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PAPER Special Section on Recent Progress in Electromagnetic Theory and Its Application

Propagation Analysis of Electromagnetic Waves in 700 MHz Band at Intersection for Inter-Vehicle Communications Using the FDTD Method

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SUMMARY Inter-vehicle communication (IVC) system using 700 MHz band to prevent car crashes has been proposed recently. In this paper, we first apply the FDTD method to the analyses of propagation characteristics at an intersection for IVC. We investigate the propagation characteristics considering the electrical conductivities, thickness and windows of building wall and pedestrians. As a result, it is shown that the electrical conductivities and thickness of building wall have a slight influence. In contrast, windows and pedestrians have a great influence on the propagation characteristics. Furthermore, the azimuth delay profiles are obtained by using the MUSIC algorithm.

key words: *inter-vehicle communication, intersection, wave propagation, FDTD method, MUSIC algorithm*

1. Introduction

Recently, the propagation analyses of electromagnetic waves are important to intelligent transport systems (ITS) technology. For example, inter-vehicle communications (IVC), dedicated short range communications for road-vehicle communications, collision avoidance radar using millimeter wave and so on. The car crash accidents at intersections is a social problem today. IVC is indispensable to prevent car crashes with invisible cars on the shadow region by buildings. In Japan, the terrestrial broadcasting will be changed over from the analog broadcasting to the digital broadcasting in 2011 year. 700 MHz band is newly assigned to IVC. However, the propagation characteristics in 700 MHz band at an intersection have not been well known.

The propagation characteristics at an intersection have been traditionally analyzed by using the ray tracing method [1]–[8]. The ray tracing method is generally fast and simple. However, the method can not analyze complex structures or objects smaller than several wavelengths [1]. Moreover, the calculation time rise when considering the penetrating waves. In the conventional study using the ray tracing, the reflected waves from the surfaces of buildings and the diffracted waves from the edges of buildings have been considered, but the penetrated waves from buildings have not been considered. Furthermore, there are not the analyses of propagation characteristics in 700 MHz band using the ray tracing method in consideration of thickness and windows of buildings wall, vehicles, pedestrians and so on at an intersection.

On the other hand, the finite difference time domain (FDTD) method is one of powerful and versatile methods [9]. Although the FDTD method is usually more inefficient than the ray tracing method, the method is suitable for heterogeneous and complex structures. The method can be applied to the problems mentioned above which are not suitable for the ray tracing method.

In this paper, we first apply the FDTD method to the analyses of propagation characteristics in 700 MHz band at an intersection for IVC. Also, before the analyses of propagation characteristics at an intersection, it is very important to know the effect of a building only in considering the penetrated waves. The following tasks are carried out in the study. 1) In order to clarify the effect of the penetrated waves from one building, the propagation characteristics of one building are analyzed. 2) The propagation characteristics at an intersection are analyzed. 3) The quasi-impulse responses at an intersection are analyzed. Furthermore, the power azimuth delay profiles are obtained by using the MUSIC algorithm [10]. These are very important to estimate the communication quality. In this study, the source was located at only one point. The distance of source point from an intersection correspond to the stopping distance for vehicle of speed 40 km/h. In the above tasks, the simulations are carried out in the two-dimensional space for qualitative analyses as a first step.

2. Propagation Characteristics of Electromagnetic Wave at One Building

In the section, the propagation loss for one building was investigated.

2.1 Propagaion Loss Analysis

Figure 1 shows one building with a cross road, where one building, roads with two lanes in each direction and sidewalks are located. Point B is the boundary between line-of-

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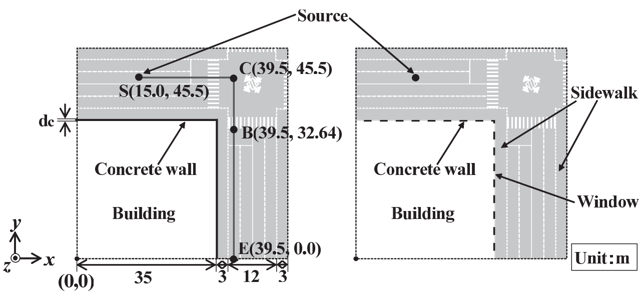


(a) Without windows (b) With windows

Fig. 1 One building with a cross road.

Table 1 Parameters used in this simulation.

Source wave	Frequency f [MHz]	720
Building wall	Thickness d_c [m]	∞
		0.5
		0.25
	Relative permittivity ε_{rc}	7.0
	Electrical conductivity σ_c [S/m]	0.0473
		0.0389
Window	Thickness d_w [mm]	8.0
	Relative permittivity ε_{rw}	6.76
	Electrical conductivity σ_w [S/m]	0.005
Spatial increment	$\Delta x = \Delta y = 8.0$ mm	
Time increment	$\Delta t = 0.182749$ ns	

sight (LOS) region and non-line-of-sight (NLOS) region.

Table 1 shows the parameters used in the simulation. Three types of wall thickness, two types of electrical conductivities and window were considered, where $d_c = \infty$ correspond to the case that a building is filled with a uniform concrete. Conventionally, the values of various electrical conductivities were used [11]. The electric conductivities of $\sigma_c = 0.0473$ and 0.0389 S/m were adopted in the study. The former is the value recommended by ITU-R for 1 GHz [12]. The latter is the experimental value in 700 MHz band [13]. The generalized perfectly matched layer (GPML) [14] was used as an absorbing boundary condition. In the study, two-dimensional FDTD analyses (E_z, H_x, H_y) were carried out because the vertical polarization was generally used in the IVC.

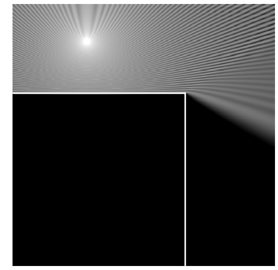
Figure 2 shows the electric field distribution. The values are normalized by one on the point S. The white lines represent the building wall. In the case of $d_c = \infty$, the white lines represent the surface of wall.

Figure 3 shows the propagation loss on the path SCBE. The propagation loss is obtained by taking the average of E_z over the vehicular width $w_v = 1.8$ m in transverse direction for path. Moreover, the propagation loss on the path is normalized by the value on the point S.

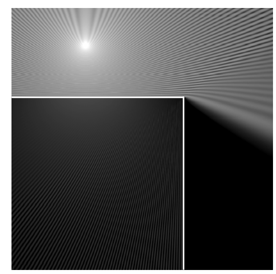
Hereafter, we investigate the influences of electrical conductivities, thickness and windows of building wall.

First, the influences of electrical conductivities and thickness of building wall are described. As shown in Fig. 3, the electrical conductivities σ_c for $d_c = \infty$ have no influence on the propagation loss. The propagation loss depend on values of electrical conductivities σ_c and thickness d_c usually used.

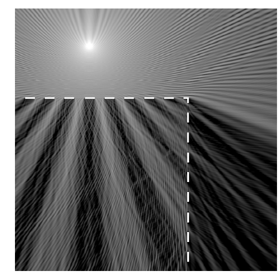
Next, the influence of windows is described. As shown in Fig. 2(c) and Fig. 3(b), the relatively strong waves penetrate the windows of a building. Therefore, the windows have a great influence on the propagation loss.



(a) $d_c = \infty$

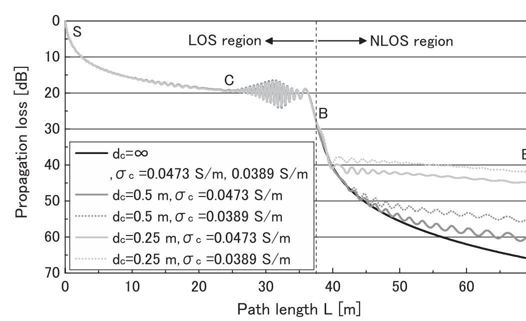


(b) $d_c = 0.25$ m

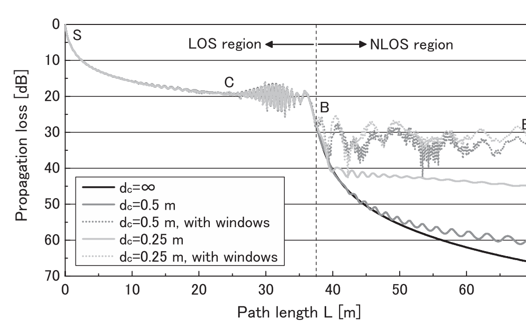


(c) $d_c = 0.25$ m, with windows

Fig. 2 Electric field distribution for the case of one building, where wall conductivity $\sigma_c = 0.0473$ S/m.



(a)Effect of electrical conductivity and thickness of wall.



(b)Effect of windows, where wall conductivity $\sigma_c = 0.0473$ S/m.

Fig. 3 Propagation loss on the path SCBE for the case of one building.

3. Propagation Characteristics of Electromagnetic Waves at an Intersection

Next, the propagation characteristics at an intersection have been investigated. The analyses of propagation loss and the quasi-impulse response were carried out in the section. In the analyses of propagation loss, pedestrians were newly considered here.

3.1 Propagation Loss Analysis

Figure 4 shows an intersection, where four buildings and pedestrians are located, respectively. Points P_1 and P_2 correspond to the observation locations for the quasi-impulse response analyses. In the two-dimensional space, the influence of electric constants of pedestrian on the propagation characteristics seems to be larger than one in the three-dimensional space. For this reason, as an example, the electric constants of pedestrian were assumed to be $\varepsilon_{rp} = 3.0$ and $\sigma_p = 0.05$ S/m as approximately 1/10 of the realistic values. The realistic values of equivalent electric constants of pedestrians are $\varepsilon_{rp} = 37.6$ and $\sigma_p = 0.61$ S/m which can be obtained as 2/3 of the values of human muscle [15]. The shapes of pedestrians were assumed as circles with a radius $r_p = 0.12$ m. The other conditions were the same as for one building case.

Figure 5 shows the electric field distribution, Fig. 6 shows the propagation loss on the path SCBE, respectively.

Hereafter, we investigate the influences of electrical conductivities, thickness and windows of building wall, and pedestrians.

First, the influences of electrical conductivities and thickness of building wall are described. As shown in Fig. 6(a), the propagation loss as a whole does not depend on values of electrical conductivities σ_c and thickness d_c usually used.

Second, the influence of windows is described. As shown in Fig. 5(c) and Fig. 6(b), relatively strong waves penetrate the windows of a building similarly to one building case. However, the reflected waves from buildings located at opposite side are stronger than the penetrated waves at near the center of intersection. Therefore, the influence of windows on the propagation loss can be ignored near the center of intersection. In contrast, the influence of windows can not be ignored at far from the center of intersection.

Finally, the influence of pedestrians is described. As shown in Fig. 5(d) and Fig. 6(c), the electric field distribution are much changed by considering pedestrians. Furthermore, the propagation loss at the NLOS region is the largest in all cases. Therefore, the influence of pedestrians can not be ignored. From these results, it is predicted that the existing of pedestrians have a great influence in the three-dimensional case.

3.2 Quasi-Impulse Response Analysis

Strictly speaking, the analyses using the impulse waves should be carried out, but the FDTD method can not treat the pure impulse waves. For this reason, the analyses of quasi-impulse response were carried out by using the modulated gaussian pulse wave in the section. The modulated gaussian pulse wave with center frequency $f_c = 720$ MHz and half-power band width $f_0 = 60$ MHz was input to the point S.

The time response of relative received power and the power azimuth delay profile were observed on the points P_1 and P_2. The power azimuth delay profile were obtained by using the multiple signal classification (MUSIC) algorithm

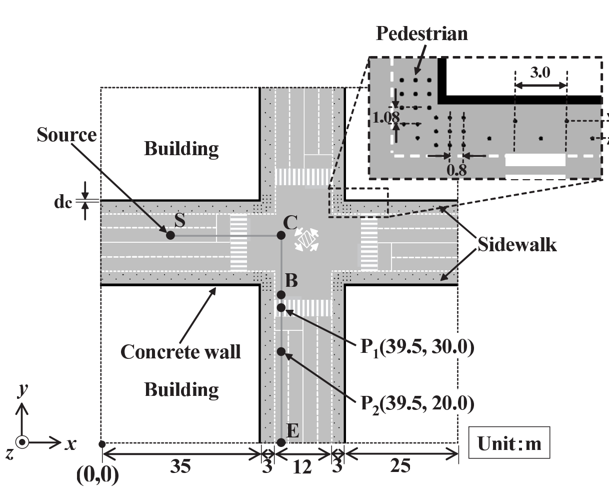
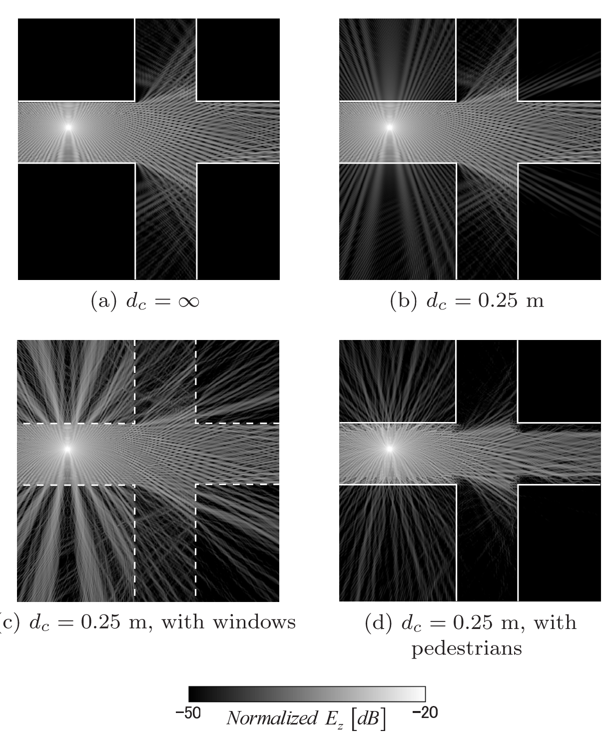


Fig. 4 An intersection.



(a) $d_c = \infty$

(b) $d_c = 0.25$ m

(c) $d_c = 0.25$ m, with windows

(d) $d_c = 0.25$ m, with pedestrians

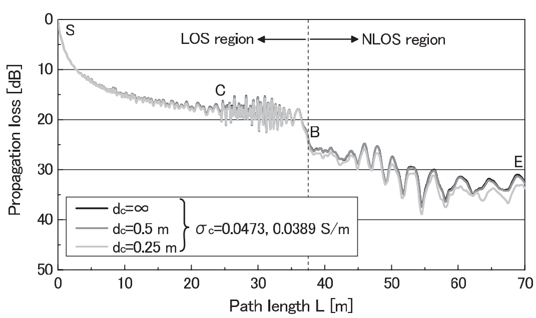
Fig. 5 Electric field distribution for the case of an intersection, where wall conductivity $\sigma_c = 0.0473$ S/m.

[10]. The elements of array antenna were lined in the x-direction at the observation points. The number of elements was five, and each distance was set to 8.0 mm.

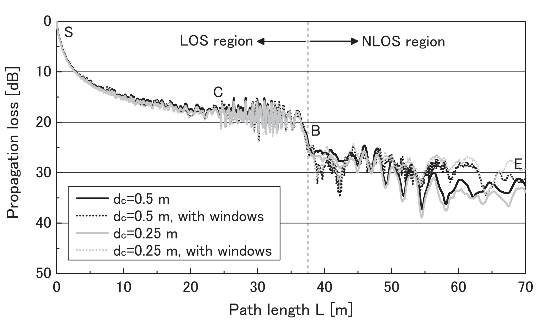
Figure 7 shows the instantaneous electric field distribution. The values are normalized by the maximum value on the point S. The ray tracing method can show the propagation path for each ray. In contrast, the FDTD method can provide us the spatial propagation characteristics for impulse response.

Figure 8 shows the time response of relative received power. The values are normalized by the maximum value on the point S.

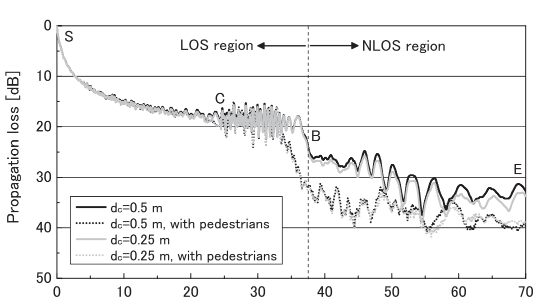
Figure 9 shows the power azimuth delay profile. The relative received power are normalized similarly to Fig. 8, and the arrival angle is measured from x-axis. As shown in Fig. 8 and Fig. 9, when considering thickness and windows of walls, pulse waves through a building are observed. Especially, in the case of that windows exist, many strong waves arrive from various directions.



(a)Effect of electrical conductivity and thickness of wall .

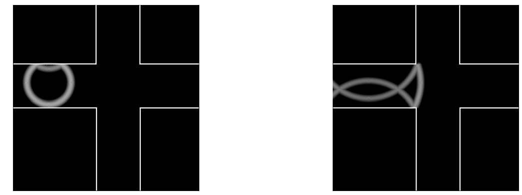


(b)Effect of windows.

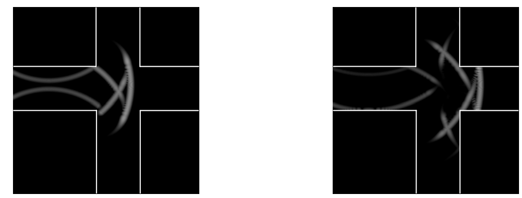


(c)Effect of pedestrians.

Fig. 6 Propagation loss on the path SCBE for the case of an intersection.

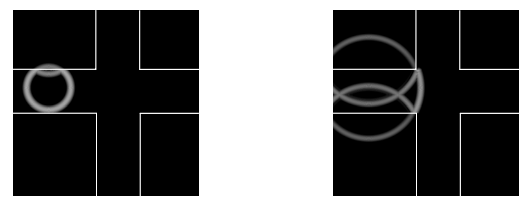


(a-1) $t = 42$ ns (a-2) $t = 83$ ns



(a-3) $t = 125$ ns (a-4) $t = 167$ ns

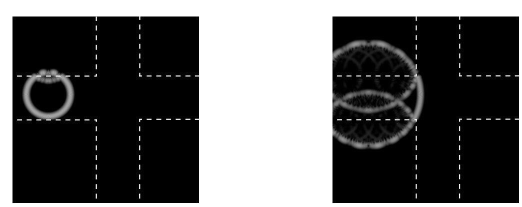
(a) $d_c = \infty$



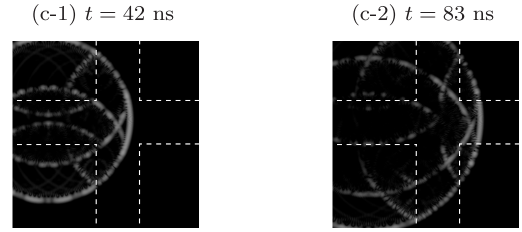
(b-1) $t = 42$ ns (b-2) $t = 83$ ns

(b-3) $t = 125$ ns (b-4) $t = 167$ ns

(b) $d_c = 0.25$ m



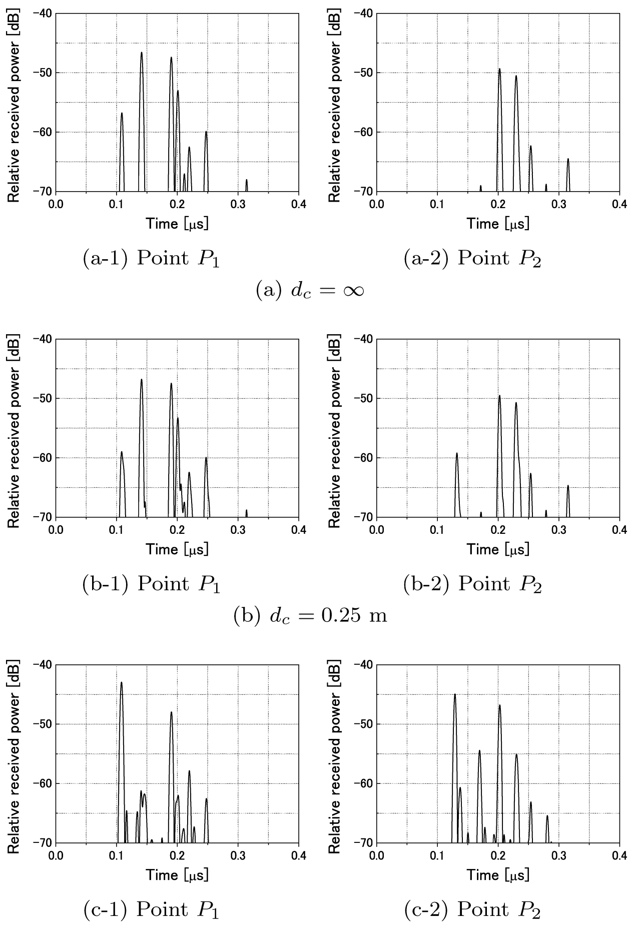
(c-1) $t = 42$ ns (c-2) $t = 83$ ns



(c-3) $t = 125$ ns (c-4) $t = 167$ ns

(c) $d_c = 0.25$ m, with windows

Fig. 7 Instantaneous electric field distribution for pulse wave input, where wall conductivity $\sigma_c = 0.0473$ S/m.



(a-1) Point P_1 (a-2) Point P_2

(a) $d_c = \infty$

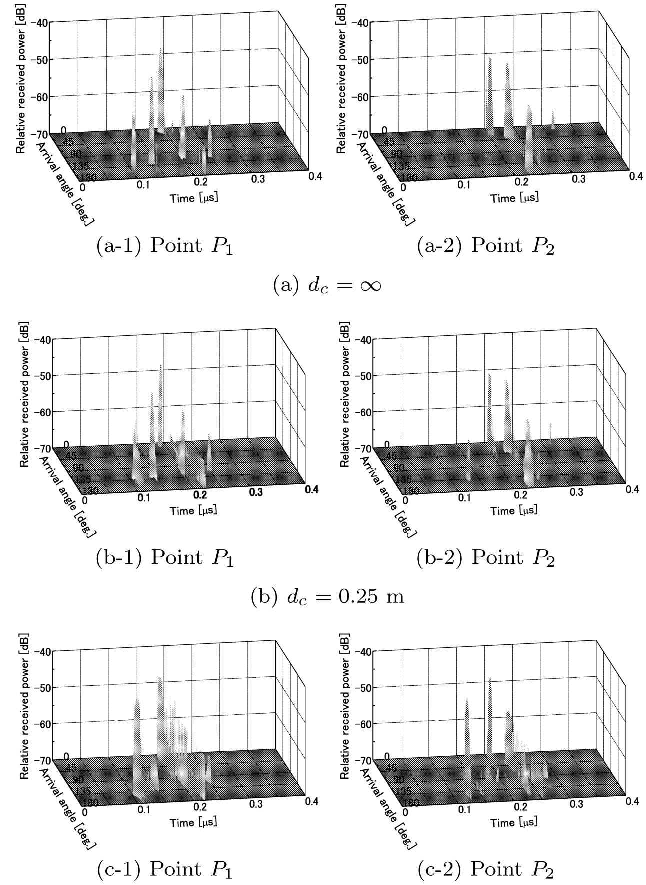
(b-1) Point P_1 (b-2) Point P_2

(b) $d_c = 0.25$ m

(c-1) Point P_1 (c-2) Point P_2

(c) $d_c = 0.25$ m, with windows

Fig. 8 Quasi-impulse response of relative received power, where wall conductivity σ_c = 0.0473 S/m.



(a-1) Point P_1 (a-2) Point P_2

(a) $d_c = \infty$

(b-1) Point P_1 (b-2) Point P_2

(b) $d_c = 0.25$ m

(c-1) Point P_1 (c-2) Point P_2

(c) $d_c = 0.25$ m, with windows

Fig. 9 Power azimuth delay profile, where wall conductivity σ_c = 0.0473 S/m.

4. Conclusion

This paper shows that the FDTD method can be applied to the analyses of propagation characteristics in 700 MHz band at an intersection for the first time. We investigated the propagation characteristics considering the electrical conductivities, thickness and windwos of buildings wall and pedestrians by using the FDTD method. As a result, following new knowledge are obtained; 1) The reflected waves from buildings located at opposite side are dominant near the center of intersection, 2) the electrical conductivities and thickness of building wall usually used have a slight influence, 3) the windows of building have a relatively great influence the NLOS region far from the center of intersection, 4) the pedestrians on the sidewalk have a great influence on the propagation characteristics.

In the future, we will investigate the propagation characteristics taking account of the ground, antennas and vehicles in the three-dimensional space. Finally, we should derive an approximate equation of propagation loss considering the source locations.

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