ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2007. No. 6(78)
ELEKTRONIKA IR ELEKTROTECHNIKA

T170 ELECTRONICS
ELEKTRONIKA

Refraction Seasonal Variation and that Influence on to GHz Range Microwaves Availability

D. Serdega, G. Ivanovs
Riga Technical Univercity, Institute of Telecommunications,
LV – 1010, Azenes 12 st., Riga, Latvia

Introduction

Terrestrial radio relay systems operate in the frequency ranges between about 1 GHz and 40 GHz. A distinction is made between line-of-sight and over-the-horizon connections. The vast majority of radio links are line-of-sight connections. Connections beyond the horizon deliberately exploit atmospheric scatter effects, but they require a considerably higher investment in equipment and are only used in exceptional circumstances, e.g. if distances are to be spanned far in excess of the visible horizon. For this reason, we are limiting ourselves in this set of transparencies to propagation effects on radio relay line of-sight connections.

The generation of the radio wave requires antennas on the transmit side which radiate energy supplied by the RF transmitter into free space. A receive antenna of the same type absorbs a proportion of the radiated energy and passes it to the receiver.

If we first assume antennas are isotropic radiators, which radiate energy evenly in all directions, then the basic free-space transmission loss a can be calculated according to the formula

$$A[dB] = 92{,}4 + 20\lg D[km] + 20F[GHz], \qquad (1)$$

where D – the distance in km between antennas; F – the transmission frequency in GHz.

Inserting the typical values D = 50 km and F = 6.7 GHz in the equation gives A = 142.9 dB. This value is very high and can only be accommodated at reasonable cost by the use of directional antennas. For this reason, the energy is concentrated and radiated in the direction of the receiving antenna.

The top of this transparency shows a signal wave radiated from a directional antenna using the representation method of geometric optics. The initial assumption is that a radio signal propagates along straight lines in vacuum. The earth's atmosphere however consists of gases and water vapour and has a dielectric constant **$\varepsilon > 1$**. This is not constant, but **ε** decreases as the altitude above the earth's surface increases, since the density of the atmosphere also decreases with altitude. The gradient of the dielectric constant is the physical cause for the continuous deflection of the signal as it passes through the atmosphere. This deflection is always from the thinner toward the denser medium and under normal atmospheric conditions causes as light bending of the ray toward the earth's surface.

This effect is a great advantage to radio relay connections. As the top diagram on this transparency shows, the bending means that the radio horizon is further from the transmitter antenna than the optical horizon. Since light has much shorter wavelengths than those of a radio signal, the effect of the dielectric constant on the optical propagation is negligible.

Meaning of K factor

The K factor is used as a measure for the bending of the radio signal:

$$K = R/Ro, \qquad (2)$$

where R – the effective radius for the radio signal; Ro – the radius of the earth.

Radio hops are often planned on the basis of the value K= 4/3 which is typical for the earth's atmosphere.

In abnormal weather or under specific geographical conditions, the K factor deviates from 4/3. A radio hop for various K values is shown in the middle diagram.

It is clear that as the K value decreases the radio signal is forced closer to the earth. This can lead to fading and even to interruption of the signal.

When planning radio hops the graphic technique shown in the bottom diagram is often used. The concept of the apparent radius of the earth is introduced and a permanently straight-line propagation of the radio signal is assumed. Where K = 1 the apparent radius of the earth is equal to the actual radius; when K= 4/3, the apparent radius R is greater than the actual radius Ro by a factor of 4/3. If Ro = 6370 km, the apparent radius of the earth is then R = 8493 km. The apparent radius of the earth is also termed the effective earth radius.

Phenomena’s produced by Earth atmosphere

The term "fading" refers to the time-dependent behavior of the received signal. This can be subject to marked fluctuations in phase, polarization and amplitude due to the effects in the earth's atmosphere. The propagation of electromagnetic waves is affected to a lesser or greater extent by the meteorological conditions.

A distinction is made between multipath fading and attenuation fading.

Multipath fading occurs primarily in the transmission of frequencies below about 10 GHz. Due to the considerable dependence on frequency, multipath fading is also referred to as " selective fading " .

The cause of multipath fading is multipath propagation, in which several individual signals originating from the same transmitting antenna are picked up by the receiving antenna. At the receiving antenna the field components are added together. If these signals are in phase they can amplify each other, while if they are in antiphase they can weaken or even cancel out each other.

Effect of refractivity index variations

The gradient of the refractive index dN/dh is responsible for the bending of the propagation direction of the electromagnetic wave. If it is negative, the signal bends downward. This is desirable and occurs under normal meteorological conditions.

Fig. 1, 2 and 3 shows examples of multipath fading under specific meteorological conditions, in which the refractive index N of the earth's atmosphere does not have a linear relationship with increasing height h above the earth's surface, but displays boundary layers or even increases.

Fig. 1 shows the occurrence of multipath fading due to surface inversion layers. In an inversion layer, the temperature increases with altitude and the refractive index declines. Below the border layer, dN/dh is greater than 0 and the signal bends upward. The propagating signal above the border layer remains unaffected.

Fig. 2 shows the creation of a tropospheric reflection. Between the border layers, the gradient dN/dh is greater than outside the borders. Due to the pronounced bending of the signal of this layer a second propagation path is permitted.

If the refractive index characteristics of the atmosphere are such that the radio signal is guided over a longer route parallel to the earth's surface, this is referred to as a duct. Fig. 3 shows the creation of a surface duct where dN/dh has risen sharply. The reflection at ground level causes a second signal to reach the receive antenna.

In the case of loss fading, only a part of the radio signal reaches the receive antenna. Since this fading is not as frequency selective as multipath fading, it is also termed flat fading. Attenuation fading can last considerably longer than multipath fading and affect transmission for several hours, since the weather conditions that cause it are stable.

Figure d shows flat fading caused by an inversion layer that extends above the antenna height. Only an upwardly curved ray can be formed which is strongly attenuated by the earth's surface.

Figure e shows flat fading caused by a tropospheric reflection. Since the signal is partly reflected at the boundary, the antenna situated above this boundary receives energy of the signal reaches the receive antenna.

Even precipitation -especially rain and wet snow - causes flat fading which has a particular effect in frequency bands above 10 GHz. Countermeasures include increasing the transmitter power and reducing the receiver noise figure. Reducing the length of the radio hops similarly has a positive effect.

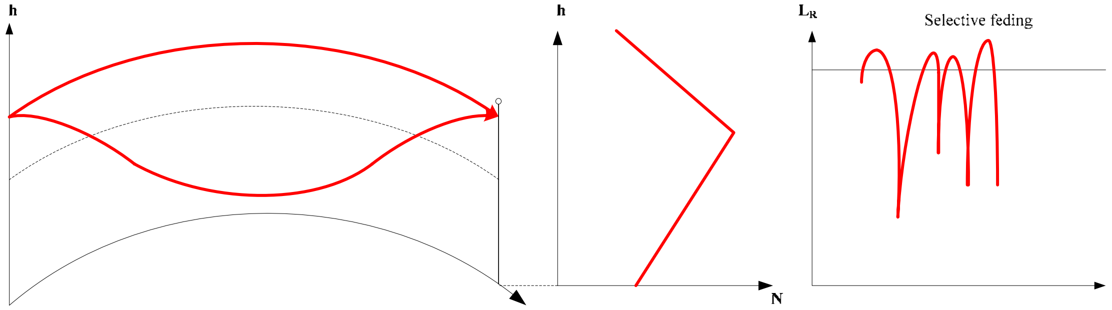

Fig. 1. Multipath fading due to surface inversion layer

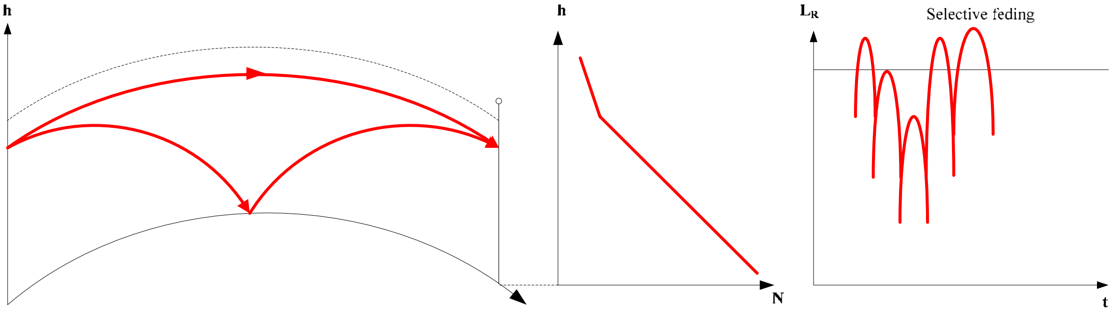

Fig. 2. Multipath fading due to tropospheric reflection

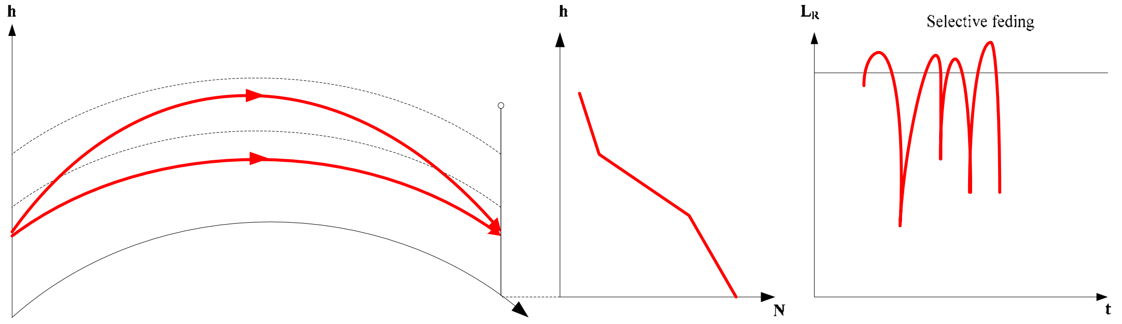

Fig. 3. Multipath fading in surface duct

Taking into account all above mentioned we can conclude following main atmosphere refractivity index variations impacts on to Gigahertz microwave lines propagations

Sub-Refractive propagation (k<4/3, G>-40 N units/km) usually associated to atmosphere density increasing with height (warm air over cool air or moister surface). The ray curvature is reduced or even is bent upward (k<1, G>0), the ray path iscloser to the ground (maximum obstruction probability when k is minimum).

Super-Refractive propagation (k>4/3, G< -40 N – units/km) observed when temperature inversion happens or other phenomena makes atmosphere density decreasing with height (cool dry air over a warm body of water). The equivalent earth reduces its curvature, for k - ∞ the ray is parallel to the earth and propagation may extend its range (unexpected interference may appear). In extreme super-refraction conditions (G <-157 N – units/km, negative k) the ray is bent towards ground and no signal arrives at the Rx antenna (black-out).

Variable – G profiles: with better approximation, the Refractivity Gradient can be assumed as constant only in limited height ranges (layered atmosphere).Under this model, the ray curvature changes when passing from one atmosphere layer (G=G1) to the higher (or lower) one (G=G2). Even if, if in the real case, the transition from one layer to another is smoothed in some way, a layered atmosphere model is useful in explaining.

Multipath propagation: the different ray curvature in atmospheric layers may produce a number of separate propagation paths from the transmitter to the receiver.

Duct formation: the atmosphere layers are such that the rays at the duct lower boundary tend to bent upward, while rays close to the upper boundary tend to be bent downward. The result is that propagation is confined within a limited height ranges, with the duct, a stronger signal will be received. If the Rx antenna is out of duct, rather long signal fading are observed.

Refractivity index seasonal predictions and calculation rules.

As we decline above Refractivity Index is the ratio of Velocity of Light in vacuum to the velocity in a different medium. Since the Velocity of Light in the atmosphere is very close to that in vacuum, then the Refractive Index in the atmosphere is grater than, but very close to 1. However, also small variations in the atmosphere Refractive Index have significant effects on the propagation of Electromagnetic Waves. For this reason, instead of using the Refractive Index n (close to 1), it is convenient to define the refractivity N as

$$N = (n-1)\times 10^6 , \qquad (3)$$

that is the number of parts per million that the Refractive Index exceeds unity. The Refractivity is a dimensionless parameter, measured in N-units.

The atmosphere Refractivity is a function of Temperature, Pressure, and Humidity, and it is constant with height. The ITU – R Rec. 453 gives the formula

$$N = (77{,}6/T)\times(P + 4810e/T) , \qquad (4)$$

where: T – absolute temperature (Kelvin deg); P – atmospheric pressure (hPa, numerically equal to milibar); e – water vapour pressure (hPa).

The average value of N at sea level is about N=315. The ITU-R gives world maps with the mean values of N in February and August.

The Vertical Refractivity Gradient G (measured in N-units per km, N/km) is defined as

$$G = (N_1 - N_2)/(H_1 - H_2) , \qquad (5)$$

where N_1, N_2 – the refractivity values at elevations H_1 and H_2, respectively. In Standard Atmosphere model, the Vertical Refractivity Gradient is assumed as constant in the first kilometre of the atmosphere: G=(-40) N/km. This corresponds to the Standard Propagation conditions.

Deviation from the Standard Atmosphere condition leads to Anomalous Propagatin. Such anomalies are usually associated with particular meteorological conditions, like temperature inversion, very high evaporation and humidity, passage of cold air over warm surfaces or vice versa.

In these conditions, the Vertical Refractivity Gradient is no longer constant. A number of different profiles have been observed and measured. It is worth nothing that, at grater altitude, the Refractivity Index is, in any case, closer and closer to 1, so the refractivity N goes to zero, according to exponential function.

Practical research of refractivity gradient seasonal variation in Latvia.

As we described above seasonal variation of refractivity gradient can cause microwave systems unavailability. This mean that for microwave network planning we shall either calculate using ITU-R materials either predict using statistical data refractivity index variation. Otherwise wrong refractivity coefficient prediction can lead to microwave lines long term unavailability which cause as financial loses as customer complaints. Preparing this scientific article we made calculation based on 10 years meteorological observation in 4 different Latvian towns Liepaja, Ventspils, Riga, Daugavpils. Two of the towns are situated on Baltic sea cost, Riga are situated on Lielupe river estuary and Daugavpils is situated in continental part of Latvia. Below you can see drawing which was produced after statistical data obtain for 10 years period of observation.

As we can see from the Fig. 3 n value has glaring expressive Gaussian distribution character.

Table 1. Practically obtained N units for Latvian towns

	N	
	February	**August**
Liepāja	315	339
Ventspils	314	338
Rīga	313	335
Daugavpils	313	332

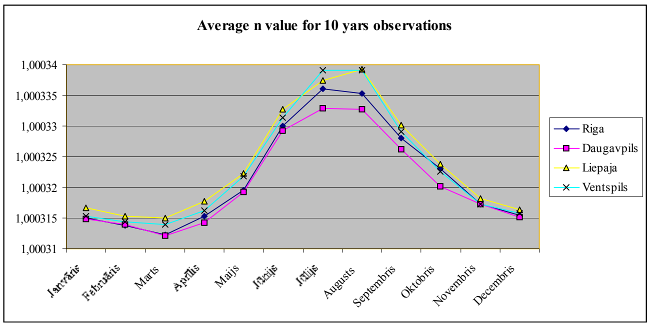

Fig. 4. Average n value obtained from 10 years practical observations

Also we can conclude that refractivity gradient variation has bigger influence in coastal regions of Latvia during the summer time neither in winter time. It is also well connected with empirical observation of microwave systems unavailability during sun set and sun rise in summer time.

According to Rec. ITU-R P.453-9 we can seethat theoretical refraction coefficient for Latvian tretory for February is ~310 N and for August ~340 N

Analysing practically we get following results: for February ~313N and for August ~336N as shovn in Table 1.

References

1. **Luebbers R. J.** Finite conductivity uniform GTD versus knife edge diffraction in prediction of propagation path loss. IEEE Trans., 1984, AP–32, (1).
2. **Debye P.** Polar moleculares. – Dover Publ., 1957. – P. 89–90.
3. **Smith E. K., Weintraub S.** The constants in equation for atmospheric refractive index at radio frequencies // Proc. IRE. – 1953. – P. 1035–1037.
4. **Bean B. R., Dutton E. J.** Radio meterology. National Bureau of Standards Monograph 92. Ch.1.
5. **Recommendation ITU–R.** The radio refractive index: its formula and refractivity data, 2001. – P. 453–8.
6. **Hall M. P. M.** Effect of thetroposphere on radio communications. – Peter Peregrinus Ltd, 1979.
7. **Liebe H. J.** An updated model for millimeter wave propagation in moist air. Radio Sci. – 1985, 20. – P. 1069–1089.
8. **Yilmaz U. M., Kennedy G. R., Hall M. P. M.** A GaAs FET microwave refractometer for tropospheric studies. – AGARD CP-346, 1983, 9. –P. 1–5.
9. **Wait J. R., Spies K. P.** Internal guiding of microwave by an elevated duct // Radio Sci. – 1964. – 4, – P. 319–326.
10. **Craig K. H.** Root of the mode equation for propagation in an elevated duct // IEE Conf. Pub.248, (ICAP85). –P. 274–278.
11. **Ko H. W., Sari J. W., Thomas M. E., Herchenroeder P. J., Martone P. J.** Anomalos propagation and radar coverage through inhomogeneous atmospheres. AGARD CP-346. – 1984, 25. – P. 1–14.

Submitted for publication 2007 03 07

D. Serdega, G. Ivanovs. Refraction Seasonal Variation and that Influence on to GHz Range Microwaves Availability // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 6(78). – P. 39–42.

Microwave transmission can be affected by deep fading, which can cause bit errors or even transmission loss. It happened when the Rx (receiving) signal is produced by a large number of components (vectors with random phases), then the Rx power level is variable with Rayleigh statistics. It depend from seasonal variations of refractivity index. Aim of this scientific work was to estimate refractivity index variations during the last 10 years and depending from geographical position of observed region (coastal, continental). Also we compare obtained result with ITU-R recommendations. Ill. 4, bibl. 11 (in English, summaries in English, Russian and Lithuanian).

Д. Сердега, Г. Ивановс. Влияние сезонных вариаций градиента рефракции на распространение радиоволн в ГГц диапазоне // Электроника и электротехника. – Каунас: Технология, 2007. – № 6(78). – С. 39–42.

Передача информации по радиорелейной линии может быть нарушена в связи с глубокими замираниями сигнала, которые могут вызывать ошибки или даже перерывы передачи информации. Это происходит, когда приёмный сигнал складывается из множества компонентов (т.е. векторов с различной фазой и амплитудой), поэтому приёмный сигнал варьирует в соответствии со статистической моделью распределения Релея. Эти вариации зависят от индекса рефракции. Задача данной научной работы выявить колебания индекса рефракции в течении последних 10-ти лет в зависимости от географического местоположения наблюдаемого региона (побережье, континент). Так же мы сравнили полученный результат с рекомендациями МККР. Ил. 4, библ. 11 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Serdega, G. Ivanovs. Sezoninis lūžio rodiklio kitimas ir jo įtaka GHz diapazono mikrobangų priėmimui // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 6(78). – P. 39–42.

Radijo bangomis perduodama informacija gali būti sutrikdyta, todėl gali atsirasti klaidų arba net galima prarasti informacijos. Taip atsitinka tada, kai perduodamas signalas susideda iš daugelio vektorių su skirtingomis fazėmis, tuomet perduodamo signalo forma atitinka Reilėjaus skirstinį. Tai priklauso nuo reakcijos trukmės. Darbe ištirta, kaip per pastaruosius 10 metų priklausomai nuo geografinės padėties keitėsi refrakcijos (lūžio) indeksas. Gauti rezultatai palyginti su Tarptautinės telekomunikacijų sąjungos rekomendacijomis. Il. 4, bibl. 11 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).