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# Estimation and Comparative Analysis of Atmospheric Refractivity and Fade Depth for Microwave Links in Calabar

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**Abstract:** Generally, to radio link engineers, determination of fade depth and refractivity of propagation links remains very significant, especially, during radio propagation planning. It gives a good insight into the expected performances of the communication link and serves as bedrock to improve on Quality of Service (QoS). In this paper, three years (2012 to 2014) radiosonde atmospheric parameter data from Nigerian Meteorological Agency was used to determine the point refractivity gradient along with fade depth for Calabar, in Cross River state of Nigeria. In respect of the refractivity gradient for Calabar, the results showed the highest occurrence is in January with refractivity gradient of -33.0018 N units and the lowest refractivity gradient occurred in August with value of -305.2692 N units. Furthermore, the fade depth from the three different International Telecommunication Union (ITU) models; namely, ITU-R P.530-16 model, ITU-R P.530-14 model, and ITU-R P.530-9 model also indicated monthly and seasonal variations, with yearly average values of 139.74576 dB, 129.79196 dB and 154.57691 dB respectively.

**Keywords:** Refractivity, Refractive Gradient, Fade Depth, Multipath Fading, Microwave Link

## 1. Introduction

Over the years, line-of-sight (LoS) microwave communication systems have been widely used in civil and military operations. Terrestrial fixed radio links operating at microwave frequencies on line of sight paths are flexible, reliable and economical means of providing point to point communications [1]. Consequently, diverse terrestrial communication systems in microwave frequency bands are increasingly being use for various applications such as data, video and voice.

In view of it importance and wide applications, researchers and practitioners have done extensive studies on the essential factors that must be considered in order to realize large capacity and high quality microwave communication systems. Notably, the atmosphere, which is the main medium of propagation for LoS microwave signal, varies in its refractive indices; the atmosphere refractive index varies with atmospheric height, giving rise to refractive gradient in the various atmospheric layers. Among other things, the refractive gradient of the atmosphere causes variations in the multipath fading. In addition, the atmospheric refractive gradient is greatly affected by the specific nature of the environment; different terrain gives rise to different refractive gradient. Hence, microwave communication equipment designed for use in the temperate region may not be suitable in the tropics because the characteristics of the different layers of the atmosphere as the medium of propagation differ appreciably [2]. Therefore, it is of immense importance to gain a good insight of this atmospheric variation in refractive index for proper radio propagation planning. The propagation of radio waves in the atmosphere is affected by, especially its vertical profiles or vertical distribution of the refractive index of the air [3]. In this paper, three years (2012 to 2014) radiosonde atmospheric parameter data from Nigerian Meteorological Agency is used to determine the point refractivity gradient along with fade depth for Calabar, in the South South part of Nigeria. The purpose is to examine variations in the refractive gradient and fa` de depth due to the site specific atmospheric conditions in Calabar which is located in the south-south part of Nigeria.

## 2. Review of Relevant Literatures

Various atmospheric mechanisms, such as refractivity index and multipath propagation do occur in wireless communication links and these atmospheric phenomena have detrimental effects on the radio propagation. According to Valma et al. [4] radio refractivity index refers to the ratio of velocity of the radio wave propagation in free space to its propagation velocity in a given medium. The value of radio refractivity index is usually greater than unity by a small fraction [5] Close to the earth's surface, the radio refractivity index (n) is about 1.000312 at standard atmospheric environments [5].

In practice, atmospheric refractivity, N (N-units) is generally applied [6]. The variation in refractivity index gives rise to refractive gradient which contributes to multipath fade depth and the link percentage outage due to multipath fading. Clear-air fading mechanism due to extreme refractive layers in the atmosphere includes beam spreading, antenna decoupling, surface multipath and atmospheric multipath effects [1]. Particularly, multipath fading is caused by atmospheric variation which occurs randomly. Hence, prediction of multipath fading can be effectively done by statistical method. Several multipath fading prediction techniques have been in use over the years, namely, Barnett Vigant, Morita, ITU methods, among others. In all, the ITU method remains the worldwide prediction method for multipath fading.

## 3. Methodology

In this paper, three years (January 2012 to December 2014) radiosonde data are obtained from the Nigerian Meteorological Agency (NIMET). Particularly, the radiosonde data are acquired in clear air (that is no rain, fog, hail, etc) at the interval of six (6) seconds from ground level to the height of eight hundred meres (800m). The measurement are obtained in Calabar in the Cross River state of Nigeria. However, it is also of great significance to note that the major parameters obtained include temperature, pressure and relative humidity. The monthly mean refractivity values for each of the altitude levels are also computed using the measured atmospheric parameters. Inverse distance weighting spatial interpolation technique is used to obtain the missing data items. Refractivity can be computed as follows [7, 8, 9, 10,11,13,14,15]:

$$N = (n-1)(10^6) \tag{1}$$

$$\mathrm{N} = \frac{77.6}{\mathrm{T}}\left(\mathrm{p} + 4810\left(\frac{\mathrm{e}}{\mathrm{T}}\right)\right) \tag{2}$$

$$\mathrm{e} = \frac{6.112\,(\mathrm{H})}{100}\exp\left(\frac{17.5\,\mathrm{t}}{\mathrm{t}+240.98}\right) \tag{3}$$

Atmospheric pressure is denoted as p

Temperature in (Kelvin) is denoted as T

Atmospheric vapour pressure is denoted as e

In Eq 3, Humidity is denoted as H

Also, for each of the locations, the Point refractivity gradient is computed as follows [7, 8, 9, 10]:

$$\mathrm{dN_1} = \left(\frac{\mathrm{N_2}-\mathrm{N_1}}{\mathrm{h_2}-\mathrm{h_1}}\right) \tag{4}$$

where $\mathrm{N_1}$ is the lower atmospheric refractive index; $\mathrm{h_1}$ lower height; $\mathrm{N_2}$ upper atmospheric refractive index; and $\mathrm{h_2}$ upper height.

The Geoclimatic factor, K (for quick planning) can be determined based on the procedure given in each of the selected ITU models, where $\mathrm{dN_1}$ is the point refractivity gradient in the lowest 65m of the atmosphere not exceeded for 1% of an average year (Ojo, Ajewole and Adediji, 2015). Hence, according to ITU-R P.530-16, for quick planning applications the geoclimatic factor, K can be estimated as [15]:

$$K = 10^{(-4.6-0.0027dN_1)} \tag{5}$$

Also, for detailed design applications using ITU-R P.530-16, the percentage of time pw that fade depth A (dB) is exceeded in the average worst month can be estimated [15]:

$$P_w = K(d^{3.4})\left(1+|\varepsilon_p|\right)^{-1.03}(f^{0.8})10^{\left(-0.0076h_L-\left(\frac{A}{10}\right)\right)}\ \% \tag{6}$$

where:

f is the frequency (GHz) and $\mathrm{h}_L$ is the altitude of the lower antenna (i.e. the smaller of he and hr); where K is obtained from equation (5). Also, for detailed design applications using ITU-R P.530-14, the percentage of time pw that fade depth A (dB) is exceeded in the average worst month can be estimated as [16]:

$$P_w = K(d^{3.0})\left(1+|\varepsilon_p|\right)^{-1.2}10^{\left(0.033f-0.001h_L-\frac{A}{10}\right)}\ \% \tag{7}$$

where K is obtained from equation (5).

Similarly, according to ITU-R P.530-9, for quick planning applications the geoclimatic factor, K can be estimated as [17]:

$$K = 10^{(-4.2-0.0029dN_1)} \tag{8}$$

Again, for detailed design applications using ITU-R P.530-9, the percentage of time pw that fade depth A (dB) is exceeded in the average worst month can be estimated as [17]:

$$P_w = K(d^{3.2})\left(1+|\varepsilon_p|\right)^{-0.97}10^{\left(0.032f-0.0085h_L-\frac{A}{10}\right)}\% \tag{9}$$

where K is obtained from equation (8).

Let the antenna heights be $\mathrm{h}_t$ for the transmitter and $\mathrm{h}_r$ for the receiver; then the magnitude of the path inclination |εp| (mrad) is calculated as follows:

$$|\varepsilon_p| = \frac{(h_r - h_t)}{d} \tag{10}$$

where d is the path length (km).

# 4. Results and Discussion

***Table 1.*** *Fade depth, refractivity gradient and geoclimatic factor for different months in Calabar.*

| Month | ITU-R P.530-9 (dB) | ITU-R P.530-14 (dB) | ITU-R P.530-16 (dB) | DN |
|---|---|---|---|---|
| January | 137.7881 | 127.8343 | 152.6192 | -33.0018 |
| February | 135.6648 | 125.711 | 150.496 | -74.3628 |
| March | 143.8243 | 133.8705 | 158.6554 | -256.5646 |
| April | 139.9029 | 129.9491 | 154.7341 | -111.3291 |
| May | 137.5847 | 127.6309 | 152.4158 | -25.4683 |
| June | 135.6963 | 125.7425 | 150.5275 | -75.5295 |
| July | 137.9404 | 127.9866 | 152.7715 | -38.6429 |
| August | 138.9383 | 128.9845 | 153.7694 | -75.6012 |
| September | 139.3949 | 129.4411 | 154.2261 | -92.5154 |
| October | 141.9421 | 131.9883 | 156.7733 | -186.856 |
| November | 145.1393 | 135.1855 | 159.9705 | -305.2692 |
| December | 143.133 | 133.1792 | 157.9641 | -230.9606 |
| Yearly Average | 139.74576 | 129.79196 | 154.57691 | -125.50845 |

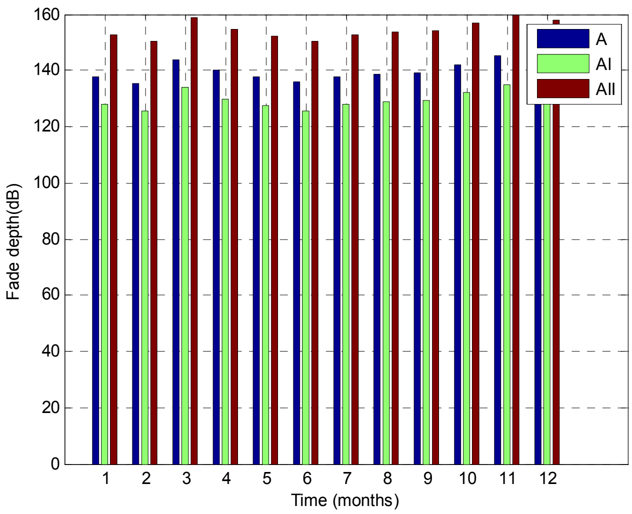


***Figure 1.*** *Fade depth for different months in Calabar.*

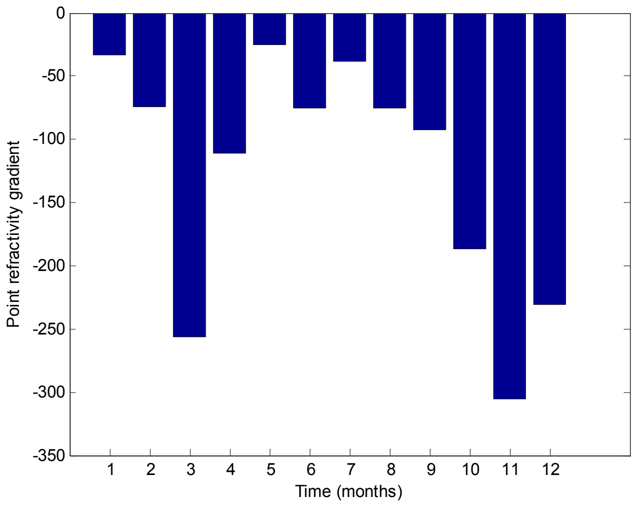


***Figure 2.*** *Point refractivity gradient for various months in Calabar.*

For ITU-R P.530-9, the least fade depth occurs in February with 135.6648 dB and the highest fade depth of 145.1393 dB occurred in November. However, high fade occurrence are mainly observed between the months of October and December which can be deduced that there is high fade depth in this period due to the occurrence of high atmospheric activity within the period. The ITU-R P.530-14 detailed planning model shows that the lowest fade occurrence is mostly experienced in the month of June with 125.7425dB and the highest in November with 135.1855dB. The distribution also shows a relative increase in fade occurrence between July and December but are higher in fade as compared to ITU-R P.530-9. ITU-R P.530-16 model shows that the least fade occurrence takes place in June with 150.5275dB which is high as compared to previous two models. The highest fade also occurred in November with 159.9705dB which appears high when compared with the other two ITU-R models considered. The months of May to November also show a relatively higher fade occurrence due to higher air pressure and water vapour in the atmosphere in those months.

The refractivity gradient $(dN_1)$ distribution for Calabar (Table 1) shows that for Calabar, $dN_1$ ranges between -305.2692 to -33.0018 across the twelve months distribution. The highest refractivity gradient occurs in January with -33.0018N-units and the lowest in August with -305.2692 N-units. It is also seen from Table 1 that $dN_1$ is relatively high between May and September which are particularly rainy season months.

# 5. Conclusion

Three years radiosonde atmospheric parameters datasets made available by Nigerian Meteorological Agency are used to determine the point refractive gradient and fade depth in Calabar. Three ITU multipath fade depth models are considered in the paper, namely; recommendation ITU-R P.530-16 model, ITU-R P.530-14 model, and ITU-R P.530-9 model. The fade depth results show variations between 125.71dB and 159.9705dB and the point refractivity gradient varies between -305.2692 and -33.0018 N-gradient. Finally, the refractivity gradient $(dN_1)$ tends to be higher in the rainy season months.

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