Three-Dimensional FDTD Analysis of Radio Wave Propagation at Intersection Surrounded by Compound Walls in Residential Area for Inter-Vehicle Communications Using 720MHz band

K. Taguchi 1, R. Aoyama 1, S. Imai 1, T. Kashiwa 1
1 Dept. of Electrical and Electronic Eng., Kitami Institute of Technology, Kitami 090-8507, Japan, ktaguchi@mail.kitami-it.ac.jp

1. Introduction

The widespread use of automobiles has resulted in a correspondingly high number of car accidents, and this number shows no sign of any significant decline. Many accidents occur at poor-visibility intersections. To avoid such incidents, an inter-vehicle communication (IVC) system has been proposed [1]-[7]. In Japan, with the changeover in terrestrial broadcasting from analog to digital broadcasting, part of 720 MHz band will be newly assigned to the IVC system. It is possible that this system can prevent car accidents at blind spots in such the intersections, because waves of 720MHz band have high diffraction effect relative to those of 5.8-5.9GHz band used in the dedicated short range communication system. Furthermore, the system using 720MHz band could potentially be adapted to prevent short-range emergency collisions.

In Japanese residential areas, intersections are often surrounded by houses with compound walls that limit visibility at these intersections. We have previously investigated the basic impact of such compound walls on propagation characteristics of 720 MHz band at intersections in the two-dimensional space [7]. However, in real life, the wall height and the ground may also influence these characteristics.

In this paper, radio wave propagation characteristics at an intersection surrounded by compound walls are investigated for the IVC system using 720 MHz band. These characteristics in the three-dimensional space are obtained for the first time by using the finite-difference time-domain (FDTD) method. Specifically, we investigate the qualitative impact of wall thickness, wall height, the ground, and source locations on propagation loss. Furthermore, the power delay profile and power angle profile are analyzed to clarify the physical mechanism of radio wave propagation. These characteristics are important to design communication systems.

2. Intersection Surrounded by Compound Walls

Figure 1 shows an intersection surrounded by compound walls in a residential area. Bidirectional single-lane roads come together at this intersection. The compound walls and the

Figure 1: Intersection Surrounded by Compound Walls.
ground are made of lightweight concrete and asphalt, respectively [8], [9]. A small dipole antenna with vertical polarization is used as a source. Parameter $S$ corresponds to a distance from the intersection to point T. The yellow line indicates the path for propagation loss analysis. Points A and B are observation locations for power delay profile analysis. Here, heights of observation line and points are 1.5 m. The spatial increment $\Delta$ was set to 1.0 cm in the FDTD analysis.

3. Radio Wave Propagation Characteristics at Intersection Surrounded by Compound Walls

3.1 Propagation Loss Analysis

Figure 2 shows four types of intersections for the propagation loss analysis. The propagation loss at these intersections is analyzed to clarify qualitative impact of the wall thickness, wall height, and the ground. Here, Fig. 2 (a) corresponds to the intersection of Fig. 1.

Figure 3 illustrates the propagation loss along path TCQ at the intersections. The propagation loss is obtained by averaging $|E|$ over the vehicular width $w_v = 1.8$ m in the transverse direction to the path. Moreover, the loss along the path is normalized by using the value at a source location in free space analysis.

![Figure 2: Vertical Cross-Sectional View of Intersections for Propagation Loss Analysis.](image)

![Figure 3: Propagation Loss Along Path TCQ at the Intersections.](image)
Figures 3(a), and 3(b) show the effect of walls and the ground, and source locations for the intersection of Fig. 1, respectively. Here, $S = 20$ m corresponds to the stopping distance for a vehicle traveling at a speed of 40 km/h. As shown in Fig. 3(a), the propagation loss for case (b) becomes very large because the propagating waves do not penetrate walls. Furthermore, in cases (c) and (d), the loss becomes large, possibly because of the influence of waves disturbed by top of walls and waves reflected off the ground, respectively. As shown in Fig. 3(b), the propagation loss does not depend strongly on the source location $S$. It seems that disturbed waves by top of walls and penetrating waves through walls are dominant at non line of sight region.

3.2 Power Delay Profile Analysis

Although a strict impulse response analysis should be conducted to analyze the power delay profile, the FDTD method cannot treat pure impulse waves. Therefore, quasi-impulse response analysis was conducted by using a modulated Gaussian pulse wave. The center frequency and half bandwidth at power half maximum of the modulated Gaussian pulse wave were set to $f_c = 720$ MHz and $f_0 = 150$ MHz, respectively.

Figures 4, 5 and 6 show the power delay profile, power angle profile, and delay time for the intersection of Fig. 1, respectively. Here, the power angle profile was obtained by using a Poynting vector calculation. The delay times correspond to peak times of pulse waves in power delay profiles. We can estimate propagation paths of radio waves from the power angle profile and delay time. As can be seen from Figs. 5 and 6, the first two pulses and other pulses in Fig. 4 correspond to arrival waves from the direction of a source and reflected waves from an opposite side wall, respectively. The arrival waves from the source direction are stronger than the reflected waves from the wall. Furthermore, the first waves have the spread of arrival angle in the $\theta$ direction. Of these waves, the strongest wave is the disturbed wave by top of walls, followed in order by the penetrating wave through walls, and the reflected wave by the ground.

![Point A](image1.png)  ![Point B](image2.png)

Figure 4: Power Delay Profile.

![Point A](image3.png)  ![Point B](image4.png)

Figure 5: Power Angle Profile.
4. Conclusions

This paper describes the propagation characteristics at an intersection surrounded by compound walls in a residential area. These characteristics were analyzed in three-dimensional space for the first time using the FDTD method. The propagation loss was shown to be affected by the wall height and the ground. In contrast, the propagation loss was almost independent of source location. Furthermore, it was shown that arrival waves from the direction of a source are dominant at non line of sight region at the intersection in a residential area. In the near future, we will investigate the propagation characteristics considering cars and antennas.

Acknowledgments

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References

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