Simplified Near-Magnetic Field of the Resonators in Wireless Power Transfer

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Abstract**—This paper presents the simplified modeling of near-magnetic field using equivalent magnetic dipole in wireless power transfer. In modeling of magnetic resonators, it is practice to ignore the small volume of the resonator in comparison with the transferring-wavelength and consider it into the magnetic dipole on the ground plane. And this analysis presented here leads to simulated results compare well with full-wave simulation. This approach is useful for the case when the human safety with respect to electromagnetic fields (EMFs) and radio frequency interference (RFI) problems should be considered in the design of wireless power transfer system for high-power applications.**

Keywords—Magnetic Dipole, Wireless Charging, Wireless Power, Magnetic Resonator

I. INTRODUCTION

Since the wireless power transfer using magnetic resonance technology was presented from MIT in 2007, many engineers and researchers have developed the wireless charging system [1-3]. Especially, the wireless power company consortiums such as WPC, A4WP, and PMA have been developing the standard. As a result, without the distinction of wireless power transferring mechanism, many kinds of the wireless power charging devices for mobile phones, docent robot and the variety of home appliances are presented in the market [4, 5]. And high-power technology is being applied to charge the electric vehicles [6].

Even though the wireless power solutions are needed to support the cleanness and convenience, EMF on the energy transfer path, interference with nearby electric devices and SAR (Specific Absorption Ratio) should be considered before use and referred to the guidelines [7]. Moreover, it takes such a long time to analyze and understand the near-field of the various wireless power transfer system.

In this paper, the simplified analysis for the wireless power transfer using magnetic dipole is demonstrated and also verified with the comparison results according to the variables.

II. NEAR-FIELD EVALUATION FOR WIRELESS POWER TRANSFER

Fig. 1 shows the general test environment to evaluate the near-field characteristics for wireless charging system.

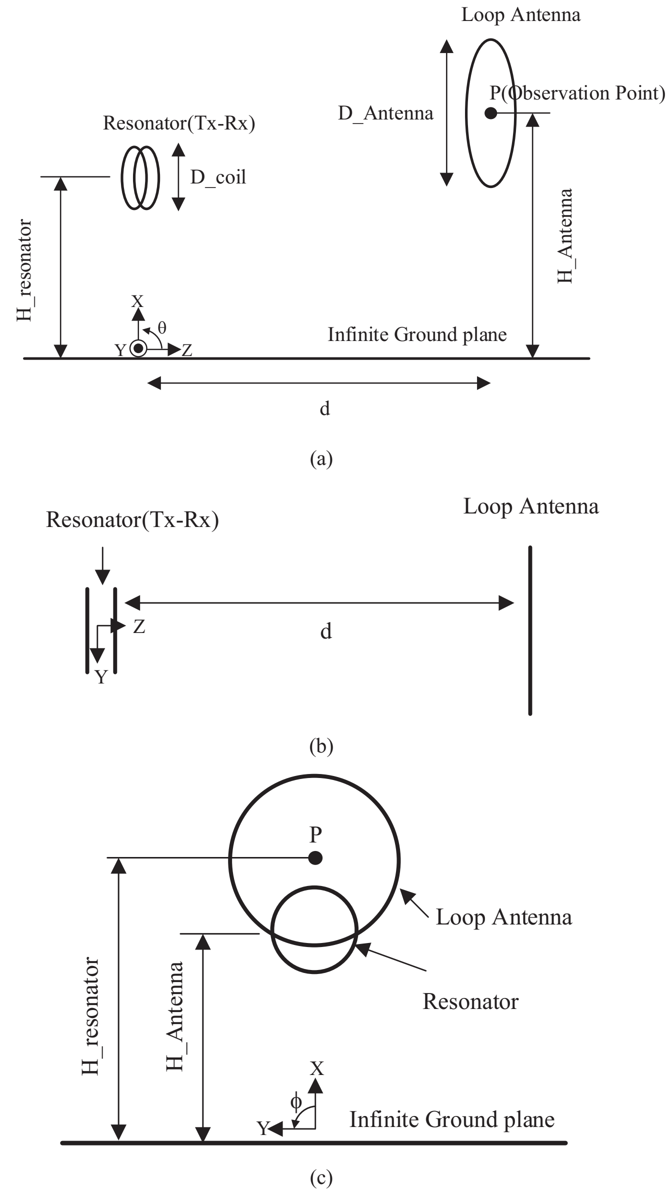

Fig. 1. The Near-Field Test Environment of Wireless Charging System (a)XZ-plane (b)YZ-plane (c)XY-plane

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The distance (d) between the resonators and the receiving loop antenna is 3 m and the height of resonator (*H_resonator*) is 0.8 m. The height (*H_Antenna*) and diameter (*D_Antenna*) of the receiving loop antenna is 1.3 m and 0.6 m, respectively. Generally, the resonators are rotated on the X, Y, Z-axis until the maximal magnetic field is detected on the antenna.

III. SIMPLIFIED ANALYSIS OF THE NEAR-MAGNETIC FIELD IN WIRELESS POWER TRANSFER

In modeling of magnetic resonator, it is useful to ignore the small volume of the resonator in comparison with the transferring-wavelength and consider it into the magnetic dipole on the ground plane. Fig. 2 shows the modeling for the resonators in wireless power transfer. As shown in Fig. 1, when the axis of the symmetry of the resonators is parallel with the large ground-plane, the resonators can be equivalent to the magnetics dipole presented in Fig. 2 [8, 9].

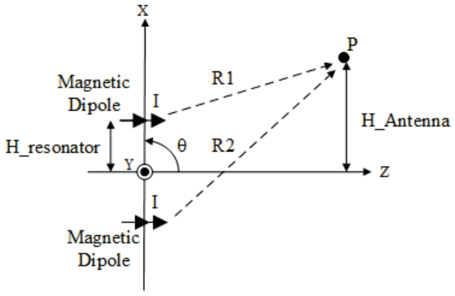

Fig. 2. The Resonator Modeling with Magnetic Dipole and Image Theory

And the magnetic field of the resonators can be approximated as follows [10]:

$$H_R = -\frac{j\omega\mu_0 m}{4\pi\eta_0}\beta^2 2\cos\theta\left[\frac{1}{(j\beta R)^2}+\frac{1}{(j\beta R)^3}\right]e^{-j\beta R} \quad (1)$$

$$H_\theta = -\frac{j\omega\mu_0 m}{4\pi\eta_0}\beta^2\sin\theta\left[\frac{1}{j\beta R}+\frac{1}{(j\beta R)^2}+\frac{1}{(j\beta R)^3}\right]e^{-j\beta R} \quad (2)$$

where $\beta = \omega\sqrt{\mu_0\varepsilon_0}$ and the magnetic dipole moment $m = j\beta/I$. For 50 Ohm matched system, the uniform current I of the magnetic dipole can be obtained from the input power and insertion loss between Tx and Rx-resonator.

Even though the accurate magnetic field could be obtained with the impedance and diameter of the resonator [8], the maximum value acquired from (1)-(2) was used to compare with the magnetic field of the full-wave simulation based on FEM and MoM, respectively[10, 11].

Fig. 3 shows the normalized magnetic field of the resonator according to H_Antenna (point P, the center of the receiving loop antenna). The diameter of the resonator is 0.3 m and distance (d) is 3 m, respectively. The transfer frequency and input power is 6.78 MHz and 1W, respectively. And the insertion loss between Tx and Rx-resonator is 0.66dB.

From Fig. 3, the normalized Hz-component of the magnetic dipole compares well with that of the simulation. And Table 1 shows the comparison of the maximum value of Hz-component between the analysis and simulation result.

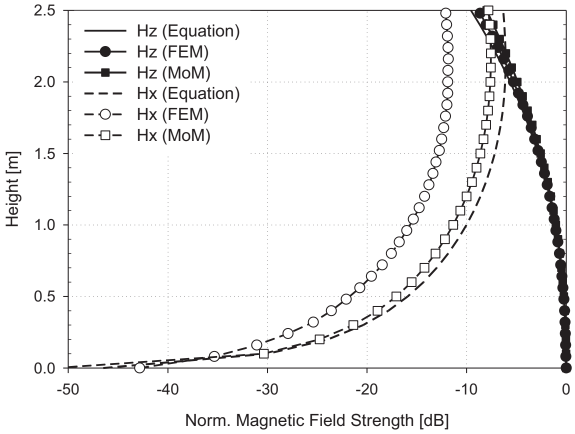

Fig. 3. The normalized magnetic field of the resonator according to H_Antenna (the center of the loop antenna) (d=3 m, ϕ=0 deg)

Table 1. The comparison of the maximum values of Hz

	Hz_max [mA/m]
Analysis from (1)-(2)	1.34
Simulation [10]	1.80
Simulation [11]	1.87

However, because of neglecting the diameter and physical characteristics of the resonator, there are some errors between the Hx(Equation) and Hx(FEM, MoM).

Next, the variation of magnetic field versus the distance (d) is shown in Fig. 4. The magnetic dipole modeling exhibits the agreement with simulations.

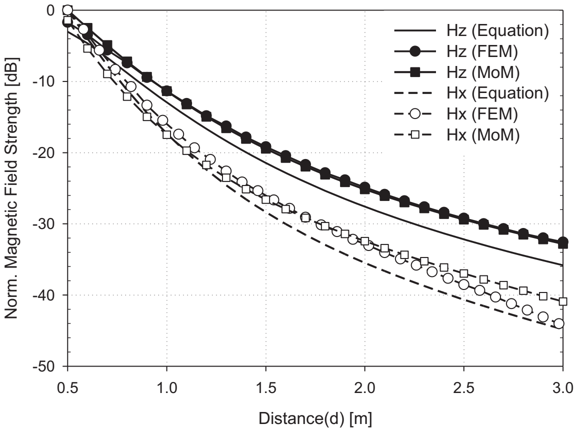

Fig. 4. The normalized magnetic field of the resonator according to distance (d) (ϕ=0 deg)

IV. CONCLUSION

The simplified analysis of near-magnetic field using magnetic dipole and image theory in wireless power transfer is presented. The analysis for the various models is verified and compare well with full-wave simulation. This approach is useful for EMF and RFI problems considered in the design of wireless power transfer system for high-power applications.

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