Co-Plane Co-Axial Inductive Coils for Wireless Power Transfer

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***Abstract*—Many attempts have been exposed in designing energy-efficient and reliable wireless power transfer module at low frequency. This wireless power transfer technology is expected to modify the scenario of electrical power distribution for the consumer. A new concept of wireless power transfer coils is proposed to increase the output power capacity. This can be made possible by using coaxial inductive coils, just like a transformer. There will be less air gap in between the transmitter and the receiver coils. Hence, electromagnetic field loss by radiation and fringing effect can be reduced. The angular displacement between the inductive coils is kept to the minimum. In case of the distance between coils, the proposed design will reduce the distance up to 2 times. This design helps reduce magnetic flux waste and improve the electromagnetic energy transfer. Overall system performance and efficiency will be improved, compared to the inductive coils used in conventional wireless power transfer systems. Full 3-D simulations are performed to observe the performance in energy transfer of the proposed co-plane co-axial inductive coils, in terms of its the geometrical configuration.**

***Index Terms*—Wireless Power Transfer; Inductive Coils; Low-Frequency; Co-Axial; Co-Plane.**

I. INTRODUCTION

Wireless charging is a technology of transmitting power through an air gap to electrical devices for the purpose of energy replenishment. The transmitter and receiver electrodes form a capacitor, with the intervening space as the dielectric. Radio was developed for communication uses, but could not be used for power transmission due to the fact that the relatively low-frequency radio waves spread out in all directions and little energy reached the receiver [1].

The recent progress in wireless charging techniques and development of commercial products has provided a promising alternative way to address the energy bottleneck of conventionally portable battery-powered devices [2].

Wireless power transmission system is widely used as power transmission medium for most electronic devices instead of physical wires. The first attempt of producing wireless power transfer is done by Nikola Tesla well known as the Tesla Coil. Tesla demonstrates the transmission of electrical energy without wires during a lecture in 1891. In 1826, André-Marie Ampère developed Ampère's circuital law showing that electric current produces a magnetic field [3].

An alternating voltage generated by the transmitter applied to the transmitting plate, and the oscillating electric field induces an alternating potential on the receiver plate by electrostatic induction, which causes an alternating current to flow in the load circuit [4]. This set of partial differential equations forms the basis for modern electromagnetics, including the wireless transmission of electrical energy. For power transmission, efficient transmission required transmitters that could generate higher-frequency microwaves, which can be focused in narrow beams towards a receiver [5], [6].

Based on the previous studies, we can state that a low-frequency wireless power transfer can be a huge success by harvesting the findings. Nowadays, there are more studies about the wireless power transfer (WPT) for mobile charging, implantable biomedical devices, and other applications [7]. In this project, we propose a study on the coaxial system of inductive coils for wireless power transfer system, in order to determine the optimum configuration in terms of the physical configuration of the coils to achieve the best transmission. The expected output should be 200 – 220 Volts at 50 to 60 Hz [5], [8].

II. METHODOLOGY

Before the design process of these inductive coils is started, literature reviews on past researches regarding wireless power transfer are made. All the important aspects and knowledge about wireless power transfer, mutual coupling, and insulating layer are covered up before the design process [9], [10]. The source of knowledge and information that is essentials to idealize a “Co-Plane Co-Planar Inductive Coils for Wireless Power Transfer” is as follows [11] - [14].

A. Designing the inductive coils

There are a few variations of design in order to produce the less flux leakage, high inductance for each coil. These coils are designed based on the co-axial and co-plane manner whereas the receiver coils will be enclosed by the transmitter coils. A side view and 3-Dimensional view of the Co-Plane Co-Axial Inductive Coils for Wireless Power Transfer is shown in Figure 1 and Figure 2 respectively. The scale of this inductive coil design is quite small which is about 6 mm radius and 2.5cm height.

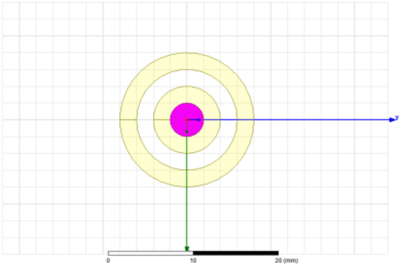

Figure 1: A side-view of the inductive coils.

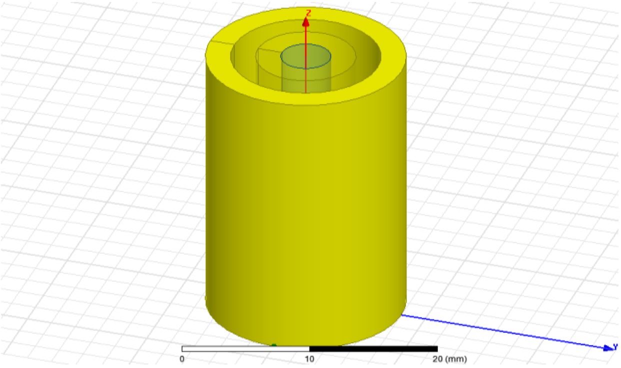

Figure 2: A 3D-view of the inductive coils.

B. Simulating the inductive coils

For simulation purposes a few parameters must be considered which is the radial distance between the two coils, the sliding value of receiver core, the material used for the coils and the magnitude of the current running through the transmitter coils [15], [16]. Each of this parameters affects the mutual coupling of the system as well as power transfer efficiency. A parametric sweep experiment is done to produce the desired outcome.

The process of simulating the parametric process involves a few settings that must be configured. The configuration includes how many passes and percentage error.

III. RESULTS AND DISCUSSIONS

As shown in Figure 3, the results of the experiment which produces a field overlay image of magnetic field's vector. The magnetic field is accumulated at the core. And based on the right-hand rule, the vector of the magnetic field is facing downwards as the current flows anti-clockwise [17], [18]. And the magnitude reading of the magnetic field is also higher at the center. In Figure 4, the XY plot shows the data gained from the experimental setup with parameter sweep. The parameter includes Z slide which is from 0mm to 25mm to study magnetic field output as the inner coils are moved as in Figure 5.

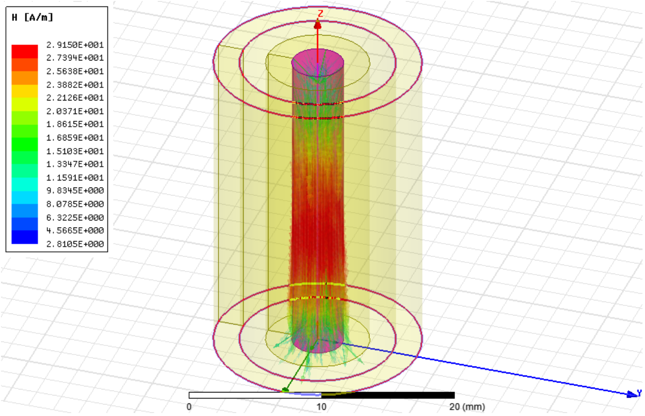

Figure 3: A 3D-view of the inductive coils.

A 3-dimensional plot for the magneto static setup is produced and shown in Figure 6. This plot shows the distribution of Inductance, L of this coils as the Z-Slide and radial distance differs. Inductance is a property of the coils which produce an electromotive force with the presence of current [19], [20]. Based on the plot, the inductance is almost at its peak as the radial distance increases, in other words, both of the transmitter and receiver coils are getting closer to each other.

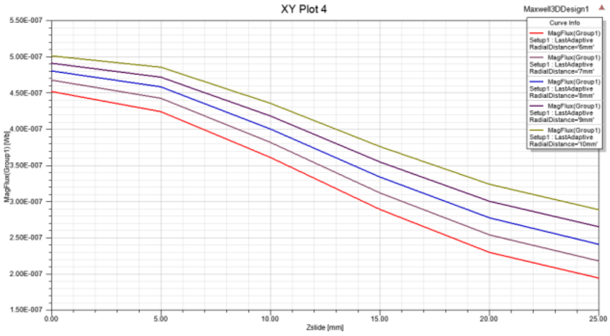

Figure 4: A Plot of Magnetic Flux against Z-slide parameter for specific Radial distances.

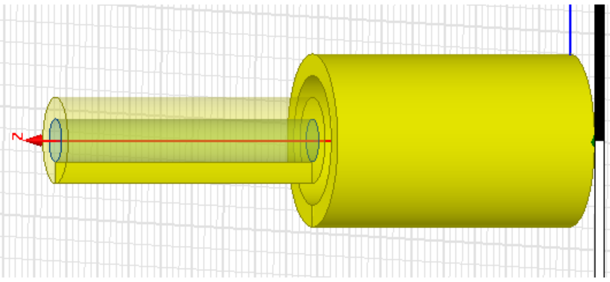

Figure 5: An image of inductive coils with maximum Z-slide

On the other side, the inductance is inversely proportional to the Z-slide parameter. About 1326 iterations of tests had been carried out to obtain the final value of the mutual inductance. Each parameter is tested using a different range of coils diameter and Z-slide and the average total inductance, flux linkage between two coils and the mutual coupling coefficient is obtained and shown in Table 1.

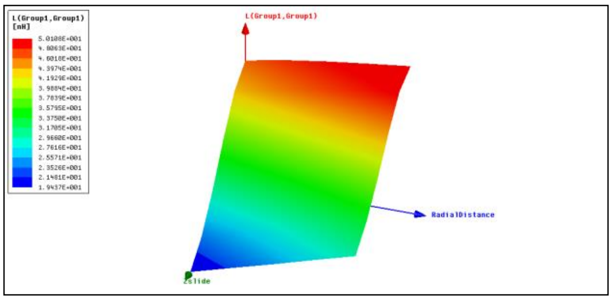

Figure 6: A 3-Dimensional plot for Inductance, Z-Slide and Radial Distance.

Table 1
A 3-Dimensional Plot for Inductance, Z-Slide and Radial Distance

Parameter	Value
Total Inductance	12.205 nH
Flux Linkage	1920 mx
Coupling Coefficient	0.8217

A prototype hardware system is produced in order to compare the findings with the simulation results. The output for receiver coils is tested using an oscilloscope and the value obtained is recorded. The schematic circuit and the result are tested using Mooshimeter and is provided in Figure 9. In this experiment, the VRMS reading shows a value of approximately 169 V.

To further increase these findings, another simulation are tested and the experiment is done in transient analysis. Transient analysis is analysis in time-domain and a set of data must be pre-configured to achieve nearly sine-wave initial graph. However, the system and can only configured with Vp-p and the datasets provide a triangle shape graph. This experimental setup is set to run-test the simulation in a 20 seconds time. A formula is used to simulate the induced voltage over time are as follows:

$$Vi = Vp + 25sin100\pi\ * t + 5 * Dp$$

$Vi =$ Voltage Induced
$Vp =$ Voltage Base
$t =$ Time
Dp= Data Period

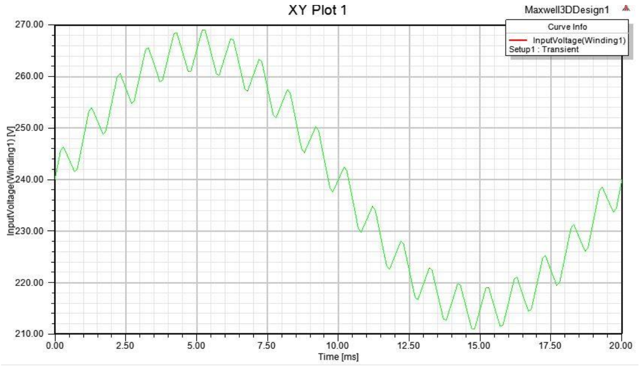

Figure 7: A Plot of induced voltage in the receiver coils.

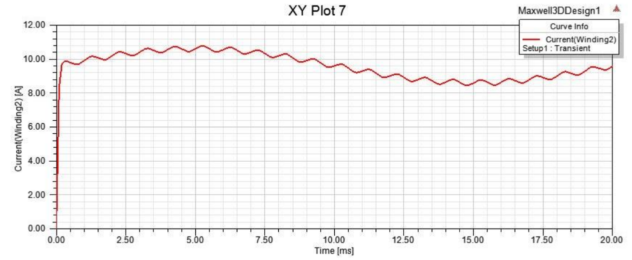

Figure 9: A plot of induced current in receiver coils.

After successfully analyzing the simulations, an XY plot of readings from each coil can be obtained. A plot of induced voltage and current in the receiver coils is shown in Figure 8 and Figure 9 respectively. The current produced by the system is about 10 A at 25k Ohm impedance. The value of Vrms obtained in the simulations is 190.91 which produce a total error of 11.47%.

IV. CONCLUSION

"Co-Plane Co-Axial Inductive Coils for Wireless Power Transfer" presents a modern and reliable configuration for wireless power transfer design. This project is capable of delivering higher power at maximum efficiency for a wireless power transfer system. Besides, this system can be applied to any high power electrical devices as power transfer medium which reduces any fatal injury regarding electrical safety as power can be transferred wirelessly and more efficient.

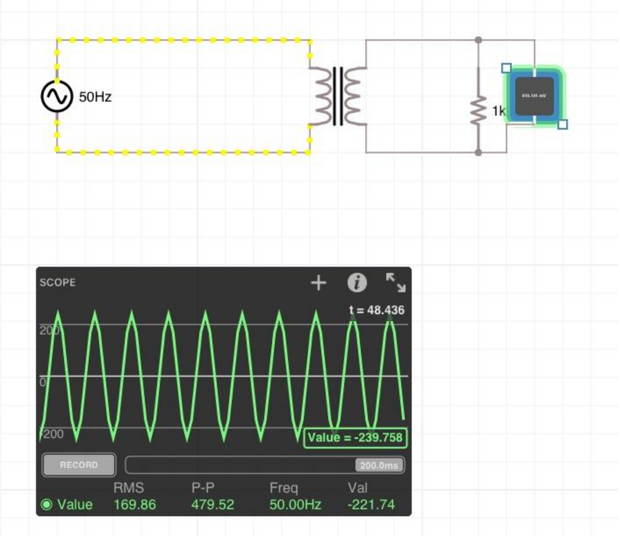

Figure 8: A schematic circuit design for this project.

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