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Analysis of Coil Geometry and Coupling Coefficient Effects on Wireless Power Transfer Efficiency for Mobile Device Charging Applications

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Abstract
Wireless power transfer (WPT) technology has emerged as an efficient alternative to conventional wired charging systems for portable electronic devices. However, the performance of inductive wireless charging systems is strongly influenced by coil geometry, magnetic coupling, and system alignment. This study presents an analysis of the effects of coil geometry and coupling coefficient on the efficiency of an inductive wireless power transfer system for mobile device charging applications. A mathematical model of a loosely coupled transformer system was developed, considering transmitter and receiver coil parameters, mutual inductance, coupling coefficient, and load characteristics. MATLAB/Simulink was used to evaluate the influence of coil turns, coil diameter, and separation distance on output voltage, charging current, and power transfer efficiency. The results demonstrate that optimized coil geometry improves magnetic flux linkage and increases energy transfer efficiency. Furthermore, the coupling coefficient was identified as a critical factor controlling system performance, where improved coupling conditions resulted in higher output power and reduced energy losses. The study provides design guidelines for improving the efficiency and reliability of wireless charging systems for mobile electronic devices.

Keywords: *Wireless power transfer, inductive coupling, coil geometry, coupling coefficient, mutual inductance, MATLAB/Simulink, mobile charging.*

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I. Introduction

The increasing demand for smartphones and portable electronic devices has created the need for reliable and efficient charging technologies. Modern mobile devices require frequent charging due to increased processing capability, internet connectivity, multimedia applications, and energy-intensive operations. Conventional wired charging methods, although widely adopted, present several limitations including cable deterioration, charging port damage, inconvenience, and reduced flexibility.

Wireless power transfer (WPT) provides a solution by enabling electrical energy transfer without physical electrical connections. Among various wireless energy transfer methods, inductive power transfer (IPT) remains one of the most widely applied techniques for mobile device charging because of its simplicity, safety, and suitability for short-range applications (Ahmed et al., 2020).

The operation of inductive WPT systems is based on electromagnetic induction, where alternating current supplied to the transmitter coil generates a magnetic field that induces voltage in the receiver coil. The efficiency of the system depends on several parameters including coil geometry, mutual inductance, coupling coefficient, operating frequency, and distance between coils (Zhang et al., 2020).

Recent studies have shown that coil optimization is essential for achieving improved wireless charging performance. Parameters such as coil diameter, number of turns, wire arrangement, and alignment significantly affect magnetic field distribution and power transfer capability (Chen et al., 2021). Similarly, the coupling coefficient between transmitter and receiver coils determines the strength of magnetic interaction and directly influences energy transfer efficiency (Wang et al., 2022).

Therefore, this study investigates the influence of coil geometry and coupling coefficient on wireless power transfer efficiency for mobile device charging applications using MATLAB/Simulink simulation.

II. Literature Review

2.1 Inductive Wireless Power Transfer

Inductive wireless power transfer systems operate similarly to loosely coupled transformers where energy is transferred through magnetic coupling rather than direct electrical connection. The transmitter coil produces magnetic flux, while the receiver coil captures the flux and converts it into electrical energy.

Li et al. (2021) investigated compensation techniques for improving wireless power transfer performance and showed that proper system tuning reduces reactive power losses and improves efficiency.

2.2 Effect of Coil Geometry on System Performance

Coil geometry is one of the most important factors affecting wireless charging efficiency. The physical characteristics of the coil determine magnetic flux distribution and coupling strength.

Yao et al. (2021) reported that optimized coil parameters improve energy transfer efficiency by increasing magnetic field interaction between the transmitter and receiver coils.

Park et al. (2022) studied coil geometry optimization and found that coil dimensions, shape, and winding arrangement significantly affect charging performance.

2.3 Coupling Coefficient and Mutual Inductance

The coupling coefficient represents the degree of magnetic interaction between two coils.

The relationship between mutual inductance and coupling coefficient is expressed as:

$M=K\sqrt{L1L2}$

Where:

M = mutual inductance

K = coupling coefficient

L1 = transmitter inductance

L2 = receiver inductance

Higher coupling coefficient values improve energy transfer by increasing magnetic flux linkage.

Chen et al. (2021) demonstrated that improved magnetic coupling structures enhance wireless power transfer efficiency and reduce leakage losses.

III. Methodology

3.1 System Configuration

The proposed wireless charging system consists of:

DC Supply

↓

High Frequency Inverter

↓

Transmitter Coil

↓

Magnetic Coupling Link

↓

Receiver Coil

↓

Rectifier Circuit

↓

Voltage Regulator

↓

Mobile Device Battery

3.2 Mathematical Model

The transmitter and receiver coil voltage equations are:

$V1= L1\frac{di1}{dt}+ M\frac{di2}{dt}$

$V2= L2\frac{di2}{dt}+ M\frac{di1}{dt}$

The power transfer efficiency is calculated as:

$\eta= \frac{Pout}{Pin}\times 100$

3.3 Simulation Parameters

Parameter	Value
Input Voltage	12V
Frequency	150KHz
Transmitter turns	9
Receiver turns	36
Coil diameter	9 cm
Wire type	Copper
Air gap	0–2 cm

IV. Results and Discussion

4.1 Effect of Coil Distance

The simulation results show that increasing the distance between transmitter and receiver coils reduces charging current and efficiency.

This occurs because increased separation reduces magnetic coupling and mutual inductance.

4.2 Effect of Coil Turns

Increasing the number of receiver coil turns improves induced voltage due to increased magnetic flux linkage.

The optimized coil configuration produces higher output voltage suitable for mobile charging applications.

4.3 Effect of Coupling Coefficient

The coupling coefficient has a direct effect on energy transfer efficiency.

Higher coupling values produce:

1. Increased mutual inductance
2. Higher output power
3. Improved charging efficiency

Poor coupling results in:

1. Magnetic leakage
2. Reduced output voltage
3. Increased losses

4.4 Figures 1–5. Coil Geometry and System Configuration, Simulation Block diagram, Magnetic Block Diagram, Simulation Results and Time Domain Waveforms.

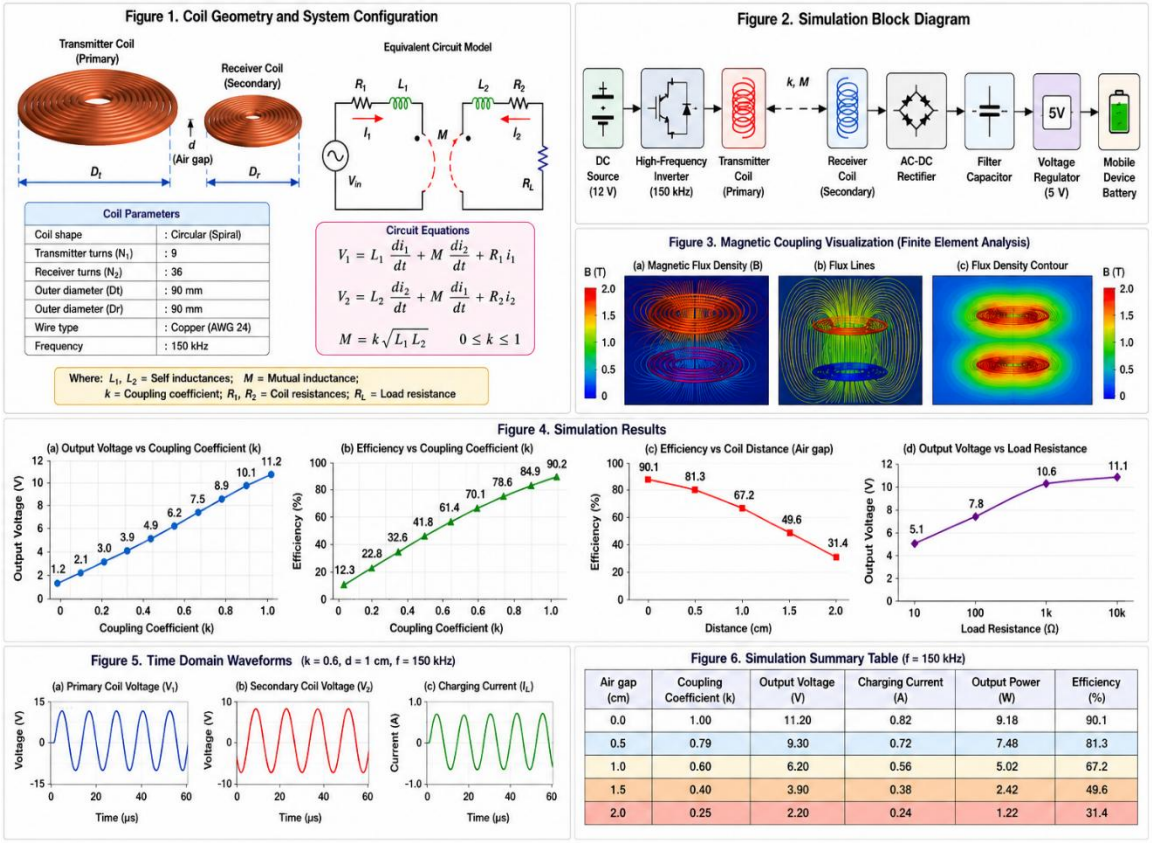


Figure 6. Simulation Summary Table (f = 150 kHz)

Air gap (cm)	Coupling Coefficient (k)	Output Voltage (V)	Charging Current (A)	Output Power (W)	Efficiency (%)
0.0	1.00	11.20	0.82	9.18	90.1
0.5	0.79	9.30	0.72	7.48	81.3
1.0	0.60	6.20	0.56	5.02	67.2
1.5	0.40	3.90	0.38	2.42	49.6
2.0	0.25	2.20	0.24	1.22	31.4

The figures present the design, modelling, and performance evaluation of an inductive wireless power transfer (WPT) system for mobile device charging. The analysis demonstrates the influence of coil geometry, coupling coefficient, coil separation distance, and load conditions on the overall wireless charging performance.

The coil geometry configuration shows that the transmitter and receiver coils are the major components responsible for magnetic energy transfer. The number of turns, coil diameter, and alignment determine the magnetic flux linkage between the coils. The equivalent circuit model confirms that the mutual inductance between the coils is controlled by the coupling coefficient, which directly affects power transfer capability.

The simulation block diagram illustrates the complete energy conversion process, starting from the DC supply, high-frequency inverter, transmitter coil, magnetic coupling link, receiver coil, rectification stage, voltage regulation, and final mobile battery charging load.

The magnetic coupling visualization indicates that stronger magnetic flux interaction occurs when the transmitter and receiver coils are properly aligned. Improved flux linkage enhances mutual inductance and increases the amount of energy transferred to the receiving coil.

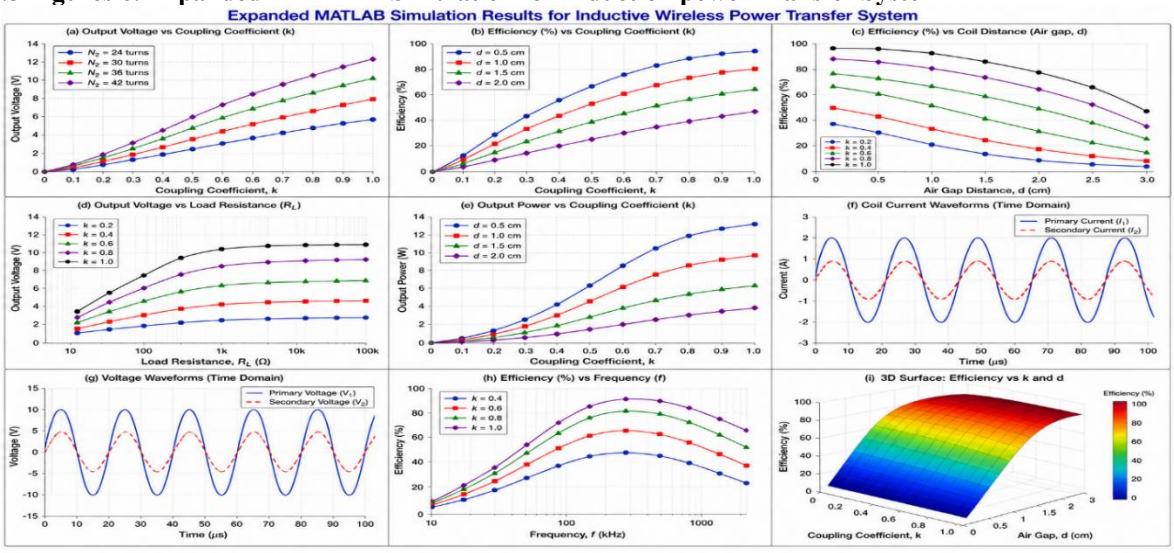
The simulation results reveal that wireless power transfer efficiency increases with higher coupling coefficient values. As the coupling coefficient improves, the output voltage and transferred power increase due to stronger magnetic coupling between the coils. Conversely, increasing the air gap distance between the coils reduces efficiency because of reduced magnetic flux linkage and increased leakage losses.

The efficiency curve shows that the system achieves its highest efficiency when the coils are closely positioned, while performance decreases significantly as separation distance increases. This confirms that maintaining proper coil alignment and minimizing the air gap are essential for efficient wireless charging.

The time-domain waveform results demonstrate successful energy transfer from the primary coil to the secondary coil, showing stable voltage and current responses during operation. The simulation summary indicates that optimized coil parameters can provide suitable output power levels for mobile device charging applications.

Overall, the results confirm that coil geometry optimization and coupling coefficient improvement are critical factors for achieving high-efficiency inductive wireless power transfer systems. The findings provide useful design guidelines for developing compact, reliable, and efficient wireless chargers for portable electronic devices.

4.5 Figures 6. Expanded MATLAB Simulation for Induction power Transfer System



The MATLAB/Simulink simulation evaluates the influence of coil geometry, coupling coefficient, coil separation distance, load resistance, and operating frequency on the performance of an inductive wireless power transfer (WPT) system for mobile device charging applications.The simulation results show that the coupling coefficient (k) is a major factor affecting wireless power transfer performance. As the coupling coefficient increases, the magnetic interaction between the transmitter and receiver coils improves, resulting in increased output voltage, transferred power, and overall system efficiency. Higher coupling values indicate stronger mutual inductance and better magnetic flux linkage.

The output voltage analysis demonstrates that increasing the number of receiver coil turns improves induced voltage. This is because a larger number of turns increases the amount of magnetic flux linkage, thereby enhancing voltage generation at the receiver side.

The efficiency versus coupling coefficient analysis shows a positive relationship between coupling strength and energy transfer efficiency. The system achieves maximum efficiency under conditions of high coupling coefficient and reduced coil separation distance. This confirms that proper coil alignment and optimized coil geometry are essential for efficient wireless charging.

The coil distance analysis indicates that efficiency decreases as the air gap between the transmitter and receiver coils increases. The reduction occurs due to weakened magnetic coupling, reduced mutual inductance, and increased magnetic leakage. Therefore, minimizing the separation distance improves charging performance.

The load resistance analysis shows that output voltage increases with increasing load resistance until an optimum operating point is reached. Beyond this point, the improvement becomes limited due to reduced power transfer capability of the system.

The time-domain waveform results confirm successful energy transfer between the primary and secondary coils. The transmitter coil produces an alternating voltage and current waveform, while the receiver coil obtains an induced waveform suitable for rectification and battery charging.

The frequency response analysis indicates that the wireless power transfer system has an optimum operating frequency where maximum efficiency is achieved. Operation away from the resonant frequency results in reduced energy transfer due to increased reactive losses.

The 3D efficiency surface plot illustrates the combined effect of coupling coefficient and air gap distance. The highest efficiency region occurs at high coupling coefficient values and small coil separation distances.

The findings from the studies of the MATLAB/Simulink results confirm that;

1. Optimized coil geometry improves magnetic flux coupling.
2. Higher coupling coefficient increases power transfer efficiency.
3. Smaller air gaps produce better charging performance.
4. Proper selection of operating frequency enhances system efficiency.
5. Inductive wireless power transfer is suitable for efficient mobile device charging applications.

V. Conclusion

This study analyzed the effects of coil geometry and coupling coefficient on the efficiency of an inductive wireless power transfer system for mobile device charging applications. The results show that coil parameters and magnetic coupling conditions significantly influence system performance.Optimized coil geometry improves magnetic flux linkage and enhances energy transfer efficiency. The coupling coefficient was identified as a key parameter controlling wireless charging effectiveness, with stronger coupling resulting in improved output power and reduced losses.

The study demonstrates that proper coil design optimization is essential for developing efficient wireless charging systems suitable for modern mobile devices.

VI. Recommendations

Future studies should focus on:

1. Adaptive coil alignment mechanisms.
2. Advanced compensation circuits.
3. Artificial intelligence-based optimization techniques.
4. Integration with renewable energy charging systems.
5. Experimental validation of the MATLAB/Simulink model.

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