Two-dimensional Wireless Power Relay Plane based on Rectangular Switchable Units

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***Abstract* ─** In this paper a two-dimensional wireless relay plane consists of square resonant units is proposed. Power transfer between the transmitting coil and receiver above any unit can be achieved by resonance through the shortest routes on the plane. The self-resonant frequencies of units on the planned route are adjusted to be identical for efficient power transfer, while units beyond the route are isolated from power exchange due to frequency shift. Full wave electromagnetic simulation is executed and analyzed. According to the simulation results, concentrated power transfer can be realized on the power relay plane, and the highest transmission efficiency is 73.93%.

***Index Terms* ─** Resonance coupling, routing, wireless power transfer.

I. INTRODUCTION

Wireless power transfer (WPT) has been an active research field in recent years. [1-3] focus on transmitter and receiver topology of WPT method in multi-load applications. [4-6] aim to extend power transmission distance by increasing number of relay coils. Here we consider the situation where receiver will appear in arbitrary locations of a two-dimensional plane with power requirement. A high-frequency wireless relay plane is proposed, which can deliver power directionally from transmitting coil to the receiver while avoiding excess power dissipation.

II. ANALYSIS MODEL

Considering a two-dimensional WPT plane in Fig. 1 (a), high frequency AC power is coupled to a start point *A* through a transmitting coil to power a receiver, of which B_1 and B_2 are two randomly selected positions. The plane is divided into small square power transfer units, all of which have their own circuit self-resonant frequency. As illustrated in Fig. 1 (b), power in each unit can be transferred to its adjacent units in *x* and *y* directions. The power transfer between two circuits with different self-resonant frequencies is weak. However, when some units have identical self-resonant frequency, magnetic coupling resonance occurs among these units and leads to an efficient power exchange. Take advantage of this principle, a concentrated propagation of power can be achieved along resonant units.

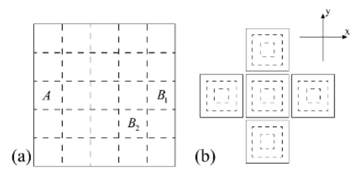

Fig. 1. (a) A two-dimensional power relay plane. *A* is the start unit, and B_1, B_2 are two locations of the receiver. (b) Each unit can transfer power to its adjacent units in *x* and *y* directions.

A planar rectangular coil is selected as the inductance of a unit, with two ends connected to a relay switch. The circuit diagram of each unit is shown in Fig. 2 (a). A control circuit is linked to each unit in parallel, responsible for switch on-off control. When both relay switches of two adjacent units are turned off, the circuit can be equivalent to Fig. 2 (b). Every unit consists of the coil equivalent inductance and resistance, and two parallel capacitors, the parasitic capacitance of the coil and the equivalent capacitance of the relay switch. Power can be efficiently transmitted between these two units through resonant coupling, and the state of these units is called activated state. On the contrary, when switch of one unit is turned on, its equivalent capacitance is short-circuited as shown in Fig. 2 (c). Change in circuit capacitance leads to an increase of unit resonant frequency compared to the activated units. This frequency divergence will destroy the resonance, which is equivalent to isolating the unit from power exchange. Therefore, this is called the hibernated state of unit.

Among all the power transfer routes from transmitting coil to the destination, those that pass through the least amount of units are defined as the shortest. Initially, all units are in hibernated state. The power source frequency is set to the resonant frequency of activated units. When a receiver enters the power relay plane, units on the shortest route are activated to power

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the receiver, while the other units remain in hibernated state. As the receiver changes its location, the shortest route is continuously recalculated, resulting in incessant state-switching of related units between activated and hibernated states.

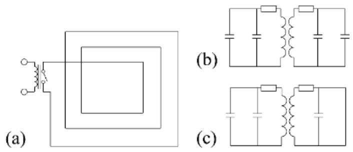

Fig. 2. (a) Circuit diagram of a unit, including a rectangular coil, a relay switch, and a control circuit. (b) Equivalent circuit of two activated units. (c) Equivalent circuit of an activated unit and a hibernated unit.

III. ELECTROMAGNETIC SIMULATION RESULTS

The design of a unit in simulation model is shown in the red box in left Fig. 3 (a). It's a rectangular 4-turn spiral copper coil with a size of 1016*mm* × 1016*mm* × 1.6*mm*. The copper strip width and the gap between each turn are 16*mm*. As illustrated in Fig. 3 (a), units are arranged together with a spacing of 18*mm* to form a 5 × 5 matrix as the model of power relay plane. Two 960*mm* × 956*mm* × 1.6*mm* single-turn copper coils are placed 13*mm* above the coils. Each coil is connected to a port of 50Ω impedance. One is located at position *A* as the transmitting coil, feeding power into the plane through coupling with the rectangular coil below. And the other one plays the role of the receiver, floating above positions B_1 and B_2. The shortest routes from position *A* to B_1 and B_2 are respectively high-lighted in left Figs. 3 (a) and (b). Coil beyond the power transfer route is short-circuited by connecting two ends with a short copper strip to simulate a hibernated unit, while the coil with both ends open is an activated unit as the switch in off state.

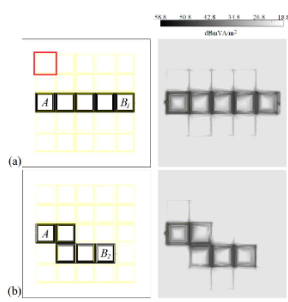

Fig. 3. (a)A 5 × 5 matrix model. Power transfer route from *A* to B_1 is high-lighted on the left. In the red box is the model of single unit. On the right is the power flow. (b) Power transfer route from *A* to B_2 on the left, and power flow on the right.

The S_{21} results of the receiver acquired from electromagnetic simulation at position B_1 and B_2 are drawn in Fig. 4, with a power transmission efficiency of 73.93% and 68.96% at 17.72MHz. The power flow is specifically verified at resonant frequency 17.72MHz with 0.5W input power. The results are displayed on the right column in Fig. 3. It can be seen from the power distribution maps that the energy is concentrated in the power transfer route. Intuitively, the power exchange is interrupted when an activated unit is encountered with a hibernated coil, and hibernated coils have almost no access to the AC power.

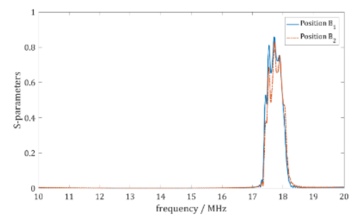

Fig. 4. S_{21} simulation results when the receiver is in position B_1 and B_2.

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