Mutual Coupling Analysis of Antennas in Layered Media through Equivalent Sources for Wireless Power Transfer

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In recent years, wireless power transfer has received much attention and been widely studied. Wireless power transfer has many applications. For example, there are the systems that transfer energy wirelessly to an electric car, sensors buried in a wall, devices beyond a wall, and devices in the ground. The one of the modeling method for such systems is to assume that antennas are in layered media and solve the mutual coupling between antennas. In this work, we propose the method for calculating the Z-parameter between antennas in layered media and the maximum power transfer efficiency of a wireless power transfer system.

According to spherical wave theory (R. J. Pirkl, IEEE Trans. Antennas Propag., vol. 60, no. 12, pp. 5654–5662), the S-parameter between two antennas in arbitrary environments can be calculated using the generalized scattering matrix of an antenna. When we calculate the S-parameter using this method, the specified antenna structures are not needed. A canonical minimum scattering (CMS) antenna is an antenna that does not scatter electromagnetic fields when its feeding ports are open-circuited. Many antennas that are small relative to the wavelength can be considered CMS antennas. Therefore, we can assume that antennas are CMS antennas when we analyze wireless power transfer. The generalized scattering matrix of a CMS antenna can be determined solely from the radiation pattern and radiation efficiency. Therefore, the maximum power transfer efficiency of a wireless power transfer system depends on only the radiation pattern and radiation efficiency of CMS antennas. Let the antenna structures in two wireless power transfer systems be different. If the radiation pattern and radiation efficiency of the antennas in the two wireless power transfer system are identical, the maximum power transfer efficiency of the two wireless power transfer system are the same because the S-parameter of the two systems are the same. Therefore, we can change the original antenna structures to the current distributions that have the same modal transmitting pattern as the original antennas to calculate the maximum power transfer efficiency. To analyze wireless power transfer, we change the original antenna structures in layered media to simple equivalent sources. The Z-parameter between antennas can be determined from equivalent sources using the induced EMF method. From the Z-parameter, we can investigate the characteristics of wireless power transfer.