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Determination of Radio Refractive Index using Meteorological Data

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Introduction

The value of radio refractive index of troposphere is an important parameter for the planning and design of microwave communications systems. The radio refractive index is defined as the ratio of the velocity of propagation of radio wave in a free space to the velocity of propagation of radio wave in a specified medium [1]. At standard atmosphere conditions near the Earth's surface, the radio refractive index, n, is equal to approximately 1.0003 [1].

The anomalous propagation is observed when the conditions of the propagation in the atmosphere vary from the standard one. Such anomalies are incident with some meteorological conditions (inversion of temperature, high evaporation and humidity, passing of the cold air over the warm surface and conversely). Refractive index is not constant under conditions mentioned above. The refractive index of the atmosphere depends on the temperature, humidity, atmospheric pressure and water vapour pressure. The changes in the value of the radio refractive index can curve the path of the wave. Even small changes in these variables can make a significant influence because radio signals can be refracted over whole of the signal path [2]. These parameters are highly variable and change rapidly in time and from place to place. For this reason, measurements of atmospheric pressure, temperature, and relative humidity were conducted in Akure (7.15°N, 5.12°E) to determine the radio refractive index [3]. The results obtained in [3] show that the local climate has an appreciable influence on the radio refractivity.

At high altitudes, the value of the refractive index n approximates to 1. In a well–mixed atmosphere, pressure, temperature and humidity decrease exponentially as a function of height h above the Earth's surface [4]. The vertical profiles of atmospheric pressure and optical refractive index have been theoretically analyzed in [5]. At the ground surface, the N–values vary from 1.00027 up to 1.00035 in [6]. The gradient of the refractive index is responsible for the bending of the propagation direction of the electromagnetic wave [7]. If it is negative, the signal bends downward. In [7], refraction seasonal variation in Latvia is presented.

Lithuania, being in the transition geography zone from the Baltic Sea climate to Atlantic and continentals East Europe climate, may be to distinguished for its variable climate. Humid weather predominates in Lithuania all over the year. The annual average precipitation is equal to 662 mm. 68% of this collection vaporize. The relative humidity is 85–90 % in winter, and it is about 70 % in spring, and in summer [8]. The relative humidity minimum was only 14% in Šilutė (in April 1995). The maximum temperature t = 37.5°C was in Zarasai on 30 July 1994. The minimum temperature t = -42.9°C was in Utena on 1st February 1956 [9]. The influence of rain and clouds on the electromagnetic wave propagation in Lithuania is analyzed in [10, 11]. The radio refractivity as far as we know has not been analyzed under Lithuanian climate conditions.

In [6], it was mentioned that the specific attenuation of microwave increases by 0.07273 dB/km when the temperature increases by 10%. And the specific attenuation increases by 0.1251 dB/km when the relative humidity increases by 10%. The peculiarities of Lithuanian climatic conditions which are named above proves to become reasons for using local geographical and meteorological data when analyzing radio refractive index.

For low latitudes (smaller than 22°) the seasonal variations are not very important. For high latitudes (higher than 45°) these variations are more pronounced [12]. As it was described in [7], the seasonal variation of the refractivity gradient can cause microwave systems unavailability. The geographical data of the localities investigated here is presented in Table 1. It is seen that the latitudes of all investigated here localities here are higher than 45° and the seasonal variations of the refractive index – value may be observed in these localities.

The main goals of this paper were to apply the well-known model [13] to determine the radio refractive index – values using local geographical and meteorological data of Lithuanian localities in different seasons of a year and different day times and to compare these values with average value of refractive index at a ground level under standard atmosphere conditions.

Estimation of the value of the refractive index

The atmospheric radio refractive index, n, can be calculated by the following formula [1, 4, 7, 13]

$$n = 1 + N \cdot 10^{-6}, \quad (1)$$

where N, is the radio refractivity (N–units).

The N–units are used in order to notice the changes in the values of the refractive index which are usually small. These N–units are obtained by subtracting 1 from the refractive index and multiplying the remainder obtains units by a million ($N = (n\text{-}1)\cdot10^6$) [4]. In this way more manageable numbers are obtained.

The radio refractivity N is expressed by [1, 7]

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right), \quad (2)$$

where P is atmospheric pressure (hPa), e is water vapour pressure, and T is absolute temperature.

It is noted [7], that this expression may be used for all radio frequencies up to 100 GHz; the error is less than 0.5%.

The relationship between water vapour pressure e and relative humidity is given by [13]

$$e = \frac{He_s}{100}, \quad (3)$$

with

$$e_s = a\exp\left(\frac{bt}{t+c}\right), \quad (4)$$

where H is relative humidity (%), t is Celsius temperature (°C), e_s is saturation vapour pressure (in hPa) at the temperature t (in °C). For water a = 6.1121, b = 17.502, c = 240.97 (valid between –20ºC and +50ºC, with an accuracy of ±0.20%) [1], [13].

The results and discussion

As it was mentioned above, the climate of Lithuania is variable and it was important to analyze the differences in the seasonal and daily variations of the radio refractivity N in the localities of Lithuania. We chose four localities of Lithuania situated in different climatic regions of Lithuania (see Table 1). The meteorological data were taken from [14].

The dependences of average N – values on the time of day in different seasons of a year are presented in Figs. 1–4. Some regularities and differences have been observed when analyzing the dependences presented in Figs. 1 – 4. The maximum average value of radio refractivity was in Klaipėda (only in July at 9 o'clock these values were exceeded in Kaunas) and minimum one was in Vilnius during all the seasons and throughout all the daily time.

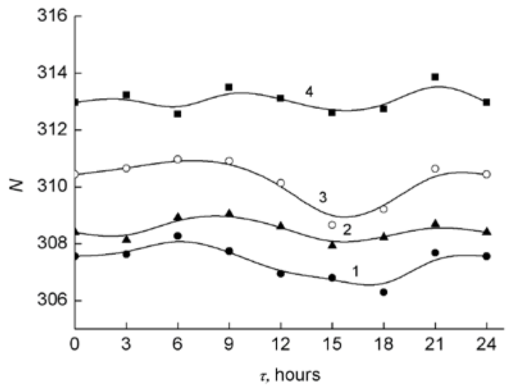

Fig. 1. Dependences of average N – values on the time of day in Vilnius (curve 1), Mažeikiai (curve 2), Kaunas (curve 3), and Klaipėda (curve 4) in February 2009

The variations in the daily N – values are the least in Klaipėda in July, October, and April. In February, the least daily variation was observed in Mažeikiai (see Table 2). The most noticeable variations in the daily N – values were observed in April and July in Vilnius and Kaunas. In Mažeikiai, the most noticeable variations in the daily N – values were observed in July.

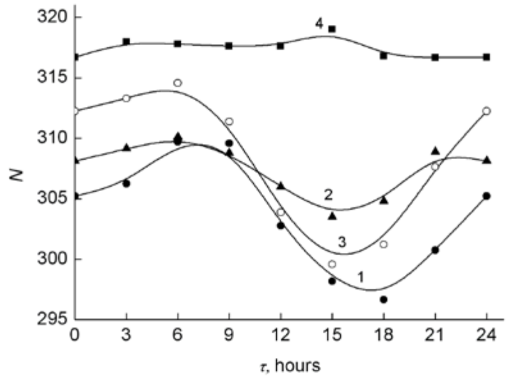

Fig. 2. Dependences of average N – values on the time of day in Vilnius (curve 1), Mažeikiai (curve 2), Kaunas (curve 3), and Klaipėda (curve 4) in April 2009

The differences in maximum yearly N – values and minimum ones are: 35.85 N – units in Vilnius, 32.03 N – units in Mažeikiai, 41.48 N – units in Kaunas, and 27.66 N – units in Klaipėda. In Klaipėda, this difference was minimum and maximum one was in Kaunas. It is worth to mentioning that the maximum N – value (N = 341.06 in July) and minimum one (N = 299.58 in April) were observed in Kaunas (see Table 3).

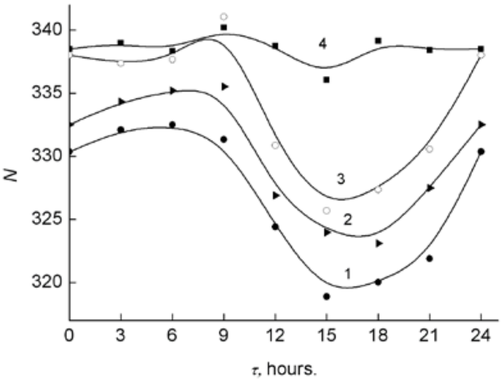

Fig. 3. Dependences of average N – values on the time of a day in Vilnius (curve 1), Mažeikiai (curve 2), Kaunas (curve 3), and Klaipėda (curve 4) in July 2008

It is clearly seen that the N – values vary in the wider range in October and April than in February in Vilnius. It can be explained by the variation of the humidity – values ΔH in the periods mentioned above: ΔH = 75 % in April, ΔH = 52 % in October, ΔH = 32 % in February.

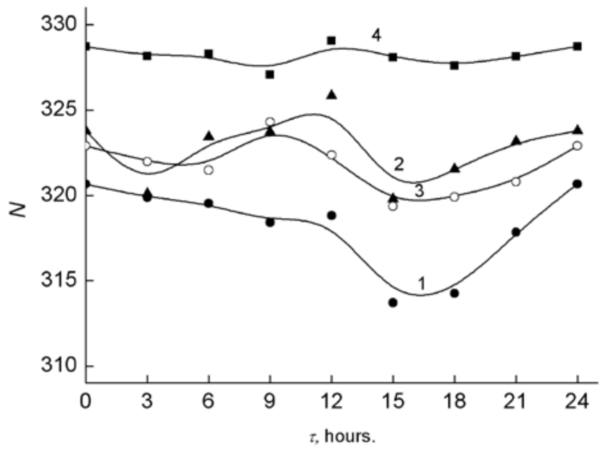

Fig. 4. Dependences of average N – values on the time of day in Vilnius (curve 1), Mažeikiai (curve 2), Kaunas (curve 3), and Klaipėda (curve 4) in October 2008

In Klaipėda, the difference in maximum and minimum yearly values of radio refractivity obtained here is by 1.66 N – units higher than one in Latvia presented in [7]. In Latvia, N – values varied starting from 313 up to 315 in February and from 332 up to 339 in August.

In all the localities investigated here the values of the refractivity N were higher than one at the standard atmosphere conditions presented in [1] in July, October and February. Only in August, on 3 PM these values were lower in Vilnius and Kaunas.

Table 1. Geographical data

Locality	**Longitude** (East)	**Latitude** (North)	**Altitude**, m	**Climatic region**
Vilnius	$25^0$06'	54°38'	162.0	Southeastern Plain
Kaunas	23°50'	54°53'	77.0	Middle Lithuania Lowland
Klaipėda	21°04'	55°44'	6.0	Coastial Lowl
Mažeikiai	22°20'	56°18'	62.0	Samogitian Highland

Table 2. Daily variations ΔN_s in average values of N_s in the localities of Lithuania at the ground surface

Month	**July**	**October**	**February**	**April**
Locality	ΔN_s	ΔN_s	ΔN_s	ΔN_s
Vilnius	13.63	6.96	1.98	13.07
Kaunas	15.37	4.93	2.31	14.99
Klaipėda	4.16	1.99	1.29	2.33
Mažeikiai	12.42	6.07	1.12	6.59

Table 3. Yearly variations in average values of N in the localities of Lithuania at the ground surface

Locality	**Maximum N–value**	**Minimum N–value**
Vilnius	332.50	296.65
Kaunas	341.06	299.58
Klaipėda	340.22	312.56
Mažeikiai	335.52	303.49

Conclusions

Considering that the temperature, atmospheric pressure and water vapour pressure change with geographical location and this can influence on the value of radio refractive index, we recommend the usage of local geographical and meteorological data.

The values of the refractive index in Klaipėda and Kaunas are higher than in other investigated here regions of Lithuania in all the seasons and throughout the daily time.

The values of the radio refractive index calculated here under the local climate conditions differ from the value of average atmospheric radio refractive index close to the ground surface [1] by starting from 1.82–N–units in Vilnius (the minimum value) up to 41.06–N units in Kaunas (the maximum value).

The daily variations of N – values are most noticeable (in average, 14.1 N – units) in July (in Vilnius, Mažeikiai, and Kaunas) and in April (in Kaunas and Vilnius). In Klaipėda, the maximum value of daily variation of N – value is 4.16 N–units. The minimum variation of N – values was observed in February in all the localities investigated here (in average, 1.7 N – units). The values of N were higher than one at the standard atmosphere conditions presented in [1] in July, October, and February except the cases in August on 3 PM in Vilnius and Kaunas. In Klaipėda, the difference between maximum and minimum values of radio refractivity obtained here is by 1.66 N – units higher than one in Latvia presented in [7].

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The International Telecommunications Union – Radiocommunications (ITU–R) model was used for calculation of the radio refractive index according to the peculiarities of climatic conditions in Lithuania. For the first time the radio refractive index for different localities in Lithuania have been determined using this model. The values of the radio refractive index have been determined at altitude by starting from 6 m up to 162 m above the sea level in the troposphere. The daily and the seasonal variations of the radio refractive index – value have been determined. It was obtained, that the maximum values of radio refractivity are in Klaipėda and Kaunas and the minimum one was determined in Vilnius. The obtained data was compared with the known value of average atmospheric radio refractive index close to the ground surface at the standard atmosphere conditions and with ones measured in neighbour state Latvia. Ill. 4, bibl. 13, tabl. 3 (in English; abstracts in English and Lithuanian).

E. Valma, M. Tamošiūnaitė, S. Tamošiūnas, M. Tamošiūnienė, M. Žilinskas. Radijo bangų lūžio rodiklio apskaičiavimas pagal meteorologinius duomenis // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 10(106). – P. 125–128.

Radijo bangos lūžio rodiklis apskaičiuotas Tarptautinės telekomunikacijų sąjungos (ITU–R) rekomenduojamu metodu, atsižvelgiant į Lietuvos klimato ypatumus. Pirmą kartą radijo bangos lūžio rodiklio vertės apskaičiuotos Lietuvos vietovėms, kurios yra nuo 6 m iki 162 m virš jūros lygio. Gautos vertės palygintos su gerai žinoma atmosferos lūžio rodiklio verte prie Žemės paviršiaus standartinės atmosferos sąlygomis ir su vertėmis, išmatuotomis kaimyninėje šalyje Latvijoje. Ištirtos radijo lūžio rodiklio priklausomybės nuo paros ir metų laiko. Nustatyta, kad didžiausios radijo bangos lūžio rodiklio vertės yra Klaipėdoje ir Kaune, o mažiausios – Vilniuje. Gauti duomenys gali būti naudojami projektuojant naujus radijo ryšio tinklus Lietuvoje. Il. 4, bibl. 13, lent. 3 (anglų kalba; santraukos anglų ir lietuvių k.).