H2



Figure 4.11 : Output waveform of matching impedence

13.56 MHz 14MHz

16MHz

17MHz

18MHz

13MHz

4.5 Result and Analysis for Hardware Measurement

All result from hardware measurement for 2 condition which included different dielectric material air and acrylic sheet. CWPT full circuit and CWPT equivalent circuit is been analyzed. As both circuit preview different parameter. An additional result with different dielectric material has been compile along into this report to make a comparison between acrylic sheet and air as dielectric material.

4.5.1 Overall of Experiment Setup



Experiment Setup For Matching Impedance Testing

Figure 4.13 : Voltage Transfer Process

4.5.2 CPT Coupler with Inductor



Figure 4.15 : Nano VNA installed with JIG connection

4.6 Result of VNA Matching Impedence



Figure 4.16 : Output waveform in magnitude and phase from NanoVNA

A 13.56-MHz 1cm air-gap CWPT prototype has been built and tested. The dielectric material is acrylic sheet, which is labelled as test parameter 1. The oscilloscope depicted the measured waveforms of the prototype system. Figures 4.17 and 4.18 show that the efficiency of each condition is quite similar. As can be seen, the 13.56-MHz system is significantly more efficient across the majority of the output power range.



Figure 4.17 : Experimental set up

4.7.1 Test Parameter 1 (Acrylic Sheet)







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4.8 Comparison between Air and Acrylic Sheet as Dielectric Materials (Hardware Measurement)

Dielectric Materials	Coupling Capacitance	Capacitance	Inductance
Acrylic Sheet (12cm x 5cm)	53pF	106pF	1.47uH
Air (12cm x 10cm)	72pF	144pF	1.45uH

4.9 Summary

For simulation, both condition circuits have been constructed using LTspice software. Initial condition constructed circuit using calculated value the next one is measurement value from hardware fabrication. The first circuit is known as full CWPT circuit and the other one is equivalent CWPT circuit. In order to get the full CWPT, equivalent CWPT circuit must be done first where all the value of the component is determined by using derivation of the equation as state in chapter 3. This is because in the software of LTSpice equivalent circuit can result the output waveform and matching impedence of CWPT itself. However full circuit will be analyzed of input or out of voltage and current of CWPT system. When 2 types of constructed circuits are simulated with different values and models, it has been found that both simulations produce different outputs and can conclude each design circuit have their characteristic. In order to get the result, all simulations is run at 13.56Mhz. However for experimental measurement there is slightly difference compared to the simulation. To prove the experimental measurement result is true, CWPT circuit is then been connected from function generator as supply and oscilloscope to display the performance of 13.56MHz CWPT.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis analyses and summarises the most recent advancements and innovations in 13.56MHz capacitive wireless power transfer with different dielectric materials for charging devices. This conclusion describes a charging system employing CWPT technology with a big airgap and high performance. A simulation 13.56-MHz 1.0cm air-gap capacitive WPT system is constructed and assessed using LTSpice software.

Four capacitive wireless transfer techniques are developed and investigated in this chapter. The design parameters have been thoroughly examined. The dielectric breakdown voltage is estimated to better understand the proposed CWPT configuration's voltage control capability. Because metallic interconnects are low resolution at very high resonance frequencies, this concept offers a viable solution. The power of a CPT system is linked to the switching frequency, inductances, and voltages in between metal plates, according to an examination of its essential working principle.

Classification and evaluation are done on the basis of parameters such as performance and compensation types, and coupler types. Biomedical and short-distance integrated circuits use CPT technology, while long-distance transportation uses CPT technology. Coupler designs are primarily designed to reduce electric field emissions or increase coupling capacitances, according to a study. CPT applications and their advantages and downsides are thoroughly examined in this chapter. Many benefits can be derived by using this technology, such as reduced size and weight, improved alignment tolerances, and reduced electric field emissions.

5.2 Recommendation

For future recommendation, efficiency of CPT system can be improved by several method as follow;

- i. Implemented LCLC compensation network topologies which enhance system power capability and coupling coefficients.
- ii. Model the dynamic performance of the resonant circuit and resulting rapid response solution.
- iii. Proposed voltage control for the coupling coupler of the CPT system where its limit voltage between coupling to a safe range.

5.3 Potential Commercialization

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CWPT has a wide range of potential to enter the global market for commercialization. This is the possibility of CWPT to become an everyday consume asset.

- i. Wireless charging pads for smartphones and other portable devices.
- ii. Charging for electric vehicles, such as the Charging Spot for Electric Vehicles(EVs), which uses CWPT to charge a vehicle without having to use a plug.
- iii. Utilized in industrial automation and robotics to power sensors and other equipment wirelessly, enhance productivity while also minimizing the use of cables and other physical connections.

REFERENCES

- 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.
- 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.
- [3] A. Triviño, J. M. González-González, and J. A. Aguado, "Wireless power transfer technologies applied to electric vehicles: A review," *Energies*, vol. 14, no. 6. MDPI AG, Mar. 02, 2021. doi: 10.3390/en14061547.
- [4] H. Mahdi, B. Hoff, and T. Ostrem, "Maximum available power of undersea capacitive coupling in a wireless power transfer system," Jun. 2021. doi: 10.1109/WPTC51349.2021.9458006.
- [5] L. Yang, M. Ju, and B. Zhang, "Bidirectional Undersea Capacitive Wireless Power Transfer System," *IEEE Access*, vol. 7, pp. 121046–121054, 2019, doi: 10.1109/ACCESS.2019.2937888.
- [6] B. Regensburger, A. Kumar, S. Sinha, and K. Afridi, "High-Performance 13.56-MHz Large Air-Gap Capacitive Wireless Power Transfer System for Electric Vehicle Charging," Sep. 2018. doi: 10.1109/COMPEL.2018.8460153.
- [7] D. Rozario, N. A. Azeez, and S. S. Williamson, "Analysis and design of coupling capacitors for contactless capacitive power transfer systems," Jul. 2016. doi: 10.1109/ITEC.2016.7520244.
- [8] S. C. Chung, U. Tunku, and A. Rahman, "NEW METHODS FOR CAPACITIVE WIRELESS POWER TRANSFER," 2013.
- [9] S. Maji, S. Sinha, M. Khatua, and K. K. Afridi, "Theoretical Limits and Optimal Operating Frequencies of Capacitive Wireless Charging Systems," Jun. 2021. doi: 10.1109/WoW51332.2021.9462874.
- [10] Instituto Tecnológico de Buenos Aires, Institute of Electrical and Electronics Engineers, and IEEE Industrial Electronics Society, Proceedings, 2020 IEEE International Conference on Industrial Technology : Buenos Aires Institute of Technology (ITBA), Buenos Aires, Argentina, 26-28 February, 2020.
- [11] Y. Zhang, S. Chen, X. Li, and Y. Tang, "Design of High-Power Static Wireless Power Transfer via Magnetic Induction: An Overview", doi: 10.24295/CPSSTPEA.2021.00027.
- Z. Wang, Y. Zhang, X. He, B. Luo, and R. Mai, "Research and Application of Capacitive Power Transfer System: A Review," *Electronics (Basel)*, vol. 11, no. 7, p. 1158, Apr. 2022, doi: 10.3390/electronics11071158.
- [13] R. Matthes, J. H. Bernhardt, A. F. McKinlay, and International Commission on Non-Ionizing Radiation Protection., *Guidelines on limiting exposure to non-ionizing* radiation : a reference book based on the guidelines on limiting exposure to nonionizing radiation and statements on special applications. International Commission on Non-Ionizing Radiation Protection, 1999.

- [14] N. Ashraf, S. A. Sheikh, S. A. Khan, I. Shayea, and M. Jalal, "Simultaneous Wireless Information and Power Transfer with Cooperative Relaying for Next-Generation Wireless Networks: A Review," *IEEE Access*, vol. 9. Institute of Electrical and Electronics Engineers Inc., pp. 71482–71504, 2021. doi: 10.1109/ACCESS.2021.3078703.
- [15] Y. Ye, C. Zhang, C. He, X. Wang, J. Huang, and J. Deng, "A Review on Applications of Capacitive Displacement Sensing for Capacitive Proximity Sensor," *IEEE Access*, vol. 8. Institute of Electrical and Electronics Engineers Inc., pp. 45325–45342, 2020. doi: 10.1109/ACCESS.2020.2977716.
- [16] M. A. Ullah, R. Keshavarz, M. Abolhasan, J. Lipman, K. P. Esselle, and N. Shariati, "A Review on Antenna Technologies for Ambient RF Energy Harvesting and Wireless Power Transfer: Designs, Challenges and Applications," *IEEE Access*, vol. 10. Institute of Electrical and Electronics Engineers Inc., pp. 17231–17267, 2022. doi: 10.1109/ACCESS.2022.3149276.
- [17] S. Y. R. Hui, "Non-Radiative Wireless Power Transfer," 2016.
- [18] K. N. Mude and K. Aditya, "Comprehensive review and analysis of two-element resonant compensation topologies for wireless inductive power transfer systems," *Chinese Journal of Electrical Engineering*, vol. 5, no. 2, pp. 14–31, Jun. 2019, doi: 10.23919/CJEE.2019.000008.
- [19] L. Yi and J. Moon, "Design of Efficient Double-Sided LC Matching Networks for Capacitive Wireless Power Transfer System," Jun. 2021. doi: 10.1109/WoW51332.2021.9462873.
- [20] T. M. Mostafa, D. Bui, A. Muharam, R. Hattori, and A. P. Hu, "A Capacitive Power Transfer System with a CL Network for Improved System Performance; A Capacitive Power Transfer System with a CL Network for Improved System Performance," 2018.
- [21] elettronica Federazione italiana di elettrotecnica *et al.*, 2020 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE) : November 18-20, 2020.
- [22] 2020 IEEE Applied Power Electronics Conference and Exposition (APEC). IEEE, 2020.
- [23] 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.
- [24] S. Maji, S. Sinha, B. Regensburger, F. Monticone, and K. K. Afridi, "Reduced-Fringing-Field Multi-MHz Capacitive Wireless Power Transfer System Utilizing a Metasurface-based Coupler," Nov. 2020. doi: 10.1109/COMPEL49091.2020.9265739.
- [25] A. Muharam, S. Ahmad, R. Hattori, and A. Hapid, "13.56 MHz scalable shieldedcapacitive power transfer for electric vehicle wireless charging," in 2020 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer, WoW 2020, Nov. 2020, pp. 298–303. doi: 10.1109/WoW47795.2020.9291299.
- [26] 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.