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A Methodology for Efficiency Recovering in Wireless Power Transfer Applications with Misalignment

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Abstract

A methodology for efficiency recovering in Wireless Power Transfer (WPT) systems under a misalignment condition between driver and receiver is presented. The configuration is made by an array of passive resonant elements placed in the proximity of the driver coil of a common 2-coils system. The method is based on one numerical full-wave evaluation of the scattering parameters matrix of a 2-coils system together with a passive resonant array of (*N*-2) elements, made resonant by tuning capacitors. By a post-processing evaluation of the S_{NxN} matrix of the system, it has been demonstrated possible to partially recover the efficiency from the drastically reduced value caused by a misalignment of the receiver coil into respect to the driver coil, by acting only on the tuning capacitors.

1 Introduction

Misalignment issues in Inductive resonant Wireless Power Transfer systems are common amongst the scientific community, as well as in industry. Researchers are continuously working to mitigate the efficiency drop problem that arises from the misalignment between driver and receiver coils in a common inductive WPT system; such effect can be easily explained by the Faraday's law, principle on which the system is based on.

Such system is not particularly robust in terms of misalignment, because small changes in the mutual position of the coil lead to a reduced induced electromagnetic field on the receiver; consequently for all the existing inductive WPT systems their efficiency is maximized when the coils are coaxial, otherwise, when the misalignment is present, it rapidly decreases due to the smaller coupling area.

In recent years, in the scientific literature the use of slabs presenting resonant unit cells and capable of focusing the magnetic field of a common two-coils system has been widespread. It has been shown that this solution allows increasing the overall efficiency of the system. These systems, also known as metamaterials [1], have been recently proved also able to reduce the amplitude of the electric field for safety concern [2]. In addition, some research groups have approached the study of these systems even in a very early tunable version with the aim of magnetic field focusing purposes [3]. Other researchers, starting from an analytical formulation, have optimized the system by varying the distances between the single unit cells in the array: while this approach can be very interesting from a theoretical point of view, some additional work should be addressed before implementing such solution [4].

In our work, starting from a 2-coil WPT system with the presence of a slab consisting of unit cells of fixed size, shape and distances, made resonant by capacitive loads, we aim to propose a method that allows a quick and reasonably accurate modification of the response of the whole system thus making it more efficient to deal with problem related to misalignment. Exploiting an initial single full-wave simulation, we then elaborate in post-processing the entire system working with the scattering parameters that represents the system. We demonstrate through an opportune test-case that this approach is very effective to quickly study the system for recovering the efficiency lost due to the accidental misalignment between driver and receiver.

2 Methods

The proposed method aims to speed-up the procedure for designing a Spiral Resonators Array (SRA) with the purpose of improving the efficiency level of a standard WPT 2-coils system when a misalignment is present. Firstly, full-wave numerical simulations of the 2-coils system with and without the presence of the resonator matrix must be performed.

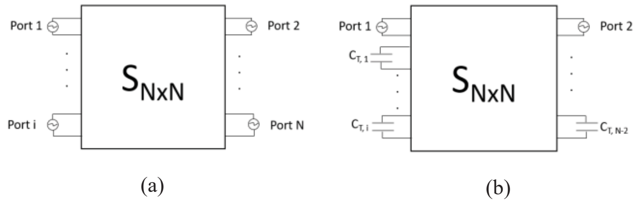
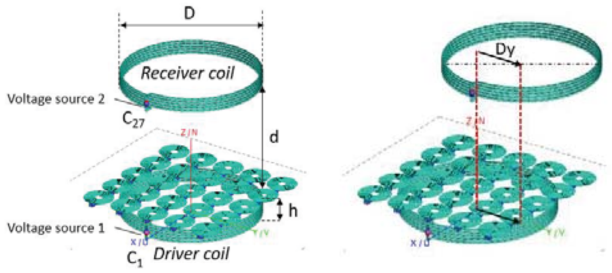


Figure 1. Circuit model of the system: (a) circuital representation at STEP 1; (b) circuital representation at STEP 2: the added tuning capacitors can be highlighted.

In addition, to prove our method, we also performed a simulation when a certain misalignment between driver and receiver coils is present. At this step (STEP 1), all the feeding ports (*P*) and all the lumped elements (*L*) are considered as standard 50 Ω ports. The aim of the two last simulations is obtaining the *S* parameters matrix having $N \times N$ elements, where $N=P+L$, which completely describes the system: in this way, the system can be interpreted as a black box.

Therefore, a circuital optimization of the complete equivalent system (STEP 2) can be performed by feeding the actual ports and inserting all the tuning elements as shown in Fig.1 (b).

Specifically, an optimization of the values of the tuning capacitors can be developed in order to enhance the performance of the array used in the WPT system for a desired frequency or to make it more robust to the misalignment, as in the proposed study.



(a) (b)

Figure 2. Numerical CAD models of the proposed WPT system with SRA configurations: (a) aligned; (b) with a *Dy* misalignment along *y* axis.

2 Numerical design

The numerical simulations were carried out with an electromagnetic solver based on the Methods of Moments (Feko suite, Altair, Troy, MI, USA).
The first step involved the design of a classical 2-coils system which represents the most common configuration used in WPT applications. Both driver and receiver consist of the same resonant 4 turns solenoid, with a diameter equal to D = 18 cm, made of a 4 mm diameter copper wire. They were placed at a distance d = 16 cm, in a coaxial fashion (Fig. 2 (b)). We added, for both the coils, a capacitive load of $C_1 = C_2$ = 81 pF to obtain the resonance at the chosen working frequency (6 MHz); then, we inserted the spiral resonator array between the driver and receiver coils.

The array was composed by a 5×5 matrix of passive resonant planar spirals: we placed the array as close as possible to the driver coil (1 mm away), in order to preserve the useful working distance (i.e., the available space between the array and the receiver coil). The average diameter of the single spiral resonator is equal to 40 mm with a number of turns equal to 8. Finally, the unit cells for each case were equipped with lumped capacitors (i.e. capacitors from C_1 to C_{25} depicted in Fig. 3) in order to ensure that the overall array resonance remains at 6 MHz. At this stage, all the existing lumped elements are considered as ports. Finally, we slightly misaligned the receiver into respect the driver position, as shown in Fig. 2(b). We applied a translation to the receiver of *Dy* equal to 6 cm from the center of the coil along the *y* axis.

3 Results and Conclusions

As shown in Table I, by post-processing the circuital simulations, we obtained: the efficiency levels of the two-coils WPT system when driver and receiver are perfectly aligned and the array tuning capacitors have the same values C_0 = 585pF; the efficiency levels of the two-coils misaligned WPT system when all the array tuning capacitors are equal to C_0 = 585pF; the efficiency levels of the misaligned two-coils WPT system when all the array tuning capacitors have been properly optimized as shown in Fig.3 with the aim of recovering the efficiency losses due to the misalignment.

We achieved a +6.39% of efficiency enhancement with respect to the case in which the driver and receiver coils are misaligned along *y* axis of *Dy* = 6 cm. As shown in Fig. 3, we obtained the last result by short-circuiting the spiral resonators reported in light grey and by choosing the values equal to C_{opt} = 575 pF for all other capacitors in the matrix (dark gray).
The obtained promising results suggest that an *ad-hoc* optimization can be performed by applying the proposed method, making the system more robust to the misalignment in real scenarios.

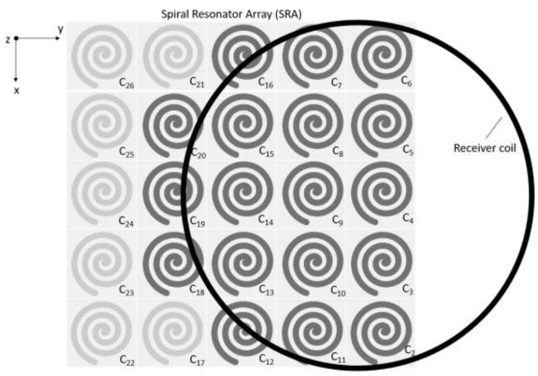


Figure 3. Schematic representation of the SRA with respect to the receiver translation: z = 0 plane (drawings not in scale).

TABLE I
EFFICIENCY OF THE ANALYZED SYSTEMS

	No resonators array	*With resonators array*	*Misaligned*	*Misaligned recovering*
Efficiency [%]	5.5	35.8	27.38	29.13

4 References

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