Review Study of Tunable Intermediate-Resonator for Selective Wireless Power Transfer System Over Various Distances

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***Abstract*—This paper presents a selective magnetic resonant wireless power transfer (WPT) system, consisting of a transmitter (TX), a tunable intermediate-resonator, and a receiver (RX). In the proposed WPT system, the tunable intermediate-resonator can be either a relay resonator or an intermediate-RX by varying its variable resistance, demonstrating the flexibility of the intermediate-resonator to be used for different topologies and applications. This flexibility will enable the proposed WPT system to transfer maximum energy efficiency to various distances between the TX and the RX, to longer distances for the WPT relay system and to shorter distances for the intermediate-RX system. In this case, the WPT intermediate-RX system has a larger power transfer efficiency than the WPT relay system.**

***Index Terms*—Wireless power transfer (WPT), intermediate-resonator, magnetic coupling, power transfer efficiency.**

I. Introduction

Nowadays, there are lots of devices that can be charged wirelessly by using wireless power transfer (WPT) systems. In fact, the WPT systems have opened up an avenue for the betterment of people's life and provided customers with convenience and comfort, and therefore have a wide variety of practical applications, e.g., biomedical implants [1]−[3], portable devices [4], [5], electric vehicles [6]−[8], to name a few.

Non-radiative WPT has attracted considerable interests recently due to its high efficiency for delivering power to electric loads. That is to say, the non-radiative WPT is a technology based on near-field magnetic coupling between a transmitter (TX) coil and a receiver (RX) coil within a distance less than a wavelength. It can be classified as a magnetic inductive WPT [9], [10], which is normally used for short-range applications up to about several millimeters to centimeters, and a magnetic resonant WPT [11]−[13], which has been applied to significantly enhance the efficiency and range of WPT compared with the magnetic induction (MI).

With magnetic resonant coupling, the total reactive power consumption in the system is effectively declined due to resonance and therefore high power transfer efficiency is achieved over longer distances than the conventional MI. For this reason, the magnetic resonant WPT has significantly drawn attention. In [13], [14], theoretical analyses and experiments were carried out on non-radiative WPT via strongly coupled magnetic resonance over a distance of around 2 meters. In addition, magnetic resonant WPT has been widely studied, and more experiment and simulation results have been conducted in recent years [15]−[18]. Lots of researches, e.g., into WPT relay systems [19]−[23], multiple TXs and RXs [24]−[29], magnetic beamforming [30], [31], have been reported in the literature.

In this paper, a tunable intermediate-resonator deployed between a TX and a RX for near-field WPT systems is investigated. A variable resistance is applied to the intermediate-resonator for tuning. As a consequence, a WPT relay system or an intermediate-RX can be realized by varying the variable resistance of the intermediate-resonator, which indicates a flexible approach for selective magnetic resonant WPT systems. Therefore, we can transfer energy efficiency to various distances between the TX and the RX.

This paper is arranged as follows. Section II provides the system model of the proposed magnetic resonant WPT system. Section III presents mutual coupling effects of adjacent and non-adjacent resonators on the proposed WPT system and determines theoretical analyses. Section IV draws conclusions.

II. System Model

Fig. 1 illustrates the schematic and equivalent circuit model of the proposed magnetic resonant WPT system, which is comprised of a transmitter (TX), a tunable intermediate-resonator, and a receiver (RX). V_S is source voltage and R_S is source internal resistance, which both are connected to the TX. R_i, L_i, and C_i $(i = 1, 2, 3)$ are internal resistance, self-inductance, and capacitance connected in series to resonator i, respectively. In addition, the C_i is the capacitance that makes each resonator i resonate at the same resonant frequency (f_o) given by

$$\omega = 2\pi f_o = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}} = \frac{1}{\sqrt{L_3 C_3}} \qquad (1)$$

where ω is the angular frequency. $M_{ij} = k_{ij}\sqrt{L_i L_j}$ $(i, j = 1, 2, 3; i \neq j)$ is mutual inductance between resonator i and resonator j, and k_{ij} is magnetic coupling coefficient between resonator i and resonator j. This magnetic coupling coefficient has a reciprocal property, i.e., $k_{ij} = k_{ji}$. I_i is ac current in resonator i, which generates magnetic fields. R_{va} and R_L are the variable resistance of the intermediate-resonator and the load resistance of the RX, respectively.

The intermediate-resonator of the proposed WPT system is able to be either a relay resonator by setting the variable resistance equal to zero, $R_{va} = 0$, or an intermediate-RX by setting the variable resistance equal to the load resistance, $R_{va} = R_L$, and in this case we have two RXs in order to increase the power transfer efficiency compared to once we use the relay resonator. In fact, we aim to employ the intermediate-RX for shorter distances and the relay resonator for longer distances between the TX and the RX, d_{13}, for a given distance of d_{12}. As a result, a selective near-field WPT over various distances is achieved by using a tunable intermediate-resonator. The variable resistance R_{va} can be easily implemented by a switchable binary weighted resistor bank, resulting in tuning the R_{va}.

The circuit equations of the proposed WPT system in Fig. 1 can be obtained by using the Kirchhoff's voltage law (KVL) and, therefore, determined by

$$\begin{bmatrix} Z_1 & j\omega M_{12} & j\omega M_{13} \\ j\omega M_{12} & Z_2 & j\omega M_{23} \\ j\omega M_{13} & j\omega M_{23} & Z_3 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_S \\ 0 \\ 0 \end{bmatrix} \quad (2)$$

where the equivalent input impedance, Z_i, in each resonator is defined as

$$\begin{aligned} Z_1 &= R_S + R_1 + j(\omega L_1 - \frac{1}{\omega C_1}), \\ Z_2 &= R_{va} + R_2 + j(\omega L_2 - \frac{1}{\omega C_2}), \\ Z_3 &= R_L + R_3 + j(\omega L_3 - \frac{1}{\omega C_3}). \end{aligned} \quad (3)$$

III. Magnetic Coupling Effects

We will now consider the effects of magnetic coupling of adjacent and nonadjacent resonators on the power transfer efficiency of the proposed WPT system.

A. The Effects of Magnetic Coupling of Adjacent Resonators

Considering only the mutual coupling of adjacent resonators, the circuit equations in (2) can be rewritten as

$$\begin{bmatrix} Z_1 & j\omega M_{12} & 0 \\ j\omega M_{12} & Z_2 & j\omega M_{23} \\ 0 & j\omega M_{23} & Z_3 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_S \\ 0 \\ 0 \end{bmatrix}. \quad (4)$$

As a consequence, using (4), the current in each resonator can be expressed by

$$\begin{aligned} I_1 &= \frac{V_S}{Z_1 + \frac{\omega^2 M_{12}^2 Z_3}{\omega^2 M_{23}^2 + Z_2 Z_3}}, \\ I_2 &= -\frac{j\omega M_{12} Z_3}{\omega^2 M_{23}^2 + Z_2 Z_3} \cdot I_1, \\ I_3 &= -\frac{\omega^2 M_{12} M_{23}}{\omega^2 M_{23}^2 + Z_2 Z_3} \cdot I_1. \end{aligned} \quad (5)$$

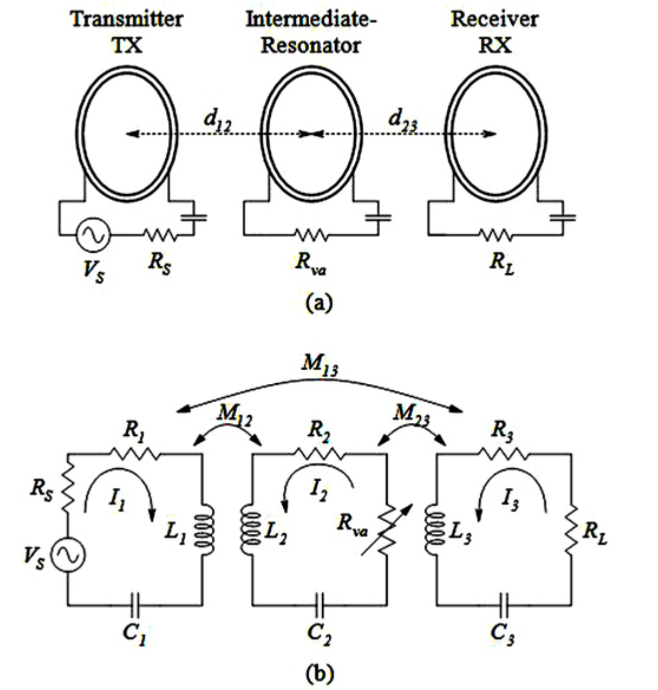

Fig. 1. (a) Schematic and (b) equivalent circuit model of the proposed selective magnetic resonant WPT system.

As we mentioned in the previous Section, two different cases (i.e., a WPT relay system and a WPT intermediate-RX system) have to be included for evaluating the magnetic coupling effects of adjacent resonators on the maximum efficiency of the WPT system in Fig. 1. First, we consider a WPT relay system by setting $R_{va} = 0$. Generally, the efficiency, η, is defined as the ratio of the dissipated power in the load to the total input power. Therefore, the efficiency of the WPT relay system is given by

$$\begin{aligned} \eta &= \frac{R_L |I_3|^2}{(R_S + R_1)|I_1|^2 + R_2|I_2|^2 + (R_L + R_3)|I_3|^2} \\ &= \frac{R_L |\frac{I_3}{I_1}|^2}{(R_S + R_1) + R_2|\frac{I_2}{I_1}|^2 + (R_L + R_3)|\frac{I_3}{I_1}|^2}. \end{aligned} \quad (6)$$

For WPT relay systems which have equal distances, $d_{12} = d_{23}$, and a given overall distance d_{13} equal to $60cm$, the maximum efficiency occurs at the resonant frequency and transferred powers have a roughly symmetrical shape around the resonant frequency [32].

Second, if we set $R_{va} = R_L$, we will have a WPT intermediate-RX system, which its efficiency can be defined as

$$\begin{aligned} \eta &= \frac{R_{va}|I_2|^2 + R_L|I_3|^2}{(R_S + R_1)|I_1|^2 + (R_{va} + R_2)|I_2|^2 + (R_L + R_3)|I_3|^2} \\ &= \frac{R_{va}|\frac{I_2}{I_1}|^2 + R_L|\frac{I_3}{I_1}|^2}{(R_S + R_1) + (R_{va} + R_2)|\frac{I_2}{I_1}|^2 + (R_L + R_3)|\frac{I_3}{I_1}|^2} \end{aligned} \quad (7)$$

where $R_{va}|I_2|^2$ and $R_L|I_3|^2$ are the power delivered to the intermediate-RX and the load, respectively. $R_i|I_i|^2$ is the power loss in the TX or RX parasitic, and $R_S|I_1|^2$ is the dissipated power in the TX.

With the given parameters of the resonators (i.e., R_i, L_i, and C_i) in the proposed WPT system, the mutual inductances between every two resonators can be obtained by the distances between the resonators. As a consequence, the power transfer efficiency can be expressed as a function of the operating frequency, the distances of every two adjacent resonators and the load, which is determined by

$$\eta = f(\omega, d_{12}, d_{23}, R_L) \quad (8)$$

therefore, we can optimize the WPT system based on (8) [32].

If resonators are in over-coupled region, which meant that mutual coupling between the resonators is strong (k_{12} or k_{23} is large enough), the frequency splitting will occur [33], [34]. In fact, the original resonant frequency will be split into several different frequencies, and, therefore, the transferred power and the maximum efficiency will be observed at the split frequencies rather than the original resonant frequency. Once the intermediate-RX and the TX are in proximity, the split frequencies can be approximated as

$$\omega_{split} = \frac{\omega_o}{\sqrt{1+k_{12}}}, \frac{\omega_o}{\sqrt{1-k_{12}}} \quad (9)$$

where $k_{12} < 1$ [34]. From (9), it can be observed that by increasing the magnetic coupling coefficient, k_{12}, the transferred power and, thus, the efficiency at the resonant frequency declines dramatically, making the degradation of WPT systems.

According to [35], the maximum power transfer efficiency of WPT intermediate-RX systems is always larger than that of WPT relay systems, for a given distance of the intermediate-resonator and the RX (i.e., d_{23}). Whereas, this condition is achieved once the optimal position of the TX is closer to the intermediate-RX compared to the relay resonator, as the quality factor of the relay resonator, ($Q = \omega L_2/R_2$), is far larger than that of the TX/RX, ($Q = \omega L_i/(R_{S,L} + R_i)$), provided that the source/load resistance is large enough. In fact, the distance between the TX and the RX, d_{13}, for the WPT relay system is longer than that for the WPT intermediate-RX system.

B. The Effects of Magnetic Coupling of Nonadjacent Resonators

Using (2) and considering the cross-coupling between the TX and the RX, the current in each resonator can be expressed by

$$\begin{aligned} I_1 &= \frac{V_S}{Z_1 + \frac{\omega^2 M_{12}^2 Z_3 + \omega^2 M_{13}^2 Z_2 - 2j\omega^3 M_{12} M_{13} M_{23}}{\omega^2 M_{23}^2 + Z_2 Z_3}}, \\ I_2 &= -\frac{\omega^2 M_{13} M_{23} + j\omega M_{12} Z_3}{\omega^2 M_{23}^2 + Z_2 Z_3} \cdot I_1, \\ I_3 &= -\frac{\omega^2 M_{12} M_{23} + j\omega M_{13} Z_2}{\omega^2 M_{23}^2 + Z_2 Z_3} \cdot I_1. \end{aligned} \quad (10)$$

Similarly, the two cases should be considered for assessing the cross-coupling effects on the maximum efficiency of the WPT system. With the consideration of the mutual coupling of nonadjacent resonators for an equally spaced WPT relay system ($d_{13} = 60cm$), the maximum power transfer efficiency is not observed at the resonant frequency and also the transferred powers do not have a symmetrical shape around the resonant frequency [32]. However, the power transfer efficiency can be improved by finding the optimum frequency, distances, and the load resistance (refer to (8)). According to these optimization conditions, the maximum efficiency will be achieved if the relay resonator is closer to the TX when the R_L is small and closer to the RX once the R_L is large [32].

The same condition will happen for a WPT intermediate-RX system. In fact, the maximum power transfer efficiency will occur at the split frequencies (refer to (9)) when the cross-coupling of nonadjacent resonators is included or the distance between resonators is small [36]. However, the mutual coupling of nonadjacent resonators will be ignored if the distance between nonadjacent resonators, d_{13}, is relatively large (e.g., larger than the diameter of the resonators) [32], [35]. Furthermore, there is a reactance compensation method [37], in which the cross-coupling of nonadjacent resonators can be eliminated even if d_{23} is short. By connecting the compensatory reactance term $\tilde{X}_i$ to the resonator i, (2) can be rewritten as

$$\begin{bmatrix} Z_1 - j\tilde{X}_1 & j\omega M_{12} & j\omega M_{13} \\ j\omega M_{12} & Z_2 - j\tilde{X}_2 & j\omega M_{23} \\ j\omega M_{13} & j\omega M_{23} & Z_3 - j\tilde{X}_3 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_S \\ 0 \\ 0 \end{bmatrix}. \quad (11)$$

To compare (11) with the equation in (4), where the cross-coupling of nonadjacent resonators is neglected ($k_{13} = k_{31} \approx 0$), in order to equalize the two equations, the compensatory reactance terms can be easily given as

$$\begin{aligned} \tilde{X}_1 &= \omega M_{13} \cdot \frac{I_3}{I_1}, \\ \tilde{X}_2 &= 0, \\ \tilde{X}_3 &= \omega M_{13} \cdot \frac{I_1}{I_3}. \end{aligned} \quad (12)$$

IV. Conclusion

A selective near-field wireless power transfer (WPT) system for having maximum power transfer efficiency is proposed in this paper. A tunable intermediate-resonator using a variable resistance is deployed between a transmitter (TX) and a receiver (RX) to improve efficiency as well as distance. The proposed WPT system is very flexible, since by varying the variable resistance, the intermediate-resonator will convert into either a relay resonator or an intermediate-RX. The relay resonator and the intermediate-RX will be utilized for longer and shorter distances between the TX and the RX, respectively. As a result, the energy efficiency will be transferred to various distances for the proposed WPT system.

References

[1] K. Na, H. Jang, H. Ma, and F. Bien, “Tracking optimal efficiency of magnetic resonance wireless power transfer system for biomedical capsule endoscopy,” *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 1, pp. 295-303, Jan. 2015.

[2] A. K. RamRakhyani, S. Mirabbasi, and M. Chiao, “Design and optimization of resonance-based efficient wireless power delivery systems for biomedical implants,” *IEEE Trans. Biomed. Circuits Syst.*, vol. 5, no. 1, pp. 48-63, Feb. 2011.

[3] Q. Xu, H. Wang, Z. Gao, Z. H. Mao, J. He, and M. Sun, “A novel mat-based system for position-varying wireless power transfer to biomedical implants,” *IEEE Trans. Magn.*, vol. 49, no. 8, pp. 4774-4779, Feb. 2013.

[4] Y. Jang and M. M. Jovanovic, “A contactless electrical energy transmission system for portable-telephone battery chargers,” *IEEE Trans. Ind. Electron.*, vol. 50, no. 3, pp. 520-527, Jun. 2003.

[5] H. Jabbar, Y. S. Song, and T. T. Jeong, “RF energy harvesting system and circuits for charging of mobile devices,” *IEEE Trans. Consum. Electron.*, vol. 56, no. 1, pp. 247-253, Feb. 2010.

[6] U. K. Madawala and D. J. Thrimawithana, “A bidirectional inductive power interface for electric vehicles in V2G systems,” *IEEE Trans. Ind. Electron.*, vol. 58, no. 10, pp. 4789-4796, Oct. 2011.

[7] S. Li and C. C. Mi, “Wireless power transfer for electric vehicle applications,” *IEEE Trans. Emerg. Sel. Topics Power Electron.*, vol. 30, no. 1, pp. 4-17, Mar. 2015.

[8] M. Ibrahim, L. Bernard, L. Pichon, E. Laboure, A. Razek, O. Cayol, D. Ladas, and J. Irving, “Inductive charger for electric vehicle: advanced modeling and interoperability analysis,” *IEEE Trans. Power Electron.*, vol. 31, no. 12, pp. 8096-8114, Jan. 2016.

[9] C. Kim, D. Seo, J. You, J. Park, and B. H. Cho, “Design of a contactless battery charger for cellular phone,” *IEEE Trans. Ind. Electron.*, vol. 48, no. 6, pp. 1238-1247, Dec. 2001.

[10] W. Chwei-Sen, O. H. Stielau, and G. A. Covic, “Design considerations for a contactless electric vehicle battery charger,” *IEEE Trans. Ind. Electron.*, vol. 52, no. 5, pp. 1308-1314, Oct. 2005.

[11] J. Shin, S. Shin, Y. Kim, S. Ahn, S. Lee, G. Jung, S. Jeon, and D. Cho, “Design and implementation of shaped magnetic-resonance-based wireless power transfer system for roadway-powered moving electric vehicles,” *IEEE Trans. Ind. Electron.*, vol. 61, no. 3, pp. 1179-1192, Mar. 2014.

[12] Y. Li, J. Li, K. Wang, W. Chen, and X. Yang, “A maximum efficiency point tracking control scheme for wireless power transfer systems using magnetic resonant coupling,” *IEEE Trans. Power Electron.*, vol. 30, no. 7, pp. 3998-4008, Jul. 2015.

[13] A. Karalis, J. Joannopoulos, and M. Soljacic, “Efficient wireless non-radiative mid-range energy transfer,” *Ann. Phys.*, vol. 323, no. 1, pp. 34-48, Jan. 2008.

[14] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljacic, “Wireless power transfer via strongly coupled magnetic resonances,” *Science*, vol. 317, no. 83, pp. 83-86, Jul. 2007.

[15] O. Jonah, S. V. Georgakopoulos, and M. M. Tentzeris, “Optimal design parameters for wireless power transfer by resonance magnetic,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1390-1393, Nov. 2012.

[16] S. Y. R. Hui, W. Zhong, and C. K. Lee, “A critical review of recent progress in mid-range wireless power transfer,” *IEEE Trans. Power Electron.*, vol. 29, no. 9, pp. 4500-4511, Sep. 2014.

[17] Y. Zhang, Z. Zhao, and K. Chen, “Frequency decrease analysis of resonant wireless power transfer,” *IEEE Trans. Power Electron.*, vol. 29, no. 3, pp. 1058-1063, Mar. 2014.

[18] D. W. Seo, J. H. Lee, and H. Lee, “Study on two-coil and four-coil wireless power transfer systems using z-parameter approach,” *ETRI Journal*, vol. 38, no. 3, pp. 568-578, Jun. 2016.

[19] M. Dionigi and M. Mongiardo, “Magnetically coupled resonant Wireless Power Transmission systems with relay elements,” in *Proc. IEEE MTT-S Int. Dig.*, 2012, pp. 223-226.

[20] D. Ahn and S. Hong, “A study on magnetic field repeater in wireless power transfer,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 1, pp. 360-371, Jan. 2013.

[21] W. X. Zhong, C. K. Lee, and S. Y. R. Hui, “General analysis on the use of teslas resonators in domino forms for wireless power transfer,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 1, pp. 261-270, Jan. 2013.

[22] B. H. Choi and J. H. Lee, “Design of asymmetrical relay resonators for maximum efficiency of wireless power transfer,” *Int. J. Antennas Propag.*, pp. 1-8, May 2016.

[23] J. Lee, K. Lee, and D. H. Cho, “Stability improvement of transmission efficiency based on a relay resonator in a wireless power transfer system,” *IEEE Trans. Power Electron. Lett.*, vol. 32, no. 5, pp. 3297-3300, May 2017.

[24] I. J. Yoon and H. Ling, “Investigation of near-field wireless power transfer under multiple transmitters,” *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 662-665, Jun. 2011.

[25] K. Lee and D. H. Cho, “Diversity analysis of multiple transmitters in wireless power transfer system,” *IEEE Trans. Magn.*, vol. 49, no. 6, pp. 2946-2952, Jun. 2013.

[26] M. Fu, T. Zhang, C. Ma, and X. Zhu, “Efficiency and optimal loads analysis for multiple-receiver wireless power transfer systems,” *IEEE Trans. Microw. Theory Technol.*, vol. 63, no. 3, pp. 801-812, Mar. 2015.

[27] K. Lee and D. H. Cho, “Analysis of wireless power transfer for adjustable power distribution among multiple receivers,” *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 950-953, 2015.

[28] Y. Zhang, T. Lu, Z. Zhao, F. He, K. Chen, and L. Yuan, “Selective wireless power transfer to multiple loads using receivers of different resonant frequencies,” *IEEE Trans. Power Electron.*, vol. 30, no. 11, pp. 6001-6005, Nov. 2015.

[29] Y. Zhang, Z. Zhao, K. Chen, F. He, and L. Yuan, “Wireless power transfer to multiple loads over various distances using relay resonators,” *IEEE Microw. Wireless Compon. Lett.*, vol. 25, no. 5, pp. 337-339, May 2015.

[30] B. H. Choi, B. C. Park, and J. H. Lee, “Near-field beamforming loop array for selective wireless power transfer, *IEEE Microw. Compon. Lett.*, vol. 25, no. 11, pp. 748-750, Nov. 2015.

[31] G. Yang, M. R. V. Moghadam, R. Zhang, “Magnetic beamforming for wireless power transfer, in *Proc. IEEE Int. Conf. Acoustics, Speech, and Signal Processing (ICASSP)*, pp. 3936-3940, Mar. 2016.

[32] C. K. Lee, W. X. Zhong, and S. Y. R. Hui, “Effects of magnetic coupling of non-adjacent resonators on wireless power domino-resonator systems,” *IEEE Trans. Power Electron.*, vol. 27, no. 4, pp. 1905-1916, Apr. 2012.

[33] A. P. Sample, D. A. Meyer, and J. R. Smith, “Analysis, experimental results, and range adaptation of magnetically coupled resonators for wireless power transfer,” *IEEE Trans. Ind. Electron.*, vol. 58, no. 2, pp. 544-554, Feb. 2011.

[34] D. Ahn and S. Hong, “A study on magnetic field repeater in wireless power transfer,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 1, pp. 360-371, Jan. 2013.

[35] K. Lee and S. H. Chae, “Power transfer efficiency analysis of intermediate-resonator for wireless power transfer,” *IEEE Trans. Power Electron.*, vol. 33, no. 3, pp. 2484-2493, Mar. 2018.

[36] D. Ahn and S. Hong, “Effect of coupling between multiple transmitters or multiple receivers on wireless power transfer,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 7, pp. 2602-2613, Jul. 2013.

[37] C. Zhong, B. Luo, F. Ning, and W. Liu, “Reactance compensation method to eliminate cross coupling for two-receiver wireless power transfer system,” *IEICE Electron. Express*, vol. 12, no. 7, Mar. 2015, Art. no. 20150016.