Frequency-Selective Planar Coil Architecture Modeling for WPT Access Control

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Abstract **─** In this paper, an approach to access control in wireless power transfer (WPT) systems via frequency-selective architecture is proposed. We perform modeling of planar square loop resonance behavior in GHz range using Ansys HFSS®. Power transfer efficiency is found from the accepted power and radiated power. Using a multi-coil design, where the transmitter and receiver switch between coils of different resonance frequencies in sync, can provide for effective access control.

Index Terms **─** Access control in WPT systems Ansys HFSS, power transfer efficiency, resonant coupling, wireless power transfer.

I. INTRODUCTION

Wireless power transfer (WPT) techniques have received considerable interest in recent years [1–3]. For the near-field (non-radiative) range, WPT can be achieved via inductive coupling and magneto-dynamic coupling. In [1], the authors have proposed to utilize resonant inductive coupling to achieve non-radiative mid-range energy transfer. By utilizing strong resonant coupling between the primary and secondary coils, the efficiency was shown to reach nearly 40% over the distance as great as 2 meters. With the growing interest in extending WPT range, access control may become problematic as mid-range WPT systems can proliferate as widely as Wi-Fi in the near future. Our previous work focused on experimental validation of one approach to implementing access control via multiple tunable coils [4]. In it, we also introduced a method of pseudo-random frequency hopping. The experimental prototype was intended for the low-frequency range of operations. In this work, we consider WPT access control for multiple GHz in frequency.

Frequency-selective WPT multi-receiver design has been investigated in [5], where different resonance frequencies were used to achieve selective power transfer. Resonant coupling naturally results in minimum interaction with nearby off-resonant objects and free space. With this well-established physical principle, access control can be achieved by utilizing multiple coils and switching between them in a fashion known to the authorized receiver only. WPT efficiency can then reach its maximum only if the primary and secondary coils are in resonance, while for other off-resonant receivers the power transfer efficiency (PTE) will be extremely low.

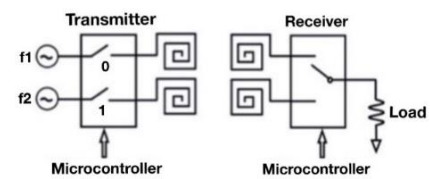

Fig. 1. ACMC system block diagram.

II. PROPOSED ACCESS-CONTROLLED ARCHITECTURE

A block diagram for the access-controlled multi-coil (ACMC) system is shown in Fig. 1. The transmitter (TX) can choose which oscillator and coil are enabled at each transmission interval. Only the authorized receiver (RX) can follow the switching pattern of the transmitter. An un-authorized single-coil device will be out of resonance for a significant duration of time, thus achieving much lower PTE. Synchronization between TX and RX is outside the scope of this paper and will be addressed in the future.

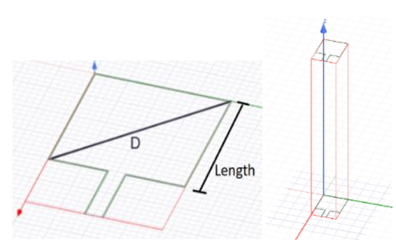

Fig. 2. Simulation model: (a) single planar coil; (b) two identical coils spaced by 5D.

The simulation model of a single-loop primary coil is shown in Fig. 2. This single planar copper coil is modeled with Ansys HFSS® for a range of dimensions,

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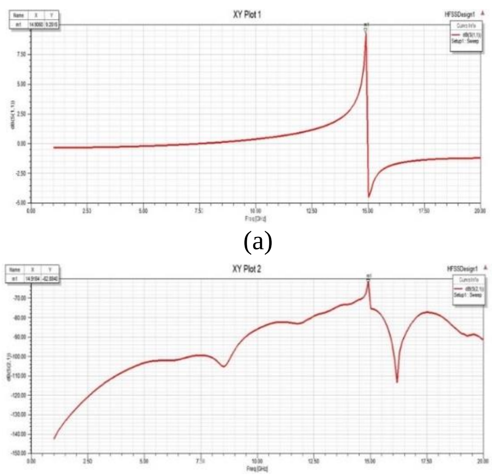
with the coil length of 70 mm, 1 mm trace width and 0.1 mm trace height. The secondary coil is identical to the first one and is placed at distances from D to 5D, where D is the length of the loop diagonal.

III. SIMULATION RESULTS

The HFSS® simulations were run for a frequency span from 1 GHz to 20 GHz. "Infinite Sphere" radiation option was set up to calculate the accepted and radiated power. Reflection loss, S_{11} and insertion loss, S_{21} were analyzed to ascertain the resonance frequency of a single coil, and the PTE between any two coils, respectively. Coil dimensions and distance between the coils were also varied. An example of S_{11} and S_{21} for the 70 mm-length coil is shown in Fig. 3.



(a)

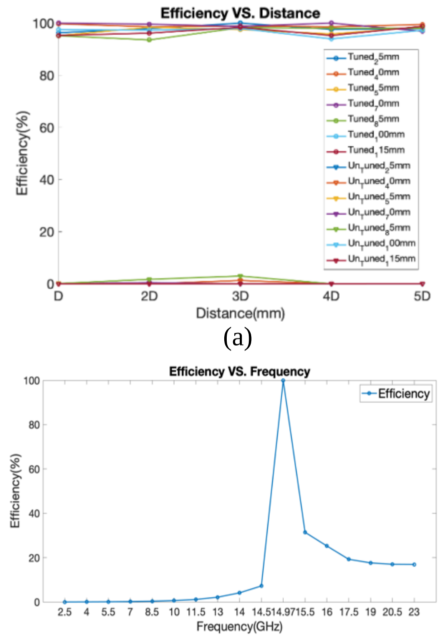
(b)

Fig. 3. System's S-parameters: (a) S_{11}; (b) S_{21}.

To demonstrate the access control potential, two 70 mm-length coils were placed 396 mm apart and frequency sweep simulations were run from 2.5 GHz to 23 GHz. Figure 4 (a) shows PTE of tuned and untuned coils as a function of distance between them. Figure 4 (b) shows PTE as function of frequency – e.g., PTE reaches nearly 100% at 14.97 GHz, while detuning results in 7.2% PTE at 14.5 GHz. Our modeling confirms that the proposed approach is viable for creating ACMC systems.

IV. CONCLUSION

In this work, we have modeled an approach to ACMC WPT system design based on resonance frequency selectivity for planar square coils in the GHz frequency range. Our findings confirm the feasibility of the approach in which an authorized receiver switches between its multiple coils in-sync with the transmitter, which leads to maximum PTE for the tuned systems and provides for much lower efficiency of an unauthorized single-coil interceptor. Our future work includes building an experimental ACMC WPT system based on a frequency multiplier and implementing synchronization strategies.



(a)

(b)

Fig. 4. HFSS® simulation results: (a) PTE vs. distance; (b) PTE vs. frequency.

REFERENCES

[1] A. Kurs, A. Kaalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless power transfer via strongly coupled magnetic resonances," *Science*, vol. 317, no. 5834, pp. 83-86, July 2007.

[2] 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.

[3] Ansys HFSS Blog: Wireless Power Transfer (website).
Available: https://www.ansys.com/blog/wireless-power-transfer, 2019.

[4] T. Maschino, "Frequency-selective design of wireless power transfer systems for controlled access applications," *M.S. Thesis*, Miami University, 2016.

[5] 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, 2015.