On the Usefulness of a Magnetic Dipole Model for Calculating Leakage Magnetic Fields in Dynamic Wireless Power Transfer

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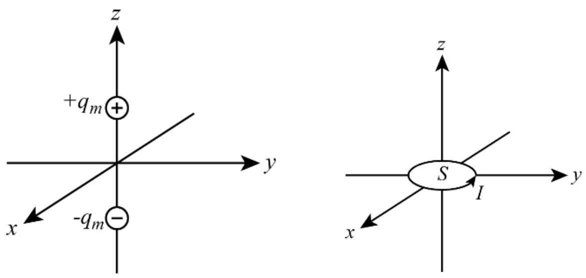
This paper investigates the range of applicability of the magnetic dipole model for evaluating leakage magnetic fields in inductive (coupled) wireless power transfer systems, with a particular focus on dynamic wireless power transfer. First, by taking ($r/\lambda = 1/2\pi$) as the boundary between the near and far fields, we show that 85-kHz-band WPT operates in an extremely short-range quasi-static, very-near-field region compared with the wavelength, based on an examination of the wave impedance and the ($1/r^3$), ($1/r^2$), and ($1/r$) field components (Fig. 1). Using a rectangular 85 kHz coil for electric vehicles as a case study, we compare electromagnetic field simulation results with calculations based on the magnetic dipole model and demonstrate that the two are in good agreement at distances on the order of 0.7–1 m, which are much shorter than the near–far boundary of approximately 562 m (Fig. 2, Fig. 3, Fig. 4). This confirms that the magnetic dipole model can serve as a simple yet effective analytical tool for evaluating leakage magnetic fields even in the very-near-field region as small as ($\lambda/3500$). Furthermore, we clarify the difference between the intuitive near/far-field concepts conventionally used in EMF/EMI evaluation and the physically defined near and far fields, thereby providing a clear sense of the relevant length scales for practical design. These results suggest that, when assessing compliance with EMF/EMI regulations and in the early design stages of cancellation coils and shielding structures, it is possible to obtain a reasonable estimate of the leakage magnetic field without relying exclusively on expensive full-wave electromagnetic simulation tools.



(a) Magnetic dipole (b) Small current loop

Fig. 1 Magnetic dipole and its small-current-loop representation

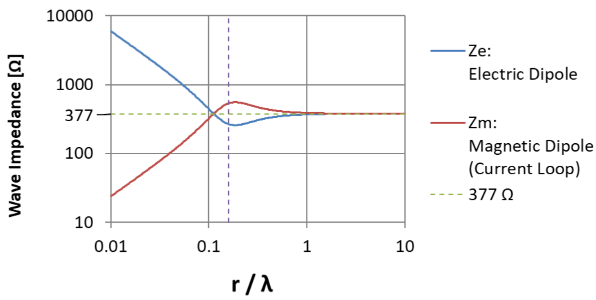


Fig. 2 Wave impedance and the boundary between the near and far fields

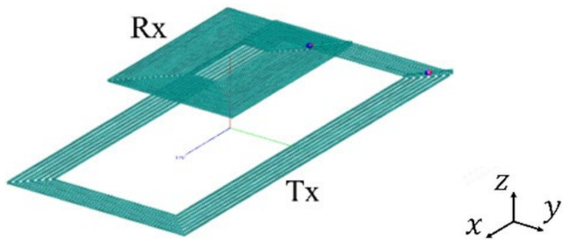


Fig. 3 Magnetically coupled coils used in the calculation [11]

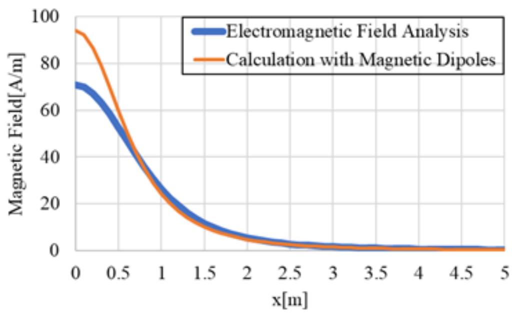


Fig. 4 Magnetic field in the x-direction obtained by electromagnetic field simulation and the magnetic dipole model