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Prediction of Electromagnetic Waves Attenuation due to Rain in the Localities of Lithuania

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Introduction

The electromagnetic waves propagating through the atmosphere are attenuated by various factors. The free space losses, the excess losses due to the atmospheric gases, oxygen molecules, salt, and hydrometeors (rain, snowflakes, fog, and clouds, etc) consist make the losses of the propagating electromagnetic wave ("excess" in this context means in excess of free – space loss) [1]. The possible values of the electromagnetic waves attenuation due to the hydrometeors (the atmospheric particles of the water with a diameter of 1 μ or larger) must be estimated when new wireless telecommunication systems are projected.

The attenuation due to the rain (rain attenuation) is one of the most noticeable components of excess losses, especially at frequencies of 10 GHz and above. It can exceed that of all other sources of excess attenuation above 18 GHz [1]. The methods of the prediction of the rain attenuation can be grouped into two types: the physical (exact) models and the empirical ones. The empirical methods are used widely and frequently and very successfully. In determination of the rain attenuation, the main parameter of the rain is rain rate R expressed in mm/h. Gauges at the surface measure the accumulation of rain water (flux) in a known time interval and report the result as a rain rate (accumulation per unit time) averaged over some measurement or aggregation interval [2]. The evaluation of R – value is the first step of the rain attenuation prediction. The rain attenuation depends on the meteorological conditions in the localities. This is the reason to analyze the rain attenuation under concrete meteorological conditions (for example, in Latvia [3], in Malaysia [4], in India [5], and in Japan [6]).

First attempts to predict the rain attenuation under Lithuanian climate conditions are described in [7–12]. The significant differences in annual, seasonal, monthly, and daily amounts of rainfall are observed in localities of Lithuania. The noticeable local differences in rainfall amounts are characteristic of Lithuania as well. Not a single month in a year can be described as "an average month" in Lithuania. This is the reason to revise the suitability in Lithuania of the models derived under climatic conditions other than Lithuanian ones. In [7], the specific rain attenuation was determined by using well-known model and values of R starting from 0.25 mm/h up to 150 mm/h. The models using only annual amount of rainfall was analyzed in [8]; considering the peculiarities of Lithuanian climate, the change in Chebil's model [4] was made. Revised model for the electromagnetic waves attenuation due to rain medium in atmosphere is presented for the first time in [9]. Calculation of radio wave attenuation using annual precipitation and heavy rainfall data is described in [10]. Investigation of electromagnetic wave attenuation due to rain using rainfall data of long and short duration is presented in [11]. The importance of the integration time of rainfall measurements was mentioned. The rain rate value was expressed as function of rainfall amount in the months starting from May up to September. The rainfall data of the period of years starting from 1999 up to 2004 was analyzed in [11] and [12]. However, the showers with high rainfall rates were observed in the later years as well, and analysis of the rainfall data of this period was the objective of interest.

The main goals of this paper were to analyze the rainfall data measured in Lithuanian weather stations during the period of five years starting from 2003 up to 2007 in Vilnius, Kaunas, and Klaipėda, to determine the rain rate values for 0.01 percents of time, and to determine the specific rain attenuation.

The prediction of specific rain attenuation

One of the most accepted rain attenuation prediction methods is an empirical relationship between the specific rain attenuation α (dB/ km) and the rain rate R (mm/h) [1]

$$\alpha = aR^b, \tag{1}$$

where a and b are functions of frequency f and rain temperature t; the value of R is the value for an exceedance of 0.01% of the time for point rainfall rates with an integration time of one minute.

As it was mentioned above, the values of rain rate are expressed in mm/h. However, the time intervals between the readings of rainfall amount (integration time τ) should be much shorter in many cases. In [3] and [11], it was mentioned that the period of the time between the readings of the rainfall amounts values is a very important parameter. It can strongly change the value of R. Almost all the rain attenuation methods require "one – minute" $R_{(1\ \min)}$ (mm/h) value (the R–value for 0.01% of time obtained by using the rainfall amount value measured within the time interval of one minute and multiplied it by 60).

The shower with $R_{0.001\%}$ = 117.6 mm/h was registered in Vilnius in 2005. The duration of this shower was 5 minutes (about 0.001% of the time of the year). However, the value of R = 39.2 mm/h was obtained in the same rain event when the integration time was 15 minutes. It confirms propositions expressed in [3] and [11] that high values of R quasi hide away when long duration integration time is used.

In 2005 July 7, the rainfall amounts were analyzed in Vilnius. The values of R determined by using this rainfall amounts data are: 58.8 mm/h; 73.2 mm/h; 12.0 mm/h; 7.2 mm/h; 2.4 mm/h (with integration time τ = 10min); 48 mm/h (with integration time τ = 20min); 37.8 mm/h (with integration time τ = 30 min); 30.7 mm/h (with integration time τ = 50 min). It is clearly seen, that the highest value of R measured within 10 minutes integration time is approximately by 2.4 times higher than the R-value measured with 50 minutes integration time.

The rainfall amounts measured on the 18th of July 2005 in Vilnius show that the highest value of R determined by using this rainfall amounts data was 160.2 mm/h. It was measured with integration time Δt = 3 minutes. However, the R = 72.2 mm/h would be obtained in the same rain event when τ = 10 minutes. It was mentioned in [13], that although rainfall statistics have been collected at thousands of locations worldwide, for more than 100 years in many instances, data collection was oriented towards agricultural and hydrological purposes, for which annual, monthly, daily, and less commonly, 3– and 6–hourly totals were collected. This is the reason to use the models for conversion of R –value obtained by using the rainfall data measured with the integration time of long duration (τ minutes) $R_{(\tau\ \min)}$ into one – minute rain rate value ($R_{(1\ \min)}$. A review of models for estimation of 1 min rainfall rates for microwave attenuation calculations are presented in [13].

One of the conversion models of rain rates measured with the integration time of long duration (τ minutes) $R_{(\tau\ \min)}$ into one – minute rain rate value ($R_{(1\min)}$ was presented in [14]

$$R_{(1\min)} = \left(R_{(\tau\min)}\right)^d, \tag{2}$$

where $d = 0.987(\tau)^{0.061}$.

Presented in [11], model for determination of $R_{(1\ \min)}$ using rainfall amount data and considering the climatic peculiarities of the period investigated here can be written as

$$R_{(1\min)} = \frac{\ln\left(0.0144\frac{M_W}{t}\right)}{0.03}, \tag{3}$$

where M_w is amount of rainfall precipitated in May–September, and t is the number of hours in the year when the value of rain rate would be equal or exceeds this value.

Results and discussion

Almost all the rain attenuation determination methods require the value of $R_{0.01\%}$ (the R–value that would be equal or exceeded by 0.01% of the time of the year). We selected the highest values of rainfall amounts so that the summarized time periods of these rainfall events would come to 53 minutes (about 0.01% of the time of the year). We summarized the rainfall amounts that fell out during the period mentioned above. The average value of rain rate $R_{0.01\%}$ expressed in mm/h was obtained by dividing the rainfall amount into 53 minutes and multiplying by 60.

Table 1. The average values of rain rates $R_{0.01\%}$ determined in the localities of Lithuania in the period of years starting from 2003 up to 2007 when τ = 10 min

Locality	Vilnius	Kaunas	Klaipėda
$R_{0.01\%}$, mm/h	31.1	39.9	25.1

The average values of $R_{0.01\%}$ are presented in Table 1. In Vilnius, the average value of $R_{0.01\%}$ during the period of the years 2003–2007 is $R_{0.01\%}$ = 31.1 mm/h. The average value $R_{0.01\%}$ = 34.9 mm/h during the period of the years 1999–2004 in Vilnius was presented in [11] and it was by

3.8 mm higher than the value obtained here. The most of values of $R_{0.01\%}$ presented in Table 1 were obtained by measuring the rainfall amounts with $\tau = 10$ minutes. Therefore, by using equation (2) we converted average value of $R_{0.01\%}$ = 31.1 mm/h obtained with τ = 10 min in Vilnius into the value of $R_{0.01\%\ (1\ \text{min})}$ = 49.6 mm/h. It is by about 1.8 times higher than ITU (International Telecommunication Union) – value $R_{0.01\%}$ = 27 mm/h.

The values of $R_{0.01\%}$, in Kaunas and Klaipėda are presented in Table 1 as well. By using equation (2) we converted average value of $R_{0.01\%}$ = 39.9 mm/h obtained with τ = 10 min in Kaunas into the value of $R_{0.01\%\ (1\ \text{min})}$ = 65.9 mm/h. It is by 2.4 times higher than ITU–value $R_{0.01\%}$ = 27 mm/h [15]. The average value of $R_{0.01\%\ (1\ \text{min})}$ = 38.9 mm/h obtained in Klaipėda is by 1.6 times higher than ITU–value $R_{0.01\%}$= 25 mm/h ascribed to Klaipėda.

Table 2. The $R_{0.01\%\ (1\ \text{min})}$ values obtained are determined by using equation (3) and measured rainfall amount data

Localities	Vilnius	Kaunas	Klaipėda
$R_{0.01\%\ (1\ \text{min})}$, mm/h	44.2	55.0	43.8

The $R_{0.01\%\ (1\ \text{min})}$ data obtained by determining using equation (3) is presented in Table 2. The value $R_{0.01\%\ (1\ \text{min})}$= 49.6 mm/h mentioned above is by 5.4 mm/h higher than one $R_{0.01\%\ (1\ \text{min})}$ = 44.2 mm/h obtained here by determination using equation (3). The average value of $R_{0.01\%\ (1\ \text{min})}$ = 43.8 mm/h determined in Klaipėda by using equation (3) is by 4.9 mm/h higher than the value mentioned above. The error of measured meteorological data is about 10%. Therefore, we can conclude that the equation (3) can be used in determination of average $R_{0.01\%\ (1\ \text{min})}$–value. However, the “worst year” (the year with a heavy fall of rain) $R_{0.01\%\ (1\ \text{min})}$ – value might be higher.

In Kaunas, the value of rain rate of 55.0 mm/h was obtained by using equation (3). The discrepancy in the values of rain rates determined by various method can be explained by the fact that in Kaunas the driving rains and showers were observed in 2006 and 2007. Therefore, the analysis of rainfall data of the longer period must be carried out.

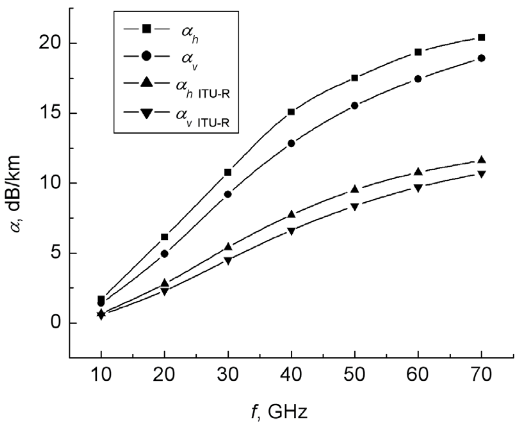

Fig. 1. The dependences of the specific rain attenuation α (α_h for horizontal polarization and α_v for vertical polarization) in Kaunas on the frequency f

In [15], it was pointed out that for once–per–year 20 min. duration maximum rainfall intensity determined in Vilnius meteorological station is 0.55 mm/min and one of 0.43 mm/min in Klaipėda. By using equation (2) we converted this data to “one – minute” R–values and obtained the values of 63 mm/h (in Vilnius) and 47.1 mm/h (in Klaipėda). However, these rain rates values were obtained for about 0.003% of time and they would be lower by 0.01% of time. It is confirmed by our results and the conclusion presented in [15], that lowest rain intensities occurred in Klaipėda in the majority of cases.

The dependences of the specific rain attenuation α (α_h for horizontal polarization and α_v for vertical polarization) were determined by using equation (1) when $R_{0.01\%\ (1\ \text{min})}$ = 55.0 mm/h and t = 20°C. They are presented in Fig. 1. $\alpha_{h\ \text{ITU-R}}$ and $\alpha_{v\ \text{ITU-R}}$ are the values determined using ITU–value ($R_{0.01\%}$ = 27 mm/h). The values of coefficients a and b as function of frequency f were taken from [1]. The values of α_h approximately by 1.2 times are higher than the values of α_v. It was noted in [1] that horizontally polarized waves suffer greater attenuation than vertically polarized waves because large raindrops are generally shaped as oblate spheroids and are aligned with the vertical rotation axis. The values of α determined by using ITU – value are by about 2 times lower than ones obtained using the value $R_{0.01\%\ (1\ \text{min})}$ = 55.0 mm/h.

Conclusions

The value of $R_{0.01\%(1\ \text{min})}$ = 55.0 mm/h (in Kaunas) obtained here is by about 2 times higher than ITU– value. The average value of $R_{0.01\%\ (1\ \text{min})}$ = 43.8 mm/h obtained in Klaipėda is lower than the ones in Vilnius and Kaunas and this fact is associated with the climatic peculiarities of the localities mentioned above.

The analysis of rainfall data of the longer period (of several decades) must be carried out and the model relation (3) can be revised according to this data. The values of α determined by using ITU – value are by about 2 times lower than ones obtained using the value $R_{0.01\%\ (1\ \text{min})}$ = 55.0 mm/h.

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The rain attenuation must be taken into account when new Telecommunication systems are projected. Attenuation due to rain depends on the rain rate. The rain rate values exceeded for 0.01% of the time obtained from the data of rainfall amount measured with one – minute intervals of the time must be used in calculation of rain attenuation. One – minute rain rate data are not always readily available from local weather agencies. Only the average annual, daily, hourly or ten – minutes precipitation amounts are available in many cases. The relations between the one – minute rain rate and the value obtained by using the rainfall amount data of longer duration may be used. The one – minute rain rate values in the localities of Lithuania were determined by using the rainfall amount values measured in the Lithuanian weather stations with ten – minutes integration time. They were compared with rain rate –value determined by using model presented in the previous paper and ITU – value. By using the values mentioned above and the known method the one – minute rain rate values were determined. The lowest values of rain rates were obtained in Klaipeda. Using the rain rate value obtained here and the ITU – value, the values of the specific rain attenuation have been determined. The specific rain attenuation values obtained using the local hydro meteorological data measured in Kaunas is by about 2 times higher than ones determined by using the ITU – rain rate – value. Ill. 1, bibl. 15, tabl. 2 (in English; abstracts in English and Lithuanian).

M. Tamošiūnaitė, S. Tamošiūnas, V. Daukšas, M. Tamošiūnienė, M. Žilinskas. Elektromagnetinių bangų silpnėjimo dėl lietaus įvertinimas Lietuvos vietovėse // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 9(105). – P. 9–12.

Projektuojant naujas radijo ryšio sistemas, būtina atsižvelgti į radijo signalo silpnėjimą dėl lietaus, o norint jį apskaičiuoti, reikia žinoti lietaus intensyvumą tam tikram metų laiko procentui, gautą matuojant, kiek kritulių iškrenta per minutę („vienos minutės“ vertę). Kai kritulių kiekis matuojamas ilgesniais laiko tarpais, „vienos minutės“ lietaus intensyvumo vertė gali būti gauta pasinaudojus žinomu sąryšiu tarp jos ir lietaus intensyvumo vertės, apskaičiuotos pasinaudojus ilgesnės trukmės matavimų rezultatais. „Vienos minutės“ lietaus intensyvumo vertės Lietuvos vietovėse apskaičiuotos pasinaudojus lietaus kritulių kiekio vertėmis, išmatuotomis 10 minučių laiko tarpais, ir pritaikius žinomą metodą. Gautos vertės palygintos su ITU (Tarptautinės telekomunikacijų sąjungos) rekomenduojama verte ir ankstesniame darbe pateiktu modeliu. Nustatyta, kad lietaus intensyvumo vertės Klaipėdoje yra mažesnės nei Kaune ir Vilniuje. Pasinaudojus apskaičiuotomis lietaus intensyvumo vertėmis, pagal žinomą sąryšį apskaičiuotas elektromagnetinės bangos silpnėjimas dėl lietaus Kaune. Savitojo silpnėjimo vertės, apskaičiuotos pasinaudojus vietine kritulių statistika, maždaug du kartus didesnės už ITU rekomenduojamą vertę. Il. 1, bibl. 15, lent. 2 (anglų kalba; santraukos anglų ir lietuvių k.).