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# Comparison of FDTD(2,4) and FDTD(2,2) Methods for Dipole Antenna Impedance Calculations

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## 1. Introduction

Various numerical techniques such as the Method of Moments, the Finite Element Method and lately the Finite Difference Time Domain (FDTD) method, have significantly developed in the last decade for a variety of antenna and electromagnetic scattering problems. These methods have significant simulation capabilities on digital computers[1]. Especially the FDTD method is widely used for many electromagnetic problems including scattering problem, because, of its own applicability to the complex geometries and capability for obtaining the practical level of the accuracy.

The finite difference error of the original FDTD method in which a first order center difference approximation is used are in the order of $(\Delta t)^2$ and $(\Delta x)^2$ temporally and spatially where $\Delta t$ and $\Delta x$ are temporal and spatial increments. For this reason, the original FDTD method is often symbolized as FDTD (2,2). On the other hand, the original FDTD method can be easily modified by applying, a higher-order finite difference approximation to the Maxwell's curl equations. Though some binds of higher-order FDTD methods are possible, FDTD (2,4) method[2] in which the 4th order finite difference approximation is used spatially, is often used, and can reduce the numerical phase velocity error or a numerical dispersion error for wave propagation. In this paper, the FDTD (2,4) method is applied to calculate an input impedance of a dipole and patch antennas, and compared with the original FDTD (2,2) method. From the results, it was shown that the FDTD(2,4) method could not improve the calculation accuracy significantly for antenna analysis.

## 2. FDTD(2,4) method

In FDTD(2,4) method, a fourth order difference approximation formula of the Maxwell equations is used to solve spatial differential, the approximation can be expressed as

$$\frac{\partial F}{\partial x} \approx \frac{9}{8\Delta x}\left\{F(x+\Delta x/2, y, z, t) - F(x-\Delta x/2, y, z, t)\right\} - \frac{1}{24\Delta x}\left\{F(x+3\Delta x/2, y, z, t) - F(x-3\Delta x/2, y, z, t)\right\} + O(\Delta x)^4 \quad (1)$$

where $\Delta x$ is the spatial discrete distance which according to the cell size in $x$-direction. The derivatives of time is same approximation as the original FDTD(2,2). It has been shown that the dispersion error of the FDTD(2,4) is very small compare with the FDTD(2,2) when an appropriate relation between $\Delta x$ and $\Delta t$ is satisfied[2].

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## 3. Treatment of PEC in FDTD(2,4) method

Fig.1 shows the electric and magnetic fields placement in FDTD method which include thin PEC. In FDTD(2,4) method, a special treatment is needed near PEC region. In order to obtain updated electric field $E^{n+1}(Q)$ and magnetic field $H^{n+1}(P)$ near PEC, $H(P')$ and $E(Q')$ are used due to 4th order difference. Therefore, discontinuous difference over PEC is used. This calculation can not be calculated correctly. In order to overcome these difficulties, special treatment is needed. In Ref.[4], in order to overcome this problem, the sub-grid method was used. On the other hand, we apply FDTD(2,2) method near antenna cells which expressed as eq.(2). Then, $E^{n+1}(Q)$ and $H^{n+1}(P)$ are obtained not using discontinuous fields. This scheme is indicated in Fig.2.

$$\frac{\partial F}{\partial x} \approx \frac{F\left(x+\frac{\Delta x}{2}, y, z, t\right) - F\left(x-\frac{\Delta x}{2}, y, z, t\right)}{\Delta x} + O(\Delta x)^2 \tag{2}$$

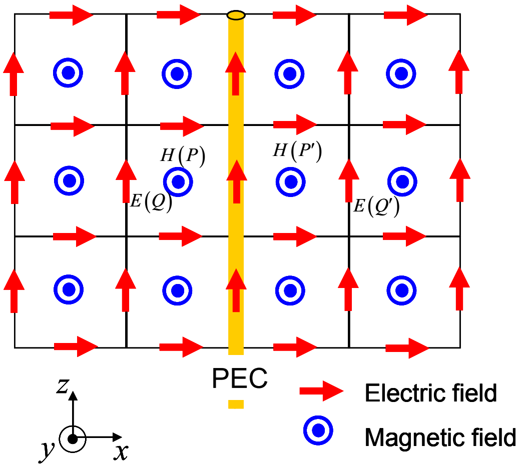



Fig1. electric and magnetic field placement in FDTD method

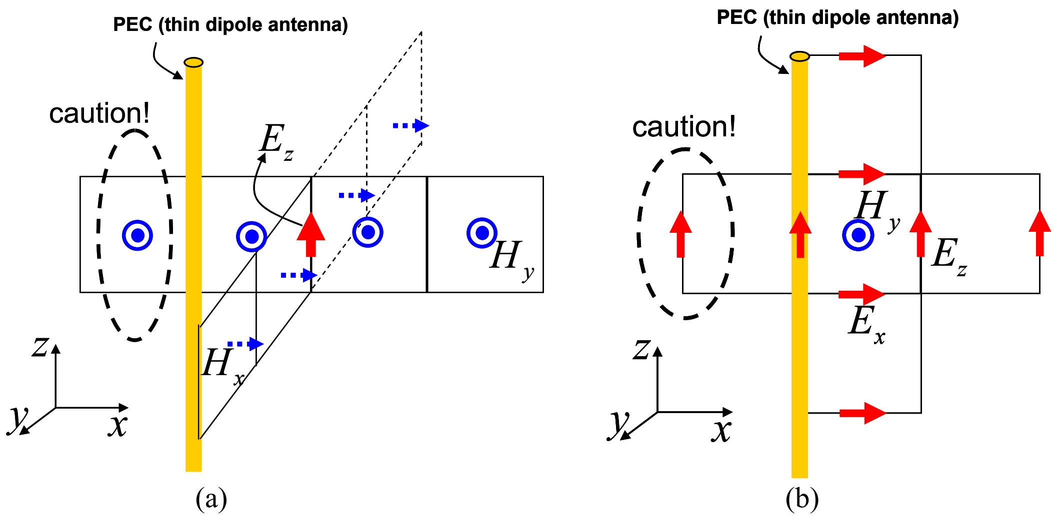



Fig.2. Applying FDTD(2,4) method to the PEC neighborhood. (a) an electric field component from magnetic components. (b) a magnetic field component from the electric components.

## 4. Numerical results

In order to confirm the accuracy of FDTD(2,4) method, we calculated the input impedance of the dipole antenna as shown Fig.3. The length of the antenna is 15cm.

Fig.4. shows the input impedances at frequency domain which analyzed by FDTD(2,2) and FDTD(2,4) methods. Fig.5(a)(b) show the input impedance at 3GHz and 1GHz with changing cell size.

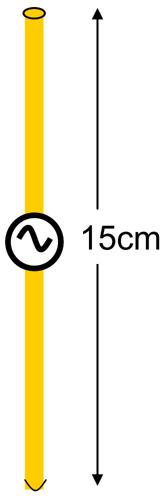



Fig.3. analytical dipole antenna model.

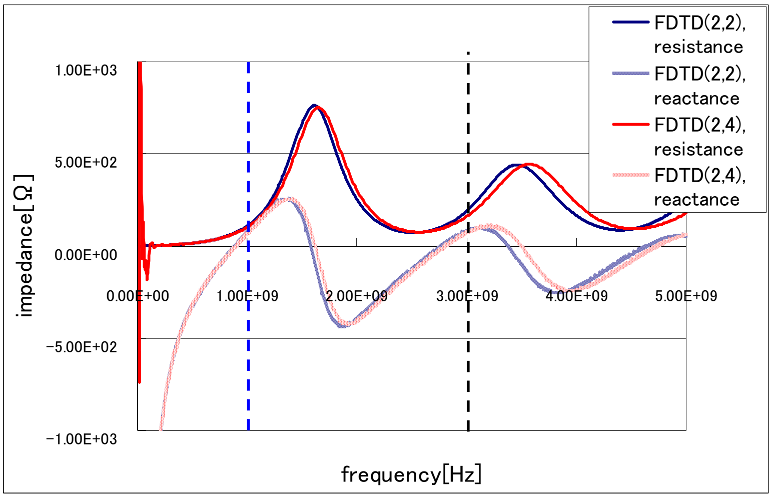
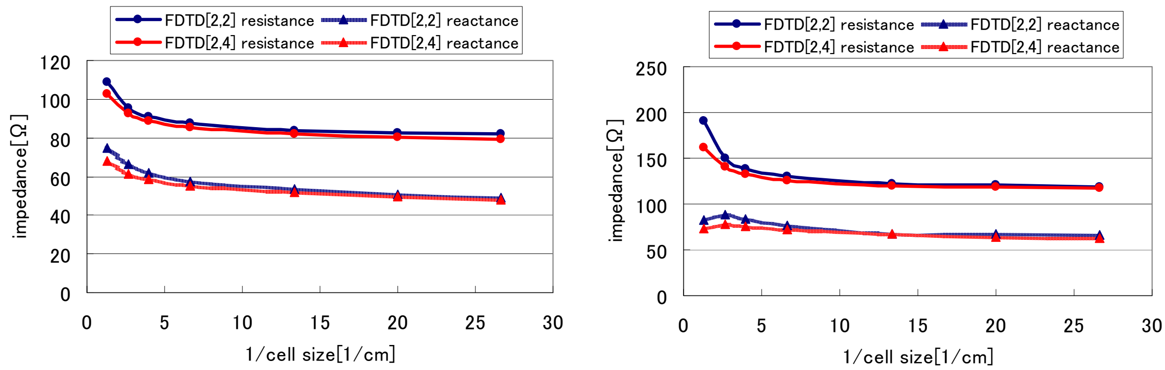



Fig.4. input impedance frequency characteristic




(a)At 1.0GHz point

(b) At 3.0GHz point

Fig.5. input impedance convergence at one frequency. (a) At resonant frequency 1.0GHz. (b) At frequency 3.0GHz.

It is found that the FDTD(2,4) and the FDTD(2,2) gives almost the same result. Thus the FDTD(2,4) method is not effective for impedance calculation of dipole antenna. The reason is considered that the electric fields changes rapidly near antenna region, but the FDTD(2,4) method have to use 2nd order difference near antenna conductor due to the mentioned above.

Next, we calculated the reflection coefficient of the rectangular patch antenna as shown in Fig6. The cell sizes were set $\Delta x$ =0.389mm, $\Delta y$ =0.40mm, $\Delta z$ =0.265mm. Calculated results are shown in Fig.7. The measured data is also shown in this figure. It is found that the FDTD(2,4) and the FDTD(2,2) gives almost the same result. On the other hand, the result "Quasi-static" which indicated as in Fig.7 is calculated by Ref.[5]. This method include Quasi-static field to FDTD(2,2) method. This result gives extremely accurate result even if FDTD(2,2) method used.

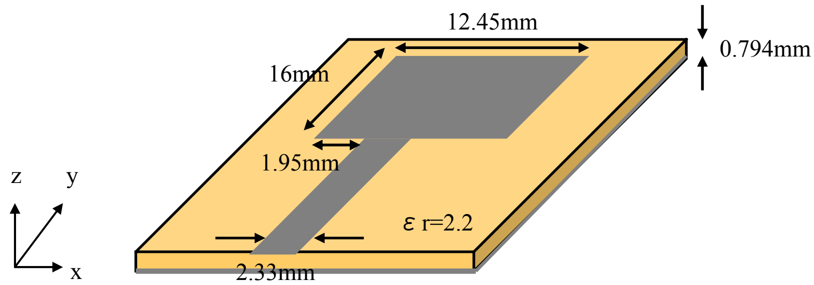



Fig.6. The stadied patch antenna

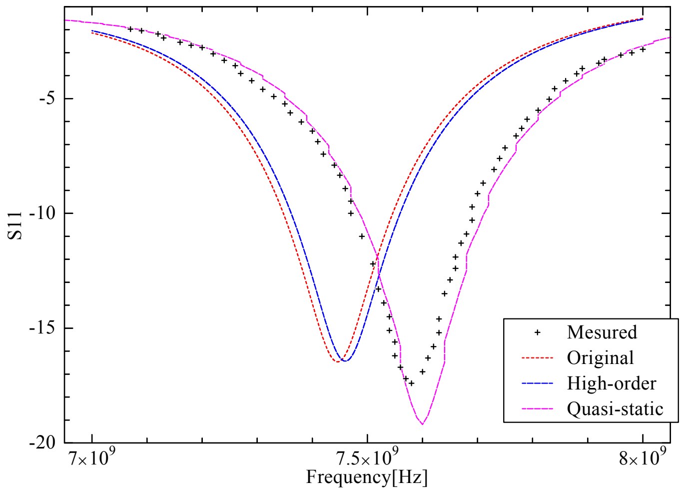



Fig.7. Reflection coefficient of the antenna

## 5. Conclusion

In this paper, the FDTD(2,4) method was applied to the impedance calculations of the dipole and patch antennas. It has been show that the FDTD(2,4) method is not effective for improving the accuracy of impedance calculation.

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