Characterization of microwave fading over coastal cities of Nigeria.

E T Omotoso, J S Ojo, S E Falodun, A G Ashidi and A B Akinnagbe
Department of Physics, Federal University of Technology, Akure, Nigeria
e-mail: omotosoemmanuel13@gmail.com

Abstract. Atmospheric meteorological parameters (relative humidity, atmospheric pressure, and temperature) are unique due to the constant difference between them. This paper characterizes the fading associated with the microwave radio signals based on 10 years (2006 to 2015) re-analyzed data at 00 hours local time (LT), 06 hours LT, Noonday, and 18 hrs LT (synopsis hours) over seven (7) Coastal cities in Nigeria (Port-Harcourt, Warri, Calabar, Arogbo, Oron, Yenagoa and Lagos Island). The reanalysis data was obtained from the European Center for Medium-Range Weather Forecasts (ECMWF) at a resolution of 0.25 by 0.25 resolutions in the selected cities. Radio Refractivity (RR), Radio Refractivity Gradient (RRG), Point Radio Refractivity (PRR), and Geoclimatic Factor (GF) are obtained from the data. Fade Depth Percentages Exceedance (FDPE) that occurred at the study locations were deduced to determine the level of signal degradation at the microwave radio links over the coastal regions of Nigeria.

Keywords- Geoclimatic factor, Radio refractivity gradient, Fades Depth Percentage Exceedance, Radio refractivity.

1. Introduction
Multipath is regarded as a scenario that causes the radio propagation signal sent from a transmitting antenna to get to the receiving antenna by dual paths [1]. It can be caused by ionospheric reflection, reflection from terrestrial objects and water bodies, ionospheric refraction, and atmospheric ducting [2-4]. Propagation of multipath has negative effects on the signal transmission which includes phase-shifting of the signals, constructive and destructive interference. Fading is defined as the rapid differences in the amplitude and phases of a radio propagation signal over a short travel distance [5-6]. The effect of dual-path fading on terrestrial microwave radio signals such as the reduction in the amplitude of the signal, signal nulling, data corruption, and increased signal amplitude make estimating the multipath phenomenon more important [7, 8].

Although, several works have been carried out on fading due to multipath using meteorological parameters [6, 9-11], however, the dynamic nature of the atmospheric components requires a constant investigation especially at the coastal regions with unique features. Hence, this work focuses on the characterization of microwave radio fading based on the meteorological parameters (pressure, temperature, and relative
humidity) to assess the level of Radio Refractivity Gradient (RRG), Geoclimatic Factor (GF), Path Inclination (PL), and Fade Depth Percentages Exceedance (FDPE) for the worst-month scenario in the coastal cities of Nigeria.

2. Theoretical background

Radio refractivity is related to the refractive index, \( n \) of the atmosphere using [10]:

\[
N = (n - 1) \times 10^6 = \frac{77.6}{T} \left( P + 4810 \frac{e}{T} \right)
\]

where \( n \) represents the refractive index of the atmosphere, \( P \) denotes the atmospheric pressure (hPa), \( T \) is the temperature in Kelvin, \( e \) represents water vapour pressure (hPa), and \( N \) is the atmospheric refractivity.

The degree of the variation of radio refractivity with height is referred to as Radio Refractivity Gradient (RRG). RRG which is represented as \( dN/dh \) is of more concern to the designers of the Line of Sight (LoS) link. The atmospheric refractivity gradient that varies with height can only determine the multipath fading. Hence, RRG is calculated from [10] as:

\[
dN = \frac{N_2 - N_1}{h_2 - h_1}
\]

where \( N_1 \) is the atmospheric refractivity at height \( h_1 \) (2 m) and \( N_2 \) is the atmospheric refractivity at heights \( h_2 \) (100 m) [12, 13].

The Geoclimatic factor (GF), which is denoted as \( K \) is calculated using [13]:

\[
K = 10^{-(4.2 + 0.0029dN_1)}
\]

where the point refractivity gradient is denoted as \( dN_1 \) in equation (3).

Fade depth is can be expressed in decibels as reported in [13]. The path inclination, PL, which can be denoted as \( |\epsilon_p| \) is obtained using the expression [12].

\[
Path \text{ Inclination} |\epsilon_p| = \frac{|h_e - h_r|}{d}
\]

where the path length, \( d \) is assumed to be 52 km, \( h_e \) is the height of receiver antenna (82 m) and \( h_r \) is transmitter antenna height (134 m) above sea level as provided in [12].

In LoS propagation links, FDPE (\( P_o \)) is associated with the Geoclimatic factor (K), path length (d), and the station frequency (\( f \)) [13].

\[
P_o = Kd^3 (1 + |\epsilon_p|)^{-1.2} x e^{-0.033f - 0.001h_e} \%
\]

where the altitude of the lower antenna is represented as \( h_L \) and other parameters retains the usual meaning as earlier defined [13].

The percentage time that a given fade depth (\( P_t \)) exceeded over an average worst month in a year is:

\[
P_t = P_o x 10^{-A/10} \%
\]

where the fade depth at a specific values of 10 dB is represented as \( A \) is

3. Study location

The water area of Nigeria is about 13,000 sq km while the area covers by land are about 910,768 sq km [6]. The coastline of Nigeria facing the Atlantic Ocean is about 853km and lies between longitude 2°45' to 8°35' E and latitude 4°10' to 6°20'N. Figures (1a) and (1b) shows the map of Nigeria displaying the coverage areas of study and the selected sites (Coastal States) respectively.
4. Result and discussion

The specific parameters used for the calculations are as follows: 52 km for the Path length, 10 dB as the specific fade depth, the station frequency is 12.25 GHz, the transmitting antenna height is given as 134 m and 82 m is the receiving antenna heights [12]. Generally, the result shows that the FDPE attained the maximum value at Noonday while the off-peaks were observed at 00:00 hour LT. This dynamic nature of the FDPE may be linked to the activity of solar radiation. A decrease in relative humidity in the atmosphere leads to an increase in the temperature of the atmosphere due to an increase in the intensity of the solar radiation incident and vice versa.

![Maps of Nigeria showing (a) the study locations and (b) the specific study locations.](image1)

Figure 1: Maps of Nigeria showing (a) the study locations and (b) the specific study locations.

Figure 2 showed an example of the daily variation for all the study locations for FDPE at different hours on a typical day (April 1, 2010). The selected month is associated with the transition period from the dry to wet season. The result from Fig. 2 shows that at 00:00 hour LT, the FDPE ranged between 0.10% and 0.50% for the off-peak period; and at 06:00 hour LT, the values increased steadily between 0.20% and 0.90%. However, at Noon, FDPE increases sharply between 0.70% and 1.30%. In addition, at 18:00 hour LT, FDPE values sharply decrease between 0.20% and 0.50% for the studied locations.

![Figure 2: Daily variation of PDPE on a typical day (1st April, 2010).](image2)
At different seasons of the year (wet and dry season), the variation of PDPE was also examined for some selected stations namely; Oron, Warri Port Harcourt, and Yenagoa respectively as presented in Figures 3(a) to 3(d) at 6:00 hrs LT. Overall, the results showed that the dry season (December and January) recorded the minimum values, and June to August recorded the peak values. For example, in Fig 3a for Oron, peak values were observed in September while minimum values were observed between January and December. Warri recorded low values of PDPE in June while high values of PDPE were recorded in November and March as presented in Figure 3b. Port-Harcourt has low values in June while the peak values were observed in August and September as presented in Figure 3c. Yenagoa showed high values between September and October and low values in December and January as depicted in Figure 3d. The same pattern was observed in other locations although not presented in this report due to the paucity of space. The dynamic trends continue throughout the year.

Figure 3: Seasonal variation of PFDE in (a) Oron (b) Warri (c) Port Harcourt and (d) Yenogoa at 6 hours LT.
The values of PDPE for the study locations showed that peak values were obtained at Noon due to the high intensity of solar radiation and low values were recorded at 00:00, 06:00, and 18:00 hours LT. As presented in Figure 4(a-c), the result showed high values at different periods of the year, of 1.00% for Calabar, 2.00% for Arogbo, and 1.00% for Lagos-Island.

Figure 4: Annual variation of FDPE in (a) Arogbo, (b) Calabar and (c) Lagos-Island.

5. Conclusion
In this work, the distribution of PDPE was presented based on diurnal, seasonal and annual trends. The results indicated that lower values were recorded during the early morning at 00:00 hour, 06:00 hour and 18:00 hours LT while high values were obtained at noon. It was also observed that November to March
recorded the lowest values during the dry season due to low water vapor pressure in the atmosphere and high temperature during this period while April and October recorded the peak values in the wet season which may be attributed to low temperature and high water vapor pressure in the atmosphere. Generally, the results will assist microwave radio systems designers in the appropriate link-budgeting for the coastal regions of Nigeria.

Acknowledgment

ECMWF is appreciated for the availability of the satellite data.

References

[1] Adediji A T and Ajewole M O 2008 Vertical profile of radio refractivity gradient in Akure, South-West Nigeria Progress in electromagnetics research C 4 pp 157-68.
[2] Falodun S E and Ajewole M O 2006 Radio refractivity index in the lowest 100 m layer of the troposphere in Akure, South Western Nigeria Journal of atmospheric and solar–terrestrial physics 86, pp 236-43.
[3] Agarwal D P and Zeng Q A 2007 Introduction to Wireless and Mobile Systems (Nelson), (India: Thomas learning)
[4] Ghasemi A, Abedi A and Ghasemi F 2012 Propagation engineering in wireless communications 1st edition, (Springer science+business media, LLC, 233 Spring street, New York, NY 10013, USA)
[5] Barnett W T 2013 Multipath propagation at 4, 6, and 11 GHz, Bell system technical Journal, 51, Issue 2, pp 321–61
[6] Ugwu E B I, Umeh M C and Ugbonabo O J 2015 Microwave propagation attenuation due to earth’s atmosphere at very high frequency (VHF) and ultra-high frequency (UHF) bands in Nsukka under a clear–air condition. Int J of phys sciences 10 pp 359-63
[7] Barringer H M and Springer K D 2008 Radio wave propagation, (section 2: Broadcast towers and systems), pp 187-99.
[8] Haykin S and Moher M 2002 Modern wireless communications, Singapore (Pearson Education, Inc).
[9] Asiyo M O and Afullo J O 2013 Statistical estimation of fade depth and outage probability due to multipath propagation in Southern Africa. Progress in electromagnetic research B, 46, pp 251-74.
[10] Odedina P K and Afullo J O 2008 Estimation of secondary radioclimatic variables and its application to terrestrial LOS link design in South Africa. Proceeding of IEEE AFRICON conference, Wind coast Sun, South Africa.
[11] Odedina P K and Afullo J O 2007 Use of spatial interpolation technique for determination of geoclimatic factor and fade depth calculation in Southern Africa. Proceeding of IEEE AFRICON conference, Windhoek, Namibia.
[12] Ojo O L, Ajewole M O, Adediji A T and Ojo J S 2015 Estimation of clear-air fades depth due to radio climatological parameters for microwave link applications in Akure, Nigeria. Int J of eng and appl sci. Vol. 7, 03. ISSN 2305-8269.
[13] ITU-R P. 530-14 2012 Propagation data and prediction methods required for the design of terrestrial line of sight systems.