DEVELOPMENT OF PROBE FEEDING SIMULATION TECHNIQUE BY APPLYING OF PROBE CURRENT COMPENSATION METHOD IN FDTD

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Abstract

This paper presents a method to develop probe feeding technique by applying of probe current compensation method (PCCM) for microstrip antenna simulation. The compensation of probe current computation (PCC) is necessary because of differentiation error in PCC. Probe current analysis is compensated by multiplying with a coefficient which is computed from the surfaces of integral closed paths in Ampere's circuital law. This paper presents two applications of PCCM in probe feeding simulations. The First one is applied when the probe is defined in rectangular coordinate. The second one is in cylindrical coordinate, in this case, overlapping-grid technique is applied. By using the PCCM in cylindrical probe structure simulation, the differentiation error is reduced. The contour path error for cylindrical probe structure is also reduced by the overlapping-grid technique. It is also confirmed that the measurement results of two kinds of antennas are shown reasonable agreement with prediction.

I. BACKGROUND

The FDTD algorithm is based on the differentiation of Maxwell's curl equations (Ampere's and Faraday's Laws) using central difference approximations of spatial and time derivatives [1]. Nowadays, FDTD has been an exact tool simulation to support studiers in design of antennas and RF structures for several applications ranging from simple microstrip antennas to complex phased-array antennas and mobile communication system. In FDTD, probe-feeding model is studied further more. The study consists of input impedance, return loss, probe current, sub-cell technique and contour path, etc. [2]. This paper applies the gap feeding model which consists of a feeding structure realized as a voltage generator placed at a small gap patch and ground plane as shown in Fig. 1.

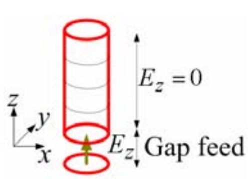


Fig. 1 Gap feeding model

Fig. 2 (a) and (b) show front view and equivalent circuit of microstrip patch antenna model with probe feeding structure, respectively. Fig. 2 (b) has two parts equivalently, one part is microstrip antenna, and another one is the source of the antenna structure. The source part consists of a voltage source and an internal resistor 50 ohm. The source part is considered on microstrip passive antenna as input impedance Z_{in} . In Fig. 2 (b), the two parts which are divided by the dotted line communicate with each other at gap feeding position only, and the dotted line means gap feeding boundary area as shown in Fig. 1.

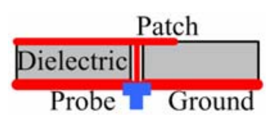


Fig. 2 (a) Front view

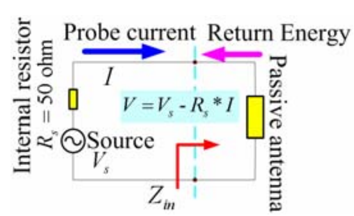


Fig. 2 (b) Equivalent circuit

Fig. 2 Microstrip passive antenna model

Voltage at gap feeding position is $V_s - R_s * I$. In the source part, an internal resistor is used to absorb reflecting energy that is returned to the source.

This paper considers on cylindrical shape of probe feeding structure in FDTD simulation. The Fig. 3 and Fig. 4 show cross section of probe feeding structure in rectangular coordinate and cylindrical coordinate, respectively. We assume that in probe, the current distribution is the same one at any frequency. The closed path C_0 and C_2 show cross section of real probe structure and the calculated region of probe which is defined in FDTD.

In the Fig. 3, the probe is defined in rectangular coordinate. The center of each cell is location of electric field E_z with respect to the z-direction. Edge of each cell is also assumed the location of magnetic field with respect to the x- and y-direction [3]. Since C_0 is not equal to C_2 in FDTD analysis, the current distribution error of probe is occurred. To solve this problem, we consider the coordinate transformation in order to realize the practical analysis structure.

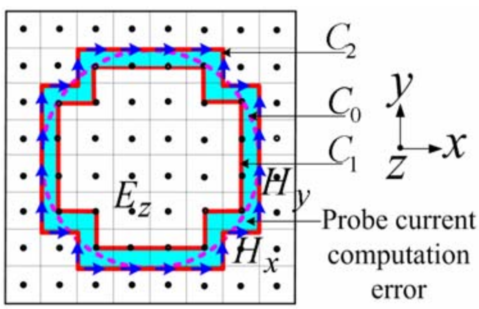


Fig. 3 Cross section of probe feeding structure in rectangular coordinate

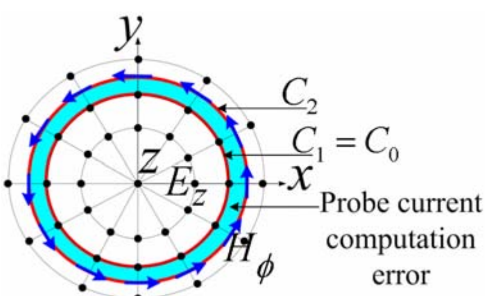


Fig. 4 Cross section of probe feeding structure in cylindrical coordinate

Fig. 4 shows cross section of probe feeding structure expressed by the cylindrical coordinate. The intersection between each circular and radius is location of electric field toward the z- direction. Around the electric field at the z-direction is the magnetic field location of r and ϕ direction.

By the expression of the cylindrical coordinate, the closed paths C_0 and C_2 have the same position as shown in Fig. 4.

By applying of Ampere's circuital law in (1), the current is computed by taking the integral of magnetic field around the closed path C_2. Therefore, in probe feeding simulation, the probe current is corresponding to all electric fields in the z-direction which is limited by the closed path C_2 as shown in Fig. 3 and Fig. 4.

$$I = \oint_{C2} \vec{H} d\vec{l} \quad (1)$$

The equation in (2) is an example which shows a solution to compute probe current in cylindrical coordinate. $n, \Delta r$ and $\Delta\phi$ are discreteness of the probe radius, cell sizes r and ϕ direction, respectively.

$$I = \sum_{\phi_i=0}^{2*\pi/\Delta\phi} (n+0.5) * \Delta r * \Delta\phi * H_{\phi_i} \quad (2)$$

Finally, by applying of FFT (Fast Fourier Transform), the current and voltage source are transformed from the time domain to the frequency domain. The input impedance of the antenna is obtained by equation (3), where R_s is internal resistor 50 ohm of source [2].

$$Z_{in} = V(f)/I(f) - R_s \quad (3)$$

Internal resistor R_s is used to absorb the reflecting wave which comes back the source. V and I are the gap source voltage and input current probe feeding structure, respectively.

II. DIFFERENTIATION ERROR IN PROBE FEEDING SIMULATION

In FDTD, the accurate modeling of probe shape is very important for FDTD analysis. If shape of the probe feeding model is not defined exactly, it can be cause of shifting frequency error and instability in simulation. Commonly, the shape of the real probe is cylindrical type. Therefore, this paper also considers cylindrical coordinate in definition of probe structure to reduce contour path error.

Fig. 3 and Fig. 4 also show differentiation error model in probe current computation when the probe is defined in rectangular coordinate and cylindrical coordinate. The closed path C_1 is connected by the nearest electric intensities toward z direction from the edge of practical probe structure.

From Ampere's circuital law (1), when we take integral following the closed edge C_2, the probe current is corresponding to all electric intensity z direction which is right insight of the closed edge C_2. However, From Fig. 3 and Fig. 4, we can see that the locations of neighbor field vectors are discontinuous. The distance from the nearest electric field toward z direction to the integral closed path

C_2 is a half of cell. Thus, there is error in probe feeding computation. The probe current computation error is the surface which is located between the closed path C_1 and C_2.

For the next step, we consider how the probe current computation error effects to simulation result. From microstrip passive antenna model in Fig. 2, the voltage at gap feeding position is $(V_s - R_s * I)$. So, from (4) electric source at gap feeding position E_z is computed from the voltage source V_s and internal resistor R_s. Δz is cell size z direction.

$$E_z = -\frac{V_s - R_s * I}{\Delta z} \tag{4}$$

In here, probe current I contains not only the information about reflection energy but also probe current computation error. Commonly, internal resistor is used to absorb reflection energy so simulation time can be reduced. However, in this case, by using internal resistor, probe current computation error can be fed backed. That reason can be cause of wrong data, instability or amplification in FDTD simulation.

Thus, we have to find out a solution to solve this problem. This paper presents a method to reduce probe current computation error. This method is probe current compensation method which will be presented in the next section.

III. CURRENT COMPENSATION IN PROBE FEEDING SIMULATION

In order to reduce differentiation error in probe feeding computation, the probe current computing result is compensated by multiplying with a coefficient which is computed from the surfaces of the corresponding integral closed paths C_1 and C_2, (5) as shown in Fig. 3 and Fig. 4.

$$I = I * \frac{\oint_{C1} dl}{\oint_{C2} dl} \tag{5}$$

The closed paths C_1 and C_2 are integral closed path. If cell size becomes to zero, the distribution of electromagnetic field is continuous in simulation space, C_1 and C_2 become to the same one. In this case, probe current compensation coefficient become to one. Thus, there is no error in probe current computation. However, that case cannot be happened. So probe current computation error is still exist and the probe current compensation method is presented above to solve this problem.

By applying of the equation in (6), probe current in cylindrical coordinate is compensated.

$$I = I * \frac{\pi * (n * \Delta r)^2}{\pi * (n * \Delta r + \Delta r / 2)^2} \tag{6}$$

The Fig. 5 shows the probe currents with and without applying the probe current compensation method in rectangular coordinate and cylindrical coordinate. The light solid line shows the probe current without applying the probe current compensation method in rectangular coordinate. In this case, we can realize that the probe current is amplified. However, if the probe current compensation method is applied, the probe current will be stable as shown in the dotted line.

The dash line is probe current without applying the probe current compensation method in cylindrical coordinate. From here, we can realize that the phenomenon in cylindrical coordinate is different from that of rectangular coordinate. In cylindrical coordinate, the probe current without applying the probe current compensation method is not amplified. As presented above, in probe current computation, the differentiation error depends on the structure of probe which is defined in FDTD such as the integral closed path and cell size x, y or r, ϕ directions.

Commonly, internal resistor is used to absorbed reflection energy (4). In here, by using internal resistor, the probe current computation error can be fed back the source. If probe current computation error is large enough, probe current can be amplified as shown in Fig. 5.

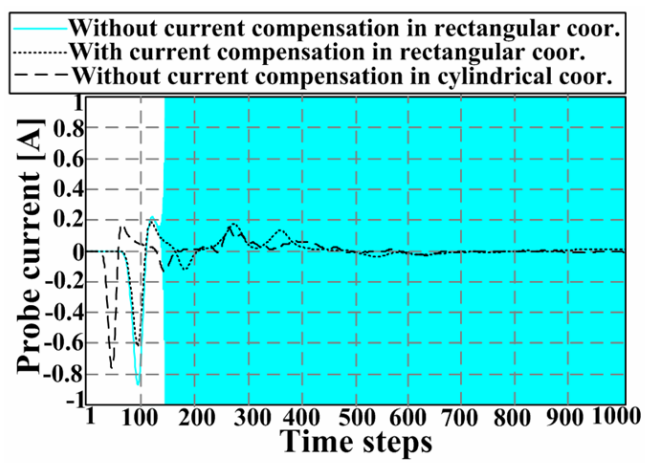


Fig. 5 Probe current compensation

IV. OVERLAPPING-GRID TECHNIQUE

In other to apply cylindrical coordinate in definition of probe structure, we must consider overlapping-grid technique in FDTD.

The Fig. 6 (a) shows overlapping-grid model in 3-dimensions [4]. The simulation space is divided into 2 regions. The rectangular coordinate region (I) does not contain probe feeding structure. In the region (I), rectangular coordinate is only used. The overlapping-grid region (II) contains probe feeding structure. In the region (II), rectangular coordinate and cylindrical coordinate are used simultaneously. Because two kinds of coordinates are used simultaneously in the same region, the region is called the overlapping-grid region. The most important thing in overlapping-grid region is making the communication between two coordinates. The Fig. 6 (b) show the overlapping-grid model in 2-dimension.

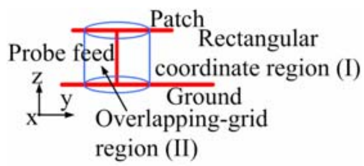


Fig. 6 (a) Overlapping-grid model

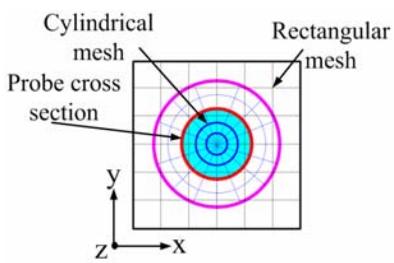


Fig. 6 (b) Overlapping-grid model

In the next, we will consider how to make the communication between cylindrical coordinate and rectangular coordinate in the overlapping-grid region. The Fig. 7 shows field interpolation algorithm.

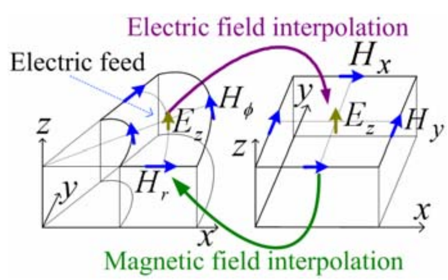


Fig. 7 Field interpolation algorithm

The Fig. 7 shows that at gap feeding position, in the cylindrical coordinate, the electric source E_z is set by using (4). After that, electric field z direction which contains electric field z direction of the all overlapping-grid region is interpolated into electric field z direction of rectangular coordinate by using the electric field interpolation method. And next, by using magnetic field interpolation method, magnetic fields H_x and H_y of rectangular coordinate are interpolated into H_r , H_ϕ of cylindrical coordinate. This field interpolation algorithm does not consider on other field components. This field interpolation algorithm is very important. From the electric field interpolation step, the rectangular coordinate region can receive information about the source and probe feeding structure. From the magnetic field interpolation step, overlapping-grid region as well as probe feeding structure can receive information about antenna structure and reflection energy which comes back the source.

Fig. 8 and Fig. 9 show electric fields at z plane of patch when probe is defined in corresponding rectangular coordinate and cylindrical coordinate. These results are received from the FDTD simulation of the antenna (b)-type as shown in the Fig. 10. In the Fig. 8 and the Fig. 9, the electric fields data are received at 300 time steps. In the Fig. 9, the electric field has more ripples when compared with the electric field in Fig. 8. A reason for this phenomenon is the interpolation error which occurs when we make a communication between two coordinates in overlapping-grid region. However, in a general view, the wave transmitting as shown in Fig. 9 is more exact than that of Fig. 8, because the shape of probe is cylindrical and EM wave goes out from the probe. Thus, in the Fig. 9, radiation pattern is improved more than that of the Fig. 8.

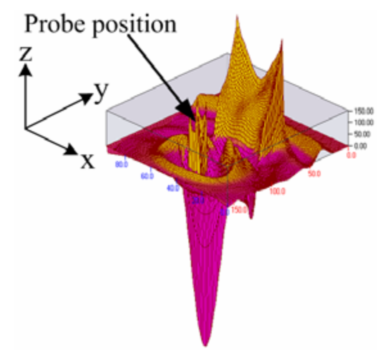


Fig. 8 Electric field at z plane of patch when probe feeding structure is defined in rectangular coordinate

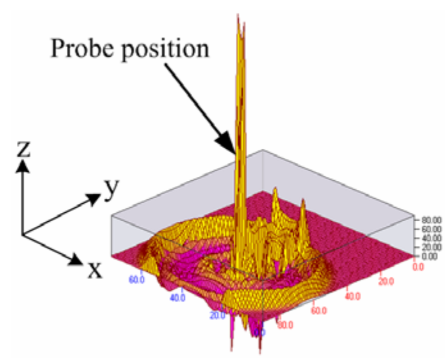
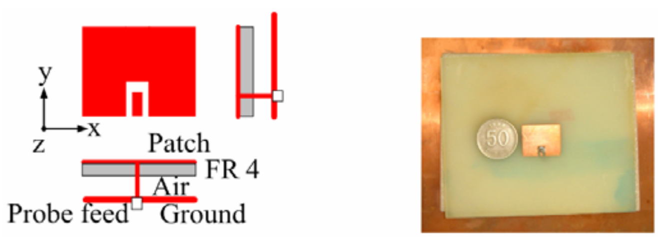


Fig. 9 Electric field at z plane of patch when probe feeding structure is defined in cylindrical coordinate

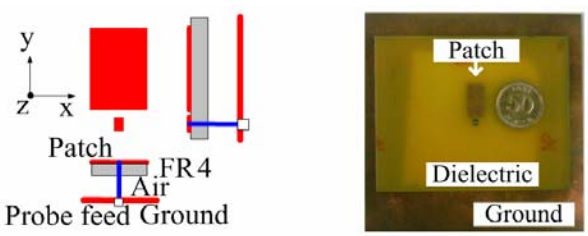
V. RESULTS AND DISCUSSIONS

Two probe feeding models of microstrip antennas which have the capacitive feeding type have been analyzed using the FDTD method and the results are compared with commercial tool simulation results and measurements results. Fig. 10 shows structures and pictures of broadband patch antennas (a)-type and (b)-type which this paper used in simulations and result comparisons [5], [6]. Fig. 11 shows the return loss of corresponding broadband path antenna (a)-type and (b)-type. Fig. 12 shows radiation patterns of corresponding broadband patch antennas (a)-type and (b)-type. In two examples of simulations and comparisons, FDTD simulation results are compared with measurement results and simulation results of a commercial simulation tool. The commercial simulation tool is considered in here is Ensemble software.

In this paper, the FDTD simulations are considered on two cases. The first case is applied when probe current compensation method is used and probe is defined in rectangular coordinate. The second case is applied when probe current compensation method is used and probe is defined in cylindrical coordinate. In two examples of FDTD simulation, if probe current compensation method is not applied, FDTD simulation will be instable and electromagnetic field will be amplified. From Fig. 11, FDTD simulation results in two cases show a good agreement with measurement results as well as Ensemble simulation results. Especially, the light solid lines-FDTD simulation results which probe current compensation method and overlapping-grid technique are used show the much closed lines with the corresponding dark solid lines-measurement results.

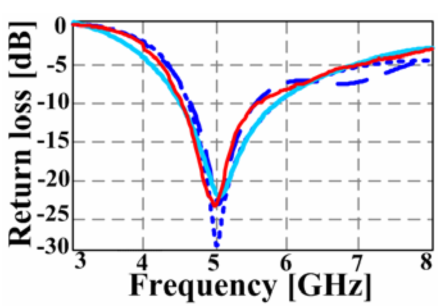


(a) (a)-type antenna

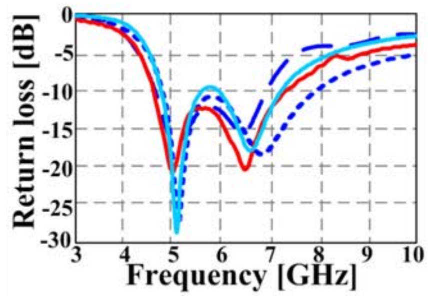


(b) (b)-type antenna

Fig . 10 The structure and picture of fabricated probe feeding broadband patch antenna



(a) (a)-type antenna



(b) (b)-type antenna

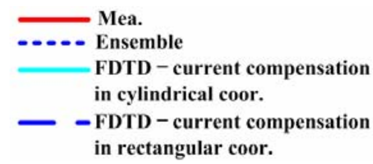
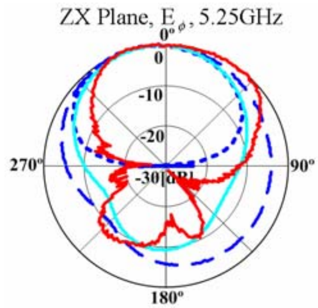


Fig. 11 The return loss of broadband patch antenna

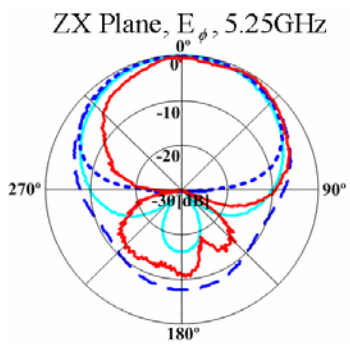
From Fig. 12, FDTD simulation results in two cases are also show a good agreement with measurement results and Ensemble simulation results.
With the same phenomenon in Fig. 11, the Fig. 12 shows that when the probe current compensation method and overlapping-grid technique are applied, FDTD simulation results are more closed with measurement results than FDTD simulation results which only the probe current compensation method is applied. From the Fig. 11 and Fig. 12, we can realize that contour path error effect the radiation pattern of FDTD simulation results more than the return loss of FDTD simulation results when compared with measurement results.

When overlapping-grid technique is applied, probe is defined in cylindrical coordinate. Thus, contour path error is removed in definition of probe, radiation pattern of FDTD simulation result is improved very much. The reason is that shape of antenna structure effect on antenna radiation pattern more than return loss of that antenna. This paper presents the improvement of probe feeding simulation using the probe current compensation method and overlapping-grid technique.

From that we can realize that by applying of the probe current compensation method and overlapping-grid technique, we can get an exact solution to improve the probe feeding simulation. In two examples of FDTD simulation, the error between FDTD simulation results and measurement results are caused by some reasons which depend on two cases. In the first case, when probe is defined in rectangular coordinate, the reason is the fabricated error of a sample antenna operating at high frequency and contour path error. In the second case, when overlapping-grid technique is used, the reason is the antenna fabricated error operating at high frequency and interpolation error which occurs when we make a communication between two coordinates in overlapping-grid region.



(a) (a)-type antenna



(b) (b)-type antenna

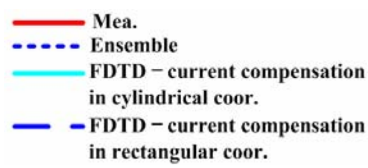


Fig. 12 The radiation pattern of broadband patch antenna

VI. CONCLUSION

This paper presents the improvement of probe feeding simulation using the probe current compensation method and overlapping-grid technique. In order to reduce numerical error by differentiation of Maxwell's equations, current compensation of probe feeding model is realized for multiplying probe current with a coefficient computed from surface of the corresponding integral closed path. This paper presents the application of the current compensation method in two cases. One case is in rectangular coordinate. Another case is in cylindrical coordinate where we use overlapping-grid technique to define probe feeding structure. By this current compensation method we can obtain good agreement results as shown in Fig. 11 and Fig. 12. From that, we recognized that in applying overlapping-grid technique case, the simulation results are more exact when compared with another case because overlapping-grid technique and current compensation method are applied to define probe feeding structure, the contour path error and differentiation error in probe feeding simulation is reduced. This paper shows that in probe feeding simulation, differentiation error and contour path error should be considered and can be reduced by applying the current compensation method and overlapping-grid technique.

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