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Wireless Universal Power Plug For Load

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Abstract: Wireless concept is a type of power transfer between two objects that are not connected by the wire and it is the simplest way to eliminate the use of copper wire. The traditional power plug has brought some limitation such as use of conventional copper cable and current carrying wire that will leads some power loss and inconvenient for users. The main objective of the project is to design a wireless universal power plug for load and scope of the project is focus on the near field wireless power transfer. Transmitter circuit and receiver circuit are designed for wireless universal power plug. As the results, the relaxation oscillator circuit produced high AC power and frequency almost 180 kHz while full bridge rectifier circuit produced DC power and 5 V output voltage. When the distance between transmitter coil and receiver coil is increased, the performances of the system are decreased. In conclusion, the innovation for the wireless universal power plug will increase the efficiency of power transmission since reduces the power loss due to wire. Higher number of turns of copper wire can be used for future work so that the power can be transmitted in longer distance.

Keywords: Near Field, Rectifier, Wireless Power Transfer

1. Introduction

Wireless universal power plug is the type of power transmission between two objects that not connected by wire. Wireless universal power plug is for home applications. Wireless concept is one of the simplest and convenient way to eliminate the use of conventional copper wire [1]. Due to results of research in wireless power transfer (WPT), various categories are defined based on power efficiency, power transmission distance and strength of power [2]. WPT has two fields that are far field WPT and near field WPT [3]. Concept of inductive coupling between transmitter coil and receiver coil is the important key to success the project. Electromagnetic coil such as copper wire is a type of electrical conductor that can form in shape of spiral, coil and helix. CST Studio Suite software is used to identify

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either the properties of copper coils between transmitter coils and receiver coils are suitable for magnetic induction or not. Different shapes of electromagnetic coil have different strength of magnetic field [4]. The more number of turns of coil, the stronger the magnetic field produced [5].

2. Equipments and Methods

The equipments and methods section is also known as methodology. This section will describes all the necessary information that is required to obtain the results of the study.

2.1 Equipments

Specifications and properties of equipments used in the project are described in Table 1.

Table 1: Specifications and properties of equipments used in the project

Equipment	Function
Oscilloscope	Observe the input and output waveform
DC power supply	Supply DC power
Resistors (33 ohms, 47 ohms, 220 ohms, 560 ohms)	Control current flow
Capacitors (0.1nF, 1nF, 0.022uF, 0.1uF, 1000uF)	Smoothen the output
Inductor (680uH)	Storing energy
Diode (1N4007)	Allow current flow in one direction
Voltage regulator (LM7805CT)	Regulate the output voltage become 5V
555 timer IC	Oscillate the voltage and pulse generation
Copper wire	For inductive coupling
Frequency counter	Measure the output frequency
Multimeter	Measure input & output current and voltage

2.2 Methods

Figure 1 shows the block diagram of the universal wireless power plug. The transmitter circuit consists of an oscillator circuit, whereas the receiver circuit consists of a rectifier circuit. The oscillator circuit was constructed using the NI Multisim software shown in Figure 2. TLC551CD Timer IC is a 555 IC Timer. The DC power supply is the circuit input. The 555 IC timer is used to oscillate the generation of voltage and pulse. L1, R7 and C7 in series connections are low-pass filters. The low pass filter circuit is designed to alter the output and transform the pulse wave into a sinusoidal waveform.

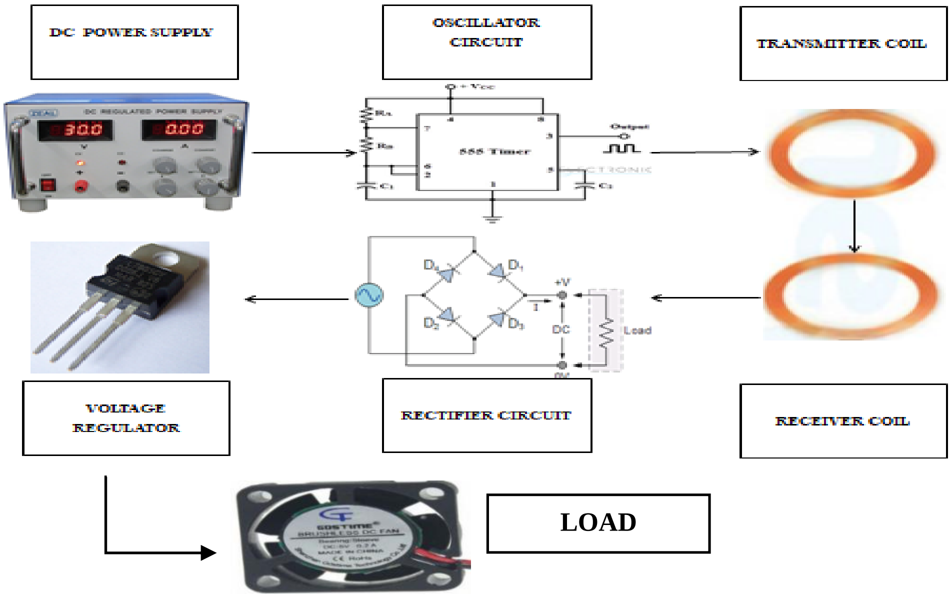


Figure 1 : Block diagram of wireless universal power plug

Figure 3 shows the schematic diagram of the rectifier circuit in the NI Multisim software. According to the authors in [6], the AC power supply is typically 50 Hz in frequency. The 50 Hz frequency is therefore used in the rectifier circuit in the Multisim software. 6 Vrms is used for the AC power supply. Four diodes (1N4007) are connected in series together with a 1000µF capacitor. Capacitors are used to smooth the waveform output to produce a pure DC voltage. The LM7805CT voltage regulator is used to maintain a 5V DC output. The voltage regulator helps to reduce the power loss by adjusting the voltage value needed for the load.

Transmitter coil and receiver coil are the core elements of this project. As a result, ANSYS software is used to construct the transmitter coil and the receiver coil in order to obtain inductive coupling data. The transmitter coil and receiver coil were designed based on the law on electromagnetism in the near-field region [7]. The ANSYS software used to identify either the number of turns for the copper coil, the coil radius and the distances between the transmitter coil and the receiver coil are suitable for inductive coupling or not. Spiral shape coil is used because the thickness of the shape of the coil is smaller compared to the other shape of the coil. The materials used in the coil are copper for inductive coupling. The reason for the use of copper is because of its low electrical resistance. As a result, the current can easily flow through the copper coil. The copper coil radius used was 0.03 m and the copper coil used was 3.8 m in length. As a result, the number of turns for copper coil used in the software simulation is 20 turns based on the Eq. 5 and Eq. 6, respectively. Besides, the copper coil with a diameter of 0.51 mm was used so that the coil was not too thin and could not quickly be heated faster due to power losses. The designed frequency of the transmitter circuits approximately 180 kHz, therefore based on the formula in Eq. 7 and Eq. 8, the inductive coupling distance, x between the transmitter and the receiver coils, can be constructed within a range of 11 cm, as shown in Figure 4. Therefore, parametric studies on different ranges of x were carried out in order to see the performance of the design.

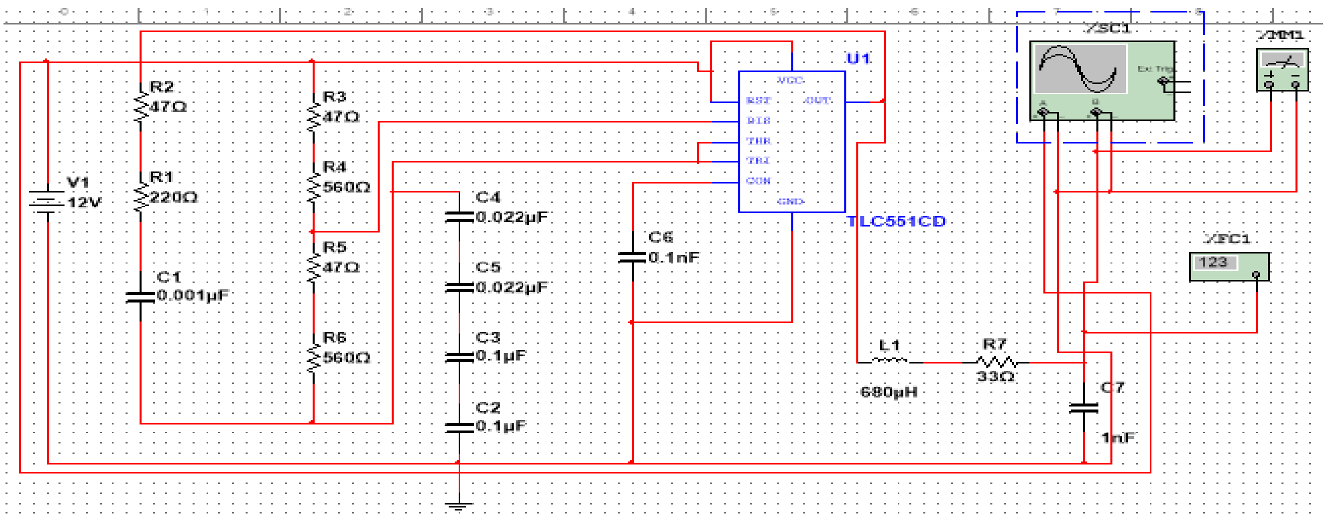


Figure 2 : Oscillator circuit in NI Multisim software

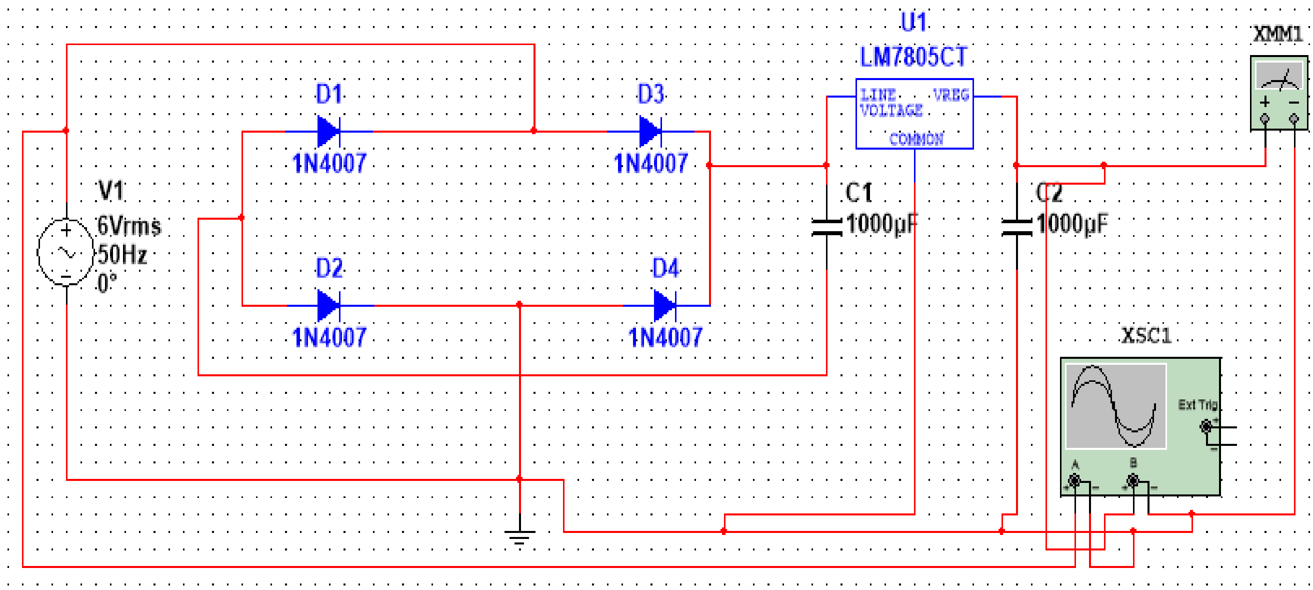


Figure 3 : Schematic diagram of rectifier circuit in NI Multisim software

The simplified RLC circuit was used to determine the voltage output and current output of the circuit. All resistances, inductances and capacitances of the oscillator circuit, rectifier circuit and transmitter coil and receiver coil have been added to form a simplified RLC circuit of wireless power transmission system based on Eq. 1 to Eq. 4. The design of the simplified RLC circuit diagrams of wireless power transmission in NI Multisim as shown in Figure 5 and the values of the parameters were based on distances between 2 cm, 4 cm, 6 cm, 8 cm and 10 cm coils as shown in Table 2.

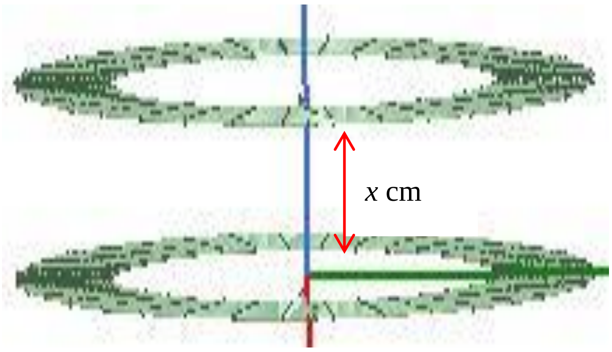


Figure 4: Distance between transmitter and receiver coils in x cm

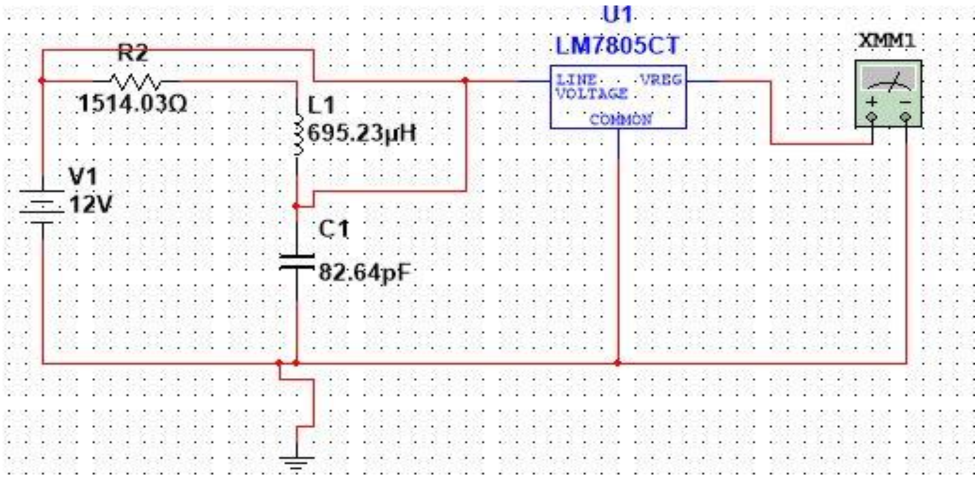


Figure 5 : Simplified RLC circuit

Table 2: Parameters values for the simplified RLC circuit

Parameters	Transmitter & receiver coils	Combination of WPT system
2cm	R_{2cm} = 33.50mΩ , L_{2cm} = 15.23uH	R_{2cm} = 1514.03Ω, C=82.64pF, L_{2cm} = 695.23uH
4cm	R_{4cm} = 22.42mΩ, L_{4cm} = 6.74uH	R_{4cm} = 1514.02Ω, C=82.64pF, L_{4cm} = 686.74uH
6cm	R_{6cm}= 11.94mΩ, L_{6cm} = 3.48uH	R_{6cm} = 1514.01Ω, C=82.64pF, L_{6cm} = 683.48uH
8cm	R_{8cm} = 5.08mΩ, L_{8cm} = 1.87uH	R_{8cm} = 1514.01Ω, C=82.64pF, L_{8cm} = 681.87uH
10cm	R_{10cm} = 2.33mΩ, L_{10cm} = 1.10uH	R_{10cm} =1514.00Ω, C=82.64pF, L_{10cm} = 681.10uH

Resistances or inductances in series connection: (R/L)Total = (R/L)1+(R/L)2+(R/L)3+… Eq. 1

Resistances or inductances in parallel connection: $\frac{1}{(R/L)_{Total}} = \frac{1}{(R/L)_1} + \frac{1}{(R/L)_2} + \frac{1}{(R/L)_3} + \cdots$ Eq. 2

Capacitances in series connection: $\frac{1}{C_{Total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$ Eq. 3

Capacitances in parallel connection: CTotal = C1+C2+C3+… Eq. 4

Circumference of copper wire, $d = 2r\pi$,Eq. 5

where r is radius of copper wire

Number of turns, $N = \frac{L}{d}$, Eq. 6

where L is length of copper wire

Wavelength, $\lambda = \frac{c}{f}$, c is the speed of light and f is frequency Eq. 7

Reactive near field distance $\leq 0.62\sqrt{\frac{L^3}{\lambda}}$ Eq. 8

$B = \frac{\mu_{0NIa^2}}{2(a^2+d^2)^{\frac{3}{2}}}$ Eq. 9

where B is the magnetic flux density, μ_0 is magnetic permeability of vacuum, I is current, a is the radius and d is the distance of separation between coils.

$\emptyset = BA$, Eq. 10

where A is area of coil and $\emptyset$ is magnetic flux.

$L = \frac{N\emptyset}{I}$, Eq. 11

where L is inductance.

$R = \frac{\omega L}{Q}$, Eq. 12

where ω is the operating frequency, R is resistance and Q is quality factor.

$X_L = 2\pi fL$, Eq. 13

where X_L is reactance

$Z = \sqrt{R^2 + X_L{}^2}$, Eq. 14

where Z is impedance

$M = k\sqrt{L_1 L_2}$ Eq. 15

where M is mutual inductance, k is coupling coefficient and L1&L2 are transmitter and receiver inductances.

3. Results and Discussion

The simulation results that had collected in the project will be described in this section. The results that had obtained will be analysed in this topic.

Figure 6 shows the output frequency of 183,775 kHz and the output voltage of 20,073 V in the oscillator circuit. Meanwhile, Figure 7 shows the input and output waveform of the circuit measured by the oscilloscope. For the rectifier circuit, Figure 8 shows the input and output waveform of the circuit measured by the oscilloscope and the output voltage of the circuit measured by the multimeter. The output voltage of the circuit is 4.985 V.

Table 3 shows the data obtained by the software simulation at distances of 2 cm, 4 cm, 6 cm, 8 cm and 10 cm between the transmitter coil and the receiver coil. Tx represents the transmitter coil, whereas Rx represents the receiver coil. Based on Table 3, the coefficient of coupling, self-inductance, resistance and impedance between the transmitter coil and the receiver coil is decreased when the distance between the transmitter and the receiver coil is increased. The magnetic flux for the transmitter coil and the receiver coil also decreased when the distance between the transmitter and the receiver coil increased.

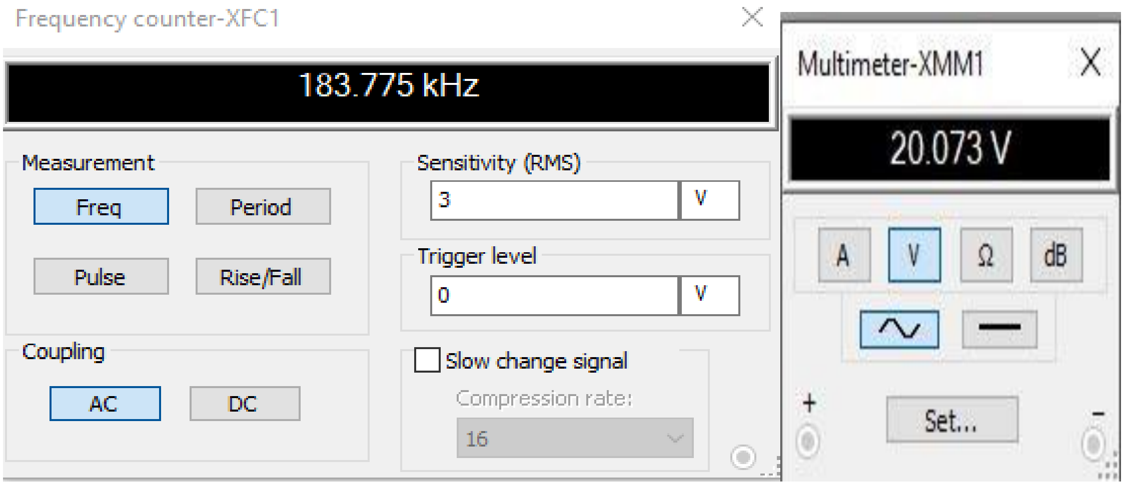


Figure 6 : The output voltage and frequency

Table 3 : Summaries of the data obtained

	Distance between Tx and Rx: 2cm	Distance between Tx and Rx: 4cm	Distance between Tx and Rx: 6cm	Distance between Tx and Rx: 8cm	Distance between Tx and Rx: 10cm
CplCoef(Tx,Rx)	0.316302	0.138226	0.069964	0.038314	0.022988
L(Tx,Rx)(uH)	15.231107	6.738141	3.475878	1.873527	1.101797
R(Tx,Rx) (mOhm)	33.502827	22.416556	11.938708	5.076490	2.325383
Z(Tx,Rx) (ohm)	0.033503+ 17.225976i	0.022417+ 7.620658i	0.011939+ 3.931126i	0.005076+ 2.118909i	0.002325+ 1.246103i
MagFlux(Tx) (Wb)	0.000048- 0.000015i	0.000049- 0.000007i	0.000050- 0.000003i	0.000049- 0.000002i	0.000048- 0.000001i
MagFlux(Rx) (Wb)	0.000015- 0.000048i	0.000007- 0.000049i	0.000003 0.000050i	0.000002- 0.000049i	0.000001- 0.000048i

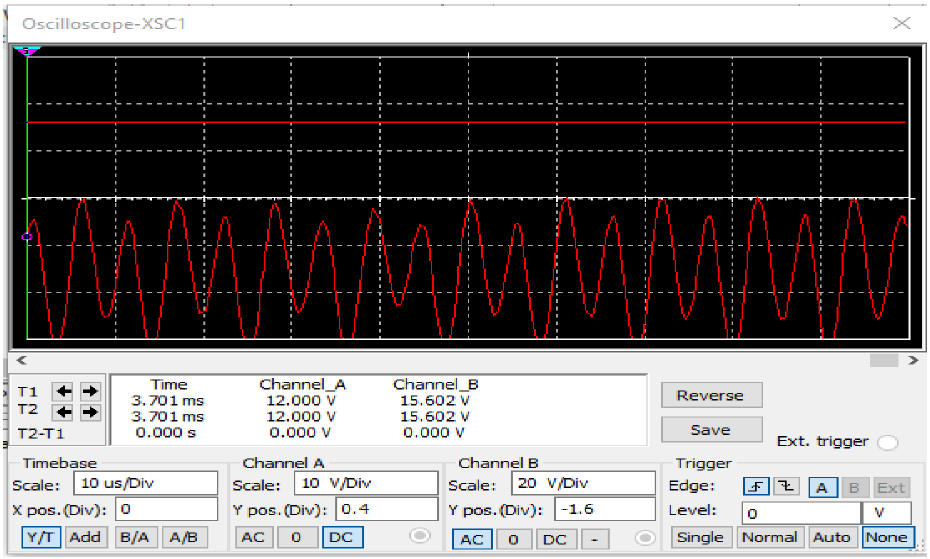


Figure 7 : The input and output waveform

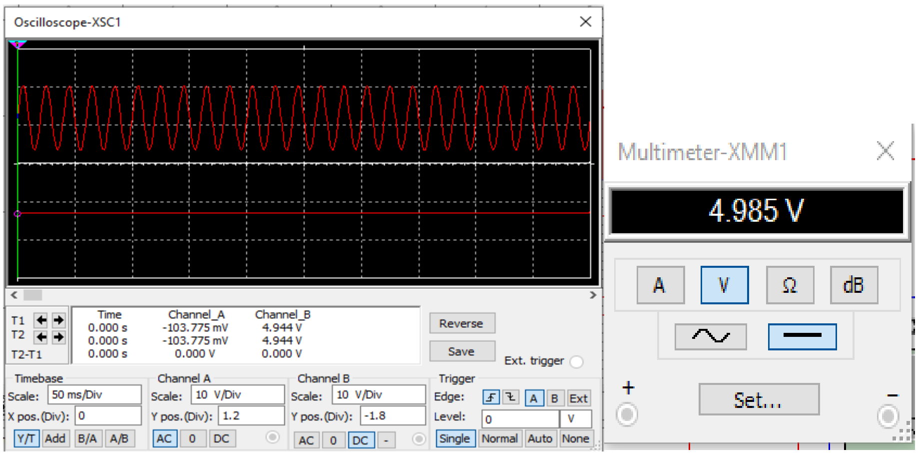


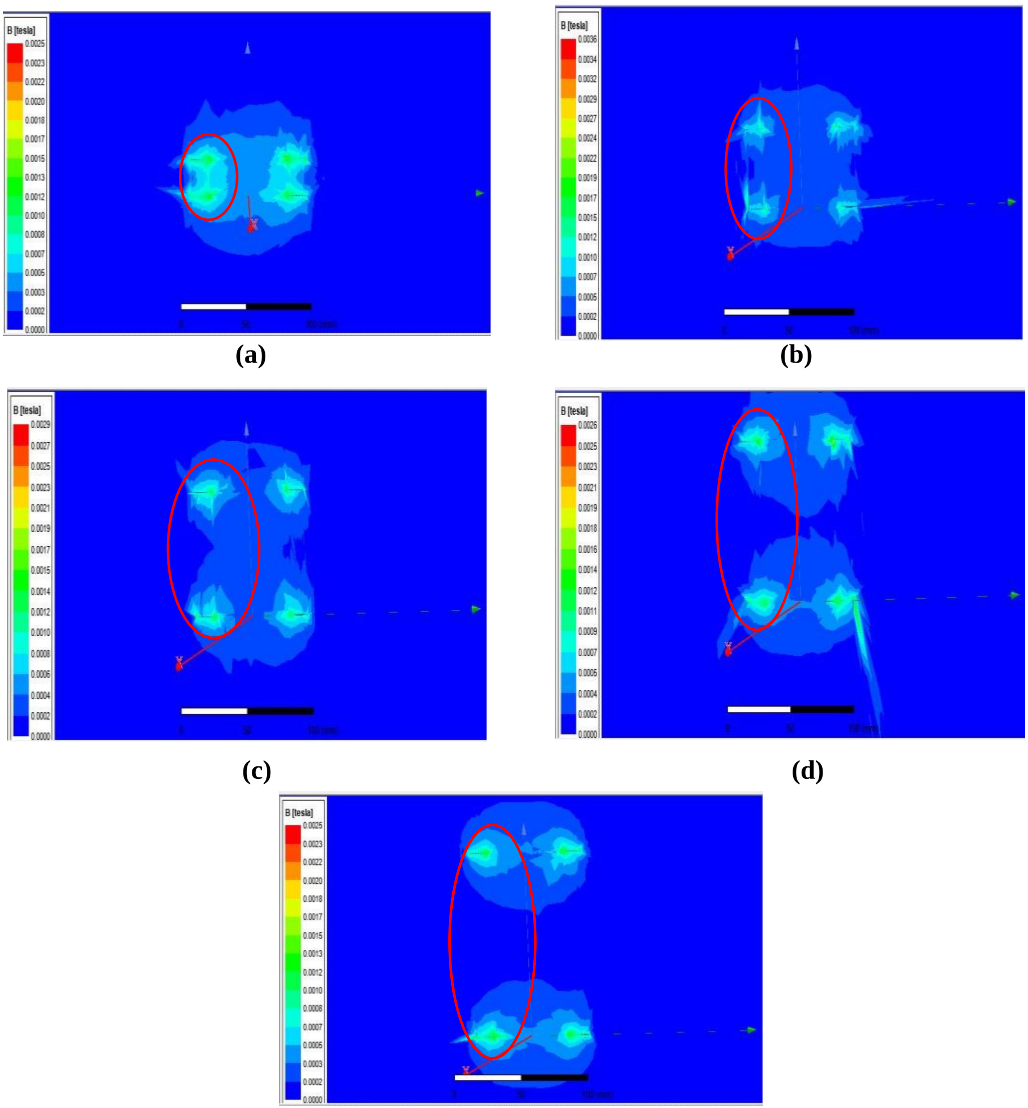
Figure 8 : The input & output waveform and output voltage

Figure 9 (a) to (e) are plotted in order to observe the magnetic field between the transmitter coil (positioned at the bottom) and the receiver coil (positioned at the top) in 2 cm, 4 cm, 6 cm, 8 cm and 10 cm, respectively. Existing magnetic field and coupling coefficient means that an inductive the coupling has occurred between the transmitter coil and the receiver coil. The magnetic field generated is evaluated on the basis of the colours and areas of the magnetic field. Based on the red circles in the figures, it can be clearly seen that the magnetic field strength between the coils is reduced when the distance between the transmitter coil and the receiver coil is increased.

Figure 10 shows the output voltage and output current obtained by multimeter in distances between 2 cm, 4 cm, 6 cm, 8 cm and 10 cm coils. Based on software simulations, the output current and output voltage generated are the same as 5,002 V and 6,701 A, although the distances between the coils are different.The mutual impedance, $Z = -\frac{\mathrm{Vin}}{\mathrm{Iout}}$. Therefore, $Z = -\frac{12\mathrm{V}}{6.701\mathrm{A}} = -1.79$ ohms.

Eq. 9 is the formula based on the Biot-Savart's law concept. Therefore, based on the formula, when distance of separation between the transmitter and receiver coils increased, magnetic flux density generated by transmitter will be decreased. Furthermore, based on Faraday's law of induction, magnetic flux of coil is defined as Eq. 10. Since magnetic flux density generated by transmitter coil is decreased when distance between the coils is increased, therefore theoretically magnetic flux that passed through the coils is decreased. Besides, self-inductance of the coil is given by Eq. 11. Since magnetic flux of coils is decreased when distance between coils is increased, therefore the number of magnetic field that opposed the current change is decreased. Since L of coils is decreased when distance between coils is increased, therefore R of coils will be decreased based on Eq. 12.

In addition, when L of the coils is decreased, X_L of the coils also will be decreased based on Eq. 13. Therefore, the impedance (Z) between the coils is decreased when the distance between the coils is increased based on Eq. 14. Lastly, mutual inductance between the coils is defined as Eq. 15. Since inductances for the coils are decreased when distance between coils is increased, therefore mutual inductance between the coils also decreased. Thus, coupling coefficient also decreased when distance between coils is increased due to mutual inductance. This means that the fraction of magnetic flux produced by current in one coil that linked with another coil is reduced. Biot-Savart's law had stated that Eq. 9. Therefore, this means when distance between the coils (d) is increased, strength of magnetic field between the coils will be reduced, so the magnetic flux density (B) between the coils is decreased. The output current and output voltage obtained are the same although distances between coils are different because the changing of resistance and inductance between the coils that obtained in ANSYS software are very small. Besides, the voltage regulator also had regulated the voltage to 5 V.



(a) (b) (c) (d) (e)

Figure 9 : Magnetic field between transmitter coil and receiver coil in x cm

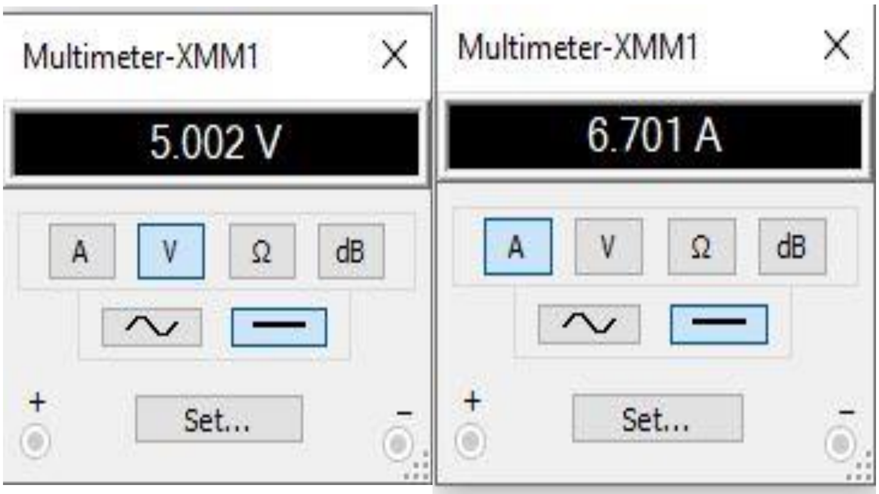


Figure 10 : The output voltage and current obtained by using multimeter

4. Conclusion

The wireless universal power plug is a type of power plug that can transfer power between two non-wire-connected objects. The transmitter circuit consists of a relaxation oscillator circuit used to convert DC power to AC power and to produce high-frequency oscillating electronic signal voltage [8]. The receiver circuit consists of a full bridge rectifier circuit, which is used to convert the AC power back to DC power and to control the voltage required [9]. The transmitter coil in the transmitter circuit is connected to the oscillator circuit which is used to transmit the signal and the power to the receiver coil which is connected to the rectifier circuit. The receiver coil receives the signal and receives the power through the inductive coupling between the transmitter coil and the receiver coil. Finally, the received power is transferred to the connected load. The oscillator circuit successfully produced a frequency of almost 180 kHz that is suitable for near-field wireless transmission over 100 kHz [10]. As can be seen from the results obtained, the performance of the WPT system between the coils is decreased when the distance between the transmitter and the receiver coil is increased. There is a suggestion that could improve the project, as the sensor can be placed on the receiver circuit to detect the battery status of the device. The Arduino can then design the data on the transmitter circuit. If the battery is low at a certain level, the system will automatically start charging the phone.

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