

A New TEAM Problem for Benchmarking Numerical Methods by Building Self-resonant WPT Devices Having Different Types of Conductors and Stray Capacitance

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With wider and wider application of wireless power transfer (WPT) devices, self-resonant ones are attracting more and more attention thanks to their merits such as high-power densities. However, the simulation of self-resonant type WPT devices is facing new challenges like taking into account the stray capacitance, the appearance of different types of conductors, the need to simultaneously consider the electric field in conductors and insulating objects and the magnetic fields in the whole domain. For the self-resonant WPT devices, typically they are usually composed of solid conductor layers, stranded Litz coil, dielectric substrates and possibly a magnetic core. As a result, one need to consider the complicated electromagnetic fields resultant from combined effect of full electromagnetic material parameters and different types of conductors. To this end, in this work a benchmark testcase is proposed for checking the numerical result by finite element analysis. Different settings by changing the material parameters will be carried out and measurement will be also implemented to rigorously check the accuracy of the numerical scheme regarding the nodal field values.

Index Terms—Benchmark, stray-capacitance, wireless power transfer.

I. INTRODUCTION

WIRELESS POWER TRANSFER (WPT) TECHNOLOGY enables non-contact transfer of power from a transmitter to a receiver through variations of the electromagnetic field, which has been widely adopted in consumer electronics, electric vehicle, unmanned aerial vehicle, etc [1].

In recent years, due to merits like high power density, lightweighting, and no need to introduce the compensation network in practice, the self-resonant WPT (SR-WPT) structure has been proposed. [2] realized a self-resonant system with a PCB layer and two thin copper trace or foil layers. To reduce additional components, an integrated coupler based on plate and coil is proposed [3]. For the numerical simulation and design of such kind of WPT devices, the numerical simulation methods are facing challenges like simultaneously considering coupled inductive and capacitive effects, resolving thin eddy current layers, taking into account the use of different kinds of conductors, etc. For simple structures, the approximate simplified models of equivalent electric circuit can be introduced for analysis [4]. But for general cases where the electromagnetic fields are not uniformly distributed, at least for partial analysis region, one has to resort to numerical methods such as finite element method (FEM). This indicates that the accuracy of FEM calculations is crucial, especially for the complicated problems here by considering different kinds of conductors and combined inductive and capacitive effects.

To this end, novel SR-WPT system benchmark testcases are proposed for benchmarking and validating the FEM computational result. The corresponding finite element formulation by taking all the above-mentioned factors will be proposed for numerical simulation of the electromagnetic fields. Comparisons will be made for the nodal magnetic and electric field values. Also the field-circuit coupling by addressing different kinds of conductors will be given later.

II. SELF-RESONANT WPT SYSTEM AND MEASUREMENT PATH

In this paper, the system architecture and geometric dimensions of the proposed SR-WPT system, having solid conductor and stranded conductors and also dielectric layers, is shown in Fig. 1. The main circuit of the system consists of a DC power supply, high-frequency full-bridge inverter, SR-WPT device, rectifier, and the load resistance R_L . Wherein, the power transmission and reception end of SR-WPT device are composed of 22-turn stranded Litz wire coils and two vertically aligned solid parallel plates.

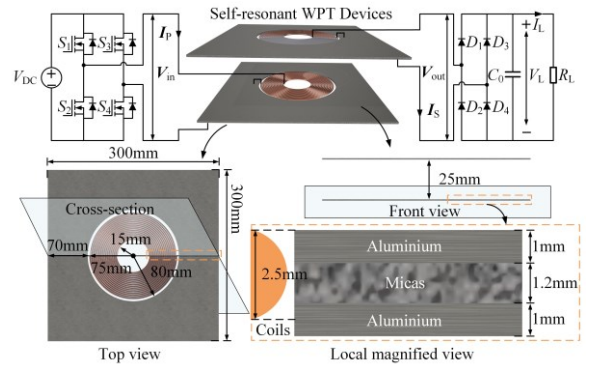


Fig. 1. Self-resonant WPT system.

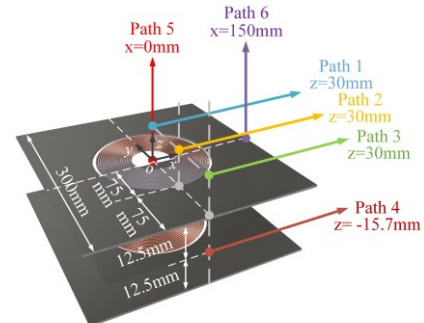


Fig. 2. Electric field and magnetic field measurement path.

To lower the operating frequency of the WPT system, a mica dielectric layer is added between the plates to increase the parasitic capacitance between the solid conductor plates. The coils and plates form an series-series topology, which can achieve self-resonance at a certain fixed frequency. In order to benchmark the electromagnetic field computation methods, six measurement paths are defined where both the magnetic and electric field values are measured, as shown in Fig. 2.

III. EXPERIMENTAL SETUP

The experiment setup is shown in Fig. 3, where the frequency of the excitation is chosen to be 728kHz, the distance of the sender and receiver is 25mm vertically. The inductance parameters of the stranded coil winding and the capacitance of the conductor plates are given in Table I. The AC excitation voltages and the currents for the sender and receiver are also listed.

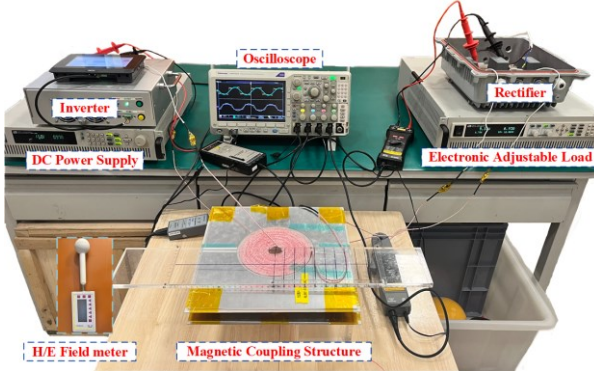


Fig. 3. Experimental WPT system setup.

TABLE I
EXPERIMENTAL PARAMETERS

Parameters	Explanation	Value
f (kHz)	System operating frequency	728
d (mm)	Transmission distance	25
L_p (μ H)	Primary coil inductance	31.2
L_s (μ H)	Secondary coil inductance	29.9
C_p (nF)	Primary plate capacitance	1.21
C_s (nF)	Secondary plate capacitance	1.25
R_L (Ω)	System load	10
V_{in} (V)	The RMS of ac voltage output by inverter	16.2
I_p (A)	The RMS of ac current output by inverter	1.21
V_{out} (V)	The RMS of ac voltage input to rectifier	11.2
I_s (A)	The RMS of ac current input to rectifier	1.25

IV. NUMERICAL METHODS

Regarding the numerical methods for this benchmark problem, one has to take into account the stray capacitance between the solid conductor plates, and also the coexistence of solid conductor and stranded conductor coils which are connected together to form the overall current path and establish the coupled electromagnetic fields. For the first question, the authors have carried out research on addressing the stray capacitance [5]. But for the electrically connected solid conductors and stranded conductors, which is not common to see to the best of our knowledge, it is worthy of investigation and will be addressed in the full paper.

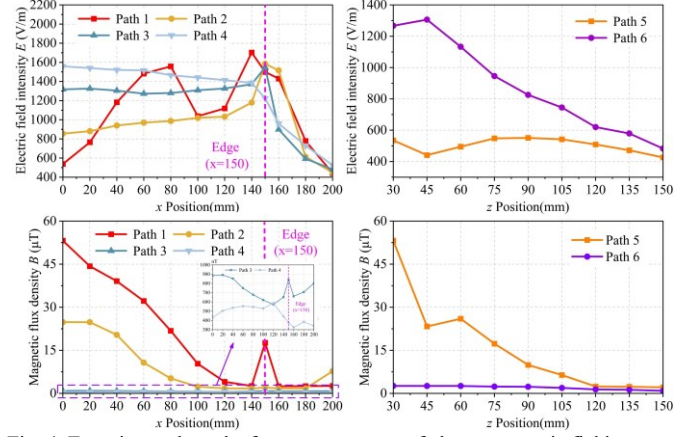


Fig. 4. Experimental results for measurements of electromagnetic field.

V. EXPERIMENTAL RESULTS

The measurement results of the electric field and magnetic field distributions along the six measurement paths proposed in Section 2 are shown in Fig. 4, where one can observe that the magnetic flux density is higher when becoming close to the coil, while the electric field intensity is higher near the plates and is relatively stabilise. This indicates that the stranded coil primarily provides magnetic field energy, while the solid conductor plates primarily provide electric field energy. In the SR-WPT system proposed in this paper, the efficient utilization and conversion of near-field electromagnetic energy within the WPT system are well demonstrated.

VI. CONCLUSION

The self-resonant wireless power transfer (SR-WPT) system can involve significant coupling of inductance, capacitance effects, and different kinds of conductors, which pose numerous challenges in the numerical calculation of the electromagnetic fields for such systems. In this work, a benchmark testcase is first proposed for validating the finite element computational result in future. The finite element simulation method, capable of simultaneously calculating both electric and magnetic fields has been proposed by the author. In the full paper, the combined solid/stranded conductors and combined inductive/capacitive effects will be simulated numerically.

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