Tunable Metamaterial-Inspired Resonators for Optimal Wireless Power Transfer Schemes

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Abstract

The advent of wireless power transfer (WPT) technology has offered a gradually evolving research field with a multitude of triggering applications, like electric vehicles, bio-medical implants and wireless charging media for consumer electronics. However, since the initial establishment of its principal characteristics, instructive WPT efficiencies have been implemented only for rather small distances. Research on this issue has revealed that WPT through electromagnetic resonance can achieve a relatively high efficiency, when these circuits share the same resonance, while the relation between the coupling coefficient and total losses is optimal. Potential candidates for the fulfillment of these requisites are the metamaterials - i.e. synthetically engineered media with unique electromagnetic properties, not available in nature - on condition that a wide bandwidth is provided. For the latter attribute, numerous mechanisms have been utilized to accomplish radical bandwidth reconfigurability. Typical metamaterials, employed for this purpose, are various types of split-ring resonators (SRRs). Such configurations offer a negative effective relative permeability within a spectrum above their resonance frequency, when excited by a suitably oriented external electric/magnetic field. Therefore, a magnetic resonance that increases the magnetic coupling between the SRRs is generated. As WPT is attained through the magnetic coupling of the equivalent coils of two resonators, elements with pure electric properties above their resonance frequency are not expected to improve dramatically the efficiency of the system. However, the necessity of compactness in modern technology opts for further miniaturization of such structures to enable portability.

Based on the above aspects, a class of metamaterial resonators is introduced in this paper for the significant efficiency improvement of contemporary WPT topologies. Furthermore, the incorporation of programmable edge-coupled SRRs (EC-SRRs) and E2 SRRs, in the form of periodic metasurfaces, which can mitigate proximity effects when interacting with the source and load loops, is thoroughly investigated. Essentially, the

metasurface operates as the resonator of the featured device, guaranteeing increased levels of efficiency. In this manner, the proposed design methodology retrieves the optimal dimensions and electromagnetic parameters of the aforementioned metamaterial-based forms in order to provide advanced levels of WPT efficiency. The performance of every setup is numerically extracted and assessed by means of the COMSOL Multiphysics® computational package (simulations conducted via the RF module), which implements the finite element method (FEM). Specifically, the impact of the different system parameters (metamaterial dimensions, distance between the resonators, and distance between each SRR and the corresponding coil) on the overall performance is comprehensively explored. Moreover, a variety of the optimally-designed designed has been fabricated in the form of laboratory prototypes to facilitate the appropriate comparisons in terms of realistic operation conditions. Results and comparisons certify the merits of the analysis and support our concept for the effective use of controllable metamaterial-oriented arrangements in modern WPT systems.

Figures used in the abstract

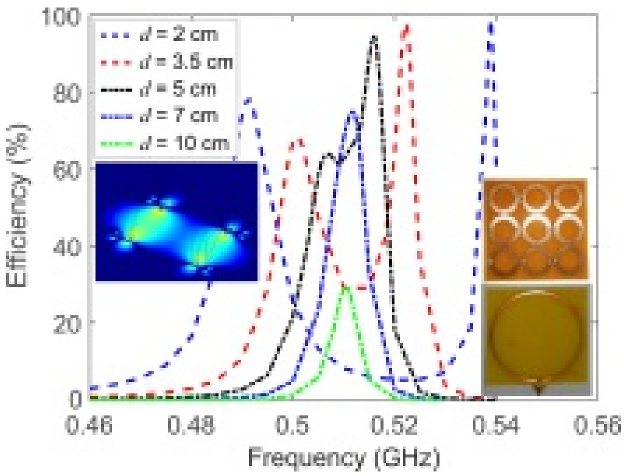

Figure 1: Efficiency of the proposed WPT system for the EC-SRR case and different distances, d, between the transmitter and the receiver