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2024 International Symposium on Antennas and Propagation (ISAP 2024)
November 5~8, 2024 / Songdo Convensia, Incheon, Republic of Korea

An Effect of Time Reversal Based Multiple Beacon Selection on Wireless Power Transfer Performance

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***Abstract*—This paper investigates the effectiveness of multiple beacon (multi-beacon) systems in Wireless Power Transfer (WPT), focusing on improving overall RF-DC efficiency. Through simulations within a 5.64 GHz scenario, limiting a dynamic range of TXA element radiation power to a maximum of 20 dBm, and using a RXA rectifier within a specific range, multi-beacon configurations significantly enhanced RF-DC efficiency compared to single-beacon setups. The results showed that multi-beacon systems achieved 43.07% RF-DC efficiency and a RXA DC power of 1.20 W at a distance of 0.5 m, compared to 13.49% and 2.40 W with a single-beacon configuration, demonstrating the appropriateness of multi-beacon selection in our system design. On the other hand, trade-offs are evident: while multi-beacon systems bring high RF-DC efficiency, they also degrade absolute power and require high hardware complexity. This underscores the importance of adaptive beacon selection, taking into consideration the dynamic range specifications of both TXA and RXA.**

Index Terms*—Array antenna, Microwave power transmission, Near field, Time reversal, Wireless power transfer.

I. Introduction

RF-WPT conventionally uses a transmitter array (TXA) and a receiver array (RXA) to transmit and receive power. This system requires an appropriate transmit pattern to send power efficiently, which is achieved by controlling the magnitude and phase of each element in the TXA. Various methods can generate effective transmit patterns, such as beamforming [1], feedback [2], retro-reflective [3], near-field focusing [4], and time reversal (TR) [5]. TR is a good candidate for fast and efficient transmit pattern determination, with Lerosey *et al.* [6] first reporting the focusing property in EM waves.

This study focuses on the TR method. Fig. 1 illustrates a common TR-based WPT system with a single beacon. In this setup, a focal spot is generated at the location of the beacon, resulting in a concentric degraded power distribution at the RXA [4], [7]. Consequently, the edge elements of the RXA become ineffective due to their low received power. This paper addresses this issue by proposing a method to utilize all received power at the RXA elements more effectively, aiming to achieve as uniform a power distribution as possible.

The focus of this study is on enhancing the RF-DC efficiency by selecting multi-beacons in RXAs, which uniforms the received power distribution. We account for the RF-DC

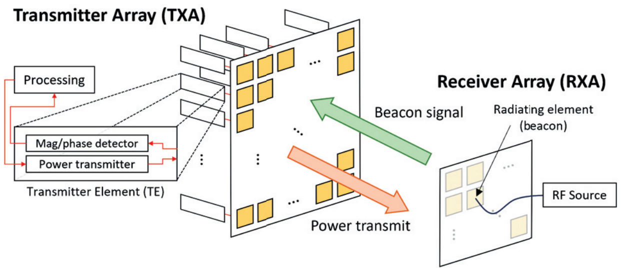

Fig. 1. Block diagram of a conventional TR based WPT system. Beacon can be located anywhere in RXA.

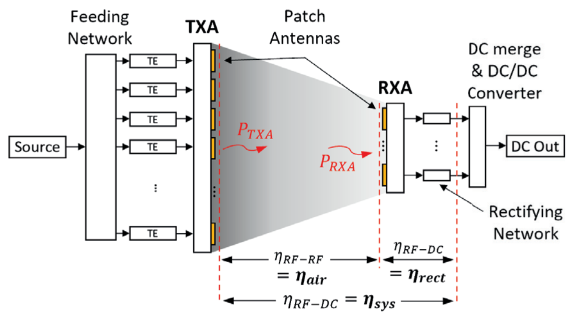

Fig. 2. Major efficiencies of WPT system. RF-RF efficiency between TXA and RXA is notated as η_{air}, RF-DC conversion efficiency by rectifier as η_{rect}, and the multiplication of both as η_{sys}.

conversion efficiency of the rectifier at the RXA, thus considering the improvement from TXA RF power to RXA DC power, as illustrated in Fig. 2. The structure of this paper is as follows: Section II explains the conventional TR system operation. Section III presents simulation results. Finally, Section IV offers the conclusions.

II. Time Reversal WPT Systems

Fig. 1 depicts the conventional TR setup in WPT systems. Some elements of the RXA are connected to the signal source and radiate an EM wave (which acts as a beacon), where the TXA detects the magnitude and phase. The TXA processes the transmit pattern by conjugating the phase and scaling the magnitude in various ways. In this paper, we simply scaled up the magnitude and normalized it. Due to the properties of TR, assuming a single beacon, a focal point is sharply generated

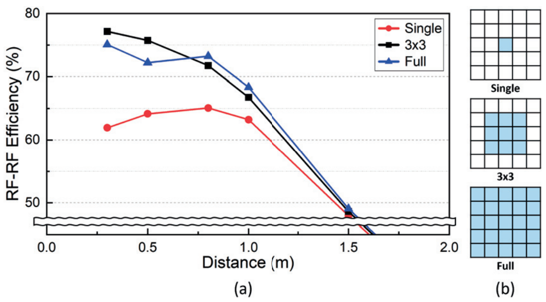

Fig. 3. (a) Distance (m) – η_{air} (%) graph, (b) Simulated three different beacon patterns.

at the RXA. This system can be effective for single antenna or small RXA scenarios. However, as the RXA size increases, the deviation in received power makes other regions less effective. In this case, simultaneously operating multi-beacons can create a smoother received power pattern.

III. Simulation Results

We employed a MATLAB-based simulator for simulations within the 5.64 GHz scenario, utilizing a TXA of size 16×16 and an RXA of size 5×5 in a LOS and boresight environment. The antenna element spacing was designed as 0.6λ, with antenna pattern simulated by HFSS. Leveraging the knowledge of TR and reciprocity, three different beacon patterns were simulated: single, 3×3, and full.

In Fig. 3(a), it is evident that employing a suitable multi-beacon approach can enhance efficiency, with η_{air} reaching about 64.15% with a single beacon and 72.21% with a full beacon at 0.5 m. Furthermore, it is observed that as the distance increases, efficiency converges due to the approximate negligible differences in patterns in the far-field region. Fig. 4 illustrates the received power pattern, indicating that the single beacon yields the sharpest distribution, whereas the full beacon yields a more uniform distribution. This shows that TR using a full beacon can effectively utilize the entire area of the RXA.

Fig. 5 displays the measured PCE graph of the designed rectifier (HSMS 282C), which was selected as suitable for our system. The RF-DC efficiency, η_{rect}, was calculated as 21.03% with a single beacon and 59.64% with a full beacon at a distance of 0.5 m. By multiplying η_{air} and η_{rect}, the full beacon achieved an overall RF-DC efficiency (η_{sys}) of 43.07%, whereas the single beacon achieved only 13.49%. This substantial difference underscores the importance of uniformity at the RXA in maintaining system efficiency.

IV. Conclusion

In conclusion, this study demonstrates the effectiveness of multi-beacon systems in enhancing total RF-DC efficiency, achieving 43.07% efficiency compared to 13.49% with a single beacon, showing that multi-beacon systems significantly enhance performance within our TXA and RXA dynamic range. However, Fig. 6 illustrates the trade-offs, as multi-beacon increase efficiency while also degrading absolute RF powers due to the TXA nulls generated by summed beacons.

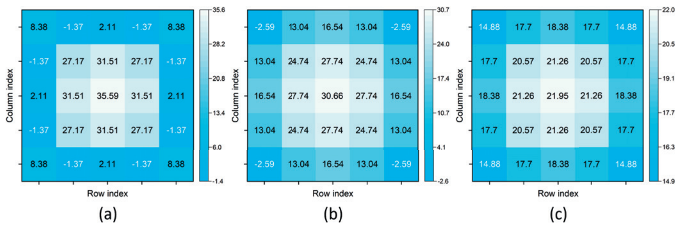

Fig. 4. RXA received RF power heatmap in dBm. (a) single, (b) 3×3, (c) full beacon patterns, respectively.

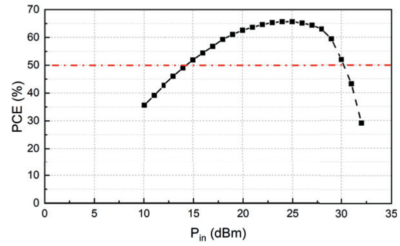

Fig. 5. Measured P_{in} (dBm) – PCE (%) graph of the designed rectifier. The peak PCE is 65.6%, and PCE over 50% range is [13.6, 32.5] dBm.

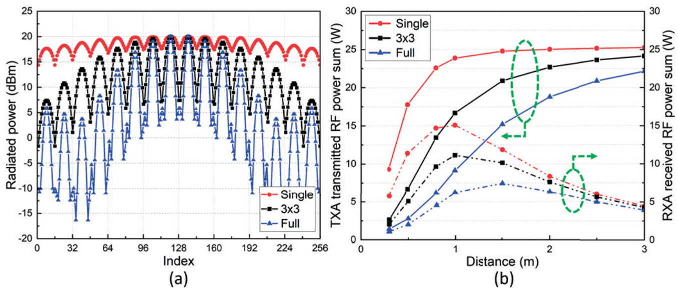

Fig. 6. (a) Radiated power (dBm) of TXA plotted by 1D index with 20 dBm normalization, (b) TXA/RXA RF power sum (W) plotting by distance (m).

This underscores the necessity of selecting appropriate multi-beacon layouts within the given TXA and RXA dynamic ranges. These trade-offs requires future research to explore more efficient methods of controlling magnitude and managing the hardware complexity resulting from multi-beacon use.

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