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Characteristic study for wireless Charging system

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Abstract—Power is an essential requirement in these modern lifestyles. Electronic gadgets like cell phones, laptops, etc., need the least power to charge. The utilization of Wireless Power Transmission (WPT) has been a hot issue among researchers these days. Nowadays, the application of wiring is becoming very inconvenient since everything cannot be used as there are some limitations and dangers. Therefore, several techniques have been found to carry out the wireless charging purpose in this study. The power transmission through the air is much easier to implement, more efficiently and persistently charged without the demand of connection physically. In this paper, a comparison between the three techniques for wireless power chargers has been determined. Among these three, it is found that the utilization of inductive coupling techniques is the best way to implement the system.

Keywords: *Wireless Power Transfer, Wireless charging, WPT*

1. INTRODUCTION

Recently, power has been a significant source in our everyday life. The usage of power that is required in every device like a phone, laptop, and other electronic gadgets has to be powered every minute. An individual is vigorously reliant on gadgets because of different intentions, including correspondence, web surfing, and enjoyment. These gadgets are reliant on batteries for their activity. The motivation behind these batteries is to store vitality and convert that putaway vitality into an electrical frame at whatever point is required. These days, the necessity of wiring installation has been very hassle, dangerous and sometimes impossible.

Wireless power transfer is beneficial and popular among the urban generation with flexibility, especially for gadgets that need frequent changing of batteries or needs cables for charging purposes. However, it is not practical to consistently acquire a plug point or even maintain the charger with oneself. Latterly, the evolution of the cordless charging mechanism is considered a transformation technology in the mobile world with the aid of many massive smartphone manufacturers involving Samsung and Apple.

There is a large market interested in this field as it is an easy, inexpensive and standardized resolution for consistently empowered devices. Therefore, it is helpful to classify these sciences in terms of their fundamental power exchange component to comprehend the significance of a range, adjustment, and effectiveness.

2. WIRELESS CHARGING TECHNOLOGIES

The consequence of wireless technology has been rooted in Nikola Tesla, who demonstrated lighting 200 bulbs apart 40km away through wireless power transmission [1]. A coil called resonant transformation or tesla coil has been formed, but its electrical field was dispersed. Although the experiment had little success, wireless power transfer was the most researched area in his time. Presently, electronic gadgets have been increasing as it uses batteries for their work. Without a battery, all these gadgets cannot be used since the heart requires frequent charging. A rectifier, filter, and cable of a certain length are the main component of ordinary charging which indirectly reduces the portability of the gadgets during the charging. Today, there are already implementations of wireless charging around the world. Fig. 1 illustrates a typical wireless power transfer system (WPTS).

The transmitter is fed by the input power and converted from AC to DC by rectification. Next, the DC voltage is converted back into AC with variable frequency. A high frequency is used in the transformer to increase the magnetic fields. The high frequency is delegated to the transmitter coil via a certain circuit based on the block

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diagram above. At a certain frequency level, the receiver coil receives this transmitted power. From here, the load is not directly be fed. After rectifying, the power is disposed to a voltage regulator that manages the voltage to avoid damage to the load. A connection between the receiver output and transmitter input is rooted in the needed level of power transmitted to the load. The transmission should be stopped via the controller, and else ways extreme supply of power will harm or affect the load.

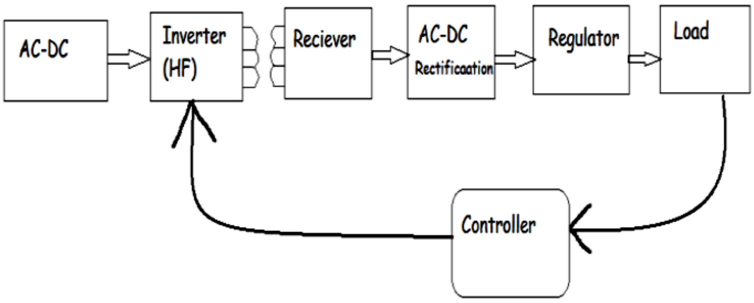

Fig. 1: Flow diagram for WPT [2]

Wireless technology generally can be divided into three techniques: magnetic inductive coupling that the most used; magnetic resonance coupling, which is moderately used; and non-directive RF radiation, which is relatively new in this area [2]. Radically, the magnetic inductive and magnetic resonance coupling acted on a short distance range where the propagated electromagnetic fields lead to the area near the transmitter or circulation object. The near-field power is dissipated based on the cube of the reciprocal of the charging length. In another way, microwave radiation should be used for the far-field because of the distance range. According to the square of the reciprocal charging length, the far field power will decline as the range of distance increases.

Additionally, the radiation penetration does not impact the transmitter using the far-field technique. Yet, the penetration of radiation affects the load on the transmitter. The reason is that the antenna of the transmitter and receivers are not coupled when using the far-field technique. Meanwhile, the transmitting and receiving coils are coupled for the near field [2].

2.1 Inductive coupling

Inductive coupling is when the magnetic field induction delivers the electrical energy between two coils. For example, inductive power transfer (IPT) produced during a primary transmitter's primary coil propagates a broadly changing magnetic field across the secondary coil of the receiver inward the field that is shorter than a wavelength. As shown in Fig. 3, the short distance magnetic power induces the voltage/current via the secondary coil of the receiver inward the field [2]. The secondary coil must be integrated at the operating frequency.

Many scholars have used this technique for research purposes. Many of them successfully use this technique to provide wireless charging for gadgets. According to a research paper [3], they proposed to charge a laptop that produces a voltage of 19.5V at 2.3A, using a single-ended primary inductor converter at the receiver to buck-boost the voltage and PI controller for controlling the output for variation in the distance within the transmitter and receiver coils. Respectively, the output gain is 20.7V at 2.5A [3].

Another study introduced a cognitive wireless charger (CWC) that can cope with the operating frequency in real-time using implicit response from detecting for optimal operation [4]. Subsequently, when the CWC is switched off, their prototype has a commensurable function to the Qi wireless charger. When the CWC is switched on, the prototype indicates a powerful improvement over modern wireless charging [4]. A self-alteration power transfer location wireless charging system has been proposed and demonstrated related functionalities of the desired wireless charging via the Bluetooth Low Energy (BLE) Module [5].

There are some favours of magnetic inductive coupling, including the easiness of implementation, adaptable operation, excellent performance at close distance and security. Thus, it is the most frequent technique used primarily for mobile gadgets.

2.2 Magnetic Resonance Coupling

Based on Fig. 3 above, an illustration of a working system for magnetic resonance coupling is shown as the electrical energy between two resonance coils by changing or oscillating magnetic fields generated and transferred by evanescent wave coupling [2]. Surprisingly, it is reported that MagMIMO had distinguished and cast greater energy for a phone even it is put inside the pocket. More presently, an innovation of wireless charging technology published by Massachusetts Institute of Technology (MIT) Scientist which successfully charged wireless gadgets maximize up to 30cm.

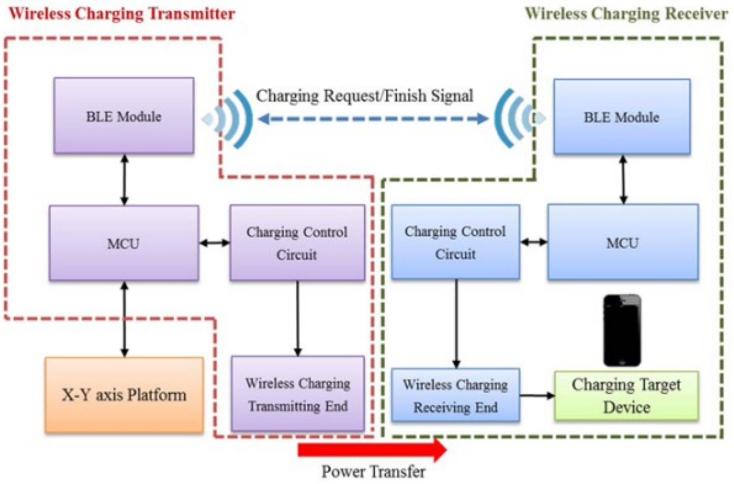

Fig. 2: BLE Module for WPT [5]

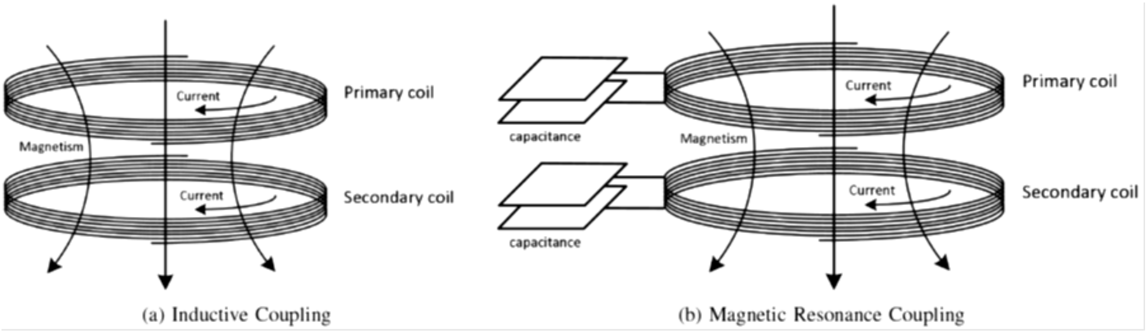

Fig. 3: Inductive coupling (a) and magnetic resonance coupling (b)

Besides this, another successful finding is the ability to charge a phone with more than 3W in a range of 5 to 15cm with varying angles, which are using a resonance frequency of 6MHz [6]. Moreover, the distance range between transmitter and receiver (phone) can maximize up to 20 cm for lower charging. It is beneficial to use this technique as it is simple, low-cost and provides a large area for both wireless charging, either handheld or on-table charging. A paper uses a microstrip to implement a radiator for transmitting and receiving at a frequency of 10MHz AC signals that detach each other in minimal space to gain the optimum coupling. As a result, the researcher demonstrates a 0.8mm distance of radiator the wireless power charging system with the capacity to supply 4.08V DC as the output of the receiver circuit that charges a phone battery. In contrast, the voltage at the transmitter circuit is equal to a 12Vpp AC signal.

It is found that implementing a repeater coil that is located at the transmitter active coil at the identical plane as the transmitter coil beyond a direct feeding can accommodate more power transfer efficiency, which is more than 10%, with a maximum spacing distance of about 300mm. Regarding this paper [7], the authors discover source-to-load inductive connection under resonance restriction for power transmission through contactless. They use two different load quantities: one load-loop and two load-loop. Magnetic reflected impedance plots with changing load and frequency restriction show a progression under resonance frequency identical to the power source [7].

One more study presented [8] a result with a maximum distance of 1.21m with a full design system consisting of a function generator, Class B power amplifier, transmitter helical coil, and rectangular planar receiver. The difference is that they are using transmitter and receiver similar to each other in terms of sizing and shape [8].

2.3 RF Radiation

RF radiation is defined as a diffusion of RF/microwave as an intermediate to carry beaming energy that is applied by the RF radiation. RF/microwave increases over the space at the speed of light, basically in line-of-sight with a common frequency range between 300MHz and 300GHz [2]. Therefore, the structure of the microwaves power transmission system is built for a far-field wireless charging system. In the latest research in a paper [9], researchers are using the Wi-charging approach that utilizes a laser as an optical source to charge wireless devices, but, unfortunately, this concept has a poor coverage zone and only works in indoor bounds.

Achmad Munir also agrees with this in his paper [10], which successfully gained an average efficiency of around 58% and a high frequency of 10MHz when the division between 2 stacked radiators is 0.8mm, where the radiator is constructed using the spiral shape of microstrip patch. Furthermore, an antiparallel resonant loop was designed in a paper. A reduction of magnetic field effectiveness of almost 6dB is gained and differentiated to a conventional loop at a calculated length maximum of 10m. Thus, a good improvement is achieved when using this technique with a variety of methods.

In conclusion, the best method to use is using Magnetic Resonance Coupling. It is because the optimal charge can be achieved as the system's architecture is not too complicated. Besides, it also has the advantage of being used at a range of distance far more than Magnetic Inductance Coupling, which is far field. The difference between these two techniques is electrical energy gained by the resonance coupling through a varying or oscillating magnetic field. Regarding the RF/microwave radiation, this technique was not yet well-known by many people as the efficiency was low because of the line of sight. Thus, radiation is not suitable for choosing as a good technique for wireless charging systems for gadgets.

3. ALGORITHMS FOR WIRELESS POWER TRANSFER

The theory of inductive coupling for wireless power transfer was based on Maxwell's equation. First, magnetic flux was produced by the current going through a conductor. Then the electric field is created by different magnetic fields. Thus, this electric field will accelerate the electric charge, and the current will produce. The circuit's geometrical shape, conductor structure, and permeability of the medium will define the inductor coil. Furthermore, the inductor of two coils is controlled by the range and relative structure of these coils. The coupling coefficient is defined as:

$$k = \frac{M}{\sqrt{L1\,L2}} \qquad 0 \le k \le 1 \tag{1}$$

This coefficient calculates the magnetic coupling of these coils and is self-reliant on the number of turns in these two coils. The phase shifts can be created because of these two elements, which are inductances and capacitances. The impedance equation determines the phase shift.

$$Z_l = j\omega L \tag{2}$$

$$Z_C = \frac{1}{j\omega C} \tag{3}$$

In the engineering and physics world, the Quality factor (Q-factor) is determined by a greatness parameter that defines an oscillator's aspect or another named a resonator. Q-factor is said to be higher if the greater amplitude. For an ideal circuit of RLC, Q-factor is defined as:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{4}$$

Where R is resistance, L is inductance, and C is capacitance, respectively. For a single layer inductance (air-core), Wheeler's formula is used to calculate the value of inductance as the formula:

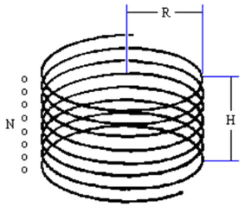

Fig. 4: Illustration of the coil

$$L = \frac{N^2R^2}{2.54(9R+10H)} \tag{5}$$

Were,

L = inductance (micro-Henry)
N = number of turns of copper wire
R = radius of the coil (cm)
H = height of the coil (cm)

4. SIMULATION USING PSPICE

In this project, a rough simulation of the circuit is conducted. Following is the schematic circuit of the simulation using PSPICE. During this process, simulations between inductance and resonance are conducted. RF radiation technique was not conducted as it needs a proper line of sight propagation. The inductance schematic circuit is shown in Fig 5.

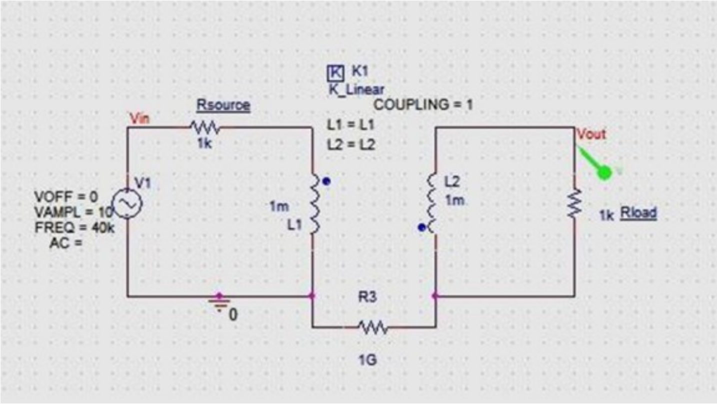

Fig. 5: Schematic diagram for Inductive Coupling circuit

Next, magnetic resonance coupling simulation was taken care of with different positions of capacitance was constructed to determine the variation of the data taken. The figures above show that 1G Ohm of resistance was structured. It is due to the simulation environment presenting reference and DC track to entire nodes. If the resistance is not implemented, the simulation will notice an error in the floating point. This resistance will effectively provide secondary inductance floating and give a DC track and a ground remark for the whole simulation.

The results of these simulations are included in section V. Here, the air gap separates the transmission unit and receiver unit to get complete power transfer without any obstacles.

5. RESULT EXPERIMENTAL

Fig. 6 shows the complete experimental setup used to verify the theoretical model based on the simulation result in the PSPICE. The transmitter part consists of an NPN3055 transistor and a 1kΩ resistor. The transistor is connected to the function generator to generate frequency accordingly. This transmission part is associated with the primary coil linked with the DC power supply of 9V. The enameled-copper wire produces magnetic propagation between the transmitter and receiver. The diameter of the enameled-copper wire used is 0.06mm. It was built with the air-core inside. The copper wire is winded side by side without overlap in 10cm diameter of cardboard. The part consists of a resistor of 10kΩ and 0.01µF of the capacitor at the receiver. This resistor and capacitor are connected in parallel along with the secondary coil. It can be seen that the transmitter and the receiver are not connected. They communicate with each other only in the wireless medium. The simulation result shows that magnetic is a better choice than inductive coupling. The power increases as the frequency also increase. Even though the outcome seems similar, if we change the parameter of the simulation, there will be slight differences in data corresponding to the frequency used, the number of turns, and the value of the capacitor. The prototype was built based on the simulation circuit of the inductive coupling method but using different values. Fig. 6 shows the complete setup of the prototype.

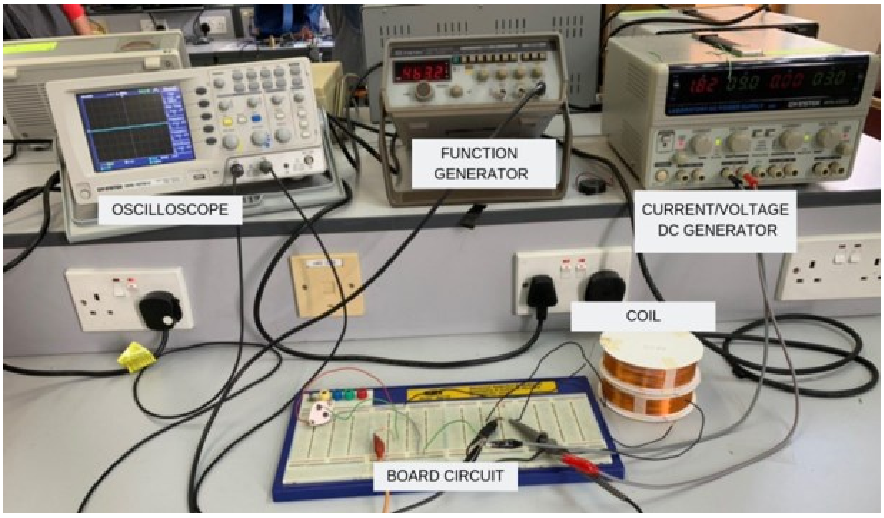

Fig. 6: Full setup of the prototype

The result of the project was taken first with a variation of frequency with the distance of zero between two coils. Then, the number of turns differs as a pair of 10 turns was created, also for 20 turns and 30 turns. The diameter of the coil is 10cm. The coil was set up and down, as shown in the figure, and the value of Voltage peak-peak was taken. The design parameters and inductance value are shown in Table 1.

Table 1: Parameters values

Coil	Resistor (kilo-Ohm)	Capacitor (micro-Farad)
Transmitter	1	-
Receiver	10	0.01

After the optimum value was reached, the voltage rapidly decreased with higher frequency. It is observed that 10 turns of coil need a higher frequency than 20 and 30 turns of coil to reach its optimum value. Besides that, the voltage value for 10 turns is less than the other two coils. However, it is slightly different for the 20 and 30 turns. Therefore, the optimum voltage value is almost the same with different frequencies. Next, the power received from the measured value of voltage is calculated by using the formula as follows:

$$P = \frac{V^2}{R} \tag{6}$$

Fig. 7 shows the power received at the receiver part according to the number of turns. As seen in the figure, the value of the power is at the highest when the value of the coil is 30, equal to 0.621W. When the number of turns is 20, the power is equal to 0.596 W and at 10 turns equal to 0.110W. It is proved that the power is directly proportional to the voltage. At a certain point, when it reaches the optimum value, the power value decreases with a higher frequency. This is because of the resonant frequency where the system oscillates with larger amplitude at several frequencies.

The experiment is varied with different capacitor values at the receiver part with 1.5nF Farad. Voltage peak-to-peak of 10, 20 and 30 turns are measured accordingly. Thus, the result of the power is calculated. As shown below are the result of the experiment. The power value of this experiment can be seen as a bit of bit low than the previous value of the capacitor. In this experiment, the maximum power that can be reached for 30 turns is equal to 0.292W, followed by 0.141W for 20 turns and 0.017W for 10 turns of the coil. The value of power decreases with the decreasing value of the capacitor. Thus, in other words, the power received depends on the value of the capacitor.

To determine the efficiency of the power received from this project is by changing the distance between the transmitter coil and the receiver coil. By separating these two coils (air gap), the ability to transfer power between the transmitter unit and receiver unit can be calculated. This experiment is conducted based on the optimum frequency value from the previous experiment. As the value of voltage decreases by the value of distance, only a few data can be collected for n =10. The value of L for n =10 is 1cm, 2cm for n = 20 and 3cm for n = 30.

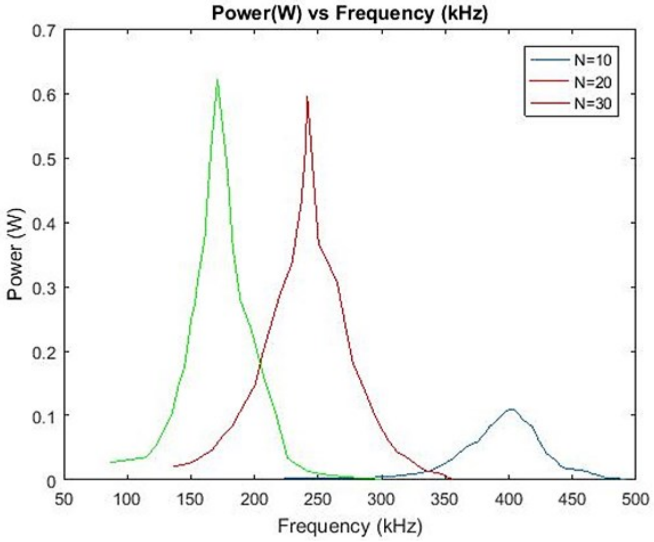

Fig. 7: Power versus frequency with different values of n

Here, the most challenging part of experimenting with is to fix the coil of the receiver part placed at a parallel distance. To get the value, we place a giant plate at the top of the coil and the ground so that we can vary by putting an object side by side near the coils. Based on the figures, 30 turns of a coil can transfer up to 2.304mW at a 13cm air gap. Therefore, power transfer for this experiment is horrible because of the only small amount of power that can be transferred. Therefore, the best solution for this inductive coupling is to put the transmit unit and receiver unit very close to each other to have a more efficient power transfer.

6. CONCLUSION

In conclusion, this project will bring future advancements in wireless power transfer technology for electronic gadgets. By using inductance and magnetic resonance coupling, wireless power transfer has their specialization according to the method used. The optimum value using inductance coupling had been measured and calculated. The inductance coupling method can achieve up to 0.621W in zero distance between the transmitter and receiver. However, the ability to transfer the power with an air gap is up to 13cm, and the power is only 2.304mW. Thus, it is not suitable for wireless power transfer along with distance.

The verification and simulation technique has been done for inductance and magnetic resonance coupling. However, only inductance coupling data is determined using an experimental hardware test.

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