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Rain Attenuation at Terahertz

S. Ishii[1], S. Sayama[1], K. Mizutani[2]

[1]Department of Communications Engineering, National Defense Academy, Yokosuka, Japan; [2]Department of Intelligent Interaction Technology, University of Tsukuba, Tsukuba, Japan.
Email:

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ABSTRACT

Rain attenuation values were calculated using empirical raindrop-size distributions, which were, Marshall-Palmer (M-P), Best, Polyakova-Shifrin (P-S) and Weibull raindrop-size distributions, and also calculated using a specific rain attenuation model for prediction methods recommended by ITU-R. Measurements of Terahertz wave taken at 313 *GHz* (0.96 *mm*) *were compared with our calculations. Results showed that the propagation experiment was in very good agreement with a calculation from the specific attenuation model for use in prediction methods by ITU-R.*

Keywords: *Rain Attenuation, Raindrop-Size Distribution, Terahertz Waves, P-S Distribution, Weibull Distribution, ITU-R*

1. Introduction

Recent advances in electronic and electro-optical Terahertz devices, and improvements in system technology, have stimulated in imaging and sensing applications in the security and non-destructive testing field [1].

Rain attenuation is one of important obstacle to overcome for imaging and sensing system to detect the hazardous things using Terahertz waves above 300 GHz because of its masking action. Raindrop-size distribution has been found to play an important role in monitoring rainfall and in predicting the rain attenuation. The rain attenuation is particularly severe and greatly dependent on various models of raindrop-size distribution in a Millimeter and Terahertz wave system.

2. Raindrop-Size Distribution

Many raindrop-size distributions have been proposed. Marshall and Palmer [2] proposed the following well-known empirical expression by fitting their data and the Laws and Parsons data. Their data was taken in Ottawa, Canada in 1946 using the filter paper method. The fit of this distribution to the experimental points was not very good for drops less than $D = 1$ mm.

$$\begin{aligned} N(D) &= N_0 e^{-\Lambda D} \\ N_0 &= 8000\,\mathrm{m}^{-3}\,\mathrm{mm}^{-1} \\ \Lambda &= 4.1R^{-0.21}\,\mathrm{mm}^{-1} \end{aligned} \quad (1)$$

where D is the diameter in mm, and R is the precipitation rate in mm/hr.

Best [3] proposed a drop-size distribution model after analyzing a large amount of experimental data in 1950. This is written as

$$\begin{aligned} N(D) &= \frac{13.5W}{\pi a^4}\left(\frac{D}{a}\right)^{-1.75} e^{-\left(\frac{D}{a}\right)^{2.25}} \\ W &= 67R^{0.846}\,\mathrm{m}^{-3}\mathrm{mm}^{3} \\ a &= 1.3R^{0.232}\mathrm{mm} \end{aligned} \quad (2)$$

Litovinov proposed a model [4] in 1957 and [5] in 1958 due to Polyakva and Shifrin (P-S) using the Russian data for all three types of rain. This model was also described by Krasyuk, Rozenberg and Chistyakov [6] in 1968 and by University of Tennessee [7] in 1975. It is one case of Gamma distribution proposed by Atlas and Ulbrich [8] in 1984:

$$N(D) = N_0 D^2 e^{-\Lambda D} \quad (3)$$

N_0 and Λ vary based on the rain types of thawing:

Type of Rain	N_0 m^{-3} mm^{-1}	Λ mm^{-1}
Thawing of Pellets (Hail)	64500 R$^{-0.5}$	6.95 R$^{-0.27}$
Thawing of Granular Snow (Sleet)	11750 R$^{-0.29}$	4.87 R$^{-0.2}$
Thawing of Non Granular Snow (Snow)	2820 R$^{-0.18}$	4.01 R$^{-0.19}$

Sekine and Lind [9] proposed a Weibull distribution in 1982 by using the FOA data (from the National Defence Research Institute) in Sweden:

$$N(D) = N_0 \frac{c}{b} \left(\frac{D}{b}\right)^{c-1} e^{-(\frac{D}{b})^c}$$

$$N_0 = 1000\text{m}^{-3} \qquad (4)$$

$$b = 0.26R^{0.44}\text{mm}$$

$$c = 0.95R^{0.14}$$

This distribution is retained for microwave applications for drizzle, widespread rain, and shower rain cases [10-22].

3. Rain Attenuation

3.1. Calculations

Rain attenuation was calculated by using three types of raindrop-size distributions and a specific attenuation model for use in prediction method recommended by ITU-R.

For calculations using by raindrop-size distributions, rain specific attenuation A in dB/km is calculated by integrating all of the drop sizes as

$$A = 4.343 \int Q(D, \lambda, m) N(D) dD \qquad (5)$$

where Q is the attenuation cross section that is a function of the drop diameter D, the wavelength of the radio wave λ, and the complex refractive index of the water drop m, which is a function of the frequency and the temperature, and $N(D)$ is the drop-size distribution. The attenuation cross section Q is found by applying the classical scattering theory of Mie for a plane wave radiation to an absorbing sphere particle. According to Hulst [23], the cross section Q is expanded as

$$Q(D, \lambda, m) = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1) \operatorname{Re}\left[a_n + b_n\right] \qquad (6)$$

where a_n and b_n are the Mie scattering coefficients, which are complex functions of m, D, and λ. The complex refractive index of liquid water m was taken from [24]. The "Mie scattering coefficients" a_n and b_n in Equation (6) represent a contribution to the scattered field from the multi poles induced in the sphere, such as raindrops [23].

For calculation by using the recommended prediction methods by ITU-R [24], rain specific attenuation γ_R dB/km is obtained from the rain rate R mm/hr using the power-law relationship:

$$\gamma_R = kR^{\alpha} \qquad (7)$$

Values for the constants for the coefficients k and α are determined as functions of frequency, f GHz, in the range from 1 to 1000 GHz, from the equations which have been developed from curve-fitting to power-law coefficients derived from scattering calculations. It is shown in ITU-R P.838-3 [25].

3.2. Experiments and Computations

Figure 1 shows the results of 313 GHz under a rain fall rate of up to 12 mm/hr. This rain attenuation experiment was carried out by Babkin *et al.* [26] in the central part of the European part of the former Soviet Union during June and July 1969. The transmitter and receiver were spaced 1 km apart for the measurement.

For the calculations, rain drop-size distributions were used for M-P, Best, P-S and Weibull which were described in Equations (1), (2), (3) and (4) respectively, and specific attenuation model recommended by ITU-R was used for ITU-R which was described in Equation (7). M-P stands for Marshall and Palmer, P-S stands for Polyakva and Shifrin. Best, Weibull and ITU-R used the same name.

An experimental fit curve (shown by the broken line) derived from the raw data with triangular dots was described as $A = 1.53\ R^{0.638}$ [26].

The experimental data obtained from the rain attenuation was shown in **Figure 1**. It was compared with the calculations of rain attenuations. The departure of the empirical data and the calculated rain attenuations were estimated by calculating the root mean square error (rmse).

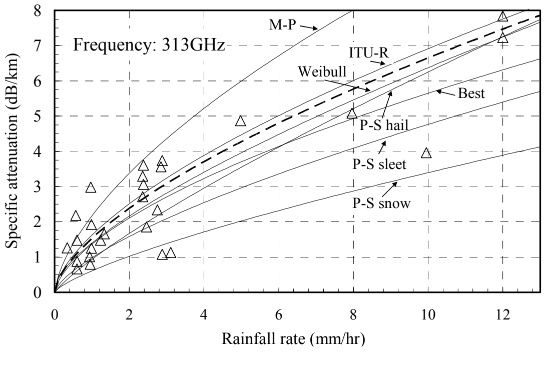

Figure 1. Comparison between calculations and measurements at 313 GHz.

Table 1. Values of rmse for various raindrop attenuations.

Calculations	TTU-T	Weibull	M-P	Best	P-S hail	P-S sleet	P-S snow
rmse	0.21	0.27	1.94	0.72	0.59	1.45	2.50

These were shown in **Table 1**. Result showed that the calculation from Weibull and ITU-R were very good agreement with the experimental data. And the best fit was the calculation from ITU-R with the smallest rmse.

4. Conclusions

Rain attenuation at 313 GHz was calculated by using four raindrop-size distributions and using ITU-R specific attenuation model. Calculated results were compared with propagation experiments under a rainfall intensity up to 12 mm/hr. Results showed that the propagation experiment was in very good agreement with the calculation from the specific attenuation model for use in prediction method by ITU-R provided the best fit for the experimental data. Finally, there is greater interest in the rain attenuation at Terahertz waves. An experiment on rain attenuation above 300 GHz at different rainfall rates with various raindrop-size distributions is desirable, especially at a higher rainfall intensity that may cause fatal damage to Terahertz applications.

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