Wireless Power Transfer via Inductive Coupling

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***Abstract*—Various types of wireless power transfer method have been developed in recent years. This technology has eventually impacted the human life, especially the way they harvest the electrical energy resources. The most common and the first technology of wireless power created are known as inductive coupling method, which transfers power using magnetism process. This paper proposes the design of an oscillator that produces oscillation frequency at 1MHz for near-field wireless power transfer, and it is applicable for a short range wireless power transmission only. In conjunction to that, this paper also presents a design of the resonator of an antenna using copper wire in transmitting and receiving the energy transfer for short range transmission of wireless power transfer. The proposed design uses the concept of pad charger where the coil is designed from a pancake coil properties known as flat circular coil. The coil acts as an antenna and magnetic coupled or electromagnetic induced such that when there are changes of current occur in one coil, it will induce the voltage at the other end of the coil, in which the wireless power is transferred between the transmitter and the receive. It can be concluded in this proposed method has the ability to successfully transfer the power between the transmitter and the receiver, even when some obstacles are placed between the coil antennas. Then, a rectifier was used at the receiver to convert the alternating received current to the direct current. The received power is measured to observe the variations at several distances.**

***Index Terms*—Wireless Power Transfer; Inductive Coupling.**

I. Introduction

The technology of wireless communication has been created and evolved a long time ago to increase human productivity either in the work scope or others. Wireless communication technology is considered as the most demanded technology for every human in every population. Progress has been made in the wireless power transfer field, and this technology has attracted a lot of attention. Nowadays, many types of electronic equipment require continuous power supply; subsequently, it creates a demand for on-the-go rechargeable devices. Therefore, it is important to achieve the transfer of power over air gaps with high efficiency to meet this demand.

Many types of wireless technology have been developed and used and one of the related energies is the electromagnetic energy (EM), an energy that cannot be seen by human eye. However, these types of energy are scattered everywhere in our natural surrounding [1]. Some of the technologies that scatter EM waves are potentially dangerous for human population and vice versa, and they can be divided into radiative and non-radiative electromagnetic waves. The technology of wireless communication can be characterized by their transmission properties either near-filed region or far-field region. Besides, this type of frequency that involves in transmitting the power can be divided into two: the kHz-MHz or the MHz-GHz.

Research on the methods of transferring of power wirelessly using inductive coupling method have been conducted in 2006 and proven in 2007 [2]. However, this inductive coupling method can only cover short distance transmission since it uses near-field transmission and only cover for several kHz-MHz of transmission frequency. Inductive coupling method uses the coil as resonator or antenna for the transmission of the power wirelessly. Even though, the method of inductive coupling only covers short distance transmission, the transmission of the electromagnetic wave is safe to human population because it is in the field of non-radiative transmission.

There are many types of oscillator design for the wireless power transmission. The common type used for wireless power transmission via inductive coupling are Colpitts oscillator and Hartley oscillator. These two types of oscillator are functional to generate alternating current source from the direct current source supplied. Both of these oscillators are different in term of circuit design and properties. The frequency for Hartley oscillator covers only for small frequency, which is several kHz, but the Colpitts oscillator design can cover for several kHz up to few MHz [3]. This type of frequency will give a different output for both oscillator designs.

Resonator or antenna for transmission of power via magnetic field coupling is designed using a winding copper wire. This copper wire is characterized based on the American Wire Gauge (AWG) standard. These AWG standards differentiate the copper wire by their size in diameter. A large diameter is suitable to produce a flexible design that is easy to fabricate. These copper wires will be designed by a measurement based on the resonance frequency calculation. The lumped elements, specifically the resistors and capacitors will be added based on the type of resonator design, which is either LC or LCR resonator [4].

Another method proposed by S. Saat et al. focuses on a wireless power transfer using an acoustic based method [5]. The efficiency of power transmission has been tested at different transfer medium, which are the air and metal block. The maximum distance separation was reported at 10 cm and the system is capable in transferring about 0.96V wirelessly in air. The prototype of acoustic power transfer however failed to transfer power wirelessly due to the usage of unsuitable transducer.

This paper proposes to design a non-radiative wireless power transfer using a high resonance frequency of transmission. Thus, it also focuses on circuit design of oscillator to generate high frequency alternating current that can transfer the power between the gaps using inductive coupling method. The performance of the power transfer will be analyzed based on the power received and the distance of power transferred.

II. Methodology

A. NI MULTISIM Simulation

Before proceeding to the circuit design, NI Multisim is used to simulate the circuit design. Figure 1 shows the view of the sample in NI Multisim simulation.

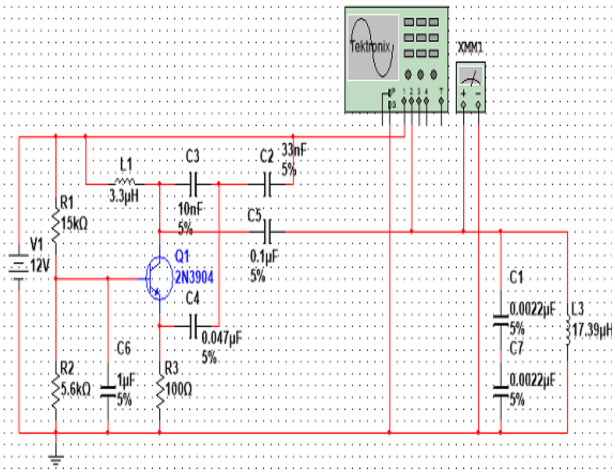

Figure1: NI Multisim simulation

The oscillator circuit on Figure 1 is designed to produce oscillation frequency at 1 MHz. This circuit has a simple design with only a few required components, which are the transistor, resistors and capacitors. The frequency of oscillation of the circuit is tuned by the LC tank, which consists of two capacitors and an inductor.

B. Design of Oscillator

Oscillator will be designed to generate the alternating current, which will be used to generate the magnetic field for the inductive coupling process [6].

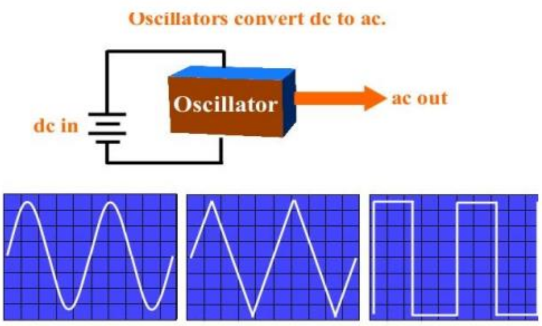

Figure 2: Some example of output waveforms

Figure 2 shows the type of generated output waveform that an oscillator can produce when a direct current voltage is supplied to the circuit.

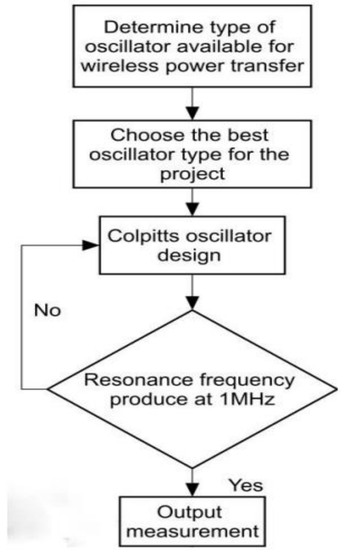

Figure 3: Flow chart of designing oscillator at frequency of 1MHz

Figure 3 shows the flow chart of the designed oscillator to generate the alternating current from the direct current that supplied the source at the frequency of 1MHz.

Table 1
The Lists of Components of Resonator and Value

Components	Value
Voltage source(DC)	12volt
Capacitor, C1	1uF
Capacitor, C2	33nF
Capacitor, C3	10nF
Capacitor, C4	47nF
Capacitor, C5	100nF
Resistor, R1	15kΩ
Resistor, R2	5.6kΩ
Resistor, R3	100Ω
Inductance, L1	3.3uH
Capacitor, C6	0.0022uF
Capacitor, C7	0.0022uF

Table 1 shows the components used to design the oscillator.

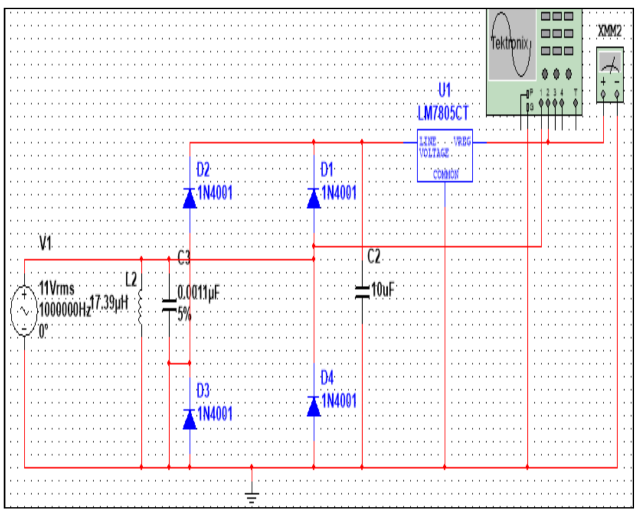

Figure 4: Receiver circuit design

Figure 4 shows the receiver of the project design. The receiver contains an arrangement of rectifier diode to form a full bridge rectifier. Meanwhile, the inductor and capacitor placed between the source and the rectifier are the components that act as transmitting antenna that will receive the power supplied from the transmitting antenna. The circuit has been tuned so that it can match the resonant frequency at 1MHz so that the power can be transferred successfully.

Before the circuit is fabricated into the PCB board, the design must be done using the Proteus software or any other software that have the PCB design features. The Proteus software has the combination of ISIS schematic and ARES PCB layout, which can be used to provide a good tool suite for any standard educational professional PCB design.

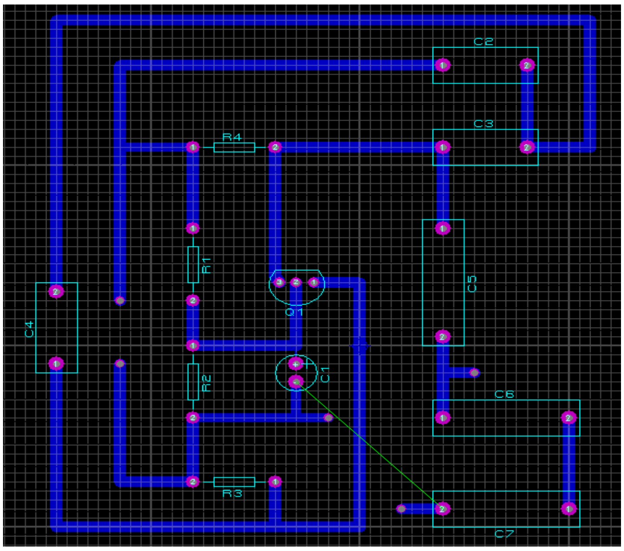

Figure 5: Gerber design of transmitter in ARES

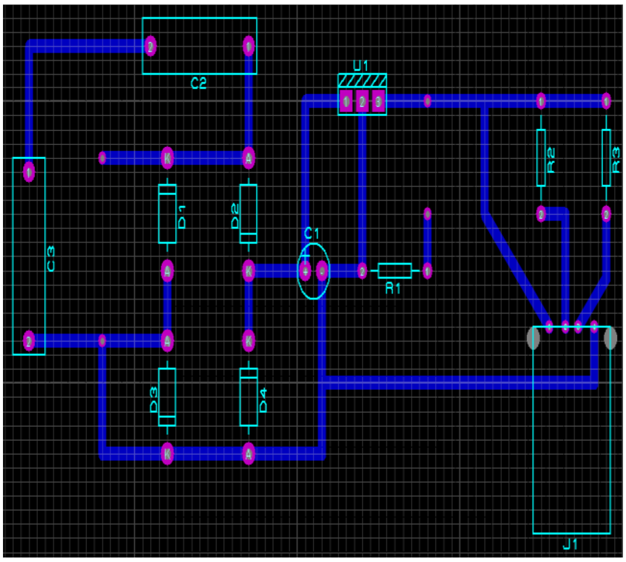

Figure 6: Gerber design of receiver in ARES

Figure 5 and Figure 6 above shows the complete design of the transmitter and the receiver in the ARES software. This exact design will then be printed to be fabricated on the PCB board.

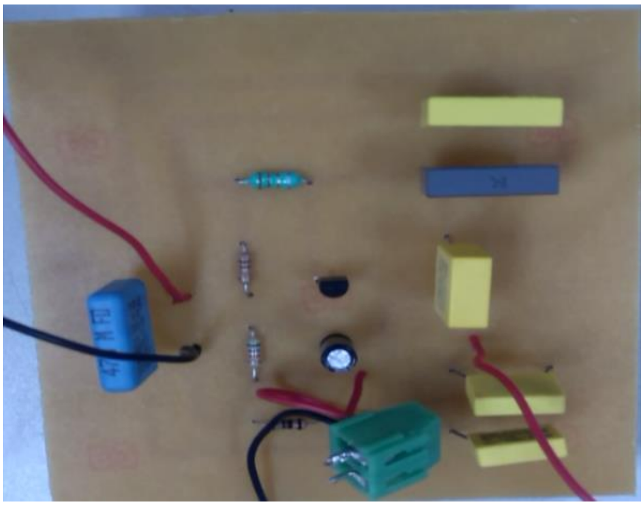

Figure 7: Completed transmitter circuit in the PCB

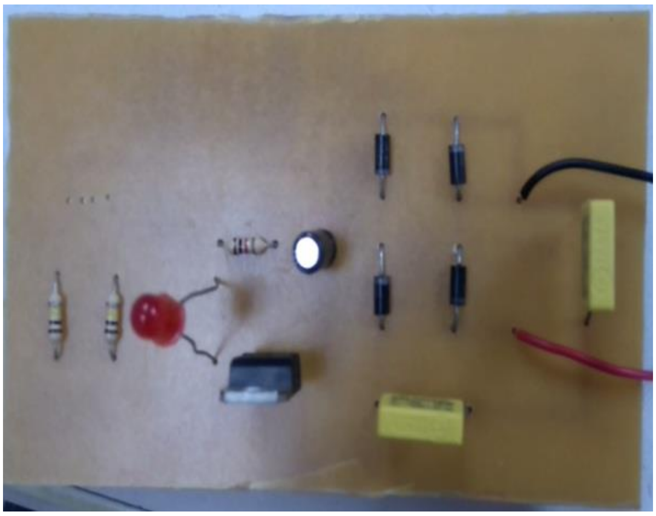

Figure 8: Completed receiver circuit in the PCB

Figure 7 and Figure 8 show the completed PCB board for the transmitter and the receiver.

C. *Design of Resonator*

There are many factors for choosing a suitable resonator design, such as the size, the cost and the ability to transmit the power wirelessly. Some of the resonator antennas that are commonly used are bifilar coil, pancake coil, and solenoid coil. After choosing the suitable design, the coil will be shaped and fabricated.

However, before producing the coil design for antenna, some calculations need to be done to calculate the inductance and resonance frequency matching. To produce the desired resonance frequency, the lumped element, which is the capacitor will be added to match it with the frequency of oscillation [7]. The inductance of the coil and resonance frequency will be determined based on the formula, as shown in Equation (1)-(3):

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$L = \frac{N^2 x A^2}{30A - 11D_1} \tag{2}$$

$$A = \frac{D_1 + N(W+S)}{2} \quad (3)$$

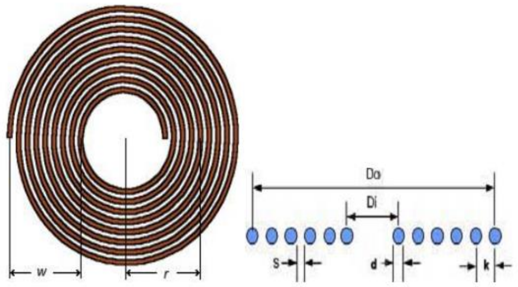

Figure 9: Design of coil at 1MHz

Table 2
The Dimensions of The Resonator

Dimension	Value
Inner diameter,Di	35 mm
Outer diameter,D_0	125 mm
Wire diameter,d	3 mm
Number of turn,N	15 turns
Inductance, L	17.39 uH
Capacitance,C	0.0011uf
Resonance frequency, f_0	1.151 MHz

Figure 10: Sample of washer placed at the center of the coil

Figure 10 shows a washer is placed at the centre of the coil to follow the measurement of the inner diameter of the coil.

Figure 11: Sample of fabricated coil in a closed perspex box

D. Voltage Measurement

The voltage is measured using oscilloscope and multimeter. This equipment is needed to verify the input and the output wave and to measure the input and output voltage of the system. The coil for the transmitter and the receiver is setup at several distances to analyze the wireless system that can be operational at several gap distances between the transmitter and receiver. The measurement of the voltage and current is done at both the transmitter and receiver and the result of the measurement is tabulated.

To ensure the wireless system works perfectly, the transmitter and receiver coil is then tested on the area in which the magnetic field can be induced. The same equipment, which is the oscilloscope is used to capture and verify the findings. The maximum distance of the gap is determined by testing the transmitter and receiver that are spaced apart from each other.

Figure 12: Minimum separation (when the two coils are in contact) and maximum distance separation between the transmitter and receiver when zero magnetic field is induced.

Figure 12 shows the minimum and maximum separation between the transmitter and the receiver without any material is placed between them (only air). The maximum separation is set when the output receiver does not produce a sinusoidal wave output anymore. This condition happens when the receiver cannot induce the magnetic field produced from the transmitter. The output produced from the tests above is then viewed on the oscilloscope.

E. Measurement Result

Table 3 shows the measured result from oscillator output. During the first testing process, only the circuit of oscillator is tested from 12 V up to 20 V of input voltage. It shows the output of 18.4V is produced on the oscillator which is sufficient enough for small electronic equipment application. However, as all the circuits are combined together, the output of the oscillator on transmitter shows a drop of voltage due to coil design properties. Table 4 shows the measurement result from the receiver output. The maximum distance separation of the transmitter and receiver is approximately 12 cm for the vertical distance separation. From the measurement of voltage and current, the power of the transmission can be calculated.

Figure 13 shows the graph of the output power versus the separation distance between the transmitter and the reciever. From figure 13, the maximum power received is 5.5 mW when the transmitter and receiver are close together with no separation between them. However, as the distance is increased, the power is reduced linearly until at the distance separation of 12 cm, which is the maximum distance separation between the transmitter and the receiver.

This shows that the power transmission is successfully achieved although with small output voltage. The final step testing is done at the output voltage of the power transfer.

Table 3
Oscillator Output

Output voltage (Volt)	Output current (Ampere)	Power (Watt)	Output voltage (V_{p-p})
6.5	0.3	1.95	18.40

Table 4
Receiver Output

Distance (cm)	Voltage (Volt)	Current (Ampere)	Power (milliwatt)
0	1.10	0.005	5.5
2	1.0	0.004	4
4	0.95	0.003	2.85
6	0.76	0.002	1.52
8	0.50	0.001	0.5
10	0.33	0.0005	0.165
12	0.15	0.0001	0.015

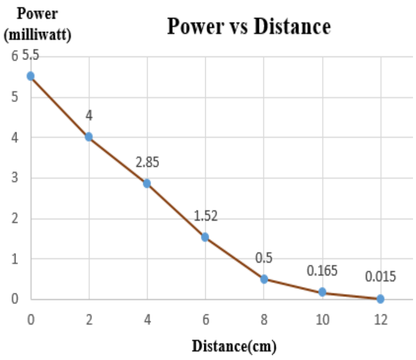

Figure 13: Graph of power versus distance

III. Conclusion

Based on the observation, it can be concluded that the analysis for theoretical and the simulation of the design of non-radiative or near field wireless power transfer system based on resonant frequency matching is operational. The analysis design shows that the method used in the design is capable of maintaining resonant condition. However, there are some improvements needs to be done on the resonator (transmitting and receiving antenna) design. First of all, the oscillator design must be the main thing to be considered in terms of frequency and output generation. The frequency of resonance depends on the type of oscillator. In the near field communication of wireless power transfer, it is more suitable to use low oscillating frequency due to the power lost during the conversion of the direct current to the alternating current in the oscillator. The frequency of transmission chosen must be based on the application of the system. So, for small electronic application, it is recommended to use low frequency because high frequency system might do some damage on the electronic equipment. Therefore, the suitable type of oscillator design that are recommended is the Hartley oscillator because the use of the components have less loss of power when generating the oscillating alternating current signal compared to the Colpitts oscillator, even though the Colpitts oscillator design is much simpler.

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