Optimization of a Wireless Power Transmission System

A. R. C. Cheah, K. H. Yeap, K. Hirasawa, K. C. Yeong, and H. Nisar

Abstract—**In this paper, we analyze the performance of a wireless power transfer (WPT) system, designed using an optimization algorithm. In our design, we have placed a parasitic wire in between the transmitter and receiver of the WPT system. In order to optimize the efficiency of wireless power transmission, we have applied Simulated Annealing (SA) to determine the parameters of the parasitic wires. By carefully adjusting the size, geometry and position of the parasitic wires, it could be seen that the peak efficiency of the power collected at the receiver could be significantly improved. In our result, we have also shown that by introducing a reactive component into the wire and optimizing its parameter, the peak efficiency can be further enhanced by approximately 0.2% and 0.3%, respectively, for a system with a parasitic square and circular wire.**

***Index Terms*— parasitic wire, reactive component, Simulated Annealing (SA) algorithm, Wireless Power Transfer**

I. INTRODUCTION

Wireless technology is one of the essential developments that culminates the technological evolution. Extensive application of this technology (e.g. cellular network, broadcasting and radio communication) in both rural and urban communities has becoming inseparably intertwined with our daily lives. [1] However the transferring power and efficiency of the typical WPT system are constrained by distance, as the performance of wireless power transfers is found to decay with increasing distance [2]. Researches have been carried out in order to complement the weakness of this technology [3-7]. It has been shown that the implementation of parasitic wires with different sizes and geometries has the ability to increase the efficiency of the power collected at the receiver to as high as twice that of a conventional wireless power transfer (WPT) system. It is to be noted, however, that the parameters of the parasitic wires (e.g. radius, length and distance between wires) were arbitrarily taken. Hence, the power efficiency attained may not be fully optimized. It would certainly be interesting to find out the parameters and the peak efficiency when the system is optimized. In this paper, we investigate the optimal behavior of a WPT system, with the presence of a parasitic square and circular wire in between the transmitter and receiver. In our design, we have applied the Simulated Annealing (SA) algorithm for optimization. We shall demonstrate that the efficiency of the system could be significantly enhanced using SA, particularly, with careful selection of reactive components in the parasitic wires.

II. SIMULATED ANNEALING

SA is a well-established stochastic algorithm which models the natural crystallization process by heating up a material (metal or glass), and slowly lowering the temperature in order to toughen it. Cooling rate in this heat treatment process is vital as cooling the material too fast or too slow may not facilitate in searching for the optimized results [8]. One of its outstanding roles over the other conventional techniques is that it has the explicit strategy to escape from the local maxima, with certain probability, allowing the moves to a solution inferior than the previous one in each iteration. The moves are determined according to the probability distribution with the scale that is proportional to the temperature. Unlike most conventional methods which usually face the predicament of being trapped in local optimum, the unique feature of reversal process in fitness selection enables SA to explore globally and continue in opting for better solutions. Detailed explanation on how SA works can be found in [9-12].

III. RESULTS AND DISCUSSION

The design configuration of our Wireless Power Transfer (WPT) is depicted in Fig. 1, where T_x is a center-driven dipole transmitter antenna, R_x a center-loaded dipole receiver antenna and P_x is the parasitic wire. A voltage source of 1V and operating at 1 GHz is applied to the transmitter; whereas, a 100 Ω load is connected to the receiver. The efficiency of the system could be affected by the geometry, size, properties and position of the parasitic wire P_x. We have selected two different geometries, e.g. a circular and a square parasitic wire P_x in our analysis. The distances between P_x and T_x (XLP_1) and between P_x and R_x (XLP_2), the resistance (R_p) and reactance (X_p) of P_x, as well as, the length (for a square P_x) and radius (for a circular P_x)

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are taken as the variables for optimization.

TABLE I
OPTIMIZED PARAMETERS OF A WIRELESS POWER TRANSFER SYSTEM WITH A SQUARE AND CIRCULAR PARASITIC WIRE

Variables	Square P_x Parameters	Circular P_x Parameters
P_x length (λ)	1.01	0.93
P_x radius (λ)	0.02	0.02
XLP_1 (λ)	0.23	0.24
XLP_2 (λ)	0.18	0.18
R_P (Ω)	0	0
X_P (Ω)	11.39	18.42

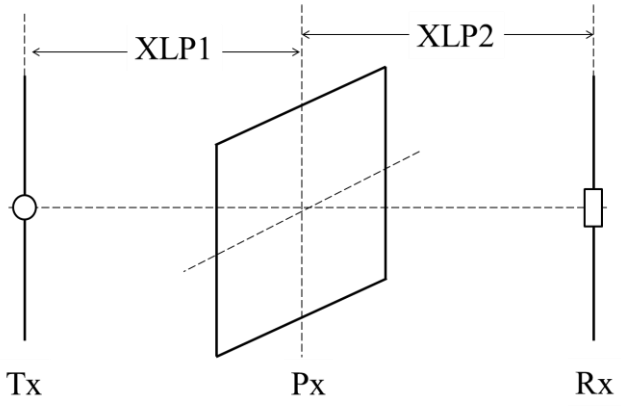

Fig. 1 Basic square PX wireless system

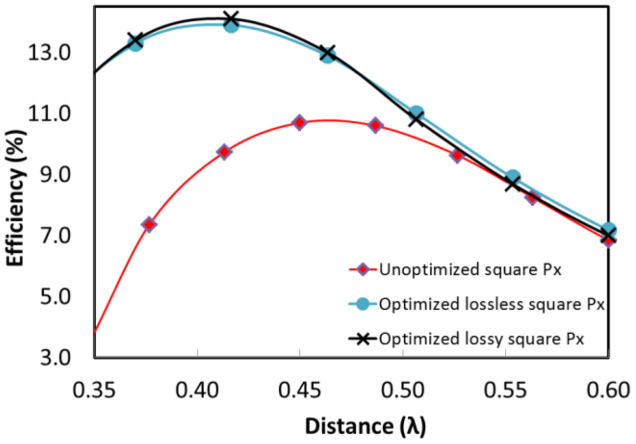

Fig. 2 Performance comparisons of square parasitic wire system with different properties at distance 0.35λ to 0.6 λ.

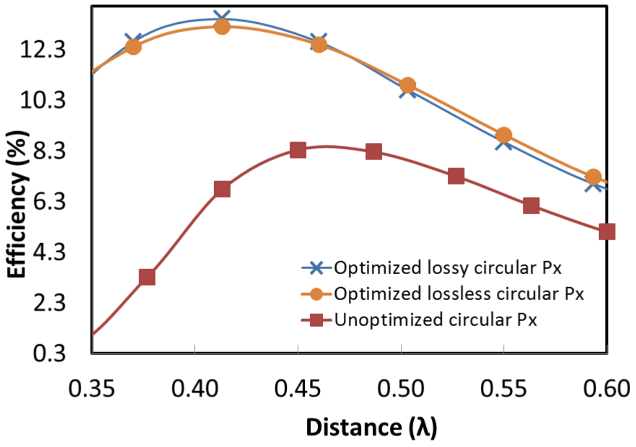

Fig. 3 Performance comparisons of circular parasitic wire system with different properties at distance 0.35λ to 0.6 λ.

TABLE II
PEAK EFFICIENCY OF WIRELESS POWER TRANSFER SYSTEM WITH SQUARE AND CIRCULAR PARASITIC WIRE

Types of Parasitic Wire	Peak Efficiency (%)
Lossless square geometry ($R_p = X_p = 0$)	13.95
Lossy square geometry ($R_p = 0$, $X_p = 11.39$ Ω)	14.14
Lossless circular geometry ($R_p = X_p = 0$)	13.23
Lossy circular geometry ($R_p = 0$, $X_p = 18{,}42$ Ω)	13.52

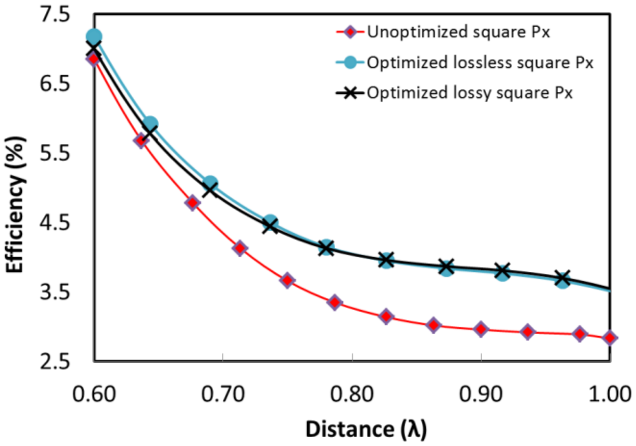

Fig. 4 Performance comparisons of square parasitic wire system with different properties at distance 0.6λ to λ.

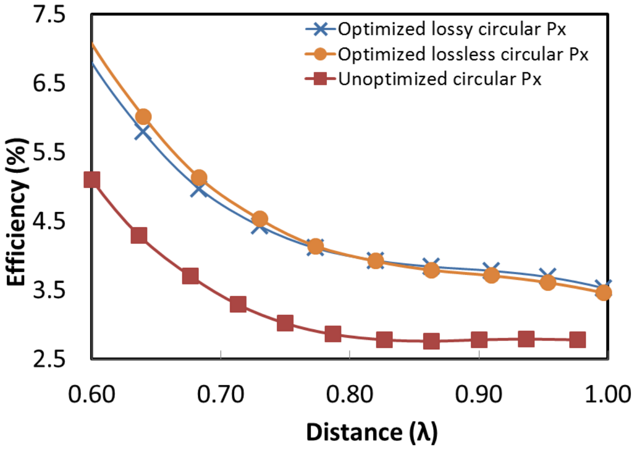

Fig. 5 Performance comparisons of circular parasitic wire system with different properties at distance 0.6λ to λ.

When running the SA algorithm for optimization, we have set P_x to be either lossless (e.g. $R_p = X_p = 0$) or lossy. For the lossy case, we have allowed the impedance in P_x to vary. The optimization algorithm is then applied to determine the R_x and X_p for the lossy case. The parameters for a square and circular parasitic wire P_x, obtained using Simulated Annealing (SA) are summarized in Table I. It is worthwhile noting that, for optimum efficiency, the resistance value R_P obtained using SA is 0 Ω as resistance contributes to loss in the system. Figs. 2 to 5 depict the power efficiency of the

WPT system, in terms of distance (λ). As can be observed from Figs. 2 and 3, the peak efficiencies of the WPT system have been significantly improved when the optimized parameters in Table I are applied. The system obtained its peak efficiencies at 0.42 λ and 0.41 λ using a square and circular P_x, respectively. The peak efficiency is some distance away from the transmitter because the receiver antenna may collect additional energy scattered from the parasitic wire in addition to the reception of direct electromagnetic energy from the transmitter. The curves in the figures show that the system gives the highest power efficiency with the presence of a lossy reactive P_x. Table II summarizes the peak efficiencies found in Figs. 2 and 3. As shown in the Table II, the peak power efficiency when a reactive component is included in P_x is about 0.2% to 0.3% higher than that of the lossless case. It can also be seen that a square reactive P_x performs better than its circular counterpart. The peak efficiency attained using the square P_x is 0.62% higher than the circular P_x. When the receiver moves farther away from the transmitter, the power coupled to the receiver antenna tends to decrease. Hence, the power efficiency decreases accordingly as well. As depicted in Figs. 4 and 5, at a distance of 0.6 λ to λ, the efficiencies using the square and circular P_x are almost comparable. Take the distance of 1 λ for example, the efficiency for systems with a circular and square P_x, are 3.27% and 3.22% respectively. It is apparent that the efficiencies obtained are very close to each other. This indicates that when the distance is sufficiently far from the transmitter, the geometry of the parasitic wire does not give any significant advantage in improving the wireless power transmission.

IV. CONCLUSION

The detailed numerical analysis in this disclosure shows that the efficiency and effective distance in a wireless power transfer system can be enhanced when the geometry, distance, size and properties of the parasitic wire are carefully designed. We have implemented Simulated Annealing (SA) in order to optimize these parameters. From the results obtained, it can be seen that the parasitic wire with inductive component embedded in it enhances the efficiency of systems by at least 30% of its overall performance compared to the existing wireless system's design.

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