Analysis of Reflection and Scattering Characteristics at the 60GHz Frequency

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Abstract —**This paper presents the analysis result of reflection and scattering characteristics for propagation prediction at the 60GHz frequency. Because the millimeter wave band has very short wavelength within a few millimeter, the scattering characteristic is occurred by the small roughness of the surface of a wall on indoor environment. In addition, because the propagation characteristics appear differently by the surface roughness of mediums, the propagation prediction is very difficult. Therefore, the scattering characteristics according to the surface roughness should be analysed for accurate propagation prediction. To predict the propagation characteristics in the indoor environments, we should have studied changes in the accordance with the rough surface. This paper analyses the reflection and scattering characteristics by the surface roughness of mediums in millimeter wave band, and studies the method for applying to the propagation prediction.**

Keywords**—millimeter wave, scattering characteristic, reflection characteristic, surface roughness, ray-tracing**

I. INTRODUCTION

Recently, the demand for high data rate and large capacity is increasing in the millimeter wave band. Among them, 60GHz frequency is a good candidate for wide-band wireless communications in the indoor wireless environments. A communication technique for low-frequency efficiency can be easily used to construct broadband communication in Multiple Gigabit Wireless Systems (MGWS). Especially, short-range communication between a TV and set-top box for a practical use of the 60 GHz band was studied. In the past, there is no need for studies on the reflection and scattering of radio waves in the 60 GHz band because the communication range is very short. However, the communication range is gradually widening owing to advances in technology, and thus research on the reflection and scattering of radio waves is needed.

Generally, the reflection characteristic is determined based on the electrical characteristic of the medium, but the reflection characteristic is determined by the scattering characteristic when the surface roughness of the medium is larger than the wavelength. Also, to predict the propagation characteristics in various environments, the channel models by various measurements or physical channel models by ray tracing are necessary, but studies on these models are incomplete Therefore, the reflection characteristic of the rough surface should be analyzed for a more accurate analysis.

In this paper, we analyzed the reflection and scattering characteristics based on the surface roughness of mediums in the millimeter wave band, and studies a method for application to propagation prediction using a theoretical generalization of these characteristics

II. THE REFLECTION AND SCATTERING CHARACTERISTICS AT THE MILLIMETER WAVE BAND

Generally, a radio wave has reflection and penetration characteristics according to a change in the medium. In the case of reflection, the direction of the reflected wave can be predicted to some extent using Snell's law. However, the predictable direction of the reflection wave using Snell's law is only possible when the surface of the obstacle is very smooth and there is therefore no diffusion. Many researches on a rough surface have been conducted. These researches are very important for a performance verification of the propagation channel prediction model in ray tracing.

A. *Effective roughness (ER)*

For a study on the scattering algorithm, Italian V. D. Degli-Esposito and El-Sallabi applied the scattering effect using the face and volume of buildings in ray tracing. The ER model (or COST-273 scattering model) was proposed through these studies, and implemented for 3D-ray tracing.

First, the definition of the scattering coefficient is necessary in order to draw the scattering pattern in the ER model. The scattering coefficient is expressed based on the ratio between the incident electric field and scattering electric field about the scattering surface area.

$$S = \left.\frac{|\bar{E}_S|}{|\bar{E}_i|}\right|_{ds} . \quad (1)$$

According to this definition and the principle of the conservation of energy, the total power balance is as follows:

$$1 = \Gamma^2 R^2 + S^2 + P_p / P_i, \quad (2)$$

where the reflection coefficient is $\Gamma = |\overline{E}_R|/|\overline{E}_i|$, and R is the reflection attenuation coefficient by scattering. In addition, P_i is the incident power and P_p is the penetration power. Also, Γ is determined based on the Fresnel reflection coefficient, and P_i/P_p does not change significantly from the non-uniformity of walls or obstacles [18]. Therefore, equation (2) can be expressed again by assuming the ideal plane ($S = 0, R = 1$).

$$1 = \Gamma^2 + P_p / P_i. \tag{3}$$

Under this condition, the relation between equations (2) and (3) is as follows.

$$R \cong \sqrt{1 - \frac{S^2}{\Gamma^2}}. \tag{4}$$

The scattering coefficient of equation (4) has to satisfy the scattering power balance as follows:

$$\begin{aligned} S^2 \left|\overline{E}_i\right|^2 d\Omega_i r_i^2 &= \int_{2\pi} \left|\overline{E}_s\right|^2 d\Omega_s r_s^2 \\ &= \int_0^{\pi/2} \int_0^{2\pi} \left|\overline{E}_s\right|^2 r_s^2 \sin\theta_s d\theta_s d\phi_s, \end{aligned} \tag{5}$$

where Ω_i is the incident angle of the ray tube on the surface, r_i and r_s are the distance between the transmitter and the scattering surface, and between the receiving point and the scattering surface, respectively. The maximum scattering power E_{S0} can be calculated by applying the scattering pattern to equation (5). The scattering pattern is determined by the non-uniformity of the obstacle, and by the following two models.

1) Lambertian Model

The maximum power of the scattering wave in the Lambertian model always exists vertically in an obstacle, and the scattering pattern is as follows:

$$\left|\overline{E}_s\right|^2 = E_{S0}^2 \cos\theta_s. \tag{6}$$

Thus, if the maximum power E_{S0} is applied to equation (6), the scattering pattern is as follows [20][21]:

$$E_{S0}^2 = \left(\frac{KS}{r_i r_s}\right)^2 \frac{\cos\theta_i \cos\theta_s}{\pi} dS, \tag{7}$$

where K is a constant determined by the incident wave.

2) Directive Model

In the directive model, it is assumed that the maximum electric field of the scattering wave is formed to the direction of the regular reflection in the scattering environment. According to this assumption, the scattering pattern of the directive model is as follows:

$$\left|\overline{E}_s\right|^2 = E_{S0}^2 \left(\frac{1 + \cos\psi_R}{2}\right)^{\alpha_R}, \tag{8}$$

where Ψ_R is the angle between the scattering wave and the regular reflection, and α_R is a parameter determining the beam width of the scattering wave. The maximum scattering power is calculated by substituting equation (8) with (5), as follows:

$$E_{S0}^2 = \left(\frac{KS}{r_i r_s}\right)^2 \frac{\cos\theta_i}{F_{\alpha_R}} dS, \tag{9}$$

where

$$F_{\alpha_R} = \frac{1}{2^{\alpha_R}} \sum_{j=0}^{\alpha_R} \binom{\alpha_R}{j} \cdot I_i, \tag{10}$$

$$I_j = \frac{2\pi}{j+1} \left[\cos\theta_i \sum_{w=0}^{\frac{j-1}{2}} \binom{2w}{2} \frac{\sin^{2w}\theta_i}{2^{2w}} \right]^{\left(\frac{1-(-1)^j}{2}\right)}. \tag{11}$$

B. Kirchhoff approximation (KA)

Many scattering theories regarding a rough surface have been studied for the solution suggestion of the scattering using an approximation of the boundary condition. The approximation methods vary, and the KA method is based on a Helmholtz integration using the boundary conditions. This method is generally known as the 'Kirchhoff method' or 'Method of Physical Optics (PO)'. The theory of the Kirchhoff general solution of the rough surface is very important because it is a basic theory to explain the scattering of the particular surface, such as a periodic or random area.

III. COMPARISON BETWEEN THEORETICAL ANALYSES USING KIRCHHOFF APPROXIMATION AND THE MEASUREMENT RESULTS

In this chapter, the scattering theory values of the millimeter wave band by the KA method mentioned in section II are drawn and compared with the measurement results.

A. The scattering characteristic of the rough surface

The rough surface can be divided into periodic and random structures. Figure 3 shows the geometric structure of incident and scattering waves. If the radio wave has incident angle θ_1 about the z-axis along the x-axis, it has elevation angle θ_2 in the x-z plane and azimuth angle θ_3 in the x-y plane, and is scattered. Under this condition, the scattering coefficient for a rough surface of a periodic structure is as follows:

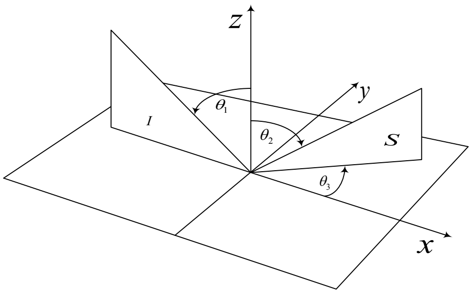


Figure 1. Mesurement system configuration

$$\rho = \frac{1}{4L\cos\theta_1}\int_{-L}^{L}\left(a\zeta' - b\right)e^{iv_x x + iv_z\zeta}dx. \tag{12}$$

In equation (9), the formulas that have to be additionally calculated are as follows:

$$\begin{aligned}\bar{v} &= k(\sin\theta_1 - \sin\theta_2)\overline{x_0} - k(\cos\theta_1 + \cos\theta_2)\overline{z_0} \\ &= v_x\overline{x_0} + v_z\overline{z_0}\end{aligned}, \tag{13}$$

$$\begin{aligned}a &= (1-R)\sin\theta_1 + (1+R)\sin\theta_2 \\ b &= (1+R)\cos\theta_2 - (1-R)\cos\theta_1.\end{aligned} \tag{14}$$

Equation (12) is a one-dimensional Kirchhoff general solution, and the scattering surface can be extended to two-dimensions using equation (13). Therefore, equation (15), which is the general solution of the one-dimensional rough surface, is expressed as follows:

$$\rho = \frac{1}{4XY\cos\theta_1}\int_{-X}^{X}\int_{-Y}^{Y}\left(a\zeta_x' + c\zeta_y' - b\right)e^{i\bar{v}\bar{r}}dxdy. \tag{16}$$

In the scattering analysis of a random surface, it is most important to determine the roughness of the surface to model the probability distribution and indicator variable. For the KA method, the characteristic of a random surface can be expressed through a deviation of the surface height and the surface correlation distance. In addition, how the number of reflections within the surface is considered is relevant to the accuracy of the modeling. Actually, one to an infinite number of reflections can occur on a random surface, and the more the reflections are analyzed, the more accurate the results will be. However, the greater the degree of the analysis is increased, the more the calculation complexity is increased exponentially. This paper applies a two-degree analysis to the KA method because the result is significantly accurate, even though only two-degree reflections are analyzed.

The scattering coefficient by a one-degree Kirchhoff is drawn using the cross section of the follow equations:

$$\sigma_{KA1} = \frac{2\pi k\cos\theta_s^{\,2} <|T_{KA1}|^2>}{L}, \tag{17}$$

$$\begin{aligned}<|T_{KA1}|^2> &= S(\theta_1,\theta_2)|R_1|^2|F|^2 \\ &\times \int dx_d\begin{pmatrix}\exp[-i(K-K_i)x_d - \sigma^2(K_z - K_{zi})^2] \\ \times\exp[<f_1 f_2>(K_z + K_{zi})^2 - 1]\end{pmatrix},\end{aligned} \tag{18}$$

where the cross section indicates the reflected area to the particular scattering angle in the total area.

The scattering coefficient by the two-degree Kirchhoff is determined by changing equation (17) as follows:

$$\sigma_{KA2} = \frac{2\pi k\cos\theta_s^{\,2} <|T_{KA2}|^2>}{L}, \tag{19}$$

$$\begin{aligned}<|T_{KA2}|^2> &= S(\theta_i)S(\theta_s)\int K_1 d\alpha \\ &\times\int K_1' d\alpha' <JJ^*> S_p(\alpha)S_p(\alpha').\end{aligned} \tag{20}$$

B. Measurement campaign and results

To predict propagation characteristic at the 60 GHz frequency, we are used KA approximation. KA approximation is given correlation on the rough surface of scattered signal. In this method, reflection characteristics of rough surface at the 60 GHz are composed of the variable of RMS height and correlation length.

Based on the above results, we made total 7 rough surfaces (2 periodic and 5 random samples). The Figure 2, it shows the measurement system configuration to analyse reflection characteristics on the rough surfaces.

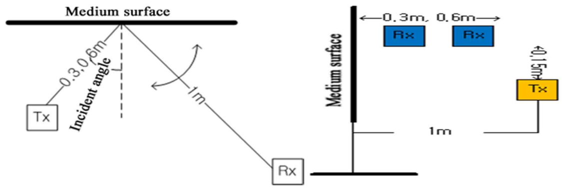
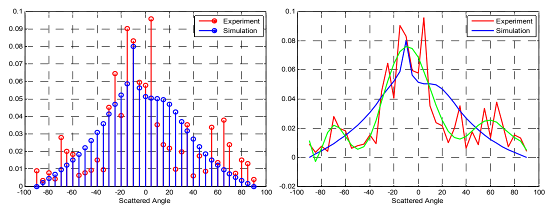


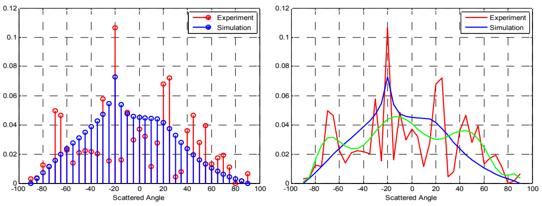
Figure 2. Mesurement system configuration

The carrier frequency was set to 60 GHz, and we were installed small HPBW horn antenna and rough surface in the stands. Measurements structures was Tx/Rx distance 0.15m, Rx/surface interval 1m, Tx/surface gap 0.3m/0.6m (2 kinds of measurement case). We measured reflection characteristics of rough surfaces in the 10°~80° incident angle(10° and 5 ° interval).

We compared with simulation and measurement results. The Figure 3 shows the results of analysis on the rough surfaces. The analysis of the entire we show only following two cases.



(a) 10 degrees in angle of incidence



(b) 20 degrees in angle of incidence

(Left: Simulation and measurement result,

Right: Simulation, measurement and curb fitting result)

Figure 3. Simulation and measurement results

C. Proposed propagation prediction method

To predict propagation characteristic at the 60 GHz frequency, we are used KA approximation. KA approximation is given correlation on the rough surface of scattered signal. In this method, reflection characteristics of rough surface at the 60 GHz are composed of the variable of RMS height and correlation length.

A method for ray-tracing in a wideband Gbyte Gbps communication system includes deriving scattering distribution characteristics of reflected signals. An electromagnetic wave scattered in an electromagnetic wave incident to an interface in the indoor environments. Average scattering power for the interface is calculated by the scattered electromagnetic wave. The propagation of the electromagnetic wave in the indoor area is analyzed based on the average scattering power. In the Figure 3, it shows the analysis process accordance with the rough surface scattering.

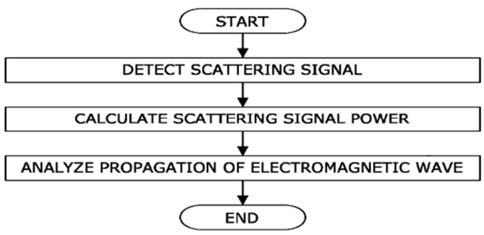
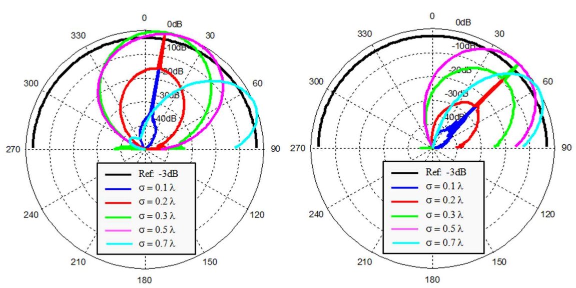


Figure 4. Simulation and measurement results

Figure 4 is diagrams schematically illustrating propagation of an electromagnetic wave in a radio wave system in accordance with the embodiment of the proposed method. The analysis of the entire we show only following two cases.



(a) Incident angle 10 degree (b) Incident angle 45 degree

Figure 5. Simulation and measurement results

IV. CONCLUSION

Propagation prediction is different flat surface and rough surface. It is depend on wave length from the surface roughness at the 60 GHz frequency. To improve these problems, this paper analysed the Kirchhoff solution of a rough surface, and derived the Kirchhoff solution of a random rough surface with a normal distribution function. Furthermore, to decrease the computing load using approximation and apply the proposed method to an indoor environment in the millimeter wave band, this paper proposed a scattering algorithm and analysed the scattering characteristics based on the surface roughness.

The results of this paper can increase the accuracy and reliability of ray tracing in a millimeter wave band. In addition, a performance improvement of the propagation prediction model can be achieved by using the frequency efficiently, and the proposed technique can be applied to the development of other millimeter wave bands.

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