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Wireless Charger for Small Scale Rechargeable Battery

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Abstract: Wireless power transfer (WPT) technologies enable power transfer between electrical networks without the use of wires or exposed connectors. A wired connection restricts their mobility and, in some situations, may not be a secure choice if they are damaged. The project aims to create a wireless charger that can be used to charge a variety of small rechargeable batteries, and its focus is on near-field wireless power transfer. Two circuits, which are the transmitter circuit and receiver circuit, are constructed for the wireless charger for small-scale rechargeable batteries. Thereby, the oscillator circuit in the transmitter circuit enabled it to generate AC power and a high frequency of approximately 180 kHz, while the full bridge rectifier circuit in the receiver circuit enabled it to generate a 5V DC voltage. The system's performance reduced as the distance between the transmitter coil and receiver coil increased. In conclusion, the WPT idea can decrease the use of cable, which reduces power transfer efficiency because of power loss. To prevent the battery from being overcharged, which might harm the battery, a cut-off system can be added to the receiver circuit, which can automatically stop charging when the battery is full.

Keywords: Wireless Power Transfer, Oscillator, Rectifier

1. Introduction

Wireless charging, also known as wireless power transfer (WPT) is a technique that allows a power source to send electromagnetic energy through an air gap to an electrical load without the use of interconnecting cables [1]. Because of its simplicity and improved user experience, this technology is attracting a wide range of applications, from low-power toothbrushes to high-power electric vehicles. Nowadays, wireless charging is fast progressing from theoretical to commonplace oncommercial items, particularly mobile phones and portable smart gadgets. Wireless charging is expected to be a $4 billion market by 2016, according to IMS Research [2]. The person who was responsible for the idea or concept of wireless power transfer was Nicole Tesla [3].

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Near-field and far-field wireless power transmissions are the two main types of wireless power transfer. Low-frequency transmission with straightforward pattern measurements is provided by a far-field approach. With comprehensive pattern data, near-field approaches offer greater frequency transmission [4]. Measurements utilising a device close to the power source are among the near-field approach. Inductive coupling and magnetic resonant coupling are the two types of near-field power transfer techniques. This project is focused on the near-field technique which is the inductive coupling method.

1.1 Inductive Coupling Method

Two LC circuits coupled together with the same resonance frequency are said to be inductively coupled. It functions by using magnetic field induction, a consequence of current flow via a wire that occurs naturally. A secondary coil at the receiver experiences a voltage across its terminals as a result of the alternating current in the main coil linked to a source creating a changing magnetic field. In inductive coupling, the primary and secondary coils are two separate coils. Each of them was connected wirelessly, and inductive coupling has become a common technology for transferring electricity without wires due to its simplicity, convenience, and safety. The range may be measured in centimeters, and the charging direction must be aligned for it to function well when the device's charging node and power receiving node are close together, typically less than a coil diameter for example [5].

2. Equipment and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Equipment

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

Table 1: Specification and properties of equipment used in the project

Equipment	Function
DC Power Supply	Supply 12V DC power to the transmitter circuit
Resistors (47Ω, 560Ω, 33Ω, 220Ω)	To control current flow
Capacitor (0.1nF, 1nF, 0.022μF, 0.1μF,1000μF)	Smoothen the DC
Inductor (680μF)	Store energy
Oscilloscope	Observe the input and output waveform
555 Timer IC	Oscillate the voltage and pulse generation
Multimeter	Measure input and output voltage
Frequency Counter	Measure output frequency
Voltage Regulator (LM7805CT)	Regulate output voltage at 5V
Diode (IN4007)	Allow current to flow in one direction

2.2 Methods

NI Multisim software is used to design the transmitter circuit with oscillator circuit and receiver circuit with rectifier circuit. The transmitter coil and receiver coil are constructed or designed using

ANSYS Maxwell software. Figure 1 shows the block diagram of the wireless charger for small-scale rechargeable batteries.

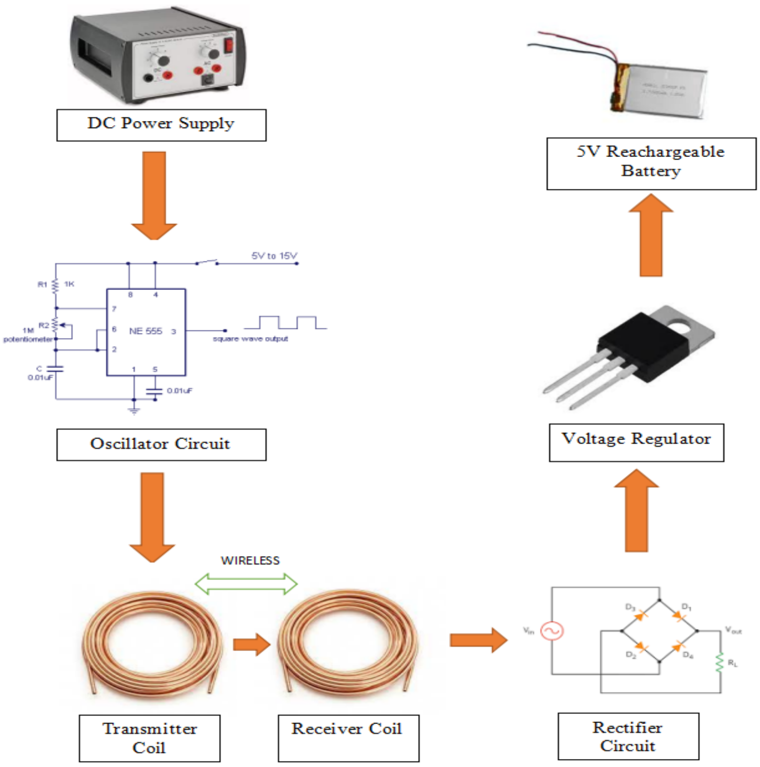

Figure 1: Block diagram of wireless charger for small-scale rechargeable battery

Figure 2 shows the transmitter circuit which consists of the oscillator circuit. 12V power supply in DC will be delivered to the transmitter circuit to power the circuit. TLC551CD Timer IC is connected with certain capacitors and also resistors to produce desired frequency which is more than 100 kHz for transferring power wirelessly purpose. There is an oscilloscope included in the circuit which to monitor or observe the waveform of input and output voltage. To obtain the value of induced output voltage, a multimeter is placed at the output of the transmitter circuit. The frequency counter that is connected to the output of the transmitter circuit will show the output frequency value.

Figure 3 shows the receiver circuit that consists of the rectifier circuit. The source given to the circuit is 6 Vrms with 50 Hz of frequency. The series of IN4007 diodes and also 1000 µF are used in this circuit. The voltage regulator that is being used in this circuit is LM7805CT which regulates the output voltage at 5V. The function of the capacitor used in the receiver circuit is to reduce the ripple and smoothen the DC voltage. A multimeter is connected at the output of the transmitter circuit to measure the value of input and output voltage while the oscilloscope is connected to the circuit to observe the input and output voltage waveform.

Figure 4 shows the transmitter coil and receiver coil that is being constructed in ANSYS Maxwell software. The aim of designing both coils in ANSYS Maxwell software is to compare the magnetic field strength and also to obtain the coupling coefficient data. The spiral shape of the coil is used because it has a thinner profile than other coil shapes. Due to its low electrical resistance, copper is utilised as the coils' material. 0.03m of the radius is used and the length of the copper coil selected is 3.8m. 20 turns then are used based on Eq. 1 and Eq. 2. The diameter of the coil that is being selected is 0.51mm to ensure not too thin and not easily hot due to power loss. The distance between the two-transmitter coil and receiver coil was set to 11 cm following Eq. 3 and Eq. 4.

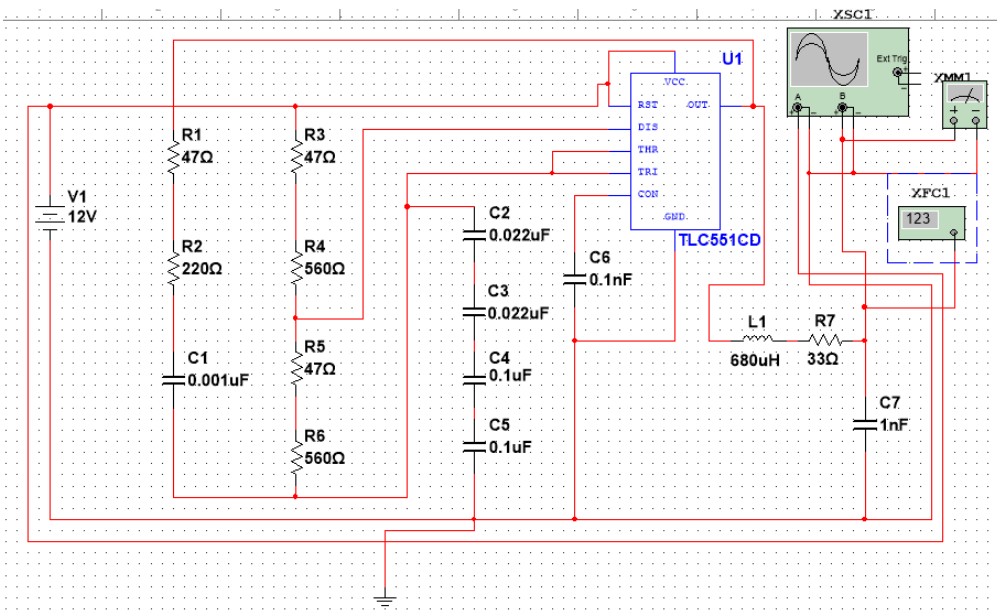

Figure 2: Transmitter Circuit

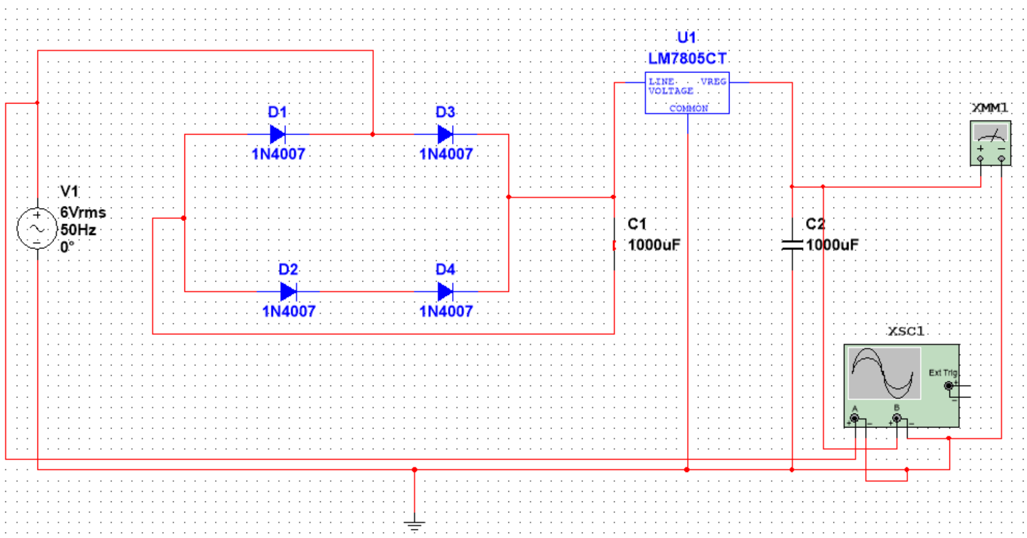

Figure 3: Receiver Circuit

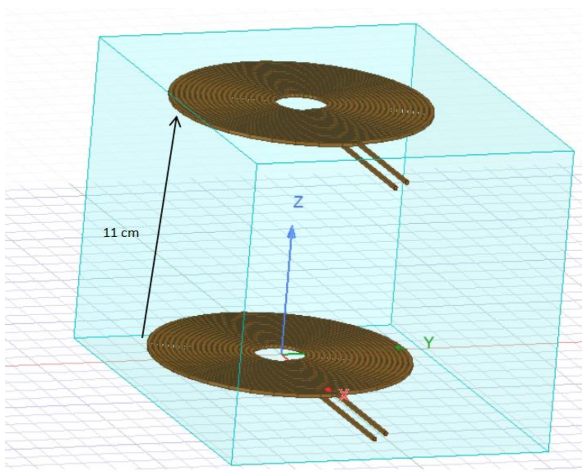

Figure 4: Transmitter coil and receiver coil constructed in ANSYS Maxwell software

2.3 Equations

The equation used is as the following:

Circumference of copper wire is given by the equation,

$$d = 2\pi r \qquad \text{Eq.1}$$

Where r is the radius of copper wire,

$$\text{Number Of Turns, N} = \frac{L}{d} \qquad \text{Eq.2}$$

Where L is the length of copper wire

$$\text{The wavelength, } \lambda = \frac{c}{f} \qquad \text{Eq.3}$$

Where C is the speed of light and f is the frequency

$$\text{Reactive near field distance} \leq 0.62\sqrt{\frac{L^3}{\lambda}}\ [6] \qquad \text{Eq.4}$$

$$B = \frac{\mu_O N I a^2}{2(a^2 + D^2)^{\frac{3}{2}}} \qquad \text{Eq.5}$$

Where B is magnetic flux density, μ_O is magnetic permeability of vacuum, I is current, a is the radius and D is a distance of separation in between coils.

$$\phi = BA \qquad \text{Eq.6}$$

Where A is an area of coil and ϕ is magnetic flux

3. Results and Discussion

The results and discussion section presents data and analysis of the study. The output voltage, output waveform and output frequency from both the transmitter circuit and receiver circuit can be obtained through the simulation in NI Multisim software. The coupling coefficient data and magnetic field strength between the transmitter coil and receiver coil can be obtained from ANSYS Maxwell simulation software. Figure 5 shows the output produced from the transmitter circuit while Figure 6 the output from the receiver circuit.

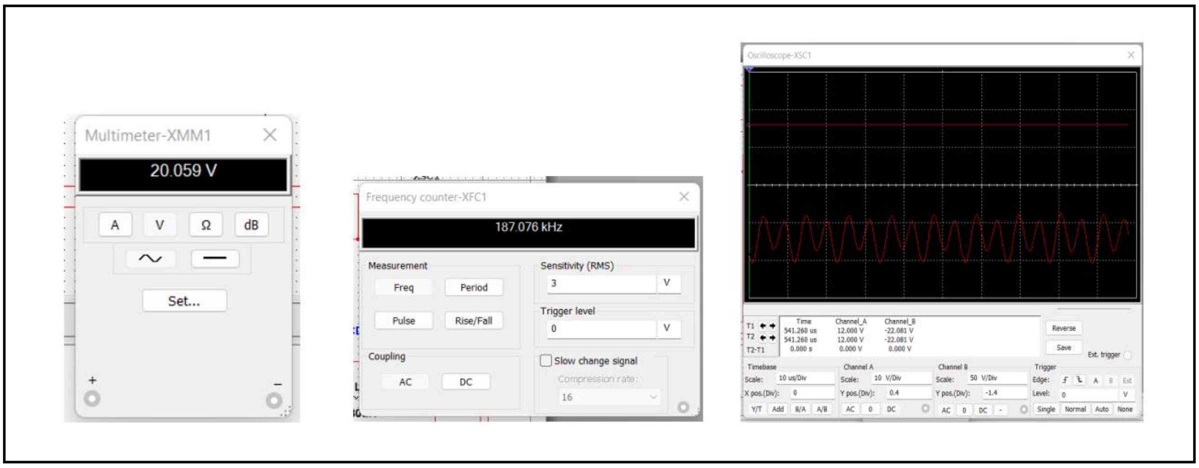

Figure 5: Output produced from the transmitter circuit

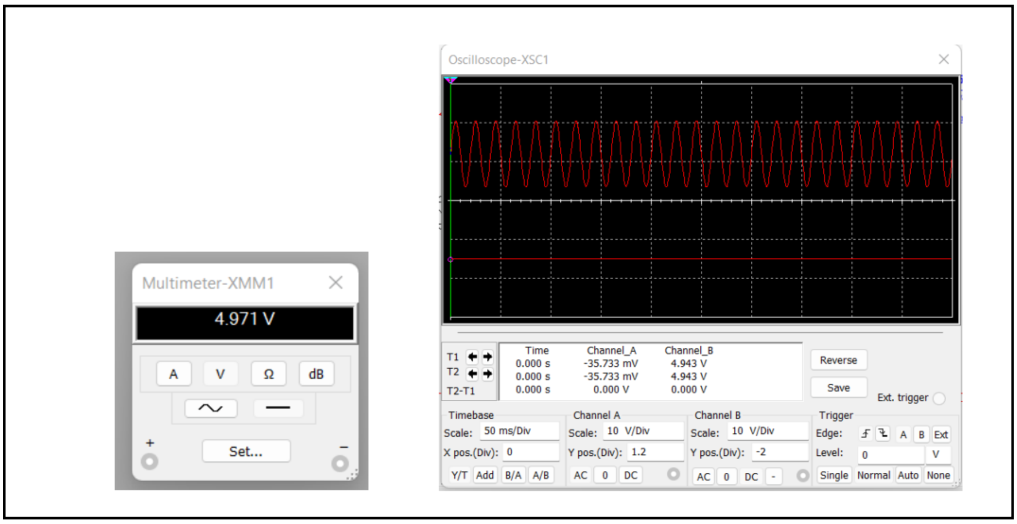

Figure 6: Output produced from the receiver circuit

The transmitter circuit can be said successfully designed for transferring power wirelessly because the output frequency obtained through the frequency counter is more than 100 kHz as can be seen from Figure 4 which is 187.076 kHz. One of the objectives for this project can be said successfully achieved which is to produce a high frequency at the transmitter circuit for wireless power transfer purposes. The waveform from Figure 4 that is observed through the oscilloscope shows two different waveforms where the top one is the input in DC and the bottom one is the output which is in AC. The oscillator circuit is the reason for the conversion from DC to AC. As can be seen from Figure 2, there are L1, R7 and C7 that are connected in series. This connection is known as a low-pass filter and it is to change the output and transforms the pulse wave into a sinusoidal waveform. So that the output voltage waveform observed from the oscilloscope is in the form of sinusoidal.

Based on Figure 5, they are two waveforms the top one is the input voltage which in AC and the bottom one is the output voltage in DC. The conversion from AC to DC is due to the rectifier circuit. As can be seen from Figure 5, the multimeter shows the value is 4.971V which is near 5V. Since the target output for this project is 5V DC, so it can be said the circuit for both transmitter and receiver circuits successfully achieves the objective which to produce a high frequency which is 187.076 kHz and outputting 5V in DC. Based on Table 2, it can be seen that the coefficient of coupling, self-inductance and magnetic flux between the transmitter coil and receiver coil decreases as the distance between the transmitter coil and receiver coil increases.

Table 2: Coupling Coefficient Data Obtained

Distance (cm)	CplCoef(Tx_1, Rx_1)	L(Tx_1,Rx_1) (uH)	MagFlux(Rx_1) (Wb)	MagFlux(Tx_1) (Wb)
2	0.274487	4.107860	0.000011	0.000083
4	0.095075	1.452366	0.000101	0.000069
6	0.035695	0.546286	0.000097	0.000065
8	0.013725	0.205757	0.000091	0.000063
10	0.004306	0.053668	0.000063	0.000063

Figure 7 shows the magnetic field profile between the transmitter coil and receiver coil for the selected distances.

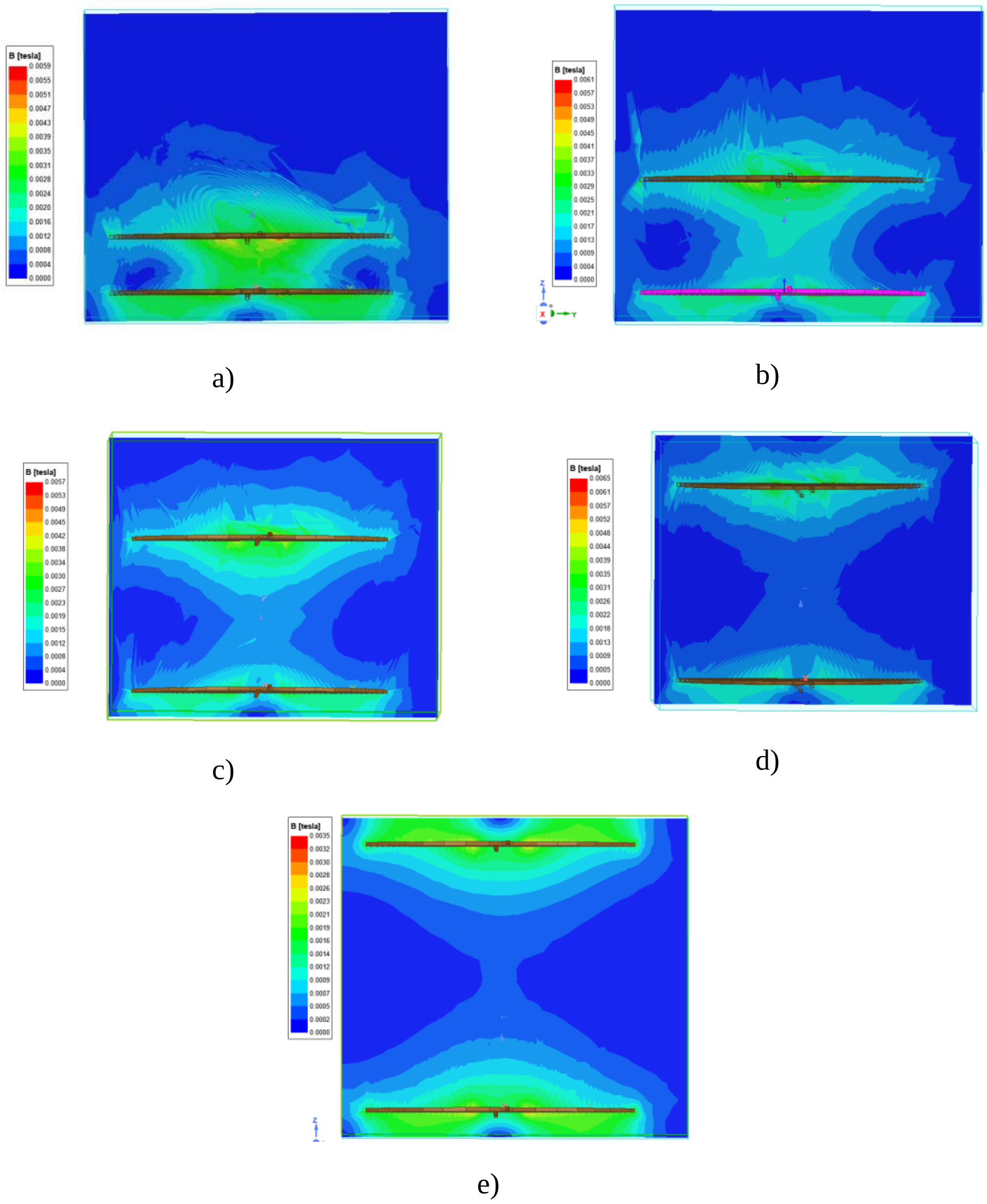

Figure 7: Magnetic field profile between two coils. a) air gap is 2 cm, b) air gap is 4 cm, c) air gap is 6 cm, d) air gap is 8 cm, e) air gap is 10 cm

ANSYS Maxwell is used to investigating the magnetic field strength and to obtain the coupling coefficient data. The magnetic field strength is tested with a different kind of distance between two coils where the selected distances are 2 cm, 4 cm, 6 cm, 8 cm and 10 cm. From Figure 7, the presence of a magnetic field and a coupling coefficient indicates that an inductive coupling between the transmitter and reception coils has occurred. The colours and areas of the magnetic field are used to evaluate the magnetic field created. It can be seen that when the distance is increases, the magnetic field strength between the two coils is reduced. Based on Bio-Savart’s law theory which is related to Eq. 5, when the distance separation distance between two coils is increased, magnetic flux density produced from the transmitter will be decreased. The magnetic flux of a coil is described as Eq. 6 based on Faraday's law of induction. Because the magnetic flux density created by the transmitter coil decreases as the distance between the coils increases, the magnetic flux that passes through the coils potentially decreases. Because the inductances of the coils reduce as the distance between them increases, the mutual inductance between them also decreases.

As a result of mutual inductance, the coupling coefficient decreased as the distance between coils increased. This reduces the fraction of magnetic flux produced by current in one coil when it is coupled to another coil and Bio-Savart's Law already stated about it based on Eq. 5. This indicates that when the distance between the coils (d) increases, the strength of the magnetic field between them weakens, lowering the magnetic flux density (B) between them.

4. Conclusion

In a conclusion, the design of a wireless charger for small-scale rechargeable batteries was successfully created. The wireless charger is a type of charger that can charge the battery without the help of a wire. The transmitter circuit consists of an oscillator circuit that is used to convert from DC to AC and produce a high frequency to the transmitter coil. The receiver then receives the power and signal from the transmitter coil via inductive coupling. The receiver consists of a rectifier circuit that converts again from AC to DC since the load is in DC. The voltage regulator in the receiver circuit helps to regulate 5V to the load. What can be concluded here is that the oscillator circuit that has been designed in the Ni Multisim software is fulfilling the project objective which is to produce more than 100 kHz frequency for power transfer purposes. The WPT performance also can be observed through ANSYS Maxwell simulation. The WPT performance decreased as the distance between the transmitter coil and receiver coil increased. The result from the simulation in ANSYS Maxwell has fulfilled the objective of this study and same as the theory about the WPT concept where if the distance between the receiver coil and transmitter coil is increased, the magnetic field is decreased. Some improvements are needed from this project to have a more functional system. A cut-off system can be added to the system to avoid the battery from being overcharged and getting damaged.

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