The analysis of dipole arrays for base stations by FDTD

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1. Introduction

In recent years most commercial base-station antennas are dipoles or patch antenna arrays mounted on a finite ground plane [1]. An antenna array mounted on a finite conducting cylinder or U-plate is a good candidate for modern mobile communication systems. Various kinds of dipole arrays mounted on a cylinder, plate ,and U-plate, etc., have been studied in the literature. The research method includes the electric surface current model [2] , the method of moments [3], and finite element method, and so on. In this paper, the FDTD method is used to analysis the type antenna arrays.

As well known, The FDTD, which was first introduced by Yee [4] in 1966 and later developed by Taflove and others, is a popular, robust and accurate technique for solving the Maxwell's equations. The fundamental ingredient of the algorithm involves the discretizations of the time dependent Maxwell's equations by the spatial and time derivatives in a central finite difference form. At present, it has been widely used to simulate various electromagnetic scattering and antenna problems because of its flexibility and versatility. About FDTD algorithm there are a lot in the literature. This paper particularly stresses on the feeding modeling of the antenna arrays mounted on a finite conducting cylinder and U-plate, comparing the convergence characteristic of different feed models and computation the radiation patterns of antenna arrays mounted on a finite conducting cylinder and U-plate.

2. FDTD Implement

The FDTD technique is a numerical approach that uses discrete approximations of Maxwell's time domain equations. The derivation as well as the practical implementation of this algorithm are covered in past literature [5-9] and as such will not be covered in this paper. In this work, the FDTD algorithm has been implemented. In this paper, the absorbing boundary condition at outer computational domain boundary applies the PML [5]. Far-zone radiation patterns are computed using an integral near- to far-field transformation [6], [7]. The FDTD notation used in the following is similar to that provided in [8]. Note that Δx , Δy , and Δz denote the spatial grid discretization sizes and Δt represents the time step size. Modeling of the feed of the dipole antenna can be accomplished using at least three different approaches. Firstly is equivalent magnetic frill modeling. The Secondly is delta-gap feed modeling. Thirdly is coaxial feed modeling, which take into account the radius of coaxial probe.

A. The equivalent magnetic frill modeling.

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The equivalent frill generator can be used by forcing the four tangential electric field components at the position of the feed surrounding the wire to a known sinusoidal function. This produces a current distribution on the surface of the dipole. The four electric fields in the center feed point as follow

$$E_x{}^n(i,j,k) = -E_x{}^n(i-1,j,k) = \frac{V(n\Delta t)}{\Delta x} = \frac{e^{-(n\Delta t - t_0)^2/T^2}}{\Delta x} \tag{1}$$

$$E_y{}^n(i,j,k) = -E_y{}^n(i,j-1,k) = \frac{V(n\Delta t)}{\Delta y} = \frac{e^{-(n\Delta t - t_0)^2/T^2}}{\Delta y} \tag{2}$$

The voltage is a Gaussian pulse whose spectrum covers the frequency range of interest.

B. Delta-gap feed modeling

The gap feed is the simplest feed modeling. In this model, the dipole is assumed to be infinitely thin. All E_z components along the dipole are set to zero except the one just in the centre. The value of E_z is set to the injected voltage by the space step in the z direction as below

$$E_z{}^n(i,j,k) = -\frac{V(n\Delta t)}{\Delta z} = -\frac{e^{-(n\Delta t - t_0)^2/T^2}}{\Delta z} \tag{3}$$

This model is analogous to the MOM delta voltage model.

C. Coaxial feed modeling

For the coaxial feed modeling, the simplest and the most efficiency method is Contour Path Technique. Because of the radius of the coaxial line is less than the grid size, in the surface of feedline and antenna junction, the usual FDTD time step equations must be modified to include the near field physics of the problem. The near scattered circumferential magnetic field and the near scattered radius electric field are assumed to vary as 1/r near the wire. The tangential electric field component on the wire is zero. as shown in Fig.1.

In terms of the contour integral interpretations of Maxwell's equation, the updating equation for the H-field along y-direction:

$$\begin{aligned} &H_y{}^{n+1/2}(i_a+1/2, j_a, k_a+1/2) = H_y{}^{n-1/2}(i_a+1/2, j_a, k_a+1/2) - \frac{\Delta t}{\mu_0 \Delta z} \\ &\left[E_x{}^n(i_a+1/2, j_a, k_a+1/2) - \frac{2}{\ln(\Delta x/r_0)}\cdot\frac{V^n(k'_{top})}{\Delta x}\right] + \left(\frac{\Delta t}{\mu_0 \Delta x}\right)\frac{2}{\ln(\Delta x/r_0)}\cdot E_z{}^n(i_a+1, j_a, k_a+1/2) \end{aligned} \tag{4}$$

$$\begin{aligned} &H_y{}^{n+1/2}(i_a-1/2, j_a, k_a+1/2) = H_y{}^{n-1/2}(i_a-1/2, j_a, k_a+1/2) - \frac{\Delta t}{\mu_0 \Delta z} \\ &\left[E_x{}^n(i_a-1/2, j_a, k_a+1/2) + \frac{2}{\ln(\Delta x/r_0)}\cdot\frac{V^n(k'_{top})}{\Delta x}\right] - \left(\frac{\Delta t}{\mu_0 \Delta x}\right)\frac{2}{\ln(\Delta x/r_0)}\cdot E_z{}^n(i_a-1, j_a, k_a+1/2) \end{aligned} \tag{5}$$

Where (i_a, j_a, k_a) is the point of the feedline and antenna junction and $V^n(k'_{top})$ is the excited voltage at the location.

In terms of above the method, the magnetic field Hx, H_z updating equations can be relatively easy to obtain. At other points along the antenna, the magnetic updating equation is easily obtained using the thin-wire mode[]. Here we are not prolixity any more.

Once the H-fields have been computed, the E-fields are updated in the conventional manner by using the adjacent H-field values.

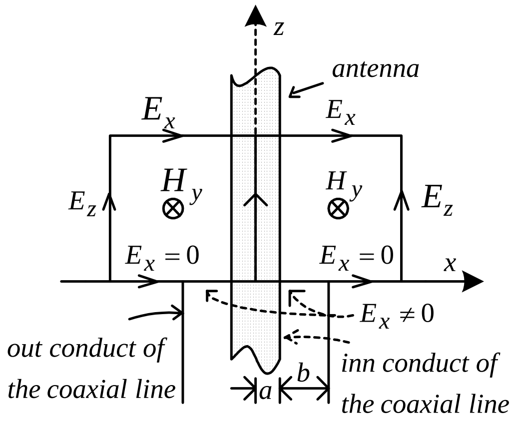

Fig.1 Hy (xoz surface)

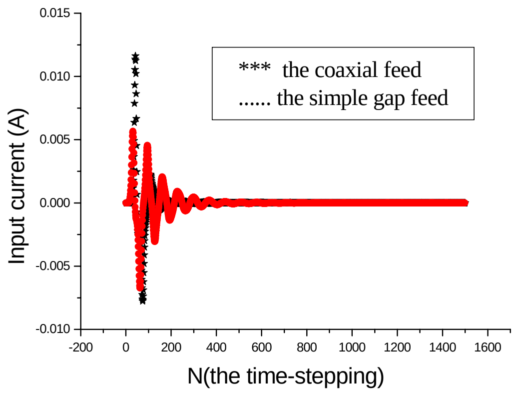

Fig.2 Time domain waveform of input current at feed location

D. Comparison convergence characteristic of the two kinds of feed modeling

Fig.2 shows the convergence characteristic curve of the Delta-gap feed modeling and the coaxial feed modeling. It is can be seen that the convergence characteristic of the coaxial feed modeling is better than the Delta-gap feed modeling.

3. Numerical results

Fig.3 shows a uniform linear dipole array conformal with a finite solid conducting cylinder, the element number is eight, the array axis is parallel to the cylinder axis. The cylinder is of height H_c and diameter D_c, each dipole is l long and 2a in diameter, the distance between adjacent elements is d, and the space from the array axis to the cylinder surface is s. Each dipole is in center feed, the absorbing boundary condition applies the PML. When f= 900MHz, H_c=6.3λ, D_c=1.0λ, l=0.5λ, s=0.8λ, d=0.6λ,2a=0.0008λ ,calculated the radiation pattern in horizontal plane shows in Fig.4. The result is in good agreement with the calculated result of the MOM[4].

Fig.5 shows a uniform dipole arrays mounted on the U-plate, the structure parameter of the dipole arrays with U-plate : L=3.75λ,W=0.8λ,h=0.005λ,d=0.75λ,H=0.25λ, the far radiation pattens sees Fig.6

4. Conclusion

In FDTD simulation, the antenna feed modeling is very important. In this paper, particular emphasis is placed on the antenna feed modeling, driving out the H-field updating equation for coaxial feed modeling in the junction surface of feed line and antenna. Comparison of the convergence characteristic of difference kinds feed modeling is provided. At last, we calculated the radiation pattern of dipole array for cellular base stations. The result agrees with the result of MOM.

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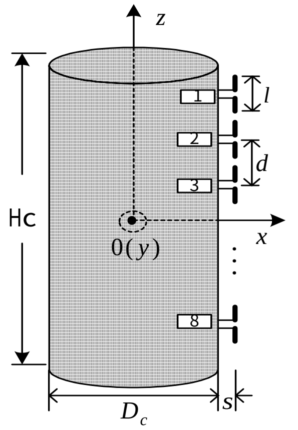

Fig.3 Uniform linear array mounted on finite solid conducting cylinder

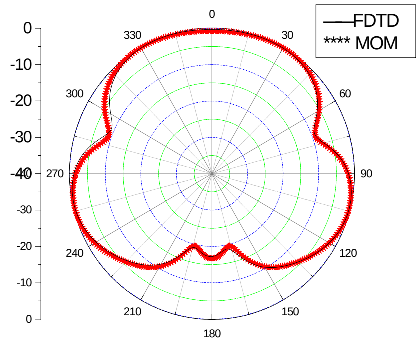

Fig.4 Comparison of radiation patterns in the horizontal plane

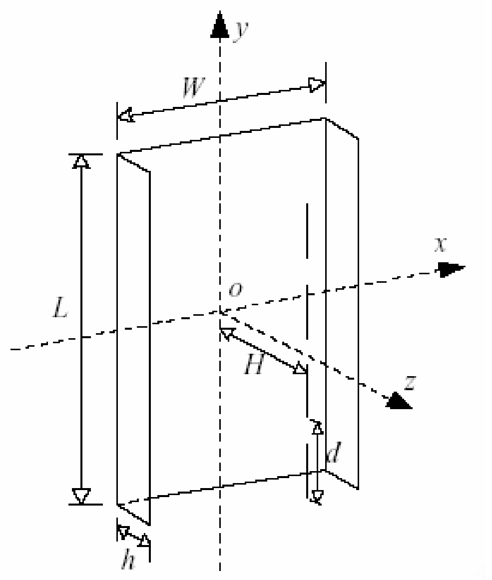

Fig.5 dipole arrays mounted on U-plate

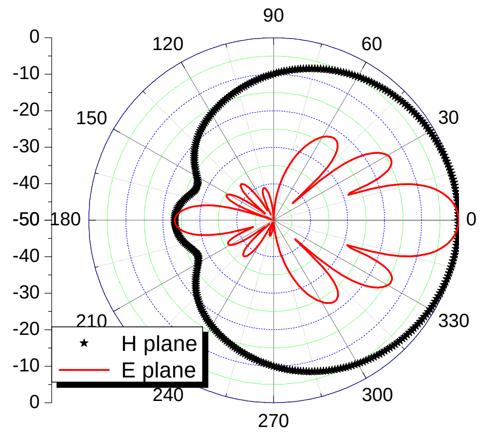

Fig.6 the patterns of dipole arrays mounted on U-plate