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ESTIMATION OF CLEAR-AIR FADES DEPTH DUE TO RADIO CLIMATOLOGICAL PARAMETERS FOR MICROWAVE LINK APPLICATIONS IN AKURE, NIGERIA.

O. L. OJO*[1], M. O. AJEWOLE[2], A.T. ADEDIJI[3] AND J. S. OJO[4]

[1]Department of Physics, Adeyemi Federal University of Education, Ondo, Ondo State, Nigeria
[2,3,4]Department of Physics, Federal University of Technology Akure, Ondo State, Nigeria.
E-mail: [1]olalekan_bisi2005@yahoo.com, [2]oludare.ajewole@futa.edu.ng , [3]kunleadediji2002@yahoo.co.uk , [4]josnno@yahoo.com

ABSTRACT

In this paper, clear-air fade depth and outage probability occurrence of microwave signals is estimated based on the effect of tropical geoclimatic factor derived from atmospheric refractivity gradient computed for three years (January 2011-December 2013) of measurement of air temperature, pressure and relative humidity for terrestrial line of sight (LOS) link design application in Akure, Nigeria. The outage probability of fade depth exceeded at a given time over a single frequency is therefore estimated at a given path length. Furthermore, the parameter needed for clear-air propagation and interference, expressed as percentage of the time with refractivity gradient below -100 N-Units/km, are also presented. The results show that geoclimatic factor which cater for geographical and climatic conditions in multipath fading distribution exhibits monthly, seasonal and yearly variation. Finally, based on the link geometrical parameters used, the fade depth exceeded in 0.01% of time can be estimated by logarithmic fits with a very high coefficient of determination.

Key words: ***Outage probabilities, Fade depth, microwave signals, LOS, tropical location***
Corresponding author:olalekan_bisi2005@yahoo.com.

1. INTRODUCTION

The propagation of electromagnetic waves around the earth is influenced by the properties of the earth and the atmosphere (ITU-R 834-4, 2003; Olsen, 1999) thereby resulting in fade depth. Fade depth is the ratio, in decibels, of a reference signal power to the power during a fade. The reference value may be pre-determined; for example, the clear-sky value often estimated as the median clear-air value. In recent times, microwaves are used in radar and communications system (Grabner et al., 2010). However, for optimum services, it is of much importance to investigate the microwave anomalous conditions experienced along the propagation path of a radiowave in the troposphere as a result of changes in climatological variables. The atmospheric parameters such as temperature, pressure, humidity and particulate density: vary in space and time. These geoclimatic variables refract electromagnetic waves in different directions (up, down, towards or away from the earth's surface) along the curvature of the earth resulting in clear-air fading phenomena. The clear-air mechanisms involved, but not limited to the following: beam spreading, antenna decoupling, surface multipath, ducting, scintillation and atmospheric multipath. Multipath fading occurs when the direct beam of the signal combines with the surface reflected beam (ITU-R 530-14, 2012). In agreement with ITU regulations, service availability of 99.99% (0.01% unavailability of time) for the worst month is the design target for fixed links; this implies an outage not exceeding 53 minutes in a year (Bogucki and Wielowieyska, 2009). In spite of the techniques provided by the ITU for estimating the percentage of time that a fade depth is exceeded in the average worst month, it has been identified that the variables that is responsible for the fading is a function of specific climatic and topographical conditions (Olsen et al., 2003; Asiyo and Afullo, 2013). In fact, the method for estimating percentage of time that a certain fades depth is exceeded are a

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function of frequency, path length and geoclimatic factor, hence the need to determine the fade depth based on each location and region of interest.

Efforts on modeling the main radio climatic variables have been made by some authors in the tropical region especially Nigeria. Some of the efforts include the works of: Owolabi and Williams, (1970); Falodun and Ajewole, (2006), Adediji and Ajewole, (2008), Igwe and Adimula, (2009), Adediji et al., (2011), Oyedum, (2012), Adediji et al., (2014a, 2014b), Ojo et al., (2014), to mention but a few. However, the estimation of fade depth at different outage probabilities based on the radio climatologcal variables have not been seriously studied, hence the present study's focus. Therefore, this work is to update the existing research and to apply the radioclimatic variables in the design of terrestrial line-of-sight links in this part of the globe.

2. GEOCLIMATIC VARIABLES DETERMINATION

The atmosphere over the earth is a dynamic medium, its properties varying with temperature, pressure and humidity. These variables are related to the radio refractivity, N as (Freeman, 1997):

$$N = (n-1)10^6 = \frac{77.6P}{T} + 3\times10^5\frac{e}{T^2} = N_d + N_w \quad (1)$$

where n is the refractive index of the atmosphere, T is temperature (K), P is atmospheric pressure (hpa) and e is the water vapour pressure (hPa). N_d and N_w are the so called dry and wet component of N. The water vapor pressure e, can be calculated from the relative humidity H (%) and saturation water pressure e_s, the last depending only on the air temperature t ^{0}C is given as (Olsen and Tjelta, 1999):

$$e = H \times \frac{6.1121 exp\left(\frac{17.502t}{t+240.97}\right)}{100} \quad (2)$$

The refractivity gradient in the atmosphere which is a function of height is related to the multipath fading and is expressed as:

$$\frac{dN}{dh} = \frac{N_1 - N_2}{h_1 - h_2} \quad (3)$$

where N_1 and N_2 are the refractivity at heights h_1 and h_2 respectively.

The point refractivity, dN_1 is obtained from two refractivity values, N_s, (surface refractivity), and N_1 (refractivity within 1 km height above the ground). Since data at exact heights are not available, the following relation is utilized (Dominguez et al., 1998):

$$dN_1 = \frac{N_s - N_1}{h_s - h_1} \quad (4)$$

where h_1 is the point nearest to 1 km height and dN_1 is calculated only if 900 m < h_1 < 1100 m

The effective earth radius factor (k-factor) is determined by (Hall, 1989):

$$k = \left[1 + \left(\frac{dN}{dh}\right)/157\right]^{-1} \quad (5)$$

The Geoclimatic factor, K (for quick planning) can be determined based on the procedure given in ITU-R. P 530-14 (2012), where dN_1 is the point refractivity gradient in the lowest 100 m of the atmosphere not exceeded for 1% of an average year considered in this work as:

$$K = 10^{-4.2-0.0029dN_1} \quad (6)$$

3. CLEAR AIR FADE DEPTH ESTIMATION

The worst month in a year for a predefined threshold for any performance degrading mechanism is that month in a period of the twelve consecutive calendar months, during which the threshold is exceeded for the longest time. It must also be noted that the worst month is not necessarily the same month for all the threshold levels (Al-Ansari and Kamel, 2008).

The narrow-band fading distribution at large fade depths in the average worst month for both quick planning and for the detailed planning purpose can be estimated based on recommendation ITU P.530-14 (2012) using the following procedures:

(i) estimating the Geoclimatic factor K;
(ii) calculating the magnitude of the path inclination; and
(iii) calculating the percentage of time that a certain fade depth A is exceeded in the average worst month, P_w.

The Geoclimatic factor K is estimated as earlier described in section 2 using equations (4) and (6).

The path inclination (η) can be determined from transmit and receive antenna heights h_t and h_r (m), above sea level and the path length d (km) from (ITU.R P.530-14, 2012):

$$|\eta| = \frac{|h_t - h_r|}{d} \quad (7)$$

Lastly, we estimated the percentage of time P_w that certain fade depth A (dB) is exceeded in the average worst month from:

$$P_W = Kd^{3.0}\left(1+|\eta|\right)^{-1.29} 10^{-0.0033f - 0.001h_L - A/10} \quad (8)$$

where P_w is the percentage of time that fade depth A (dB) is exceeded in the average worst month, f is the frequency (GHz), h_L is the altitude of the lower antenna (the smaller of h_t and h_r), d and K are path length and geoclimatic factor, respectively.

Due to the varying nature of the propagation medium, the knowledge of the probability of a fade depth of a particular magnitude to occur will lead directly to the probability of outage and hence the link availability probability, assuming the given fade depth leads to the received signal falling below the squelch level (Bogucki and Wielowieyska, 2009). The estimation of fade depth has been based on the above assumption using the ITU method.

4. SITE, INSTRUMENTATION AND DATA ANALYSIS

The experimental site for this study is the old Nigerian Television Authority (NTA) Transmitting station located at Iju in Akure North Local Government Area of Ondo State, Nigeria. The site is about 35 km by road from the campus of the Federal University of Technology Akure (7.17^{o}N, 5.18^{o}E). The device used for the measurement is the Davis Wireless Vantage Pro 2 Plus instrument equipped with the integrated sensor suite, a solar panel and wireless console in all the stations. The detailed description of the site and instrumentation set up are available in the works of Falodun and Ajewole, (2006); Adediji and Ajewole, (2008).

The data covering a period of 3 years (2011-2013) is used in the analysis. The equipment measures each of the parameters (air pressure, temperature, dew point temperature among others) at every 10 seconds and integrates over 30 minutes. It is therefore possible to evaluate the diurnal variations of the meteorological parameters (vertical profiles of air pressure, temperature, dew point temperature) over any time of the day. From the dew point values, the actual water vapour pressure, e (hPa) was calculated taking into account the temperature dependence of saturation vapor pressure. It is worth noting that there are few cases in some months where data was not available throughout the day due to system break down. However, such cases were only about 2% of all the data used and are therefore neglected.

Lastly, the statistics of the effects of propagation pertaining to that of worst month is essential in the design of radio communication systems.

5. RESULTS AND DISCUSSION

Figure 1 shows the monthly variations of point refractivity gradient for the three years and their averages. Results obtained indicate that the worst cases fall in the rainy months (July, September and October). The implication is that during these months, the refractivity gradient refracts more of the mean bending angle of the transmitted signals along the line-of-sight links which might lead to occasional or seasonal fluctuations of the signal at the receiving end depending on the level of the atmospheric turbulence (Freeman, 1997). In addition, the bending might enable the trans- horizon propagation of radio communication within the region, which may lead to interference on the wanted signal.

Figure 2 presents the yearly average of the point refractivity. The results reveal that the point refractivity gradient also varies annually. As shown in the figure, year 2013 has the lowest value of point refractivity gradient and the value becomes less negative in the preceding years.

As pointed out in Figure 1, the monthly variation of point refractivity gradient depends on season with worst months occurring mainly during wet season. Figs. 3 (a) and (b) show the seasonal values of point refractivity gradient with their corresponding geoclimatic factor, K values. The figures indicated that for the period of study, the worst month was in October which falls within the wet season months.

Table 2 also presents the geoclimatic factor, K and the effective earth radius factor (k-factor) variables for different months based on the 3 years of this study. The value of k - factor is required in radio link design to calculate the antenna height requirement and diffraction fade estimate, while the geomagnetic factor, K is applicable in fade depth calculation. The former has a standard value of about 1.33 for link design (Adediji et al., 2014a) while, the geoclimatic factor has no such value, but is determined by the climatic parameter of the location where link design requires (ITU-R P.453-9, 2003). However, as evident from the table, it reveals that using the recommended value of 1.33 for k-factor will not give the required antenna height for LOS link set up in location of interest. This may lead to an underestimation or overestimation of the link budget needed for the desired location.

As one of the objectives of this paper, we finally determined the value of fade depth exceeded for 0.01% of time based on equations (6) and (7) using the link parameters: $h_t = 134$ m, $h_r = 82$ m (Ojo et al., 2008) with varying frequency at a fixed hop length of 52 km as presented in Figure 4(a). Figure 4 (b) also presents the same value of fade depth exceeded in 0.01% with same link parameters by varying the path length. This value was determined at a single frequency of 12.25 GHz (Ku-band downlink frequency). The result is presented in Figure 4 (b). In Figure 4(a) for example, the probability that the fade depth exceeded increases rapidly with increase in frequency up to about 7 GHz thereafter maintain steady increase as the frequency increases. Figure 4(b) shows that path length is a function of the value of fade depth exceeded for 0.01% of the time. Longer path lengths experience higher values of fade depth exceedance. This is due to the fact that for long distance, multipath is more pronounced because of multiple reflections due to bending of radio beam by the more negative refractivity gradient (Odedina and Afullo, 2007). The fade depth exceeded for 0.01% of time can be estimated by logarithmic fits with very high coefficient of determination.

6. CONCLUSION

In this study, multipath fading has been examined in relation to the prevailing climatic conditions in Akure, South Western, Nigeria. Cumulative distribution of refractivity gradient in the first 100 m above the ground was determined, thereafter; the point refractivity gradient was estimated.

The worst month values of point refractivity gradient for Akure occurred in the month of October with an average value of about -175 N-Units/km, Geoclimatic factor K for the study location has then been predicted from the various values of point refractivity gradient. It was indicated that the geoclimatic factor which caters for geographical and climatic conditions in multipath fading distribution varies with the month, season and year. Finally, based on the link geometrical parameters used, the fade depth exceeded in 0.01% of time can be estimated by logarithmic fits with a very high coefficient of determination.

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References

1. A.T.Adediji, and M. O. Ajewole."Vertical profile of radio refractivity gradient in Akure, South-west Nigeria" Progress in Electromagnetics Research C, Vol. 4, 2008, pp. 157-168.
2. A.T. Adediji, Ajewole, M.O., Falodun, S.E. "Distribution of radio refractivity gradient and effective earth radius factor (k-factor) over Akure South Western Nigeria" J. Atmos. Sol. Terr. Phys. 73, 2011, 2300–2304.
3. A.T Adediji., J. S. Mandeep and M. Ismail, "Meteorological Characterization of Effective Earth Radius Factor (k-Factor) for Wireless Radio Link over Akure, Nigeria". MAPAN-Journal of Metrology Society of India 29(2), 2014a, pp. 131–141.
4. A.T. Adediji., Mohamed Ismail, J.S. Mandeep, "Variation of radio field strength and radio horizon distance over three stations in Nigeria". Journal of Atmospheric and Solar-Terrestrial Physics. 109, 2014b, pp.1–6.
5. K. Al-Ansari and R. A. Kamel. "Correlation between ground refractivity and refractivity gradient and their statistical and worst month distribution in Abu Dhabi" IEEE Antennas and Wireless Propagation Letters, Vol. 2, 2008, pp. 233-235.
6. O. Asiyo Mike and Afullo Thomas J. O, "Statistical Estimation of Fade Depth and Outage Probability Due To Multipath Propagation In Southern Africa. Progress in Electromagnetics Research B, Vol. 46, 2013, pp.251-274.
7. J. Bogucki,. and E. Wielowieyska, 2009. "Empirical season's fading's in radio communication at 6 GHz band. Journal of Telecommunications and Information Technology", vol. 2, 2009, 48-52.
8. A.A Dominguez. Benarroch, and J. M. Riera, 1998. Refractivity Statistics in Spain: First Results. Tech. Rep. CP52004, COST 255.
9. S.E Falodun and Ajewole M.O., "Radio refractivity index in the lowest 100 m layer of the troposphere in Akure, South-western

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Nigeria". Journal of Atmospheric and Solar-terrestrial Physics, 68, , 2006, pp.236-243.

10. R.L Freeman, 1997. "Radio System Design for Telecommunications", John Wiley & Sons, ISBN 978-0-471-75713-9.
11. M. Grabner, V. Kvicera, P. Pechac, and M. Mudroch, 2010. Multipath fading measurement and prediction on 10 GHz terrestrial link. Proceedings of 15th IEEE Conference of Microwave Techniques.
12. M. P. M Hall., 1989. Effect of the Troposphere on Radio Communication, IEEE Electromagnetic Wave Series, Peter Peregrinus Ltd, Stevenage, pp. 105–116.
13. K. C Igwe and I. A Adimula, "Variation of surface radio refractivity and radio refractive index gradients in the Sub-Sahel". Nig. J. of space research, Vol. 6, 2009, pp.135-144.
14. ITU- Rec P.453-8, 2003.The radio refractive index: Its formula and refractivity data.
15. ITU-R Rec 834-4, 2003. Effects of Tropospheric Refraction on Radiowave Propagation.
16. ITU-R P.530-14, 2012. Propagation data and prediction methods required for the design of terrestrial line-of-sight systems.
17. Odedina, P. K. and T. J. Afullo, 2007. Use of spatial interpolation technique for determination of geoclimatic factor and fade depth calculation in Southern Africa. Proceedings of IEEE AFRICON Conference, Windhoek, Namibia.
18. J.S Ojo, S.K Sarkar and A.T Adediji, "Intersystem Interference on Horizontally Polarized Radio Signals in Tropical Climate". Indian Journal of Radio and Space Physics, vol. 37, 2008, 408-413.
19. O.L Ojo., M. O. Ajewole, A.T. Adediji and J.S Ojo, "Microwave Anomalous Propagation Conditions in the First 100-m Altitude in a Tropical Location". Journal of Microwave Power and Electromagnetic Energy, 48 (2), 2014, 131-137.
20. R. L Olsen., 1999. Radioclimatological Modeling of Propagation Effects in Clear-Air and Precipitation Conditions: Recent Advances and Future Directions. Proceedings of the Third Regional Workshop on Radio Communications in Africa Radio Africa '99, Gaborone, Botswana.
21. R.L Olsen, and T. Tjelta, 1999. Worldwide techniques for predicting the multipath fading distribution on terrestrial LOS links: Background and results of tests. IEEE Transactions on Antennas and Propagation, vol. 47, No. 1.
22. R. L Olse., T. Tjelta, L. Martin, and B. Segal, 2003. Worldwide techniques for predicting the multipath fading distribution on terrestrial LOS links: Comparison with regional techniques. IEEE Transactions on Antennas and Propagation, vol. 51, No. 1.
23. O.D Oyedum. "Duct-Induced terrestrial microwave link degradation in Nigeria: Minimization factors", India Journal of Radio and Space Physics, vol. 41, 2012, pp.339-347.
24. I. E Owolawi, and Williams V.A. "Surface radio refractivity patterns in Nigeria and the Southern Cameroons", J. West Afri. Sc, Vol. 15, 1, 1970, pp. 3-17.

Table 1: Geoclimatic and *k* variables for different months

Months	Geoclimatic factor, *K*	*k*-factor
Jan	1.66E-04	1.14
Feb	1.41E-04	1.18
Mar	1.53E-04	1.36
Apr	2.45E-04	1.49
May	2.21E-04	1.66
Jun	2.53E-04	1.51
Jul	3.11E-04	1.69
Aug	2.18E-04	1.80
Sept	8.17E-04	1.34
Oct	8.92E-04	1.29
Nov	2.90E-04	1.31
Dec	1.32E-04	1.19

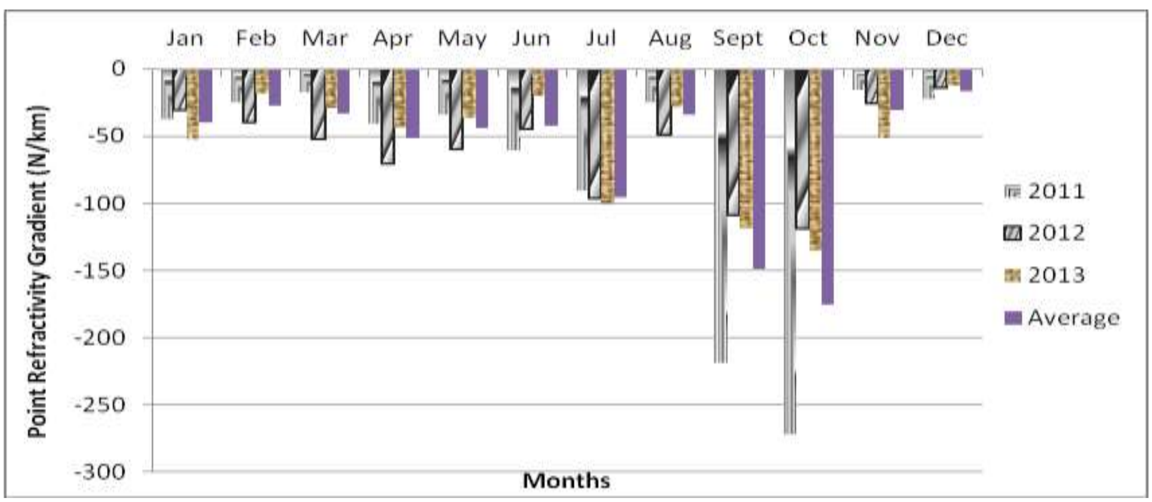


Figure 1: Monthly variation of point refractivity gradient in the lowest 100 m of the atmosphere not exceeded for 1% of an average year for Akure

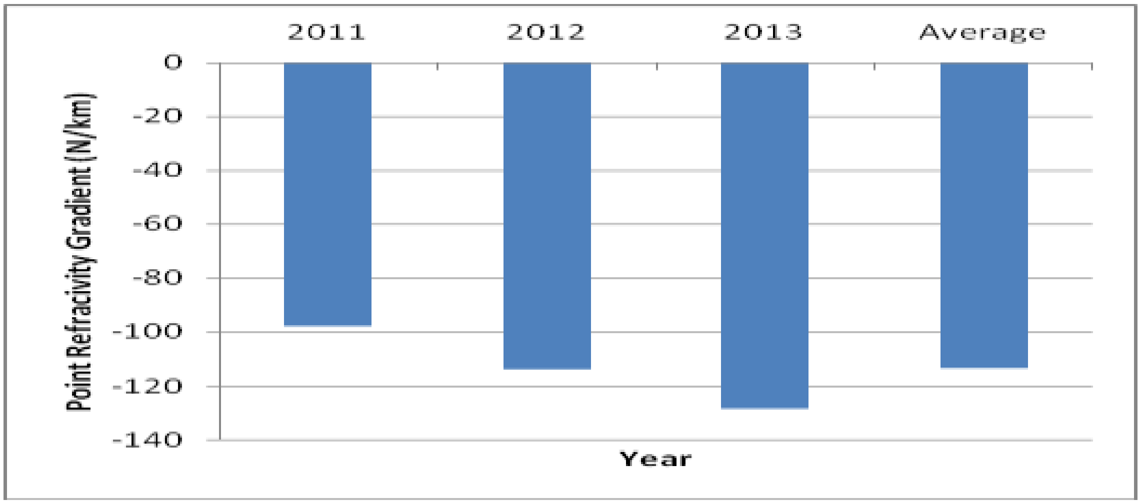
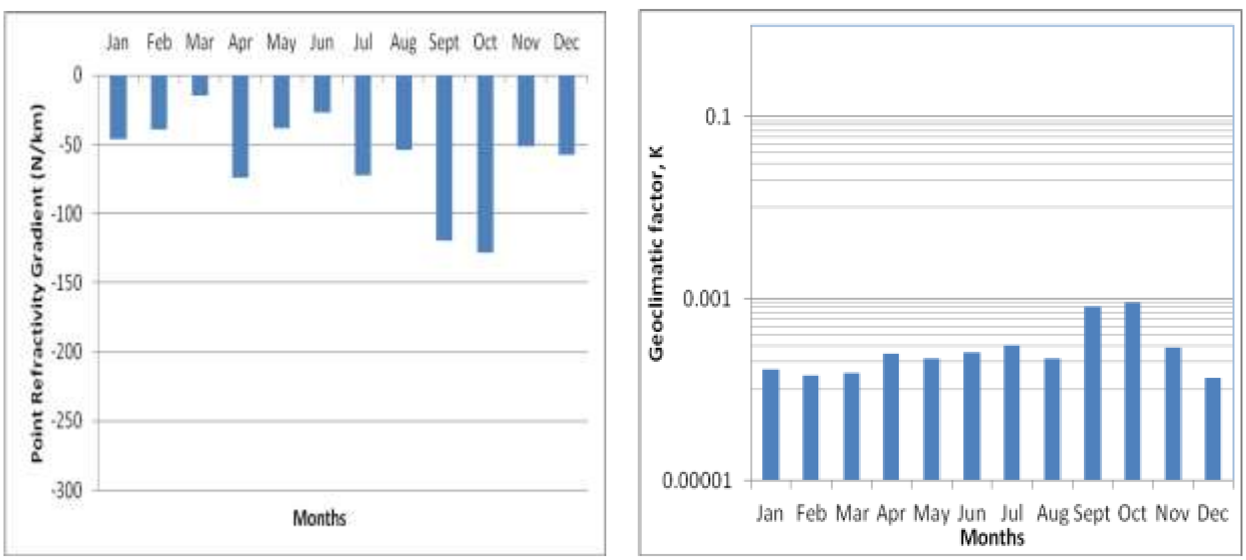


Figure 2: Yearly average of point refractivity gradient



(a) **(b)**

Figure 3: Seasonal variation of (a) point refractivity gradient in the lowest 100 m of the atmosphere not exceeded for 1% of an average year and (b) geoclimatic factor *K*.

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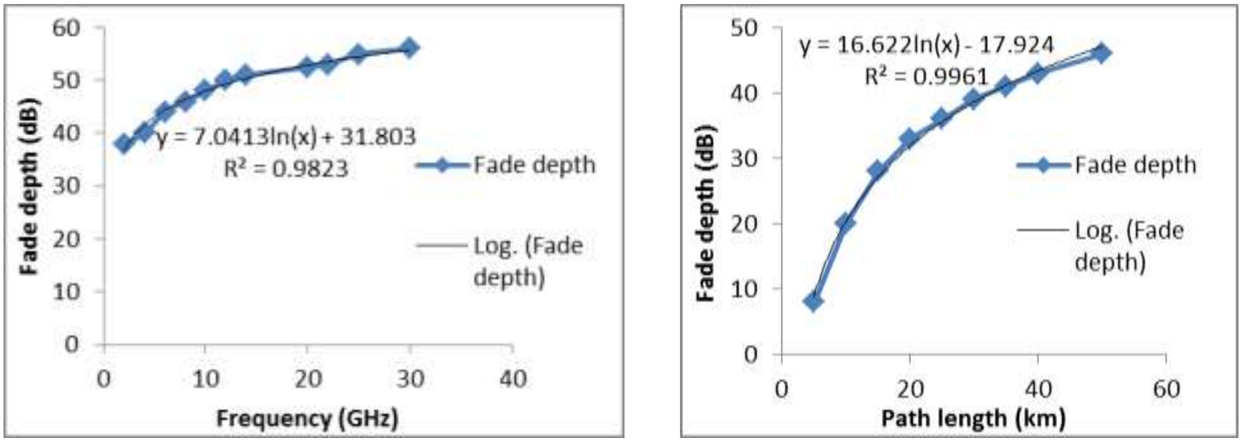

(a) (b)

Figure 4: Fade depth exceeded for 0.01% of the time (a) with varying frequency at fixed path length (52 km) and (b) with varying path length at fixed frequency (12.25 GHz).