Inductive Coupling-Based Wireless Power Transmission System in Near Field to Control Low-Power Home Appliances

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Abstract An intimidating and challenging topic is the wireless delivery of electrical power to a load. Wirelines are currently being utilized to transfer power, but there are losses associated with this method. The invention of wireless power transmission (WPT) has opened up a new world to us. A magnetic field is used to transmit power from a transmitter coil to a receiver coil in WPT utilizing inductive coupling, which is part of NFWPT. Home appliances and the healthcare industry are embracing inductive coupling as an efficient method of transferring electricity over short distances. Wireless power transfer is also boosting the popularity of electric vehicle charging stations, biomedical implants, consumer electronics, industrial applications, etc. This paper discusses low-cost prototype of WPT based on mutual coupling between two coils. Here in the proposed system, two copper windings of fixed turns and SWG are placed face two face on the same axis. Due to mutual coupling, the electrical energy is transform from the primary to secondary coils. Experimentation is carried out by varying the gap between the coils, and the coupled power at the receiving end is utilized to run a low-power house appliance.

Keywords Wireless transmission · Inductive coupling · Near-field communication

1 Introduction

There is a growing industry in which electrical power can be supplied without the requirement of interconnecting cables by transferring energy wirelessly. Wireless power transfer (WPT) using inductive coupling sends magnetic field power to a receiver coil. Wireless low-power transfer (WLPT) is a need for charging smart phones, electric vehicles, and other electrical gadgets. Medical implanted devices, in particular, have benefited greatly from the use of WPT [1]. The wireless power transmission is possible in two ways; they are far field wireless power transmission (FFWPT) and near field wireless power transmission (NFWPT) [2]. Magnetic

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coupling between two coils restricts the transmission range of the NFWPT. However, FFWPT transmission supports long-range transmission, but it is less efficient than near field transmissions.

Despite the low mutual inductance between coils, increasing power transfer while maintaining system efficiency was the major objective of WPT research. Transmission of electricity from the transmitter to the receiver is accomplished by transferring magnetic fields between two resonant circuits, known as a resonant inductive coupling [3, 4]. It is possible to transmit more power over longer distances by making use of the weaker magnetic fields in outer areas ("tails") of near fields by means of resonance. High efficiency can be achieved at a range of 4–10 times the coil diameter using resonant inductive coupling [5]. One of the factors affecting the efficacy of inductive coupling is the decrease in dipole fields between the transmitter and receivers; this is related to the cube of the transmitter–receiver distance. Hence, shorter distances achieve higher efficiency [6].

Wireless power system can be achieved by inductive or magnetic coupling between two coils. The primary winding of the WPT is used to link the power supply, and the secondary winding is used to connect the load. In [7], their work designed to achieve extremely efficient transmission, and they merged an AC/DC converter together with an antenna system with ideal coupling coefficients into a wireless power transmission system employing magnetic coupling. In [8], the authors discussed wireless power transmission system with high-frequency resonant inductive coupling. The HFWPT system is intended to operate at a fifty kilohertz resonance frequency to provide better efficiency. Several device networks and cellular networks use identical wireless transmission technique to improve their transmission efficiency. In [9], the authors are addressed issues related to high-resonance system. The frequency variation of resonance is restricted, and the effectiveness of the energy exchange varies supported the coupling magnitude in this work. In [10], the authors examined the viability of using non-radioactive fields at the ends of resonant objects for intermediate energy transfer. Intuitively, 2 resonant things with an equivalent resonant frequency tend to interchange energy effectively, whereas superfluous off resonant objects dissipate relatively very little energy. In [11], the authors designed a basic wireless power transfer system for smart home applications. An electrodynamic induction approach was used to create this apparatus to show wireless power transfer. The stability analysis of an ICPT system coupled to an electric bicycle was addressed in [12]. Magnetic resonance coupling to create a wireless power transfer system that is both efficient and powerful is presented in [13]. An antenna system's equivalent circuit and simulation were used to derive the theoretical method to optimize antenna performance [14].

2 Existing Systems

Several works are reported in the design and development of wireless power transmission systems. The basic principle behind the WPT is inductive or magnetic coupling between two coils. A block diagram of this type of system is depicted in Fig. 1.

Power transmission system based on electromagnetic coupling circuit is illustrated in Fig. 1. The coupling model was used to investigate ideal coupling coefficients in terms of mathematical expressions. Resonance frequency is critical to system design because magnetic resonance coupling entails producing a resonance and transmitting power without the emission of electromagnetic waves. The various design parameters are

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{1}$$

$$Q = \sqrt{\frac{L}{C}}\frac{1}{R} = \frac{\omega_0 L}{R} \tag{2}$$

Coil, capacitor, and resistor are all components of an electromagnetic resonance circuit depicted in Fig. 2. Energy in this circuit oscillates at a specific resonance frequency between the coil and the capacitors, which store the energy in both a magnetic and an electric field. Circuit losses are reduced as a result of an increase in the system's quality factor (the reduction of R) [15, 16].

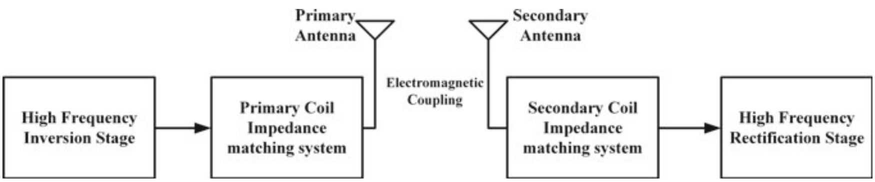


Fig. 1 WPT system's diagram

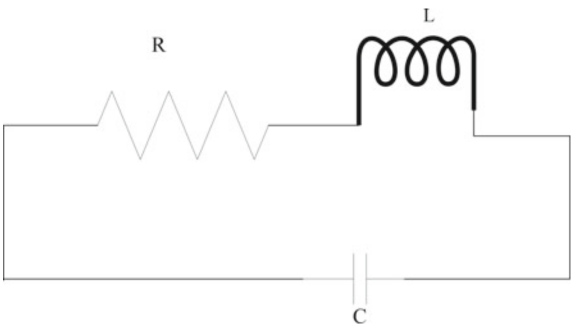


Fig. 2 Resonator circuit

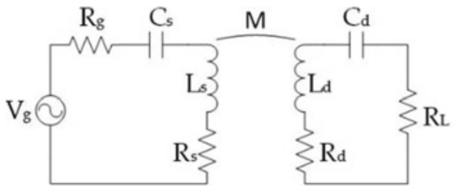


Fig. 3 Coupled resonator

It is essential that a high-resonance WPT system has an efficient mechanism to transfer energy. A high-quality factor electromagnetic resonator is often manufactured using conductive components with limited resonant frequency widths. Depending on the coupling ratio k and the particular resonator, the energy exchange will be adversely affected [17, 18]. A two-resonator system's dynamics can be identified using coupling modal theory or comparable circuit analysis. Coupled resonators circuit is depicted in Fig. 3.

R_s is the source internal resistance, and the voltage source's amplitude is referred to as V_g. Coils L_m and L_d are the source and the device resonators. The mutual inductance is represented by $M = k\sqrt{L_m L_d} * \text{E}$. A resonator is created by connecting a capacitor in series with each coil. Resistors R_s and R_d denote the ohmic and radioactive losses in each resonator's coil; R_L represents the AC load resistance. It is possible to calculate the yield of this circuit by comparing to the maximum power available from the source, the amount of energy delivered for resistance to loads [19, 20]. The expression for ratio is given in Eq. 4.

$$\frac{\text{P}_L}{\text{P}_{g,\max}} = \frac{4U^2 \frac{R_g}{R_s} \frac{R_L}{R_d}}{\left[\left(1 + \frac{R_g}{R_s}\right)\left(1 + \frac{R_L}{R_d}\right) + U^2\right]^2} \tag{3}$$

$$U = \frac{\omega M}{\sqrt{R_s R_d}} = k\sqrt{Q_s Q_d} \tag{4}$$

The optimal system performance can be achieved by selecting the right load and source resistances or by capturing alternative resistance values via an impedance matching connection. Equation 5 represents the efficiency of power transfer.

$$\eta_{\text{opt}} = \frac{U^2}{\left(1 + \sqrt{1 + U^2}\right)^2} \tag{5}$$

Systems with large U values are capable of transferring energy with high efficacy. Finding the system's performance factors, such as U, Q_s, and Q_d can help to maximize system's efficiency. An electric toothbrush is an example of an induction-based wireless power transmission system that uses high coupling values and a short range. Traditional induction systems are less efficient than high-quality resonators. In addition, low coupling values can now be achieved more effectively. It is not necessary to precisely place the source and device because of this. High value of Q maximizes the peak voltage of capacitor. Equation 6 describes the connection between capacitor voltage peak and quality.

$$V_{C_{\text{peak}}} = Q\frac{2V_s}{\pi} \tag{6}$$

3 Proposed System

Figure 4 depicts the proposed system's block diagram. It consists of the primary coil associated circuit and the secondary coil associated circuit, medium between the two coils is air. Mutual coupling of two coils determines the output voltage to drive the low-power appliance. The mutual coupling L_m is proportional to the product of the primary and the secondary coil inductance (L_p, L_s).

Here, power input is given to the primary coil via heat sink, the secondary coil is connected to the low-power home appliance via a storage device, and the voltage to the device is stabilized through a Zener diode across the capacitor. Figure 5 depicts the system that was built.

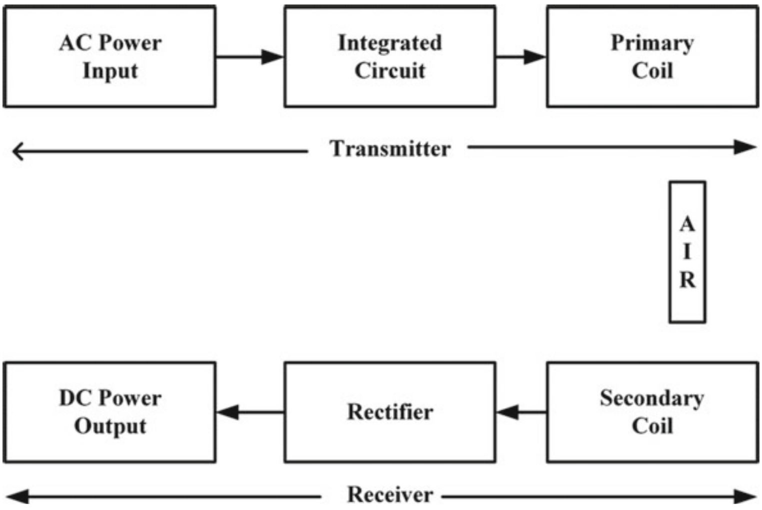


Fig. 4 Proposed work model

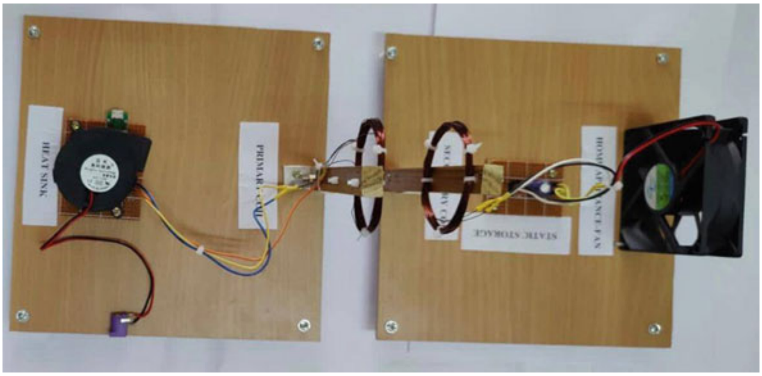


Fig. 5 Prototype of wireless power transmission system

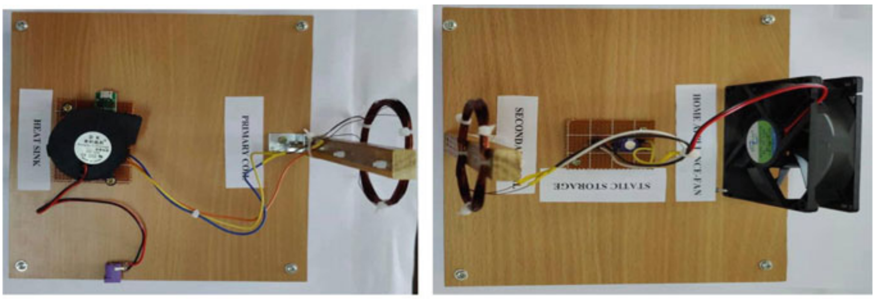
4 Results and Discussion

The setup of wireless power transmission system is shown in Fig. 5. The primary and secondary setups for experimentation are shown in Fig. 6. Figure 6.a shows the primary side of the setup which contains power supply mains, a heat sink, and coil, while Fig. 6.b shows the secondary side of the setup containing a storage device connected to an appliance.

The coupling between the coils by variation of gap between the coils is understood in Fig. 7.

As the gap between the primary and secondary coils was varied, there was a drop in the voltage and current due to the change in the mutual coupling between the coils. This is being shown in Table 1.

The input and output power obtained are tabulated and simulated using MATLAB to obtained the efficiency of the system. This is shown in Fig. 8. The efficiency of the system reduces as the coupling distance increases. By fixing an appropriate distance between the coils, the required power to run an appliance can be achieved. With



(a) (b)

Fig. 6 **a** Primary coil setup **b** secondary coil setup

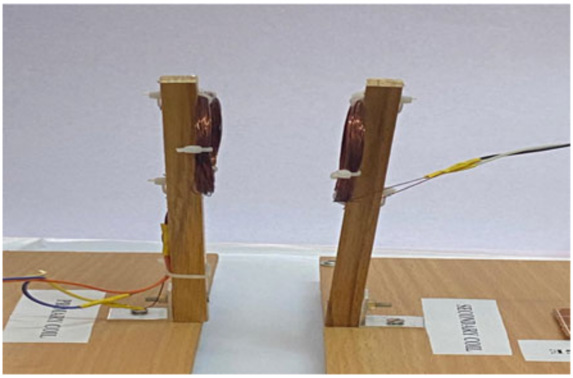


Fig. 7 Primary and secondary coupling

Table 1 Practical values of voltage and current recorded while the coils gap is varied

Distance (in cm)	V_{in} (v)	I_{in} (A)	P_{in} (W)	V_{out} (v)	I_{out} (A)	P_{out} (W)	% η
0	212	0.15	31.8	23.9	0.85	20.31	63.86
0.5	212	0.15	31.8	20.1	0.81	16.28	51.19
1	212	0.15	31.8	14.8	0.72	10.65	33.49
1.5	212	0.15	31.8	10.3	0.59	6.077	19.11
2	212	0.15	31.8	5.2	0.32	1.66	5.22
2.5	212	0.15	31.8	3.1	0.2	0.62	1.94
3	212	0.15	31.8	1.2	0.06	0.072	0.22

the present product developed, a 12 v mini fan is successfully run to check the functionality.

5 Conclusion

In the present work, a wireless power transmission system is developed that can run an home appliance. The principle of inductive coupling is to generate power wirelessly which is demonstrated, and it is further investigated the transfer of electricity wirelessly over a distance of 3 cm between the primary and secondary coils. Heat sink is used in the circuit to protect IC from power dissipation; from the simulation results, it is observed that as distance between the coils increases, it effect the efficiency of the system. Since the results of this study are sufficient to power the home appliance, so wireless power transfer can be regarded a viable option in a wide variety of other applications.

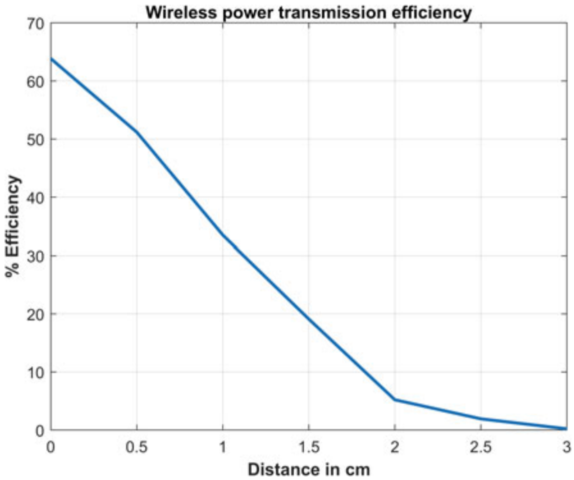


Fig. 8 Simulation results showing efficiency of WPT versus coil gap/power variations

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