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Wireless Power Transfer Device Based on RF Energy Circuit and Transformer Coupling Procedure

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Abstract

It is possible to transmit electricity wirelessly without the need for cables. Wireless power transmission makes it possible to link remote places that would otherwise be cut off from access to reliable electricity. A wireless connection to the power supply is expected in the future. This study describes the experimental results of Wireless Power Transfer (WPT) utilizing a transformer coupling approach and its future potential. This WPT device (WPTD) is used to transmit power using two procedures of energy transfer: radiofrequency coupling and transformer coupling, both of which are magnetic based, in principle. The distance between the transmitter and receiver of the system affects the amount of power that can be sent. Research is performed to establish how far apart the system's transmitter and receiver should be. Magnetic fields may transmit energy between two coils, but the distance between the two coils must be too close for this approach to work. Aside from that, it assesses the setting parameter of a value that has been tabulated using a certain application, in the findings and discussion parts.

Keywords: Wireless power transfer, transformer coupling technique, induction concept, mutual inductance, self-inductance, radio frequency antenna

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1. Introduction and Background

Without using wires or cables, wireless communication involves the transfer of energy across a distance; this distance might be small or long. Services like long-distance communications are possible because of wireless operations, but wired operations are just infeasible. When a power source is connected to an electrical load without the need for wires, it is known as wireless energy transfer or wireless power transmission [1-5].

The problem of having too many cables competing for a finite number of power outlets has given rise to the concept of wireless power transmission. The shortage of plugs for electrical gadgets is a common problem, and assumably many individuals share this experience. In order to reduce the clutter of cables surrounding power plugs, a wireless power transmission system might be used. The wireless power transfer technology is at the forefront of technological innovation. Recent successes with WPT have been in microwaves, solar cells, lasers, and electromagnetic resonance [6-8]. The primary purpose of wireless power transmission is to enable the continuous charging of electrical equipment without the need for a power connection. Figure 1 shows the block diagram of inductive concepts for power generation.

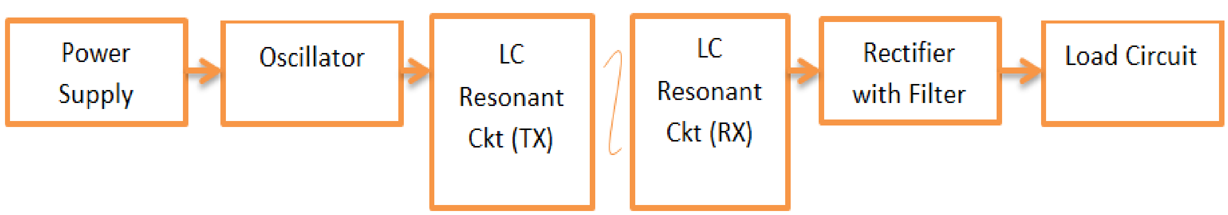

Figure 1. Inductive concepts for power generation

Throughout the globe, wires are used to transport electricity from power plants to end users' residences and workplaces. Wires and batteries may no longer be necessary due to wireless power transfer technologies. If connecting cables is difficult, dangerous, or impossible, the wireless

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transmission may be used to power electrical equipment [9 -12]. It is possible to transmit electricity wirelessly, which eliminates the need for wires composed of copper and aluminium metal. Near-field or non-radiative approaches use inductive coupling between coils of wire power, or capacitive coupling between metal electrodes, to transmit magnetic or electric fields across small distances [13, 14]. To employ inductive coupling for wireless technology, products like electric toothbrushes and RFID tags, as well as chargers for implanted medical devices like pacemakers or electric automobiles, are included [15].

1.1 MEMS semiconductor

Power microelectromechanical systems (MEMS) are one of the most prominent energy harvesters. Rectennas, which may be used for both MPT and WPT, capture energy from broadcast radio waves. The application of resonant coupling by MIT [19] in 2006 is another recent development in WPT. As a microwave filter, the resonant coupler is well-known [16].

1.2 Background

In 1904, an airship ship motor of 0.1 horsepower was powered by sending power via the air at 2.45 GHz, the frequency band reserved for ISM applications. Brown published the first paper proposing microwave energy for power transmission in 1961. In 1964, he demonstrated a microwave-powered model helicopter that received all of its power from this frequency band reserved for industrial applications [17 -21].

In 1975, at Goldstone in California, and in 1997, in Grand Basin on Reunion Island, power transmission experiments without cables were conducted. Microwave Ionosphere Non-Linear Interaction rocket experiment was demonstrated in Japan in 1983, the first MPT experiment in the ionosphere. In 1987, in Canada, the world's first fuel-free airplane has been propelled by

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microwave radiation from the ground [22- 25]. Figure 2 shows the simplified block diagram of WPT.

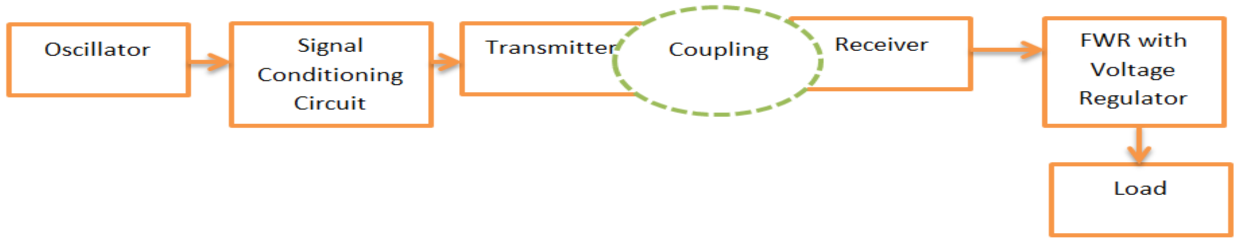

Figure 2. Simplified block diagram for WPT

The transmission and allocation of electrical power is a fundamental problem in power systems. Power production and loss are increasing in tandem with the sharp rise in demand. At some point in between generation and distribution, 26 percent is lost. Transmission and distribution losses are mostly due to the resistance of the cables used in the grid. Using high-strength composite overhead conductors and subterranean cables with high-temperature superconductors, may increase power transmission to a certain extent. This inefficiency persists regardless of the communication method [26].

According to World Resources Institute data, around 27 percent of India's electrical system is lost in transmission and distribution. According to several Indian government organizations, the percentage might be as high as 30%, 40%, or even more than 40%. Technical losses (the grid's inefficiency) and theft are to be blamed [27].

In addition to being bare, the voltage is below transmission, making it only suitable for 240 V equipment. It appears that, stealing only happens at the transmission level. There are a little energy audits by most state utilities. Villages are being served by long, low-tension lines that have been widely publicised by the government. Because the legal structure guarantees a 16 percent return on investment for power companies in the distribution industry, the majority of the losses

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are passed on to consumers via an increase in the price. The rate is never set by the electricity firms, but rather by the regulator. Transporting energy from low to high in value via wired power or energy transfer can be done effortlessly. If the energy transmission can take place without the usage of wires, then it may be quite beneficial. A wide range of ideas are used in the area of wireless data transmission. It is also important to note that energy transfer is the primary criterion for long-distance transmissions. Applied electromagnetics, RF and microwave electronics, and material science and nanotechnology, contribute to WPT, which is a fascinating and complex discipline [28].

1.3 Structure of the article

The remainder of the paper is organized as follows: Section 2 discusses the suggested approach for wireless power transfer using transformer devices; Section 3 discusses the results of the study. Experimental testing is also covered in detail in Section 3. The conclusion of the article, as well as the article's future mission, is discussed in the last part.

2. Proposed Framework

2.1 Wireless Power Transfer Device (WPTD)

To assess the feasibility of a WPTD circuit, a prototype system is built using the mathematical modelling and simulation research approach [26]. The WPTD prototype's behaviour may be simulated and mathematical equations applied before practical implementation, testing, and deployment can take place. This is the first circuit-level prototype to be built.

2.2 Accessories for WPTD

When designing an energy harvesting circuit, the factors to be taken into consideration are distance, antenna type, and energy collecting capacity. The copper wire's resistance and

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conductivity are factors in the design of the circuit. The WPT device prototype circuit's quality factor is shown using the appropriate formulas. The radio frequency power generation system that used to produce the energy through resonant circuit (LC) with megahertz range of antenna while designing the system is considered.

2.3 Working methods

Inductive coil design (including loop diameter, wire diameter), transmission distance, and coupling, all had an effect on the wireless power system's efficiency. A system that is less efficient will produce more emissions and provide less power to the receiver or output load. For the WPTD system, the prototype used a radiofrequency energy harvesting circuit that has already been examined in a slew of academic papers.

2.3.1 Power production circuit

The radio frequency power generation circuit is used to convert the incoming RF impulses into electrical power [21]. As an input load, the WPTD system uses electrical power that has been transformed by a power management system. The receiver section is connected to an oscillator circuit which is used to generate the signal (energy) [24]. Accumulated power amplifier, known as the load for the rectifier's conversion, is transferred to storage capacitors via the receiving coil. To charge a miniaturized electronic device, the voltage regulator wirelessly delivers the appropriate DC power via the battery.

2.3.2 Receiver circuit

The resistance and conductance of the wounded coil is used to measure their mutual, self-inductance for flux linkages of receiver side current flow. The full wave rectifier is used to rectify the AC signal to DC through several diode components for the RF based power generation. The RF power generated collecting circuit and the wireless power transfer circuit are separated as

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shown in the block diagram. With an antenna frequency range of up to megahertz and a ground connection consisting of an 8-foot straight copper wire tied to an 8-foot metal pole embedded in the ground [24], the RF based power collection circuit is constructed with the help of megahertz range antenna. The output has been calculated for finding the efficiency of the system.

2.3.3 Transmitter circuit

With a single transistor oscillator, a rectifier to change from alternating current into direct current [23, 24], and a capacitor for smoothing the DC output after rectification as well as for storage of the converted voltage, this circuit is complete. To convert from AC to DC, a bridge rectifier is coupled to the receiving coil and used. The voltage regulator is responsible for ensuring that the voltage supplied to the load is consistent. In order to keep the load at a constant voltage during charging, a voltage regulator is added. However, if this component is removed, the WPTD circuit will still work well.

2.3.4 Circuit parameter

When applying Equation to the WPTD circuit, it is necessary to take into account the mutual inductance of the individual coils.

$$\boldsymbol{M = k\sqrt{L_1 L_2}}$$

The L1&2 are inductance of the coil in primary and secondary. It is possible to compute the total inductance L by applying the following equation.

$$L = \frac{(no.\, of\ turns\ in\ coil)^2 * Permeability\ of\ free\ space * cross\ sectional\ area\ of\ coil}{length\ of\ the\ coil}$$

The coupling coefficient, denoted by the letter k, may be derived as follows.

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$$k = \frac{M}{\sqrt{L_1 L_2}}$$

When the dependent voltage sources are used, they may replace the coupling that exists between two circuits. This equation may be used to compute the current that flows through the secondary coil:

$$Current\ flow\ on\ the\ coil = \frac{dependent\ voltage\ of\ the\ secondary\ coil * primary\ current\ flow}{reflective\ impedance\ of\ the\ coil}$$

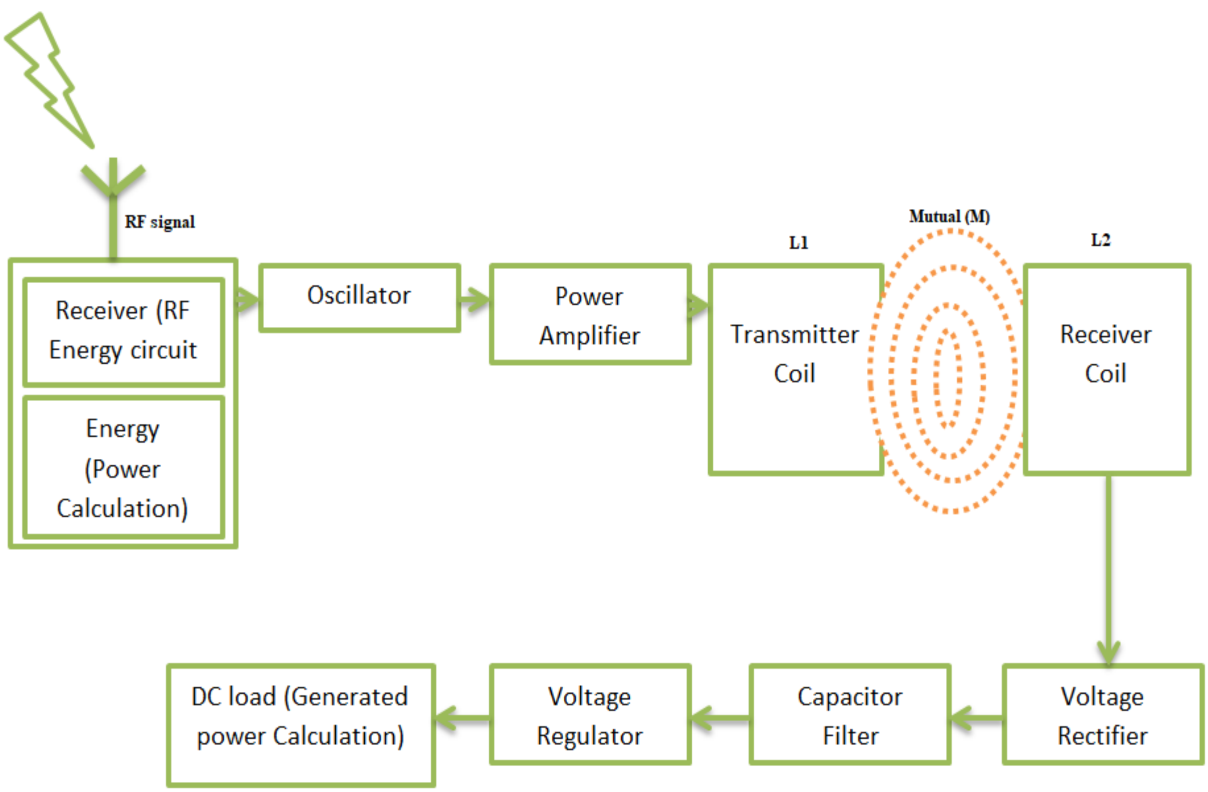

Figure 3. Block diagram of proposed framework for WPTD

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3. Results and Discussion

Electrical components that interact with magnetic fields use the mutual inductance shown in Figure 3 as their working principle. Each component of the main coil interacts with each component of the secondary (receiver) coil in this episode. The copper magnetic wire is used in the prototype WPTD circuit because a better-quality coil is more efficient in terms of power transmission than a lower grade with a greater inductance value. The charging process is started by applying +5V to the regulating component in the circuit, which regulates the necessary varying voltage to the constant input needed devices such as mobile phone battery.

Table 1. Experimental results computation

Distance between Primary and Secondary	Coil diameter (mm)	Loop diameter (mm)	Inductance	Receiving Power Calculation (RF antenna)	Power Generation at Load
2 cm	0.5	60	$1.70*10^{-13}$	2.5mW	1.79mW
4 cm	**0.5**	**60**	**$1.70*10^{-13}$**	**2.5mW**	**3mW**
8 cm	0.5	60	$1.70*10^{-13}$	2.5mW	0.8mW
10 cm	0.5	60	$1.70*10^{-13}$	2.5mW	0.23mW
20 cm	0.5	60	$1.70*10^{-13}$	2.5mW	0.002mW

Figure 4 shows a very short distance between Tx and Rx. Due to more leakage in flux linkages, power will be lesser than the optimum distance between the coil.

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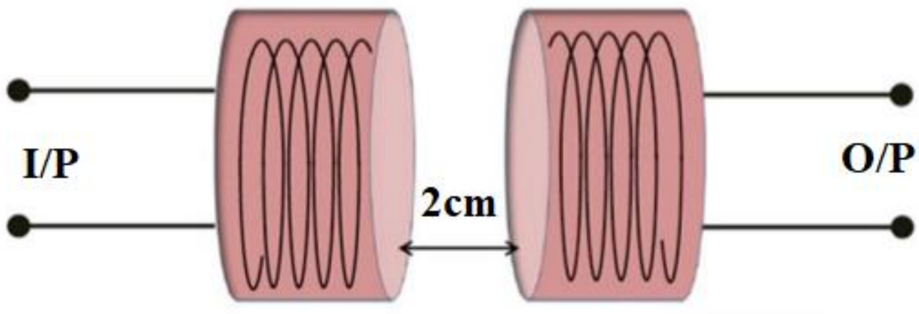
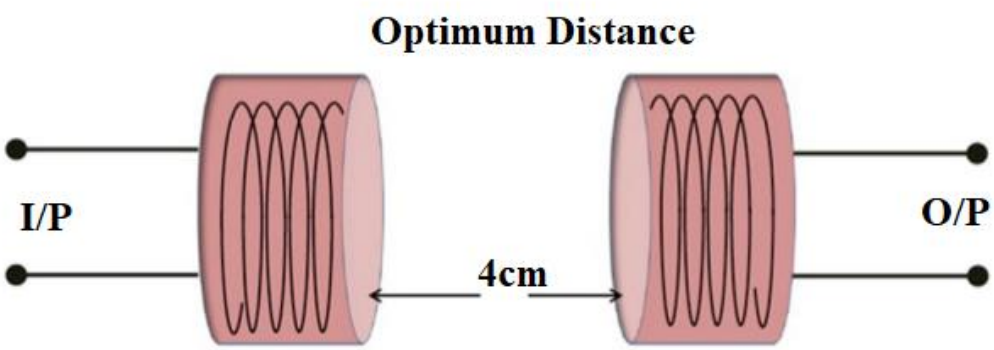
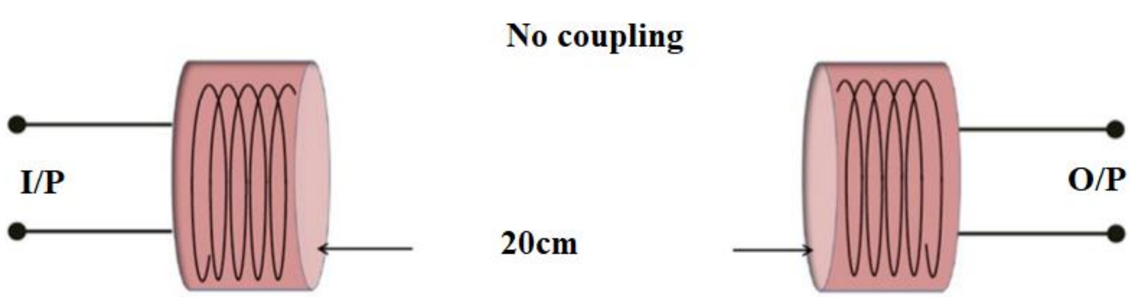


(a)



(b)



(c)

Figure 4. Experimental distance measured by Tx and Rx inductance in the proposed work [29]

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A voltage regulator's job is to bring the voltages back to a more typical range. But this optimum distance measure provides efficient power generation in the experimental setup which is shown in Figure 4 b. Moreover, the long-distance 20cm provides very little power in the load circuit which is shown in Figure 4c. Table 1 contains all computed values. It shows the maximum distance, no flux linkage and almost zero power. It is plotted in the graph shown in Figure 5.

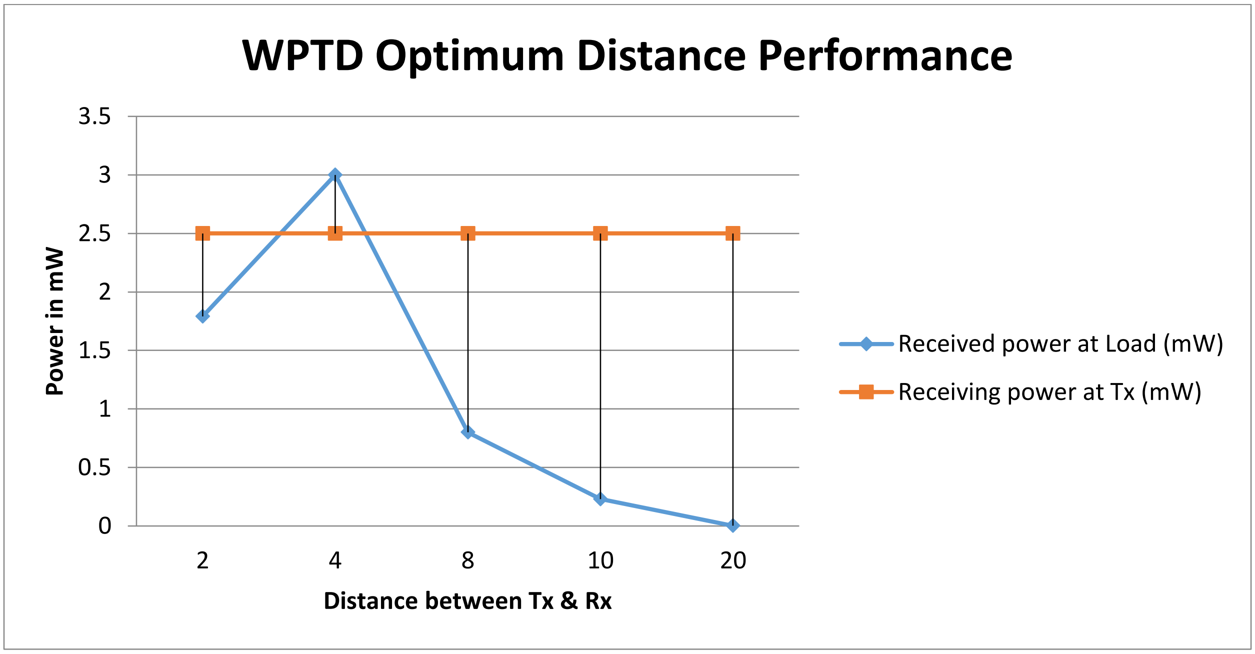

Figure 5. Performance graph of power generation at load circuit and receiver circuit

The regulator lowers down the voltage to what is expected and maintains that level throughout the supply period. A load is not applied; hence the voltage will not decrease by the use of this technique. After rectification from alternating component to direct, an extra capacitor containing the stored charge is attached to the WPTD charging circuit or load circuit. A mobile device's battery (example) may be charged wirelessly even if there is a loss of voltage due to the air gap. Based on the findings of this study report, it is inferred that wireless power transfer (WPT)

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devices can be used to recharge mobile devices' batteries. Mobile device battery charging is more efficient when harvesting energy is at its highest level.

4. Conclusion

Using magnetic resonance coupling with RF energy harvesting, wireless charging of any DC load such as mobile phone charger etc is a potential invention. The power generated at a 4cm distance is more than that generated over other lengths. This study paper finds that the best power production is limited to 3mW for this specific experimental setup with 4cm distance coils, which is consistent with previous findings. The 4 cm coil spacing between the transmitter and receiver coils of the WPTD is the ideal distance between the transmitter and receiver coils. Green energy sources and self-sustaining mobile gadgets might be promoted by this meaning. Only few studies have looked at using both technology such as RF and inductive based power generation. In the future, to maximize solar energy harvesting in orbit, a spacecraft with a solar panel may be used. Power is converted to microwaves and sent via the satellite through the microwave transmitter. The satellite in orbit sends out microwaves, which are picked up by a receiving antenna on the ground and converted to power. It may then be utilized in houses and businesses.

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