

Comparative Analysis of Litz and Planar Coils for Inductive Wireless Power Transfer Systems [†]

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Abstract

This paper presents a comparative electromagnetic study of litz-wire planar coil technologies for wireless power transfer (WPT) applications, focusing on geometrical scaling and coupling robustness. Four coil configurations are analyzed using three-dimensional finite element simulations in Ansys Maxwell, including individual coil characterization, baseline WPT performance, gap sensitivity, and loss-related evaluation. The results show that planar coil can achieve coupling performance comparable to litz-wire implementations, particularly on the receiver side, but exhibit significantly higher conduction losses in non-optimized configurations. The findings highlight the trade-off between coupling capability and loss mechanisms, emphasizing the importance of coil design optimization for compact and efficient WPT systems.

Keywords: WPT; Maxwell; numerical simulations; spiral inductor

1. Introduction

Inductive wireless power transfer (WPT) systems rely on magnetic coupling between transmitter and receiver coils, where self-inductance, mutual inductance, and coupling coefficient govern power transfer capability, while resistive losses determine efficiency [1,2]. Coil design therefore involves a trade-off between magnetic flux coupling and loss minimization [3,4]. Inductive WPT has gained significant attention in applications such as electric vehicles and compact electronic systems [5–10]. However, coil miniaturization reduces the effective coupling area, leading to decreased mutual inductance and increased sensitivity to separation and misalignment [11–13]. From a manufacturing perspective, litz-wire and planar PCB-based coils represent two widely used but fundamentally different technologies [14,15]. This work presents a systematic electromagnetic comparison between litz-wire and planar coil technologies under geometrical scaling and WPT operating conditions.

2. Modeling and Simulation Setup

2.1. Numerical Modeling Approach

The process of this work begins with the selection of reference coil designs for which manufacturer datasheets provide key electromagnetic parameters. Based on this information, three-dimensional coil models are implemented in ANSYS Maxwell 2023 R2 (ANSYS



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Inc., Canonsburg, PA, USA). After geometry definition, electromagnetic finite-element simulations are performed to analyze the coil behavior. The extracted parameters of interest are subsequently compared against the corresponding datasheet values. If sufficient agreement is achieved, the model is considered validated. Otherwise, the geometrical parameters are iteratively refined, and the simulation process is repeated.

2.2. Investigated Coil Configurations

Four coil configurations are investigated to assess the combined effects of geometrical scaling and conductor technology: big litz-wire (BL), small litz-wire (SL), big planar (BP), and small planar (SP). The coils are designed as detailed coil models to more accurately represent the electromagnetic behavior according to [16]. The SL geometry is obtained by scaling the BL design, while planar coils are adjusted to achieve comparable inductance values, enabling a fair comparison. All coils are modeled using copper conductors (with an electric conductivity of $\sigma = 5.8 \times 10^7$ S/m) and planar coils are implemented on an FR4 substrate with an underlying ferrite layer ($\mu_r = 12$). The main geometrical parameters are summarized in Table 1. A sinusoidal current excitation of 1 A at 125 kHz is applied. In the simulation models, only the transmitter coil is excited while the receiver remains an open circuit.

Table 1. Geometrical properties of coil configurations.

Coil Designator	BL	SL	BP	SP
Outer diameter [mm]	30.1	22.0	31.4	24.0
Inner diameter [mm]	12.4	12.2	12.4	12.2
Conductor thickness [mm]	0.50	0.15	0.035	0.035
Conductor width [mm]	0.50	0.15	0.50	0.15
Turns spacing [mm]	0.10	0.10	0.10	0.10
Number of turns	15	20	16	24

3. Results and Discussion

3.1. Individual Coil Characterization

Table 2 summarizes the single-coil electromagnetic parameters for the configurations investigated.

Table 2. Single-coil electromagnetic performance evaluation.

Coil Designator	L [μ H]	Rac [Ω]	Q	Loss [W]
BL	9.78	0.17	44.02	0.09
SL	17.92	0.88	16.01	0.44
BP	9.19	1.14	6.34	0.57
SP	18.43	4.68	3.09	2.34

The results show that smaller coils achieve higher inductance due to increased turn count, but at the expense of significantly higher AC resistance, leading to a reduced quality factor. Planar coil consistently exhibits higher AC resistance than its litz-wire counterparts at comparable inductance levels, with the effect being most pronounced for the small planar configuration. Figure 1 illustrates the magnetic field distribution for the litz-wire coil configurations. As an example, the comparison between the large-scale (BL) and miniaturized (SL) coils shows that the SL configuration exhibits higher local peak field values near the conductors. This behavior is attributed to magnetic flux concentration within a reduced spatial region and increased superposition of individual turn contributions in the miniaturized geometry.

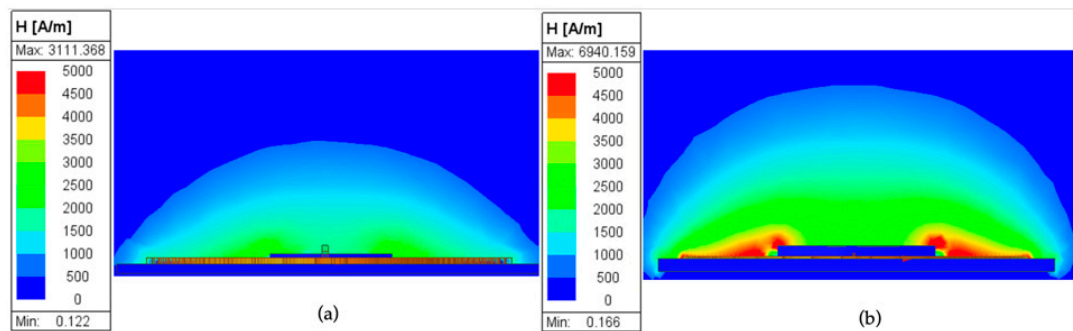


Figure 1. Magnetic field distribution of (a) BL; (b) SL.

3.2. Baseline WPT Performance

Figure 2 presents an example of the WPT system formed by two litz-wire coils called BL-BL that are separated by a vertical distance of 10 mm. Table 3 summarizes the baseline WPT performance of the investigated coil pair with 10 mm separation.

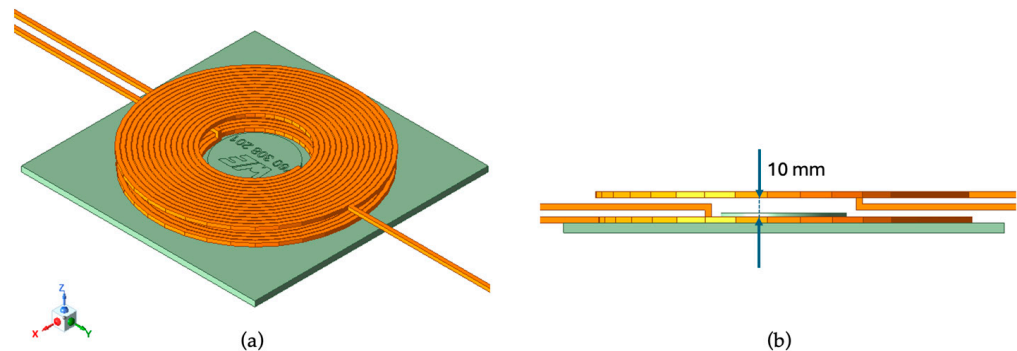


Figure 2. Example of BL-BL WPT system: (a) three-dimensional model; (b) cross-sectional view showing the 10 mm out-of-plane separation. The orange color represents the copper windings, while the green color represents the FR-4 substrate.

Table 3. WPT system electromagnetic performance.

Coil Designator	M [μ H]	k	L (Tx) [μ H]	L (Rx) [μ H]	Loss [W]
BL-BL	2.18	0.30	9.79	5.36	0.09
SL-SL	2.32	0.18	17.91	9.17	0.44
BP-BP	2.17	0.29	9.18	6.27	0.57
SP-SP	2.84	0.18	18.42	13.32	2.34
BL-BP	2.39	0.30	9.78	6.36	0.09
BP-BL	1.98	0.28	9.19	5.28	0.57
SL-SP	2.92	0.19	17.90	13.43	0.44
SP-SL	2.23	0.17	18.42	9.09	2.34

For large coils, the mutual inductance remains approximately constant ($\sim 2.2 \mu$ H), indicating that conductor technology has a limited influence on coupling at this scale. In contrast, for smaller coils, planar–planar configurations exhibit higher mutual inductance but significantly increased losses, which offset the coupling advantage. Cross-technology cases show that the receiver-side geometry plays a dominant role in flux capture, as higher mutual inductance is consistently observed when the receiver is planar. However, the coupling coefficient decreases with miniaturization due to reduced effective area. Baseline losses correspond to transmitter-side ohmic losses, as the receiver coil remains unexcited. Figure 3 presents the magnetic field intensity distribution for the BL-BL WPT system.

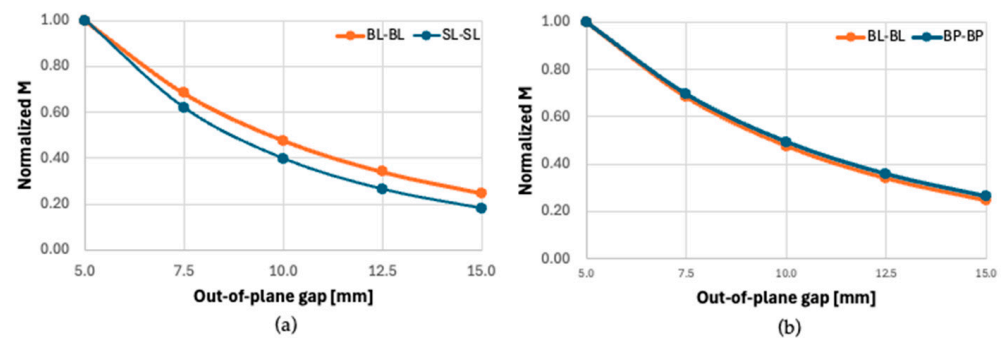


Figure 3. Normalized mutual inductance for: (a) miniaturization effect; (b) technology effect.

3.3. Gap Robustness Analysis

Gap robustness was evaluated by sweeping the out-of-plane separation from 5 mm to 15 mm. Figure 3a compares the miniaturization effect for litz-wire coil pairs (BL-BL and SL-SL) while Figure 3b compares the technology effect for large scale coils (BL-BL and BP-BP).

In Figure 3a, the normalized mutual inductance decreases with increasing separation for both configurations, but the large-scale pair consistently maintains higher values, indicating that it has improved robustness due to its larger effective area and stronger flux linkage. In Figure 3b, litz-wire and planar large-scale configurations exhibit nearly identical trends, indicating that conductor technology has a limited impact on gap robustness at this scale. Although the planar configuration shows slightly higher values, the difference remains minor, confirming that geometric scale dominates gap sensitivity, while technology-related effects are secondary.

3.4. Efficiency Impact of Receiver-Side Ferrite

This section evaluated the impact of receiver-side ferrite on magnetic coupling, and quality factor. The simulation results are stored in Table 4.

Table 4. Analysis of ferrite inclusion behavior.

Coil Designator	Ferrite Inclusion	M [μ H]	k	Q (Tx)	Q (Rx)
BL-BL	Tx only	2.18	0.30	41.14	40.86
BP-BP	Tx only	2.17	0.29	6.32	4.33
BL-BL	Tx and Rx	4.19	0.39	41.96	45.68
BP-BP	Tx and Rx	3.32	0.35	6.61	6.63

Figure 4 illustrates the magnetic field distribution for the BL–BL WPT system with different ferrite configurations.

Receiver-side ferrite increases both mutual inductance and the coupling coefficient across all configurations, confirming enhanced magnetic flux linkage. The magnetic field distribution shows an improved flux concentration between the coils and reduced leakage into the surrounding air due to the high permeability of the ferrite material. However, the improvement in the quality factor remains limited, particularly for planar coils, where AC losses dominate. While litz-wire coils benefit more significantly from ferrite inclusion, planar implementations exhibit only marginal Q improvement, indicating that conductor losses remain the primary limitation for overall efficiency.

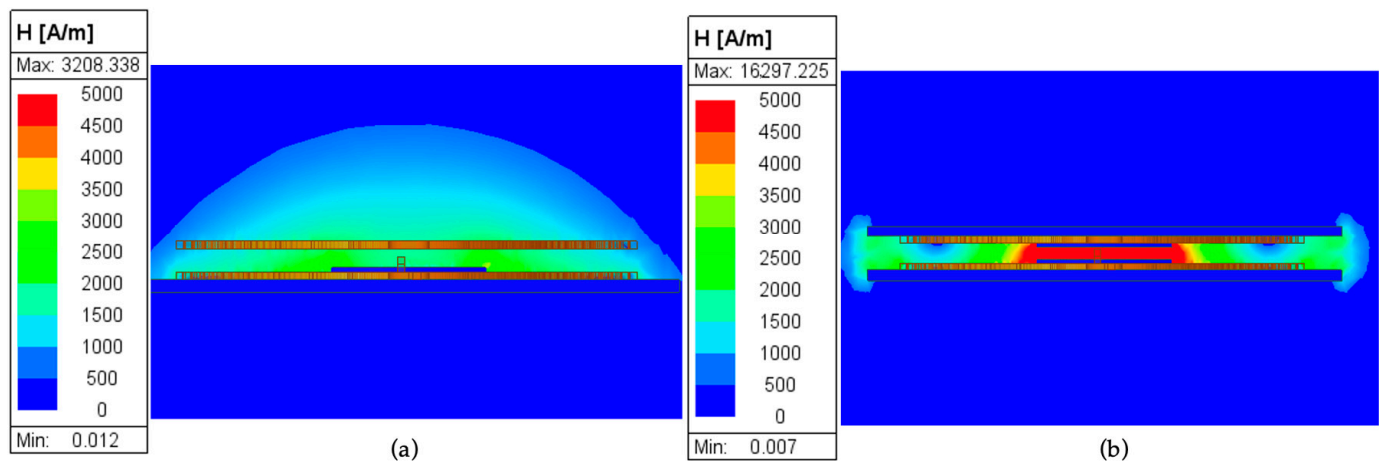


Figure 4. Magnetic field distribution for BL-BL system: (a) ferrite in Tx; (b) ferrite in Tx and Rx.

3.5. Footprint-Matched Geometry: AC-Loss Penalty and Mitigation

This section compares litz-wire and planar coils under footprint-matched conditions to isolate conductor-related effects on AC resistance and losses. Table 5 presents the results obtained.

Table 5. Geometry-matched coil comparison.

Coil Designator	L [μ H]	R [Ω]	Loss [W]	Q
BL	9.78	0.17	0.09	44.02
BP (35 μ m)	8.00	1.05	0.52	6.02
BP (70 μ m)	8.00	0.57	0.28	11.10

Under footprint-matched conditions, the planar coil exhibits a significant AC-loss penalty compared to the litz-wire baseline, with an approximately six times greater increase in resistance leading to substantially higher losses and reduced Q. Increasing the copper thickness from 35 μ m to 70 μ m reduces resistance and losses by approximately 50%, while inductivity remains unchanged. This confirms that performance differences are dominated by conductor-related AC losses rather than inductance variations.

4. Conclusions

This paper presented a systematic electromagnetic comparison between litz-wire and planar coil technologies for inductive wireless power transfer. The results demonstrate that planar coils can achieve mutual inductance and coupling coefficients comparable to litz-wire coils under controlled geometric conditions. However, coil miniaturization consistently reduces coupling robustness across all configurations. A key outcome of this study is that coupling-related metrics alone are insufficient to assess WPT coil performance. Although planar coils can provide competitive coupling, particularly when implemented on the receiver side, their efficiency related performance is strongly influenced by conduction losses. Under footprint-matched conditions, planar implementations exhibit a significant AC-loss penalty, primarily driven by increased conductor resistance rather than inductance mismatch. A basic planar-specific mitigation strategy consisting of increased copper thickness was shown to reduce losses and improve quality factor without altering the footprint. Nevertheless, under the investigated conditions, litz-wire coils remain advantageous in efficiency-critical applications. Planar coils, on the other hand, offer integration and manufacturing benefits and their performance can improve when appropriate loss-mitigation strategies are applied.

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