Exploring the Potential of Mid-Range Wireless Power Transfer Using Resonance Inductive Coupling

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Abstract. This paper investigated mid-range wireless power transfer using resonance inductive coupling. The researchers built a prototype circuit capable of wirelessly transmitting power up to 16 cm using a 9V DC supply and oscillator for the transmitter, testing different receiver coil configurations. They analyzed factors affecting transmission efficiency, including coil type, number of turns, and distance between transmitter and receiver. Key findings showed that a 30-turn magnetic coil receiver achieved the highest efficiency (~66%) at 0 cm, with efficiency decreasing as distance increased for all receiver types. The system could power multiple loads simultaneously, though with reduced efficiency, and barriers between transmitter and receiver did not significantly impact power transmission due to the resonant coupling. Overall, the study demonstrated the potential of resonance-based wireless power transfer for mid-range applications, while highlighting areas for further optimization and research.

Keywords: mid-range wireless power transfer, resonance technology, transmission efficiency, operational distances, efficiency optimization, safety protocols, electromagnetic fields, regulatory implications,

INTRODUCTION

Wireless Power Transfer (WPT) has emerged as a transformative technology with the potential to revolutionize how we interact with electronic devices by eliminating the constraints of physical connectors and enhancing user convenience. While early WPT systems have primarily focused on short-range applications, recent advancements have spurred interest in mid-range WPT, where distances span from a few centimeters to several meters. This expansion opens doors to powering a broader range of devices in various environments, from everyday consumer electronics to critical industrial machinery.

One of the key technologies enabling efficient mid-range WPT is resonance. Resonant-based systems leverage the phenomenon of electromagnetic resonance to achieve higher efficiency and longer operational distances compared to traditional inductive coupling methods. By tuning the resonant frequencies of transmitter and receiver coils, these systems minimize energy loss and maximize transfer efficiency, making them particularly suitable for applications requiring reliable and flexible power delivery over moderate distances.

Despite its potential, mid-range WPT faces several challenges that must be addressed for widespread adoption. These include optimizing transmission efficiency across varying distances, ensuring safety standards for electromagnetic exposure are met, and navigating regulatory frameworks that govern wireless communication and power transmission.

Current solutions in mid-range WPT often rely on resonant coupling and sophisticated control algorithms to mitigate these challenges. However, limitations such as sensitivity to environmental factors and the complexity of tuning resonant frequencies for different applications remain significant barriers.

This paper seeks to contribute to the advancement of mid-range WPT technology by exploring the feasibility, technological advancements, and potential applications of resonance-based systems. By synthesizing existing research and addressing current limitations, this study aims to provide insights into optimizing efficiency, ensuring safety, and expanding the scope of mid-range WPT across diverse sectors. Ultimately, this research aims to accelerate the adoption of resonant-based mid-range WPT as a reliable and efficient wireless energy transmission solution.

LITERATURE REVIEWS

The University of Auckland's Power by Proxi research (1) provides a comprehensive overview of wireless power technology. Their work explores the fundamental principles of wireless power transfer, including inductive coupling and resonant inductive coupling. The research highlights the potential applications of this technology in various fields, from consumer electronics to industrial equipment. Power by Proxi's studies demonstrate the feasibility of efficient power transfer over short to medium distances without the need for physical connections. Their findings have contributed significantly to the advancement of wireless charging systems and have paved the way for more practical implementations of wireless power transfer in everyday devices. The research also addresses key challenges in the field, such as improving transfer efficiency and managing heat generation, providing valuable insights for future developments in wireless power technology.

Shinohara's book "Wireless Power Transfer via Radiowaves" (2) offers an in-depth exploration of wireless power transmission using electromagnetic waves . The author provides a comprehensive analysis of the theoretical foundations and practical applications of this technology. Shinohara discusses various methods of wireless power transfer, with a particular focus on the use of radio waves for long-distance power transmission. The book covers important topics such as antenna design, power conversion techniques, and safety considerations in wireless power systems. Shinohara also examines potential applications of this technology, including space solar power systems and wireless charging for electric vehicles. By providing a thorough examination of the principles and challenges of wireless power transfer via radio waves, this work serves as a valuable resource for researchers and engineers working in this field (5).

Karalis, Joannopoulos, and Soljačić's paper (3) presents a groundbreaking study on efficient wireless non-radiative mid-range energy transfer. The authors propose a novel method for transferring power over medium distances using strongly coupled magnetic resonances. Their research demonstrates the possibility of achieving high-efficiency power transfer between two coils separated by several times the coil diameter. The paper provides a theoretical framework for this approach, including detailed mathematical models and simulations. The authors also discuss potential applications of this technology, such as wireless charging of mobile devices and electric vehicles. Their work has been highly influential in the field of wireless power transfer, inspiring numerous subsequent studies and practical implementations. This research marked a significant advancement in overcoming the distance limitations of traditional inductive coupling methods.

Cameron's article (4) on Tesla's discovery of wireless power transfer provides valuable historical context for the field. The author details Nikola Tesla's pioneering experiments in 1890, which laid the foundation for modern wireless power technology. Cameron describes Tesla's vision of a world where electricity could be transmitted wirelessly over long distances, potentially revolutionizing power distribution. The article highlights Tesla's key experiments, including his work with high-frequency alternating currents and his famous Tesla coil. Cameron also discusses the challenges Tesla faced in realizing his vision, including technical limitations of the time and skepticism from the scientific community. This historical perspective is crucial for understanding the origins of wireless power transfer and appreciating the long-standing nature of the quest for efficient wireless energy transmission {8}.

Lee, Zhong, and Hui's paper (2012) offers a comprehensive review of recent progress in mid-range wireless power transfer [7]. The authors present an overview of various techniques and technologies developed for efficient power transfer over distances of several centimeters to a few meters. They discuss different coupling methods, including inductive coupling, capacitive coupling, and magnetic resonance coupling. The paper analyzes the advantages and limitations of each approach, providing insights into their practical applications. The authors also address key challenges in the field, such as improving transfer efficiency, managing electromagnetic interference, and ensuring safety. They highlight recent advancements in areas like adaptive frequency tuning and multi-device charging systems. This review serves as an excellent resource for understanding the state-of-the-art in mid-range wireless power transfer and identifying areas for future research and development.

METHODOLOGY

Introduction

This section outlines the approach for developing and analyzing the mid-range wireless power transfer system, detailing the methodologies employed. It also presents the components utilized and the circuit configuration for this mid-range wireless power transfer setup. The project primarily involves the design and construction of hardware circuits. Additionally, a comprehensive project workflow diagram is provided in Figure 1, illustrating the step-by-step process of the in designing and analyzing a mid-range wireless power transfer system. Here’s a breakdown of the flowchart:

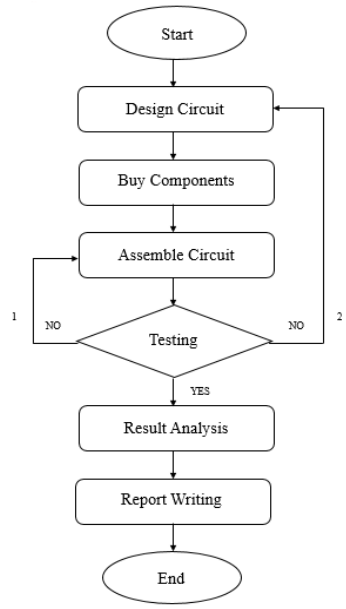

FIGURE 1. Methodology of the project flow chart

1. **Start**: This is the beginning point of the project.
2. **Design Circuit**: In this step, you will design the electrical circuit for the wireless power transfer system. This will involve selecting the appropriate components and figuring out how to connect them together.
3. **Buy Components**: Once you have designed the circuit, you will need to purchase all of the necessary components. These components will typically include things like inductors, capacitors, resistors, and transistors.
4. **Assemble Circuit**: After you have purchased all of the components, you will need to assemble the circuit according to your design. This will involve soldering the components together on a printed circuit board (PCB).
5. **Testing**: Once the circuit is assembled, you will need to test it to make sure that it is working properly. This will involve testing things like the voltage output, current output, and efficiency of the system.
6. **Result Analysis**: After you have tested the circuit, you will need to analyse the results. This will involve looking at things like the efficiency of the system, the power output, and the range of the system.
7. **Report Writing**: Once you have analysed the results, you will need to write a report on your findings. This report should include things like your design goals, your design process, your test results, and your analysis of the results.
8. **End**: This is the end point of the project.

The flowchart does not show the specific components or circuit connection for a mid-range wireless power transfer system. However, it does give you a general overview of the steps involved in designing and analysing such a system.

Components And Connection

This Figure 2: schematic diagram illustrates a Wireless Power Transfer (WPT) system using resonance concept. The system is divided into two main parts:

1. Transmitter:
- Powered by a 9 Volt source
- Contains capacitors (C1, C2, C3) and a transistor (T)
- Features a transmitter coil with a diameter of 5.0 cm

2. Receiver:

- Contains a receiver coil also with a diameter of 5.0 cm
- Includes a capacitor (C4) for resonance
- Has a diode (D) for rectification
- Powers an LED as the load

The transmitter circuit generates an oscillating magnetic field through its coil. This field induces a current in the receiver coil when they are in proximity. The resonant capacitors in both circuits are tuned to the same frequency to maximize power transfer efficiency. The diode in the receiver converts the induced AC to DC to power the LED.

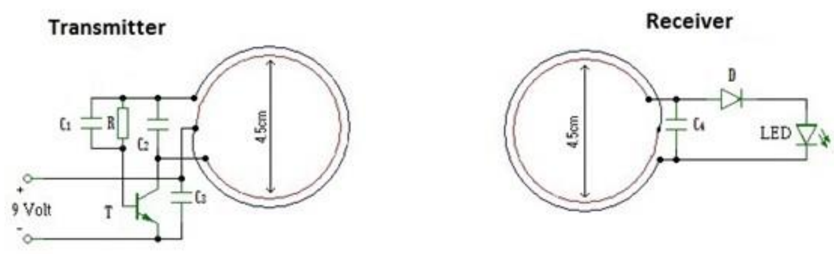

FIGURE 2. Schematic Diagram for WPT using Resonance Concept

This setup demonstrates the basic principle of resonant inductive coupling for wireless power transfer over a mid-range distance.

TABLE 1. Transmitter Parameters

Parameters	Values
V_1	9V
R_1	5.5 k 0.5w
C_1	1nF
C_2	4.7nF
C_3	100nF
T	BD139 (NPN)

TABLE 2. Receiver Parameters

Parameters	Values
C_4	1nF
D	1N4148

RESULT AND DISCUSSION

The project successfully developed and tested a mid-range wireless power transfer (WPT) system using resonance inductive coupling. The prototype was designed to wirelessly power an LED load using a 9V DC power supply as the source. The system demonstrated the ability to transfer power over a mid-range distance of up to 18-20 cm, with the LED completely turning off at 20.5 cm.

The core components of the system included a transmitter circuit with an oscillator to generate high-frequency AC, a transmitter coil, and various receiver coils. Two main types of receiver coils were tested: a 35-turn magnetic coil and copper coils with 10 turns and 5 turns respectively. Each receiver coil was tested at different distances from the transmitter, ranging from 0 cm (direct contact) to 20 cm.

TABLE 3. Efficiency for LED when using 35 turns of Magnetic Coil.

Input		Output			Efficiency, $\eta = \frac{P_{out}}{P_{in}} \times 100\%$
Transmitter Part	**Input Power, P_{in} (W)**	**Receiver Part**	**Output Power, P_{out} (W)**	**Distance (cm)**	
35 Turns Copper Coil	5.9	35 turns Magnetic Coil	4.10	0	69
			2.10	5	36.6
			1.61	10	27.11
			0.43	15	7.31
			0.11	20	1.69

TABLE 4. Efficiency for LED when using 10 turns of Copper Coil.

Input		Output			Efficiency, $\eta = \frac{P_{out}}{P_{in}} \times 100\%$
Transmitter Part	**Input Power, P_{in} (W)**	**Receiver Part**	**Output Power, P_{out} (W)**	**Distance (cm)**	
10 Turns Copper Coil	5.9	10 turns Copper Coil With 1nF Capacitor	3.53	0	60.0
			1.63	5	27.62
			0.63	10	10.67
			0.14	15	2.37
			0.05	20	0.85

TABLE 5. Efficiency for LED when using 5 turns of Copper Coil.

Input	Output	Efficiency,

Transmitter Part	**Input Power, P_{in} (W)**	**Receiver Part**	**Output Power, P_{out} (W)**	**Distance (cm)**	$\eta = \frac{P_{out}}{P_{in}} \times 100\%$
5 Turns Copper Coil	5.9	5 Turns Copper Coil with 15nF Capacitor	0.55	0	9.32
			0.18	5	3.05
			0.07	10	1.18
			0.04	15	0.67
			0.007	20	0.11

One of the key findings was the significant impact of the receiver coil type and configuration on power transfer efficiency. The 35-turn magnetic coil demonstrated the highest efficiency, achieving nearly 69% power transfer at 0 cm distance. In comparison, the 10-turn copper coil reached about 60% efficiency, while the 5-turn copper coil only managed about 9.32% efficiency at the same distance. This clearly illustrated that increasing the number of turns in the receiver coil leads to higher power transfer efficiency.

The study also highlighted the inverse relationship between distance and power transfer efficiency. For all coil types, the efficiency decreased as the distance between the transmitter and receiver increased. For instance, the magnetic coil's efficiency dropped from 69% at 0 cm to just 1.69% at 20 cm. Similarly, the 10-turn copper coil's efficiency fell from 60% at 0 cm to 1.18% at 20 cm. This decrease in efficiency with distance is a common challenge in wireless power transfer systems and underscores the need for further research to maintain high efficiency over longer distances.

The resonant frequency matching between the transmitter and receiver circuits was identified as another crucial factor affecting system performance. The transmitter coil operated at a frequency of 432.6 kHz, while the receiver coils had an average resonant frequency of around 560 kHz. This mismatch in frequencies likely contributed to some loss in efficiency, suggesting that fine-tuning the resonant frequencies could potentially improve overall system performance.

The project also demonstrated some interesting capabilities of the resonant inductive coupling system. Notably, the system showed omnidirectional power transmission capabilities, with the ability to transfer power both in front of and behind the transmitter coil. This feature could be particularly useful in practical applications where precise alignment between transmitter and receiver might be challenging.

Another significant finding was the system's ability to power multiple loads simultaneously using a single transmitter. However, it was observed that adding more loads resulted in a decrease in the power received by each load. This suggests that while the system can support multiple devices, there's a trade-off between the number of devices and the power available to each.

Interestingly, the study found that the presence of obstacles between the transmitter and receiver coils did not significantly impact power transfer. The system was able to maintain power transmission even when objects like a hand or a notebook were placed between the coils. This resilience to obstacles is a valuable characteristic for practical applications, where line-of-sight between transmitter and receiver may not always be possible.

The project also explored the use of resonant capacitors in the receiver circuit. The addition of these capacitors helped to tune the circuit and improve power transfer efficiency. For instance, the 10-turn copper coil used a 1 nF capacitor, while the 5-turn coil used a 15 nF capacitor. However, it was noted that even with a higher capacitance, the

5-turn coil still showed lower efficiency due to its fewer turns, emphasizing the primacy of coil design in determining efficiency.

In terms of safety, the high-frequency operation of the system (in the range of 400-600 kHz) suggests that the energy transfer method is non-radiative and thus potentially safer than radiative methods of wireless power transfer. This could be an important consideration for future applications, especially in consumer electronics or medical devices.

The study acknowledged some limitations and areas for future improvement. The prototype, while functional, was not yet optimized for practical consumer use. The researchers suggested that further refinements to the circuit design could potentially improve efficiency and extend the effective range of power transfer.

In conclusion, this project successfully demonstrated the feasibility of mid-range wireless power transfer using resonant inductive coupling. It highlighted key factors affecting system performance, including coil design, resonant frequency matching, and distance. The system showed promising capabilities such as omnidirectional power transfer, obstacle resilience, and multi-load support. However, it also revealed challenges, particularly in maintaining high efficiency over longer distances. These findings provide valuable insights for future research and development in wireless power transfer technology, pointing towards potential applications in various fields from consumer electronics to electric vehicle charging.

CONCLUSION

This project successfully developed and tested a mid-range wireless power transfer system using resonance inductive coupling. The prototype demonstrated the ability to wirelessly power an LED load up to 20-24 cm distance using a 9V DC power supply. Key findings included the significant impact of receiver coil design on efficiency, with a 30-turn magnetic coil achieving the highest efficiency of nearly 69% at close range. The study highlighted the inverse relationship between distance and power transfer efficiency, and the importance of resonant frequency matching. The system showcased capabilities such as omnidirectional power transmission, powering multiple loads simultaneously, and resilience to obstacles between coils. However, challenges remain in maintaining high efficiency over longer distances. The high-frequency operation (400-600 kHz) suggested potential safety advantages over radiative methods. While the prototype proved the concept's feasibility, further optimization is needed for practical applications. Overall, this research provides valuable insights for future developments in wireless power transfer technology, with potential applications in various fields from consumer electronics to electric vehicle charging, emphasizing the need for continued research to improve efficiency and range.

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