DESIGN AND EXPERIMENTAL DEMOSTRATION OF NEAR-FIELD WIRELESS POWER TRANSFER TECHNOLOGY

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ABSTRACT

This study was carried out to investigate the near-field method of wireless power transmission using inductive coupling. The problem addressed was the limitations of traditional wired power transmission systems, which reduce device mobility, introduce safety hazards, and contribute to mechanical wear due to constant physical contact and handling. To solve this, a system was designed and constructed to wirelessly transfer power over a short distance of 20cm by generating a magnetic field through a transmitter coil and capturing the field at the receiver coil. The project involved the development of a prototype system comprising transmitter and receiver modules, with the transmitter powered by a DC supply and configured to produce high-frequency AC signals. These signals were transmitted through the magnetic field generated by the coil. Measurements were taken at various distances between the coils, and obstacles of different materials such as wood, plastic, glass, and metal were placed between the transmitter and receiver to examine their effects on the transmitted power. Key electrical parameters such as voltage, current, and power were recorded under each condition, and the data were presented in tables and graphs. Performance data were collected at distance interval of 2cm, ranging from 0-20cm. In both mobile charging and LED applications, the power delivered decreased progressively as the distance increased. At the shortest distance of 0-2cm, the output power was highest e.g. 0.11W for mobile charging and 0.18W for LED illumination. But it dropped significantly to as low as 0.00081W and 0.00035W at 20cm respectively. The findings revealed that power transfer was efficient at short distances but significantly reduced as the separation increased or when metallic obstacles were introduced. For example, while the voltage without an obstacle 3.5V at 0-2cm, it dropped to 2.2V in the presence of metal barrier. At 20cm, the effect was even more significant with the voltage dropping to as low as 0.1V. The study demonstrated the viability of near-field inductive coupling for wireless power transfer within limited ranges and controlled environments. The results suggest potential applications in charging small electronic devices and sensors without physical connectors, with implications for cheaper, safer, and more flexible energy delivery systems.

Keywords: Wireless Power Transmission (WPT), Inductive Coupling, Near-Field Energy Transfer, Magnetic Resonance, Power Transfer Efficiency, Electromagnetic Induction.

1.0 INTRODUCTION

Wireless Power Transmission (WPT) has emerged as one of the most significant technological innovations in modern electrical and electronic engineering, providing an alternative means of transferring electrical energy without the use of physical conductors. As the demand for portable electronic devices, autonomous systems, electric vehicles, and biomedical implants continues to increase, conventional wired power delivery systems have become increasingly constrained by issues such as cable deterioration, limited mobility, maintenance requirements, and safety concerns. These challenges have stimulated global interest in the development of wireless energy transfer technologies that offer greater flexibility, convenience, and reliability. The concept of wireless power transmission dates back to the pioneering experiments of Nikola Tesla in the late nineteenth century, when he demonstrated the possibility of transmitting electrical energy without wires through electromagnetic fields. Although the technology was initially limited by the scientific and technological capabilities of the time, significant advances in power electronics, electromagnetic theory, and resonant circuit design have transformed wireless power transmission into a practical solution for numerous modern applications. Today, WPT is widely employed in wireless charging systems for smartphones, wearable electronics, medical implants, industrial sensors, and electric vehicles, while ongoing research seeks to extend its transmission distance and improve its efficiency.

Wireless power transmission can generally be classified into near-field and far-field techniques. Near-field methods, including inductive coupling, resonant inductive coupling, and capacitive coupling, are primarily used for short-distance power transfer through electric or magnetic field interactions. In contrast, far-field techniques such as microwave and laser power transmission are suitable for long-range applications but generally involve lower efficiency and stricter safety requirements. Among these methods, inductive coupling has gained widespread acceptance because of its simplicity, relatively high efficiency, operational safety, and ease of implementation for low- and medium-power applications. Near-field wireless power transmission based on inductive coupling operates through the interaction of magnetic fields generated between two closely spaced coils. When an alternating current flows through the transmitter coil, a time-varying magnetic field is produced around it. According to Faraday's law of electromagnetic induction, this changing magnetic field induces an electromotive force (EMF) in the receiver coil positioned within the magnetic field. The induced alternating voltage is then rectified, filtered, and regulated to produce a stable direct current suitable for powering electrical loads. The effectiveness of this process depends on several factors, including coil geometry, operating frequency, mutual inductance, coupling coefficient, resonance conditions, and the alignment and separation between the transmitter and receiver coils. Despite its numerous advantages, inductive wireless power transmission possesses several inherent limitations. The efficiency of energy transfer decreases rapidly as the separation between the transmitter and receiver coils increases because the magnetic coupling between the coils becomes weaker. In addition, coil misalignment and the presence of conductive materials, particularly metals, may significantly reduce system performance through electromagnetic shielding and eddy current losses. Conversely, non-metallic materials such as wood, plastic, and glass generally have minimal influence on magnetic field propagation. Understanding these factors is essential for optimizing system design, improving transmission efficiency, and extending the practical applicability of wireless power transfer technology.

This study focuses on the design, construction, and performance evaluation of a near-field wireless power transmission system using inductive coupling. Experimental investigations were carried out to determine the effects of transmission distance, intervening materials, and load conditions on system performance. The transmitter and receiver circuits were designed using readily available electronic components to develop a low-cost prototype suitable for laboratory demonstration and educational purposes. System performance was evaluated by measuring output voltage, current, and power under different operating conditions. The findings of this research are expected to contribute to the growing body of knowledge on wireless power transmission by providing practical validation of electromagnetic induction principles and demonstrating the feasibility of implementing low-cost inductive wireless power systems for short-range applications. The outcomes may also serve as a useful reference for future improvements in wireless charging technologies for consumer electronics, biomedical devices, industrial automation, and other emerging engineering applications.

2.0 RELATED LITERATURE

Wireless Power Transmission (WPT) has attracted considerable research interest over the past century as an alternative method of delivering electrical energy without the use of physical conductors. The concept was pioneered by Nikola Tesla in the late nineteenth and early twentieth centuries through his experiments on wireless energy transfer using high-frequency electromagnetic fields. Although the technology was not commercially feasible at the time due to technological limitations, subsequent advancements in electromagnetic theory, power electronics, and resonant circuit design have transformed WPT into a practical solution for numerous engineering applications (Brown, 1996; Carlson, 2013).

Wireless power transmission techniques are generally classified into near-field and far-field methods based on their operating principles and transmission distance. Near-field techniques include inductive coupling, resonant inductive coupling, and capacitive coupling, while far-field methods employ microwave or laser beams for long-distance energy transmission (Liu *et al.*, 2024). Among these approaches, inductive coupling remains the most widely adopted because of its relatively simple design, high reliability, operational safety, and suitability for short-range power transfer applications such as wireless charging pads, biomedical implants, and consumer electronics (Li & Mi, 2015).

Inductive wireless power transmission operates on the principle of electromagnetic induction, where an alternating current flowing through a transmitter coil generates a time-varying magnetic field that induces an electromotive force (EMF) in a nearby receiver coil. The efficiency of this process depends primarily on the degree of magnetic coupling between the coils, which is influenced by factors such as transmission distance, coil alignment, operating frequency, coil geometry, and mutual inductance (Chen *et al.*, 2015). Numerous studies have demonstrated that power transfer efficiency decreases significantly as the separation between the transmitter and receiver coils increases because the magnetic flux linking the coils becomes progressively weaker (Covic & Boys, 2013; Sample *et al.*, 2011).

To overcome this limitation, researchers have investigated resonant inductive coupling, where both transmitter and receiver circuits are tuned to the same resonant frequency. Resonance enhances magnetic coupling and allows more efficient energy transfer over relatively greater distances compared to conventional inductive systems. Studies by Kurs *et al.* (2007) and Hui *et al.* (2014) showed that resonant coupling substantially improves transmission efficiency and has become the foundation of many modern wireless charging technologies.

Another important area of research concerns the influence of environmental materials on wireless power transmission. Previous investigations have shown that non-metallic materials such as wood, plastic, and glass have minimal influence on magnetic field propagation because they possess low electrical conductivity and magnetic permeability. Consequently, these materials introduce negligible attenuation of the transmitted magnetic field. In contrast, metallic materials significantly reduce transmission efficiency by generating eddy currents and electromagnetic shielding effects, which absorb and oppose the magnetic field, thereby reducing the induced voltage in the receiver coil (Feliziani & Cruciani, 2013; Zhu *et al.*, 2017). These findings have important implications for the design and installation of practical wireless charging systems.

Recent developments in wireless power transmission research have focused on improving system performance through optimized coil design, impedance matching, resonant compensation networks, and frequency optimization. Researchers have also explored advanced coil geometries capable of improving magnetic coupling while reducing power losses (Sun *et al.*, 2020; Chen *et al.*, 2015). In the automotive sector, significant progress has been made in the development of wireless charging systems for electric vehicles, including both stationary and dynamic charging technologies that enable vehicles to receive power while parked or in motion

(Bi *et al.*, 2016; Cirimele *et al.,* 2018). Similarly, wireless power transfer has found increasing applications in biomedical engineering, where implantable medical devices and wearable health monitoring systems benefit from cable-free power delivery that improves patient comfort and safety (Choi *et al.*, 2017).

Despite these technological advancements, practical implementation of wireless power transmission still faces several challenges. System efficiency decreases rapidly with increasing transmission distance, precise alignment between the coils is often required, and metallic objects located within the transmission path may significantly impair performance. Furthermore, high-power wireless transmission systems require careful electromagnetic compatibility and safety considerations to ensure compliance with international exposure standards (Christ *et al.*, 2013).

Overall, the reviewed literature demonstrates that inductive wireless power transmission is a mature and effective technology for short-range energy transfer. While considerable improvements have been achieved through resonant coupling, optimized coil design, and advanced compensation techniques, efficient long-distance wireless power transfer remains an active area of research. The present study builds upon these previous works by designing and experimentally evaluating a low-cost near-field wireless power transmission system to investigate the effects of transmission distance, intervening materials, and load conditions on system performance. The findings provide practical validation of established electromagnetic principles while contributing experimental data that support the continued development of efficient wireless power transfer technologies.

3.0 METHODOLOGY

3.1 System Design

The wireless power transmission system developed in this study was designed based on the principle of near-field inductive coupling, where electrical energy is transferred wirelessly through a time-varying magnetic field. The system comprises two major sections: the transmitter unit and the receiver unit. These two units work together to enable the transmission and reception of electrical energy without the use of physical conductors. The transmitter unit consists of a power supply, rectification stage, voltage regulation circuit, oscillator circuit, and transmitting coil. The alternating current (AC) supplied from the mains is first stepped down by a transformer and converted into direct current (DC) using a bridge rectifier. The rectified voltage is filtered and regulated before being supplied to a transistor-based oscillator circuit. The oscillator converts the DC voltage into a high-frequency alternating current, which energizes the transmitter coil. As current flows through the transmitting coil, a time-varying magnetic field is generated around it. This magnetic field serves as the medium through which electrical energy is transferred to the receiver.

The receiver unit comprises a receiving coil, bridge rectifier, filter capacitor, voltage regulator, and electrical load. When the receiver coil is positioned within the magnetic field produced by the transmitter coil, an alternating voltage is induced in accordance with Faraday's law of electromagnetic induction. The induced AC voltage is rectified and filtered to produce a smooth DC output, while the voltage regulator ensures a stable output suitable for powering low-power devices such as light-emitting diodes (LEDs) and mobile phones. The complete system was designed using readily available and low-cost electronic components to demonstrate the practical feasibility of near-field wireless power transmission.

3.2 Experimental Setup

The experimental investigation was conducted under controlled laboratory conditions to evaluate the performance of the developed wireless power transmission system. During the experiment, the transmitter coil was fixed in position while the receiver coil was moved progressively away from the transmitter to investigate the influence of distance on power transfer. Measurements were taken at coil separation distances ranging from 2 cm to 20 cm, with intervals of 2 cm between successive measurements. At each distance, the output voltage and current were measured using a digital voltmeter and ammeter, respectively. The measurements were repeated under identical operating conditions to ensure consistency and reliability of the experimental data.

To evaluate the practical performance of the system under different operating conditions, two different electrical loads were connected to the receiver circuit. The first load was a mobile charging circuit, representing a practical consumer electronic application, while the second load consisted of an LED, which served as a low-power indicator load. The use of these two loads enabled the assessment of system performance under varying load characteristics and power requirements.

Throughout the experiment, all other operating conditions, including the supply voltage, coil dimensions, circuit configuration, and component values, were maintained constant so that any observed variations in system performance could be attributed primarily to changes in transmission distance and the presence of intervening materials.

3.3 Material Testing

In addition to evaluating the effect of transmission distance, the influence of different environmental materials on wireless power transfer was investigated. Four commonly available materials with different electromagnetic properties were selected for the study. These materials included wood, plastic, glass, and metal**.**

Each material was placed between the transmitter and receiver coils while maintaining the same experimental conditions used during the distance measurements. Output voltage and current readings were recorded for each material at the selected distances, after which the corresponding output power was calculated.

The purpose of this investigation was to determine how different materials affect magnetic field propagation and, consequently, wireless power transfer efficiency. Wood, plastic, and glass were selected because they are non-metallic materials commonly encountered in practical applications and are generally considered to have minimal influence on magnetic fields. Metal was included because its high electrical conductivity is known to generate eddy currents and electromagnetic shielding effects, which can significantly reduce the magnetic flux reaching the receiver coil.

The comparative analysis of these materials provided useful information regarding the suitability of different environments for the installation and operation of wireless power transmission systems.

3.4 Data Collection and Analysis

Experimental data were collected systematically for each test condition. The primary electrical parameters measured during the investigation were the output voltage and output current delivered by the receiver circuit. These measurements formed the basis for evaluating the performance of the wireless power transmission system under different operating conditions.

The measured parameters included:

i. Output Voltage (V)
ii. Output Current (mA)
iii. Output Power (W)

The output power delivered to the load was determined using the electrical power relationship, where:

P = Output Power (W)

V = Output Voltage (V)

I = Output Current (A)

The calculated power values were subsequently plotted against transmission distance for each load condition and material type. The resulting graphs were analyzed to determine the effect of coil separation and environmental materials on wireless power transfer performance. Comparisons were made between the different experimental conditions to identify trends in voltage, current, and power variation, thereby providing a comprehensive assessment of the developed system's operational characteristics.
The experimental methodology adopted in this study ensured that reliable and repeatable data were obtained, allowing meaningful conclusions to be drawn regarding the performance, limitations, and practical applicability of the developed near-field wireless power transmission system.

4.0 RESULTS AND DISCUSSION

4.1 Effect of Distance (Mobile Load)

Table 4.1: Power Transfer at Varying Distances (Mobile Load)

Distance (Transmitter to Receiver)	Current (mA)	Voltage (V)	Power (W)
0-2cm	32.5	3.5	0.11
0-4cm	27.5	3.2	0.09
0-6cm	20.8	3.1	0.06
0-8cm	15.8	2.2	0.04
0-10cm	12.5	2.0	0.03
0-12cm	8.7	1.6	0.01
0-14cm	5.8	1.5	0.008
0-16cm	3.3	1.4	0.005
0-18cm	1.7	1.0	0.0017
0-20cm	0.9	0.9	0.00081

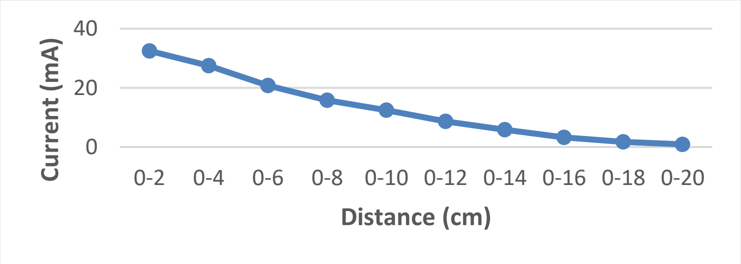

Figure 4.1: Current vs Distance

Figure 4.1 shows the variation of receiver current with distance. The current decreases sharply as the separation between the transmitter and receiver coils increases, indicating reduced magnetic coupling.

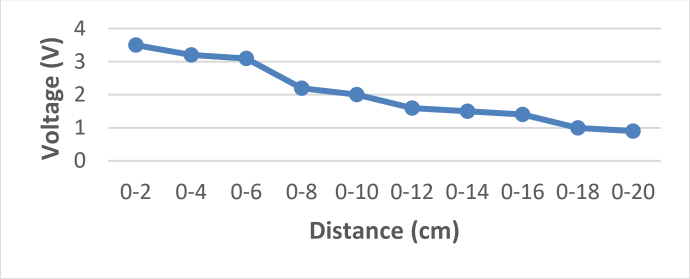

Figure 4.2: Voltage vs Distance

Figure 4.2 illustrates the relationship between output voltage and distance. A gradual decline is observed as distance increases due to reduced magnetic flux linkage.

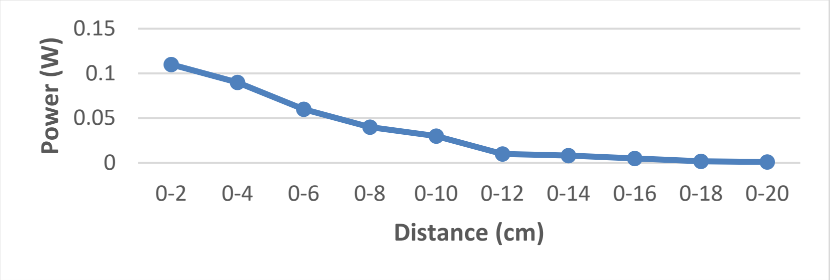

Figure 4.3: Power vs Distance

Figure 4.3 presents the power variation with distance. The output power decreases significantly with increasing distance, confirming that efficiency is highest at close proximity.

4.2 Effect of Distance (LED Load)

Table 4.2: Power Transfer (LED Load)

Distance (Transmitter to Receiver)	Current (mA)	Voltage (V)	Power (W)
0-2cm	48	3.7	0.18
0-4cm	35	3.3	0.16
0-6cm	20	2.9	0.058
0-8cm	15	2.0	0.03
0-10cm	10	1.9	0.019
0-12cm	8	1.7	0.0136
0-14cm	4	1.6	0.0064
0-16cm	2	1.4	0.0028

0-18cm	1.4	0.9	0.00126
0-20cm	0.5	0.7	0.00035

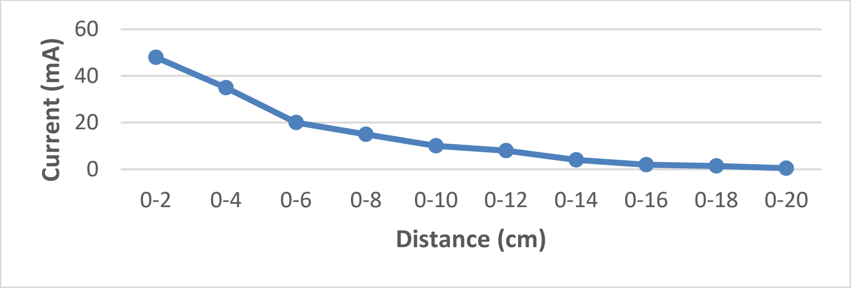

Figure 4.4: Current vs Distance

Figure 4.4 shows the current variation for the LED load. Higher current is observed at short distances, followed by a rapid decline as distance increases.

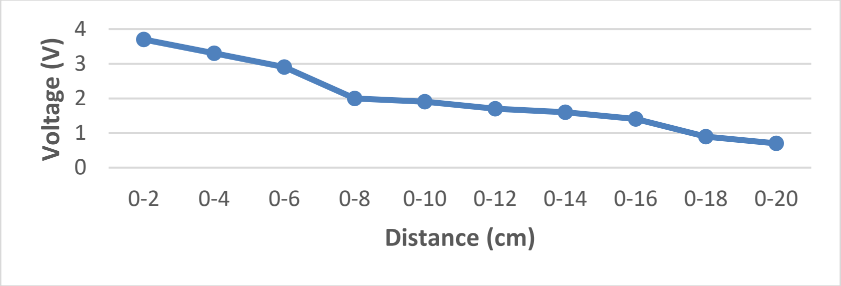

Figure 4.5: Voltage vs Distance

Figure 4.5 illustrates the voltage behavior under LED load conditions. The voltage decreases progressively with increasing separation between coils.

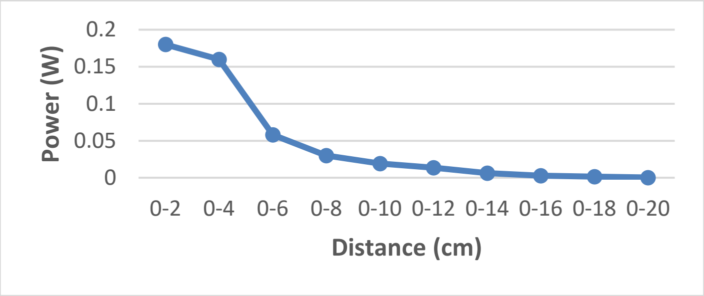

Figure 4.6: Power vs Distance

Figure 4.6 shows the power output for the LED load. The rapid decrease confirms that distance significantly affects energy transfer efficiency.

4.3 Effect of Materials

a) Wood

Table 4.3: Wood Obstacle

Distance (Transmitter to Receiver)	**Current (mA)**	**Voltage (V)**	**Power (W)**
0-2cm	46	6.4	0.29
0-4cm	30	4.5	0.135
0-6cm	24	4.2	0.101
0-8cm	20	3.9	0.078
0-10cm	18	3.6	0.070
0-12cm	12	3.2	0.038
0-14cm	10	2.8	0.028
0-16cm	8	2.5	0.020
0-18cm	3	2.1	0.0063
0-20cm	2	0.9	0.0018

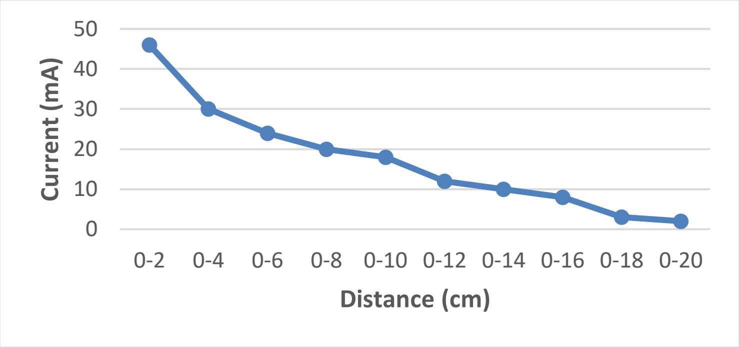

Figure 4.7: Current vs Distance (Wood)

Figure 4.7 shows that wood has minimal impact on current transfer, with behavior similar to the no-obstacle condition.

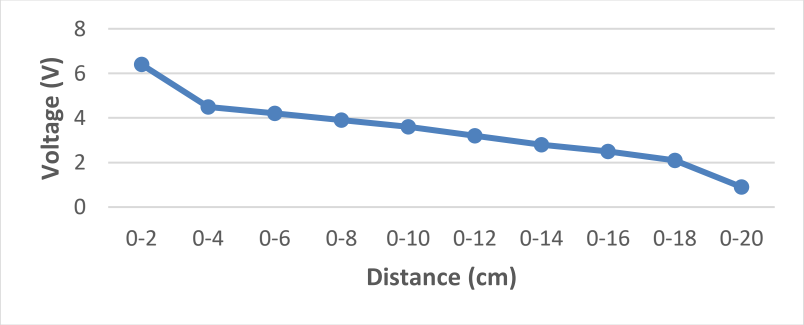

Figure 4.8: Voltage vs Distance (Wood)

Figure 4.8 illustrates that voltage reduction is mainly due to distance rather than the presence of wood.

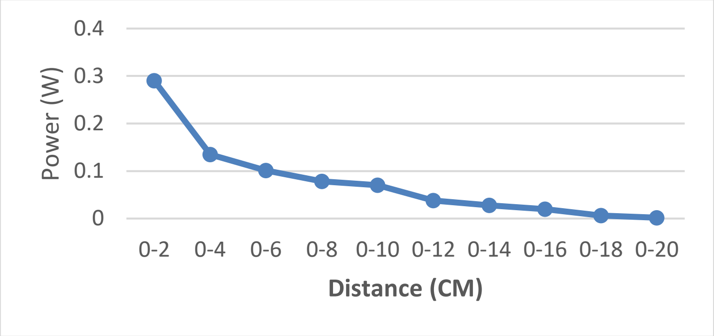

Figure 4.9: Power vs Distance (Wood)

Figure 4.9 indicates that power transfer remains largely unaffected by wood, confirming its negligible electromagnetic interference.

b) Plastic

Table 4.4: Plastic Obstacle

Distance (Transmitter to Receiver)	Current (mA)	Voltage (V)	Power (W)
0-2cm	50	6.6	0.33
0-4cm	40	5.2	0.208
0-6cm	33	4.2	0.139
0-8cm	25	4.0	0.100
0-10cm	22	3.7	0.0814
0-12cm	12	3.5	0.042
0-14cm	10	2.8	0.028
0-16cm	8	2.7	0.0216
0-18cm	4	2.4	0.0096
0-20cm	2	1.2	0.0024

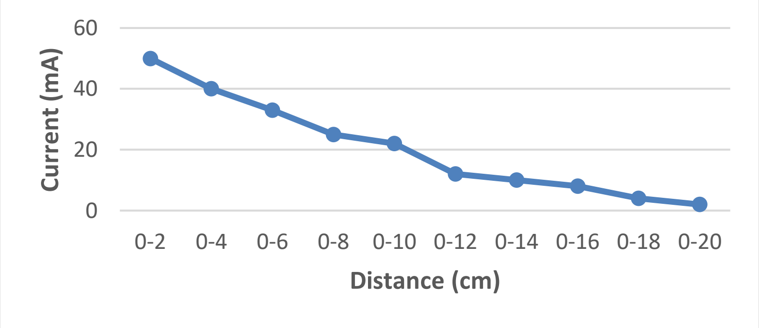

Figure 4.10: Current vs Distance (Plastic)

Figure 4.10 shows that plastic introduces negligible interference, with current trends similar to free-space conditions.

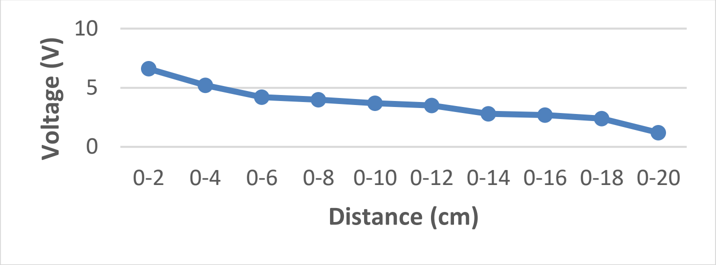

Figure 4.11: Voltage vs Distance (Plastic)

Figure 4.11 demonstrates that voltage is only affected by distance, not by the plastic material.

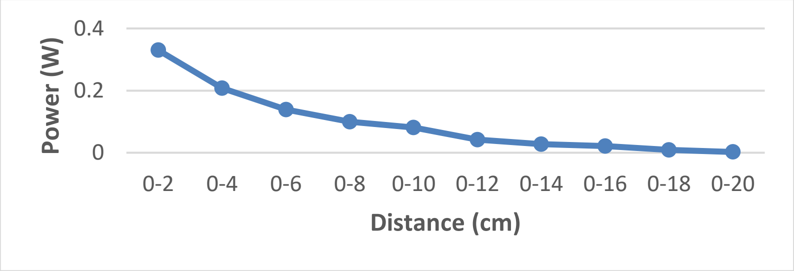

Figure 4.12: Power vs Distance (Plastic)

Figure 4.12 confirms that plastic does not significantly affect power transfer efficiency.

c) Glass

Table 4.5: Glass Obstacle

Distance (Transmitter to Receiver)	**Current (mA)**	**Voltage (V)**	**Power (W)**
0-2cm	48	6.8	0.326
0-4cm	35	5.6	0.196
0-6cm	30	4.2	0.126
0-8cm	26	4.0	0.104
0-10cm	22	3.6	0.0792
0-12cm	10	3.4	0.034
0-14cm	8	3.1	0.0248
0-16cm	5	2.9	0.0145
0-18cm	3	2.6	0.0078
0-20cm	0.9	1.8	0.00162

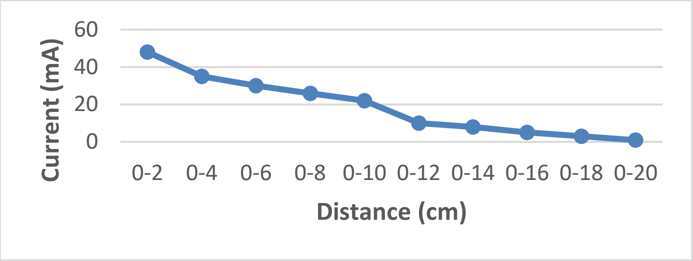

Figure 4.13: Current vs Distance (Glass)

Figure 4.13 shows that glass does not significantly affect current, maintaining a similar trend to other non-metallic materials.

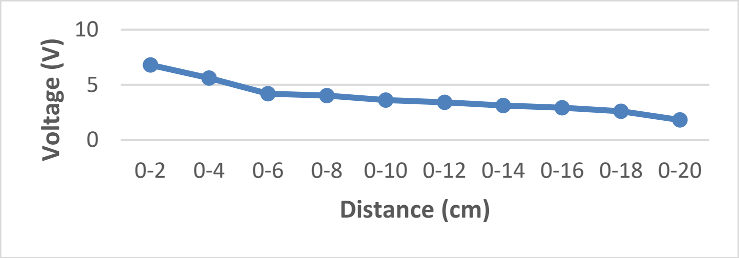

Figure 4.14: Voltage vs Distance (Glass)

Figure 4.14 illustrates minimal impact of glass on voltage transmission.

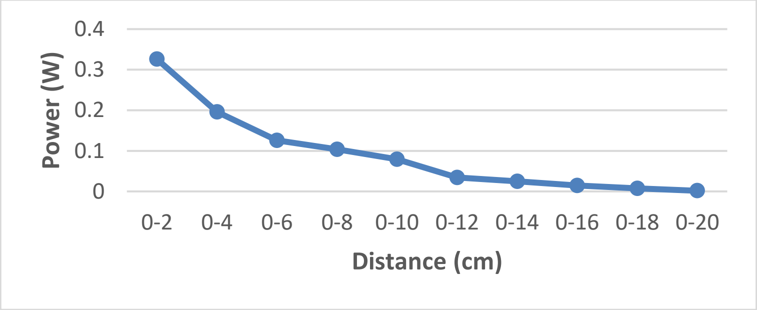

Figure 4.15: Power vs Distance (Glass)

Figure 4.15 confirms that glass allows efficient power transfer with negligible attenuation.

d) Metal

Table 4.6: Metallic Obstacle Results

Distance (Transmitter to Receiver)	**Current (mA)**	**Voltage (V)**	**Power (W)**
0-2cm	16	2.2	0.0352
0-4cm	14	2.0	0.028
0-6cm	12	0.8	0.0096
0-8cm	6.4	0.6	0.00384
0-10cm	6.2	0.5	0.0031

0-12cm	4.2	0.4	0.00168
0-14cm	3.4	0.3	0.00102
0-16cm	3	0.3	0.0009
0-18cm	2	0.2	0.0004
0-20cm	0.5	0.1	0.0005

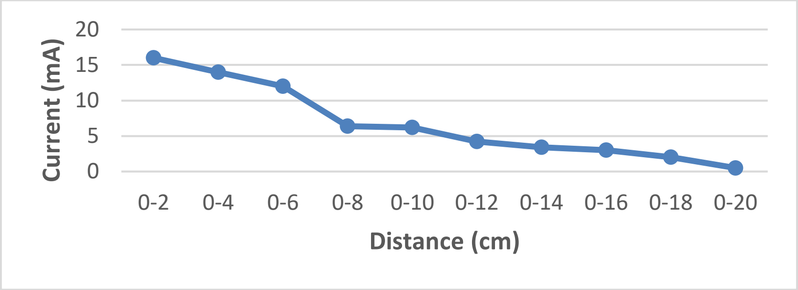

Figure 4.16: Current vs Distance (Metal)

Figure 4.16 shows a significant reduction in current due to metallic interference, highlighting strong attenuation effects.

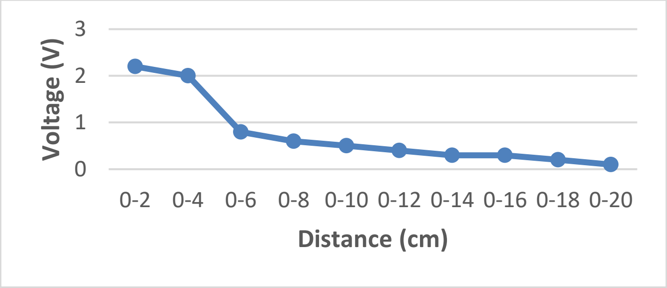

Figure 4.17: Voltage vs Distance (Metal)

Figure 4.17 demonstrates severe voltage drop caused by electromagnetic shielding from the metallic material.

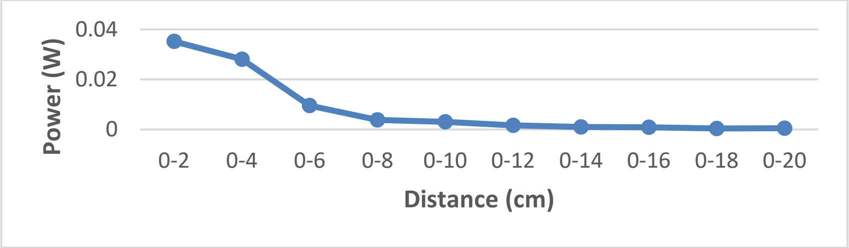

Figure 4.18: Power vs Distance Graph

Figure 4.18 shows that power output is drastically reduced in the presence of metal, confirming high energy losses due to eddy currents.

5.0 CONCLUSION

This study successfully designed, constructed, and evaluated a near-field wireless power transmission (WPT) system based on the principle of inductive coupling. The developed prototype demonstrated the feasibility of transferring electrical energy wirelessly over short distances through the interaction of time-varying magnetic fields between the transmitter and receiver coils. Experimental investigations were conducted to evaluate the effects of transmission distance, intervening materials, and load conditions on system performance using voltage, current, and power as the principal performance indicators.

The experimental results showed that the efficiency of wireless power transfer is highly dependent on the distance between the transmitter and receiver coils. Maximum power transfer was achieved when the coils were positioned in close proximity, particularly within 5 cm, while a progressive reduction in voltage, current, and power was observed as the separation distance increased. This behaviour confirms the theoretical principles of electromagnetic induction and mutual inductance, which predict a reduction in magnetic coupling as the distance between the coils increases.

The investigation also demonstrated that environmental materials influence system performance according to their electromagnetic properties. Non-metallic materials such as wood, plastic, and glass produced only negligible effects on wireless power transfer, whereas metallic materials significantly reduced system performance due to electromagnetic shielding and eddy current losses. These findings emphasize the importance of proper system placement and material selection in practical wireless charging applications.

Overall, the study establishes that inductive coupling is a practical, reliable, and cost-effective method for short-range wireless power transmission, particularly for low-power applications such as mobile device charging, LED lighting, wearable electronics, and biomedical devices. Although challenges such as rapid efficiency degradation with distance and sensitivity to metallic interference remain, the developed system provides a solid foundation for further research aimed at improving transmission efficiency, increasing operating range, and expanding the practical applications of wireless power transmission technology.

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