A Novel Coil Architecture for Interoperability and Tolerance to Misalignment in Electric Vehicle WPT

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I. INTRODUCTION ABSTRACT AND KEY WORDS

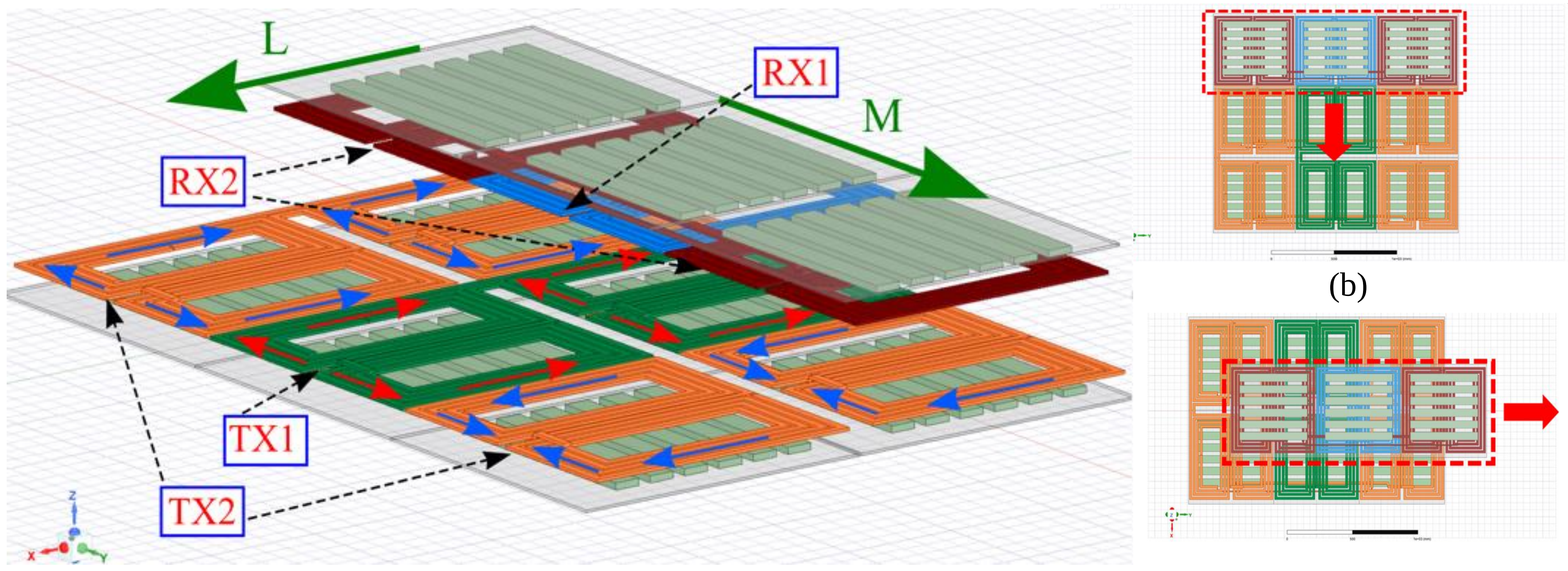
As we all know, Wireless Power Transfer (WPT) technology is expected to significantly contribute to the electrification of mobility. In this poster, we investigate a modular structure of WPT specifically dedicated to a quasi-static (such as the Electric Vehicle (EV) is parked and charging for a short time interval) or dynamic (such the EV is in moving over an array of transmitting coils) operation mode in an urban environment. However, these two operations, which are unique to WPT in contrast to the static mode of operation, produce several issues (such as tolerance to misalignment) that do not exist or are challenging to resolve. And flexibility and interoperability are the goals to be pursued in order to make such a system available for many types of vehicles. For these reasons, a new configuration is proposed that focuses on interoperability and tolerance to misalignment, and partly exploits previous results. The proposed architecture has been simulated by using commercial software. Characteristics of interoperability are analyzed when the modular transmitting and receiving coils are in proximity, and the architecture has proven to be characterized by excellent performances in terms of small interaction between each module. Finally, an improved coil design has been introduced which is characterized by good uniformity of the coupling coefficient when the receiver travels between two adjacent transmitting sections.

Key Words—Wireless Power Transfer, Novel Coil Architecture, Interoperability, Misalignment, Electric Vehicles.

II. PRELIMINARY FINDINGS

A. System Description

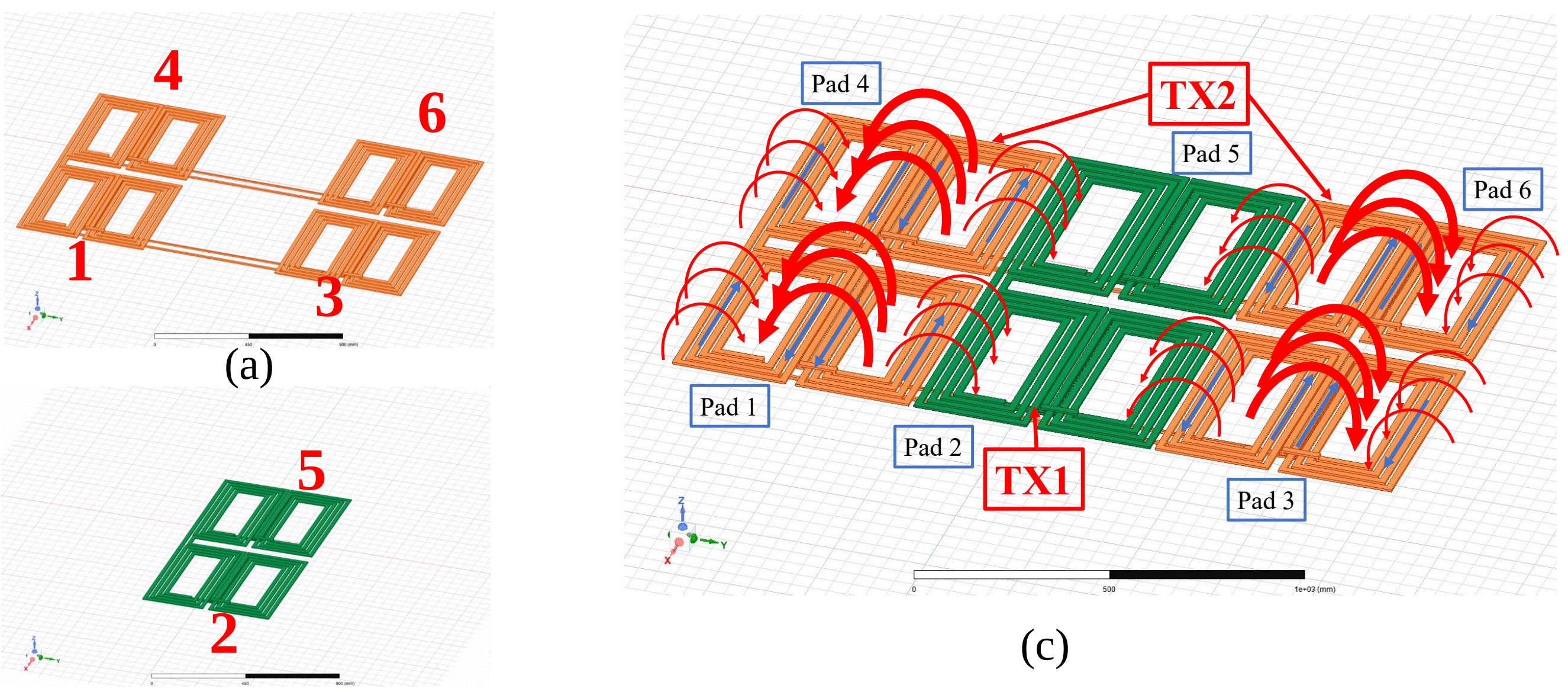
A modular structure, based on proper connections of ‘DD’ pads, is proposed for both the transmitter and the receiver to minimize mutual interaction between modules, but at the same time to guarantee coupling between transmitter and receiver. It shows the full model WPT system with transmitter and receiver, including the conductive shield and the ferrite bars, in Fig 1.



(a) (c)

Fig. 1: (a)Proposed the WPT system. The sides of each single module are 646×608 mm, the distance between transmitter and receiver is Δz=200 mm. (b) the direction of the motion 'L' is set in the range -1270~600mm. (c) the transverse direction of the motion ‘M’ is set in the range 0~650mm.

The series connection of the two green 'DD' pads stands for TX1, and the series connection of the four orange 'DD' pads stands for TX2 and form the Ground Assembly (GA). The blue 'DD' pad and the two series connected brown 'DD' pads stand for RX1 and RX2, respectively, that form Vehicle Assembly (VA). The receiving coil translates in the direction of movement (indicated by the 'L' arrow) as well as in the transverse direction (indicated by the 'M' arrow).

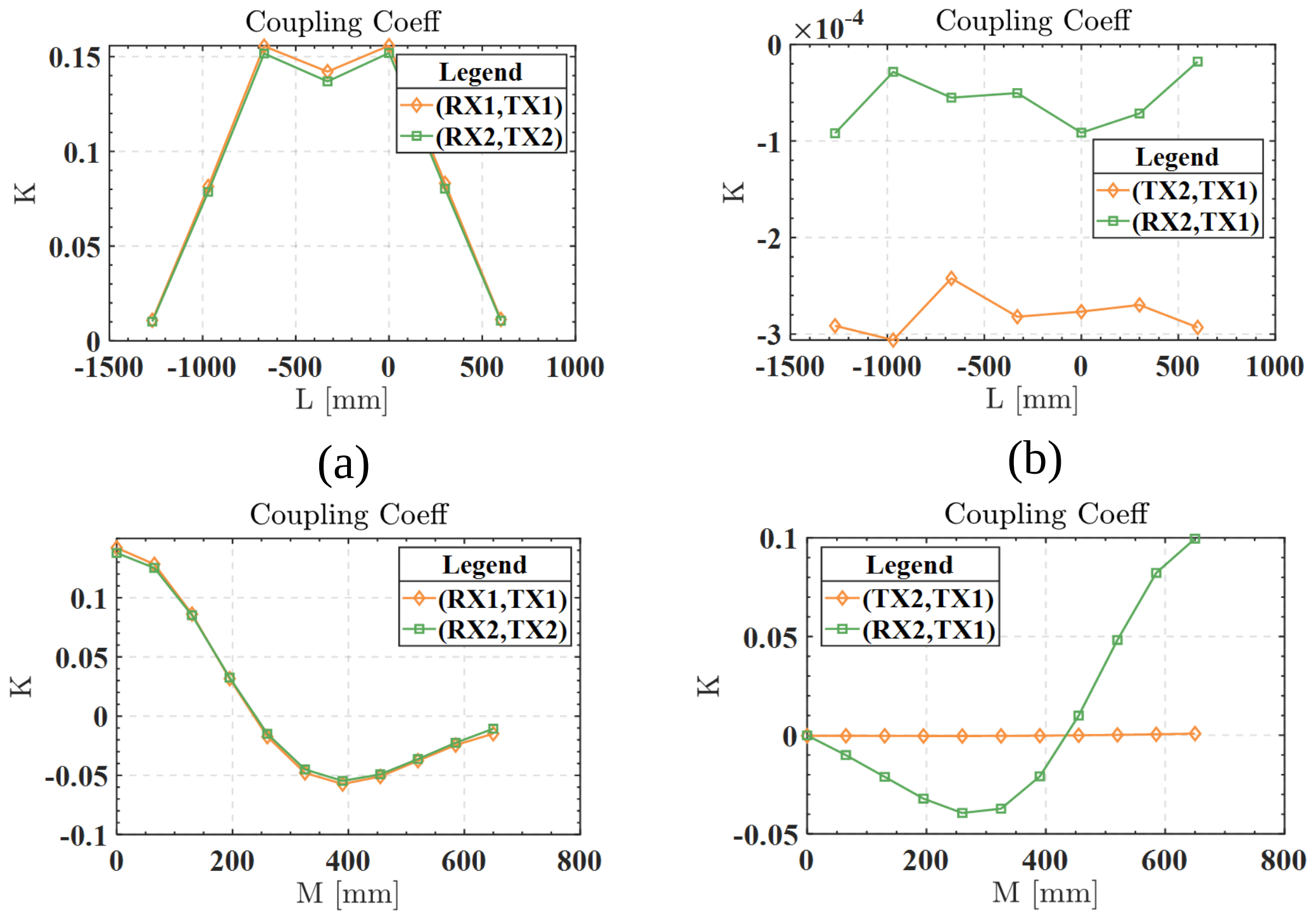


(b) (c)

Fig. 2(a): TX2 with the Pads 1-3-4-6 are series connected. (b): TX1 with Pad 2-5 series connected. (c): Flux density lines produced by current in TX2 coils are depicted.

Fig. 2(a) shows the connections between the six transmitting modules ('DD' coils) belonging to two rows in the GA. The currents in the orange coils (TX2) flow in opposite directions on both sides of the TX1. It guarantees the correct current (and magnetic field) direction while reducing the electronic circuitry burden. The fluxes generated by the transmitting coils TX2 pass through TX1 and cancel each other because of the geometrical symmetry and of the orientation of the currents in the coils of TX1.

B. Preliminary Simulation



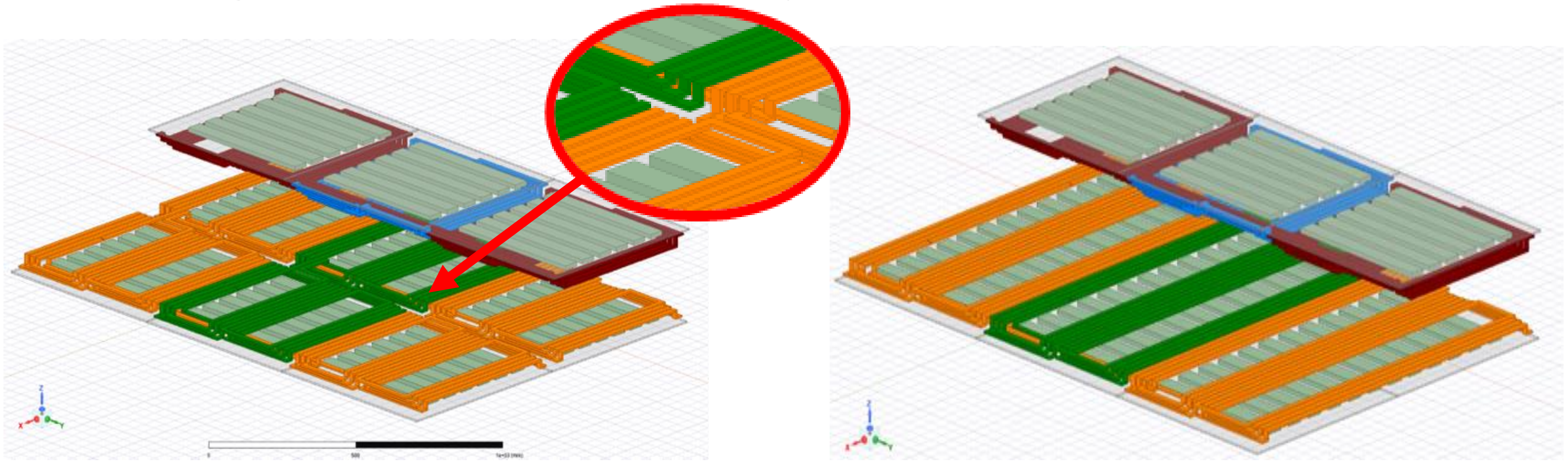
(c) (d)

Fig. 3: The Coupling Coefficients and Cross-Coupling Coefficients between the transmitting and receiving coils.

The preliminary results are reported in Fig.3, confirming the qualitative consideration of the previous subsection. The coupling coefficients between RX1-TX1 and RX2-TX2 show a reduced variation when the receiver crosses the separation between the two rows that constitutes the transmitter on the GA (ref. Fig. 3(a), while the coupling coefficients between TX2-TX1 and RX2-TX1 reported in Fig. 3(b) are neglectable (three magnitude orders less than those in Fig. 3(a)). Figs. 3(c) and 3(d) demonstrate that a lateral misalignment of ± 150 mm is still acceptable. Looking at Fig. 3(d) we see that at high misalignments the coupling coefficient between RX2-TX1 becomes high enough to envisage an energy transfer between them.

C. Improved 'DD' Coil Structure

In order to reduce the fluctuation of the coupling coefficient in correspondence of the crossing of the gap between the two TX rows, we propose the layout reported in Fig. 4(a) and named PG-OW, where the sides of the transmitter coils and the receiving coils are folded down toward the ground and up in the vehicle respectively, exploiting the space due to the thickness of the three ferrite rods. By utilizing the remaining space in the ferrite layer for the windings, coils can be arranged for maximum integration. This has required an accurate modeling of the coils that in these configurations are characterized by a 3D layout. As shown in Fig. 4(a) the conductors in the gap between the two adjacent transmitting rows are closer to each other than those in the original layout (ref. Fig. 1); considering that these conductors are characterized by opposite currents, the magnetic flux densities produced by them tend to cancel each other.



(a) (b)

Fig. 4: (a) Optimized Geometry with One row receiver coil (PG-OW). (b) Double Size geometry with One Rows receiver coil (DS-OW).

As a benchmark to this optimized geometry, a double size (in the motion direction) set of coils, see Fig. 4(b), has been simulated: in this case the coupling coefficient doesn’t present fluctuation due to the coils discontinuity. The proposed PG-OW configuration is characterized by an increased complexity in the conductor layout as shown in the inset of Fig. 4(a). The FEM model is more complex than the one used for the geometry reported in Fig. 1 (denoted as OG-OW).

D. Simulation Results of the Improved 'DD' Coil

In the actual wireless charging process, in particular in the dynamic one, the receiving and the transmitting coil may assume different relative positions. The suitability of a transmitter receiver system for dynamic WPT requires a roughly constant transferred power w.r.t. displacement in the motion direction, while maintaining a limited variation w.r.t. lateral displacement (also termed as misalignment).The coupling coefficients between the windings for the three WPT layouts are displayed in Fig. 5 as a function of the displacement L (along the motion direction) between the GA and the VA.

The DS-OW has the greatest coupling coefficient under the aligned condition (the VA is in central position w.r.t. the GA) that exceeds of about 7% those of the other layouts (under the same condition), as shown in Fig. 5(a) and (b). The coupling coefficient of the PG-OW coil shows a rough constant behavior on the interval of the displacement equal to the longitudinal length of the receiver. Fig. 5(c) and (d) show exceedingly small for all the layouts and for all the considered displacements.

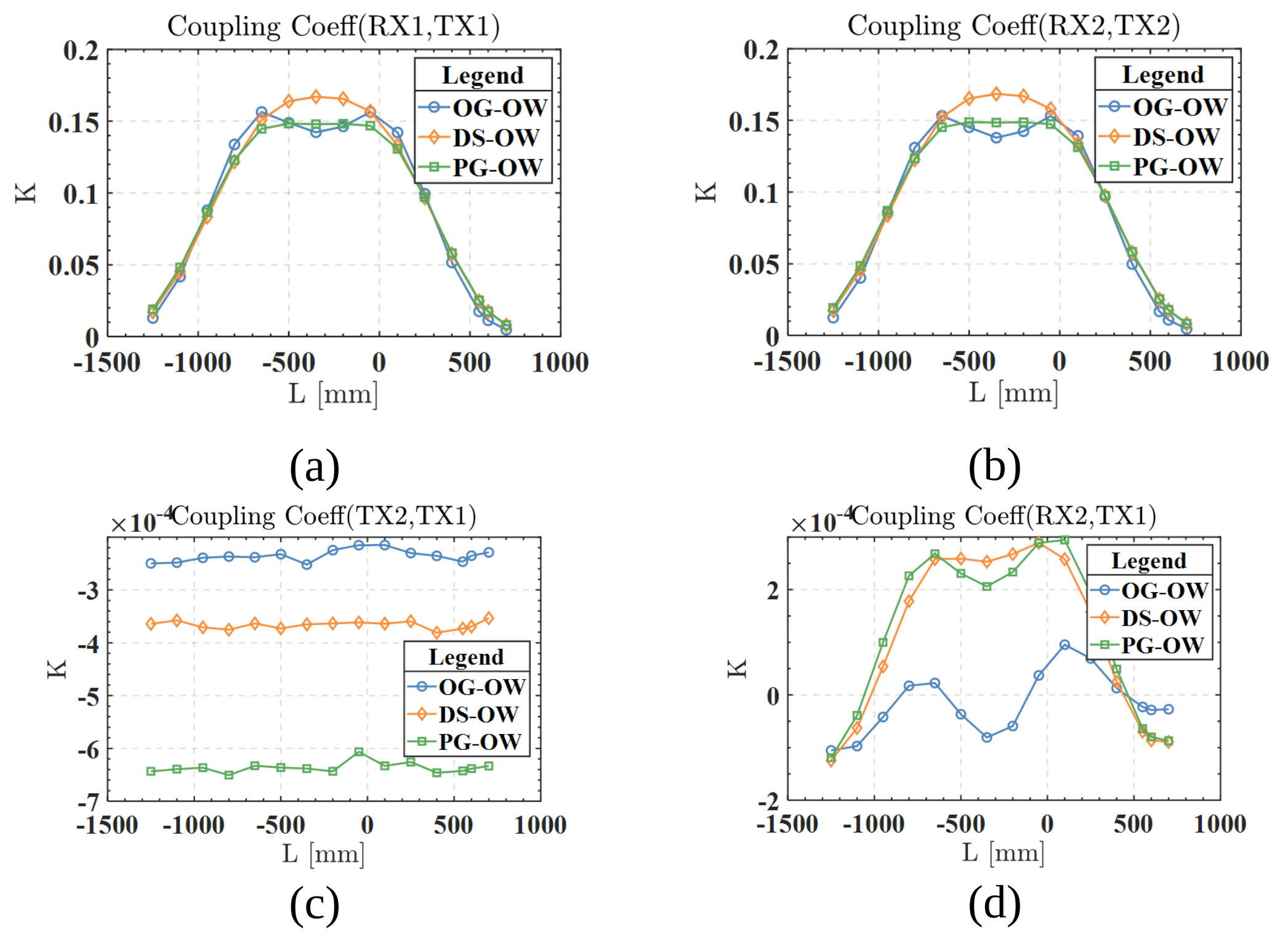


Fig. 5: Comparison of the Coupling and Cross-Coupling Coefficients between the transmitting and receiving coils of the three layouts under a displacement in movement direction.

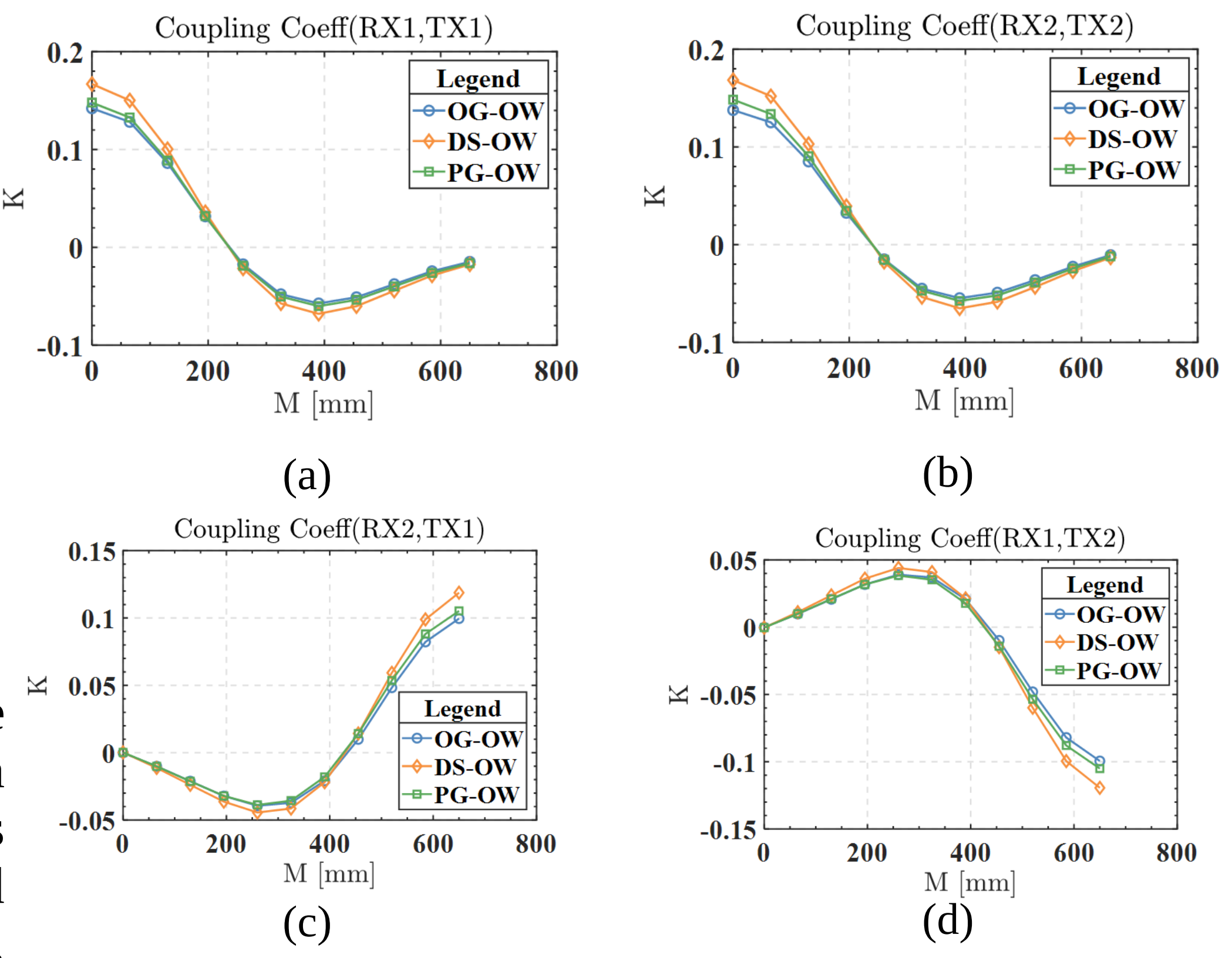


Fig. 6: Comparison of the Coupling and Cross-Coupling Coefficients between the transmitting and receiving coils of the three layouts under misalignment.

Fig. 6 shows the lateral displacement corresponds to the centered position of the receiver in the motion direction. The results reported in Fig. 6 (a) and (b) show that the coupling coefficients RX1-TX1 and RX2-TX2 gradually becomes smaller from their maxima to negative values indicating that they are decoupled. The coupling coefficients between RX2-TX1 gradually increases to values near to the ones related to RX1-TX1 when at their maxima, indicating that the energy transfer occurs between the couples RX2-TX1 and RX1-TX2. The results shows that the corresponding modules (TX1-RX1 and TX2-RX2) are characterized by coupling coefficients, which are robust enough towards misalignment.

II. CONTINUATION AND PLAN

The propose a novel coil architecture based on the traditional 'DD' coil, which can effectively achieve small interactions, tolerance to misalignment and interoperability. We considered three conductors' layouts for the proposed WPT coils system and analyzed the coupling coefficients between the GA and VA and the ability of Interoperability and tolerance to misalignment, Next, we build experimental platform for inductive wireless charging systems for electric vehicles in the quasi-static and dynamic modes.