Positioning-Free Magnetically Resonant Wireless Power Transmission Board with Staggered Repeater Coil Array (SRCA)

Hyunkeun Lim, Koichi Ishida, Makoto Takamiya, and Takayasu Sakurai
University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

***Abstract*- A magnetically resonant wireless power transmission board (MR-WPTB) on a printed-circuit board is developed. MR-WPTB wirelessly supplies the power to electronic devices such as smartphones anywhere on the board with high efficiency. In order to increase a power transmission efficiency degraded by a misalignment of a receiver coil, a transmitter coil array and a proposed staggered repeater coil array (SRCA) are stacked in MR-WPTB. 1 transmitter coil closest to the receiver coil and the surrounding 4 repeater coils are selectively activated based on the result of a position detection of the receiver coil. By adding SRCA to the transmitter coil array, the measured power transmission efficiency at the worst case misalignment increases from 4.8% to 64% at a distance of 15mm between the transmitter and receiver coils with a diameter of 40mm.**

I. INTRODUCTION

Ambient or ubiquitous charging of electronic devices such as smartphones is increasingly needed, because the smartphone requires a frequent charging due to the increased power consumption. A wireless power transmission (WPT) sheet [1-4] with a transmitter (TX) coil array and a selectively activation of a TX coil based on the position detection of a receiver (RX) coil is one of a possible solution for the ubiquitous charging. A WPT distance of the sheet, however, is short (e.g. 4-mm distance at 10% efficiency [1]), because an electromagnetic induction is used in the sheet. In order to increase the distance, a magnetic resonance [5] instead of the electromagnetic induction is used in this paper. In the newly developed magnetically resonant wireless power transmission board (MR-WPTB) on a printed-circuit board (PCB), however, WPT efficiency degradation due to a misalignment of RX coil is still large even if the magnetic resonance is used. In order to keep a high efficiency regardless of the misalignment, a staggered repeater coil array (SRCA) is proposed in this paper. By using MR-WPTB with SRCA, a positioning of RX coil is not required, thereby enabling the ubiquitous charging.

II. MAGNETICALLY RESONANT WIRELESS POWER TRANSMISSION BOARD (MR-WPTB) WITH SRCA

Fig. 1 shows a usage scene of the proposed MR-WPTB. MR-WPTB is put on a table and wirelessly supplies the power to electronic devices such as a smartphone, a keyboard, and a mouse anywhere on MR-WPTB with high efficiency. MR-WPTB has transmitter coil arrays. In MR-WPTB, the target size is 1~2m square and the target thickness is 1mm. In MR-

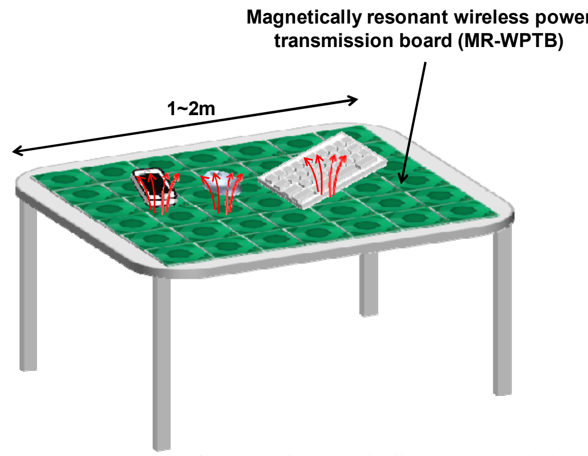


Fig. 1. Usage scene of proposed magnetically resonant wireless power transmission board (MR-WPTB).

WPTB, a transmitter coil is selectively activated based on the position detection [1-4] of RX coil. The purpose of this work is to propose the best configuration of the coil array which achieves the highest WPT efficiency at the worst misalignment condition of RX coil. In order to find the best configuration, the WPT efficiency of 4 different coil arrays are compared.

Fig. 2 shows 4 types of coils used in the coil arrays. Marks for the 4 types of coils are defined. The transmitter coil (TXC) in Fig. 2(a) is a power feeding coil. The repeater coil (RepC) in Fig. 2(b) is a short coil to extend the WPT distance. The open coil in Fig. 2(c) is a non-activated and unused coil. The 9 transmitter coils (9 TXC's) in Fig. 2(d) is 9 coils sharing a single power source.

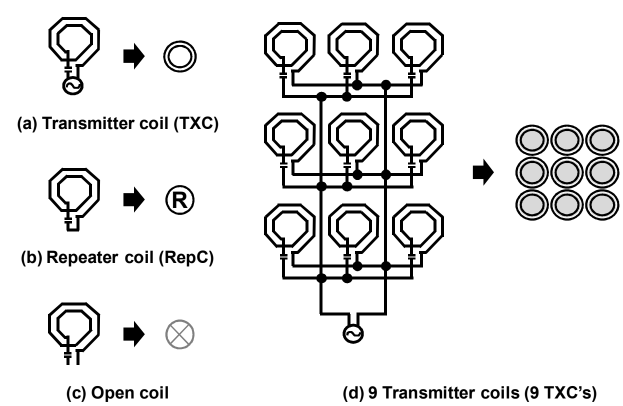


Fig. 2. 4 types of coils used in coil arrays in Fig. 3.

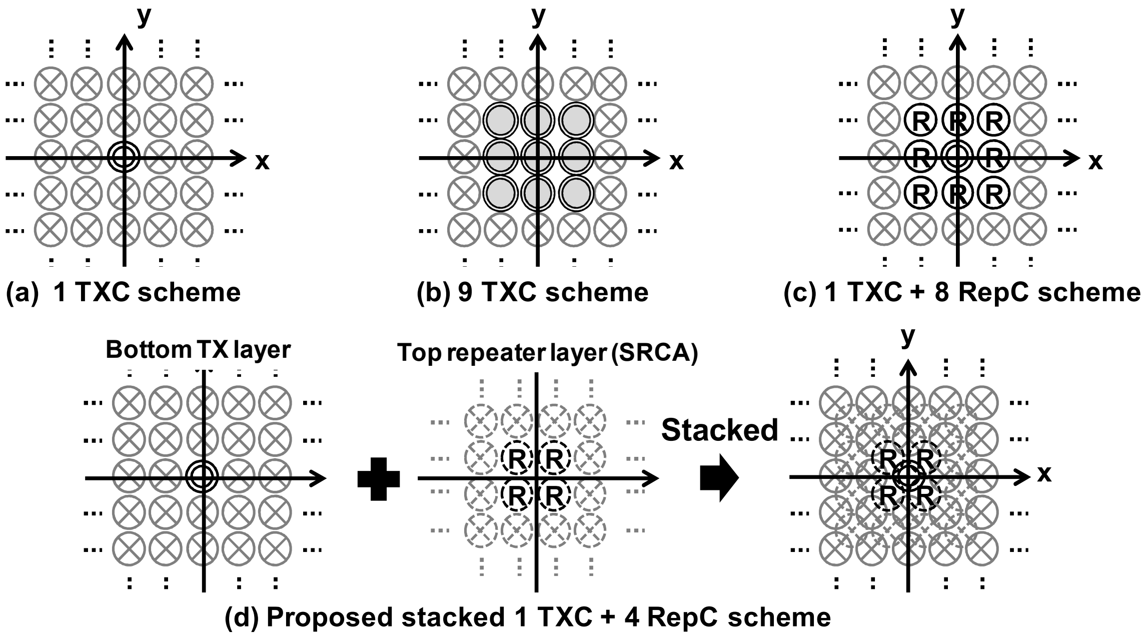


Fig. 3. 4 different coil arrays. (a) Conventional 1 TXC scheme [1, 3-4]. (b) 9 TXC scheme [2].(c) 1 TXC + 8 RepC scheme [6]. (d) Proposed stacked 1 TXC + 4 RepC scheme.

Fig. 3 shows the 4 different coil arrays compared in this paper. In the conventional 1 TXC scheme [1, 3-4] in Fig. 3(a), 1 TXC closest to RX coil is activated based on the result of a position detection of RX coil and all the other coils are open. In the 9 TXC scheme [2] in Fig. 3(b), 9 TXC's are activated. In the 1 TXC + 8 RepC scheme [6] in Fig. 3(c), 1 TXC and the surrounding 8 RepC's are activated. In the proposed stacked 1 TXC + 4 RepC scheme in Fig. 3(d), a bottom TX layer and a top repeater layer are stacked, and 1 TXC in the bottom TX layer and the surrounding 4 RepC's in the top repeater layer are activated. The repeater layer is called as SRCA, because the centers of the TX coils and the centers of the repeater coils are staggered each other.

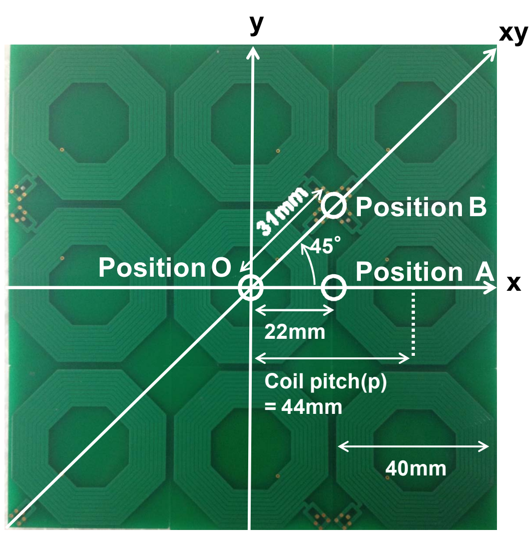


Fig. 4. Photograph 3 x 3 coil array fabricated on PCB.

Fig. 4 shows a photograph 3 x 3 coil array fabricated on FR4 PCB. The diameter of the octagonal coil is 40mm and the coil pitch (p) is 44mm. "Position O", "Position A", and "Position B" of RX coil are defined to evaluate the WPT efficiency at the misalignment conditions. Table I summarizes the coil for the magnetic resonance. The number of turns of the coil is 9 and the thickness of the metal is 35μm. Chip capacitors are used to resonate the coil for the magnetic resonance.

III. Experimental Results

In order to compare the 4 different coil arrays in Fig. 3, the dependence of the WPT efficiency on the frequency, the WPT distance, and the misalignment is measured.

TABLE I Summary of Coil for Magnetic Resonance.

Parameters	Value
Diameter	40mm
Coil pitch(p)	44mm
Number of turns	9
Line width	1mm
Line spacing	0.1mm
Thickness of metal	35μm
Thickness of PCB	1mm
Inductance	3.42μH
Chip capacitor	39pF (TXC, RepC) 33~39pF (Receiver coil)
Frequency	13.8~16.2MHz

Fig. 5 shows a photograph of a measurement setup. The WPT efficiency is measured with a network analyzer. Fig. 6 shows a definition of the WPT distance and the misalignment. The distance is defined as d. The misalignment on x-axis and xy-axis are defined as Δx and Δxy, respectively.

Fig. 7 shows a measured frequency dependence of the WPT efficiency. Figs. 7(a) and (b) show the conventional 1 TXC scheme and the proposed stacked 1 TXC + 4 RepC scheme, respectively. d is 15mm and Δxy is varied. The frequency which achieves the highest efficiency at the worst misalignment condition of Δxy = 31mm (Position B) is used in the following measurements for each 4 different coil array.

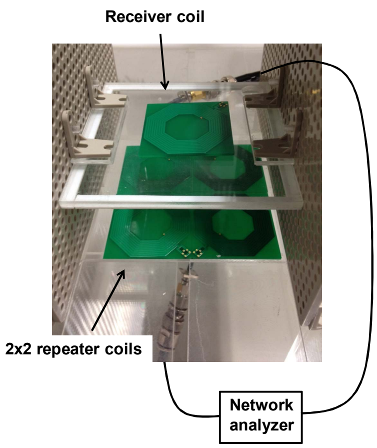


Fig. 5. Photograph of measurement setup.

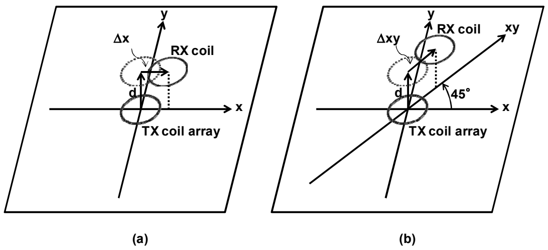
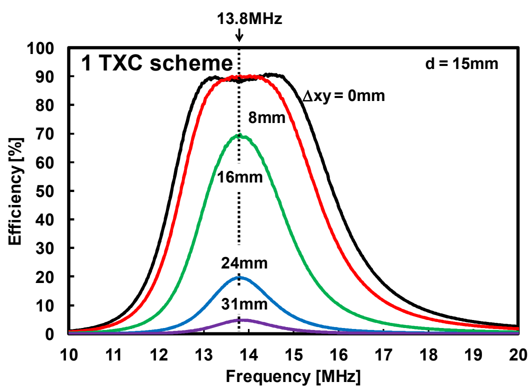
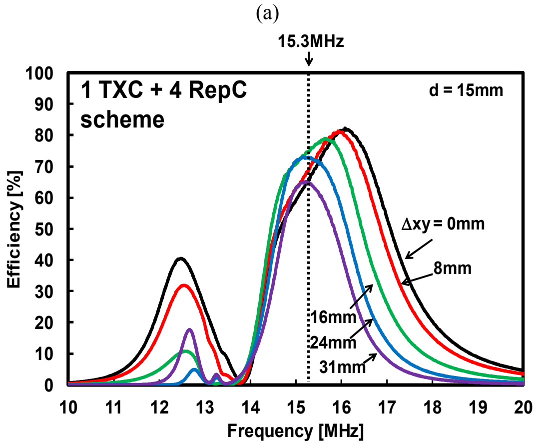


Fig. 6. Definition of WPT distance (d) and misalignment (Δx and Δxy).

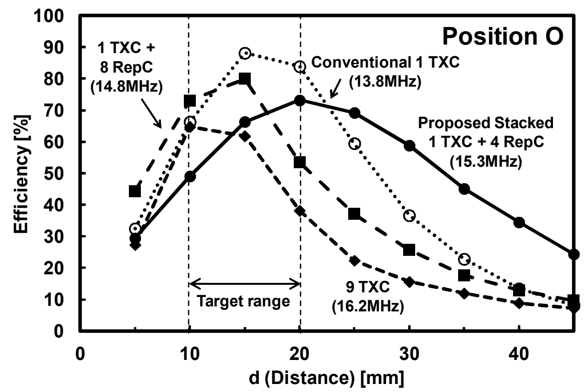


(a)

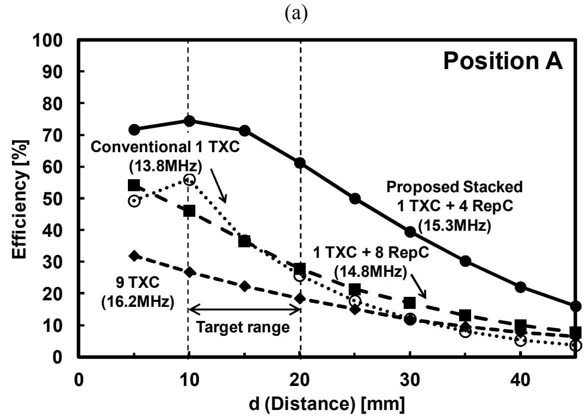


(b)

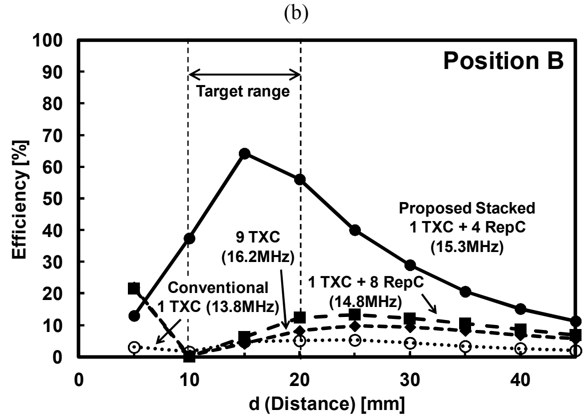
Fig. 7. Measured frequency dependence of WPT efficiency. (a) Conventional 1 TXC scheme. (b) Proposed stacked 1 TXC + 4 RepC scheme.



(a)



(b)



(c)

Fig. 8. Measured distance dependence of WPT efficiency in 4 different coil arrays. (a) Position O. (b) Position A. (c) Position B.

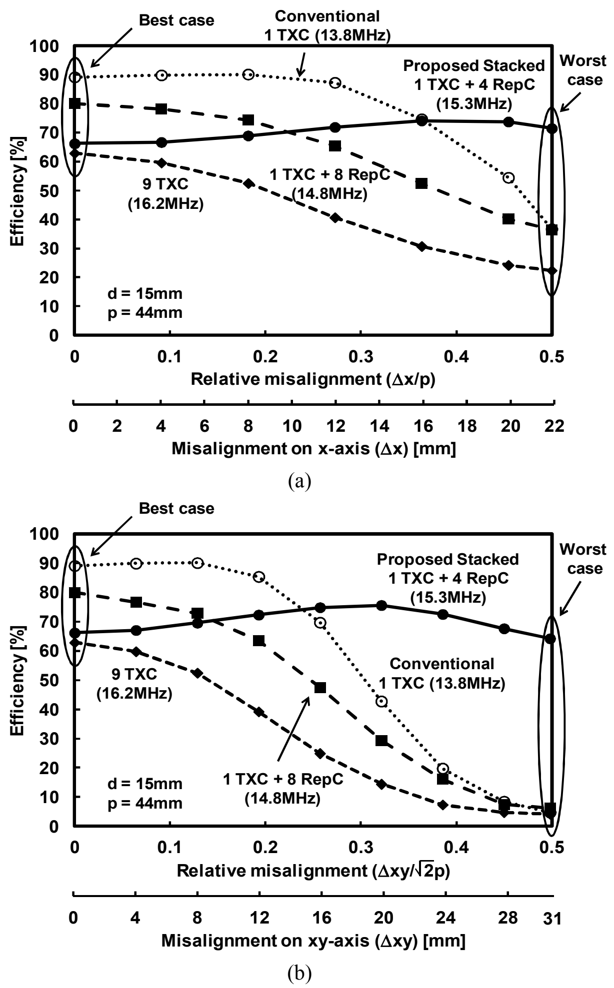


Fig. 9. Measured misalignment dependence of WPT efficiency in 4 different coil arrays. (a) Δx dependence. (b) Δxy dependence.

Fig. 8 shows a measured distance dependence of the WPT efficiency in the 4 different coil arrays. Figs. 8(a) (b) and (c) show the efficiency at Position O, Position A, and Position B, respectively. The target d in this work is 10-20mm. At Position O, the conventional 1 TXC scheme achieves the highest efficiency at d = 15-20mm. In contrast, at Position A and Position B, the proposed stacked 1 TXC + 4 RepC scheme achieves the highest efficiency at d > 5mm. The 15-mm distance which achieves the highest efficiency in the proposed stacked 1 TXC + 4 RepC scheme at Position B is used in the following measurements.

Fig. 9 shows a measured misalignment dependence of the WPT efficiency in the 4 different coil arrays. Figs. 9(a) and (b) show Δx and Δxy dependence, respectively. The horizontal axis is normalized by p. d is 15mm. As Δx or Δxy increases, the WPT efficiency decreases except for the proposed stacked 1 TXC + 4 RepC scheme. Therefore, Position O (Δx = 0 in Fig. 9(a) and Δxy = 0 in Fig. 9(b)) is the best-case misalignment, while Position A (Δx/p = 0.5 in Fig. 9(a)) and Position B (Δxy/p = 0.5 in Fig. 9(b)) are the worst-case misalignment. The WPT efficiency of the proposed stacked 1 TXC + 4 RepC scheme is more than 64% at any misalignment.

TABLE II SUMMARY OF FREQUENCY AND WPT EFFICIENCY.

Scheme	Frequency (MHz)	Efficiency		
		Position of RX coil		
		O (Best case)	A (Δx=p) (Worst case)	B (Δxy=√2p) (Worst case)
1 TXC (Conventional)	13.8	89%	37%	4.8%
9 TXC	16.2	63%	22%	4.2%
1 TXC + 8 RepC	14.8	80%	36%	6.3%
Stacked 1 TXC + 4 RrepC (Proposed)	15.3	66%	71%	64%

Table II summarizes the frequency and the WPT efficiency at Position O, Position A, and Position B in the 4 different coil arrays. Compared with the conventional 1 TXC scheme, the WPT efficiency of the proposed stacked 1 TXC + 4 RepC scheme increases from 37% to 71% at Position A, and from 4.8% to 64% at Position B. The increase of the WPT efficiency at the worst case misalignment by adding SRCA is very important, because the end-product performance of MR-WPTB is determined by the worst (=minimum) efficiency.

IV. CONCLUSION

SRCA is proposed to enable the positioning-free MR-WPTB for the ubiquitous charging of the electronic devices. By stacking SRCA and the transmitter coil array, the measured WPT efficiency at the worst case misalignment condition increases from 4.8% to 64% at 15-mm distance. The improvement of the worst (=minimum) efficiency is very important, because the end-product performance of MR-WPTB is determined by the worst efficiency.

REFERENCES

[1] T. Sekitani, M. Takamiya, Y. Noguchi, S.Nakano, Y. Kato, K. Hizu, H. Kawaguchi, T. Sakurai, and T. Someya, "A Large-Area Flexible Wireless Power Transmission Sheet Using Printed Plastic MEMS Switches and Organic Field-Effect Transistors," IEEE International Electron Devices Meeting, pp. 287-290, 2006.

[2] M. Takamiya, T. Sekitani, Y. Miyamoto, Y. Noguchi, H. Kawaguchi, T. Someya, and T. Sakurai, "Design Solutions for Multi-Object Wireless Power Transmission Sheet Based on Plastic Switches," IEEE International Solid-State Circuits Conference, pp. 362-363, 2007.

[3] E. Waffenschmidt, "Free Positioning for Inductive Wireless Power System ," IEEE Energy Conversion Congress and Exposition, pp 3480-3487, 2011.

[4] E. Waffenschmidt, "Wireless Power for Mobile Devices," IEEE International Telecommunications Energy Conference, pp 1-9, 2011.

[5] A. Kurs, A.Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, M. Soljačić, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," Science Express, Vol. 317, No 5834, pp 83-86, June 2007.

[6] F. Nishimura and H. Abe, "A Study of Array Coil for Wireless Power Transfer using Magnetic Resonance," Technical Report of IEICE WPT 2010-17, Jan. 2011.