UNIWERSYTET TECHNOLOGICZNO-PRZYRODNICZY
IM. JANA I JĘDRZEJA ŚNIADECKICH W BYDGOSZCZY
ZESZYTY NAUKOWE NR 262
ELEKTRONIKA I TELEKOMUNIKACJA 17 (2013), 5-16

TOTAL SIGNAL DEGRADATION DUE TO RAIN PRECIPITATION IN THE TROPOSPHERE IN THE AREA OF KIELCE CITY

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Summary. The article discusses the different effects contributing to the overall loss of signal propagation due to rain along Earth-space paths and analyses atmospheric attenuation. It deals with propagation concerns for satellite communications systems in the troposphere. The presence of rainfall has a considerable influence on the quality of microwaves links, especially due to absorption and reflection by raindrops, as rain acts as a rather strong source of noise. The discussion includes signal attenuation due to precipitation, an increase in noise due to precipitation and total signal degradation due to precipitation. In practice, statistical description is the only satisfactory way to show the results of modelling of microwave links in rainy weather in the area of Kielce city. The theoretical results were compared with real-time data (e.g. rain attenuation as a function of the rain rate). The data were used to determine the impact of rain intensity, polarization and radio waves frequency on the received satellite signal quality and finally to provide information about signal attenuation due to rain and suggests ways to improve the design of communication systems. The research results presented in the article can be useful to satellite communications engineers as they can improve the design and performance of satellite links and minimize the interruption or lack of communication between the terminal and the satellite to deliver the satellite services at the highest level.

Keywords: atmospheric attenuation, signal attenuation due to precipitation, an increase in noise due to precipitation, total signal degradation due to precipitation, the application of polynomial regressions, radio wave propagation in troposphere.

1. INTRODUCTION

After free-space path loss, one of the most important effect contributing to the overall loss of signal propagation along Earth-space paths is rain attenuation, which is attributable to absorption and scattering by raindrops. In the article, atmospheric losses are treated separately from the losses caused by adverse weather conditions, which are also atmospheric losses. In practice, rain attenuation is not predictable with very good precision and it is directly related to the properties of rainfall, frequencies and polarization of radio waves. The article covers attenuation of satellite links due to rain intensity, frequency and polarization of radio waves in the region of Kielce city in Poland in accordance with series of the ITU-R Recommendations in up-to-date. The long-term 1-min average rain-rate characteristics in this area is estimated to be 34,4 mm/h. All of data were used to estimate the impact of the rainfall intensity, polarization and radio wave frequency on the quality of received microwave satellite signals in Poland, especially in Kielce city [3]. In this article, the chosen experimental data are presented.

2. RESULT AND ANALYSIS

As you can see below (Fig. 1, Fig. 2), increase in the frequency bring about changes at the increase in the signal attenuation L_d, noise increase due to precipitation W_{sz} and total signal degradation *DND*, downlink degradation (sum of these components) for downlink for each type of signal polarization (horizontal and vertical, respectively) with a step of 1 GHz.

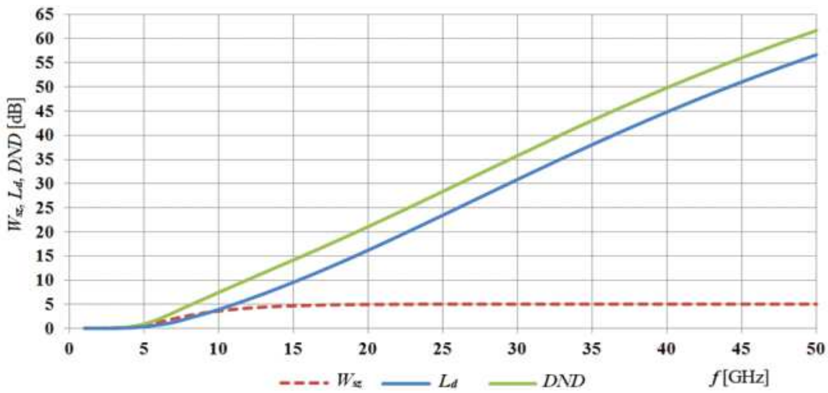

Fig. 1 . W_{sz}, L_d, *DND* [dB] vs frequency [GHz] (pol. H) [3]

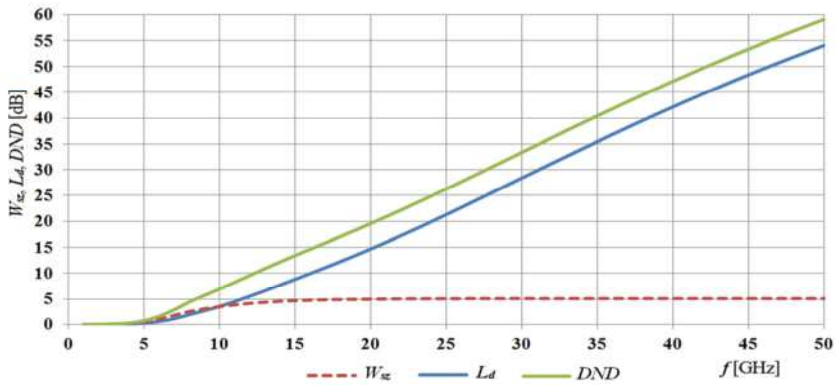

Fig. 2. W_{sz}, L_d, *DND* [dB] vs frequency [GHz] (pol. V) [3]

Although for over long distances, the atmosphere can be responsible for the polarization of a radio wave to fluctuate, the difference between horizontal and vertical becomes less significant. The results indicate (on the basis of the comparative results of the analysis of measurements for vertical and horizontal polarization) that the signal attenuation (with the same frequency and rainfall intensity) of horizontally polarized radio waves is greater than the signal attenuation of vertically polarized radio waves. Increase in the microwave signal frequency causes the increase in the difference in signal attenuation L_d between horizontally and vertically polarized radio waves. Generally, with the increase in the frequency, we can observe that the difference does not exceed 3 dB (max was approximately 2,67 dB in the frequency range from 39 GHz to 45 GHz and about 0-0,04 dB for the radio frequency exceeding 3 GHz). The procedures for the theory of correlation and regression allow – if it is necessary – to determine the analytical form of the regression function by estimating the parameters of this function for a given samples.

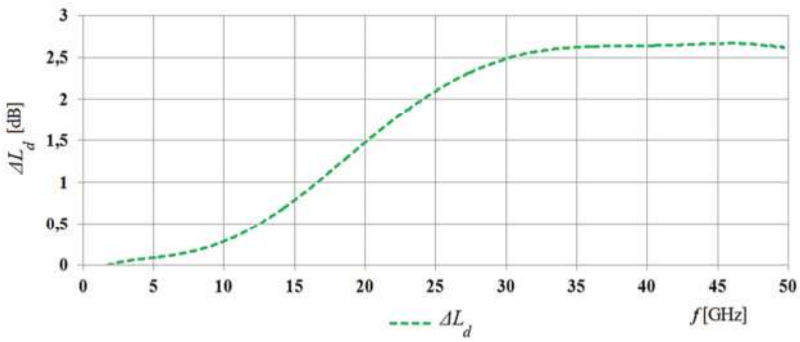

Fig. 3. Increase in L_d [dB] vs frequency [GHz] (pol. H-V) [3]

Figure 4 shows the relationship between the signal attenuation L_d [dB], increase in L_d [dB] for horizontally polarized radio waves related to vertically polarized radio waves, versus frequency to 35 GHz with a step of 10 MHz (0,01 GHz).

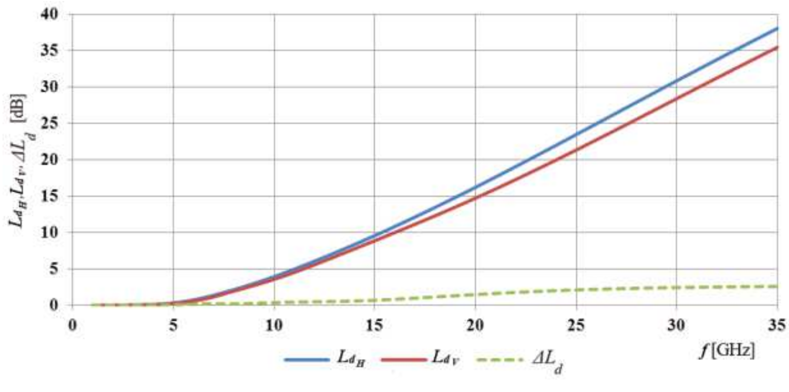

Fig. 4. L_d, increase in L_d [dB] vs frequency [GHz] (pol. H-V)

This article presents the application of polynomial regressions to provide information about signal attenuation due to rain. Each datum was processed using a bilinear interpolation scheme. The values of the signal attenuation L_d versus frequency for a selected rainfall statistics can be, as previously mentioned, analytically described by the principal component of regression model, which is the regression function. As a result of matrix operations, the predicted values of signal attenuation L_d were obtained versus frequency for both polarizations. The results are shown in Figure 5 (pol. H) and Figure 6 (pol. V).

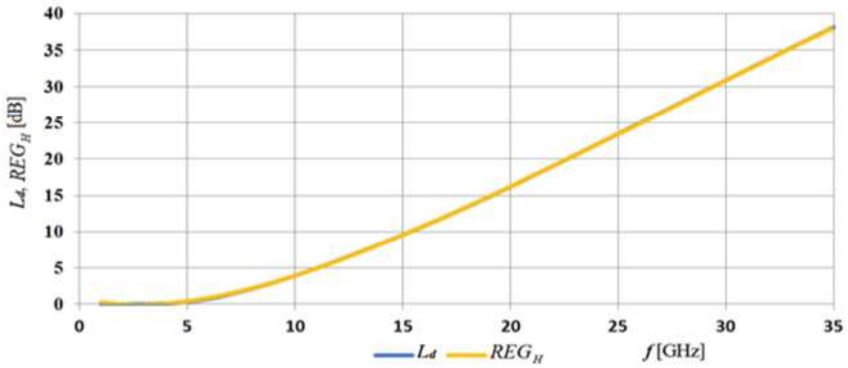

Fig. 5. REG_H [dB] vs frequency [GHz] (pol. H)

The proposed formulas of attenuation due to rain and the rain attenuation statistics in the area of Kielce city for horizontally polarized radio waves in the range of frequency of 1-35 GHz is the following (Fig. 5) [3]:

$$REG_H = -7{,}612 \cdot 10^{-9} f^6 - 4{,}933 \cdot 10^{-8} f^5 + 6{,}594 \cdot 10^{-5} f^4 - 4{,}287 \cdot 10^{-3} f^3 + 0{,}131 f^2 - 0{,}629 f^1 + 0{,}731$$

The maximum absolute value of attenuation calculated in agreement with the formula REG_H and the values obtained as the results of attenuation of radio waves in the area of Kielce city equals 0,22871 dB (for 1 GHz), whereas the minimum absolute value of attenuation is equal to from 0,00024 dB to 0,00079 dB (e.g. for 9,5 GHz, 16-16,2 GHz, 29,6 GHz, 30,1 GHz).

Similarly, the analogically determined relationship for vertically polarized radio waves versus frequency, whose takes into account the rain attenuation statistics in the area of Kielce city and changes in frequency with the step of 0,01 GHz, takes the formulas (Fig. 6) [3]:

$$REG_V = -4{,}967 \cdot 10^{-8} f^6 + 3{,}753 \cdot 10^{-6} f^5 - 5{,}066 \cdot 10^{-5} f^4 - 2{,}864 \cdot 10^{-3} f^3 + 0{,}122 f^2 - 0{,}637 f^1 + 0{,}779$$

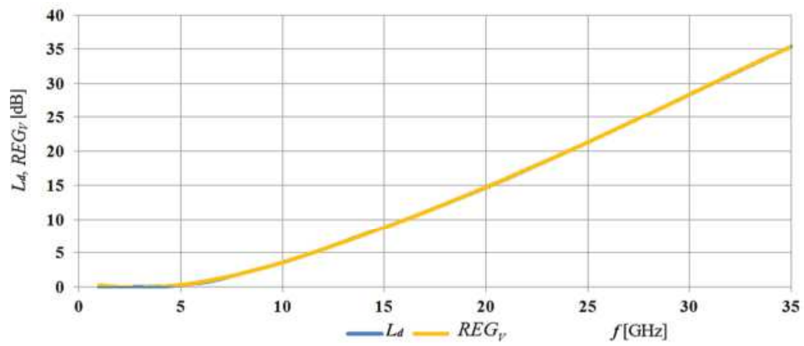

Fig. 6. REG_V [dB] vs frequency [GHz] (pol. V)

The maximum absolute value of attenuation calculated in agreement with the formula REG_V and the values obtained as the results of attenuation of radio waves in the area of Kielce city equals 0,26188 dB (for 1 GHz), but in most cases (89,44% of the absolute errors of approximation) it does not exceed the value of 0,1 dB. Because of the achieved results (Fig. 5, Fig. 6) whose correspond to the attenuation curves for horizontally polarized radio waves (Fig. 1) and vertically polarized radio waves (Fig. 2), it can be assumed that they provide a good estimate of actual values of L_d in the area of Kielce city (Fig. 7, comparatively).

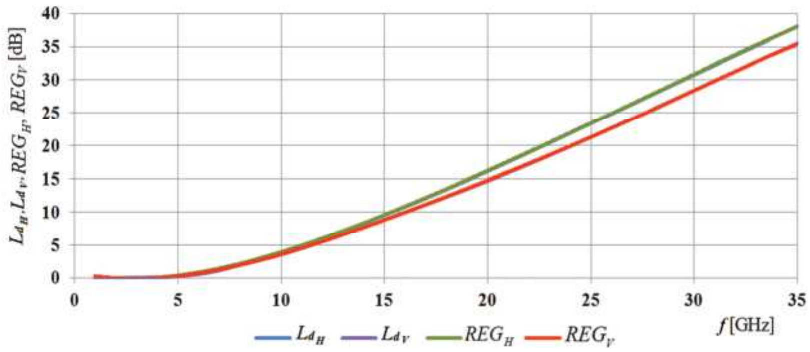

Fig. 7. L_{dH}, L_{dV}, REG_H, REG_V [dB] vs frequency [GHz] [3]

These estimates can be used to calculate the link budget analysis in the design of telecommunication systems by systems engineers as they can improve the design and performance of satellite links in adverse weather conditions and reduce the risk of interruption or lack of communication between the terminal and the satellite to deliver the satellite services at the highest level.

In practice, the signal attenuation L_d depends on the rainfall intensity as well as frequency and polarization. Because of climate changes whose affect both the mean and variability of climatic variables, the author in calculations take into account the limit values of attenuation L_d, which were predicted in Poland within 40 years (31 mm/h in Gorzow Wielkopolski and Gubin, 40,1 mm/h in Nowy Targ), additionally. This model uses bilinear interpolation to obtain an improved evaluation for a selected location from the grid neighbours and is based on many years of records collected by the European Space Agency (ESA). The Kielce University of Technology was the member of the international research project COST Action IC0802 – *Propagation Tools and Data for Integrated Telecommunication, Navigation and Earth Observation Systems*, whose main aim is to analyse the impact of weather conditions on the quality of satellite transmission [1,8]. So, the part of results of measurements which were realized in the Kielce University of Technology, as a Polish member of COST Action IC0802, is presented in this article.

The values of the signal attenuation L_d, which were obtained in this way, depending on the frequency and polarization of radio waves, in extreme cases, can illustrate the possible impact of the critical values of rainfall intensity on the extreme level of signal attenuation. Figure 8 and Figure 9 shows the diagram of the signal attenuation L_d, noise increase due to precipitation W_{sz} and total signal degradation *DND* (sum of these components) for downlink for each type of polarization (horizontally polarized radio waves and vertically polarized radio waves, respectively) in the case of the minimum rainfall intensity ($R_{0,01}$ = 31 mm/h), which was recorded in Poland within 40 years in Gorzow Wielkopolski and Gubin, versus frequency with a step of 1 GHz. Figure 11 and Figure 12 shows the diagram which was obtained for the horizontally and vertically polarized radio waves, respectively, in the case of the maximum rainfall intensity ($R_{0,01}$ = 40,1 mm/h), which was recorded in Poland in Nowy Targ within 40 years, versus frequency with a step of 1 GHz, too.

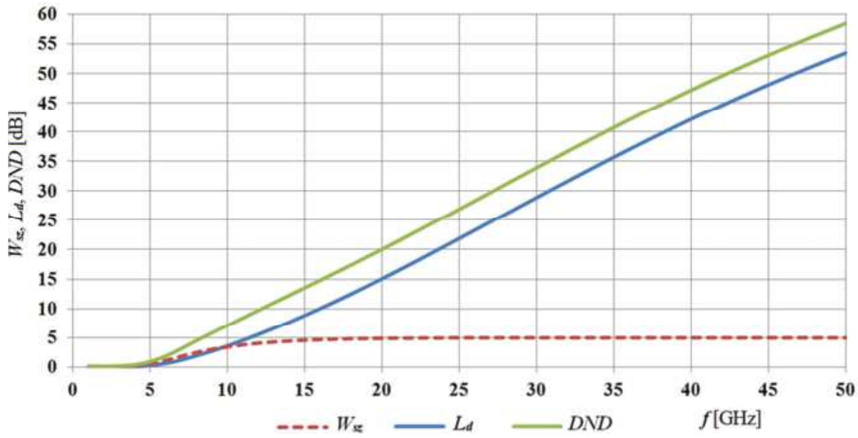

Fig. 8 . W_{sz}, L_d, *DND* [dB] vs frequency [GHz] (pol. H)

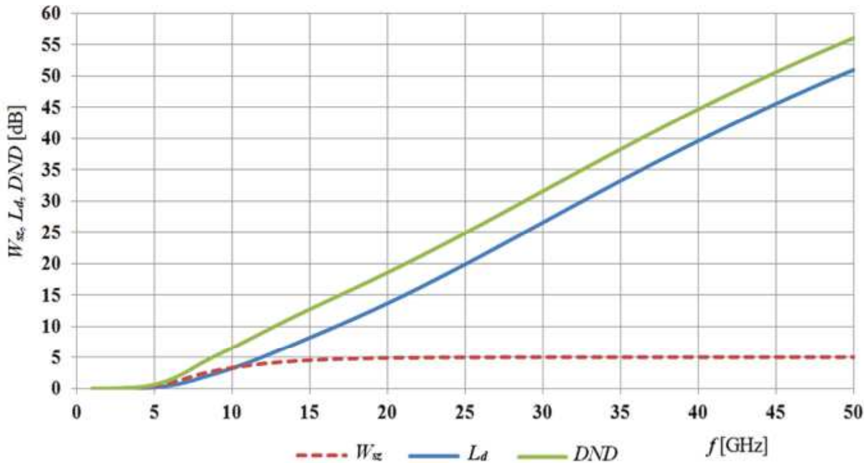

Fig. 9 . W_{sz}, L_d, *DND* [dB] vs frequency [GHz] (pol. V)

The results shown in Figure 10, directly and Figure 8, Figure 9, indirectly indicate that the maximum of increase in L_d [dB] between horizontally and vertically polarized radio waves (pol. H-V) versus frequency [GHz] in the case of Gorzow Wielkopolski i Gubin equals about 2,48 dB (above 40 GHz). Increase in the microwave signal frequency causes the increase in the difference between signal attenuation (Fig. 10). Generally, with the increase in the radio wave frequency we can observed that the difference exceeds 2 dB (above 26 GHz). Moreover, increase in L_d does not exceed 0,5 dB (below 13 GHz) and 1 dB (below 17 GHz).

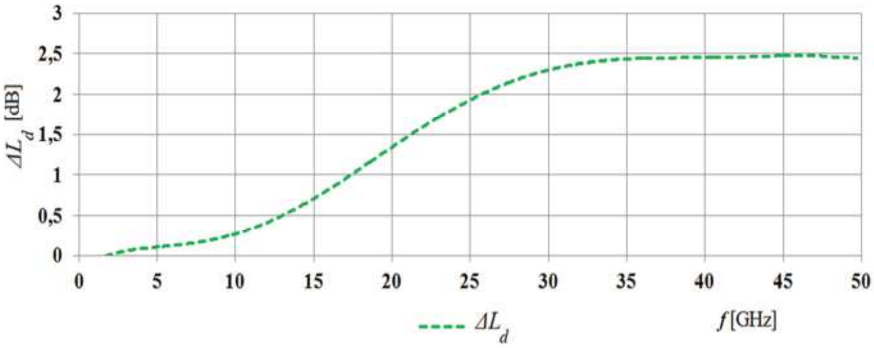

Fig. 10. Increase in L_d [dB] vs frequency [GHz] (pol. H-V)

The results obtained on the basis of the rainfall statistics from Nowy Targ seems to be the interested date on this background. The results shown in Figure 11 and Figure 12 indicate that the maximum of increase in L_d [dB] between horizontally and vertically polarized radio waves (pol. H-V) versus frequency [GHz] in the case of Nowy Targ is equal to 2,97 dB (for 41 GHz). With the increase in the frequency we can observe that the difference exceeds 2 dB (above 22 GHz) and 2,9 dB (above 35 GHz). Increase in L_d does not exceed 0,5 dB (below 10 GHz) and 1 dB (below 16 GHz) [see Fig. 13].

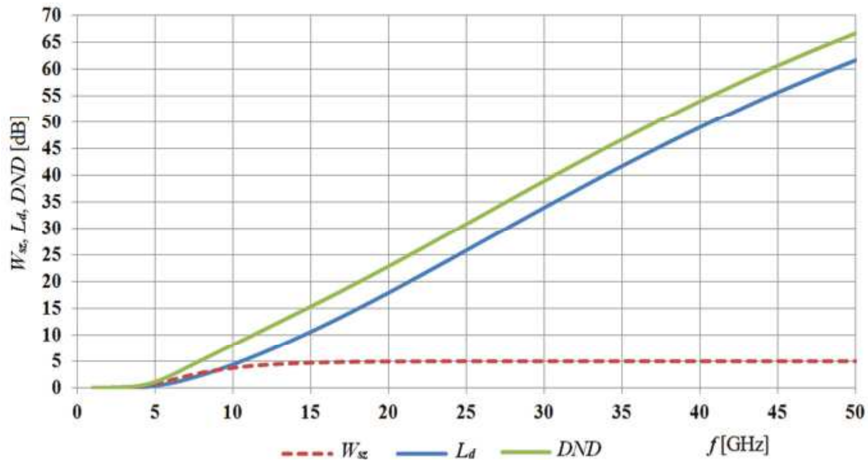

Fig. 11. W_{sz}, L_d, *DND* [dB] vs frequency [GHz] (pol. H)

By the results of the analysis (Fig. 14), we can present and compare the impact of extreme rainfall intensity in Poland on the receive microwave satellite signals in the selected area. On this basis, increase and decrease in L_d was determined, which refers to the rainfall statistics in the area of Kielce city (Fig. 15).

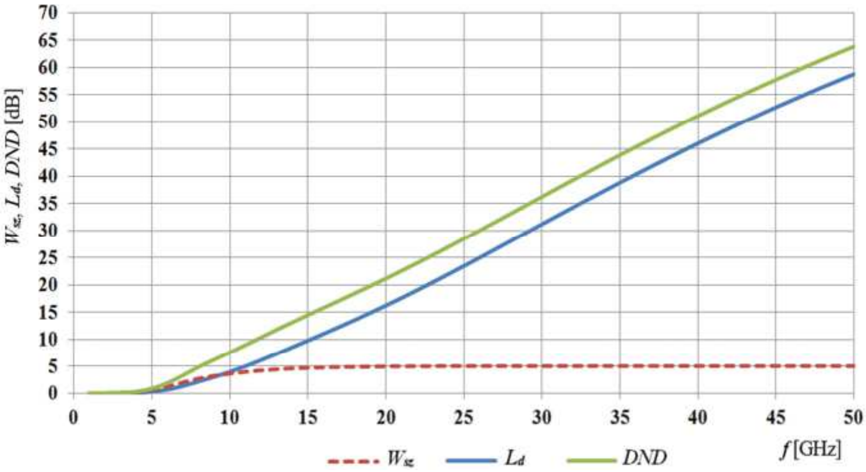

Fig. 12. W_{sz}, L_d, DND [dB] vs frequency [GHz] (pol. V)

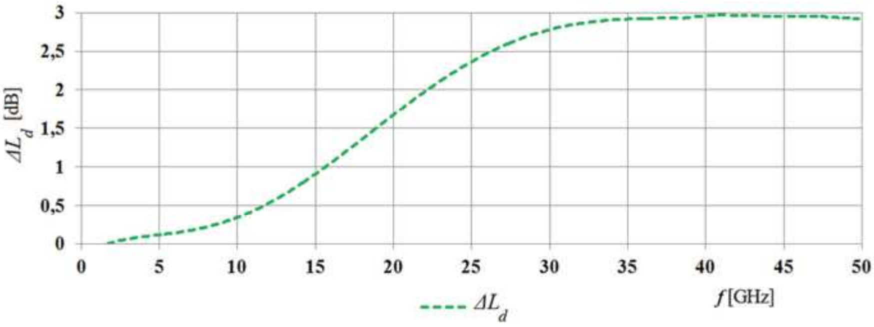

Fig. 13. Increase in L_d [dB] vs frequency [GHz] (pol. H-V)

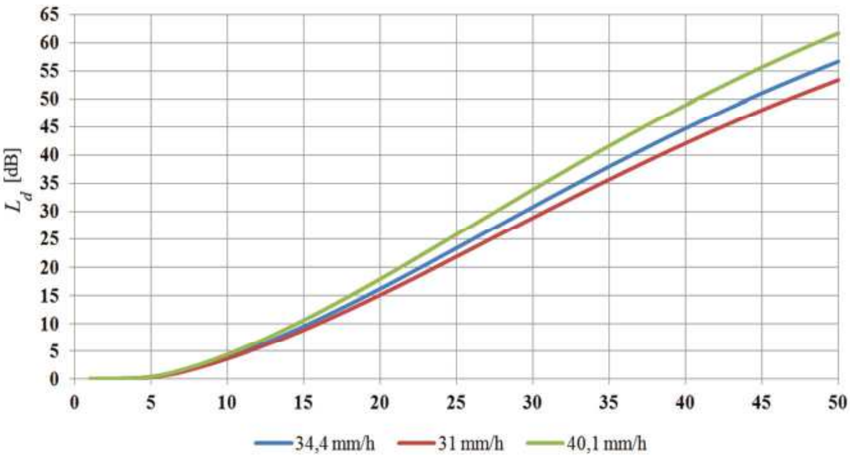

Fig. 14. L_d [dB] vs frequency [GHz] (pol. H)

Increase in L_d for frequencies below 10 GHz does not exceed the value of 0,5 dB, for frequencies below 14 GHz it does not exceed the value of 1 dB, for frequencies below 21 GHz – 2 dB, for frequencies below 29 GHz – 3 dB and for frequencies below 37 GHz – 4 dB (in the case of rainfall statistics of Nowy Targ). Starting from frequency which is equal to 38 GHz, the attenuation increases with frequency and it equals at least 4 dB.

On the other hand (in the case of rainfall statistics of Gorzow Wielkopolski i Gubin), decrease in L_d at 3,4 mm/h, which refers to rainfall statistics in the area of Kielce city, for frequency equals 50 GHz is responsible for the decrease in signal attenuation at 3,2 dB, below 12 GHz – 0,5 dB, below 18 GHz – 1 dB, below 30 GHz – 2 dB, below 45 GHz – 3 dB.

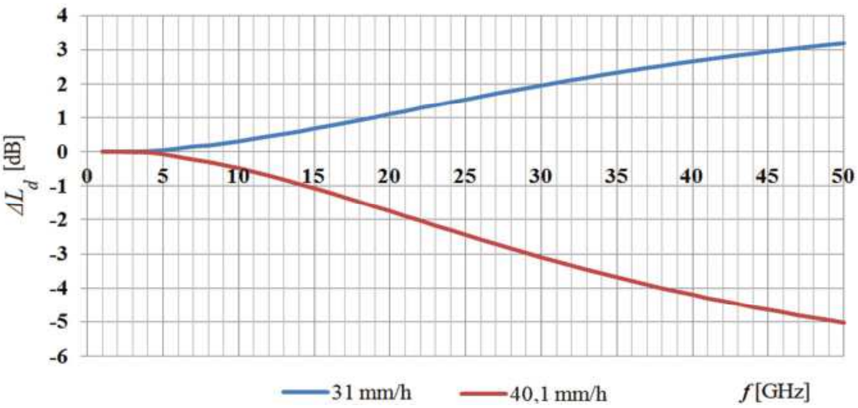

Fig. 15. Increase in L_d, decrease in L_d [dB] vs frequency [GHz] (pol. H)

Below in Figure 16 and Figure 17 you can see the analogically determined statistics for vertically polarized radio waves (versus frequency).

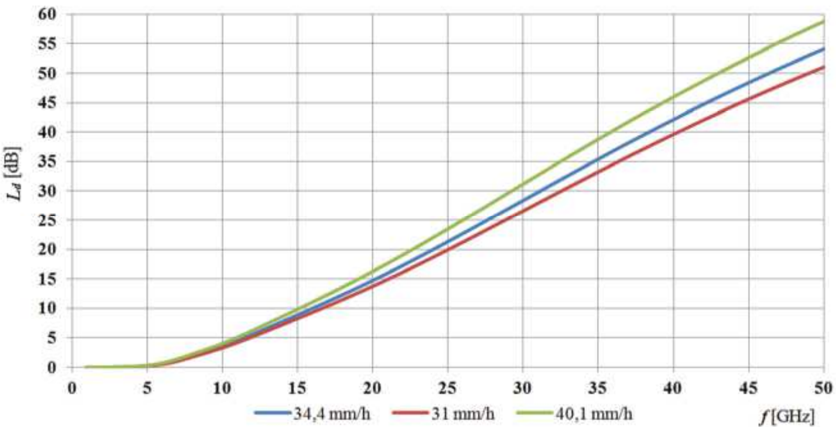

Fig. 16. L_d [dB] vs frequency [GHz] (pol. V)

If we summarize, we can see that the signal attenuation L_d for vertically polarized radio waves, as previously mentioned, reaches a lower value in comparison with horizontally polarized radio waves, so the influence of rainfall on their propagation becomes less significant. Decrease in precipitation of 3,4 mm/h (up to the level of Gorzow Wielkopolski and Gubin) is responsible for decrease in the attenuation of the vertically polarized radio waves in comparison with data obtained from the actual rainfall statistics. It fluctuates around 3 dB at 50 GHz. For microwaves with frequency up to 13 GHz – noted a difference less than 0,5 dB, for microwaves with frequency up to 20 GHz – it did not exceed 1 dB, for frequency up to 32 GHz – the difference is less than 2 dB and for frequency up to 49 GHz – it did not exceed the value of 3 dB.

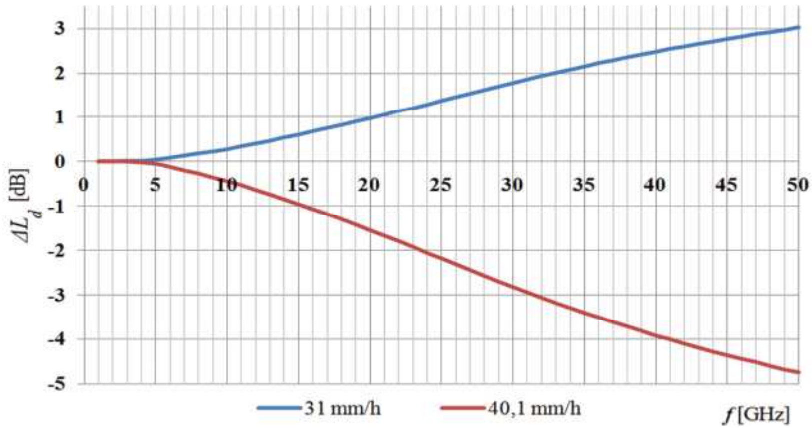

Fig. 17. Increase in L_d, decrease in L_d [dB] vs frequency [GHz] (pol. V)

Moreover, increase in the rainfall in the area of Kielce at 5,7 mm/h for vertically polarized radio waves (up to the level of Nowy Targ), in similar to the horizontally polarized radio waves, gives rise to increase in the signal attenuation relate to the rainfall statistics obtained in the area of Kielce city and Gorzow Wielkopolski and Gubin, too. In the frequency range from 1 GHz to 50 GHz attenuation does not exceed 5 dB (below 50 GHz). For the microwaves with frequency up to 10 GHz, the attenuation is less than 0,5 dB, up to 15 GHz – is less than 1 dB, below 23 GHz – is less than 2 dB , up to 29 GHz – it does not exceed 3 dB and below 41 GHz – is less than 4 dB. Above 41 GHz, attenuation was at least of 4 dB. The results seem to suggest that below 10 GHz (as Figure 15 and Figure 17 show) the impact of radio wave polarization on the microwave satellite signal reception is not meaningful.

3. CONCLUSION

The troposphere as the region of the atmosphere is very important for the mechanism of radio waves propagation [2,9]. In this context, this layer intervenes in meteorological phenomena exert the influence on radio waves especially due to rain. The troposphere, unlike the ionosphere, remains largely unpredictable. However, rain attenuation estimates can be made which allow links to be implemented and tested, obey certain laws of nature. Obviously dry seasons with low precipitation would not suffer greatly from this problem. Due to the wavelengths which are usually at least extremely short, a small-scale detailed description of this layer is quite often required. These losses (signal attenuation, increase in noise and total signal degradation due to precipitation), which increase with frequency was presented in Figure 1-17 in Poland (especially in Kielce city). Moreover, close by this city from 1974 at Psary-Kąty, was a large satellite ground station, operated by TP SA, with up to seven large parabolic antennas. Measurements in this region seems to be a good indication for system planners doing signal attenuation. The area of Kielce city is the representative region especially due to the central location in Poland, environment and morphology of terrain. Because of not spherically shape of hydrometeors, they can result in changes in the polarization, which is the another individual problem. The results of the analysis may be important when high reliability of microwave link is needed. If attenuation exceeds the link budget of a selected link, then (for example) an alternative technique is required to overcome the attenuation problem in microwaves link engineering. This is especially useful for satellite communications to have practical applications which has become more prominent as the communication community moves into higher spectrum of the available bandwidth, which in a future applications become available due to the optimization of satellite equipment [3,4,5,6,7]. The role is also to ensure the rational, efficient and economical use of the radio-frequency spectrum by many types of the radiocommunication services and carry out studies without limit of frequencies on the basis of the series of ITU-R Recommendations.

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CAŁKOWITA DEGRADACJA SYGNAŁU WKUTEK WYSTĄPIENIA OPADÓW DESZCZU W OBSZARZE MIASTA KIELCE

Streszczenie

W artykule omówiono różne efekty przyczyniające się do całkowitej degradacji sygnału, wskutek wystąpienia opadów deszczu na drodze propagacji fali radiowej oraz przeanalizowano tłumienie atmosferyczne. Skupiono się na analizie propagacji fal radiowych w systemach łączności satelitarnej w troposferze ziemskiej. W praktyce, obecność opadów znacząco wpływa na jakość sygnałów mikrofalowych, szczególnie ze względu na zjawisko absorpcji i refrakcji występujące na kroplach deszczu, stanowiących silne źródło szumów. Analizy dotyczą tłumienia sygnału wskutek wystąpienia opadów deszczu, towarzyszącego ich wystąpieniu wzrostu szumów systemowych i całkowitej degradacji sygnału. W ujęciu praktycznym, tylko poprzez statystyczny opis możliwe staje się pokazanie wyników modelowania mikrofalowych łączy satelitarnych w warunkach opadów deszczu w obszarze miasta Kielce. Otrzymane wyniki porównano z danymi rzeczywistymi, dotyczącymi np. tłumienia fal radiowych w zależności od intensywności opadów deszczu. Dane te posłużyły do określenia wpływu intensywności opadów, polaryzacji i częstotliwości fal radiowych na jakość odbieranego sygnału satelitarnego oraz poprzez przekazanie informacji – do optymalnego projektowania systemów telekomunikacyjnych. Wyniki badań są przydatne dla inżynierów łączności satelitarnej, ponieważ mogą przyczynić się optymalizacji i poprawy wydajności łączy satelitarnych oraz zminimalizowania ryzyka utraty sygnału lub przerw w ciągłości świadczenia usług, co umożliwia zaoferowanie usług satelitarnych na najwyższym poziomie.

Słowa kluczowe: tłumienie atmosferyczne, tłumienie sygnału wskutek wystąpienia opadów deszczu, wzrost szumów systemowych wskutek wystąpienia opadów deszczu, całkowita degradacja sygnału wskutek wystąpienia opadów deszczu, zastosowanie regresji wielomianowej, propagacja fal radiowych w troposferze ziemskiej.