# Wireless Power Transfer with Toroidal Inductor on Different Orientations

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***Abstract*—Wireless Power Transfer (WPT) may be understood as the conveyance of electrical power from one point to the other through emission of energy. It employs the use of electromagnetic field to transfer power from the source (transmitter) to the target (receiver) and the distances of the power transmission range from millimeters to several meters. The article presents experiments with different arrangements when placing the toroidal inductor at different angles relative to the central axis of the air core. The main purpose here is to measure the optimal voltage level for each case and determine the most optimal voltage and power level**

***Index Terms*—Wireless Power Transfer, Toroidal Inductor, Air-Core Inductor, Power Efficiency**

## I. Introduction

The concept of delivering energy via radio waves without a physical link between source and receiver was advocated a century ago [1], [2]. Wireless energy transfer research has yielded groundbreaking discoveries in a wide range of industries, including consumer electronics [3], automotive [4], and industrial control [5]. The basic principle behind WPT is the use of electromagnetic induction or magnetic resonance coupling to transfer energy wirelessly [6]. In a typical WPT system, the power source, known as the transmitter, generates an alternating electromagnetic field that induces a voltage in the receiver, which is then used to power the connected device [7]. WPT has been used in a variety of industries, including consumer electronics (phones, laptops, audio players, and tablets) [8]. Medical implant applications are used to diagnose and cure diseases in the human body [9]. WPT is also used in autonomous underwater vehicle (AUV) charging systems [10]. The wireless charging is identified as a great substitute of the wirings and batteries on many electrical devices [11]. Wirings supply enough power, but hinder mobility and have safety issues. Batteries on the other hand offer great mobility but are initially expensive and have a short span [12].

However, WPT also faces some challenges, such as efficiency losses [13], electromagnetic interference [12], and the need for precise alignment between the transmitter and receiver [14]. Ongoing research and development are aimed at addressing these challenges and expanding the range of applications for wireless power transfer [15]. In this work, our research focus is on finding the optimal voltage obtained by using a toroidal inductor connected to a rectifier circuit and a filter circuit that varies in many angles with the air core and according to environmental changes [16].

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## II. Materials and Methods

### A. Circuit Components

*1) Plasma ball:* The plasma ball is used as a signal transmitter [6]. The plasma ball is constructed in the following manner; it is a glass ball that is vacuum with a mixture of gas, which is in most cases Neon or Xenon [8]. The sphere also contains a central electrode most often a small Tesla coil that is used in the production of high frequency and high voltage, usually an AC current [5]. Considering the power transfer wirelessly, the sphere contains the power transfer through the electric field [7]. However, the energy sent out is very small and for the most part, instead of transmitting any usable electrical power, it is mainly used to ionize the gas and produce a display [4].

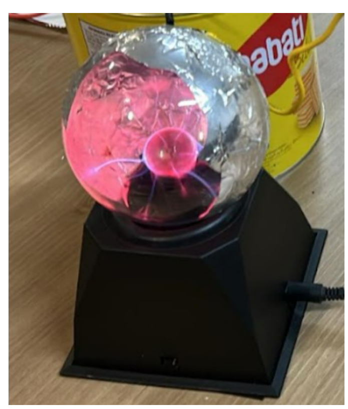

Fig. 1. Plasma ball

*2) Rectifier Circuit and Filter Circuit:* The filter circuit when combining LC components (inductors and capacitors) can have a resonant frequency, or in other words, the resonant circuit bar can capture the frequency of the emitted plasma ball [17]. In addition, filter circuits can also be used to remove noise components in electrical signals [10]. Noise here is understood as unwanted high-frequency signals generated by other devices in the circuit or from the external environment [11]. Components such as capacitors and inductors are used in circuits to block or reduce this noise, ensuring that the transmitted electrical signal is a clean signal [12]. In the rectifier circuit, the diodes conduct current to flow only in a single direction [13]. When AC current is applied, only positive half cycle will be allowed through the diodes but the negative half cycle will be blocked by the diodes [7]. Thus, the AC current when passing through the rectifier circuit will be converted to the DC current [9].

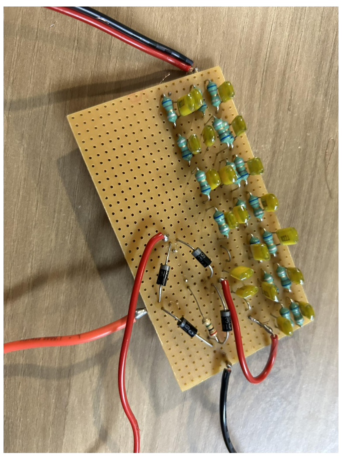

Fig. 2. Recitifier Circuit and Filter Circuit

*3) Air-core Inductor:* The air-core inductor is connected to the plasma ball air-core inductors used in creating the required magnetic field that interacts with the receiver coil [6]. This coupling allows the transfer of energy between two parts while only having them separated by an air or insulating gap [14]. Most types of wireless power transfer systems require air-core inductors as part of the transmitter and receiver coils [16]. When an A.C is applied to the coil, then it produces a pulsating magnetic field around the coil [15]. This magnetic field is very important in energy transmission without the use of a physical medium from the transmitter side to the toroidal inductor which is then linked to the receiver [4].

Fig. 3. Air-core Inductor

*4) Toroidal Inductor:* Another component in the receiver circuit is a toroidal inductor through which the magnetic field developed by the transmitter in the form of an electromagnetic field is availed and transformed into electrical power [10]. A toroidal inductor is made up of a tightly coiled wire which forms a core in the shape of a torus [14]. This core can be of any sort of material as ferrite, powdered iron or any other sort of magnetic material that is best suited for providing the desired magnetic flux concentration and transfer [6].

Fig. 4. Toroidal Inductor

### *B. Methodology and Implementation*

The experiment was conducted indoors under normal conditions, at a temperature of 27 degrees Celsius [15]. Control tests for the voltage sensor were interspersed with each experimental test to resolve sensor compensation errors and to ensure that the temperature is maintained approximately constant throughout the tests [14]. Initially, connect the components according to the circuit diagram provided [16]. Note that all results are measured using a voltage sensor connected to the Arduino to extract data and graph it in real-time [9].

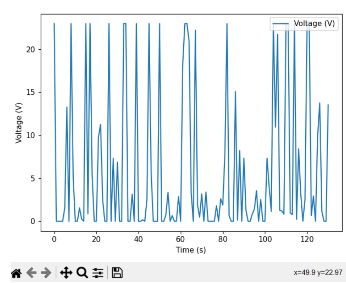


Fig. 5. The output voltage is displayed as an oscilloscope waveform.

As shown in the circuit diagram (Fig. 5), an air-core coil wire is connected so that the spark gap is within 1mm of the aluminum sheet surrounding the plasma ball acting as the transmitter, and a toroidal inductor is connected to the receiver [7]. The air-core coil has 80 turns of wire and the toroidal coil has 60 turns of wire, both placed about 30cm apart [4]. The experiment revolved around changing the angle of the axis through the toroidal inductor and the central axis of the air core inductor under normal conditions and when immersing the ground pin of the transmitter and receiver in normal water or salt water [15].

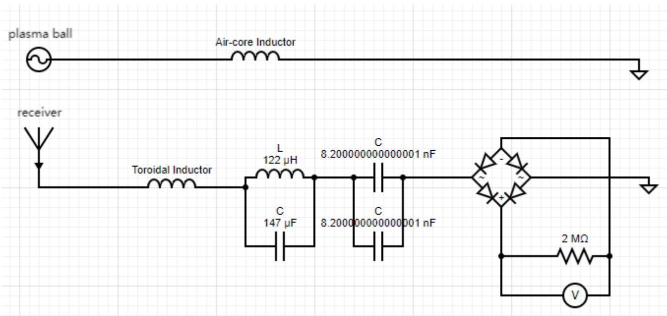


Fig. 6. Overall circuit schematic

### C. Circuit Diagram of 3 Angle Change Cases

The experiment of changing the angle of the toroidal inductor relative to the central axis of the air core coil is divided into three main cases:

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1) **0-Degree Angle**: They are wound concentric with the toroidal inductor being wound parallel to the axial plane of the air-core inductor. This setup is expected to give the maximum coupling efficiency because the alignment is best for magnetic field interaction [14].
2) **45-Degree Angle**: The toroidal inductor is rotated this way from the central axis of the air-core inductor, in this position which is 45 degree. This configuration checks the converter's performance consequent to a partial phase shift [14].
3) **90-Degree Angle**:The toroidal inductor lies perpendicular to the air core inductor's central axis. This angle characterizes the poor power coupling efficiency when the magnetic field interactions between the transmitter and the receiver windings are at the minimum

In each configuration, similar conditions are maintained to guarantee that all the observed effects cause by the configurations are as a result of the angle changes [6]. The voltage levels are recorded and analyzed to establish the effect of alignment on the power transfer efficiency for each case [17].

### D. Resonant frequency

The frequency range of the plasma ball varies from 20,000 Hz to 50,000 Hz and therefore the resonant circuit is tuned to these frequencies. The circuit is divided into 18 subcircuits, therefore a single subcircuit contains a capacitor C and an inductor L connected in parallel. Each subcircuit is connected with each other in series and in parallel fashion for the two

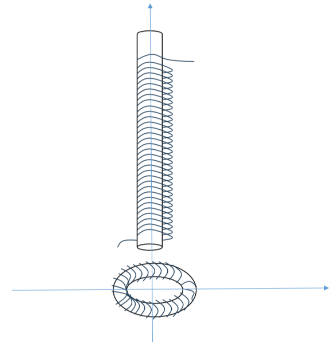

Fig. 7. 0 degree case diagram

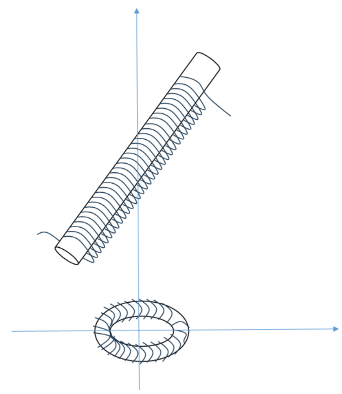

Fig. 8. 45 degree case diagram

capacitors. Employ the formula to determine the resonant frequency in the LC circuit.

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

Given that

$$C = 18.5 \times 8.2 \text{ uF}$$

$$L = 18 \times 6.8 \text{ uH}$$

Substitute the given values:

$$f = \frac{1}{2\pi\sqrt{(18.5 \times 8.2) \times (18 \times 6.8) \times 10^{-12}}} = 36.935\text{Hz}$$

## III. Results

### A. Measured Data

Experiments were conducted under various conditions to find the optimal circuit for the wireless power transmission system [12]. The output data obtained included voltage and current [15]. Therefore, the output power was calculated using the formula

$$P_{\text{out}} = \frac{V_{\text{out}}^2}{R_{\text{load}}} \tag{2}$$

where $V_{\text{out}}$ is the output voltage and $R_{\text{load}} = 2\text{M}\Omega$ [13].

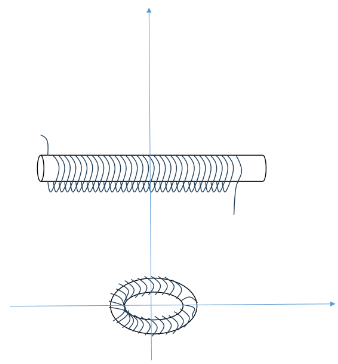

Fig. 9. 90 degree case diagram

### B. Average output power in different cases

The results in the table show the correlation in the angle of placement of toroidal coils with the wireless power transmission system [12]. It can be seen that the 0 degree angle case gives the highest power transmission, which is related to the change of magnetic field between the two coils [14]. The salt water plays a role in enhancing the transmission and the efficiency is improved [4]. For some special cases of 45 degrees, when the toroidal coil is parallel to the half bridge rectifier, the highest average power transmission is about 13.68uW. (Table I)

Another experiment was performed, this time a capacitor was connected in parallel with the load resistor to stabilize the DC output and improve the energy transmission efficiency. Then the data is collected and the average power is calculated in the table below. (Table II) To estimate the value of the capacitor, it is required to use formula for RC filter's cutoff frequency:

$$f_c = \frac{1}{2\pi RC}$$

Applying the formula:

$$C = \frac{1}{2\pi \cdot 2 \times 10^6 \cdot 36.9 \times 10^3} \approx 2.16 \times 10^{-12}\text{F} \approx 2.16\text{pF}$$

## IV. Discussion

The experimental results depict that the capacitance play a decisive role in the optimization of the wireless power transfer systems [12]. On comparing the two cases where a capacitor is connected and disconnected, it is clear that the inclusion of a capacitor enhances the steadiness and the output power within the system [15].

As for the 0-degree position, the output power is increase and it is 7.209 μW to 16.416μW. This could be due to the particular orientation and coupling of the air-core and toroidal inductors in this arrangement, implying that the capacitor's involvement could possibly be less profound in such a configuration. On the other hand, when the precursor was oriented at 45-degrees to the antenna plane, there was an enhancement in the output power from 5. 93 μW to 15. 277 μW with capacitors added, this shows an improved resonance and less energy dissipation [7].

The most significant enhancement was recorded in the configuration whereby the toroidal inductor was in parallel with only the half-bridge rectifier; the output power shot up from 11. 073 μW to 20. 415 μW for the model [17]. This implies that capacitor offers good filtering and regulating action, which enhances power quality and the power transmission efficiency [6].

Submerging the transmitter and receiver grounds in water and saltwater also affected the WPT system's performance [16]. In other cases, capacitors also stepped up the power produced and stressed the increase and improvement role of the system in relation to the different environmental changes.

In summary, evolution of capacitors not only controls the voltage in WPT systems but also minimizes losses for establishing effective power transmission especially for complicated systems [10].

## V. Conclusion

This paper has examined the effects of including capacitors in a WPT system with different orientations between toroidal inductors and an air-core inductor [7]. The outcomes revealed that capacitors are instrumental in the provisos of WPT systems' performance and steadiness improvement [18]. The researchers summarized that, in most cases, the use of capacitors enhanced the output power response of the system though the extent of this enhancement depends on the configuration of the system as well as the operating environment [19].

Power transfer efficiency increase was the greatest on the second configuration where the toroidal inductor was connected in parallel to the half bridge rectifier, this showcases the capacitors' ability to filter noise, and regulate voltage to the load [20]. Another factor, which may affect the WPT system, is the environmental condition for instance the immersion of transmitter and the receiver ground in water as well as salt water [21]. Capacitors helped increase power transformation efficiency, which we have considered as a changeable parameter [22].

Therefore, it can be stated that adding capacitors to WPT systems is useful for achieving high power rate, stabilization of voltage, and energy losses minimization. This study's first limitation is that it does not evaluate various capacitor values and configurations for WPT systems; future work can investigate other capacitances to improve WPT systems' efficiency [23].

**F**uture Work Cooperatively, in future studies, researchers should consider the various values of capacitors and its settings to assess and realize the power quality of WPT systems. Analytical research could be basically used to determine the best location and direction of capacitors that would help in achieving efficient power flow as well as minimizing on energy losses. At the same time, the effect of changes in different environmental parameters, including temperature and different types of conducting and non-conducting media, on the efficiency of WPT systems must be studied in detail [24]. The advancements in the capacitor materials and technologies can also offer new prospects of increasing WPT systems [25].

Moreover, incorporating high-level rectification and filtering solutions may enhance the efficacy of WPT systems depending on the efficacy of incorporated solutions. The application of smart capacitor networks whose properties depend on real-time system conditions, which could also be highly beneficial. Researching these fields might provide more effective systems of WPT, which will expand into other industries [26].

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TABLE I

AVERAGE VOLTAGE AND AVERAGE POWER IN WIRELESS POWER TRANSMISSION SYSTEMS IN MANY CASES

| Cases | Average Voltage (V) | Average Power (uW) |
|---|---|---|
| Degree 0 | 3.79719697 | 7.209 |
| Degree 45 | 3.444091 | 5.93 |
| Degree 45 with Toroidal Inductor parallel only Half-bridge Rectifier | 4.706044 | 11.073 |
| Degree 45 Resonance circuit parallel with Half bridge Rectifier | 4.043 | 8.172 |
| Degree 45 with Transmitter’s ground dipped Salt water | 3.940365 | 7.761 |
| Degree 45 with Transmitter’s ground dipped Saltwater and Receiver’s ground dipped into the water | 4.447536 | 9.887 |
| Degree 45 with Transmitter’s ground dipped water | 3.212197 | 5.158 |
| Degree 45 with Transmitter’s ground dipped water and Receiver’s ground dipped into salt water | 4.70811 | 11.082 |
| Degree 90 | 2.88781 | 4.167 |

TABLE II

AVERAGE VOLTAGE AND AVERAGE POWER AFTER ADDING ELECTROLYTIC CAPACITOR

| Cases | Average Power (uW) |
|---|---|
| Degree 0 | 16.416 |
| Degree 45 | 15.277 |
| Degree 45 with Toroidal Inductor parallel only Half-bridge Rectifier | 20.41567 |
| Degree 45 Resonance circuit parallel with Half bridge Rectifier | 17.27308 |
| Degree 45 with Transmitter’s ground dipped Salt water | 17.761 |
| Degree 45 with Transmitter’s ground dipped Saltwater and Receiver’s ground dipped into the water | 18.7994 |
| Degree 45 with Transmitter’s ground dipped water | 14.5906 |
| Degree 45 with Transmitter’s ground dipped water and Receiver’s ground dipped into salt water | 19.86293 |
| Degree 90 | 13.7086 |