2E2-1

Consideration of Use of Arrayed Transmitting Coils in Wireless Power Transfer with Magnetically Coupled Resonance

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1. Introduction

Recently, the research and development on wireless power transfer(WPT) attracts our attention because the WPT system enables us to charge cellular phones, notebook computers and electrical vehicles wirelessly [1]. One of the problems in the WPT with magnetically coupled resonance is a decrease in transmitting efficiency due to a misalignment of the receiving coil to the transmitting coil. Unfortunately, this problem is supposed to become more serious because of the miniaturization of electronic equipments [2] [3].

In this paper, we attempt to obtain high transmitting efficiency which does not depend on the position of the receiving coil. For the purpose, we propose here to use the array of three transmitting coils spaced in one dimension, and the transmitting efficiency is analyzed with an electromagnetic field simulator based on the Method of Moments(MoM). Specifically, we examine frequency characteristics of the transmitting efficiency corresponding to the position of the receiving coil in order to show the effectiveness of using the array of the transmitting coils.

2. Analytical Model

First, the basic model and the array model of the WPT system with magnetically coupled resonance are shown in Fig.1 and Fig.2, respectively.

Both models have the same form which is composed of a square-shaped loop coil of two turns. Each coil is 50cm long on a side and the wire of coil is made of copper, and has a thickness of 4cm and a section radius of 1mm. At the terminal (port1) of the transmitting coil(Tx1), the voltage generator(1V, 50Ω) and the tuning capacitor of 32.4pF are loaded in series. At the terminals (port2, port3) of the transmitting coils(Tx2, Tx3), only the tuning capacitor of 32.4pF is loaded. It means that the transmitting coils (Tx2, Tx3) operate as parasitic elements. At the terminal (port4) of the receiving coil (Rx), the load of 50Ω and the tuning capacitor are loaded in series. Those capacitances of the tuning capacitors are determined to resonate at 10MHz in each of the transmitting coils and receiving coil. The distance between the transmitting coils and receiving coil is 20cm as shown in Figs.1 and 2 and the distance between the adjacent transmitting coils is 2cm as shown in Fig.2.

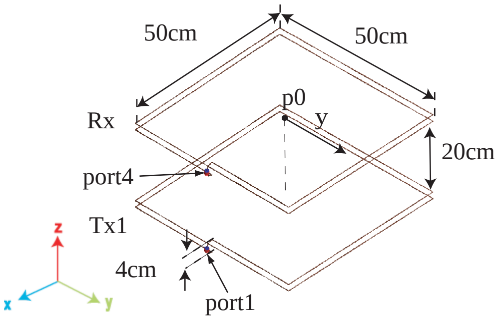

Figure 1: Basic Model.

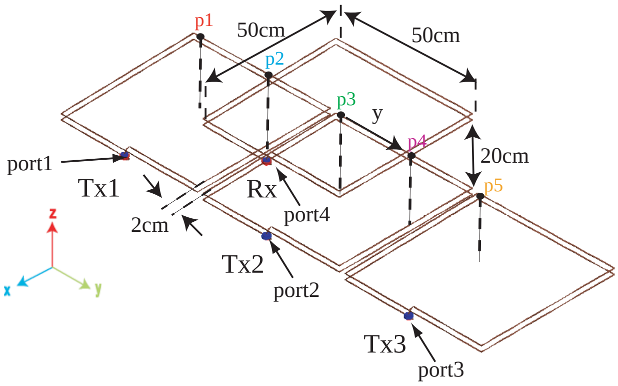

Figure 2: Array Model.

3. Performance Analysis by Computer Simulation

For the analysis, we used the Method of Moments(FEKO6.1). The computer simulation conditions are shown in Table 1, and transmitting efficiency is calculated by using eq.(1), in which S_{41} is a scattering parameter of input port(port1) and output port(port4).

Table 1: Computer simulation conditions.

Characteristic Impedance	50 Ω
Wire Materials	
Relative permeability	1
Magnetic loss tangent	0
Conductivity	5.8×10^7

$$\text{Transmitting Efficiency} \quad = |S_{41}|^2 \times 100[\%] \tag{1}$$

First, we examined the frequency characteristics of the transmitting efficiency when the receiving coil was placed at p1, p2, p3, p4 and p5 in the array model of Fig.2. The frequency characteristics obtained are shown in Fig.3, where the horizontal axis is frequency and the vertical axis is transmitting efficiency. The positions of the receiving coil and frequencies at which the transmitting efficiency is locally high in Fig.3 are extracted in Table 2.

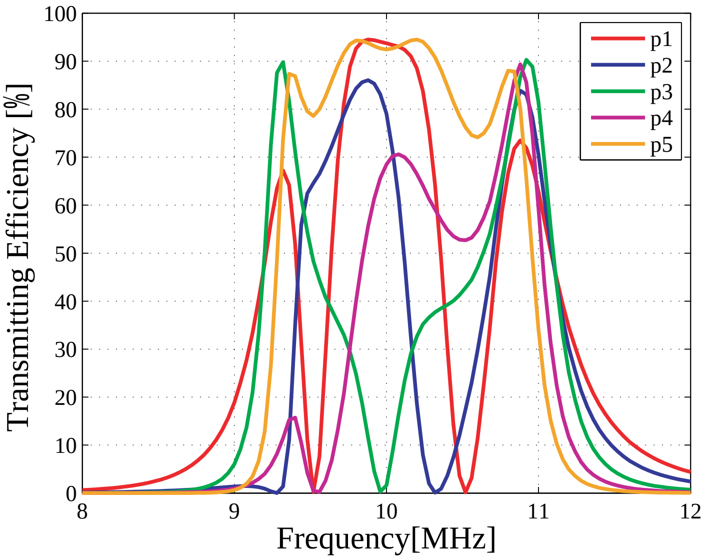

Figure 3: Frequency characteristics of transmitting efficiency of array model in Fig.2.

Table 2: Positions of the receiving coil and frequencies where the transmitting efficiency is locally high in Fig.3.

f[MHz]	Point
9.3	p1, p3, p5
10	p1, p2, p4, p5
11	p1, p2, p3, p4, p5

Next, to find the reason that there are some positions and frequencies in Table 2, we examined the magnetic field vector $\boldsymbol{H}$ produced by transmitting coils in the vicinity of the frequencies f=9.3MHz, 10MHz and 11MHz. As a result, in the vicinity of the frequency f=9.3MHz, the magnetic field $\boldsymbol{H}$ draws two ellipses which center the gap areas between the adjacent transmitting coils as shown in Fig.4, regardless of the position of the receiving coil. Similarly, in the vicinity of the frequency f=10MHz, the magnetic field $\boldsymbol{H}$ draws a ellipse which centers the Tx2 as shown in Fig5. Also, in the vicinity of the frequency f=11MHz, the magnetic field $\boldsymbol{H}$ draws the figure of 8 which centers the Tx2 as shown in Fig.6. From these results, at p2 and p4 in Fig.4 and p3 in Fig.5, the transmitting efficiency is lower because the upward and downward magnetic fluxes which penetrate into the receiving coil cancel out each other. In the vicinity of the frequency f=11MHz, on the other hand, the transmitting efficiency is higher regardless of the position of the receiving coil because the magnetic field becomes uniform over the transmitting coils.

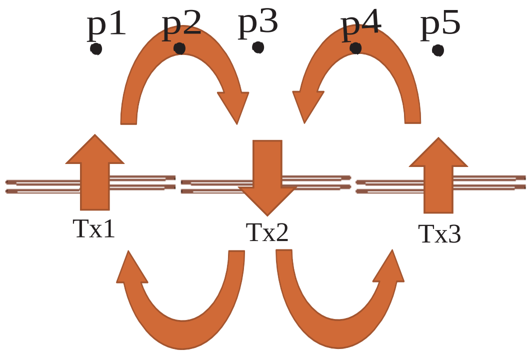

Figure 4: Magnetic field $\boldsymbol{H}$ of array model in the vicinity of the frequency f=9.3MHz.

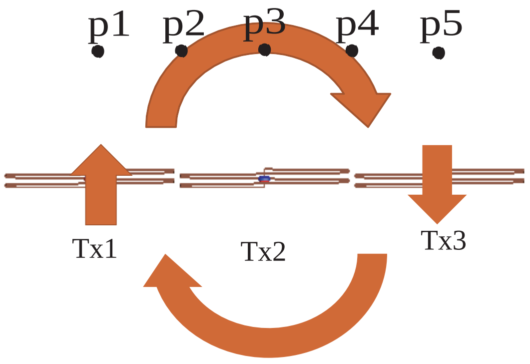

Figure 5: Magnetic field $\boldsymbol{H}$ of array model in the vicinity of the frequency f=10MHz.

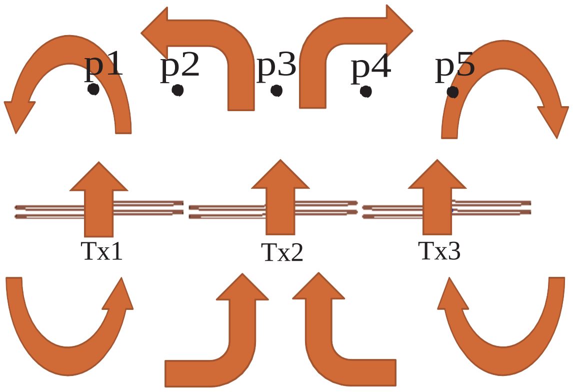

Figure 6: Magnetic field $\boldsymbol{H}$ of array model in the vicinity of the frequency f=11MHz.

Finally, we compared the transmitting efficiency of the basic model in Fig.1 and that of the array model in Fig.2 when the receiving coil was moved in the direction of the y-axis. The transmitting efficiency of the basic model when the receiving coil was moved in the range −100cm≦ y ≦ 100cm at the frequency f=10.0MHz is shown in Fig.7. In the same manner, at the frequencies f=10.0MHz and 10.9MHz, the transmitting efficiency of the array model is shown in Fig.8. The origin is p0 and p3 in the basic and array models, respectively. The horizontal axis is the position of the receiving coil, and the vertical axis is transmitting efficiency in both Fig.7 and Fig.8. From Fig.7 and Fig.8, the effective width where the transmitting efficiency is more than 80% at each frequency is extracted in Table.3. Compared with the basic model, the array model has 1.8 times the effective width at f=10.0MHz, 1.6 times at f=10.9MHz, and further 3.0 times when both f=10.0MHz and 10.9MHz are used selectively.

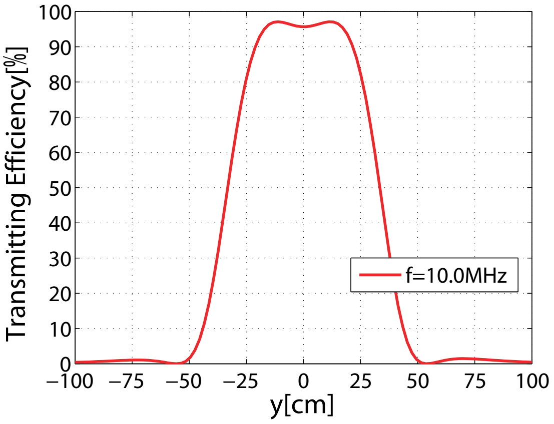

Figure 7: Transmission efficiency in changing the receiving coil position(Basic Model).

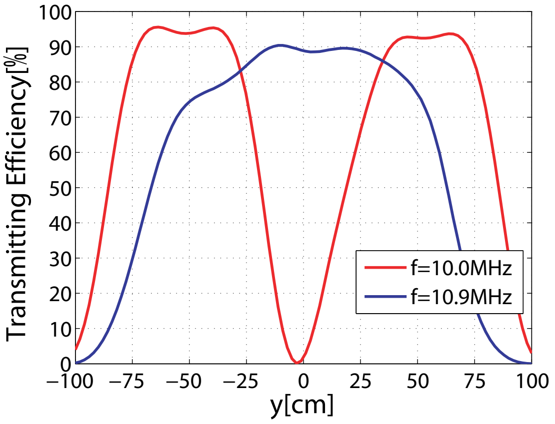

Figure 8: Transmission efficiency in changing the receiving coil position(Array Model).

Table 3: Width where the transmitting efficiency is more than 80%.

Model	Frequency f[MHz]	Width[cm]	Magnification[times]
Basic Model	10.0	50.5	-
Array Model	10.0	92.9	1.8
	10.9	78.8	1.6
	10.0, 10.9	151.5	3.0

4. Conclusions

In this paper, we have examined the transmitting efficiency when one dimensional arrayed three transmitting coils are used in the WPT system with magnetically coupled resonance. From the results of computer analysis, it is found that the optimum frequencies exist depending on the position of the receiving coil, and also that the distribution of the magnetic field vector produced by transmitting coils is different depending on the frequency. In addition, it is confirmed that in the case of using arrayed transmitting coils, the effective width where the transmitting efficiency is more than 80% is magnified considerably, and further that using selectively two frequencies expands the effective width quite greatly. In future works, we will analyze the performance of array model when the number of the transmitting coils is increased in one dimension, and when the transmitting coils are arrayed in two dimensions.

References

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