Analysis of coupling between magnetic dipoles enhanced by metasurfaces for wireless power transfer efficiency improvement

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Abstract

In this paper, we investigated the possibility of improving efficiency in non-radiative wireless power transfer (WPT) using metasurfaces embedded between two current varying coils, and presented a complete theoretical analysis of this system. We used a point-dipole approximation to calculate the fields of the coils. Based on this method, we obtained closed-form and analytical expressions ~~that~~ which would provide ~~initial~~ basic insights into the possibility of efficiency improvement with metasurface. In our analysis, we used the equivalent two-sided surface impedance model to analyze the metasurface and to show for which equivalent surface impedance the WPT efficiency will be maximized at the design frequency. Then, t~~T~~o validate our theory, we performed a full-wave simulation for ~~analysis~~ analyzing a practical WPT system, including ~~of~~ two circular loop antennas at 13.56 MHz. We then designed a metasurface composed of single-sided CLSRRs to achieve a magnetic lensing based on the calculated equivalent surface impedance. The analytical results and full-wave simulations ~~show~~ indicated ~~that~~ non-radiative WPT efficiency improvement due to amplifying the near evanescent field which can be achieved ~~by means of~~through inserting the proposed metasurface.

Introduction

Electricity supply is one of the most important challenges with the increasing expansion of electrical appliances and changes in the human lifestyle ~~of humankind~~. Wireless Power Transfer (WPT) is one of the most useful and practical solutions ~~of~~ for charging a variety of electronic~~s~~ devices [1]. The earliest suggestions of WPT ~~have been~~were proposed by Tesla in 1891, but his prototype was not safe and practical due to the lack of standard radio frequency technology at that time [2]. Wireless power transfer can be used to charge personal electrical devices (smartphones, tablets, laptops), electric~~al~~ vehicles [3], medical implanted devices [4-5] and so on. In 1963, the first microwave WPT was demonstrated by Brown [6]. Wireless power systems, mainly fall into two categories~~,~~: far-field transmission and near-field transmission. In the far-field region or radiative transmission, also called power beaming, power is transferred by beams of electromagnetic radiation, ~~like~~ such as microwaves or laser beams. In this type of WPT, the energy is transferred ~~by~~ through absorption and scattering in the atmosphere, ~~and~~ which requires a direct line of sight between the source and the device [6]-[7]-[8]. The main challenge in this WPT scheme is human electromagnetic exposure safety and WPT efficiency issues. Radiative WPT is suitable for space or military applications. In the near-filed region or non-radiative WPT, energy is transferred through near-field electromagnetic waves from the source to receiver [9]. In this WPT scheme, the operational distance between the transmitter and receiver is ~~much~~ far ~~smaller~~ shorter than the wavelength ~~that~~ which is suitable for charging~~e~~ ~~of~~ electrical devices with short and midrange distance. In this region, the oscillating electric and magnetic fields are decoupled and power can be transferred via electric near-fields ~~by~~ via capacitive coupling (electrostatic induction) [10] between metal electrodes, or via magnetic near-fields by inductive coupling (electromagnetic induction) between coils of the wire [11]. The other type of WPT schemes is magnetic resonant coupling power transfer (MRPT), where the energy