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Abstract

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Circularly polarized near field for resonant wireless power transfer

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***Abstract*—In this paper, we propose a near field coupling based wireless power transfer (WPT) system with circularly polarized magnetic field. With a pair of orthogonal resonant coils arranged to generate a circularly polarized near field, we show that the power transfer efficiency is largely maintained in case of rotational misalignment. Furthermore, by arranging the coils close to a metal surface, the power transfer efficiency is actually improved, rather than decreased as in the case of WPT system made with conventional coils. Depending on the application, the receiving coil can be either a pair of orthogonal coils, or conventional coils with flat structures. We believe that the proposed technology offers a great option toward flexible WPT applications.**

I. Introduction

Wireless power transfer (WPT) has been shown to be a practical technology of many potential application, such as wireless charging for electronic devices and medical devices, and power supply for industrial equipment. In particular, magnetic resonant coupling based WPT is favored in many cases due to its high efficiency over a short distance, and relative biological compatibility [1], [2], [3], [4], [5], [6]. In order to make the technology more practical and convenient to users, it is often desirable to allow the misalignment of power receiving devices while WPT is in process. In a typical WPT system, with one resonant coil at transmitter side, and one resonant coil at receiver side, the misalignment of the receiving resonator with respect to transmitting resonator can cause significant degradation on power transfer efficiency. A typical misalignment may involve simultaneous rotations and displacements.

In this paper, we propose a system using a pair of orthogonal resonant coils as transmitting coils, which are arranged to generate a circularly polarized near field for wireless power transfer. We show that the efficiency is largely maintained in case of rotational misalignment. Furthermore, by arranging the coils close to a metal surface, the power transfer efficiency is actually improved, rather than decreased as in the case of WPT system made with conventional coils. Depending on the application, the receiving coil can be either a pair of orthogonal coils, or conventional coils with flat structures. These features make the proposed technology suitable for flexible wireless charging applications.

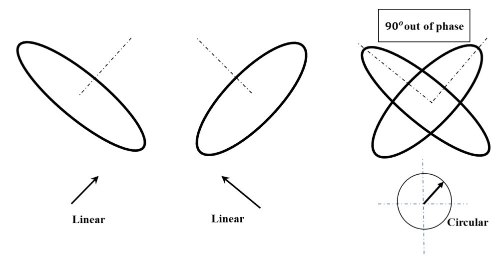

Fig. 1. A current carry loop generates a linearly polarized magnetic field. A combination of two orthogonal loops can generate circularly polarized magnetic field.

II. System Design

Polarization is an important parameter in antenna design and wave propagation. An electric field is called circular polarized if the following conditions are all fulfilled: (1) the field has two orthogonal components; (2) the two orthogonal components must have equal magnitude; (3) the two orthogonal components must have 90 degree phase difference. As an example, a dipole antenna placed vertically has linear (vertical) polarization. A dipole antenna placed horizontally has linear (horizontal) polarization. Two dipole antennas placed orthogonally and fed with 90° phase shift can generate a circularly polarized field [7]. Circularly polarized fields have been used to far field based WPT, mainly for rectenna designs [8], [9]. Similar concept can be applied to near field dominated by magnetic field, in the case of resonant coupled WPT. A WPT coil can be modeled as a current carrying loop, as shown in Fig. 1. A majority of the magnetic field in the vicinity is in the direction perpendicular to the plane where the loop lies in; the loop can thus be considered as linearly polarized along the normal direction of the loop. When two loops are arranged such that the two planes where the loops lie in are perpendicular to each other, and added 90° phase shift, circularly polarized magnetic field can be generated in the near field.

A pair of such coils can be used as WPT transmitting coil or receiving coil. In Fig. 2 a pair of rectangular coils made by split-rings is used as transmitting coil, and another pair is used as receiving coil. In the following, we will build numerical models using COMSOL Multiphyiscs, and study the power transfer performance of different cases with rotational misalignment. Each of the rectangular coil has length $L = 0.8$

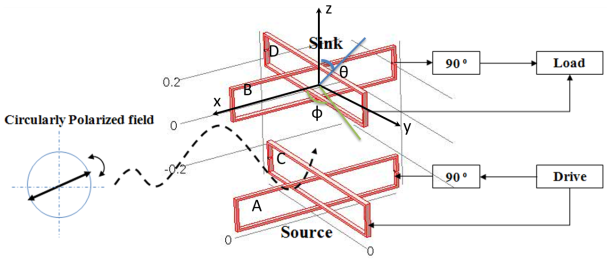

Fig. 2. The wireless power transfer system using a pair of rectangular loops and transmitting coil and another pair as receiving coil. The coordinate system with rotation angles for numerical study is also plotted.

m, width $W = 0.15$ m, and distance between center of transmitting to receiving coil is $d = 0.5$ m. A capacitor is added to the gap of each rectangular loop coil to create effective LC resonance at around 48 kHz. In order to create circularly polarized magnetic field, the pair of transmitting loop coil is fed with a 90 degree phase difference. The same phase difference is also created at the receiving side when exposed to a circularly polarized field. Numerical simulation shows magnetic field distribution in xy plane rotating around the center as a function of time.

Cases of rotational misalignment are then studied using the model, including elevation rotation, where the receiving coils rotating with different θ, and azimuth rotation, where the receiving coils rotating with different ϕ. For the case of elevation rotation, the rotation angle of the receiving coil is changed from 0 to 90°, and efficiency as function of frequency is simulated and plotted in Fig. 3(a). Peak efficiency appears around 48 kHz due to resonance. The maximum of the efficiency is about 45% for almost all the cases, although there are frequency splitting due to the change in coupling coefficient during rotation. Azimuth rotation of receiving coil is also studied, with rotation angle ϕ varying from 0 to 90°, and the efficiency is plotted in Fig. 3(b). The change in maximum efficiency is very small. At $\phi = 90°$, the most serious misaligned case, the peak efficiency drops to 39% from 45%. The case of both elevation and azimuth rotation misalignment is also studied. A 2-D pattern of power transfer efficiency is plotted in a polar coordinate system, as shown in Fig. 3(c), where the angular coordinate indicate azimuth rotation angle ϕ, while radial coordinate indicates elevation rotation angle θ. The edge of the polar plot indicates $\theta = 90°$, while the center indicates $\theta = 0$. The magnitude of power transfer efficiency was plotted as a color contour with gradient shown in the legend. The maximums are observed at the edges and the center of the graph, which indicates a perfectly aligned orthogonal wireless power transfer system. The minimum 33% is observed at $\theta = 45°, \phi = 45°$, which is the worst case. Comparing the 22% efficiency of a linearly polarized coils with 45° misalignment, the circularly polarized orthogonal wireless power transfer system can reduce the degradation of coupling efficiency due to both azimuth rotation and elevation rotation.

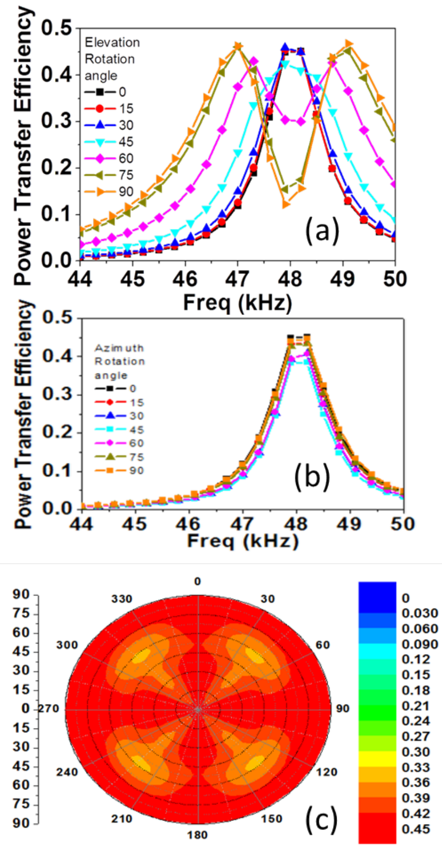

Fig. 3. Simulated efficiency of the WPT system. (a) elevation rotation with θ changing from 0 to 90°, (b) azimuth rotation with ϕ changing from 0 to 90°, (c) a 2d plot of maximum efficiency with θ changing from 0 to 90° and ϕ rotating from 0 to 360°.

A more practical and interesting WPT system is to use a relatively large transmitting coil, and a thin and relatively small receiving coil, which can be more easily adopted for wireless charging to electronic gadgets. Thus we removed one coil from the receiving side in our model, as shown in Fig. 4 and studied the misalignment cases for both circularly polarized and linearly polarized transmitting field, and the 2d polar plot for misalignment study is shown respectively in (b) and (c). Compared with linearly polarized field, the efficiency is more uniform in case of misalignment by using circularly polarized field; some extremely bad cases or dead spots in linearly polarized case are avoided with circularly polarized field.

The orthogonal coil system for WPT has another important advantage. In conventional coil system, the presence of a metal plate deteriorates the coupling and efficiency of the system. In our model, the coils are arranged to be perpendicular to a metal shield. A metal shield provides partial confinement to the magnetic field and prevents the magnetic field from the resonators from going in the opposite direction from the receiving resonator. Given the side-by-side configuration of the system, the image current (Fig. 5) of the transmitting resonator can enhance the magnetic field around the receiving resonator,

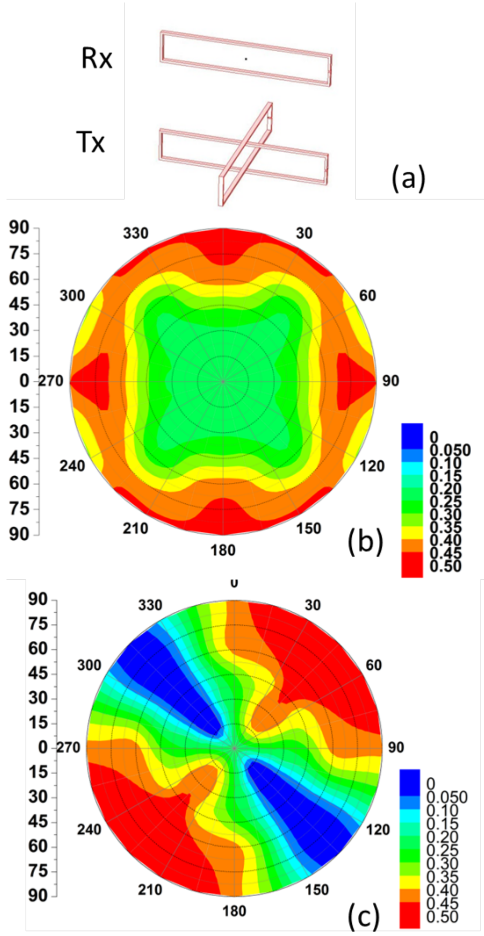

Fig. 4. A WPT system with a pair of orthogonal transmitting coil and a single receiving coil. In case of circularly polarized field (b), and linearly polarized field (c), efficiency distribution with θ and ϕ rotations is plotted.

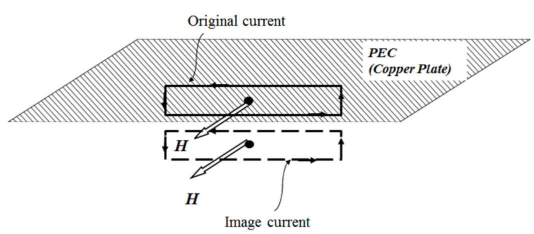

Fig. 5. A current carrying loop placed perpendicular to a metal plane. Image current due to the plane generates a magnetic field in the same direction as the source.

which leads to an increase in power transfer efficiency.

Thus we can propose a WPT system to take advantage of the findings, as shown in Fig. 6. A relatively large transmitting module has a pair of orthogonally arranged coils to generate a circularly polarized magnetic field, and a metal plane to reflect the field and work as a shield. The receive module may be smaller in size and with simpler structure, depending on different applications. It can be embedded into a mobile object. The system has better tolerance to the motion of receive module and allows more stable wireless power transfer.

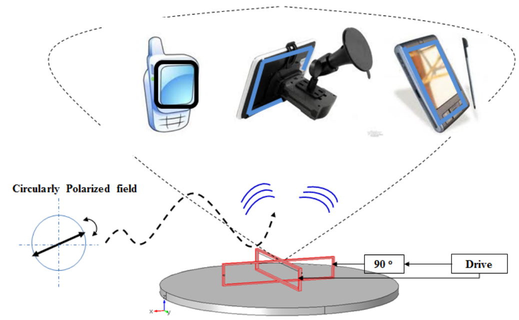

Fig. 6. A flexible wireless power system with a transmitting module composed of two orthogonal coils and a metal plane to generate a circularly polarized magnetic field. Different devices with receiving coils of various configurations and orientations are placed in the near field.

III. Conclusion

In summary, we proposed the use of circularly polarized magnetic field in near field based WPT. A pair of orthogonally arranged coils with phase difference can be used to generate such field. We show that the advantage of a WPT based on circularly polarized near field is to minimize the fluctuation in efficiency due to the rotational movement of receiving coil, and allows more stable power transfer. The orthogonally arranged coils can also allow the use of metal shield to enhance the field to receiving coil. The proposed concept has significant potential toward flexible wireless charging applications.

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