Wireless Power Transmission using additively manufactured ferrite pad

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***Abstract*— Wireless power transfer (WPT) is a promising technology for various purposes, but efficiency remains a key challenge. This research investigates using additively manufactured ferrite pads to enhance wireless power transmission efficiency. By utilizing manganese-zinc ferrite cores with precise 3D-printed geometries, the study aims to improve magnetic flux coupling and reduce energy losses. Using ANSYS Maxwell simulations and experimental setups with AWG 40 Litz wire coils, the research explored how ferrite materials impact power transfer performance. The findings demonstrate the significant improvements: simulations achieved a transfer efficiency of 89% while the experimental data showed output results increasing from 26.27 mV to 40.46 mV when using a ferrite pad. The study addresses critical WPT challenges such as coil misalignment, distance variations, and power density, offering insights into developing more efficient wireless charging solutions and other applications.**

Key Words— Wireless, 3D printing, charging, EVs, ***AC***

I. INTRODUCTION

No one had imagined when great Nikola Tesla in the 20th century was dedicated to transmitting power wirelessly. Wireless power transfer (WPT) is a rapidly advancing technology and one of the hot topics for researchers and scientists that enables the transfer of energy without the need for physical cords or wires[1]. This exceptional technology has an opportunity to transform the way humans utilize energy in a variety of applications, including low-power networks, portable electronics, implanted medical equipment, integrated circuits, renewable satellites, electric vehicles (EVs), and unmanned aerial vehicles. WPT technology, with its unique adaptability, freedom of placement, and movement ability, is regarded as a suitable future solution to power electrically driven devices [2]. Under the Paris Agreement, the U.S. committed to cutting emissions by 26-28% from 2005 levels by 2025, updated to 50-52% by 2030. As the largest GHG emitter, the U.S. transport sector contributed 28.2% of national emissions in 2018 and 69% of petroleum use in 2019, heavily impacting the environment [3]. As a result, there has been a noticeable trend toward electric vehicles (EVs), which are regarded as an important component of the answer to battle climate change. However, the growing popularity of electric vehicles creates a pressing demand for convenient and accessible charging alternatives.

Wireless charging technology has emerged as a promising option for assisting with the clean energy transition, as it is both convenient and efficient. As more people use EVs, the demand for novel charging methods will grow, paving the path for a more sustainable future in transportation [4].

One of the primary drawbacks of wireless power transfer (WPT) for electric vehicles (EVs) is its efficiency, which is reduced due to factors such as coil misalignment and variations in the distance between the transmitting (TX) and receiving (RX) coils. Previous research has shown that these features have significant effects on the coupling coefficient, and thus the efficiency of the wireless power transfer (WPT) system [5]. Although there are different solutions offered, such as specific coil designs and compensation networks, they generally add complexity, raise costs, and might reduce system reliability. Another essential factor to consider is the cost of wireless power transfer (WPT) technologies [6]. It is critical to determine whether these systems are within reach of ordinary users. Many of the designs we see today operate at higher frequencies, which improves efficiency but increases component costs and system complexity. This balancing act between efficiency and cost has significantly slowed the adoption of WPT systems in electric vehicles, particularly in the general market.

However, the difficulties of efficiency and power density in wireless power transfer (WPT) systems remain key challenges that must be addressed if these systems are to become

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mainstream for electric vehicles. This research investigates how utilizing a ferrite pad in our coil simulations can assist enhance the overall efficiency of power transfer.

Additionally, this research paper explores how factors like coil misalignment and distance can affect the efficiency of wireless power transfer (WPT) systems, which is important for their practical use in the real world. The solutions we present in this paper aim to tackle these challenges and enhance the efficiency of existing wireless charging methods.

We focus on designing both transmitting and receiving coils that work well with resonant inductive coupling or magnetic resonant coupling. We also investigate compensation circuits that can help improve power transfer efficiency. To better understand how the system performs, we create physical models and conduct simulations of our proposed system using ANSYS Maxwell and we found that it achieved a transfer efficiency of about 89%, along with an increase in power density. In our previous studies, we have studied FPGA-based variable frequency soft-starting motor drive [7] for improved harmonic performance and also developed an accessible DC motor control system [8].

II. BACKGROUND ON INDUCTIVE RESONANT COUPLING

Inductive resonant coupling facilitates efficient wireless power transfer by leveraging the principles of electromagnetic induction and resonance. In this mechanism, a transmitter coil generates an oscillating magnetic field, which induces an alternating current (AC) in a spatially separated receiver coil. Both coils are designed to resonate at the same frequency, governed by their inductive and capacitive elements, ensuring maximal energy exchange within the system.

At resonance, the system achieves minimal impedance, allowing for the seamless oscillation of energy between the magnetic field of the inductors and the electric field of the capacitors. The phase coherence between transmitter and receiver, maintained through magnetic phase-synchronization is critical for sustaining high efficiency, even when the physical alignment of the coil is suboptimal.

III. PRIOR WORKS ON FERRITE MATERIALS ON WPT SYSTEMS

Magnetic flux loss is a significant concern in wireless power transmission (WPT) systems, highlighting the importance of ferrite materials. These materials possess exceptional magnetic permeability, which ensures effective magnetic flux coupling and reduces energy losses. Their low coercivity allows for efficient energy transfer while effectively managing thermal dynamics, thus enhancing the overall reliability and performance of the system. Additionally, the lightweight and compact nature of ferrites make them particularly suitable for application in space-constrained environments, driving advancements in WPT technologies across various industries [9]. Three case studies were conducted to evaluate the performance of the wireless power transfer system and its electromagnetic field. The configurations analyzed included (1)

WPT coils [9]. (2) WPT coils with ferrite core, and (3) WPT coils with both a ferrite core and aluminum plate. The WPT coils with the ferrite core demonstrated the highest power transfer efficiency at 91% [9]. However, the addition of aluminum plates decreased the system's performance to 86.9% [9]. In contrast, the configuration without either the ferrite core or aluminum plates yielded a lower power transfer efficiency of 79.86%. These findings suggest that practical WPT systems should incorporate ferromagnetic materials in their shielding to improve power transfer [9].

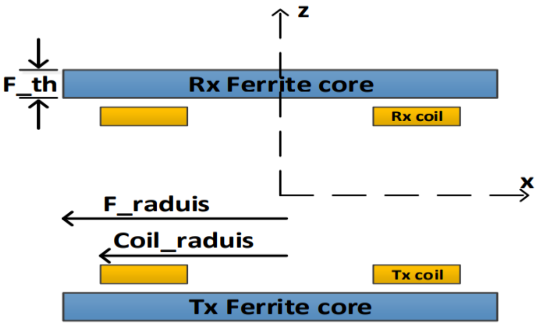


Fig1: WPT system in presence of ferrite core [7]

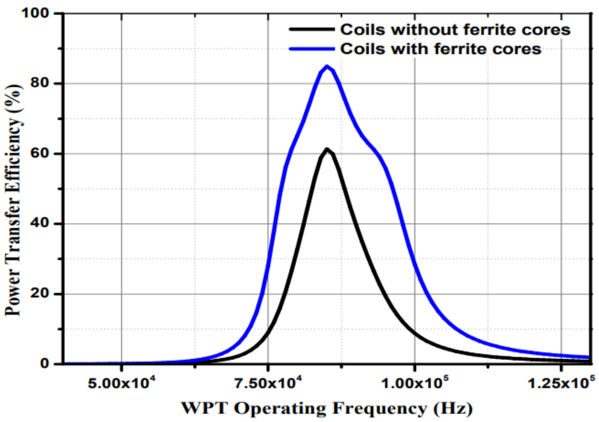


Fig 2: WPT efficiency with ferrite & without ferrite.[9]

TABLE I. EXPERIMENTAL DATA [9]

Parameters	*Tx Self-inductance(μH)*	*Rx self- inductance (μH)*
Tx Self-inductance(μH)	210.1	360.11
Rx self- inductance (μH)	212.96	360.6
Mutal inductance (μH)	33.611	77.718
The coupling coefficient (A)	0.158	0.216
Primary current (A)	12.43	5.38
Secondary current (A)	4.47	4.47

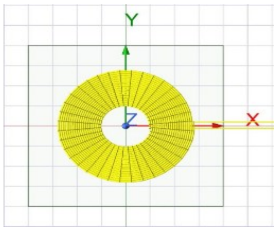
IV. SIMULATION

For the simulation in ANSYS-Maxwell, 3D, a circular coil is chosen having following parameters.

-Name of Litz Wire- 48 AWG

-Coil radius- 0.41 mm
-Starting radius- 10 mm
-Number of turns- 20

The simulation was set up with different sweeping distances for which different self-inductance and mutual inductance were got which are as follows. The coupling coefficient for different distances is also plotted. The simplorer circuit was built and a voltage of 20 V was applied with a frequency of 2.5 MHz The overall efficiency was found to be 89.92% with using ferrite material.



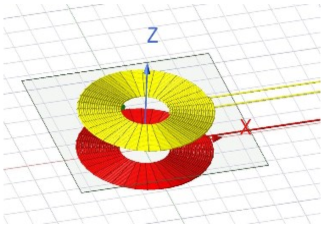


Fig 3: z-axis view of coil simulation Fig 4: Excitation of coil

TABLE II. SELF AND MUTUAL INDUCTANCE IN COIL VS DISTANCE

Parameters	Z_Space (mm)			
	10	***20***	***30***	***40***
Self-inductance (Rx) (µH)	15.785	15.782	15.773	15.760
Mutual inductance (Tx-Rx) (µH)	6.630	3.145	1.632	0.908
Mutual inductance (Rx-Tx) (µH)	6.630	3.145	1.632	0.908
Self-inductance (Tx) (µH)	15.785	15.787	15.788	15.788

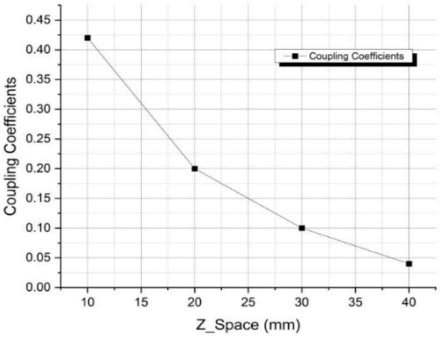
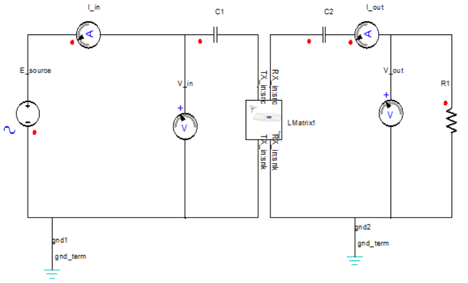


Fig5: Coupling coefficient distance with distance

Fig 6: Simplorer circuit block



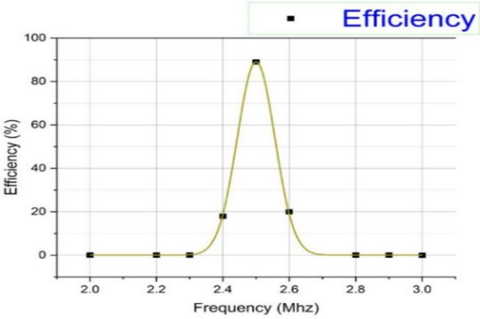


Fig 7: Efficiency Vs Frequency Plot

V. PHYSICAL EXPERIMENTAL METHODOLOGY

The experimental setup consists of two coils made up of AWG 40 Litz wire, with each coil enclosed by a 3D-printed ferrite core, serving as a magnetic shell to enhance flux confinement.

The ferrite cores, fabricated from ferromagnetic materials, were produced using additive manufacturing [10], [11], [12] to achieve precise geometries tailored for optimal magnetic performances. The ferrite that was used to in house manufacture our ferrite core was manganese-Zinc ferrites with composition of iron oxides, manganese oxides and zinc oxides. The coils were manually wound with uniform turns to ensure consistent inductance and tight coupling, thereby maximizing power transfer efficiency.

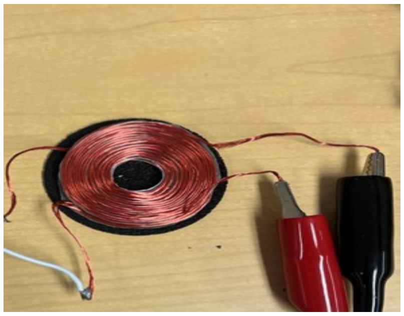


Figure 8: Transmission coil on top of ferrite pad

To maintain proper alignment between the coils, it was ensured that the center of the ferrite pads was aligned with each other to get the maximum outcome.

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Figure 9: Dwell of coil in the ferrite pad

VI. RESULTS AND ANALYSIS

It is seen that the efficiency of transmitted power has increased using ferrite material with coil in simulation. It must be now done with the physical setup of the coil and passing the power to the coil.

The result data were taken with and without a ferrite pad. In the first step, the coil was supplied with an AC of 10 VPP with a frequency of 220 kHz to the transmission coil. A similar thing was repeated in the second step but with ferrite pad this time. The use of a ferrite pad yielded a better result. The following table depicts the results obtained in the two different scenarios.

TABLE III. VIN/OUT WITH AND WITHOUT FERRITE PAD

Vout without ferrite pad at Vin = 10Vpp	**Vout with ferrite pad at Vin= 10Vpp**
26.27 mV	40.46 mV

VII. SUMMARY AND FUTURE WORK

In this paper, we presented an innovative approach to wireless power transmission utilizing additively manufactured ferrite pad. Through ANSYS Maxwell simulations, we achieved a transfer efficiency of 89%. Our design featuring manganese-zinc ferrite cores and AWG 40 Litz wire coils, addressed key challenges in WPT systems including coil misalignment and distance variations.

Future work will focus on optimizing ferrite pad geometries, developing adaptive control systems for misalignment compensation, and investigating thermal management strategies for high-power applications. This research provides a foundation for developing efficient wireless charging solutions, particularly for electric vehicles applications where reliability and performance are crucial.

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