Capacitor-less Wireless Power Transfer for Low Frequency Band Application

K. Tsukadaira[1], R. Tadika[1], T. Nakamura[1], K. Nakanishi[1], N. A. M. Nasir[2]
[1]Faculty of Engineering, Shinshu University, Asahi, Matsumoto City, 390-8621, Shinshu, Japan
[2]Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
*corresponding author's email: *24w2020g@shinshu-u.ac.jp*

Abstract – *Wireless power transfer (WPT) systems are employed in in-motion power supply applications for electric vehicles and related technologies. However, the use of resonant capacitors to achieve coil resonance often results in increased weight and cost. To address this issue, this study investigates a capacitor-less WPT system by incorporating a magnetic composite material with a high dielectric constant into the coil structure. This approach enhances both inductance and parasitic capacitance, thereby reducing the resonant frequency. A finite element method (FEM) analysis was conducted to evaluate surface electric charge distributions, and the inductance, capacitance, and resonant frequency of the coil were subsequently calculated. The coil embedded with the magnetic composite material exhibited an inductance of 30 µH and a capacitance of 2.33 nF, yielding a resonant frequency of 601 kHz. Although this represents a reduction, the value remains higher than the target frequency of approximately 85 kHz commonly used in automotive in-motion WPT systems. Further optimization of coil dimensions and structure is required to meet this specification.*

Keywords*: capacitor-less, magnetic composite material, parasitic capacitance, resonant frequency, wireless power transfer*

Article History
Received 7 April 2025
Received in revised form 6 June 2025
Accepted March 22 July 2025

I. Introduction

In the modern era of ubiquitous computing, the demand for wireless power transfer (WPT) has been steadily increasing. WPT enables power delivery without physical connectors, offering enhanced convenience and design flexibility for a wide range of applications [1]. Traditionally, WPT systems rely on resonant capacitors to achieve impedance matching between the transmitter and receiver circuits [2]-[3].

However, the inclusion of capacitors introduces additional complexity, cost, and weight to the system. To overcome these limitations, recent research has explored capacitor-less WPT approaches, particularly in the low-frequency band [4]. This strategy seeks to eliminate the need for discrete capacitors by leveraging intrinsic parasitic capacitance within the system, thereby simplifying the circuit design and potentially enhancing overall efficiency and cost-effectiveness.

II. Implementation Method of Capacitor-less WPT

A. Capacitor-less WPT

Capacitor-less WPT utilizes the intrinsic electromagnetic characteristics of the system to enable resonant power transmission without the use of discrete impedance-matching capacitors. This is accomplished by precisely designing the transmitter and receiver circuits such that they operate in a resonant state, where the inductive and capacitive reactance naturally compensate for each other. As a result, external capacitors can be eliminated from the circuit.

B. Implementation method

Fig. 1 illustrates the coil structure employed in the proposed capacitor-less WPT system. The coil consists of two layers and features an open-ended configuration. Fig. 2 presents the equivalent circuit model of the transmission side of the WPT system, which incorporates this coil topology [5]. In this configuration, a resonant circuit is formed by the parasitic (stray) capacitance between the open-ended coil windings. By utilizing this parasitic capacitance as the resonant capacitance, capacitor-less WPT operation can be achieved.

To ensure proper operation, the system must resonate at a frequency within the kilohertz range. For instance, typical in-motion wireless power supply systems for electric vehicles operate around 85 kHz [6]. The resonant frequency f_r (Hz) is given by (1).

$$f_r = 1/(2\pi\sqrt{LC}) \text{ (Hz)} \quad (1)$$

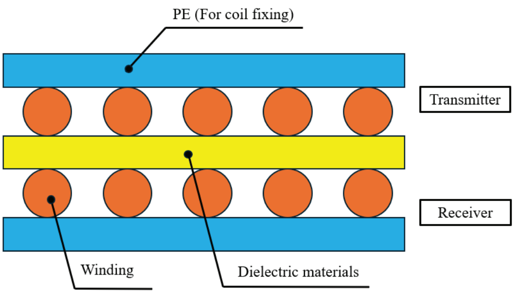


Fig.1. Structure of coil used in conventional capacitor-less WPT

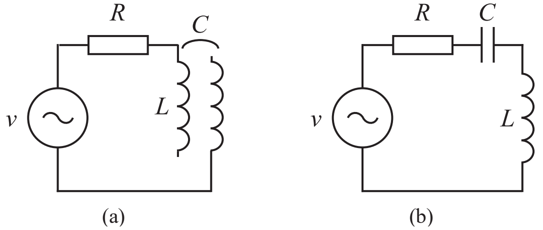


Fig. 2. (a) Circuit of capacitor-less WPT system transmission side
(b) Circuit of Capacitor-less WPT system transmission side equivalent circuit. where L (H) is the inductance and C (F) is the capacitance. Accordingly, both the inductance and the parasitic capacitance must be sufficiently large to achieve resonance at the target frequency

To address this requirement, the use of magnetic composite materials in the coil structure is proposed. Magnetic composite materials, consisting of soft magnetic powder dispersed in an insulating resin matrix, have been investigated for high-frequency applications [7]-[8]. Due to the presence of resin, these materials exhibit a higher dielectric constant compared to conventional magnetic materials such as ferrite. While this property can increase parasitic capacitance and potentially lead to dielectric losses in typical applications, it becomes advantageous in capacitor-less WPT systems, where parasitic capacitance is required for resonance.

By incorporating magnetic composite materials, both the inductance and the parasitic capacitance of the coil can be increased simultaneously. This enables a reduction in the resonant frequency without the need for external capacitors or, alternatively, allows for coil miniaturization while maintaining the target resonance.

III. Analysis Method

Fig. 3 illustrates the structural configuration of the coil used in the analysis. The coil has an outer dimension of 30mm × 40mm and consists of 12 windings arranged in two layers, with magnetic composite material inserted between the layers.

Fig. 4 presents the material characteristics of the magnetic composite used in this study. The material is assumed to be a sintered composite consisting of nanocrystalline magnetic powders of varying particle sizes, solidified using a silicon binder. The composite exhibits a specific permeability of 25.4 and a relative permittivity of 78.1, both of which are considered high for magnetic materials.

Table 1 summarizes the simulation conditions. The analysis was conducted assuming an in-motion wireless power transfer scenario, with the current and driving frequency set to 17 A and 85kHz, respectively.

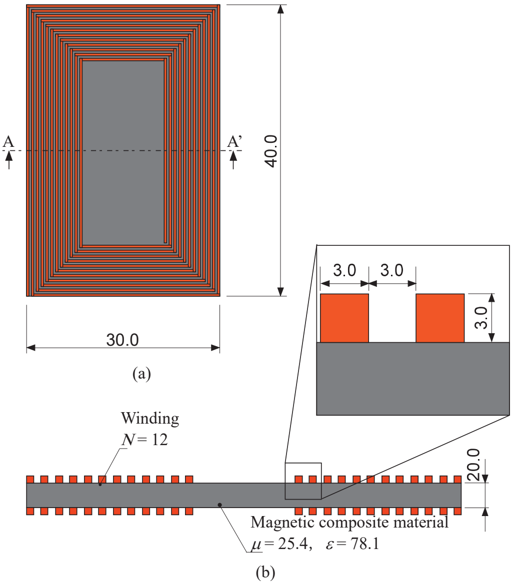
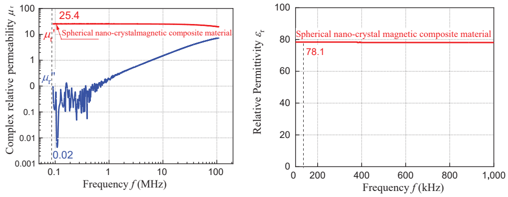


Fig.3. Analysis model (Unit : mm) (a) plan view (b) cross-section view



(a) (b)

Fig.4. Properties of magnetic composite materials (a) magnetic permeability (b) permittivity

TABLE I. ANALYSIS CONDITIONS

Contents	Item
Software	JMAG-Designer(x64)Ver.21.2
Solution	Three-dimensional electric field analysis
Voltage	$V = 600$ V
Frequency	$f = 85$ kHz
Material	1) Copper : $\rho = 1.72\times10^{-8}$ Ωm 2) Magnetic composite material : $\mu_r' = 25.4$, $\mu_r'' = 0.02$, $\varepsilon_r = 78.1$ 3) Air : $\mu_r' = 1$, $\mu_r'' = 0$, $\varepsilon_r = 1$
Mesh size	1) Winding : 1.5 mm 2) Magnetic composite material : 1 mm

IV. ANALYSIS RESULTS

Table II presents the results of the analysis. Due to the difficulty of accurately calculating inductance through three-dimensional simulation, the inductance values were determined by manual calculation. Capacitance, on the other hand, was obtained via electric field analysis. The capacitance C (F) is calculated using the following (2).

$$C = q/V \text{ (F)} \tag{2}$$

From (1) and (2), the inductance and capacitance were 30μH and 2.33nF, respectively, and the resonant frequency was 602 kHz.

TABLE II. ANALYSIS RESULTS

Contents	Item
Surface electrical charge	$q = 1.40$ μC
Inductance	$L = 30.0$ μH
Capacitance	$C = 2.33$ nF
Resonant frequency	$f = 602$ kHz

V. Conclusion

In this study, the application of magnetic composite material in the coil was proposed as a method to realize capacitor-less wireless power transfer (WPT). A coil incorporating magnetic composite material with a specific permeability $\mu_r' = 25.4$ and relative permittivity $\varepsilon_r = 78.1$ was designed and analyzed. The analysis results indicated an inductance of 30.0 μH, a capacitance of 2.33 nF, and a resonant frequency of 601 kHz. The use of magnetic composite material effectively lowered the resonant frequency of the capacitor-less WPT system to the 100 kHz range. However, further reduction to approximately 85 kHz, which corresponds to the frequency band commonly used for in-transit automotive power supply, requires an increase in coil size.

Future work includes comparing the resonant frequency f_r when using dielectric materials versus air as the interlayer medium, as well as experimentally measuring the transmission efficiency using actual coils and materials.

Acknowledgment

The authors would like to express their gratitude to Dr. Tashiro and Dr. Sato from Shinshu University, and Dr. Fairul and Dr.Raja from Universiti Teknikal Malaysia Melaka for the support and resources provided during this research.

Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

K. Tsukadaira, N. A. M. Nasir: Data collection, analysis, writing original draft preparation; R. Tadika: Supervision, draft review and editing, investigation; T. Nakamura: Conceptualization, review; K. Nakanishi: project administration.

References

[1] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, Apr. 1955.

[2] S. Tishechkin and S. Ben-Yaakov, “Adaptive capacitance impedance matching (ACIM) of WPT systems by voltage controlled capacitors,” Proc. IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), London, UK, pp. 396–400, 2019.

[3] B. Clerckx, R. Zhang, R. Schober, D. W. K. Ng, D. I. Kim, and H. V. Poor, “Fundamentals of wireless information and power transfer: From RF energy harvester models to signal and system designs,” IEEE J. Sel. Areas Commun., vol. 37, no. 1, pp. 4–33, Jan. 2019.

[4] Y. Takahashi, K. Hata, T. Imura, and Y. Hori, “Comparison of capacitor- and ferrite-less 85kHz self-resonant coils considering

dielectric loss for in-motion wireless power transfer," Proc. IEEE IECON - 44th Annu. Conf. IEEE Ind. Electron. Soc., Washington, DC, USA, pp. 5159–5163, 2018.

[5] C. M. de Miranda and S. F. Pichorim, "Alternative configuration of open-bifilar coil for self-resonant wireless power transfer system," Proc. IEEE Wireless Power Transfer Conf. (WPTC), London, UK, p. 118, 2019.

[6] K. Furusato, T. Imura, and Y. Hori, "Design of multi-frequency coil for capacitor-less wireless power transfer using high order self-resonance of open end coil," Proc. IEEE Wireless Power Transfer Conf. (WPTC), pp. 1–4, 2016, doi: 10.1109/WPT.2016.

[7] M. Sato, Y. Hattori, M. Ueda, Y. Bu, and T. Mizuno, "Improved performance of a flat-wire coil with magnetic composite material for wireless power transfer," IEEE Magn. Lett., vol. 12, 2021.

[8] K. Shimura, S. Kobayashi, M. Sato, and T. Mizuno, "Application of magnetic composite materials in windings to reduce alternating-current resistance in leakage transformers," Proc. IEEE Int. Magn. Conf. - Short Papers (INTERMAG), 2023.7498858. 2016.