Determination of Impedance Parameters of Multiple Antennas in Half Dielectric Space Using Equivalent Currents

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***Abstract* - In this paper, a method is proposed to calculate the impedance parameter of multiple antenna system in half dielectric space. The technique is based on the reciprocity and equivalent currents that consist of several elementary multi-pole currents generating the same field as original antenna. It is shown by an example that the impedance parameters of a wireless power transfer system in half dielectric space can be calculated correctly by the proposed method.**

Keywords—equivalent current, wireless power transfer, dielectric half space

I. INTRODUCTION

Recently, wireless power transfer has been received much attention. Several analysis models for wireless power transfer via near-field have been proposed in free space except a few papers. However, in practice, objects such as ground and desks exist near a wireless power transfer system. Therefore, it is needed to develop a simple analysis method that can be used when objects exist near the antennas. In this paper, we propose a simple analysis method of multiple antennas near object and apply it to wireless power transfer system in dielectric half space.

A wireless power transfer system can be viewed as a coupled antenna system because power is transferred from antenna to antenna through a coupling phenomenon. Therefore, it is important to find out the scattering, impedance, or admittance parameters among ports of antennas in the analysis of wireless power transfer. In this paper, we propose the method to calculate impedance parameters using equivalent currents that generate the same field as the field produced by an original antenna and apply the method to wireless power transfer system in dielectric half space.

II. FORMULAS FOR IMPEDANCE PARAMETERS

The relation among voltages and currents at ports of multiple antennas can be described using impedance parameters as follows:

$$V_m = \sum_{n=1}^{N} Z_{mn} I_n \tag{1}$$

where the impedance parameters, Z_{mn}, can be determined using the following formulas [1]:

$$Z_{mm} = Z_A^m - \frac{1}{I_m I_m^t}\int_G \mathbf{E}_m^t(\mathbf{r})\cdot\mathbf{J}^{(m,m)}(\mathbf{r})dv \tag{2}$$

$$Z_{mn} = -\frac{1}{I_n I_m^t}\int_G \mathbf{E}_m^t(\mathbf{r})\cdot\mathbf{J}^{(m,n)}(\mathbf{r})dv \quad \text{for } m \neq n \tag{3}$$

where Z_A^m is the input impedance of mth antenna in the presence of objects and in the absence of other antennas; $\mathbf{E}_m^t$ is the electric field generated when mth antenna is excited at feed port in the presence of objects and in the absence of other antennas; $\mathbf{J}^{(m,m)}$ is the current density of objects and antennas except for mth antenna when all other antennas are open-circuited and mth antenna is excited with a current of I_m; $\mathbf{J}^{(m,n)}$ is the current density of objects and antennas except mth antenna when all antennas except nth antenna are open-circuited and nth antenna is excited with current of I_n; I_m^t is total current flowing at the input terminals of mth antenna in transmitting mode.

In this paper, we propose to calculate (2) and (3) simply.

III. CALCULATION OF IMPEDANCE PARAMETERS USING EQUIVALENT CURRENTS

Assume that $\mathbf{E}_m^t$ in (2) and (3) are generated by $\mathbf{J}_m^{eq}$. Applying a reciprocity theorem to equation (3), the following equation is obtained:

$$Z_{mn} = -\frac{1}{I_n I_m^t}\int_G \mathbf{E}^{(m,n)}(\mathbf{r})\cdot\mathbf{J}_m^{eq}(\mathbf{r})dv \quad \text{for } m \neq n \tag{4}$$

where $\mathbf{E}^{(m,n)}$ ($m \neq n$)is the electric field generated by objects and antennas except for mth antenna when all antennas except for nth antenna are open-circuited and nth antenna is excited with a current of I_n at its input terminals. $\mathbf{E}^{(m,n)}$ can be calculated using the equivalent current $\mathbf{J}_n^{eq}$. Likewise, the self-impedance can be calculated using the equivalent current:

$$Z_{mm} = Z_A^m - \frac{1}{I_m I_m^t}\int_G \mathbf{E}^{(m,m)}\cdot\mathbf{J}_m^{eq}dv \tag{5}$$

where $\mathbf{E}^{(m,m)}$ is the electric field generated by open-circuited antennas and objects when mth antenna is excited with a current of I_m at its input terminals. $\mathbf{E}^{(m,m)}$ can be calculated using the equivalent current $\mathbf{J}_m^{eq}$.

If $\mathbf{J}_m^{eq}$ is composed of multiple infinitesimal electric dipoles and infinitesimal electric loops, the result is obtained by the superposition of all currents. Therefore, the impedance parameters are as follows:

$$Z_{nn} = Z_A^n - \frac{1}{I_n^t I_n}\left(\sum_{p=1}^{N_e^n}\left(\mathbf{E}^{(n,n)}(\mathbf{r}_{p,n}^e)\cdot\mathbf{p}_p^n\right) - \sum_{p=1}^{N_h^n}\left(\mathbf{H}^{(n,n)}(\mathbf{r}_{p,n}^h)\cdot j\omega\mu\mathbf{m}_p^n\right)\right) \quad (6)$$

$$Z_{mn} = -\frac{1}{I_m^t I_n}\left(\sum_{p=1}^{N_e^m}\left(\mathbf{E}^{(m,n)}(\mathbf{r}_{p,m}^e)\cdot\mathbf{p}_p^m\right) - \sum_{p=1}^{N_h^m}\left(\mathbf{H}^{(m,n)}(\mathbf{r}_{p,m}^h)\cdot j\omega\mu\mathbf{m}_p^m\right)\right) \quad (7)$$

for $m \neq n$

where $\mathbf{p}_p^n$ is the electric dipole moment vector of the *p*th infinitesimal dipole for antenna *n*, and $\mathbf{m}_p^n$ is the magnetic dipole moment vector of the *p*th infinitesimal loop for antenna *n*; N_e^n and N_h^n are the number of infinitesimal dipoles and infinitesimal loops for antenna *n*, respectively; $\mathbf{r}_{p,n}^e$ is the position of the *p*th infinitesimal dipole for antenna *n*, and $\mathbf{r}_{p,n}^h$ is the position of the *p*th infinitesimal loop for antenna *n*. A collection of all $\mathbf{p}_p^n$ and all $\mathbf{m}_p^n$ (*n* is fixed to one value) generates the same field as that generated by an isolated transmitting antenna *n* with current at input terminals I_n^t. $\mathbf{E}^{(n,n)}$, $\mathbf{E}^{(m,n)}$, $\mathbf{H}^{(n,n)}$, and $\mathbf{H}^{(m,n)}$in equations (6) and (7) are calculated using equivalent sources.

If field pattern is given, the equivalent current that generates the given field pattern can be found even when the geometry of an antenna is not known. If equivalent current is simple, the time needed to calculate the impedance parameters is small.

IV. EXAMPLE: TWO HELICAL ANTENNAS IN DIELECTRIC HALF SPACE

We calculate the impedance parameters between two helical antennas over dielectric half space using equivalent currents. Half of the space was free space, and half of the space was a dielectric. The dielectric constant of the dielectric was 10, and the loss tangent was 0.1. One helical antenna will be termed antenna 1, and the other antenna 2. For antenna 1, the radius was 8 cm, the height was 10 cm, the number of turns was 8, and the diameter of the cross-section of the wire was 1 mm. For antenna 2, the radius was 6.8 cm, the height was 12 cm, the number of turns was 10, and diameter of the cross-section of the wire was 1 mm. Both antenna 1 and antenna 2 were made of copper. Two antennas were both fed at the center of the wire. The resonant frequencies of antenna 1 and antenna 2 were 29.4 MHz and 30 MHz, respectively. The axes of the helical antennas were perpendicular to the dielectric surface. The shortest distance between the center of the helical antenna and the surface of the dielectric was 20 cm. The distance between the centers of the two helical antennas was 30 cm (Fig. 1).

The authors calculated the impedance parameters using (6), (7) and equivalent sources. The electromagnetic fields were calculated using the Sommerfeld integral [2], [3]. Self-impedances were calculated using only point electric and magnetic sources. The mutual-impedance was calculated using point electric and magnetic sources and quadrupole electric and magnetic sources. Fig. 2 shows the impedance parameters calculated using FEKO and using equivalent sources. There is good agreement between the two results.

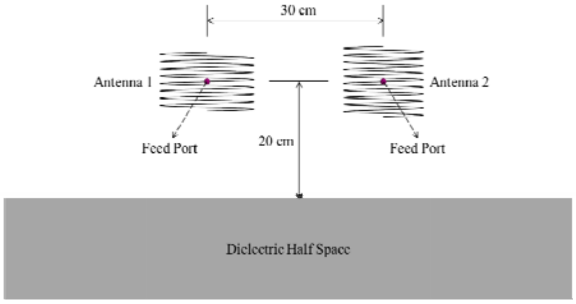
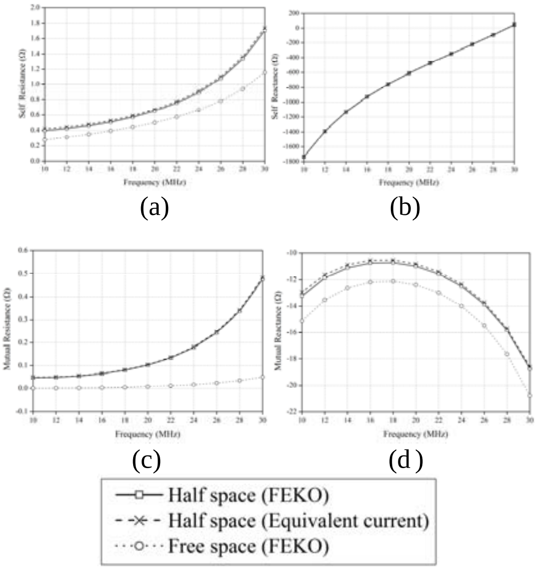


Fig. 1 Antenna configuration in half space



(a) (b)

(c) (d)

Fig. 2 Impedance parameters of antenna 1 and 2 in half space and free space. (a) real part of Z_{11} (b) imaginary part of Z_{11} (c) real part of Z_{21} and Z_{12} (d) imaginary part of Z_{21} and Z_{12}

V. CONCLUSION

In this paper, a method is proposed for calculating impedance parameters of multiple antennas near object using equivalent currents that generate the same field as that generated by the antennas. To calculate impedance parameters, field pattern, input impedance, and port current of an isolated antenna are required.

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