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SCATTERING AND ATTENUATION CHARACTERISTICS OF MICROWAVE AND MILLIMETER WAVE DUE TO RAINFALL FOR ITS AND WEATHER MEASUREMENT SYSTEM

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1. Introduction

The characteristics of electromagnetic scattering and absorption have been studied for long time and are still paid much attention to improve the accuracy of estimated specific attenuation by rain. Recently, strong demand for intelligent transport systems, satellite broadcasting system and weather measurement system, which use frequency higher than 20GHz, are raised. Rain measurement system using microwave and millimeter wave is very significantly important for disaster prevention system to foresee and prevent the occurrence of disasters and for the sensor of ITS to support safe and automatic driving. Therefore, the study for the prediction of rain attenuation has become more significant to design these application systems properly. In this study, rain region is modeled as random medium and propagation of electromagnetic wave is analyzed by FDTD method. FDTD analysis demonstrates the dynamic characteristics of wave scattering and absorption phenomena. As a result, specific attenuation on various rainfall rates are presented and discussed.

2. FDTD analysis of electromagnetic scattering and absorption in rain region

Electromagnetic scattering and absorption characteristics due to random rainfall are very important information for ITS and weather measurement systems. These characteristics can be numerically analyzed by computer simulation. In this paper, electromagnetic propagation characteristics are calculated by FDTD method. The analysis model of rain attenuation ($z_0^{(0)} \le z \le z_3^{(0)}$) is shown in Fig.1. The volume of total analysis region is defined as $\ell_X = \ell_Y$ =0.3m, $\ell_{\max}$ =1.16m. Total analysis region is divided into small regions whose length of z-direction ℓ_Z = 0.36m. Fig. 2 shows the analysis region for successive segmented FDTD method. Raindrops are distributed randomly in the volume V=$\ell_X \ell_Y \ell$ where ℓ=1.1m which is the propagation distance in rain region. The incident wave is Gaussian beam of frequency 20GHz radiated from the aperture S_0 located at z=0, whose dimension is a×b, a=b=10λ=0.15m. The intensity of electric field is observed on the observation plane S_{obs} located at z=l, to obtain the propagation loss per distance l in rain region.

The incident wave is given by the following equation,

$$E_y^{inc}(x,y,0,t) = E_0 \exp\left\{-\left(\frac{x-x_0}{w_x}\right)^2\right\} \exp\left\{-\left(\frac{y-y_0}{w_y}\right)^2\right\} \exp\left(-\left(\frac{t-t_0}{w_t}\right)^2\right) \sin(2\pi f t - \beta z)\Big]_{z=0} \quad (1)$$

$$H_x^{inc}(x,y,0,t) = -\frac{E_y^{inc}(x,y,0,t)}{Z_0} \quad (2)$$

where f=20GHz, $\beta = 2\pi/\lambda$, $x_0 = y_0 =$ 0.15m, $w_x = w_y = 2\lambda =$ 0.03m, t_0=0.15ns, w_t=0.06ns, E_0=1V/m, Z_0 is the intrinsic impedance of free space. Fig. 3 shows the spatial distribution of incident field and the time waveform is shown Fig. 4. In the first analysis region ($z_0^{(0)} \le z \le z_3^{(0)}$), $z_0^{(0)}$=0, $z_0^{(1)}$=0.1, $z_0^{(2)}$ =0.2, $z_0^{(3)}$ =0.3m. When the incident wave packet has entered in the region ($z_2^{(i)} \le z \le z_3^{(i)}, i = 0,1,2\cdots$), the electromagnetic field of wave packet is copied into the next analysis region ($z_0^{(i+1)} \le z \le z_1^{(i+1)}$) as the initial condition. So relations of z coordinate between i-th analysis region and (i+1)-th analysis region are $z_2^{(i)} = z_0^{(i+1)}$ and $z_3^{(i)} = z_1^{(i+1)}$. In FDTD, x-component of electric field is calculated by

$$E_x^{n+1}(i,j,k) = C_1 E_x^n(i,j,k) + C_2 \{H_x^{n+1/2}(i,j,k) - H_x^{n+1/2}(i,j,k-1) - H_z^{n+1/2}(i,j,k) + H_z^{n+1/2}(i-1,j,k)\} \quad (3)$$

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where, $C_1 = \dfrac{1-\sigma\Delta t/(2\varepsilon)}{1+\sigma\Delta t/(2\varepsilon)}$, $C_2 = \dfrac{\Delta t}{1+\sigma\Delta t/(2\varepsilon)}$.

The size of raindrop is considered to be small compared with the wave-length and the dimension of raindrops is modeled as cubic whose length of one side is a(mm) since a cubic cell is used to divide the FDTD analysis region. In rain region, each raindrop has cubic dimension and the length of one side is denoted by a_i, one apex coordinate is represented by (x_i,y_i,z_i). The refractive index of raindrops is n_r=6.463-j2.81.

FDTD analysis demonstrates dynamic characteristics of scattering and absorption with distribution of raindrops in time domain. In FDTD analysis, $\Delta s = \lambda/15$=0.001m and $\Delta t =$ T/33.3= 1/(33.3f) =1.5ps are used as space increment and time increment respectively, where λ is the wavelength in free space, T=1/f is the time period of incident wave. These parameters satisfy the stability condition of FDTD calculation.

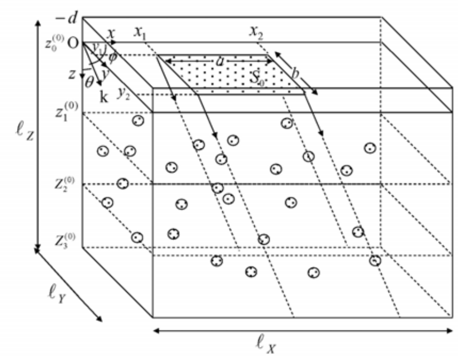


Fig. 1 Analysis region of FDTD

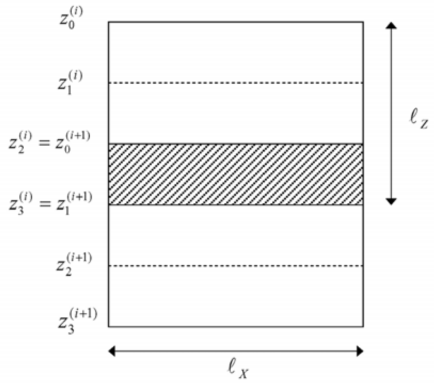


Fig. 2 Successive segmented FDTD

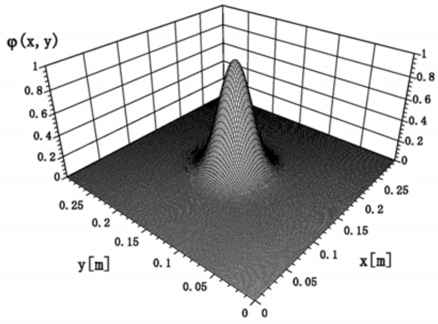


Fig. 3 Spatial distribution of incident electric field on the aperture S_0

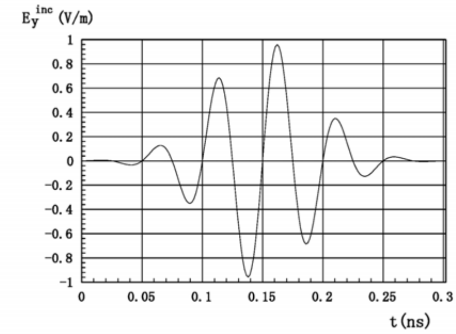


Fig. 4 Incident waveform

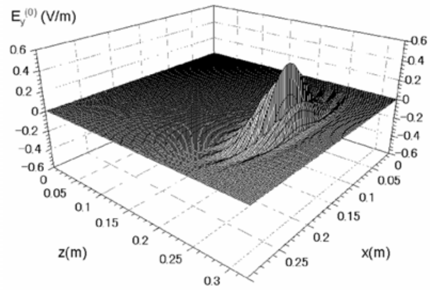
3. Scattering and absorption characteristics by FDTD analysis

To evaluate the rain attenuation characteristics, the analysis of free space is necessary to obtain criteria received signal $E_{obs}^{(0)}$. The result of free space is shown in Fig. 5. In Fig. 5 (a), (b) and (c), the wave front of wave packet reaches at z=ct=0.3, 0.6 and 1.08m, respectively. Fig. 5(d) shows the received signal on S_{obs} at z=ℓ=1.1m. A result of random medium is shown in Fig. 6. A random medium in Fig. 6 (a) is generated by giving raindrop size from one to two millimeters. The number of raindrops in rain region is given by N = 114. The rain rate R (mm/h) can be obtained by R=vtN'$\overline{a}^3\,10^{-6}$, where $\overline{a}$ (mm) is the average size of raindrops, v (m/s) is the terminal velocity of raindrops and assumed to be $4\sqrt{\overline{a}}$, t is 3600 (sec), N'=N/V is the number of raindrops per unit volume, where V=$\ell_X \ell_Y \ell$=0.099m^3 is the total volume of analysis region. From the above-mentioned argument, the medium of Fig. 4 corresponds to R=20mm/h. Fig. 7 shows the result of random medium at R=40mm/h. Random parameters of distributed raindrops for these random media are shown in Table 1 and 2. Fig. 7(d) shows that transmitted wave packet is attenuated strongly by heavy rain. The specific attenuation is obtained by

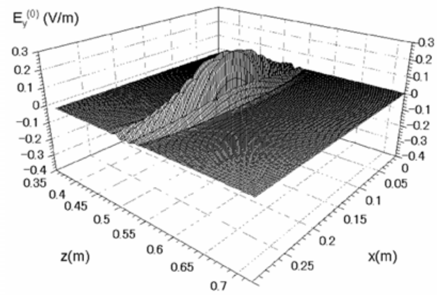
$$A = \alpha \cdot 10^3/\ell \quad \text{(dB/km)} \qquad (4)$$

$$\alpha = 20\log_{10}\left|\frac{\mathrm{Max}(|E_{obs}|)}{\mathrm{Max}(|E_{obs}^{(0)}|)}\right| \qquad (5)$$

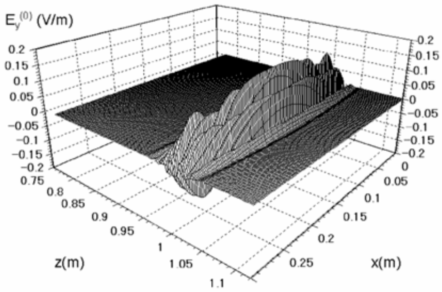
where α is the loss per propagated distance ℓ. From our analysis, A=0.64 and 9.62 are obtained at R=20 and 40, respectively. By comparing with the result of other experimental study, attenuation at R



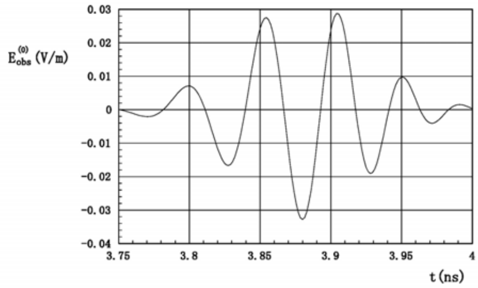
(a) Electric field after 1ns ($z_0^{(0)}$ =0, $z_3^{(0)}$=0.3m)



(b)Electric field after 2ns ($z_0^{(2)}$ =0.4, $z_3^{(2)}$=0.7m)

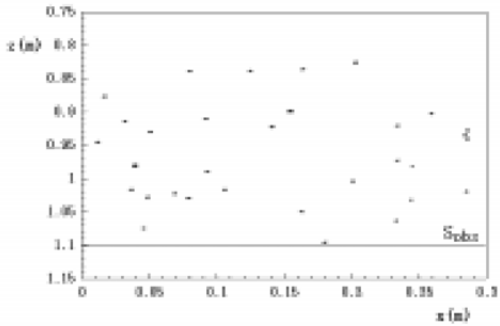


(c) Electric field after 3.6ns ($z_0^{(4)}$ =0.8, $z_3^{(4)}$=1.1m)

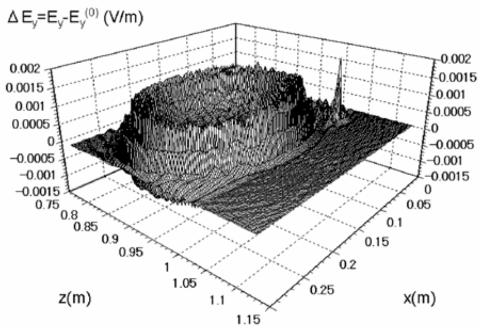


(d) Received signal at the observing plane S_{obs}

Fig. 5 Wave propagation in free space by FDTD analysis

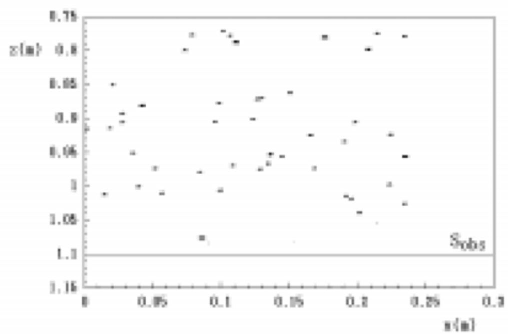


(a) Cross sectional view of raindrop distribution ($z_0^{(4)}$=0.8, $z_3^{(4)}$=1.1)

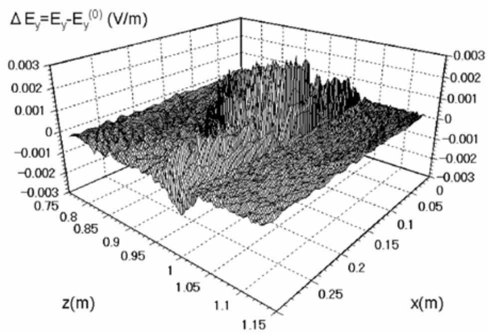


(b) Difference of electric field ΔEy after 3.6 ns

Fig. 6 Wave scattering and absorption in rain (R=20mm/h, N=114, a_i=1-2mm)



(a) Cross sectional view of raindrop distribution ($z_0^{(4)}$=0.8, $z_3^{(4)}$=1.1m)



(b) Difference of electric field ΔEy after 3.6 ns

Fig. 7 Wave scattering and absorption in rain (R=40mm/h, N=143, a_i=1-3mm)

=40 is considered to be high. Based on these FDTD analyses, statistical characteristics of electromagnetic propagation, such as average field intensities and field correlation are derived by statistical data of rainfalls, such as average and correlation of raindrop's size and position.

Table 1 Distribution of raindrops (R=20mm/h)

i	a_i(mm)	x_i(m)	y_i(m)	z_i(m)
1	2.0	0.154	0.157	0.899
2	1.0	0.204	0.229	0.134
3	2.0	0.250	0.193	0.321
⋮	⋮	⋮	⋮	⋮
113	1.0	0.234	0.284	0.921
114	1.0	0.155	0.149	0.256
Max	2.0	0.295	0.297	1.096
Min	1.0	0.003	0.001	0.100
$E[a_i]$	1.03			
$Va[a_i]$	0			

Table 2 Distribution of raindrops (R=40mm/h)

i	a_i(mm)	x_i(m)	y_i(m)	z_i(m)
1	1.0	0.154	0.160	1.084
2	1.0	0.013	0.059	0.423
3	1.0	0.203	0.226	0.366
⋮	⋮	⋮	⋮	⋮
142	1.0	0.199	0.043	0.906
143	1.0	0.208	0.131	0.219
Max	3.0	0.295	0.294	1.085
Min	1.0	0.002	0.000	0.111
$E[a_i]$	1.18			
$Va[a_i]$	0			

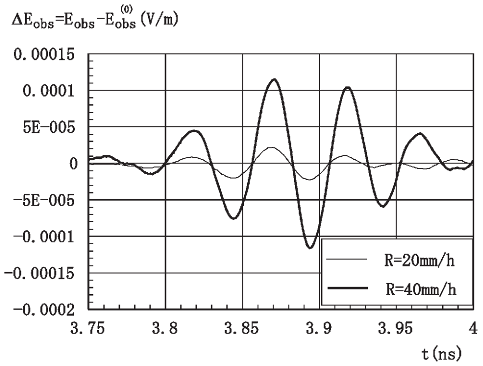


Fig. 8 Received signal at the observing plane S_{obs} in rain

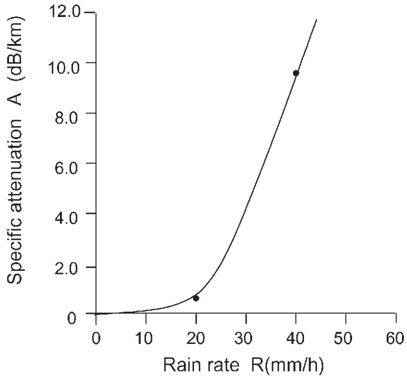


Fig. 9 Specific rain attenuation by FDTD

4. Conclusions

In this paper, FDTD method is applied to obtain the characteristics of wave scattering and attenuation those are important for designing the communication and measurement system which utilize electromagnetic wave. Rain region is treated as random media. Scattering and absorption phenomenon is evaluated numerically. To investigate the accuracy of estimation, it is necessary to perform the simulation under various rain rate conditions.

References

[1] Laws J.O. and Parsons D.A., "The relation of raindrop-size to intensity", Trans. Amer. Geophys. Union, vol.24, pp.452-460 (1943).

[2] T. Oguchi: "Electromagnetic wave propagation and scattering in rain and other hydrometers", IEEE Proc., Vol. 71, pp. 1029-1078 (1983).

[3] Le-Wei Li, Pang-Shyan Kooi, Mook-Seng Leong, Tat-Soon Yeo and Min-Zhan Gao, "Microwave Attenuation by Realistically Distorted Raindrops: Part I-Theory", IEEE Trans. Antennas & Propagat., Vol.43, No.8, pp.811-822 (1995).

[4] ——— ,"Microwave Attenuation by Realistically Distorted Raindrops: Part II-Predictions", IEEE Trans. Antennas & Propagat., Vol.43, No.8, pp.823-828 (1995).

[5] Der-Phone Lin and Hsing-Yi Chen: "An Empirical Formula for the Prediction of Rain Attenuation in Frequency Range 0.6-100GHz", IEEE Trans. Antennas & Propagat., Vol.50, No. 4, pp.545-551 (2002).

[6] Y. Miyazaki, J. Sonoda, and Y. Jonori: "Statistical Analysis of Electromagnetic Scattering of Buried Objects in Random Media Using FD-TD Method", Trans. IEE of Japan, Vol.117-C, No.1, pp.35-41 (1997).

[7] Y. Yamamoto, H. Ozo, and Y. Miyazaki: "Detection Characteristics Using Simulation Experiments on Subsurface Radar in Scale-Down Model", Trans. IEE Japan, Vol. 119-C, No.1, pp.91-96 (1999).

[8] K. Takahashi and Y. Miyazaki : " Analysis of Scattering Characteristics of Subsurface Radar Pulse by Buried Object in Random Media using 3-Dimensional FDTD Method", Trans. IEE Japan, Vol.120-C, No.12, pp.1905-1912 (2000).