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ASSESSMENT OF FADE DEPTH AND GEOCLIMATIC FACTOR FOR MICROWAVE FREQUENCY APPLICATION IN ONDO CITY, NIGERIA.

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Abstract

Time series analysis of terrestrial microwave anomalous propagation conditions in the first 100 m altitude is presented in this research work , based on in-situ measurement of meteorological parameters (pressure, temperature and relative humidity) taken over Ondo , a tropical region in Nigeria. Two years measurement data (January, 2016-December, 2017) were used to compute the radio refractivity, its daily and seasonal variations. The analysis has been based on the dependence of average value of radio refractivity, N, on different times of the day for a particular year. The vertical radio refractivity gradient and the k-factor were also deduced over this region based on the results of the analysis. The results generally show that N-values for the wet months were higher than the values in the dry months. Further results revealed a distinct relationship between the point refractivity gradient dN_1 and the geoclimatic factor (K). The overall results will be useful for the determination of optimum performance of digital terrestrial point to point links in the region.

***Keywords*:** Microwave Link, anomalous propagation, refractivity gradient, k-factor, geoclimatic factor.

1. INTRODUCTION

The importance of digital microwave links for the provision of communication services such as video, data and voice transmissions cannot be overemphasized. Among the communication services, terrestrial line-of-sight microwave links have been playing a very important role in long distance communications since the 1950s. With the development of digital technology and the need for modern satellite telecommunications, higher reliability and better performance of microwave links are needed for the transmission of high quality signals. As a signal transmission medium, the lowest part of the atmosphere directly affects the propagation of microwaves between the terminals of a microwave link. Propagation paths of electromagnetic waves are highly affected by the refractivity of the atmosphere, since the paths of propagation links are not a straight line [1]. Hence, anomalous behavior of atmospheric parameters such as temperature, pressure and relative humidity as well as clouds and rain, influence by the radio waves behaves in the troposphere [2].

In the recent time, several research works have been reported in the temperate regions [3,4] to mention but few. At the tropical region too, attempts have been made by a few researchers [5-9].

The main goals of this paper are to analyze the dependence of the average value of radio refractivity, *N*, on different times of the day during the year at Ondo, western part of Nigeria in order to examine the vertical radio refractivity gradient and k-factor needed for digital terrestrial point to point radio circuit designing.

2. Background

The radio refractivity *N* as a measure of deviation of refractive index n of air from unity and scaled up in parts per million can be expressed as:

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

where *N* is dimensionless, and also depends on other meteorological parameters such as atmospheric pressure, P (hPa), temperature, *T* (K) and partial water vapor pressure, e (hPa). These parameters are related to *N* using the expression:

$$N = \frac{77.6P}{T} + 3\times 10^5 \frac{e}{T^2} \qquad (2)$$

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where the parameter e is related to relative humidity, H (%) by:

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

e_s is the saturated vapor pressure at the given air temperature T °C, and can be obtained through:

$$e_s = 6.112e^{\left[\frac{17.502T}{(T+20.97)}\right]} \qquad (4)$$

According to [11], equations (1) - (4) are valid only for all radio frequencies up to 100 GHz with less than 0.5% error.
While, the radio refractivity gradient G (km^{-1}) in the upper air is also expressed as:

$$G = \frac{N_1 - N_2}{h_1 - h_2} \qquad (5)$$

where N_1 and N_2 are radio refractivity values at heights h_1 and h_2 respectively.
The effective earth radius factor k is finally deduced using:

$$k = \left[1 + \left(\frac{dN}{dh}\right)/157\right]^{-1} \qquad (6)$$

2.1 Calculation of the Geoclimatic Factor, *K*

The Geoclimatic factor, K (for quick planning) can be determined based on the procedure given in [11],

$$K = 10^{-4.2-0.0029dN_1} \qquad (7)$$

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.

2.2 Estimation of Fade depth

The narrow-band fading distribution at large fade depths in the average worst month for both quick planning and for detailed planning purpose can be estimated based on recommendation,[11]:
The following steps are used in the calculation
(i) estimating the Geoclimatic factor K,
(ii) calculating the path inclination; and
(iii) calculating the percentage of time that a certain fade depth A is exceeded in the average worst month

- (i) The Geoclimatic factor K is estimated as earlier described using equation (7).
- (ii) Path inclination η (m) can be determined from transmitting and receiving antenna heights h_t and h_r (m), above sea level and the path length d (km):

$$|\eta| = \frac{|h_t - h_r|}{d} \qquad (8)$$

- (iii) The percentage of time that a certain fade depth A is exceeded in the average worst month, P_w is also estimated using [12]:

$$P_W = kd^{3.0}\left(1+|\eta|\right)^{-1.2}10^{-0.0033f-0.001h_L-A/10} \qquad (9)$$

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.
Lastly, the percentage of time P_o that any fade depth A is exceeded for all shallow fading down to 0 dB is given as [12]:

$$P_o = Kd^{3.0}\left(1+|\eta|\right)^{-1.2}10^{-0.0033f-0.001h_L} \qquad (10)$$

where all parameters retain the usual notation with $A = 0$
The actual value of fade depth, A_t at which the transition occurs between the deep-fading distribution and the shallow-fading distribution is therefore given as [12]:

$$A_t = 25 + 1.2\log P_0 \qquad (11)$$

The procedure now depends on whether A is greater or less than A_t.
If the required fade depth, A, is equal to or greater than A_t:
The percentage of time that A is exceeded in the average worst month is calculated using:

$$P_w = P_o \times 10^{-A_t/10} \qquad (12)$$

Note that equation (12) is equivalent to equation (10) or (11), as appropriate.
If the required fade depth, A, is less than A_t:

The percentage of time, p_t, that A_t is exceeded in the average worst month is calculated using:

$$P_t = P_o \times 10^{-A_t/10} \quad (13)$$

Note that equation (13) is equivalent to equation (10) or (11), as appropriate, with $A = A_t$.

To calculate $q_a^{\ 1}$ from the transition fade A_t and transition percentage time P_t:

$$q_a^{\ 1} = -20\log 10\left[-1n\{(100 - P_t)/100\}\right]/A_t \quad (14)$$

Calculate q_t from $q_a^{\ 1}$ and the transition fades A_t:

$$q_t = \left(q_a^{\ 1} - 2\right)/\left[\left(1 + 0.3\times 10^{-A_t/20}\right)10^{-0.016A_t}\right] - 43\left(10^{-A_t/20} + A_t/800\right) \quad (15)$$

Calculate q_a from the required fade A:

$$q_a = 2 + \left[1 + 0.3 + 10^{-A/20}\right]\left[10^{-0.016A}\right]\left[q_t + 4.3\left(10^{-A/20} + A/80\right)\right] \quad (16)$$

where q_a and $q_a^{\ 1}$ are the constant parameters needed to calculate the fade depth and enhancement.

Calculate the percentage of time, p_w, that the fade depth A (dB) is exceeded in the average worst month:

$$P_w = 100\left[1 - \exp\left(-10^{-q_a A/20}\right)\right] \quad (17)$$

Provided that $p_o < 2\,000$, the above procedure produces a monotonic variation of p_w versus A which can be used to find A for a given value of p_w using simple iteration.

3. Study area, Instrumentation and Data analysis

The study area is Ondo city in Ondo State, Nigeria. The city lies in the low latitude 7° 10″ N and longitude 5° 05″ E. Ondo State enjoys two main noticeably different seasons (dry and wet seasons) which is one of the properties of West Africa monsoon climate, marked by different seasonal shift in the wind pattern. The rainy season occurs between March and October; while the dry season occurs from November to February when the dry dust laden winds blow from Sahara desert. Dry dust-laden Harmattan wind blow most strongly between December and January and early morning moist occurs which persists for about an hour or two after sunrise before the sun burst through and quickly rolls the mist away.

The experimental site for this work is located at Adeyemi College of Education, Ondo and the weather stations were placed at 100 m height on top of School of Sciences building. The weather station used for the in-situ measurement is the Davis 6162 Wireless Pro2 Plus equipped with the Integrated Sensor Suite (ISS), a solar panel (with an alternative battery source) and the wireless console. The weather parameters are collected by the ISS and remotely sent to the vantage Pro2 console. The ISS used in this work contains a rain collector, temperature sensor, humidity sensor and anemometer. It also adds a solar radiation sensor and a ultra-violet (UV) sensor. Temperature and humidity sensors are mounted in a passive radiation shield to minimize the impact of solar radiation on the sensor readings. The anemometer measures wind speed and direction while the solar and UV sensors are mounted next to the rain collector cone. Generally, the ISS houses the sensors for pressure, temperature, relative humidity, UV index and dose, solar radiation, among others and the sensor interface module (SIM). The SIM is located in front of the radiation shield and contains electronics that measure and store values of the weather variables for transmission to the console remotely [7] and [8]. In order to extract the stored data, the console is connected to a computer. The error margin of the ISS device for temperature, pressure and relative humidity are ±0.1 °C, ±0.5 hPa and ±2 % respectively. The fixed measuring method by a high tower was employed for the measurement with one sensor placed at the ground level for surface measurement, and the others at the altitudes of 50 m and 100 m on the tower for continuous measurement. Other detailed description of the equipment is available in the work of Ojo et al., [9] and not reiterated here for the sake of paucity of space. Figure 1 (a and b) displays the integrated sensor suite and the console respectively.

The 2-year measured data (January 2016 – December 2017) were used in this work. The measured pressure, temperature and humidity at the surface 50 m and at 100 m heights were analyzed at the different hours of the day: 0:00 h, 6:00 h, 12:00 h and 18:00 h (all times are local). Averaging each of the hours to achieve 24 hours data were also done for the diurnal variation over each month and seasonal. Other analyses were based on a case study of the month of July, 2018 with high humidity and wide range of temperature variation as earlier noticed in the work of Ojo *et al.* [2] .

Fig. 1: The experimental set-up (a) the integrated sensor suite and (b) the console

4. RESULTS AND DISCUSSION

Figure 2 shows the monthly average plot of radio refractivity, N, for the year for different time windows. It could be observed that in all the time windows of the day considered, there is a sharp drop in the values of *N* in January and November. These two months signify the peak of dry months in the area. However, the result truly shows seasonal variation over the study area as earlier reported by Adediji and Ajewole, [8] and Ayantunji, et al., [12]. It could also be observed that the maximum values of *N* averaged over the month occurred between 12 and 18 hrs LT and the minimum *N* values occurred at 18:00 hrs LT time during the year. The results generally show that *N*-values for the wet months were higher than the values in the dry months.

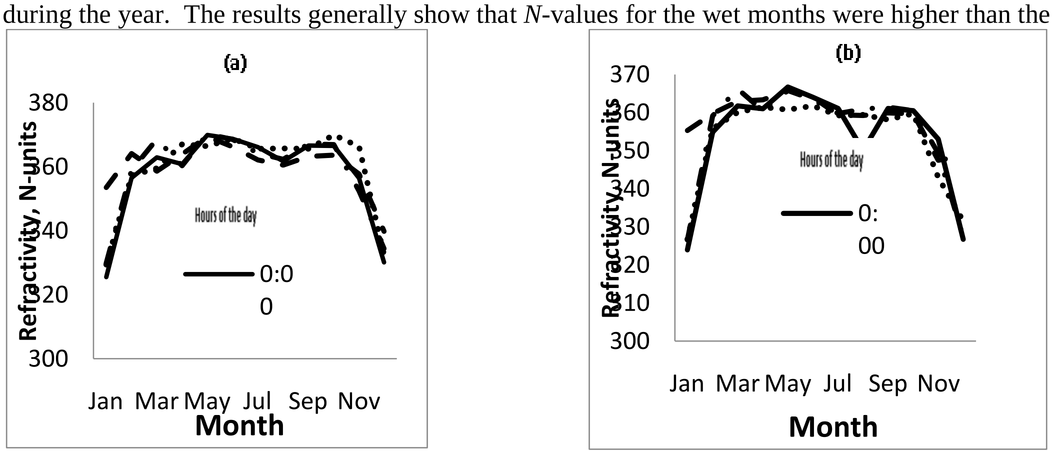


Fig. 2: The dependence of the monthly average value of radio refractivity, at (a) surface and (b) 100 m heights for different time windows of the day and season in the year.

Figure 3 also shows the vertical profile of the dependence of the average values of air temperature (T) and the partial water vapor (e) from 6:00 to 18:00 hrs LT between July 7 and 15, 2017. This period was chosen because of the occurrence of rain and high humidity. It could be observed that the two parameters decrease with height above sea level. A noticeable occurrence of a decrease in air temperature was observed at 6:00 hrs LT at 100 m height, beyond it, there was a slight increase in partial water vapor at 6:00 hrs and height of 100 m. This is a reversed of what was earlier observed at Akure [2].

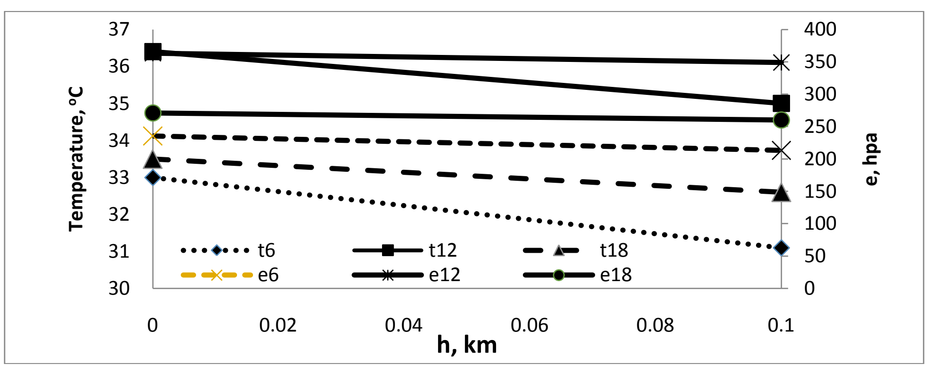


Fig. 3: Variation of the average values of the air temperature, **t** and the partial water vapor, **e** with the height above the earth surface between July 7 and 15, 2017.

Table 1 presents the result of mean monthly variation of *k* factor in the observed year. The mean values were derived from the values obtained between 6:00 and 18:00 hrs LT. The observed monthly mean had a minimum value of 0.4513 for the k-factor in the month of January, whereas the monthly mean observed maximum value of k-factor was 2.3659 and occurred in the month of October. Also, the minimum values of k-factor averaged over the month were at 6:00 LT and the maximum values averaged over the month were at 18:00 hrs LT during the year analyzed here. It could also be observed that the k-factor is low in the dry months (Jan-Mar; Nov-Dec), while the values rise during the wet months. These results agree well with the result earlier obtained by Falodun and Ajewole [6].

Table 1: Monthly mean value of *k*-factor between 6:00 and 18:00 hrs LT

	Time of the day			
Month	06:00 hrs LT	12:00 hrs LT	18:00 hrs LT	Mean-value
Jan	0.6821	0.4513	2.5697	1.2344
Feb	1.0043	1.1393	1.2054	1.1163
Mar	1.4556	1.2030	0.4266	1.0284
Apr	1.5304	1.0118	2.3291	1.6035
May	2.2454	1.1768	3.4389	2.2870
Jun	2.5051	1.5086	2.1767	1.3934
Jul	1.3749	1.4701	3.1903	2.0118
Aug	1.1818	1.1695	4.8331	2.3948
Sep	1.4104	1.8567	1.6783	1.6485
Oct	1.4563	1.9095	3.7428	2.3695
Nov	1.6585	1.4664	0. 4520	1.0280
Dec	0.4533	0.5813	0.9459	0.6602

The result of the computed radio refractivity data were used to calculate the refractivity gradient for the first 100 m of the atmosphere. From the result of the gradient, the variable of interest dN_1 in equations (8) was determined. The corresponding geoclimatic factor (*K*) was then calculated using equation 3.12 and the results are shown in Figures 4 over Ondo. It can be observed (see Figure 4) that a distinct relationship exists between the point refractivity gradient dN_1 and the geoclimatic factor (*K*). It is observed that as the value of dN_1 becomes more negative the geoclimatic factor increases.

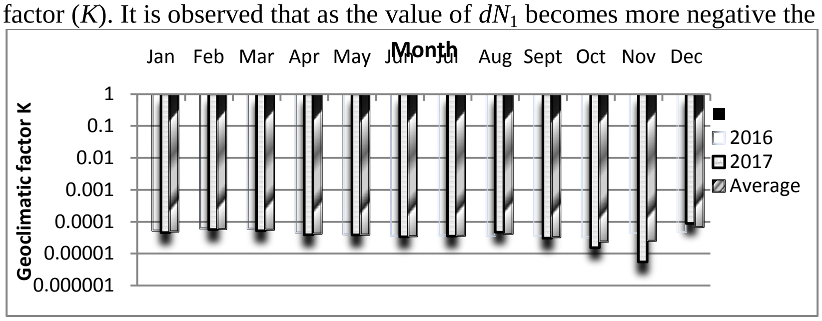
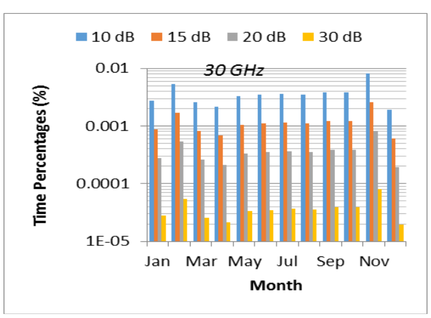
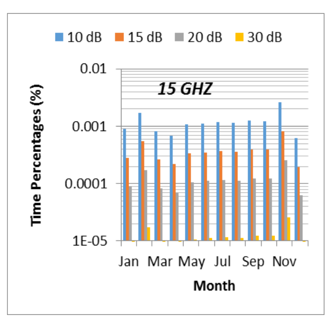
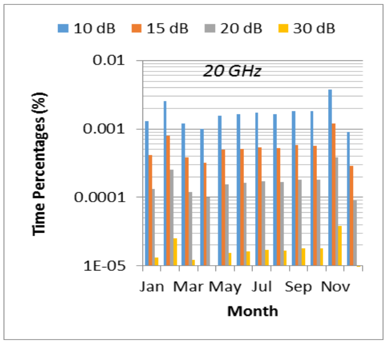


Figure 4: Yearly variability of Geoclimatic factor *K* for multipath fading prediction over Ondo.

Finally, Figure 5 shows seasonal variation of the percentage of time various values of fade depth are exceeded for Ondo. It can be seen that in all the cases, the percentage of time that a certain fade depth occur varies from season to season. For this reason, ITU-R 530-14, [11] recommends
planning around the worst month.







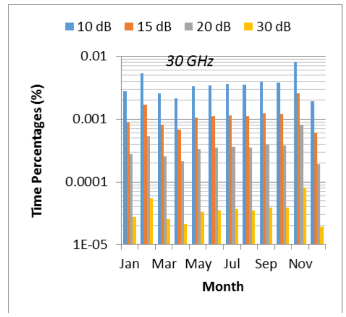


Figure 5: The percentage occurrence of fade depth over Ondo at 10, 15, 20 and 30 GHz frequency

CONCLUSION

Recent results of the investigation of microwave anomalous propagation conditions in the first 100-m height in a tropical region-, Ondo, Southwestern, Nigeria have been presented. The results generally show that *N*-values for the wet months were higher than the values in the dry months. A noticeable occurrence of a decrease in air temperature was also observed at 6:00 hrs LT at 100 m height, beyond it, there was a slight increase in partial water vapor at 6:00 hrs and height of 100 m. This is a reversed of what was earlier observed at Akure. It was observed that the observed monthly mean had a minimum value of 0.4513 for the k-factor in the month of January, whereas the monthly mean observed maximum value of k-factor was 2.3659 and occurred in the month of October. It could also be observed that k-factor is low in the dry months (Jan-Mar; Nov-Dec), while the values rise during the wet months. It can be observed that a distinct relationship exists between the point refractivity gradient dN_1 and the geoclimatic factor (K). The percentage of time that a certain fade depth occur varies from season to season. For this reason, ITU-R 530-14, [11] recommends planning around the worst month in the study location.

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