Electromagnetic Field Scattering of a High Speed Moving Source and Its Application

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***Abstract*—This paper presents the electromagnetic (EM) field scattering of a high speed moving source and a moving target by using Finite-Difference Time-Domain (FDTD) with Overset Grid Generation (OGG) method. The analysis is conducted for 750MHz band at the street intersection with OpenMP parallel processing technique. The performance of this proposed method is verified with theoretical results. The simulation results have shown comparatively good agreement in moving and stationary case. The proposed simulation study is of great importance to ground transportation in Intelligent Transportation System (ITS) applications.**

***Index Terms*—Direct Scattering; Doppler Effect; Intelligent Transportation System; Moving Source; Overlapped Grid**

I. Introduction

Finite-Difference Time-Domain (FDTD) combined with Overset Grid Generation (OGG) method has been previously proposed to investigate the characteristics of EM field from a moving and rotating body at high velocities [1]. In this paper, we report more comprehensive data and detailed discussion of the FDTD with OGG method for EM field scattering of a high speed moving source and its application. Lorentz transformation [2] is integrated in this proposed method to analyze the movement of the input source and moving target. The target, for example, moving vehicle at the street intersection is modelled by using the OGG method. This method consists of two parts; the main mesh and several sub-meshes. The meshes are overlapped with each other and can be calculated as one computational grid. This will reduce the complexity of the computational grid. A preliminary version of this paper appeared in [3].

In this paper, the analysis is done with OpenMP parallel processing technique. This parallel implementation is capable to increase the maximum solvable problem size and reduce the computational time [4]. The grid size ratio is first studied as a benchmark. Then, the EM field scattering from a moving source and to a moving vehicle in 750MHz band at the street intersection are analyzed. The analysis results show comparatively good agreement with stationary case. The proposed FDTD with OGG method has the potentials for epochal developments in nanoelectronics devices, particularly in the ITS applications [5]-[7].

II. FDTD Method In Parallel Processing Technique

The parallelism of FDTD method is implemented with OpenMP library using Fork-Join model on a shared memory system [8]. Figure 1 shows the illustration of the Fork-Join model of OpenMP. The OpenMP programs are initiated with master thread. Then, the parallel region I and II create a team of threads for electric field and magnetic field respectively by using OMP parallel coding *#pragma omp parallel*. The parallel threads will be processed in a single program when each region has completely constructed. The computational time between with and without openMP library is compared to evaluate its efficiency. A computation volume for main mesh is 1000×1000 grids while the overlapped single sub-mesh is 50×50 grids. The number of time iterations is 10000 steps. In this analysis, the sub-mesh moves with velocity, $v=0.01c$ where c is the speed of light. The parallel FDTD method is analyzed by using operating system (OS) Ubuntu 14.04 LTS (64 bit) on CPU Intel Core i7-3960X with $3.3GHz$ memory. Table 1 shows the comparison of the FDTD method performance with and without OpenMP library in a single processor. Here, it is shown that FDTD method with OpenMP is 2.87 times faster compared to the FDTD method without OpenMP.

Table 1
Performance of FDTD Method

FDTD Method	Computational Time
With OpenMP	129 sec
Without OpenMP	370 sec

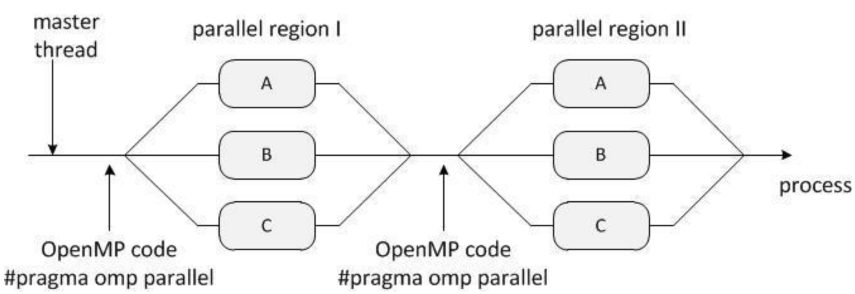


Figure 1: Illustration of Fork-Join Model of OpenMP

III. VALIDITY OF THE ACCURACY

In this section, the grid size ratio of the main mesh, x_m and single sub-mesh, x_s for FDTD with OGG method is first studied. The grid setup is shown in Figure 2. Both meshes are investigated in free space and the ratio, R is given by $R = \Delta x_s / \Delta x_m$. For a benchmark, the space increments for main mesh are set to $\Delta x_m = \Delta y_m = 0.01(m)$.

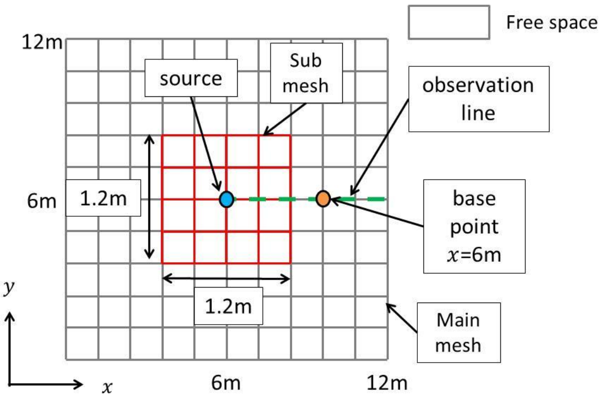


Figure 2: Numerical model

The sub-mesh is moving along x-axis with $v = 0.01c$. Here, the value of R ranging from 0.4, 0.6, 0.8, 1.0, 1.2, 2.0, 2.5, 3.0 and 4.0 are analyzed. The input source is a sinusoidal wave of 750 MHz located at source point as in Figure 2. The time increment in this analysis is set to $\Delta t = 2.66 \times 10^{-12}$ (sec). The OGG grid is terminated by the first-order Mur absorbing boundary condition [9]. The performance of this proposed method is verified with theoretical results given by [10]

$$\lambda = \frac{1-(v/c)}{1+(v/c)} \quad (1)$$

and the relative error can be obtained from

$$error_{rel} = \left| \frac{numerical - theoretical}{theoretical} \right| \quad (2)$$

The simulation result is shown in Figure 3. Here, the relative error values with various sub rate are compared with the standard deviation. It is observed that the error values for sub rate 0.4, 0.8, 1, 1.2, 2 and 3 is below than 0.01. Hence, the results show good agreements were obtained for value of sub-rate 0.4 and 1.2.

IV. NUMERICAL MODELING OF A MOVING SOURCE

A. *Simulation Setup for OGG and FDTD Method from a Moving Source*

Figure 4 shows the simulation setup to investigate the characteristics of EM field from a moving input source. The main mesh is set as a free space and dielectric objects to model the road intersection. The value of R = 1.0 in Section 3 is applied to this simulation. The space increment for both meshes are $\Delta x_m = \Delta x_s = 0.025\lambda$ and $\Delta t = \Delta x / 2c$. The objects parameter are given by $\varepsilon_r = 7.0(F/m)$ and $\varsigma = 0.0389(S/m)$. The input source of 750 MHz is set on the sub-mesh at the point A and overlapped with the main mesh.

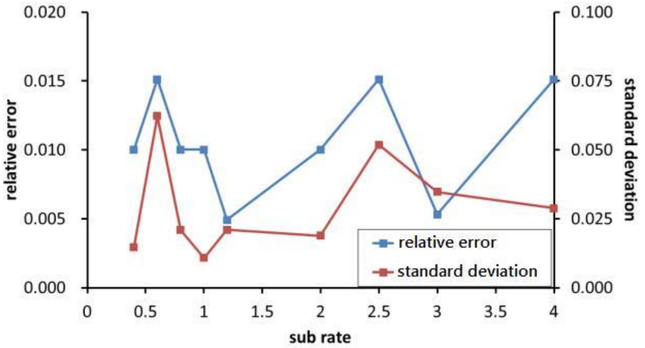


Figure 3: Standard deviation and relative error versus ratio

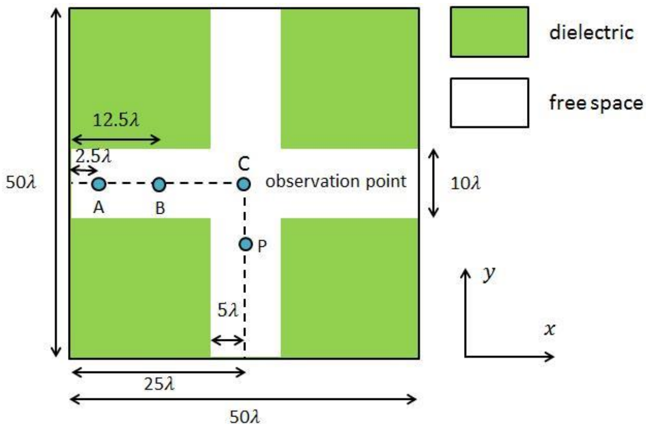
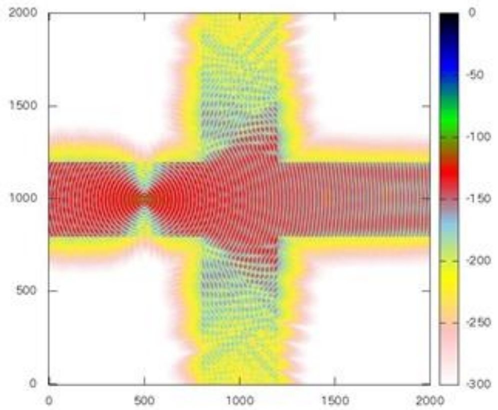


Figure 4: Road intersection model for a moving source

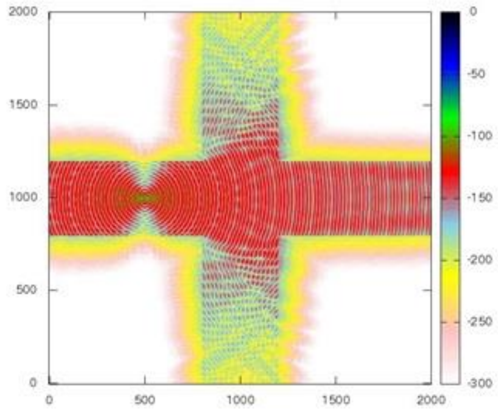
The sub-mesh with the input source is assumed to moves in free space from point A to point B with v = 0.01c. Higher velocity is chosen in this simulation is to reduce the computational time. Thus, it can be reduced to a realistic velocity which is practical to the real-time application particularly at the road intersection by taking more computational time steps with smaller Δt.

The result is depicted in Figure 5(a). In other analysis setup, the sub-mesh with static input wave is located at point B. The characteristic of the EM field scattering for stationary case is shown in Figure 5(b). The Doppler effect for both cases are shown in Figure 6.

Figure 5(a), Figure 5(b) and Figure 6 show the electric field scattering of E_y (V/m) from the stationary input wave [11] and moving wave, respectively. Horizontal line shows the length from point B to point C and point P, normalized by the wavelength. Here, the values of the peak are different as the amplitude of the EM field was calculated after the same time steps. It is observed that the phase and amplitude are shifted by the motion of the source.



(a)



(b)

Figure 5: (a) $E_y(V/m)$ at observation point B and (b) $E_y(V/m)$ from observation point A to point B.

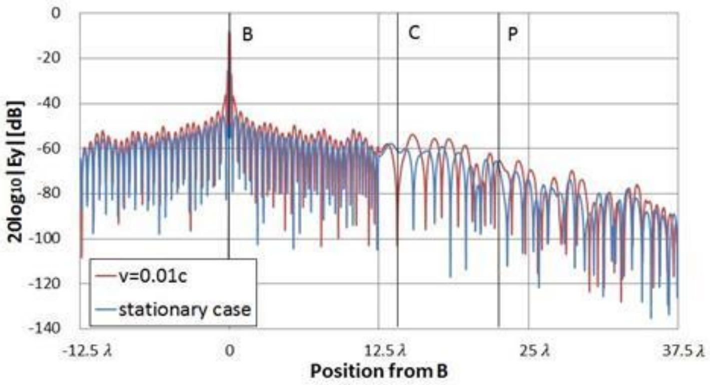


Figure 6: Doppler effect from observation point B, C and P.

B. Simulation Setup for OGG and FDTD Method for a Moving Vehicle

This simulation is further analyzed from an input moving source to a moving vehicle. The numerical model to be considered here is shown in Figure 7. The input source on the sub-mesh is assumed to moves in free space to point P. In addition, another sub-mesh is set to represent the moving vehicle. The vehicle moves oppositely from right to left towards P. The parameter used in this simulation is $\Delta x_m = \Delta x_s = \lambda / 40$, $\varepsilon_r = 7.0(F/m)$, $\varsigma = 0.0389(S/m)$ and $\Delta t = \lambda / 100c$.

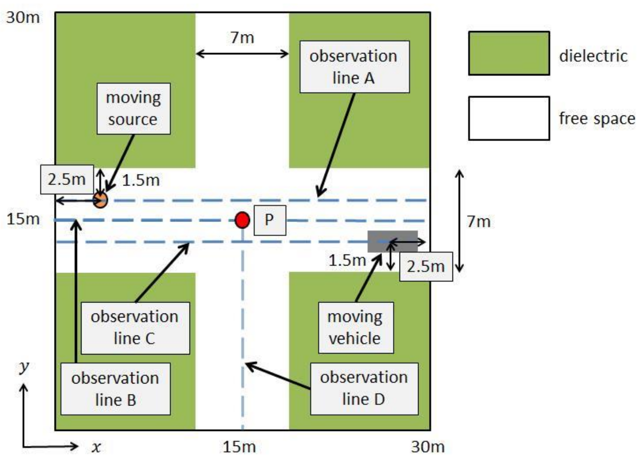


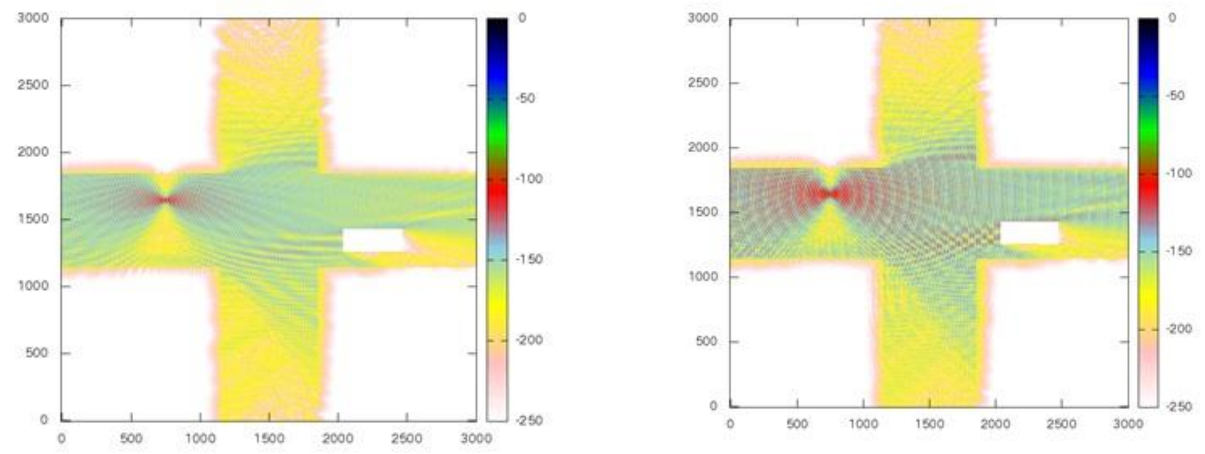
Figure 7: Intersection model for moving source and moving vehicle.

Rectangular shape with grid size of 1.72 x 4.4(m) represents the vehicle and moves at velocity $v = 0.01c$. For simulation purposes, this velocity value is chosen to reduce the computational time. Thus, it can be reduced to a realistic velocity by taking more computational time steps with smaller time increment. The simulation results of EM field scattering for a moving vehicle are shown in Figure 8 and Figure 9.

Figure 8(a) shows the E_y (V / m) wave when both input source and vehicle are in static motion. On the other notes, Figure 8(b) shows the E_y (V/m) when both vehicle and input wave move towards each other. Figure 9(a) and Figure 9(b) show the E_y (V / m) on the observation line A and line C, respectively. Changes in wavelength and amplitude show the Doppler effect occurs from both results. The values of the peak are different as the amplitude of the EM field was calculated after the same time steps.

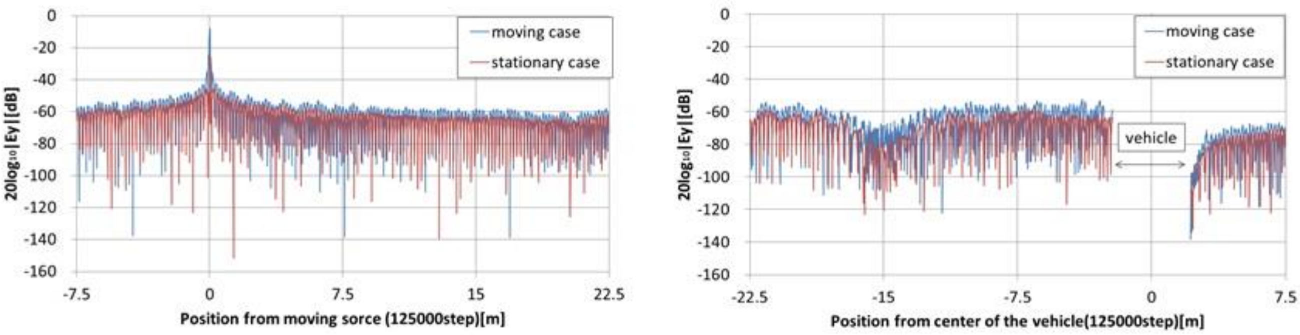
V. CONCLUSION

The modeling and simulation study to investigate the characteristics of EM field with a high speed moving target is presented. The numerical results are validated. It shown comparatively good agreement with the stationary case. The computation time is also reduced by 35% with Open MP parallel computing. The proposed simulation study is of great importance to ground transportation in Intelligent Transportation System (ITS) applications.



(a) (b)

Figure 8: (a) E_y (V / m) when input source is static and the vehicle is not moving and (b) E_y (V / m) when both vehicle and input wave move towards each other.



(a) (b)

Figure 9: (a) E_y (V / m) on the observation line A and (b) E_y (V / m) on the observation line C.

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REFERENCES

[1] S. Sahrani, H. Iwamatsu, M. Kuroda, "A Novel Approach for the Analysis of Electromagnetic Field with Rotating Body", *Applied Computational Electromagnetics (ACES)* Journal, Vol. 26, no. 8, August 2011, pp. 651-659.

[2] A. Einstein, *Relativity: The Special and General Theory*, Digireads.com: reprint edition, 2012

[3] A. Tatsuya, S. Sahrani, M. Kuroda, "Numerical Analysis of the EM Field from a Moving Source and the Application for a Moving Vehicle," *European Microwave Conference 2014*, Rome, Italy, October 2014.

[4] M.J. Quinn, *Parallel Programming in C with MPI and OpenMP*, New York: McGraw Hill Higher Education, 2003.

[5] G.W. Hanson: Fundamentals of Nanoelectronics, Pearson Prentice Hall, 2008.

[6] R. Waser: Nanoelectronics and Information Technology, Wiley-VCH, 2012.

[7] V.V. Mitin: Introduction to Nanoelectronic, Molecular Electronics, and Nanodevices, Cambridge University Press, 2013.

[8] R.Chandra, R. Menon, L. Dagum, D. Kohr, D. Maydan, J. McDonald : Parallel Programming in OpenMP 1st Edition, Morgan Kaufmann, 2000.

[9] A. Taflove, S.C. Hagness: The Finite-Dierence Time-Domain Method (3rd edn), Artech House Antennas and Propagation Library, 2005.

[10] J.V. Bladel, *Relativity and Engineering*, Springer-Verlag, 1984.

[11] K. Taguchi, T. Kashiwa, K. Ohshimo, T. Kawamura, "Propagation Analysis of Electromagnetic Waves in 700MHz Band at Intersection for Inter-Vehicle Communications Using the FDTD Method," *IEICE Trans. of Electronics*, vol. E94-C no. 1, pp. 18-23, January 2011.