A Simplified Path Interference Model in 2D Multi-Hop Wireless Power Transfer System

Ryota Shibuya, Toru Kawajiri, and Hiroki Ishikuro
Department of Electronics and Electrical Engineering, Keio University
Yokohama, Japan
shibuya @iskr.elec.keio.ac.jp

***Abstract* – This paper studies the multipath interference in a 2D multi-hop wireless power transfer system which uses magnetic resonance in two dimensional repeater array. By focusing on the current amplitude and phase in each repeaters, power combination from different path is discussed and simplified path interference model is proposed. The accuracy of the proposed simplified path interference model is compared with electromagnetic field simulation.**

***Index Terms* — wireless power transfer, magnetic resonance, repeater array, multi-hop, path interference**

1. Introduction

Recently, there has been growing interest in the wireless power transmission and it becomes to be used for such application of smart watch. The advantage of wireless charging is not only the convenience of cable remove. It can also improve reliability by removing the metal contacts of the equipment and provide water proof characteristics and immunity to electrostatic breakdown.

To improve the convenience of wireless power transfer system, some standards provide free positioning [1,2]. However "Qi" standard realizes a free poisoning by mechanical adjustment of coil position or switching the activated coil. Therefore, it is not suited for low cost implementation.

Another approach to realize the free positioning is to use a 2D multi-hop wireless power transmission by the magnetic field resonance. The efficiency of this system varies greatly depending on the position of the receiver coil [3, 4]. This is caused by the power combination from multiple paths [5, 6] in the 2D multi-hop system.

This problem can be solved by limiting the power transmission in single route depending on the receiver position. However, power transfer efficiency can be further improved if the power comes from different path can be constructively combined. To realize the constructive combination of power, the behavior of power transmission through multi-hop system should be studied which is not discussed in the previous reported work. What kind of model is discussed whether they affect the efficiency, thereafter, we examined the effect of the models assuming be applied to large-scale multi-hop system.

2. 2D multi-hop system

Typical four structures often appearing in multi-hop power transmission system are studied in this work. Fig2(a) is a case of end-to-end power transmission and there is no multi-puth interference. Fig.2(b) shows the case in which the forward propagating power and reflected power cancel at RX coil position. Fig.2(c) is the case in which the straight propagating power and power through roundabout route cancel each other at RX position. Fig.2(d) is the case where the power that comes from two routes are constructively combined. Power is transmitted and received by placing the loop coil in the position of Fig. 2 for each arrangement. (Actually, just above)

When the two coils are placed in face-to-face,

$$(R + j\omega X)I_1 + j\omega L_{12}I_2 = V \quad (1)$$

$$(j\omega X + R)I_2 + j\omega L_{12}I_1 = 0 \quad (2)$$

where X is the impedance $L - 1/\omega^2 C$, L is inductance of all the coils, C is the capacitance. At the resonant frequency, and $X = 0$ holds, and

$$I_2 = -j(\omega L_{12}/R)I_1 \quad (3)$$

This can be extended to the system continuing a multiple coils, if the resonance, a simple rule that the power phase is shifted 90 ° each time to relay coil. In the two-dimensional multi-hop wireless power transmission, the direction passing through the magnetic field is reversed, and it should be noted that the value of the mutual inductance becomes negative[7].

Fig. 1. Concept of 2D multi-hop wireless power transfer

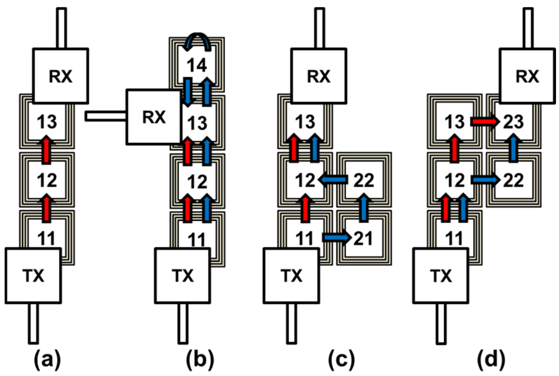

Fig. 2. Typical 4 patterns in 2D multi-hop system

3. Simulation Results and Discussion

(1) Simulation with only the mutual inductance between adjacent repeaters

For the cases in Fig. 2, the current vectors (amplitude and phase) of each repeater with reference to the current vector in the coil 11 at resonance frequency are shown in Fig. 3. The current vectors are calculated by solving circuit equations by MATLAB. The resonant frequency is 13.56 MHz, coupling coefficient extracted by electromagnetic field solver between the loop coil and the repeater is 0.7, and coupling coefficient between the adjacent repeaters is 0.06.

As mentioned in the previous section, current between the adjacent coils are shifted nearly by 90 °. From Fig.3(b) and (c), if the phase difference of power coming from two routes is 180 °, the amplitude at receiver coil is reduced by the power cancellation. Incidentally, a slight phase shift is due to the influence of the loop coil, it can be avoided by attaching a capacitor for resonance in the loop coil.

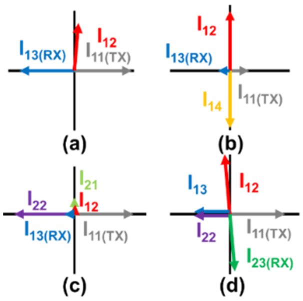

Fig. 3. Current vector in each repeater only with mutual inductance between adjacent repeaters

(2) Simulation with mutual inductance between adjacent, diagonal, and next adjacent repeaters.

Fig.4 shows the circuit simulation results which include the mutual inductance between the adjacent, diagonal, and next adjacent repeaters. For comparison, electromagnetic field simulation results are also shown.

The current vectors in the repeater are slightly affected by the coupling between the diagonal and next adjacent repeaters. However, it can be said that current vectors are roughly determined mainly by the coupling between adjacent repeaters.

From comparison between the equivalent circuit model and electromagnetic simulation, the simple circuit model with coupling between the adjacent, diagonal, and next adjacent repeaters provide enough accurate results.

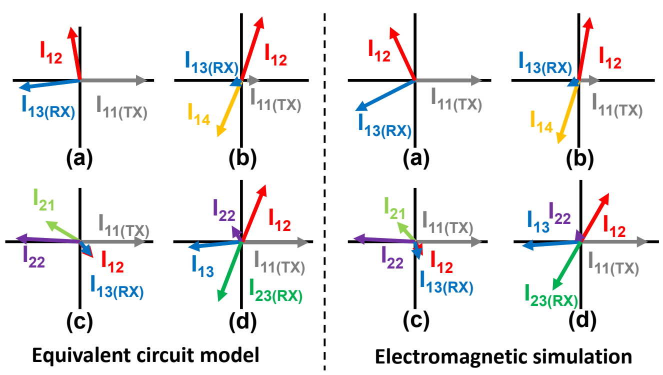

Fig. 4. Current vectors in each repeater with mutual inductances between adjacent, diagonal, and next adjacent repeaters.

4. Accuracy comparison between the equivalent circuit model and electromagnetic field simulation

The power transfer efficiencies at 13.56MHz are compared in Table 1.

Although the efficiency is changed irregularly by resonance is shifted as increase the bond calculations, the basis of the behavior is determined by the coupling between adjacent repeaters.

When comparing the simulation time, circuit calculation by MATLAB requires only a few hundred milliseconds in contrast with EM simulation that requires several hours. This results indicates that it would be enough to take into account the coupling between adjacent repeaters (or adjacent and diagonal at most) in the equivalent circuit model. If the number of the repeaters increases, simulation time for EM solver increases exponentially. Therefore, simple equivalent circuit model becomes more and more important to study the large scale 2D multi-hop system.

TABLE I, Efficiency comparison in each calculation method in Fig. 2 (a) to (d)

Pattern	EM simulation	Adjacent	Adjacent & diagonal	Adjacent, diagonal Next adjacent
(a)	74.9%	75.0%	75.0% *	74.8%
(b)	3.6%	0.4%	0.4% *	2.2%
(c)	6.8%	1.0%	5.68%	4.5%
(d)	66.6%	70.7%	64.6%	68.2%

* Diagonal does not exist

5. Conclusion

The path interference in 2D multi-hop wireless power transfer system is studied. From the equivalent circuit model and MATLAB calculation, it was shown that the current amplitude and phase in each repeater is mainly determined by the coupling between adjacent repeaters. Comparison between the results from circuit model and EM field simulation shows that the simplified equivalent circuit model can provide accurate results in much shorter simulation time.

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