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FDTD ANALYSIS OF OBLIQUELY FED PLANAR ANTENNA

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1 Introduction

The FDTD method [1, 2, 3, 4] has been widely used for analyzing many electromagnetic problems including electromagnetic scattering, antennas and so on by reason of it's high capability of modeling the complex structures within a practical level of the accuracy. However, when the highly accurate result is required a great amount of computer resources or some special techniques are often needed even if the geometry is relatively simple [5]. The obliquely fed planar antenna studied in this paper is one of the problems which may not be calculated succesfully in the original FDTD framework. On the other hand, the UWB wireless communication system is recently investigated actively. For this system the development of the super wideband or multiband antennas is required. The self-complementary antenna[8] may be suitable for the UWB communication because it indicates a constant impedance feature for any frequency. The planar self-complementary antennas are usually fed obliquely. So, in this paper we propose the obliquely fed model for the planar antenna in FDTD method. The validity of our proposed method is confirmed by analyzing some self-complementary antennas.

2 The obliquely feeding model in FDTD method

Fig.1 shows a bow-tie antenna whose flare angle is 90 degrees which is the typical self-complementary antenna. The electric field cells of the original FDTD are placed as shown in Fig.1(b) in order to easily model the antenna feed. However, the staircase error becomes large in this case. In order to reduce the error, the CP method has been proposed [6, 7], but the remarkable improvement of the accuracy for a wide frequency band was not achieved.

Fig.1(c) shows the cell placement studied in this paper. In this case no staircase error is considered, but the input voltage is fed obliquely.

2.1 Modeling of feeding voltage

Fig.2 shows the FDTD electric and magnetic fields around the feed region, the gray cells indicate the antenna conductor. $\boldsymbol{E}^{ex}$ is an input electric field. When the input electric

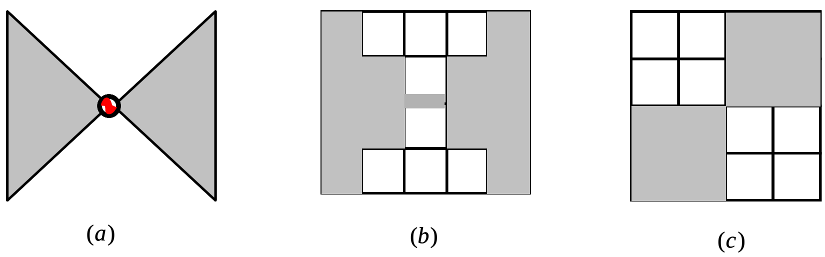

Fig. 1: bow-tie antenna and cell arrangement near feed point

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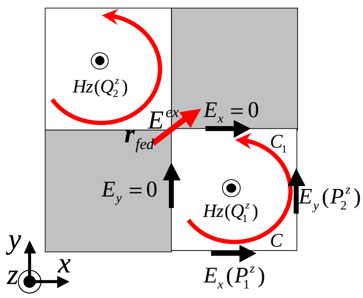

Fig. 2: Hz component

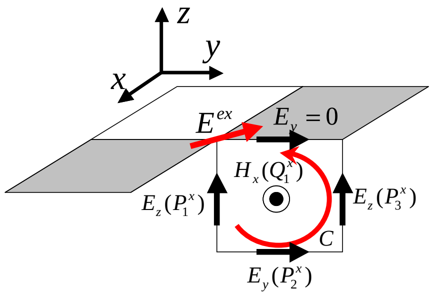

Fig. 3: Hx component

field $\boldsymbol{E}^{ex}$ inclines 45 degree to the FDTD cell, $\boldsymbol{E}^{ex}$ is expressed as

$$\begin{cases} \boldsymbol{E}^{ex}(\boldsymbol{r}) = V\delta(\boldsymbol{r} - \boldsymbol{r}_{fed})\hat{s_0} \\ \hat{s_0} = \frac{1}{\sqrt{2}}\hat{x} + \frac{1}{\sqrt{2}}\hat{y} \end{cases} \tag{1}$$

The magnetic field $H_z(Q_1^z)$ is calculated by applying the Faraday's law to the contours C shown in Fig.2 as follows.

$$\begin{aligned} \oint_C \boldsymbol{E} \cdot d\boldsymbol{l} &= 0 + E_x(P_1^z)\Delta x + E_y(P_2^z)\Delta y + 0 - V\hat{s_0} \cdot \hat{s_0} \\ &= -\mu_0 \frac{\partial H_z(Q_1^z)}{\partial t} \Delta x \Delta y \end{aligned} \tag{2}$$

Substituting $t = n\Delta t$ into equation (2), then the magnetic field update equation for $H_z^{n+\frac{1}{2}}(Q_1^z)$ can be obtained. Similarily applying the Faraday's law to the cell on $y - z$ plane in Fig.3, then $H_z^{n+\frac{1}{2}}(Q_2^z)$ can be described as

$$\begin{aligned} \oint_C \boldsymbol{E} \cdot d\boldsymbol{l} = &- \quad E_z(P_1^x)\Delta z + E_y(P_2^x)\Delta y + E_z(P_3^x)\Delta z + 0 + V\hat{s_0} \cdot \frac{1}{\sqrt{2}}\hat{x} \\ &= -\mu_0 \frac{\partial H_x(Q_1^x)}{\partial t} \Delta x \Delta y \end{aligned} \tag{3}$$

Thus the update equations for H_x, H_y, H_z near the feed point are obtained as follows.

$$\begin{aligned} &H_x^{n+\frac{1}{2}}\left(i_{fed}, j_{fed} + \frac{1}{2}, k_{fed} - \frac{1}{2}\right) = H_x^{n-\frac{1}{2}}\left(i_{fed}, j_{fed} + \frac{1}{2}, k_{fed} - \frac{1}{2}\right) \\ &- \frac{\Delta t}{\mu_0 \Delta y \Delta z}\left\{\Delta y E_y^n\left(i_{fed}, j_{fed}, k_{fed}\right) - \frac{V}{2}\right\} \\ &+ \frac{\Delta t}{\mu_0 \Delta y}\left\{E_z^n\left(i_{fed}, j_{fed}, kfed\right) - E_z^n\left(i_{fed}, j_{fed} + 1, k_{fed}\right)\right\} \end{aligned} \tag{4}$$

$$\begin{aligned} &H_y^{n+\frac{1}{2}}\left(i_{fed}, j_{fed} + \frac{1}{2}, k_{fed} - \frac{1}{2}\right) = H_y^{n-\frac{1}{2}}\left(i_{fed}, j_{fed} + \frac{1}{2}, k_{fed} - \frac{1}{2}\right) \\ &+ \frac{\Delta t}{\mu_0 \Delta x \Delta z}\left\{\Delta x E_x^n\left(i_{fed}, j_{fed}, k_{fed} - 1\right) - \frac{V}{2}\right\} \\ &- \frac{\Delta t}{\mu_0 \Delta x}\left\{E_z^n\left(i_{fed}, j_{fed}, k_{fed} - 1\right) - E_z^n\left(i_{fed} + 1, j_{fed}, k_{fed} - 1\right)\right\} \end{aligned} \tag{5}$$

$$\begin{aligned} H_z^{n+\frac{1}{2}}\left(i_{fed}, j_{fed} - \frac{1}{2}, k_{fed} + \frac{1}{2}\right) &= H_z^{n-\frac{1}{2}}\left(i_{fed}, j_{fed} - \frac{1}{2}, k_{fed} + \frac{1}{2}\right) \\ &+ \frac{\Delta t}{\mu_0 \Delta y}\left\{E_x^n\left(i_{fed}, j_{fed} + 1, k_{fed}\right)\right\} \\ &+ \frac{\Delta t}{\mu_0 \Delta x \Delta y}\left\{\Delta y E_y^n\left(i_{fed}, j_{fed}, k_{fed}\right) - V\right\} \end{aligned} \tag{6}$$

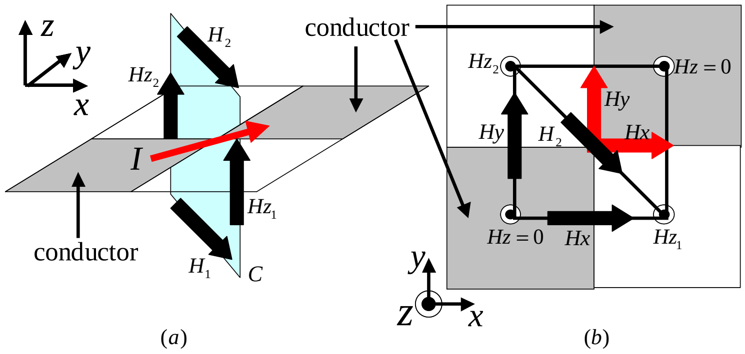

Fig. 4: feed current

2.2 Feed current

The feed current is calculated by appling the Ampere's law

$$I = \oint_C \boldsymbol{H} \cdot d\boldsymbol{l} \tag{7}$$

to the contour C shown in Fig.4(a), however no magnetic fields are assigned on C in the FDTD. In this paper the magnetic fields H_1 and H_2 are calculated from FDTD magnetic field H_x and H_y as shown in Fig.4(b). Then H_1 and H_2 is expressed as

$$H_1 = \frac{H_x\left(i_{fed}, j_{fed} - \frac{1}{2}, k_{fed} - \frac{1}{2}\right) - H_y\left(i_{fed} - \frac{1}{2}, j_{fed}, k_{fed} - \frac{1}{2}\right)}{\sqrt{2}} \tag{8}$$

$$H_2 = \frac{H_x\left(i_{fed}, j_{fed} - \frac{1}{2}, k_{fed} + \frac{1}{2}\right) - H_y\left(i_{fed} - \frac{1}{2}, j_{fed}, k_{fed} + \frac{1}{2}\right)}{\sqrt{2}} \tag{9}$$

3 Numerical examples

In order to confirm the validity of our proposed method, we analyzed the infinitely long bow-tie antenna whose flare angle is 90 degrees. The calculated input impedance is shown in Fig 5. The result of the CP method is also shown. In this calculation, the cell size is set to $\Delta x = \Delta y = \Delta z = 1[mm]$ which correspond to $\frac{1}{300}$ wavelength at 10 GHz. Our method agrees very well with the theoretical input impedance of the self-complementary antenna

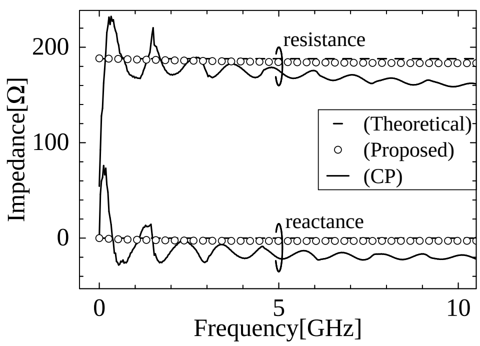

Fig. 5: Input impedance

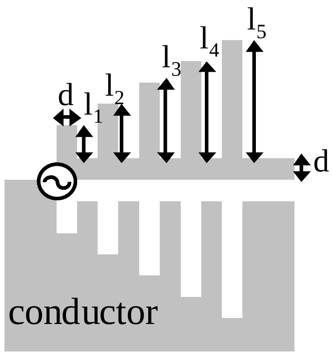

Fig. 6: unbalanced self-complementary antenna

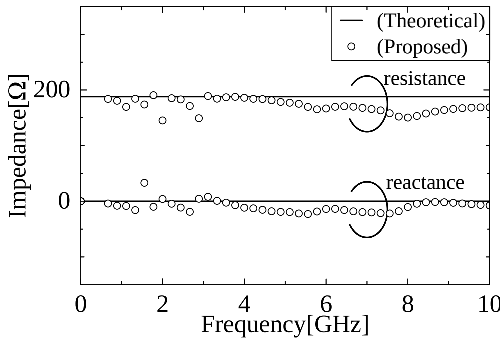

Fig. 7: input impedance

$60\pi \simeq 188[\Omega]$ for the wide frequency range.

We also analyzed the unbalanced self-complementary antenna as shown Fig.6. The length of conductor is set to $l_1 = 15, l_2 = 25, l_3 = 35, l_4 = 45, l_5 = 55[mm]$, the width of conductor is set to $d = 5[mm]$ of all conductors. The FDTD cell sizes are $\Delta x = \Delta y = \Delta z = 1[mm]$. The proposed method gives the impedance near the theoretical value $60\pi \simeq 188[\Omega]$, but does not agree with it significantly This reason is considered that the spatial distribution of electric fields near the antenna conductor of antenna changes rapidly.[9]

4 Conclusion

In this paper, we have proposed the feed model in FDTD framework for the obliquely fed planar antenna. The validity of proposed method has been confirmed theoretically by computing with the frequency characteristics of two types of the self-complementary antennas. It has been also found that the high accuracy calculation can be performed by fitting conductor cell edge to FDTD cells rather than using the CP method.

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