Wireless Power Transfer

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***Abstract*—This research paper delves closely into the cutting-edge subject of Wireless Power Transfer (WPT) technology, with a focus on its uses in low-voltage devices, including chargers for phones and headphones, among other low-voltage devices. Making use of Ansys Maxwell's sophisticated features, we have painstakingly created WPT coils with helical and spiral configurations. In order to maximise power transfer efficiency and precisely meet the requirements of low-voltage electronics, this design technique was carefully selected. A substantial and crucial portion of our investigation was devoted to carrying out an extensive thermal examination. This research was essential to guaranteeing the WPT systems' safe functioning, especially since small electrical equipment are very susceptible to overheating.**

Moreover, complex circuit simulations using MATLAB were utilised to offer a comprehensive comprehension of the WPT system's functionality in different scenarios. These simulations played a key role in estimating the operational reliability and efficiency of the WPT system as well as in analysing its electrical behaviour. Our results provide novel insights into the field of WPT, especially with regard to improving low-voltage consumer devices' safety and efficiency. We have determined the main variables that affect WPT system performance and have put up creative fixes to make these systems more user-friendly. Our study's findings represent a significant advancement in the area and have the potential to completely change how electricity is supplied to tiny, portable devices. This research has a significant influence on the creation of more effective and user-friendly electronic gadgets as it not only tackles present technological issues but also opens the door for future advancements in wireless power transfer.

Keywords: Ansys Maxwell, MATLAB, Circuit Simulation, Efficiency, Safety, Coil Design, Heating Analysis, Low-Voltage Devices, Phone Charging, Headphone Chargers, Wireless Power Transfer.

I. Introduction

The field of low-voltage devices, such as smartphones and wireless headphones, has been greatly impacted by the widespread use of Wireless Power Transfer (WPT) technology. The construction and optimisation of WPT systems for these devices is the main topic of this research. Ansys Maxwell is used to build sophisticated coils in spiral and helical designs. The thorough thermal analysis we carried out to guarantee the secure and effective operation of these WPT systems is a crucial component of our research.

With the aid of Ansys Maxwell, we were able to precisely build coils for low-voltage applications and conduct a thorough analysis of the thermal effects related to wireless power transfer. This thermal study is essential because it reduces the possibility of overheating, which is especially dangerous for consumer electronics. To offer a comprehensive understanding of the system's performance, the electrical parts of the system were modelled using MATLAB's circuit simulation capabilities, which complemented the thermal study.

Given the growing need in the consumer electronics sector for effective, secure, and easy charging options, this research is pertinent and current. Using a combination of theoretical and practical approaches, we address important issues in WPT for low-voltage devices, such as efficiency optimisation, distance restrictions, thermal management, and user safety.

II. Literature Survey

A. "Inductive coupling for wireless power transfer and near-field communication"

An extensive study of wireless power transfer (WPT) systems is presented in this research, with a special emphasis on magnetic coupling as a means of improving power transfer efficiency. To maximise power transfer efficiency, or the total power transmitted, the research entails a thorough analysis and optimisation of load calculations and matching procedures. The improved inductive coupling efficiency, which is especially apparent in the MHz frequency range and is essential for applications like charging electric vehicles, biomedical implants, and smartphone batteries, is one of the main findings. Along with covering frequency characteristics, bandwidth concerns, and the effect of metallic surfaces on inductive coupling, the study also explores the complexities of load modulation for data transfer in RFID and NFC systems. The results of the study significantly advance the area by increasing dependability and efficiency across a range of WPT applications.

B. "Topology With Coupled Inductors for MHz-WPT Applications"

With linked inductors and a push-pull Class E topology, this paper explores a novel design strategy for WPT systems intending to enhance their performance. A unique design technique that improves soft-switching performance, load management, and overall efficiency is provided by the analytical model presented in the paper. Particularly in terms of efficiency and performance, the results show a significant improvement over the traditional inductor-coupled Class E topologies. This improvement in the design and execution of efficient WPT systems is especially important for MHz-frequency applications. The research presents a solid and novel approach to coil design and circuit topology, consequently improving the performance and application of WPT systems in a variety of technical domains.

C. *"Design of High-Efficiency WPT Battery Charging System"*

This study describes a series-series (SS) WPT system that includes a semi-active rectifier (SAR). To attain maximum efficiency, the system employs a mix of variable frequency and impedance matching techniques, particularly in battery charging applications. The findings show a considerable boost in efficiency, addressing the important requirement for better energy management in battery-powered devices. This system's optimised design improves the charging process and adds significantly to the topic of sustainable energy solutions in WPT technology.

These works collectively provide major contributions to the field of WPT, providing novel insights and solutions that significantly improve the technology's efficiency. They span a wide variety of applications, from daily consumer electronics to more specialised applications such as vehicle charging, demonstrating WPT technology's adaptability and transformational potential. The research focuses on inductor design and system optimisation, with the goal of creating more efficient, dependable, and user-friendly wireless power transmission systems. The combined findings of these research provide a solid platform for future improvements in the area, emphasising the significance and extensive application of WPT technology in current technological breakthroughs.

III. Block Diagram

The Wireless Power Transfer (WPT) system block diagram incorporates the required output current and is designed to give a 5V DC output at 2A. The system starts with a 24V DC supply, which serves as the power source. The inverter then converts this direct current (DC) to alternating current (AC) in preparation for wireless transmission. The output of the inverter powers the transmitter coil, which produces a magnetic field that fluctuates with the alternating current.

Within this magnetic field, the receiver coil collects the energy and transforms it to an alternating current voltage via electromagnetic induction. An AC rectifier converts the induced alternating current voltage in the receiver coil to direct current.

The system uses a voltage regulator with Pulse Width Modulation (PWM) control to regulate this DC to a steady 5V output at 2A. To correctly regulate the output voltage, the voltage regulator modulates the PWM signal. The regulator may control the average voltage and current delivered to the load by altering the duty cycle of the PWM. This method is energy-efficient and maintains the intended output even when input circumstances or load demands change.

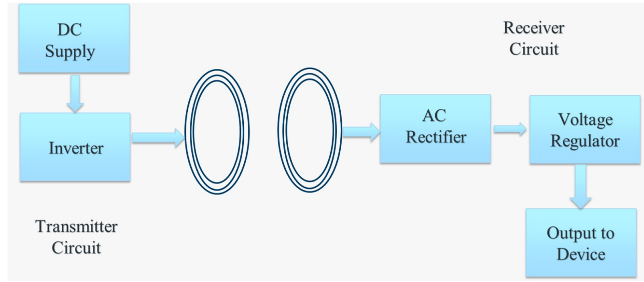

Fig. 1: Project Block Diagram

$$L = \frac{(V_o - V_{in}) * D}{\Delta I_L * V_{in} * F_s}$$

Fig. 2: Inductor Calcuation

IV. Design Procedure

Wireless power transfer (WPT) systems have gained significant attention due to their potential applications in various fields such as small devices up to the electric vehicle charging. This report contains the design process, methodology, and strategy of a Wireless power transfer (WPT) system, emphasizing constraints such as input voltage, output voltage, current the distance between the coils, and efficiency. We have chosen the inductive coupling method for wireless power transfer; the method is a widely used approach and it provides better efficiency and reliability compared to the other available techniques in the engineering world. In this project, we have used the Ansys Maxwell and MATLAB Simulink for coil designing and circuit designing respectively. ANSYS provides advanced electromagnetic simulation capabilities, while MATLAB Simulink facilitates the analysis of the electrical circuit. The transmitter design and receiver design is done in the ansys maxwell, the resonant frequency for the design is calculated by formula Resonant frequency(Fs) =1/(2pi sqrtLC)

Where, Fs = is the resonant frequency L= Total inductance(Self-inductance and mutual inductance) C = Total capacitance of the circuit Circuit designing was also a crucial part of the project. Looking at the available components in the market we have kept the input voltage as 24 volts and tried to get the 10w power at output i.e. 5v output at 2 Amps. We have used the MOSFET switching using the H-Bridge design in the primary transmitter circuit. Which is operating at the resonant frequency i.e., 4.972KHz. The standard resonant frequency in the market is around 5K. The input and output parameters plays the crucial role in designing the inductance of the coils, so considering the parameters we have calculated the inductance of the coils by Fig. 2

Where, Vin = 24V, Vo = 5V, Fs = 50KHz, Po=10W D = Vo/Vin = 0.2083 âIL=0.8*Io =0.8*2A =1.6A L = 7.46ÂμH

The relation between the coupling coefficient(K), Efficiency and distance between the coils can be determined by following the formula Fig.3 Where K = coupling coefficient Âμ =

$$K = \frac{\mu A/d}{\sqrt{L1,l2}}$$

Fig. 3: Coupling Coefficient and Distance formule

$$V_c(k) = V_c(k-1) + K_p$$
$$\{V_E(k) - V_E(k-1)\} + K_i V_E(k)$$

Fig. 4: Error Voltage correction Formule

$freespace 4pix10 - 7A = Crosssectionalareaofcoild = distancebetweencoils.$

In this we have added a controller for performing analyses and getting better efficiency, the controlled gate pulses are provided for the dc-dc converter switches. The reference DC voltage (V dc) is checked with the measured DC voltage (Vdc)and the error DC voltage (Ve) is obtained as The error voltage is then provided to controller, from which the reference-controlled voltage VC is obtained as follows.(Fig. 4)

Where k denotes the sampling period. The pulses generated for the dc-dc converter are of by comparing the control signal VC with high frequency carrier signal MC as If MC less than to VC,pulse is ON. If MC greater or equal toVC,pulse is OFF.

V. Circuit and Simulation

The Simulink model depicts a Wireless Power Transfer (WPT) system designed to produce a 5V output at 2A with a 24V input at 0.5A, providing a power output of 10W. To assist power transfer, the system includes a complete bridge converter that connects with the inductor coil and a resonance capacitor.The mutual inductance of the primary and secondary coils in the arrangement is 7.6H. The resonance frequency is set at 4.972kHz, and the system is designed to function throughout a range of coupling coefficients from 1 to 0, where 1 indicates that the coils are close enough to transfer energy successfully, while 0 indicates that the coils are too far away to transmit energy effectively. The system's resistive load is 2.5 ohms.

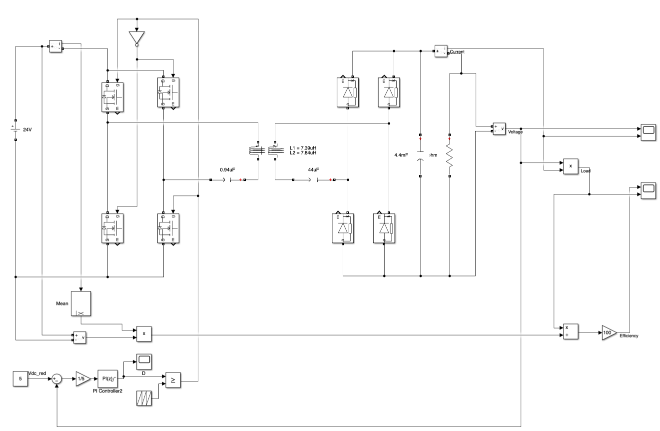

Fig. 5: Circuit Diagram

The output voltage and current are monitored to monitor the system's performance. This enables the computation of input power, which is required to determine the system's efficiency. To determine the error voltage, the output voltage is continually compared to the reference value of 5V. This error voltage is then transformed to a per-unit number that represents the proportional difference between the desired output and the error voltage.This per-unit error is utilised to tune the system to rectify any variation from the 5V reference by adjusting the duty ratio of the converter. The PWM pulse generator employs a high-frequency carrier wave of 50kHz while accounting for the duty ratio from the converter. This procedure is performed recursively, resulting in a ramp signal that constantly adjusts to keep the output voltage at the correct level.

The PWM output of this control loop is utilised to drive the gates of switches S1 and S2, with an inverted PWM signal driving S3 and S4. This generates the switching required for the complete bridge converter to function properly. The circuit then connects to a coupling inductor with a value of 7.8H, which promotes the transmission of electromagnetic force (EMF) from the primary to the secondary coil.

Following the transmission of power to the secondary coil, the alternating current is rectified to create a steady 5V DC output that powers the load. This rectification is critical for converting the induced AC back to the needed DC output for the powered device. The control system guarantees that the output voltage and current remain at the target levels despite fluctuations in the coupling conditions or load variations via its feedback loop and PWM modulation.

The coil design shown in the figure below shows the two different designs with Helical and spiral structure respectively. The result we got are almost identical. The major effect of design is the placement of the device being charged. More the surface area more will be the efficiency. The spiral structure gave the more area compared to the helical structure so it is efficient in the placement. But for the better efficiency the helical coils are the better options.

The Table above shows the observed relation between the Efficiency, Distance between the two coils, and coupling coefficient. It is observed that with a change in the distance of the coils, the coupling coefficient value also changed and it is directly proportional. Where on the other hand with the increase in distance between the coils the efficiency of the output decreases. That means the efficiency and the distance are two inversely proportional quantities.

VI. Results

The project delves into the development of efficient wireless power transfer (WPT) systems utilizing resonant inductive coupling. Key performance metrics such as the coupling coefficient, mutual and self-inductance, and their impact on the distance between coils and efficiency rates are investigated. The study identifies a direct correlation between these parameters, noting efficiency percentages ranging from 50 to 97

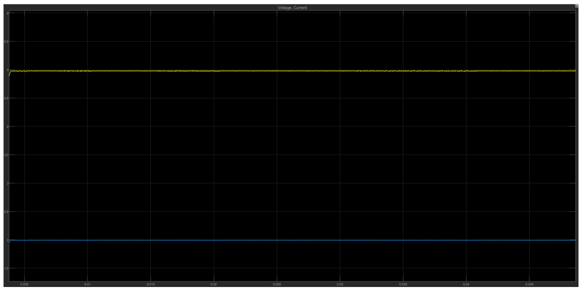

Fig. 6: Voltage And Current Output

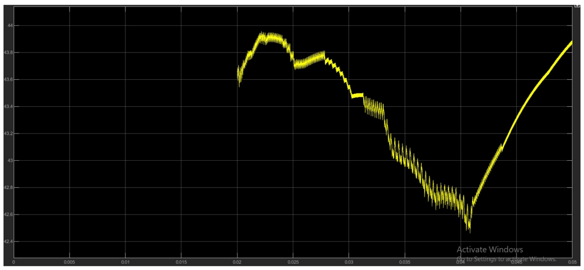

Fig. 7: Efficientcy at 0.25 Coupling Coefficient

percentage as the coupling coefficient varies. The project addresses several challenges, including minimizing energy losses during transfer, optimizing coil designs for peak efficiency, managing heat to prevent overheating issues, and ensuring compatibility across different devices.

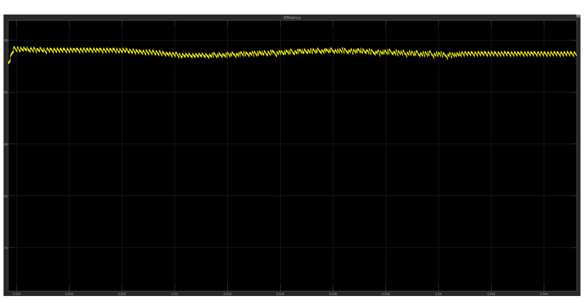

Fig. 8: Efficientcy at 0.95 5Coupling Coefficient

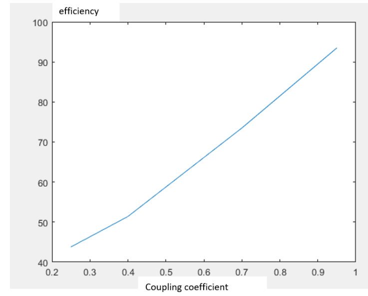

Fig. 9: Efficientcy vs K

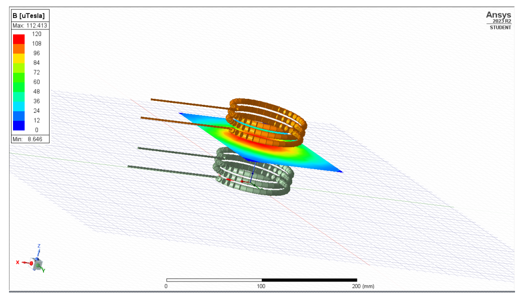

Fig. 10: Helical Coil Structure Analysis

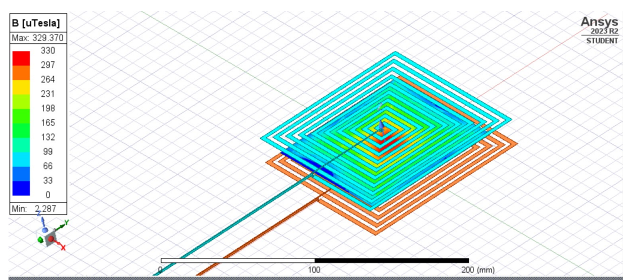

Fig. 11: Spiral Coil Structure Analysis

L Table 3

	distt [mm]	Matrix1.L(Rx_in,Rx_in) [uH] Setup1 : LastAdaptive	Matrix1.L(Tx_in,Rx_in) [uH] Setup1 : LastAdaptive	Matrix1.L(Rx_in,Tx_in) [uH] Setup1 : LastAdaptive	Matrix1.L(Tx_in,Tx_in) [uH] Setup1 : LastAdaptive
1	10.000000	6.403649	3.675127	3.675127	6.414035
2	15.000000	6.468784	3.051840	3.051840	6.459303
3	20.000000	6.466045	2.558575	2.558575	6.492145

Fig. 12: Inductance Table vs Distance

Coupling Coefficient (K)	Distance(mm)	Efficiency(%)
0.95	8.7549	97
0.75	11.095	75
0.60	13.950	70
0.50	16.643	60
0.40	20.804	50

Fig. 13: K vs Distance vs Efficiency