Electrical Engineering Project

Department of Electrical Engineering

Faculty of Engineering

Kasetsart University

Demonstration of Resonant Wireless Power Transfer using Toy Racing Cars and Tracks

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Academic Year 2022

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Submitted in partial fulfillment of the requirements for the degree of

Bachelor degree of Engineering

Electrical Engineering

Approved by

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Tanit Wisessri and Chatpisut Promsatarporn Academic Year 2022

Demonstration of Resonant Wireless Power Transfer using Toy Racing Cars and Tracks

Bachelor degree of Engineering, Department of Electrical Engineering
Faculty of Engineering, Kasetsart University

Abstract

Nowadays, spending time charging your car at a charging station is a waste of time and a waste of job opportunities. Charging a car may require booking a charger or queuing to charge and it may take about 30 minutes to fully charge. In this project will be a demonstration of resonant wireless power transfer using toy racing cars and tracks. To make a wireless power transfer and the car is moving smoothly, a dynamic wireless power transfer (DWPT) system was chosen for transfer power and the alternately coupled magneto inductive (ACMI) waveguide with alternate magnetic coupling polarities between successive resonator cells is proposed for a true nulls-free DWPT system with no use of active components for moving smoothly. This project starts with buying an oscillator that can generate 13.56 MHz, buying an amplifier to expand 1000 times of the signal from the oscillator and design attenuator PCB board that decreases approximately 25 dBM. Then, design DWPT and ACMI. Finally, customizing a car and testing its performance on a track. First, test the car without any load and with load. Then, add a 100-ohm resistor to the circuit and test the car's performance with the load. During tests, measure the direct voltage and current. Additionally, calculate the output power in dBm for each test.

Keywords: Oscillator, Attenuator, DWPT and ACMI

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Tanit Wisessri

Chatpisut Promsatarporn

Author

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Symbols and Abbreviations

μ	represents	One millionth of a unit of measure
M	represents	A factor of one million
π	represents	A constant the ratio of the circumference
WPT	stands for	Wireless power transfer
DWPT	stands for	Dynamic wireless power transfer
ACMI	stands for	Alternately Coupled Magneto Inductive
VNI	stands for	Vector Network Analyzer
PCB	stands for	Printed circuit board
DC	stands for	Direct current
FEA	stands for	Finite element analysis
CFD	stands for	Computational fluid dynamics
RF	stands for	Radio frequency
AC	stands for	Alternating current

1. Introduction

For EV charging, wireless power transfer (WPT) technology has been used. Through electromagnetic coupling, the WPT system may transport power from the transmitting side to the receiving side. As a result, when the EVs are close to the WPT facilities, the batteries can be charged without physical touch. When compared to traditional charging methods, WPT provides advantages to drivers such as safety, convenience, and ease of use. However, the stationary WPT system has yet to tackle two intrinsic problems: a longer charging time than typical fuel-filling time and a lower mileage than engine-powered vehicles.

The dynamic wireless power transfer (DWPT) system is a promising solution to the concerns raised above. DWPT allows the EV to be powered constantly while in motion by the transmitter installed beneath the roadway. It is possible to charge and consume energy at the same time. As a result, the driving range of EVs can be greatly enhanced. Meanwhile, the battery capacity, as well as the cost and weight, might be reduced.

Despite the benefits listed above, the multiple-individual transmitter architecture still has certain major issues that must be solved. One difference is signal transmission stability.

1.1. Objectives

1. To capture people's interest in the topic of electromagnetic waves.
2. To design dynamic wireless power transfer and the alternately coupled magneto inductive that is functional and useful in everyday life.

1.2. Scopes

The scope and operation of the system can be shown in Fig.1 of the system as shown below.

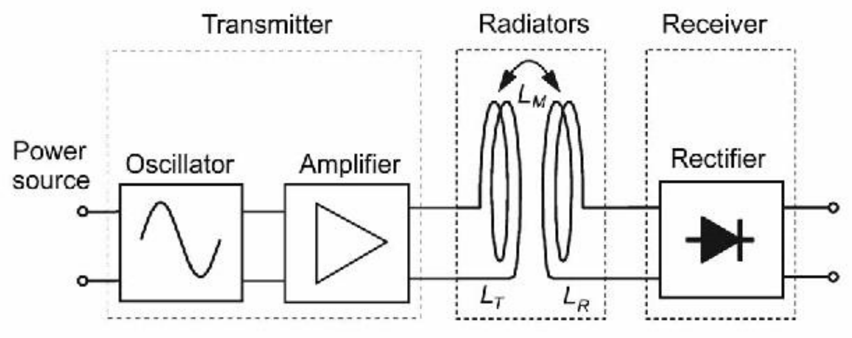


FIGURE 1 System Overview

1.2.1 The work of transmitter

- Produce a 13.56 MHz signal from oscillator and transmit it through an SMA Cable to an attenuator.
- Use attenuator to reduce the signal level by a factor of 100 and transmit it through the SMA Cable to the amplifier.
- Use amplifier to increase the signal level by a factor of 1000 and pass it through the SMA Cable to the transmit coil.

1.2.2 The work of Radiators

- Transmit a signal from the transmit coil on the track to the receive coil on the Tamiya car using magnetic coupling.

1.2.4 The work of Receiver

- Create rectifier full bridge circuit to convert AC voltage to DC voltage.
- Use capacitor to stabilize the voltage.
- Change new motor and design new wheel and tire by using 3D print to decrease weight of the toy car.

2 Related Theories

Theory

In the Demonstration of Resonant Wireless Power Transfer using Toy Racing Cars and Tracks project for wireless receiver and transmitter circuits at 13.56 MHz frequency. In order to gain knowledge that can be used in project work, it is necessary to study the related theories, models and techniques in design and a wireless power transmission system that uses radio frequency by studying and researching from books and various research, the essence is summarized as follows.

2.1. Theory of wireless power transmission

2.2. Wireless Power Transmission System Infrastructure

2.3. Types of EV Wireless Charging Technology

2.4. Alternately Coupled Magneto inductive

2.1. Theory of Wireless Power Transmission [1]

Wireless power transmission is the process of converting electrical energy into other forms of energy that can travel without the use of conductors. It involves using a transmitter to send power to a receiver, which then converts the energy back into electrical energy. The concept of wireless power transmission was pioneered by Nicola Tesla in 1899 during his tests at the Colorado Springs Electric Company. One of his experiments involved a massive square coil measuring 60m x 60m, which could generate a 150 kHz signal with a power output of up to 300 kW. In this experiment, a rectangular wire was installed with a metal pole, and a large copper ball with a diameter of 1m was placed on top of the pole. Tesla's experiments demonstrated that when energy was discharged from the copper ball, it induced a DC voltage of approximately 100 MV in the air, as illustrated in Fig.2.

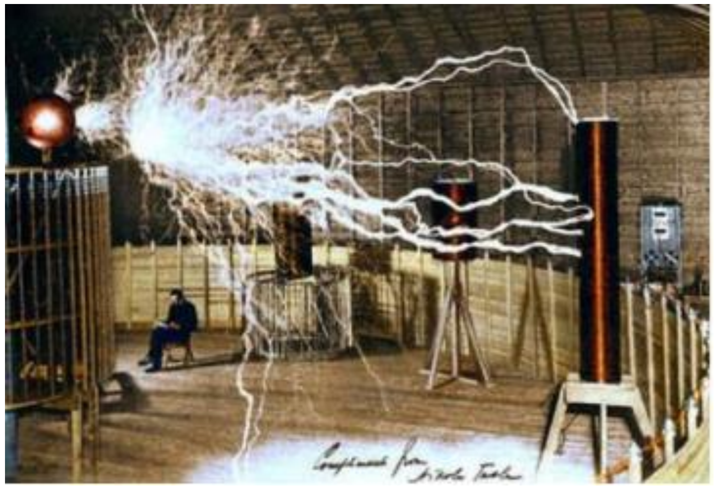


FIGURE 2 Tesla Wireless Power Transmission Test

Tesla also achieved wireless power transmission using balloons to receive and transmit electrical power. The balloon was suspended in the atmosphere, and the distance between the two balloons was 42 km. During the test, over 200 bulbs, each consuming 50 watts of power, were successfully lit. Following this breakthrough, wireless power transmission continued to be a major research interest. In 1933-1934, a researcher named H.V. Noble built on Tesla's ideas and theories to develop a more efficient method of wireless power transmission. Noble replaced the copper ball responsible for transmitting power with a dipole antenna, which transmitted power at a frequency of 100 MHz and the receiving pole was capable of handling up to 100 W of power.

2.2. Wireless Power Transmission System Infrastructure [1]

1) Wireless Power Transfer Technology

Wireless power transmission can be classified into two types based on the transmission distance: Electromagnetic Induction, which is a short-range transmission, and Electromagnetic Radiation, which is a long-range transmission. Fig.3 illustrates that short-range energy transmission can be further classified based on the type of energy used. Electrodynamic Induction uses magnetic and electromagnetic induction, while Electrostatic Induction transfers energy using an electric field.

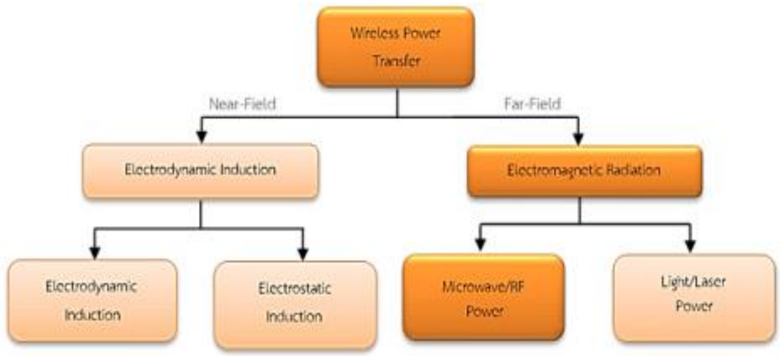


FIGURE 3 Schematic diagram of wireless power transmission

2) Electrodynamic Induction

Wireless electric power transfer using magnetic fields can be employed to transfer electrical energy from low voltage to high voltage by using coils as the transmitting and receiving devices of the system. The use of coils causes the induction of a magnetic field, which is why such connections are called magnetic connections. Efficient electric energy transfer by magnetic fields occurs at the resonant frequency of the system.

2.3. Types of EV Wireless Charging Technology [2]

Static Wireless Charging System

The stationary wireless charging method allows electric vehicles to charge while stationary. To use this method, one can park the EV in a dedicated parking space or a garage that includes a wireless charging station. The receiver, located on the vehicle's undercarriage, receives the charge from the transmitter installed underground. Before leaving the vehicle to complete the charging process, the transmitter and receiver must be aligned properly. The time required to charge the vehicle is influenced by several factors, including the distance between the transmitter and receiver, the size of their pads, and the power output of the AC source.

FIGURE 4 Static Wireless Charging System

Dynamic Wireless Charging System

Dynamic Wireless Power Transfer (DWPT) is an effective way to reduce range anxiety in electric vehicles and lower the cost of onboard batteries. Wireless charging is becoming more widespread in pure electric vehicles and allows for charging even when the car is in motion. In this technology, a stationary transmitter sends electricity over the air to a moving vehicle's reception coil. With the Dynamically Wireless Charging System, continuously recharging the batteries while driving an EV on roads and highways could extend the vehicle's trip range. The weight of the vehicle can also be reduced since enormous energy storage is no longer necessary.

2.4. Alternately Coupled Magneto inductive [3]

The Alternately Coupled Magneto Inductive (ACMI) coil arrangement is a new way of implementing the Dynamic Wireless Power Transfer (DWPT) system. This arrangement aims to achieve nulls-free power transfer in DWPT. Conventional DWPT using Magneto Inductive Waveguides (MIWs) is known to suffer from power transfer nulls caused by standing waves, which are a result of the changing phase associated with the propagation of MIWs along the line and the reflection at the termination. Such destructive interference is inevitable in any waveguide where oppositely propagating waves with the same magnitude become out-of-phase, resulting in a total cancellation of power and nulls in the MI line. However, this characteristic can be utilized to overcome power transfer nulls with minimum increase in complexity and cost using the ACMI arrangement.

3 Materials

3.1. Hardware

3.1.1. Oscillator

An oscillator is an electronic circuit that generates a periodic signal without requiring an external input signal. The output signal of an oscillator is a repetitive waveform that can be a sinusoidal, square, triangular, or sawtooth waveform, among others. The frequency and amplitude of the output signal are determined by the components and design of the oscillator circuit. Oscillators are used in various electronic devices, including radios, televisions, and computers, where they generate clock signals and carrier signals for communication.

Spec: Operating frequency: 13.56MHz

Output power: 7dBm~23dBm (5~200mW, the voltage is 1.4~8.8Vpp on the 50-ohm RF load)

Working voltage: 12V

Working current: 60mA

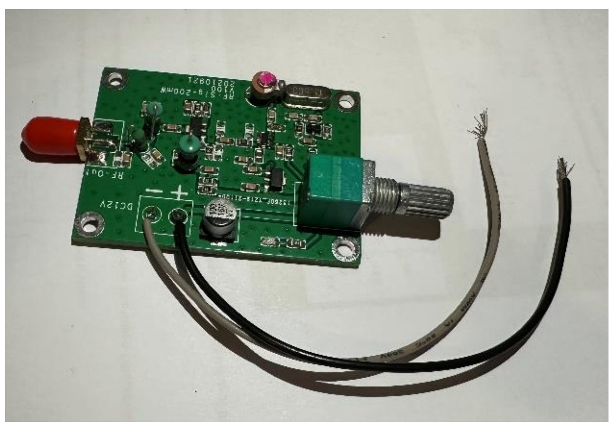


FIGURE 5 Oscillator

3.1.2. Attenuator

An attenuator is an electronic device that reduces the amplitude or power of a signal without significantly distorting its waveform. Attenuators are commonly used in electronic circuits to control the amplitude of signals that are too strong for a particular application. Use to decrease power for connect to amplifier.

Spec: Attenuation value 20-25 dBm

FIGURE 6 Attenuator

3.1.3. Amplifier

An amplifier is an electronic device that increases the power or amplitude of an electrical signal. Amplifiers are commonly used in a variety of applications, such as in audio systems, radio and television broadcasting, telecommunications, and scientific research.

There are many types of amplifiers, but they all work by taking a weak signal and increasing its strength. Some of the most common types of amplifiers include:

1. Audio Amplifiers: These are used to amplify audio signals, such as those produced by a musical instrument, a microphone, or a CD player. Audio amplifiers are commonly used in home and professional audio systems.
2. Radio Frequency (RF) Amplifiers: These are used to amplify signals in the radio frequency range, typically from a few kilohertz up to several gigahertz. RF amplifiers are used in radio and television broadcasting, radar systems, and wireless communications.
3. Operational Amplifiers (Op-Amps): These are used as building blocks in many electronic circuits, such as filters, oscillators, and signal conditioners.
4. Power Amplifiers: These are used to amplify high-power signals, such as those used in industrial and scientific applications.

Amplifiers are available in a range of power levels, from milliwatts to megawatts, and can be designed to operate at various frequencies and voltage levels. They can be built using discrete components, such as transistors and resistors, or as integrated circuits (ICs) with multiple functions built into a single chip.

Spec: Input: 2 Milliwatt

Maximum Output: 2.5 Watt

Working voltage: 15 Volt

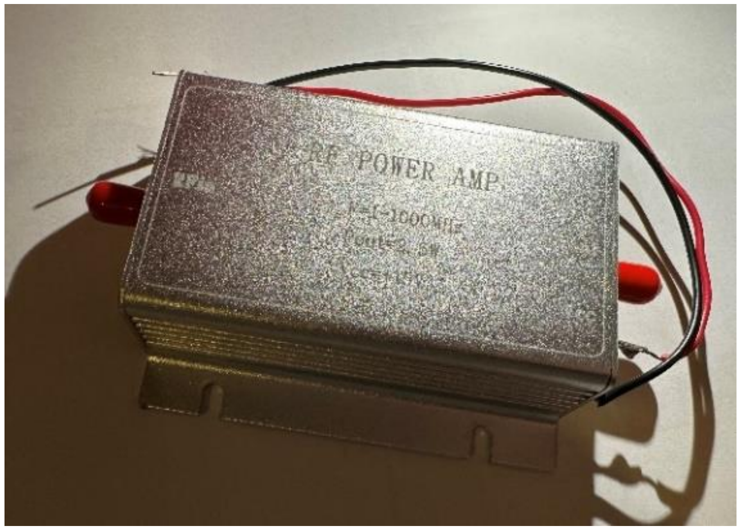


FIGURE 7 Amplifier

3.1.4. Coils

A coil is a conductor of electricity, like a wire in the form of a coil, spiral, or spring. Electromagnetic coils are used in electrical engineering, in applications where an electric current interacts with a magnetic field, in devices such as inductors, electromagnets, transformers, and sensor coils. Either an electric current is passed through the wire of the coil to create a magnetic field, or conversely, a time-varying external magnetic field across the inside of the coil creates an EMF in the conductor.

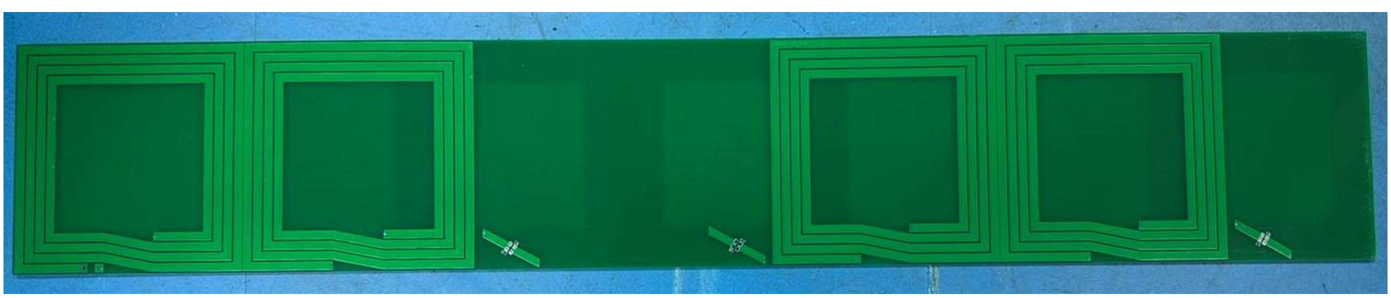


FIGURE 8 Coils

3.1.5. Tamiya toy car

FIGURE 9 Tamiya car

3.1.6. Tamiya toy car track

FIGURE 10 Tamiya track

3.1.7. SMA cable

An SMA cable is a type of coaxial cable that uses a Subminiature version A (SMA) connector. SMA connectors are used to transmit high-frequency signals, typically in the range of 0 to 18 GHz. SMA cables are commonly used in radio frequency (RF) applications, such as in wireless communication systems, radar systems, and test and measurement equipment.

SMA cables are designed to provide high signal quality and low signal loss over relatively short distances. They are available in a variety of lengths and can be terminated with different connector types, depending on the application. SMA cables can be made with a variety of materials, such as copper, silver, or gold, depending on the required performance characteristics.

SMA cables are commonly used in conjunction with other RF components, such as antennas, amplifiers, and filters, to create a complete RF system. They are widely available from many manufacturers and suppliers and can be purchased in a range of sizes and configurations to suit various applications.

FIGURE 11 SMA Cable

3.1.8. Rectifier

A rectifier is an electronic circuit that converts an alternating current (AC) signal into a direct current (DC) signal. The rectifier is used in a wide range of electronic devices and power supplies, where a steady DC voltage is required for their operation. The rectification process involves removing the negative or positive portions of the AC signal, leaving only the positive or negative portions respectively, and smoothing out the resulting waveform to produce a steady DC voltage.

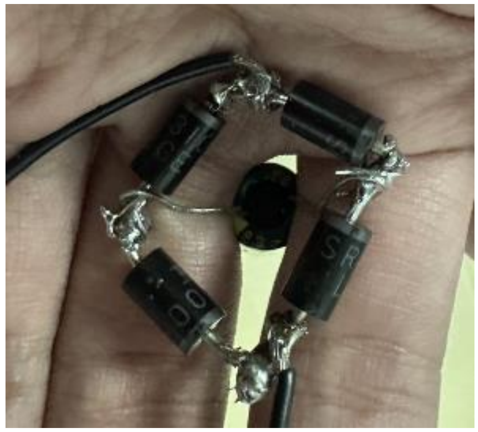


FIGURE 12 Rectifier

3.1.9. N20 Motor gear

The N20 motor gear is a small DC motor that is commonly used in a variety of applications, such as in robotics, model cars, and other small electronic devices. It is named after its size, which is approximately 20mm in length and 12mm in diameter. The N20 motor gear typically operates on a low voltage, usually between 3V and 12V DC. It is known for its high torque-to-size ratio, which means it can deliver a lot of power in a small package. The motor has a gear attached to its shaft, which is used to transfer the rotational motion of the motor to another part of the system.

FIGURE 13 N20 Motor gear

3.1.10. Spectrum analyzers

A spectrum analyzer is a device that is used to measure the magnitude and frequency of the signals in an electronic device or system. It is commonly used in the field of electronics to analyze and characterize radio frequency (RF) signals. A spectrum analyzer works by taking an input signal and breaking it down into its individual frequency components, or spectrum. It then displays this information on a screen as a graph, where the horizontal axis represents frequency, and the vertical axis represents signal strength. This graph can help technicians and engineers to identify and troubleshoot problems with electronic devices or systems that involve RF signals.

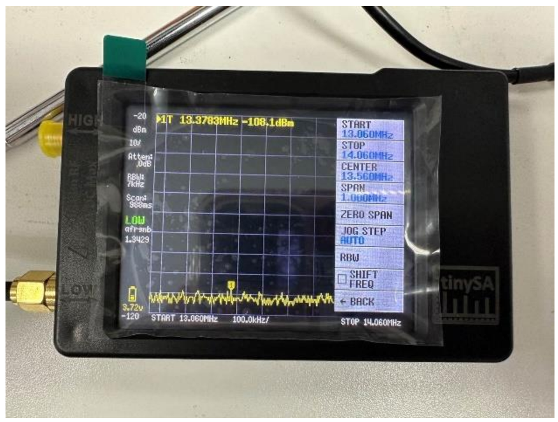


FIGURE 14 spectrum analyzers

3.1.11. Vector network analyzer

A Vector Network Analyzer (VNA) is an electronic test instrument used to measure the electrical performance of high-frequency circuits and components. It is primarily used for measuring S-parameters, which are a set of complex numbers that describe how signals are transmitted and reflected in a circuit. A VNA operates by sending a test signal through a circuit or component and measuring the reflected and transmitted signals at various frequencies. This data is then used to characterize the electrical behavior of the circuit or component, such as its impedance, gain, and insertion loss, over a range of frequencies. VNAs are commonly used in research, development, and production of RF/microwave components and systems, including amplifiers, filters, antennas, and transmission lines.

FIGURE 15 Vector network analyzer

3.2. Software

3.2.1. Easy EDA

EasyEDA is a web-based electronic design automation (EDA) tool for designing and prototyping electronic circuits. It is a free, open-source software suite that allows users to design schematics, simulate circuits, and create printed circuit board (PCB) layouts using an intuitive graphical interface.

EasyEDA is a cloud-based tool, which means that users do not need to download or install any software on their computer to use it. Instead, users can simply access the EasyEDA website and start designing their circuits immediately. The tool includes a library of pre-built components and templates, which can be used to speed up the design process.

Some of the key features of EasyEDA include:

1. Schematic capture: EasyEDA allows users to create and edit electronic schematics using an intuitive drag-and-drop interface.
2. PCB layout: Users can create printed circuit board (PCB) layouts using the same interface as the schematic editor. EasyEDA includes an auto router that can automatically route connections between components.
3. Simulation: EasyEDA includes a built-in Spice simulator, which allows users to simulate the behavior of their circuit designs.
4. Collaboration: EasyEDA supports collaboration between multiple users, allowing them to work on the same project simultaneously.

Overall, EasyEDA is a powerful and easy-to-use tool for designing and prototyping electronic circuits. It is particularly useful for hobbyists, students, and small businesses who need to create electronic designs quickly and easily.

Operation: Design Attenuator and Coils.

3.2.2. Protel 99 SE

Protel 99 is a design software for analog and digital circuits that can be simulated. (Simulation) the operation of the circuit, electrical signal simulation and printed circuit board (PCB) design by combining all functions in a single program. The Protel program stores all information related to this circuit design in the Design Database. There are two types of file formats that can be stored: MS Access database and Windows file.

Operation: Convert file from easy EDA to file (.PCB) to determine size 1x1 inch.

3.2.3. Sonnet version 17.56

Sonnet is an electromagnetic (EM) simulation software for designing and analyzing high-frequency electronic components and circuits. It is particularly useful for simulating microwave and radio frequency (RF) circuits, such as antennas, filters, couplers, and transmission lines.

Sonnet uses a method of moments (MoM) approach for EM simulation, which allows it to accurately model complex 3D structures with high accuracy. The software can handle a wide range of materials and geometries, including layered substrates, rough surfaces, and non-planar structures.

Some of the key features of Sonnet include:

1. 3D EM Simulation: Sonnet is a full-wave 3D electromagnetic simulator, meaning that it can accurately model complex 3D structures.
2. Integrated Environment: Sonnet provides an integrated environment for designing and simulating circuits, which allows users to quickly and easily optimize their designs.
3. Accurate Modeling: Sonnet uses a MoM approach, which allows it to accurately model the behavior of high-frequency circuits.
4. Built-in Analysis Tools: Sonnet includes a range of built-in analysis tools, including S-parameters, radiation patterns, and electromagnetic field visualization.
5. Automation: Sonnet can be easily integrated into larger design automation workflows, such as with scripting and automation tools like Python.

Overall, Sonnet is a powerful tool for designing and simulating high-frequency electronic circuits. It is particularly useful for designers who need to work with complex 3D structures and require high accuracy in their simulations.

Operation: Design coil and simulate electromagnetic coils.

3.2.4. Computer-Aided Three-dimensional Interactive Application (CATIA)

CATIA is a powerful software tool used in various industries, including aerospace, automotive, and industrial design, to design and simulate complex 3D models. It offers a wide range of features for designing, drafting, modeling, and analyzing complex mechanical and industrial components and systems.

Some of the key features of CATIA include:

1. Parametric Design: CATIA allows users to create parametric models that can be easily modified and updated based on changing design requirements.
2. Assembly Design: CATIA supports assembly design, allowing users to create and simulate complex mechanical assemblies.
3. Drafting and 2D Layout: CATIA includes powerful drafting and 2D layout tools, which allow users to create detailed engineering drawings.
4. Simulation and Analysis: CATIA provides advanced simulation and analysis tools for structural, thermal, and fluid dynamics simulations.
5. Integration with Other Tools: CATIA can be integrated with other tools, such as finite element analysis (FEA) and computational fluid dynamics (CFD) software, to provide a complete design and analysis solution.

Overall, CATIA is a powerful software tool for designing and simulating complex 3D models in various industries. Its extensive capabilities make it a popular choice for engineers and designers working on complex mechanical and industrial systems.

Operation: Design wheel, tire for Tamiya car and Base of coil and track.

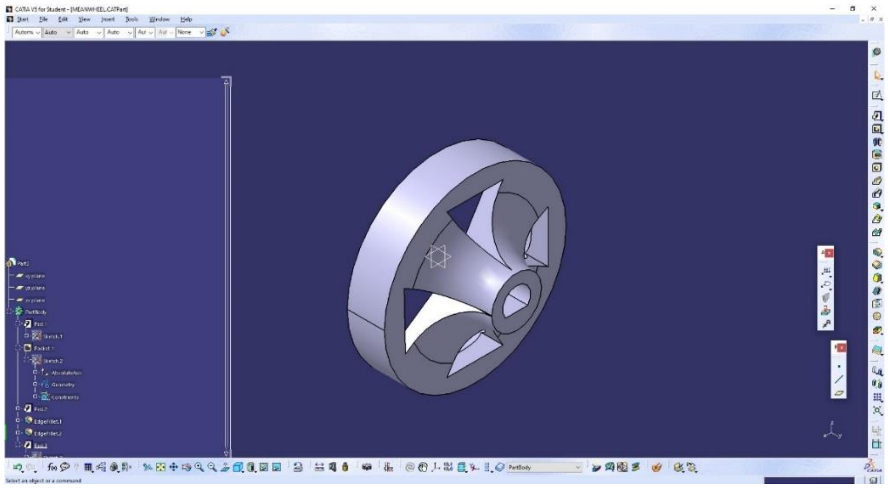


FIGURE 16 Design wheel in CATIA

3.2.5. Ultimaker Cura

Ultimaker Cura is a free and open-source software program used for 3D printing. It is designed to prepare 3D models for printing by converting the model into a set of instructions that a 3D printer can understand.

Ultimaker Cura supports a wide range of 3D printers and file formats, making it a popular choice for 3D printing enthusiasts and professionals. It includes a wide range of features that allow users to customize the printing process to their specific needs, including:

1. Model Preparation: Ultimaker Cura allows users to prepare 3D models for printing by adding support structures, adjusting orientation, and scaling the model to fit the printer.
2. Material Selection: Ultimaker Cura includes support for a wide range of materials, including plastics, metals, and composites.
3. Customizable Settings: Users can customize a range of settings, including layer height, print speed, and temperature, to optimize their print quality and printing time.
4. Gcode Viewer: Ultimaker Cura includes a Gcode viewer that allows users to preview the 3D print before it is sent to the printer.
5. Plugins: Ultimaker Cura supports a wide range of plugins that extend its functionality, including tools for automatic support generation, mesh repair, and more.

Overall, Ultimaker Cura is a powerful and user-friendly software tool for preparing 3D models for printing. Its ease of use and extensive features make it a popular choice for 3D printing enthusiasts and professionals alike.

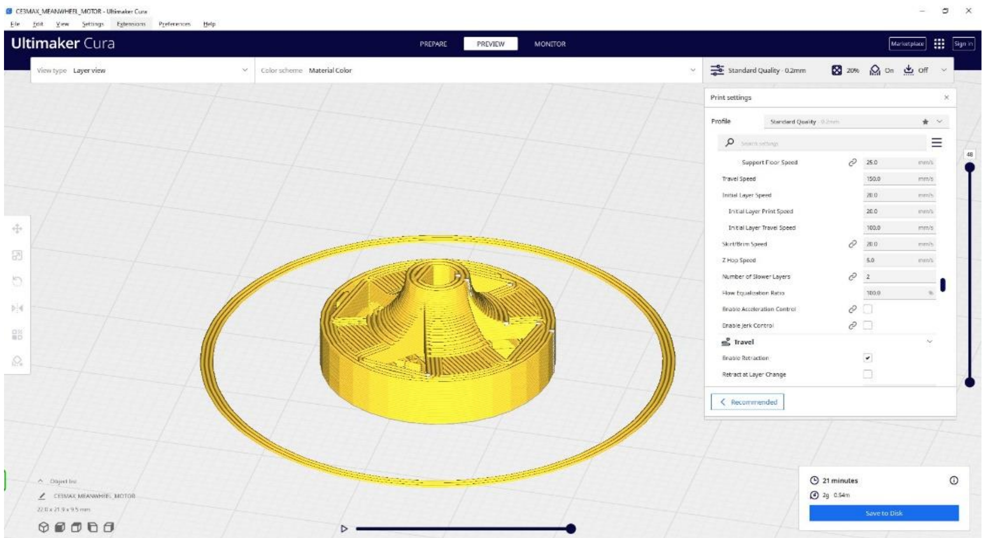


FIGURE 17 Wheel in Ultimaker Cura

4 Methods

In the creation of a wireless energy transmission system for toy cars, the researchers identified the significance of the Electro Magnetic field in the future, as it will attract students to take an interest in this subject. The research process includes the steps shown in Fig.18 and details are as follows.

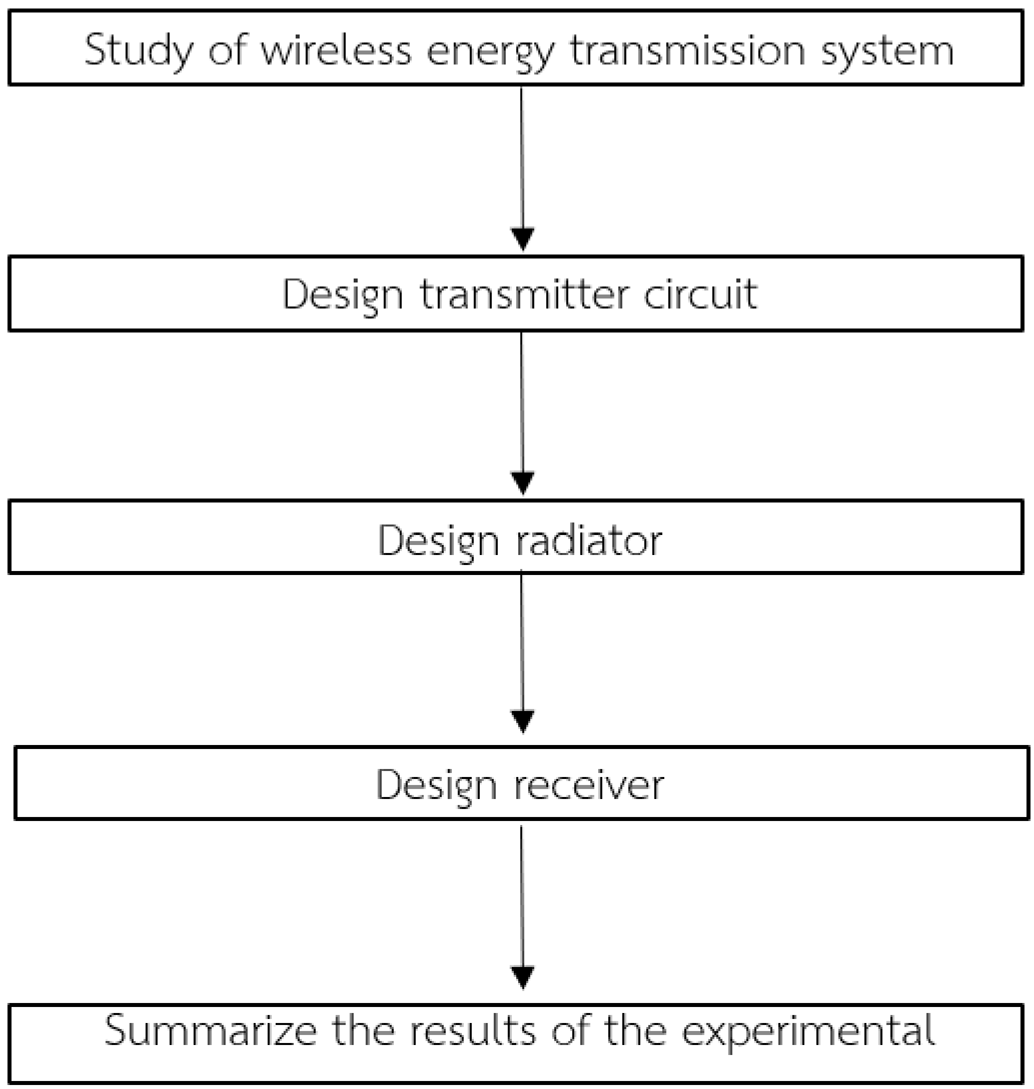


FIGURE 18 Schematic of method

4.1. Study of wireless energy transmission systems.

Conduct research on wireless power transmission by exploring various sources on the internet and take a closer look at research projects related to this field at King Mongkut's University of Technology North Bangkok.

4.2. Design transmitter circuit

Design a transmitter circuit that uses a frequency of 13.56 MHz to transmit power. The transmitter circuit will consist of three components, namely: Oscillator, Attenuator and Amplifier. This section will contain the method for designing an attenuator, as well as the results from each component.

4.3. Design radiator

To design the radiator, we need to design both the transmitter coil and receiver coil. This section will cover the coupling coefficient and overlapping displacement selection method, the method for designing the coils, as well as the method and results of selecting the capacitance of the coil.

4.4. Design receiver

Design the receiver, we need to create a receiver circuit to use with 13.56 MHz, customize toy car components and base coil. This section will cover the method that we design receiver circuit and the method how to we design the new component of toy car and base coil.

4.5. Summarize the results of the experimental

This section shows the results output of direct voltage current connect on distance without load and the results output of direct voltage current connect on distance with load.

5 Result and Discussion

5.1. Study of wireless energy transmission systems.

Wireless Power Transfer (WPT) is a technology that allows for the transmission of power wirelessly from a power source to a device without the need for a wired connection or communication. WPT systems operate by utilizing the principles of magnetic induction and electromagnetic wave transmission without physical contact. Devices that require power must have the ability to convert received energy, which can be achieved using wireless signal receivers connected to power receiving devices. WPT technology has gained attention in various sectors, such as wireless charging of mobile phone batteries, industrial use, and as a means for wireless data exchange and communication.

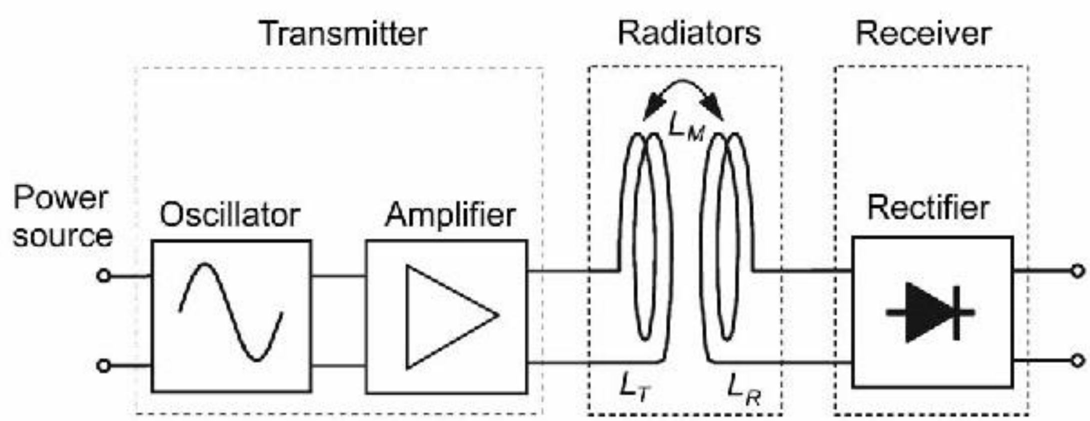


FIGURE 19 Overall system

5.1.1. Transmitter

1. An oscillator is a circuit that generates a periodic electric waveform. It is an important device in creating frequency and waveform signals used in many applications, such as wireless signals, radio, television, and others.
2. An amplifier is a circuit that increases the magnitude of an electric signal, allowing it to be controlled and used effectively. This device is used to amplify small signals into larger signals, such as sound, radio signals, and television signals.

5.1.2. Radiators

Coil coupling is a method of transferring energy from one coil (known as the primary coil) to another coil (known as the secondary coil) using electromagnetic induction. When an alternating current (AC) flows through the primary coil, it generates a magnetic field that passes through the secondary coil. As a result, a voltage is induced in the secondary coil, which can be used to power a device or charge a battery. The efficiency of coil coupling depends on the distance between the two coils, the size and number of turns in each coil, and the frequency of the AC power source. The closer the two coils are to each other, the more efficient the energy transfer will be. The size and number of turns in each coil also affect the amount of energy that can be transferred. Finally, the frequency of the AC power source is critical because it determines the strength and frequency of the magnetic field generated by the primary coil, which affects the amount of voltage induced in the secondary coil. Overall, coil coupling is a widely used method of transferring energy wirelessly, and it has many applications, including wireless charging of devices, wireless power transmission, and electromagnetic induction in electric motors and transformers.

5.1.3. Receiver

A rectifier is an electrical circuit that converts alternating current (AC) to direct current (DC). AC voltage alternates in polarity and direction, while DC voltage remains constant in polarity and direction. The process of rectification involves using diodes to allow the flow of current in only one direction, effectively converting AC to pulsating DC.

There are two main types of rectifiers: half-wave and full wave. Half-wave rectifiers use a single diode to allow the flow of current in only one direction, resulting in a waveform that is missing half of the input signal. Full-wave rectifiers use either two or four diodes to allow the flow of current in only one direction, resulting in a waveform that is a smoother and more consistent DC signal.

Rectifiers are commonly used in electronic devices that require DC voltage to operate, such as power supplies, battery chargers, and electronic devices like radios, televisions, and computers.

5.2. Design transmitter circuit

5.2.1. Oscillator

Selecting an oscillator can generate 13.56 MHz because it is within the legal limit for transmitting wireless signals. This helps to reduce the risk of breaking wireless transmission laws. Furthermore, 13.56 MHz is a stable frequency and is commonly used in wireless communication technologies such as RFID and NFC. These technologies have widespread applications and use 13.56 MHz for their wireless signal transmission. Therefore, 13.56 MHz is suitable for wireless power transfer not only due to its properties that are favorable for this application, but also because it is a commonly used frequency in various wireless technologies.

To test oscillator by following Fig.20-21.

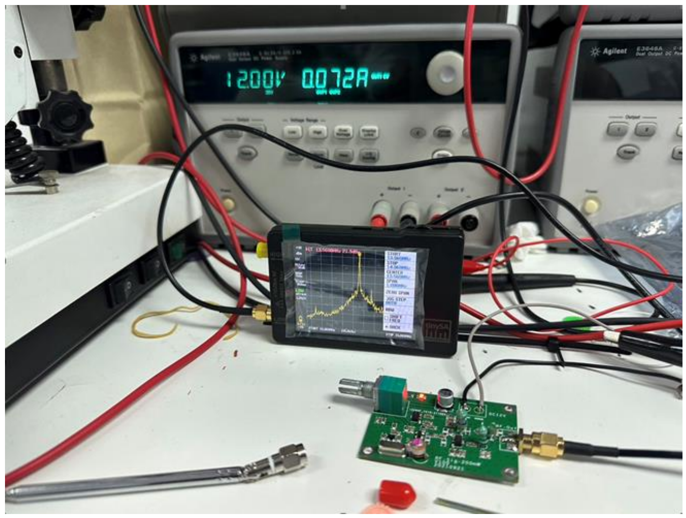


FIGURE 20 powering 12 V oscillator

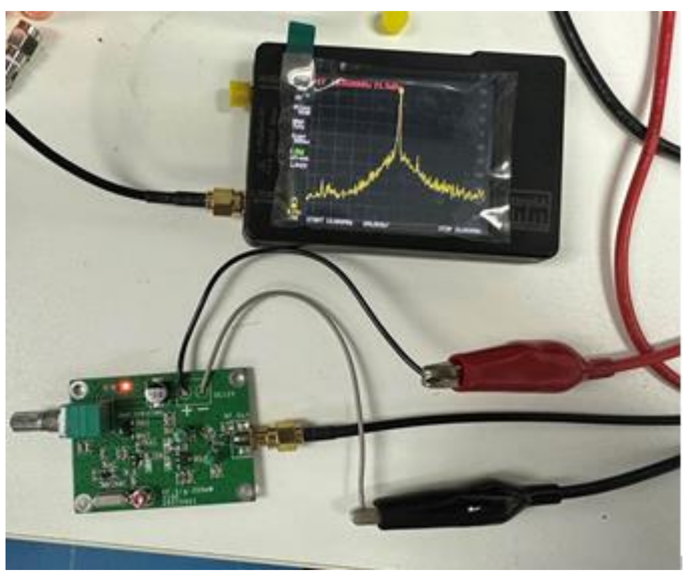


FIGURE 21 connects oscillator to spectrum analyzers.

Testing result: This oscillator can generate 13.56 MHz with 21.9 dBm, it is approximate to 2.454 Milliwatt. Graph of output from oscillator is shown in Fig. 22

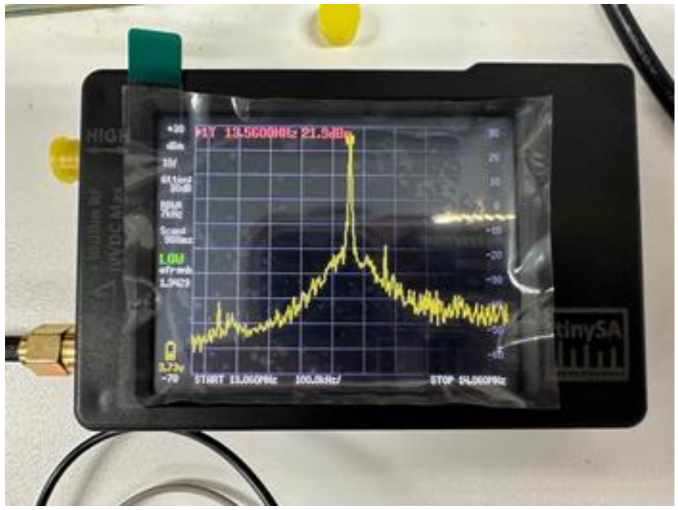


FIGURE 22 result of oscillator.

5.2.2. Attenuator

Before connecting to amplifier, it requires the attenuator to reduce power for damage to the amplifier. Design a printed circuit board (PCB) for an attenuator using the EasyEDA program.

1. Draw circuit diagram for pi attenuator. We use Chip Resistors 0805 and SMA connector.

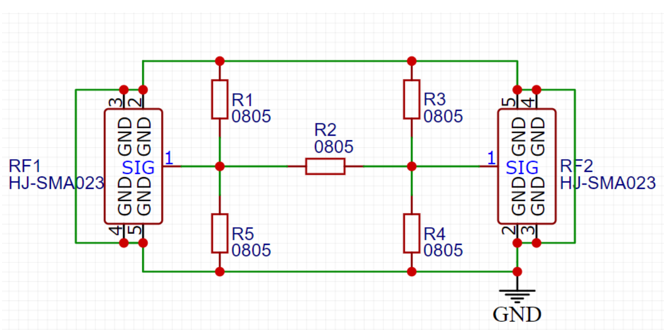


FIGURE 23 Attenuator circuit diagram

2. Change circuit diagram to PCB board.

2.1 Setting size of PCB 1 inch x 1 inch.

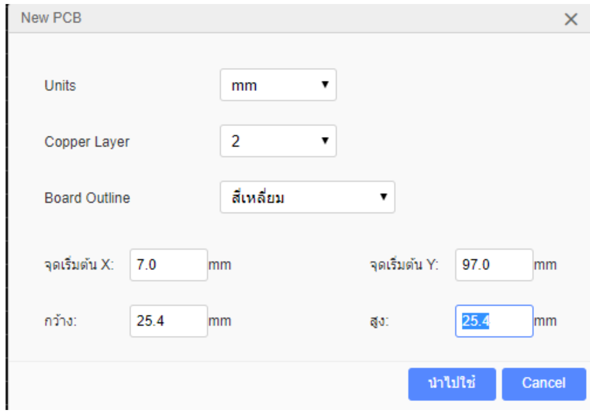


FIGURE 24 Setting size for Attenuator.

2.2 Place resistor and connector in PCB board.

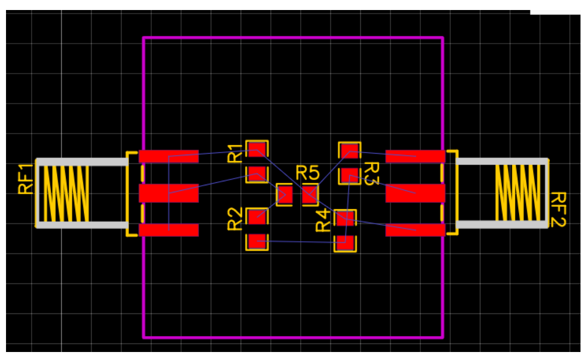


FIGURE 25 Place component in attenuator

2.3 Draw a signal line and ground.

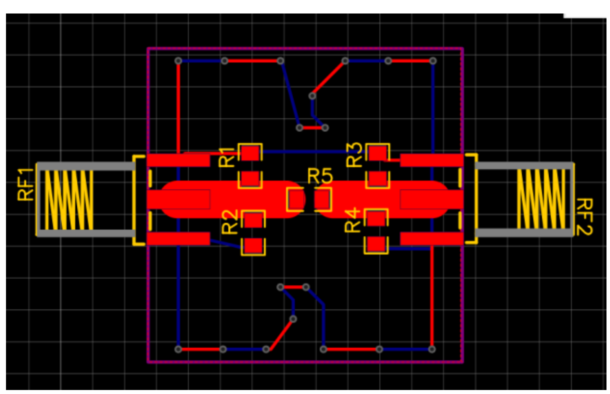


FIGURE 26 Draw signal line in attenuator.

2.4 Place the copper area in the top layer and bottom layer.

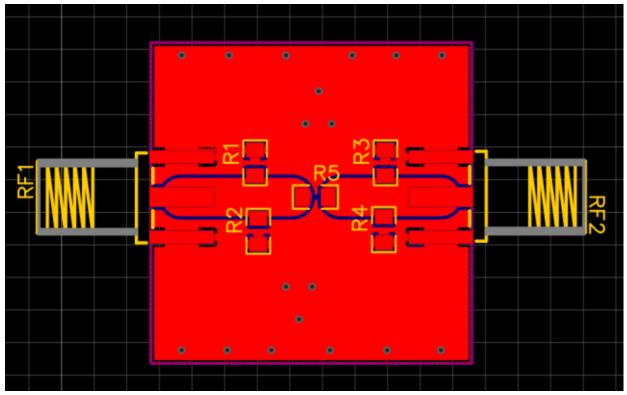


FIGURE 27 Copper area for attenuator.

We used the link https://leleivre.com/rf_pipad.html to calculate the appropriate resistance for our needs. When we opened the link, the display showed an automatic calculation of the resistance based on the assigned attenuation or resistance, as well as the resistance of the SMA cable, as shown in Fig. 28 We assigned 25 dB and obtained the resistance value shown in Fig. 29 We then adjusted the resistance to achieve an attenuation value close to 25 dB because we have to buy the resistor, as shown in Fig. 30. The completed attenuator is shown in Fig. 31.

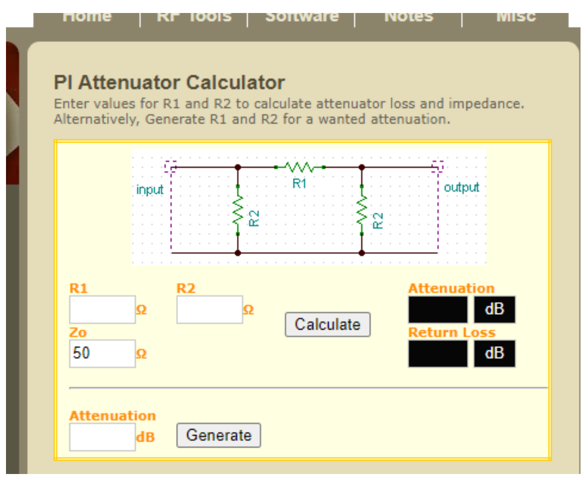


FIGURE 28 Pi attenuator circuit diagram

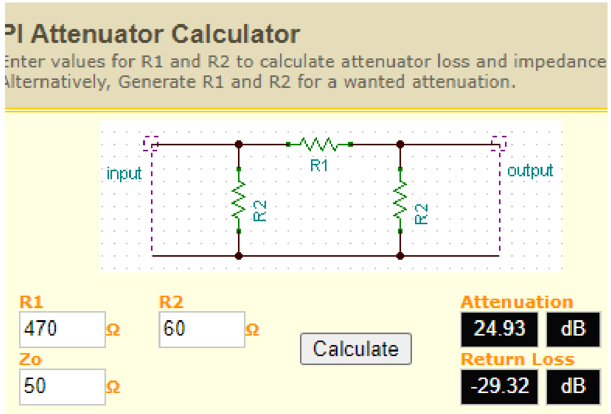


FIGURE 29 Value of resistor for attenuator

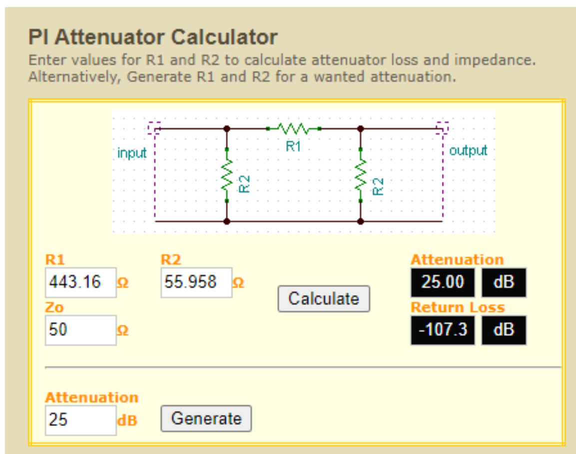


FIGURE 30 Value of resistor that we choose

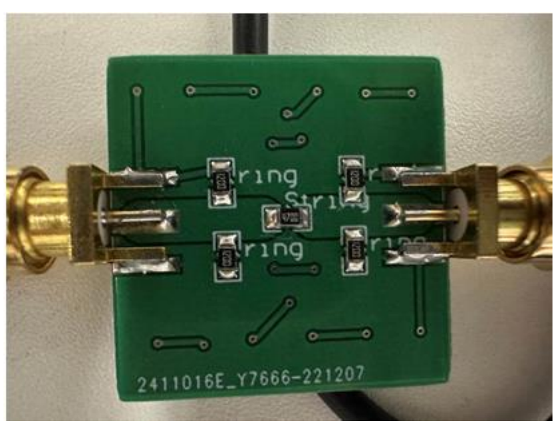


FIGURE 31 Complete attenuator

Testing result: This attenuator can reduce magnitude of signal from 21.9 to -2.1 as show in Fig.32.

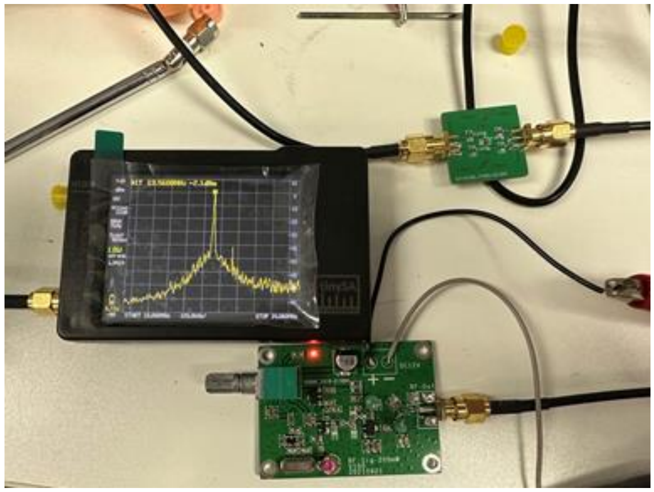


FIGURE 32 Testing attenuator

5.2.3. Amplifier

Testing all components in transmitter circuit as show in Fig.33. It can generate 13.56 MHz with 29.9 dBm or 0.977 Watt as show in Fig.34.

FIGURE 33 Connect amplifier.

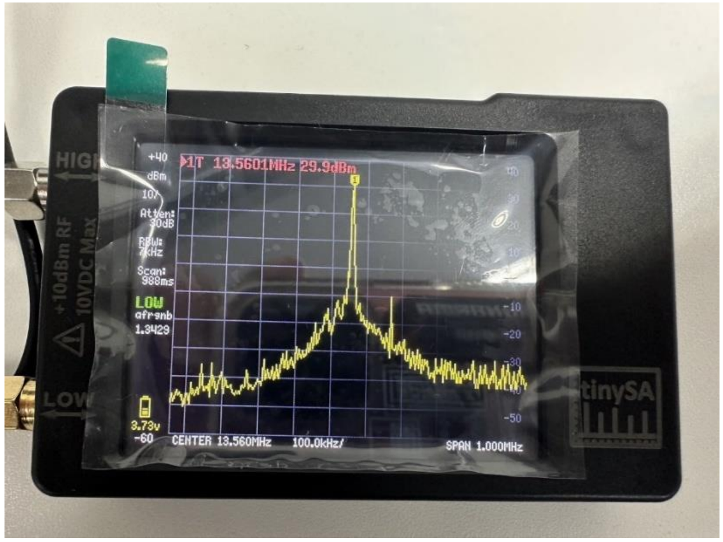


FIGURE 34 Output from amplifier

The output harmonic at 27 MHz will decrease by approximately 15 dBm compared to the output harmonic at 13.56 MHz, while at 40 MHz, the output harmonic will decrease by approximately 21 dBm compared to the output harmonic at 13.56 MHz as show in Fig.35.

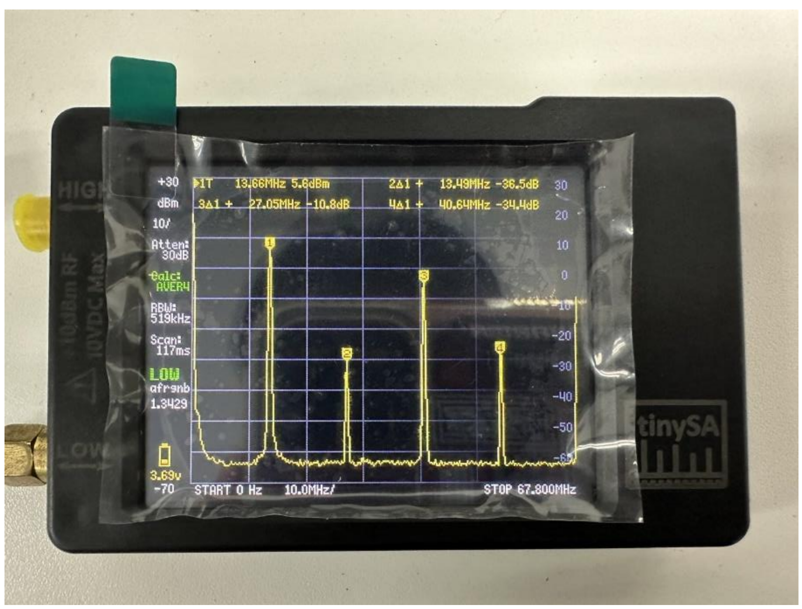


FIGURE 35 Output harmonic

5.3. Design radiator

First, we Design coil form sonnet (version 17.56) to find the difference of coupling coefficient (k) caused by the distance between two coils.

From this formula:

$$k = \frac{M}{L} \ (1)$$

M: Mutual inductance

L: Self inductance

So, we need to design a 10x10 cm^2 single rectangular coil to find self-inductance and 10x10 mm two rectangular coils to find mutual inductance.

Single rectangular coil

1. Create the linear structure as show in Fig.36, coil is a 10 × 10 cm^2 four-turn square spiral, with a 3.3-mm trace width and a 1-mm gap.

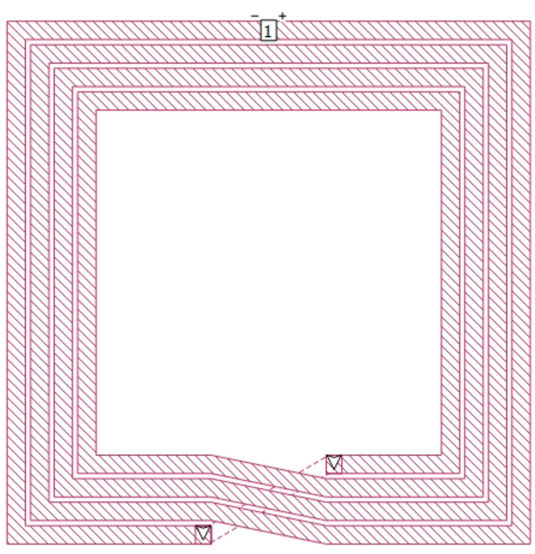


FIGURE 36 Linear structure coil 10 x 10 cm2

Setting up the output of the coil as shown in the following Fig.37

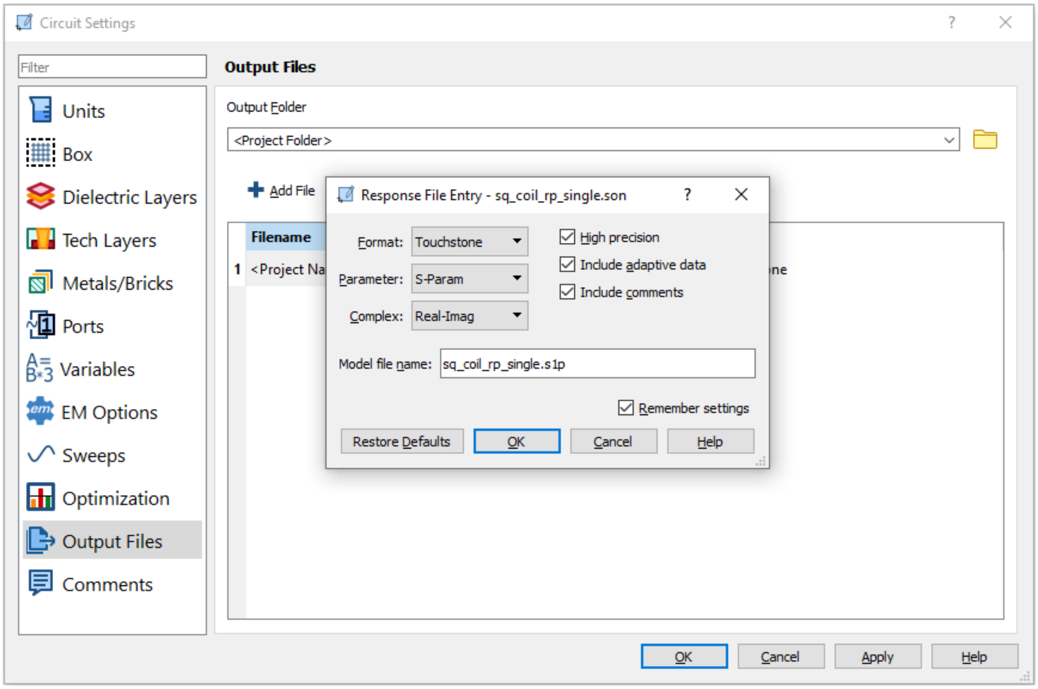
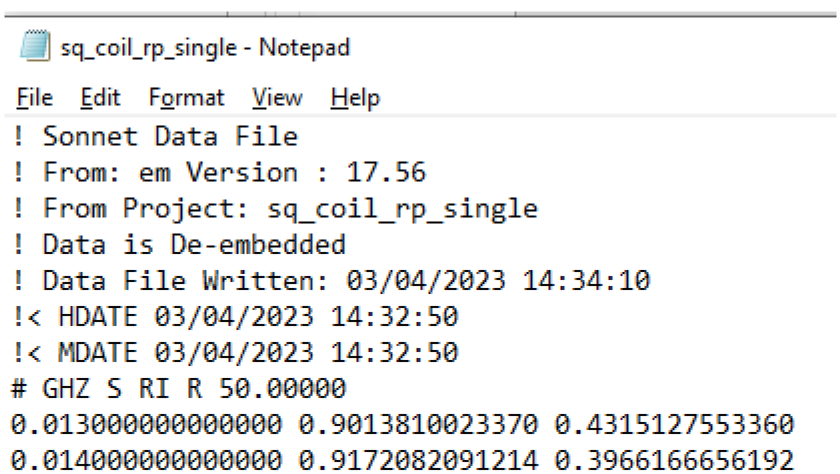


FIGURE 37 Setting output of coil

This file displays the output data obtained through EM simulation in the Sonnet program. It includes the frequency and the inductive reactance of the coil, as shown in the following Fig.38.


sq_coil_rp_single - Notepad

File Edit Format View Help

```
! Sonnet Data File
! From: em Version : 17.56
! From Project: sq_coil_rp_single
! Data is De-embedded
! Data File Written: 03/04/2023 14:34:10
!< HDATE 03/04/2023 14:32:50
!< MDATE 03/04/2023 14:32:50
# GHZ S RI R 50.00000
0.013000000000000 0.9013810023370 0.4315127553360
0.014000000000000 0.9172082091214 0.3966166656192
```

FIGURE 38 Output data from coil

2. We utilized a GitHub repository created by Asst. Prof. Denchai Worasawate as show in Fig.39 available at https://github.com/githubdcw/KU-WPT to determine the self-inductance and mutual inductance. The GitHub repository includes two folders, s1p and s2p as shown in Fig.40, which we used for our analysis.

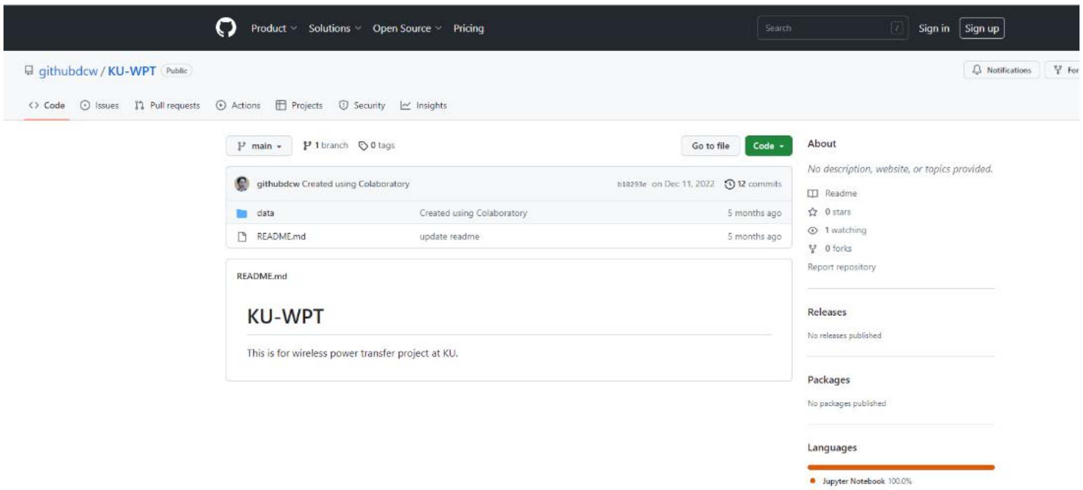


FIGURE 39 GitHub KU-WPT

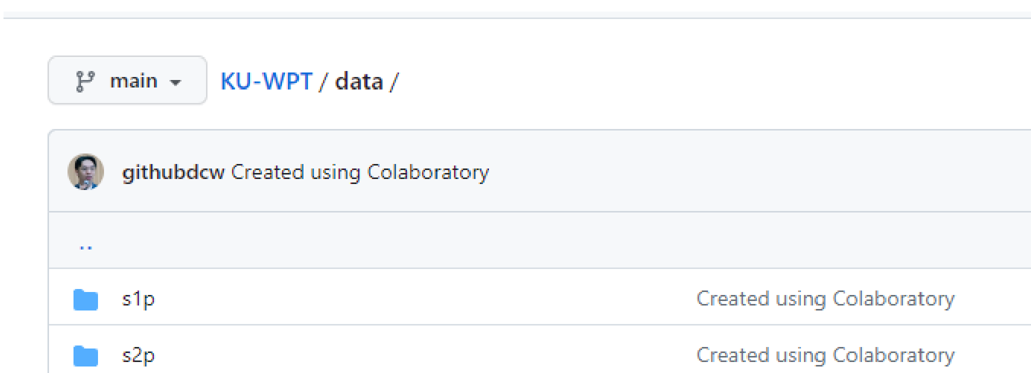


FIGURE 40 GitHub KU-WPT data

3. The s1p folder is designed to calculate self-inductance and contains the following files: a link to an online Python compiler, an output file from Sonnet, and a Sonnet file as show in Fig.41.

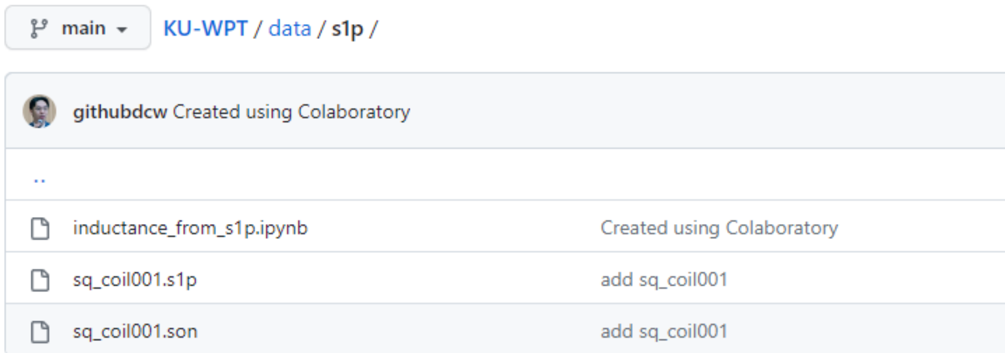


FIGURE 41 Data of s1p

4. Open the first link, and you will see the Colaboratory as shown in Fig.42.

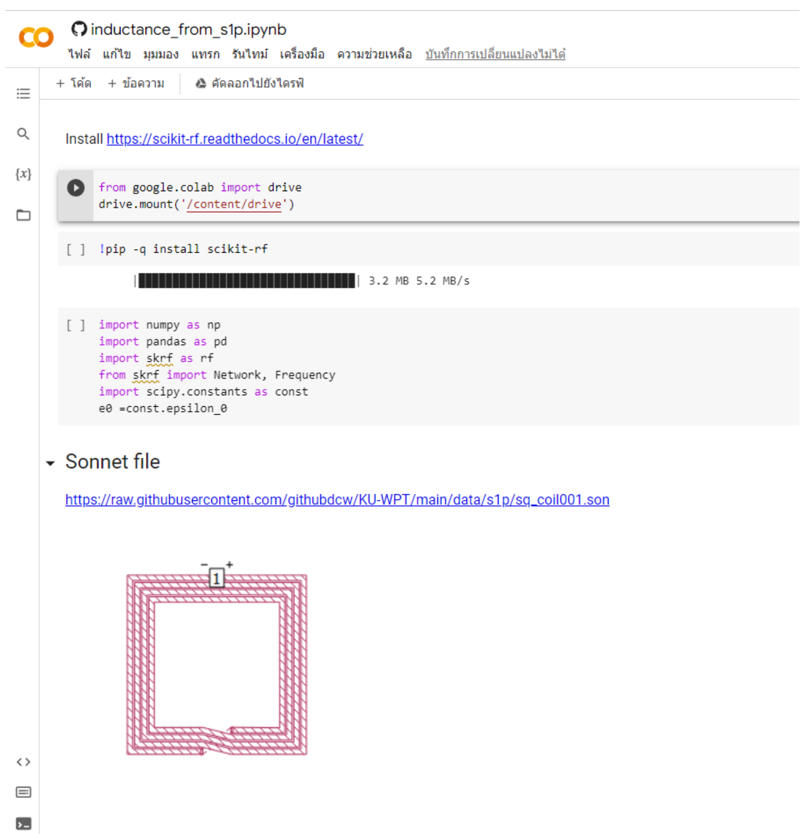


FIGURE 42 Open Colaboratory

5. Upload your s1p file as shown in the following Fig. 43-44.

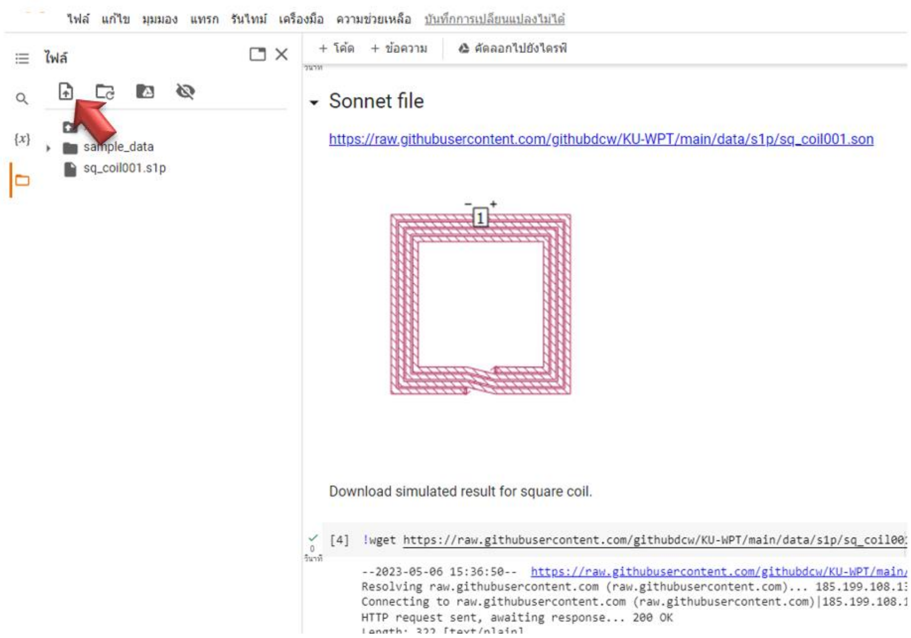


FIGURE 43 Upload file s1p

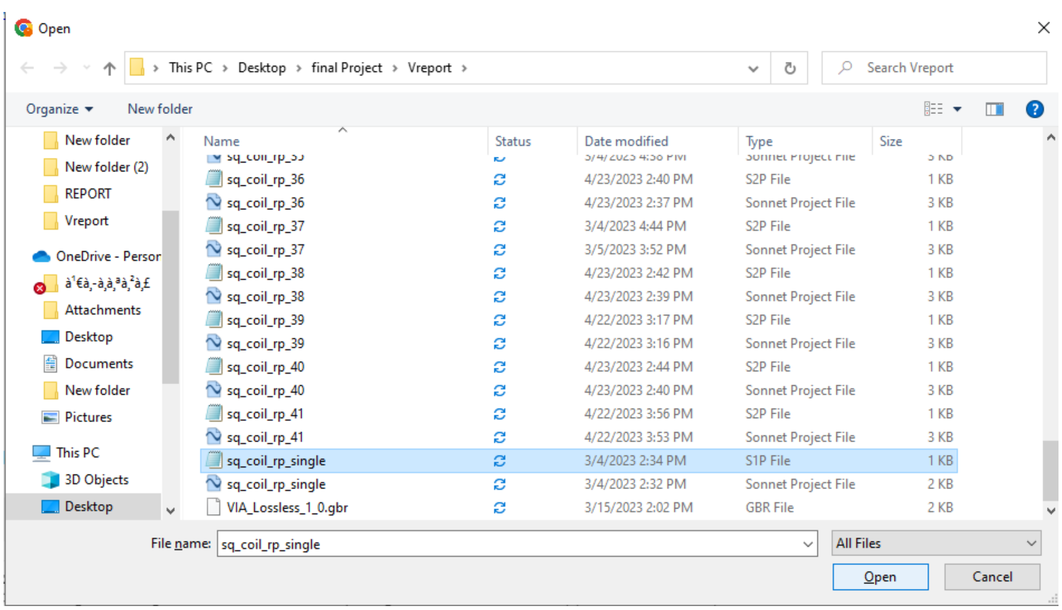


FIGURE 44 Select s1p file.

6. Copy direction of file and replace in line 5 as show in Fig.45.

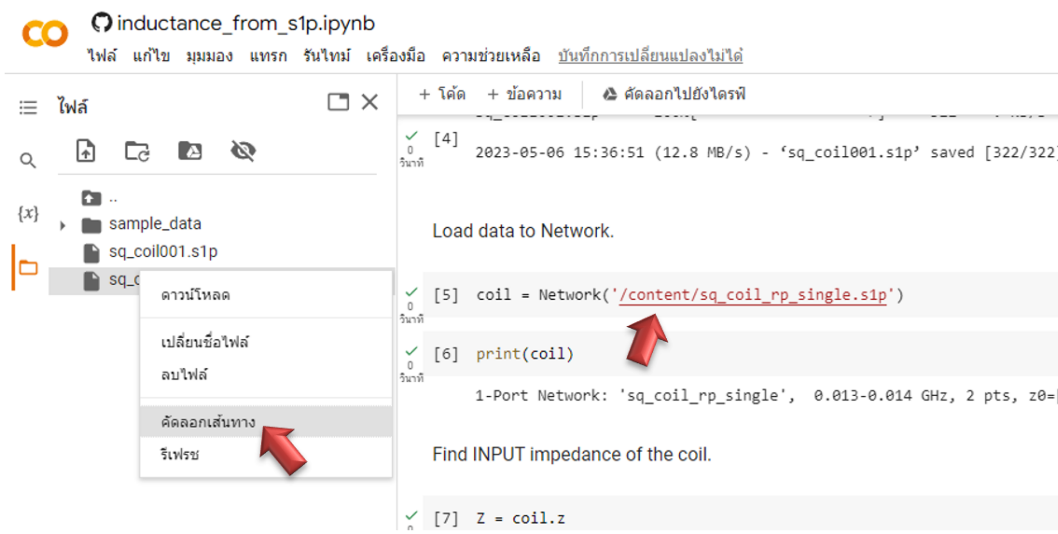


FIGURE 45 Copy direction of file

7. Run all cell and you will get the result: Self-inductance (L) = 2.7 µH at frequency 13.0 MHz and 2.75 µH at 14.0 MHz as show in Fig.46.

```
[8] tmp = Z
    print('Inductance of the coil at', coil.frequency.f[0],'Hz is', tmp [0][0][0].imag/(2*np.pi*coil.frequency.f[0]), 'H')
    print('Inductance of the coil at', coil.frequency.f[1],'Hz is', tmp [1][0][0].imag/(2*np.pi*coil.frequency.f[1]), 'H')

    Inductance of the coil at 13000000.0 Hz is 2.6963221130000576e-06 H
    Inductance of the coil at 14000000.0 Hz is 2.7466142510330773e-06 H

[9] tmp = Z
    print('Inductance of the coil at', coil.frequency.f[0]/1e6,'MHz is', "{:.2f}".format(tmp [0][0][0].imag/(2*np.pi*coil.frequency.f[0])*1e6), 'uH')
    print('Inductance of the coil at', coil.frequency.f[1]/1e6,'MHz is', "{:.2f}".format(tmp [1][0][0].imag/(2*np.pi*coil.frequency.f[1])*1e6), 'uH')

    Inductance of the coil at 13.0 MHz is 2.70 uH
    Inductance of the coil at 14.0 MHz is 2.75 uH
```

FIGURE 46 Result from run cell

The program is using inductive reactance of the coil as show in Fig.47 to calculate self-inductance by using following formula:

$$L = \frac{X_L}{2\pi f} \qquad (2)$$

L : Self inductance

X_L: Reactive Inductance

f : Frequency

```
[7]  Z = coil.z
     print(Z)

     [[[0.33405745+220.23938929j]]

      [[0.43382313+241.60480829j]]]
```

FIGURE 47 Inductive reactance of single coil

Two rectangular coils

1. Create 2 coils as shown in Fig.48 which will start to overlap from 0mm to 40mm. To see how different coupling coefficients are. From the study according to [3], the coils must have overlap for eliminating unreliable energy transmission or in the article say, “True Nulls-Free Magneto inductive”.

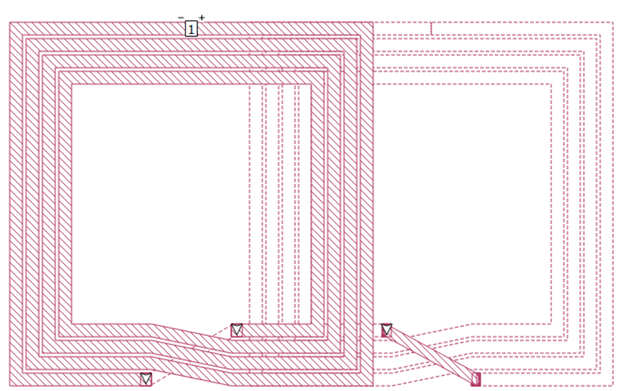


FIGURE 48 Overlapping coil

2. Use the same GitHub repository, but this time use the s2p folder as show in Fig. 49 and follow the same method as mentioned above.

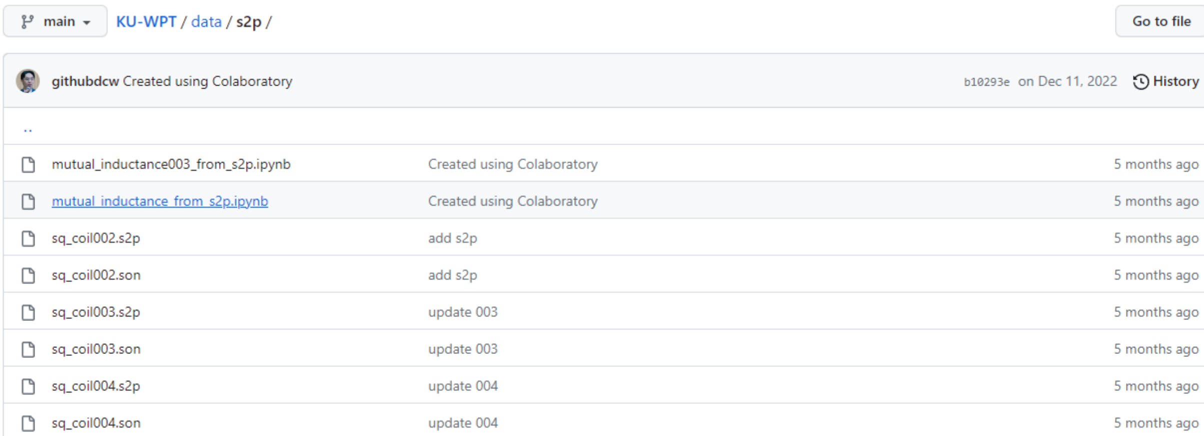


FIGURE 49 data s2p file

The s2p file will include four inductive reactance as show in Fig.50, but we will only use the third inductive reactance.

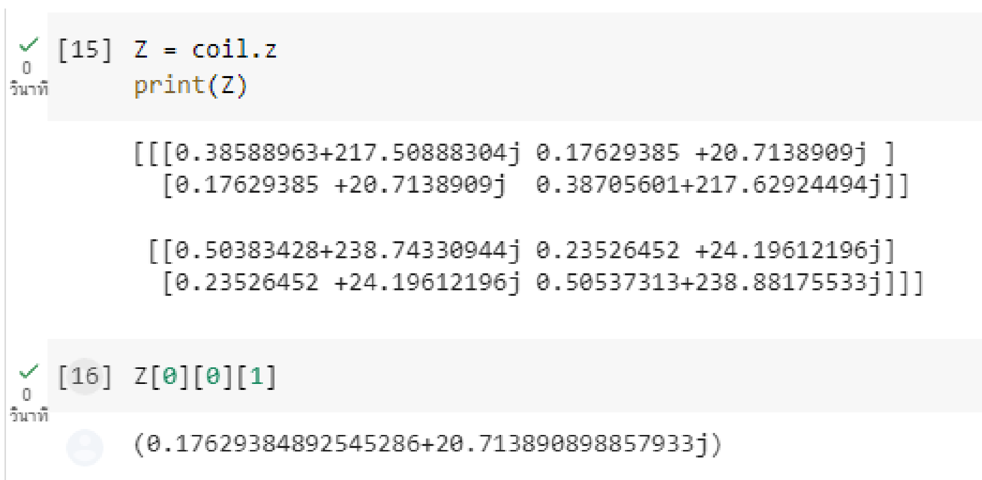


FIGURE 50 Result inductive reactance for s2p

The result is shown in Table.1.

Table 1 Result of Mutual Inductance

overlapping displacement (mm)	Mutual inductance (μH)	
	13.00 MHz	14.00 MHz
0	-0.21	-0.21
2	-0.24	-0.25
4	-0.27	-0.27
6	-0.30	-0.31
8	-0.34	-0.35
10	-0.38	-0.39
12	-0.41	-0.44
14	-0.44	-0.46
16	-0.46	-0.49
18	-0.43	-0.46
20	-0.34	-0.36
22	-0.25	-0.26
24	-0.16	-0.16
26	-0.06	-0.05
28	0.02	0.04
30	0.12	0.13
32	0.19	0.21
34	0.25	0.28
36	0.64	0.65
38	1.47	1.52
40	1.52	1.57

From formula 1, we can get the coupling coefficient (k) following Table.2 and Table.3.

Table 2 Coupling Coefficient of Frequency 13.00 MHz

Frequency 13.00 MHz	
overlapping displacement (mm)	coupling coefficient
0	-0.0778
2	-0.0889
4	-0.1000
6	-0.1111
8	-0.1256
10	-0.1407
12	-0.1519
14	-0.1629
16	-0.1704
18	-0.1593
20	-0.1259
22	-0.0925
24	-0.0593
26	-0.0222
28	0.0074
30	0.0444
32	0.0704
34	0.0926
36	0.2370
38	0.5444
40	0.5629

Table 3 Coupling Coefficient of Frequency 14.00 MHz

Frequency 14.00 MHz	
overlapping displacement (mm)	coupling coefficient
0	-0.0763
2	-0.0909
4	-0.0982
6	-0.1127
8	-0.1272
10	-0.1418
12	-0.1600
14	-0.1672
16	-0.1782
18	-0.1672
20	-0.1309
22	-0.0945
24	-0.0582
26	-0.0182
28	0.01454
30	0.0473
32	0.0764
34	0.1018
36	0.2364
38	0.5527
40	0.5709

Figure.51-52 show the graph of coupling coefficient versus overlapping displacement (mm)

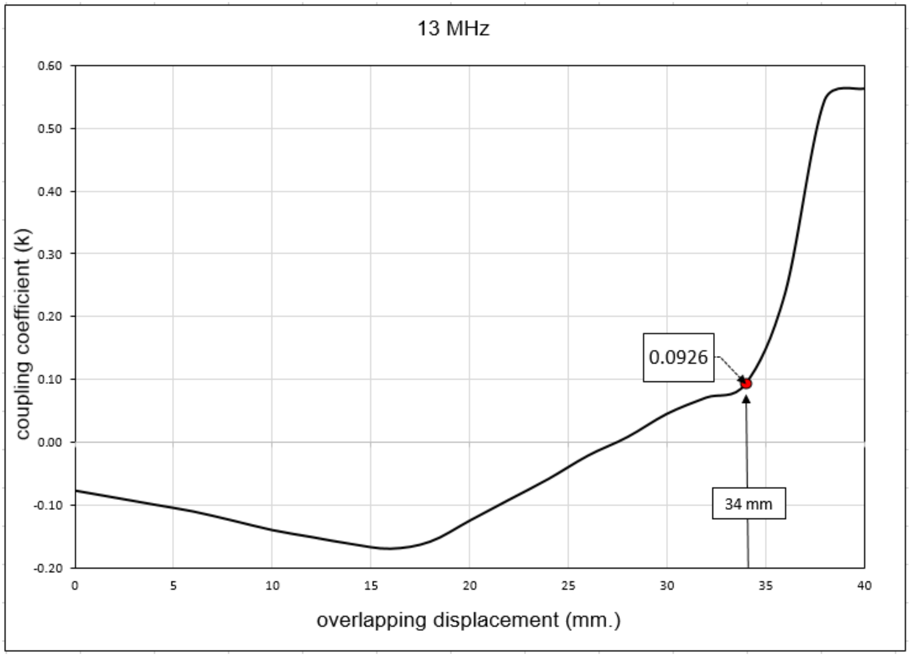


FIGURE 51 Graph of coupling coefficient versus overlapping displacement 13 MHz

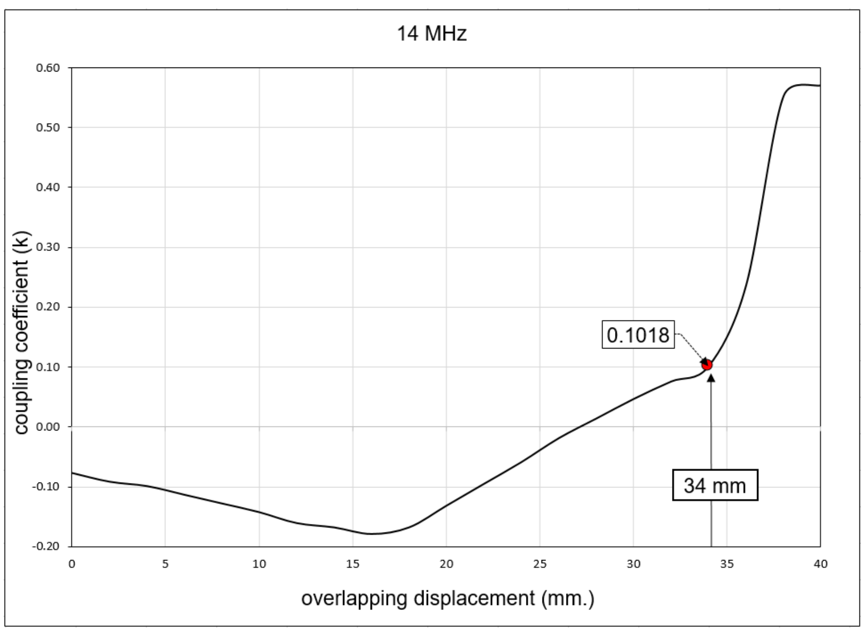


FIGURE 52 Graph of coupling coefficient versus overlapping displacement 14 MHz

From the result, it can generate different coupling coefficient depending on overlapping displacement between two coils. The design condition 34 millimeters overlapping displacement for 0.0926 coupling coefficient (significant is dependent on the setting of the direction of source in sonnet) were selected for the overlapped coils implementation.

5.3.1. Transmitter Coil

1. The Sonnet suites professional 17.56 program was utilized to design a rectangular coil measuring 10 x 10 cm^2 with a thickness of 3.5mm, which was divided into 7 pieces with overlapping sections of 34mm at even positions (coil cell #2-#3, coil cell #4-#5, and coil cell #6-#7). A gap was also incorporated within the coil in the opposite direction to accommodate a capacitor with an 0805 size footprint. In addition, a gap was created in coil cell #1, close to the via but in the opposite direction of the coil, to allow for the soldering of an SMA connector as show in Fig.53.

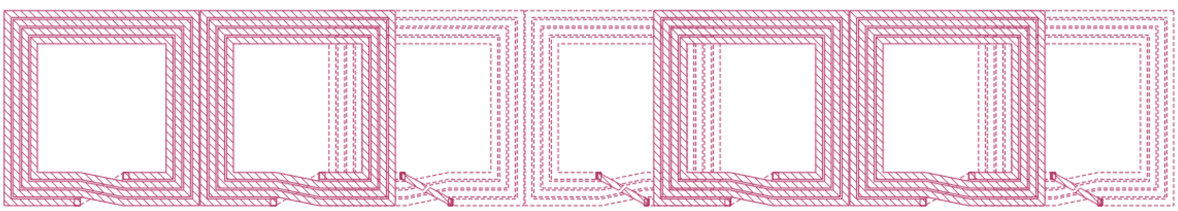


FIGURE 53 Transmitter coil from sonnet suites professional

2. After designing a rectangular coil with Sonnet suites professional 17.56 program as show in Fig.54, the coil was exported to EasyEDA program for further processing. In EasyEDA, the coil was covered with a solder mask by setting a solid region to cover all the coil. In addition, the coil was divided into 7 cells, with coil cell #1, #2, #5, and #6 placed on the top layer and coil cell #3, #4, and #7 placed on the bottom layer. This was achieved by utilizing the layer setting functions in EasyEDA.

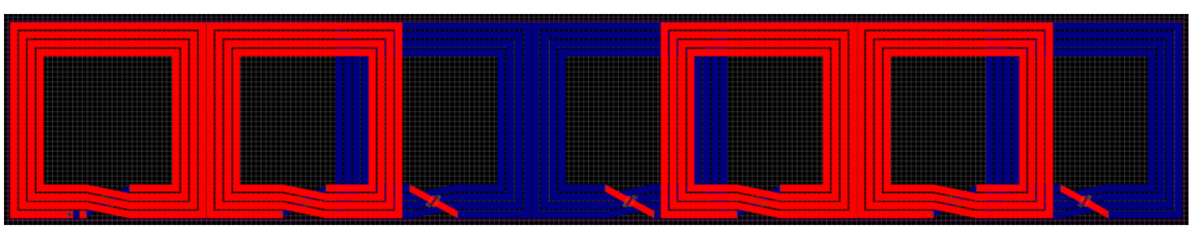


FIGURE 54 Export coil to EASYEDA

3. Put 2 footprints of capacitor 0805 size and create pad and gap for SMA connector as show in Fig.55.

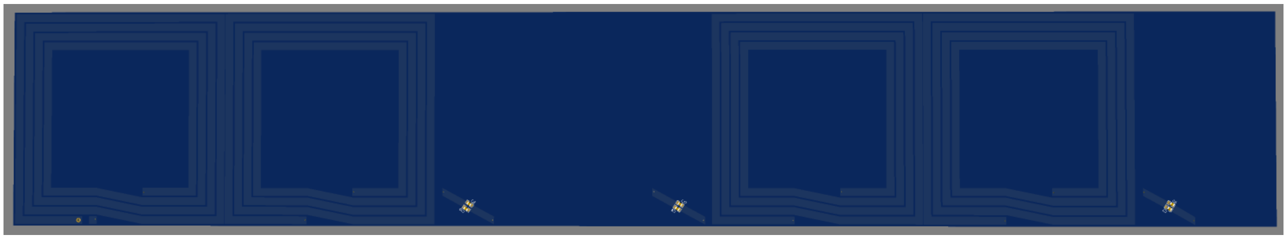


FIGURE 55 Footprint of Rectangular coil

4. Open solder mask at a gap that is created for solder SMA connector as show in Fig.56. Complete transmitter coil is shown in Fig.57.

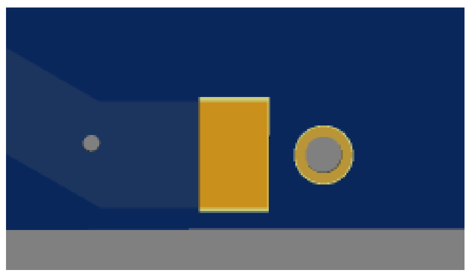


FIGURE 56 Gap for solder SMA connector

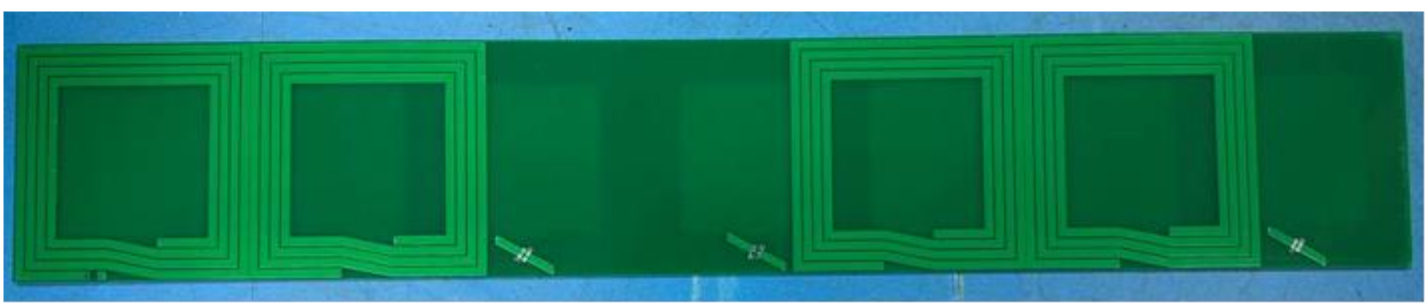


FIGURE 57 Complete Transmitter coil

5.3.2. Receiver Coil

1. The Sonnet suites professional 17.56 program was utilized to design a rectangular coil with a thickness of 2.5mm, custom-fitted to the Tamiya toy car. The coil design included a gap in the bottom layer to allow for the addition of both an SMA connector and a capacitor as show in Fig.58.
2. Export to EASYEDA program to generate solid region and create via and set layer of coil as show in Fig.59.
3. Put 2 footprints of capacitor 0805 size and create pad and gap for SMA connector as show in Fig.60.
4. Open solder mask at a gap that is created for solder SMA connector as show in Fig.61.

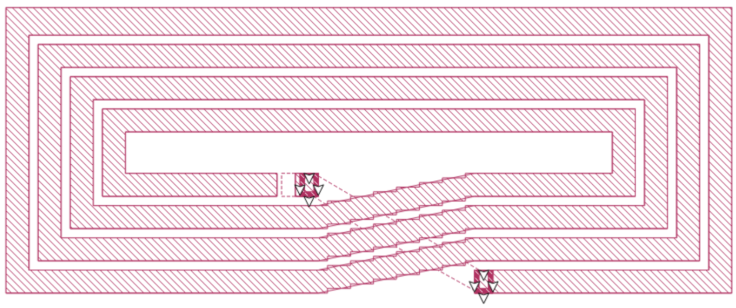


FIGURE 58 Receiver coil from sonnet suites professional

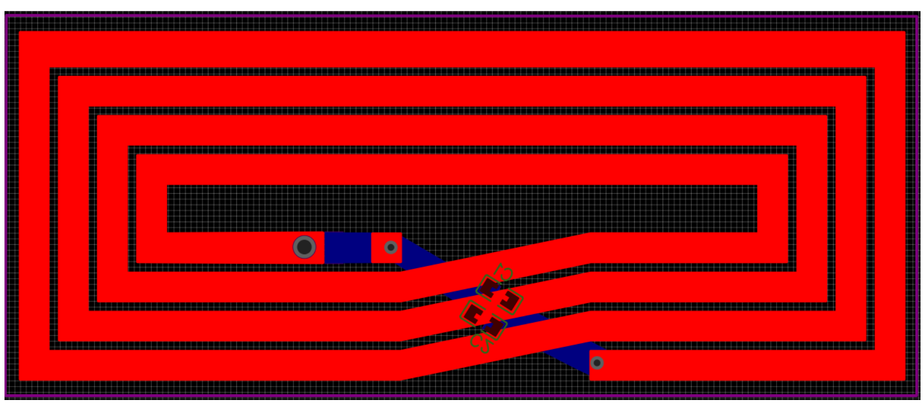


FIGURE 59 Complete design of receiver coil

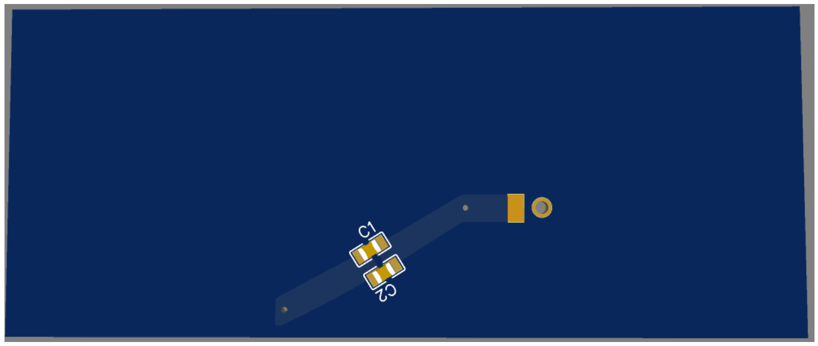


FIGURE 60 Footprint in receiver coil

FIGURE 61 Complete receiver coil

5.3.3. Measure the Inductance

1. Short circuit of Transmitter coil and Receiver coil as shown in Fig.62.

FIGURE 62 Short circuit of transmitter coil and receiver coil

2. The XL value of both the transmitter coil and receiver coil were measured using a vector network analyzer. The measurement of XL provides an indication of the inductance of the coil and is an important parameter for determining the performance of the wireless power transfer system as shown in Fig.63.

FIGURE 63 Measure XL from coil

3. Determine the value of XL of transmitter coil and receiver coil from the measurement as show in Fig.64.

FIGURE 64 Value of XL from transmitter coil and receiver coil

4. Calculate XC using the measured value of XL by applying the equation XC equals XL because in a radiator coil or antenna, impedance matching is important to achieve maximum power transfer from the transmitter to the antenna and to avoid signal reflections that can reduce efficiency and cause interference. Adding a capacitor (XC) to cancel out the inductance (XL) is part of the process of designing a matching network to achieve impedance matching and improve the efficiency of the system. We use equation (3). and value XL from Vector network analyzer for transmitter coil is 64 ohms and receiver coil are 231 ohms after calculation get the transmitter coil yields a value of 51 pF, and the receiver coil yields a value of 180 pF.

$$X_L = \frac{1}{2\pi f C} \quad (3)$$

X_L : The inductive reactance in ohms

π : 3.1416

f : The frequency in hertz

C : capacity in farads

5.4. Design receiver

5.4.1. Receiver circuit

1. Select Schottky diodes for high frequency applications.
2. Solder the diode into the full-bridge rectifier circuit.

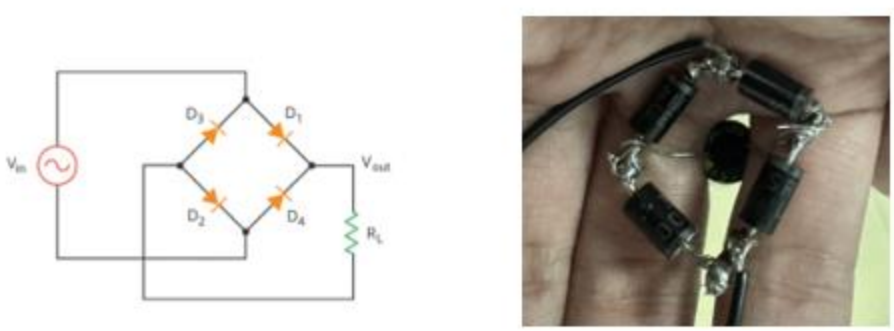


FIGURE 65 Rectifier circuit

3. Solder a 2200 μF capacitor in parallel to stabilize the voltage.

4. Solder the wire from the capacitor leg to both terminals of the N20 motor gear.

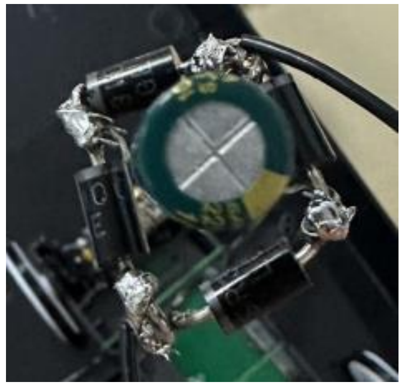


FIGURE 66 Rectifier circuit and parallel with capacitor

5.4.2. Toy car

1. We tested the motor that came with the toy car we purchased by powering it, as shown in the Fig.67 The results indicated that the motor consumed a significant amount of current, so we decided to replace it with an N20 gear motor, which is shown in the Fig.68 The new motor consumes less current.

FIGURE 67 Measure current from begin motor.

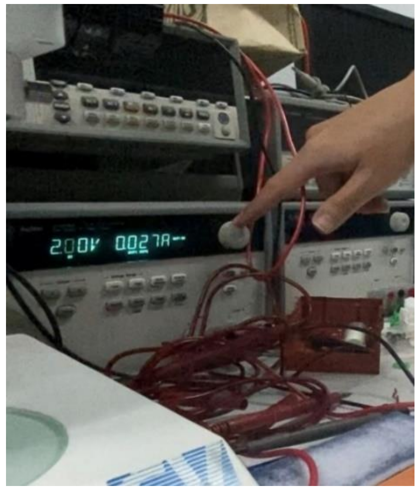


FIGURE 68 Measure current from new motor

2. We used the CATIA and Ultimaker Cura programs to modify the car's wheels to create space for placing the receiver coil underneath the car and reduce its weight. First, we designed the car wheel in the CATIA program, as shown in Fig.69. We then uploaded the STL file to Ultimaker Cura to set up the data for 3D printing as shown in Fig.70. Next, we uploaded the file to the network for printing the wheels, as shown in Fig.71-73.

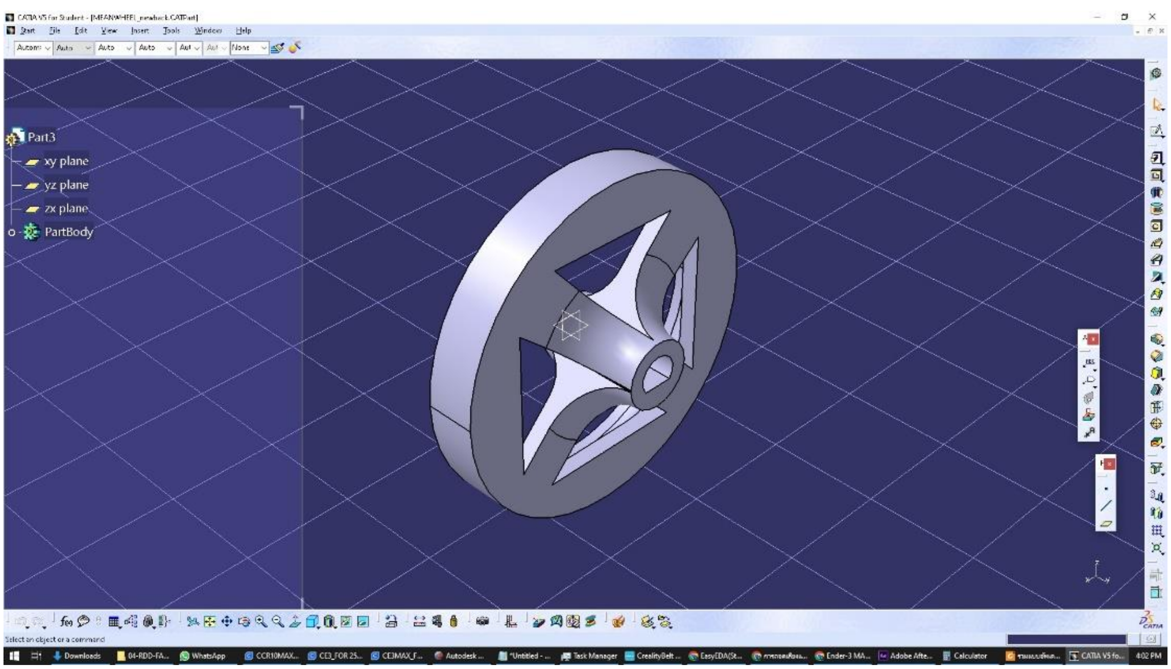


FIGURE 69 Design wheel car

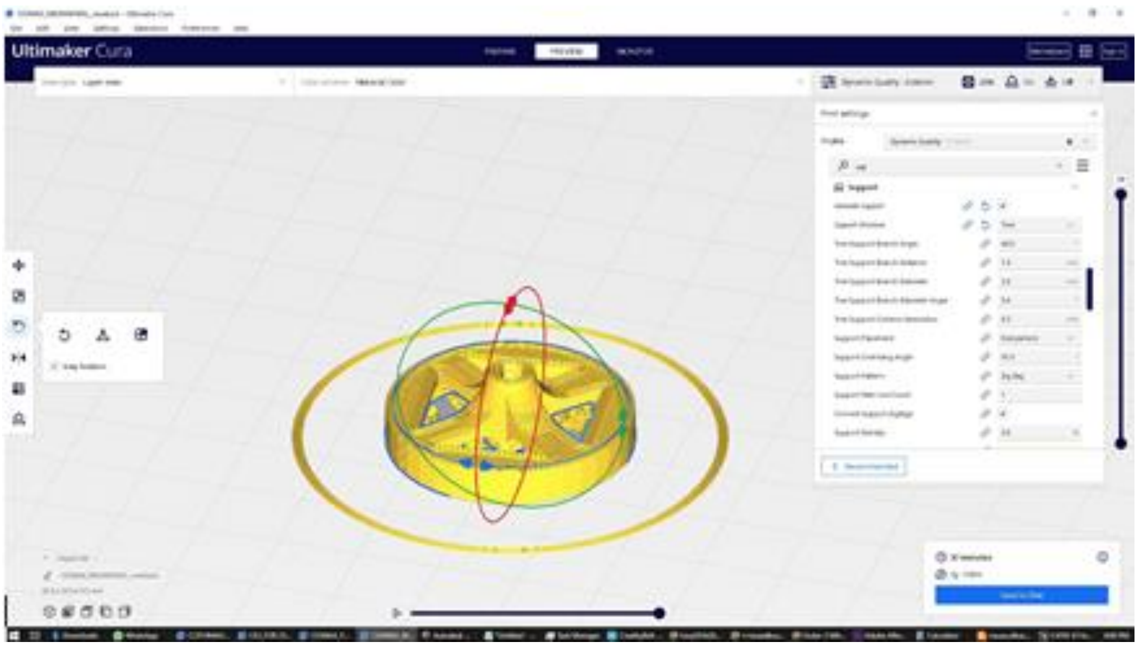


FIGURE 70 Set up function for ready to print

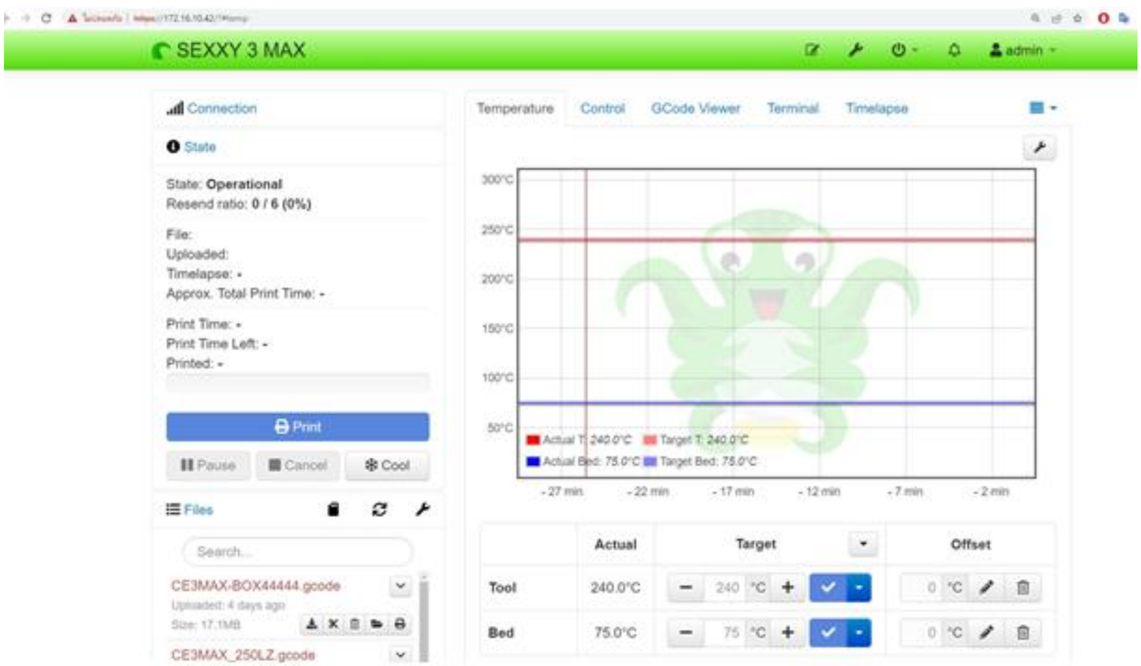


FIGURE 71 Display of Sexxy 3 Max

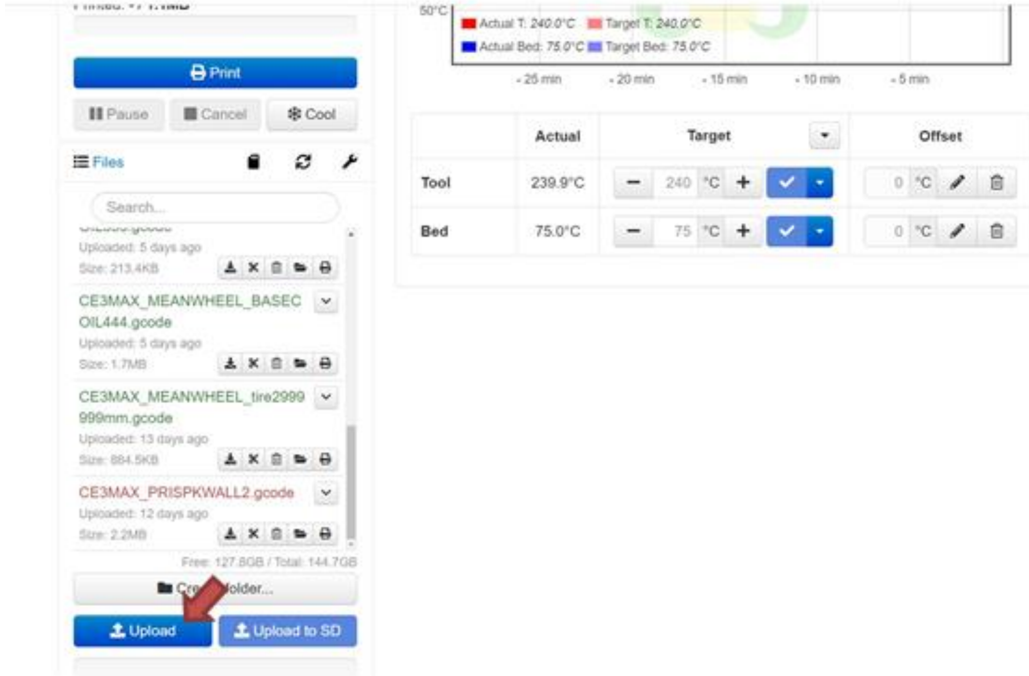


FIGURE 72 Upload File to Sexxy 3 Max

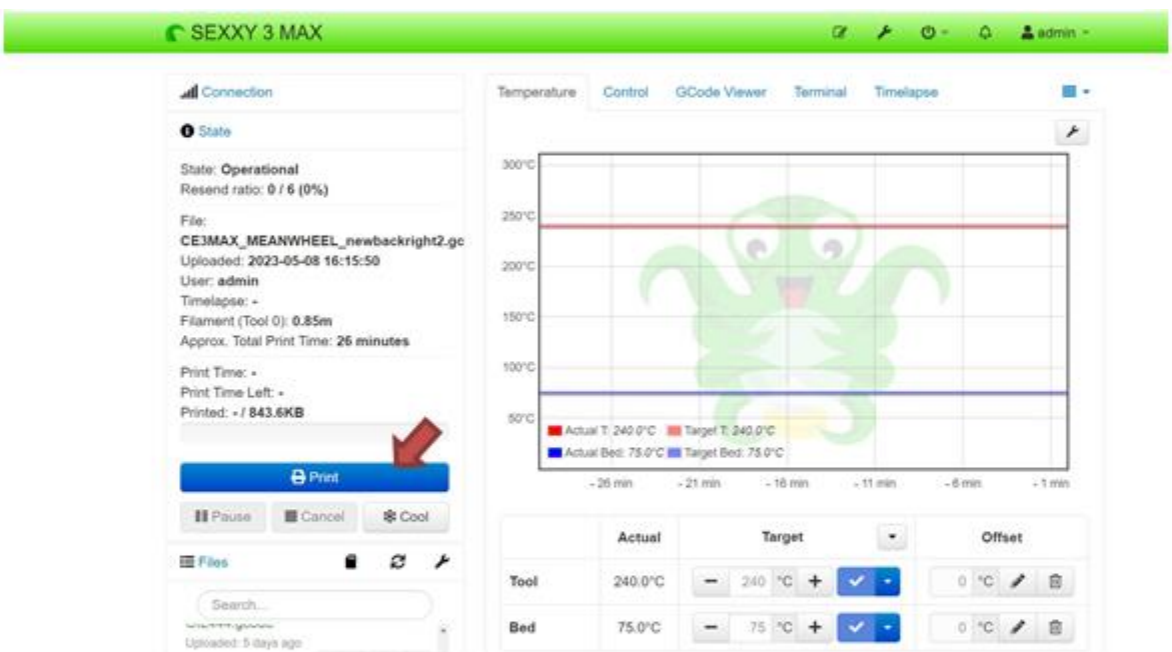


FIGURE 73 Print 3D model of wheel

3. We created a tire for the wheels that provides friction using CATIA and Ultimaker Cura programs. We followed the same method as before but used TPU 95A as the material for the tire as show in Fig.74.

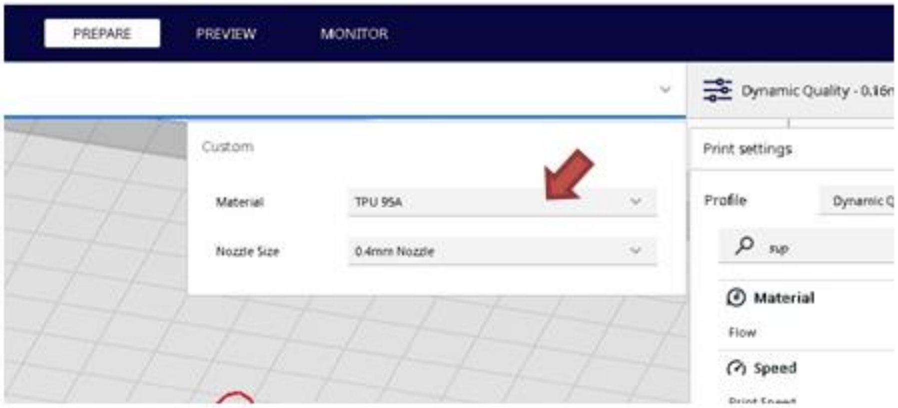


FIGURE 74 Choose TPU 95A

FIGURE 75 Complete wheel

FIGURE 76 Complete tire

5.4.3. Assembly base

We created a base for convenience and aesthetics, we followed the same method as before shown in Fig.77-79 and complete coil is show in Fig.80.

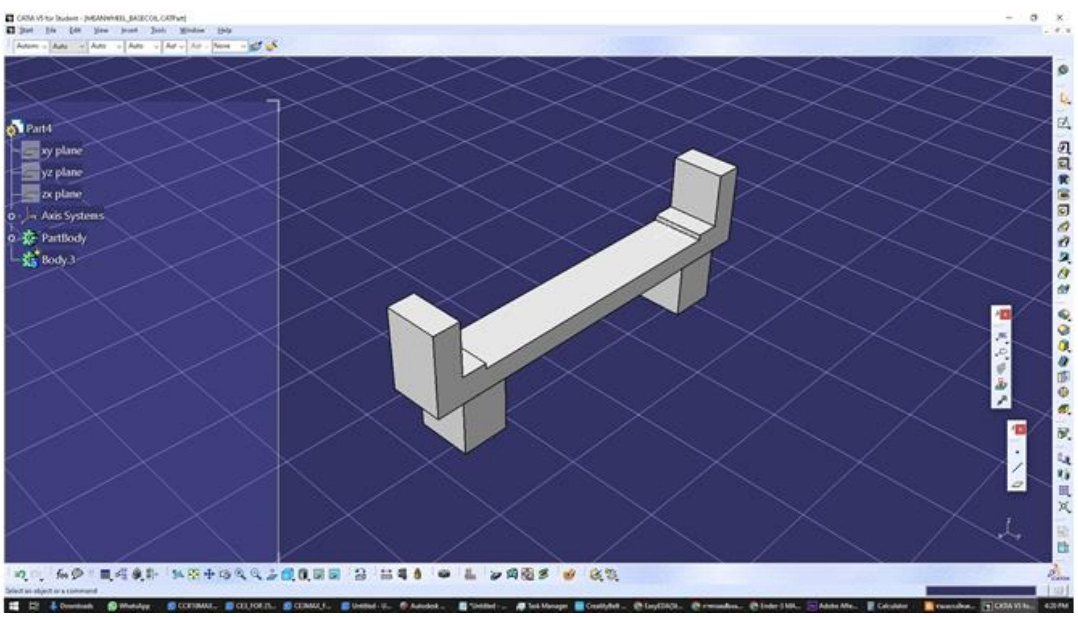


FIGURE 77 Design assembly base

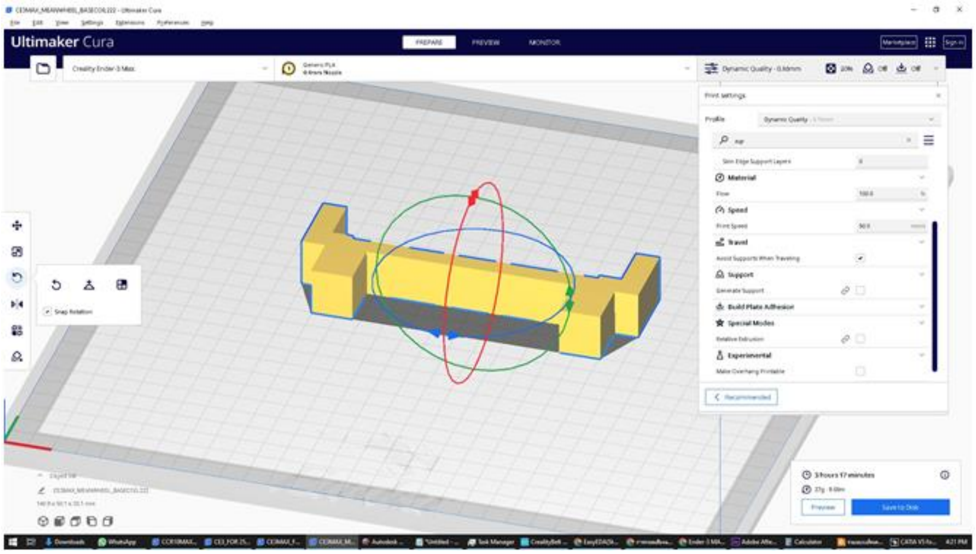


FIGURE 78 Set up function for ready to print.

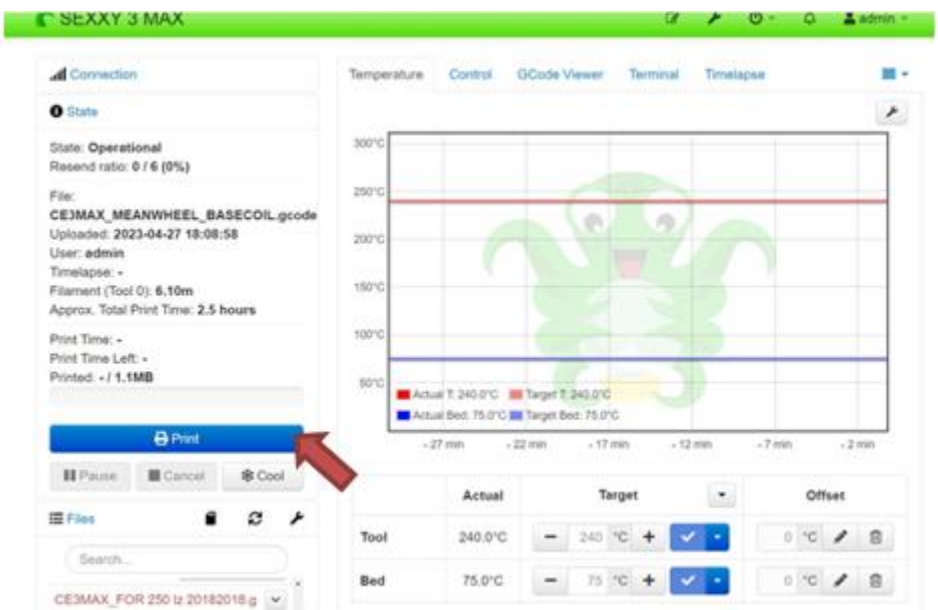


FIGURE 79 Print 3D model of assembly base

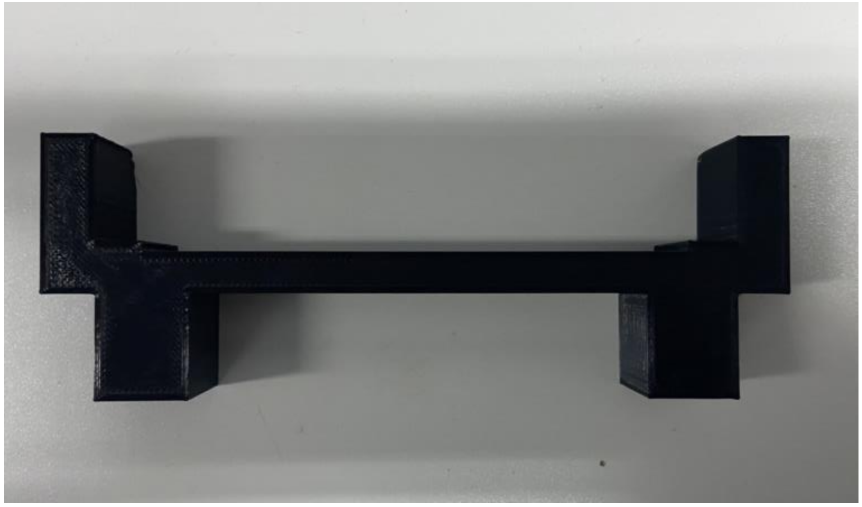


FIGURE 80 Complete assembly base

5.5. Summarize the results of the experimental

Linear ACMI-Based DWPT Line: For the linear nulls-free ACMI line, the Rx locations for measurement were specified by dividing its length between the centers of the Tx cell 1 and the termination cell 7 into 50 uniform steps yielding the normalized Rx positions 0–50. The nominal Rx height was determined at 2 cm. The power transfer efficiency (η) was calculated by equation 4.

$$\eta = \frac{Pout}{Pin} x100 \quad (4)$$

η : The measured efficiency

P_{OUT} : The power of an electrical appliance output (W)

P_{In} : The power of an electrical appliance input (W)

5.5.1. Connect transmitter circuit, radiator, and receiver without load to measure voltage output.

We can obtain a direct voltage and current measurement of approximately 10 V without any load using the measurement equipment as show in Fig.81

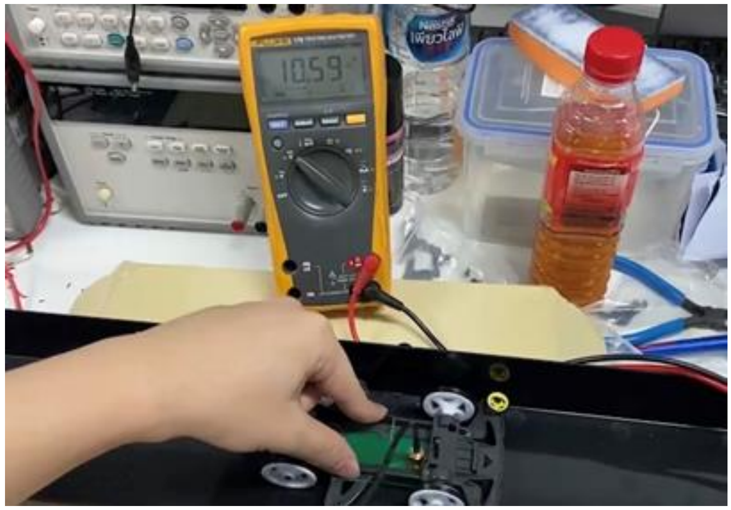


FIGURE 81 Voltage without load

5.5.2. Connect transmitter circuit, radiator, and receiver with load 50 ohms from spectrum analyzer to measure efficiency.

We measure output from amplifier, and we get approximately 1 watt or 29.9dBm as shown in Fig.82. Then, we measure output from receiver coil as shown in Fig.83 and result show in Table.4. The measured efficiency (η) at 13.56 MHz versus the normalized Rx positions are given in Fig.84.

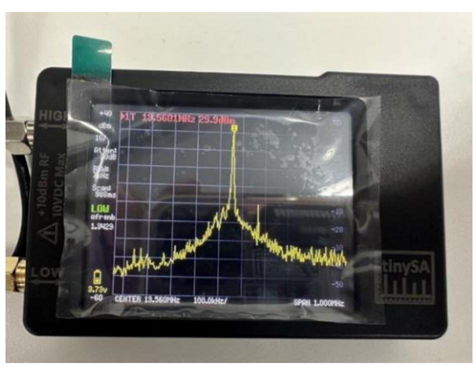


FIGURE 82 Output from amplifier

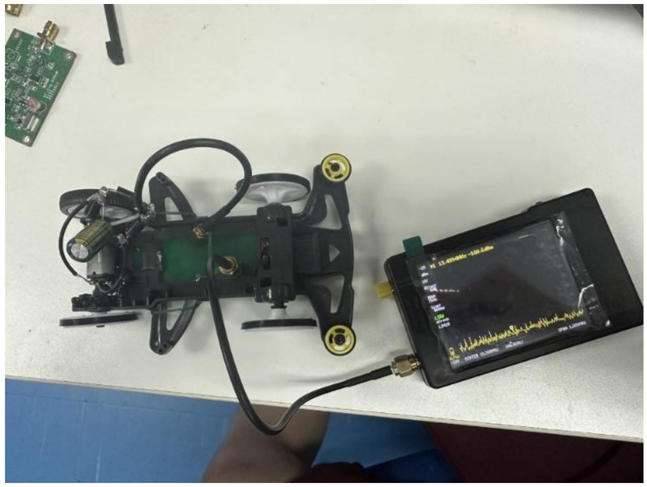


FIGURE 83 Measure output from receiver coil

Table 4 Output power with load 50 ohms from spectrum analyzer

Distance(cm)	Power(watt)
0	0.6165
5	0.5495
10	0.4365
15	0.4365
20	0.8709
25	0.6918
30	0.2187
35	0.3467
40	0.1096
45	0.3467
50	0.3467

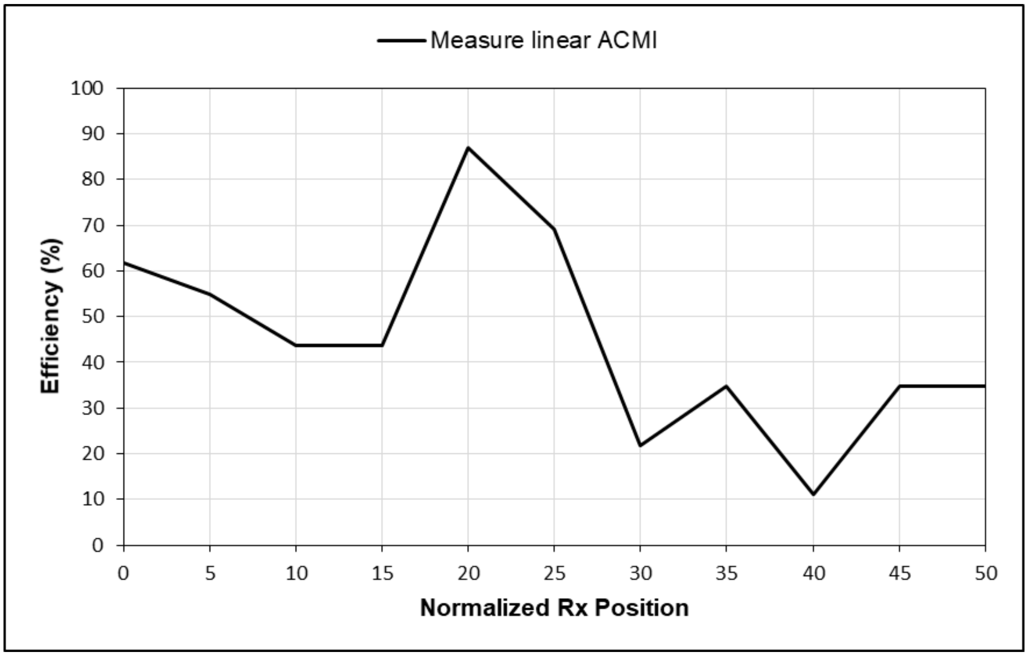


FIGURE 84 Graph efficiency for load 50 ohms from spectrum analyzer

5.5.3. Connect transmitter circuit, radiator, and receiver with load.

In Fig.82 show the power of the input to the transmitter analyzed from the spectrum analyzer with a 50 Ω load and the Table.5 show output of power by using resister 100 Ω to measure voltage and calculate by using equation 5 At the nominal height of 2 cm, the measured efficiency (η) at 13.56 MHz versus the normalized Rx positions are given in Fig.85.

$$P = \frac{V^2}{R} \quad (5)$$

P : The power of an electrical appliance (W)

V : The voltage across an electrical component (V)

R : The resistance of an electrical component (Ω)

Table 5 Output power and direct voltage current when connect with resister 100 ohms

Distance(cm)	Voltage(V)	Power (W)
0	5.48	0.30
5	6.96	0.48
10	6.42	0.41
15	3.74	0.14
20	4.08	0.17
25	7.01	0.49
30	8.55	0.73
35	3.86	0.15
40	2.07	0.04
45	6.58	0.43
50	7.79	0.61

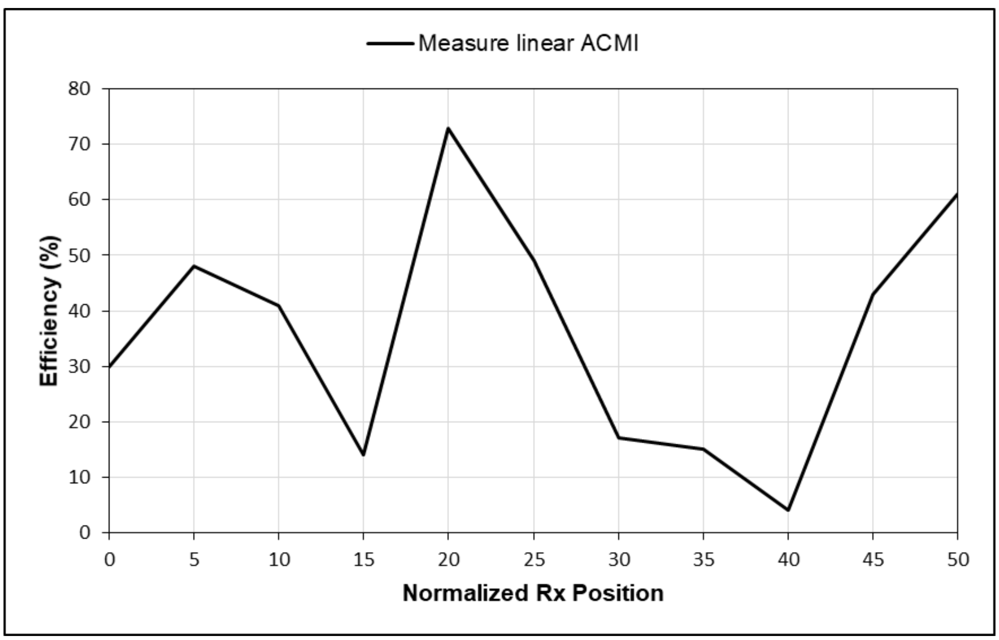


FIGURE 85 Graph efficiency for 100 ohms resister

5.5.4. Compare output signal and harmonic output between 1 and 2 receivers.

In Fig.86 and Fig.87 it appears that the output will decrease by approximately 0.2 dBm or 0.001 watt when there are two receiver coils on the transmitter coil. And In Fig.88 and Fig.89 show this reduction in output will affect both the 27 MHz and 40 MHz frequencies.

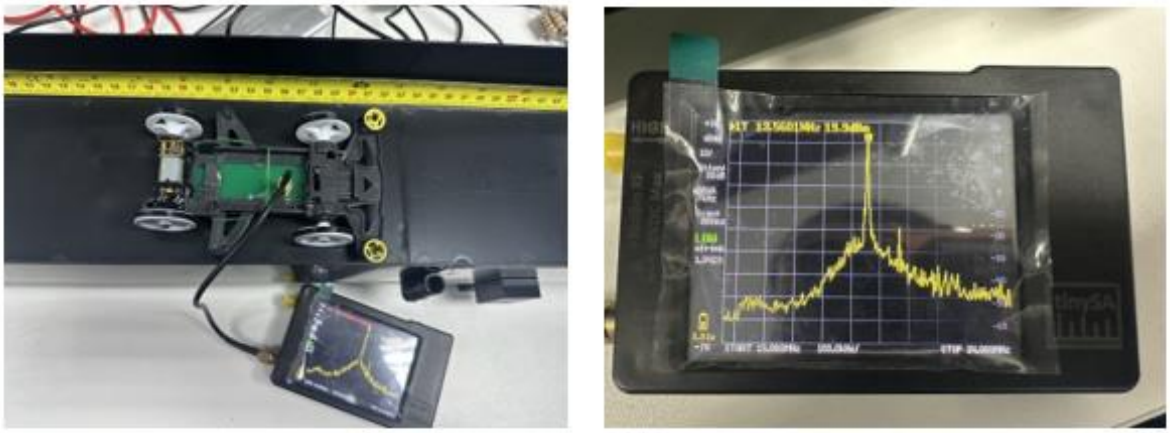


FIGURE 86 Output signal of one receiver

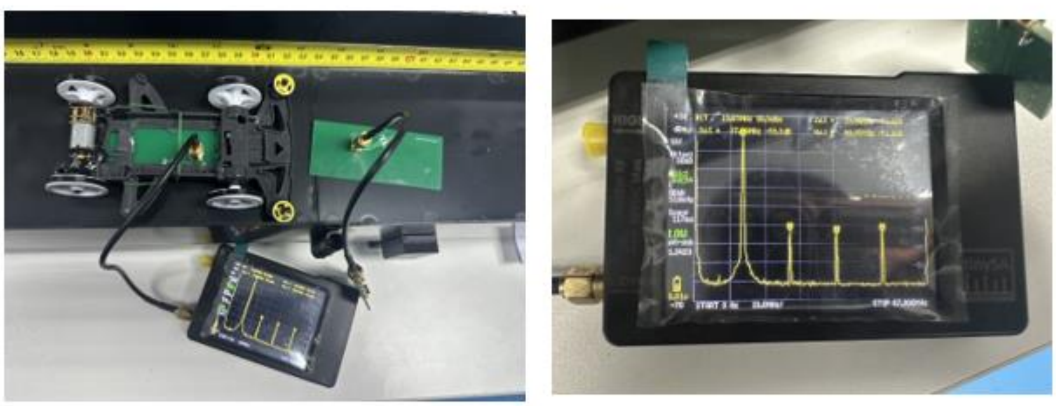


FIGURE 87 Output signal of two receivers

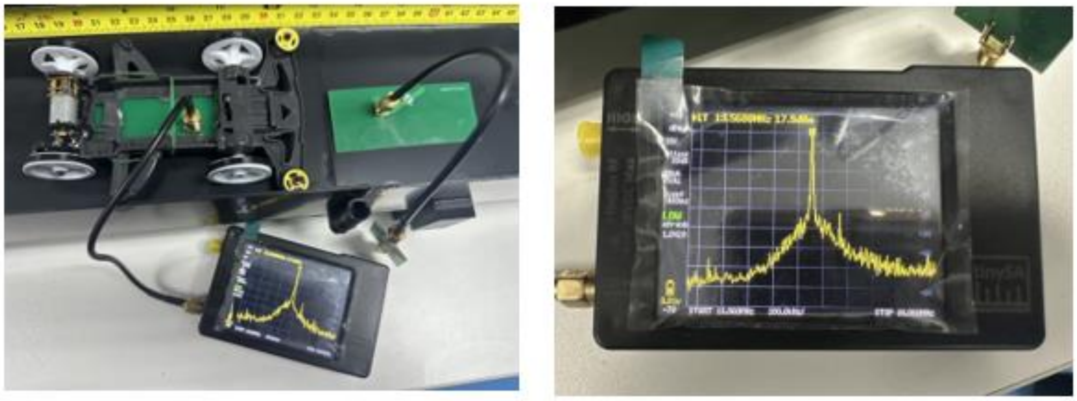


FIGURE 88 Output harmonic 1 receiver

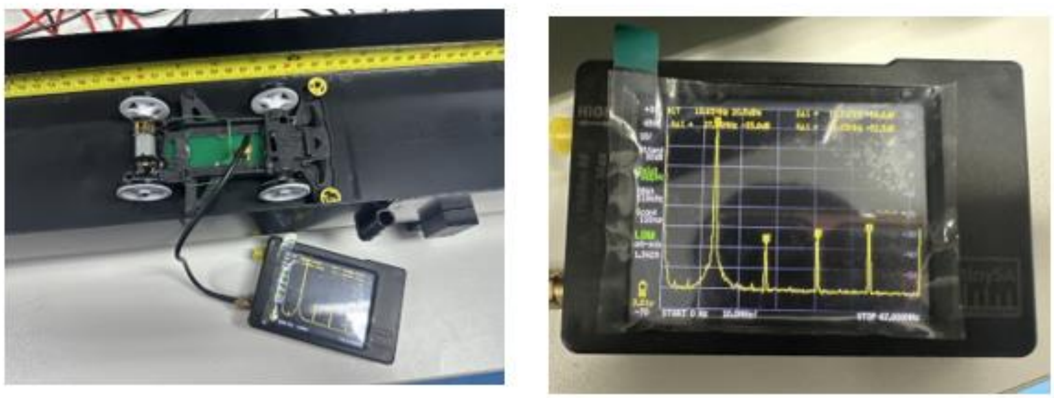


FIGURE 89 Output harmonic 2 receivers

6 Conclusion and Suggestion

6.1. Conclusion

After studying and working on ACMI, which is a technology for wireless energy transfer called Dynamic Wireless Power Transfer (DWPT), that uses the principle of magnetic-inductive coupling and communicates through an electrical path. It is small, easy to install, and has higher energy transfer accuracy than other wireless energy transfer technologies. It was found to be practical and efficient, with an efficiency graph showing that up to 80 percent of energy can be transferred before loading. Although there is a range where energy transfer is only 10 percent, it can still transfer energy without any power loss, or true nulls-free. It was also tested by providing energy to load and making the car run. The motor of the car was adjusted to use less current so that the car could run on the track without being powered externally.

6.2. Problem and obstacle

Problem and obstacle during development Demonstration of Resonant Wireless Power Transfer using Toy Racing Cars and Tracks project are as follows.

1. Some software is outdated, and it can be challenging to find information to study.
2. It is complicated to order PCB production.
3. Shipping of some devices may experience delays
4. We ordered the wrong size of hardware that is needed for our use.

6.3. Development guidelines

Development guidelines for Demonstration of Resonant Wireless Power Transfer using Toy Racing Cars and Tracks project are as follows.

1. Develop the track to the circular form and long distance.
2. Incorporate a speed measurement system to measure the velocity of the toy car.
3. Develop a car by using microcontroller to control direction and speed of car.

6.4. Suggestion

Suggestion for Demonstration of Resonant Wireless Power Transfer using Toy Racing Cars and Tracks project are as follows.

1. Select software that is readily accessible and regularly updated.

2. Select device for measurement that have dual-source architecture, which enables fast and accurate measurement of 2-port devices without requiring any switching. This makes it ideal for high-throughput testing of complex components such as filters and amplifiers.

7 Reference

[1] A Comparative Study of the Efficiency of Dynamic Wireless Power Transfer with Resonant Frequency, http://digital_collect.lib.buu.ac.th/project/b00257293.pdf [Retrieved on December 2022].

[2] Developing a dynamic wireless power transfer system that supplies electricity to the car while driving, https://bit.ly/3uXdXni [Retrieved on December 2022].

[3] C. Rakluea, A. Worapishet, S. Chaimool, Y. Zhao and P. Akkaraekthalin, "True Nulls-Free Magnetoinductive Waveguides Using Alternate Coupling Polarities for Batteryless Dynamic Wireless Power Transfer Applications," in IEEE Transactions on Power Electronics, vol. 37, no. 8, pp. 8835-8854, Aug. 2022, doi: 10.1109/TPEL.2022.3145579.

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