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MONTHLY CLASSIFICATION OF TROPOSPHERIC REFRACTION AND DUCT HEIGHT NEAR SEA–LEVEL, LAGOS STATE OF NIGERIA

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Abstract: The effect of evaporation ducting on millimeter electromagnetic wave on sea surface may lead to path loss, poor line of sight and sometime complete loss of signal due to refraction in shadow zone and noise in the signal. In Nigeria, the refractive gradient varies due of the significant change in climatic condition from the coastal region to southern region through semi–arid region and to the northern region. These effects are more pronounced in Lagos, which fall in a coastal region in Nigeria. The data used for the study were collected from NIMET in Lagos state. This study characterized the monthly variation of refraction types' base on refractivity gradient and estimates the evaporation duct height using P–J model technique. The evaporation ducting only occurred in few months and the mean height is 14.52$\pm$0.52m with standard deviation of 1.80m.
Keywords: P–J model, duct height, refractive gradient, refraction types

1. INTRODUCTION

Radio propagation is affected by many factors such as: Free space loss, Absorption losses, Diffraction, Multipath, Terrain, Buildings and vegetation, and Atmosphere. The structure of the radio refractive index, n, at the lower part of the atmosphere is a very important parameter in planning of the communication links. The atmosphere which is the propagation medium for radio transmission is characterized by different refractive indices at different levels (Oyedum and Gambo 1994). At standard atmosphere conditions near the Earth's surface, the radio refractive index is equal to approximately 1.0003 (Freeman L., 2007). According to Grabner and Kvicera (2008), multipath effects also occur as a result of large scale variations in atmospheric radio refractive index having different horizontal layers of refractivity. Since the value of refractive index is very close to unity, then the refractive index of air in the troposphere is often measured by a quantity called the radio–refractivity N, which is related to refractive given as $N = (n-1) \times 10^6$ (Willoughby et al., 2002; ITU–R, 2003).

The atmosphere which is the propagation medium for radio transmission is characterized by different refractive indices at different levels (Oyedum and Gambo 1994). These are associated with the change in weather in different seasons of the year. And these variations in meteorological parameters have resulted in refractivity changes. The variation of refractive index is very significant in Nigeria because of the significant change in climatic condition from the coastal region southern region, through semi–arid region and to the northern region. The important meteorological parameters which influence this are the pressure, humidity and temperature, that lead to variation of vertical gradient from the troposphere and caused the radio wave propagation to bend along its path and the extent to which this changes occur with time gives rise to different refraction types.

The refractive gradient is used to estimation the types of refraction which occurred in a particular place and time. They are sub–refraction, standard refraction, super–refraction, scattering and ducting on transhorizon paths and their effects on practical problems ranging from designing reliable ground–to–ground microwave communication systems and VHF field strength at points beyond the horizon. However, surface refractivity measurements are common in Nigeria, because of unavailability of equipment, such as masts that can be employed at various heights. The vertical gradient measurements has been relied on the computed values of surface measurements, using the relation of the decrease of refractive index with height h, through the whole troposphere, which may be approximated by $N(h) = N_s \exp(-h/h_0)$, where N_s is the surface value of refractive index and h_0 is a 'scale height' (Hall,1989, p. 23). Changes in the value of the troposphere radio refractive index can curve the path of the propagating radio wave (shown in Figure 1 and Figure 2) (Hughes, 1993). According to Willoughby, (2002), atmosphere has an important feature, vertical gradient of the refractive index, G. The vertical gradient of the refractive index is responsible for bending of propagation direction of the electromagnetic wave.

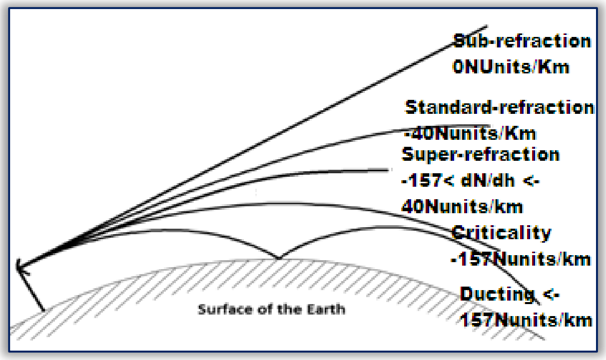

Figure 1: Types of refraction

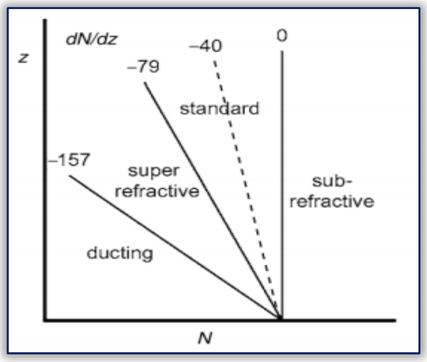

Figure 2: Classification of refraction based on the value of N

2. TRAPPING LAYER AND DUCTING PROFILES

Modified refractive index, M can be used to show the effect of refractive ray relative to the ground surface and for the study of radio propagation, it can be expressed in terms of refractive index, n as

$$M = \left((n-1) + \frac{z}{a} \right) \times 10^6 \quad (1)$$

$$M = \frac{dN}{dz} + 0.157z \quad (2)$$

where z is the height above the ground surface, a is the radius of the earth which is $6387km$. The importance of M in radio propagation is because of the variation dM/dz of M with height, where dM/dz is the change in M–units per meter. At considerably high altitudes the dielectric constant and hence M are usually independent of height. Here M, as defined above increases $0.158M$ –units per meter. However, near the surface of the earth, the dielectric constant over land normally decreases linearly with increasing height. Hence, the value of M near the earth's surface increases linearly with a constant rate that is less than $0.158M$ –units per meter

The M–curve shown in Figure 3(c) occurred when the moisture content of the air at the surface of the earth is very high, but decreases as the height is increasing depend on the local weather condition. The curve of Figure 3(c) have some region where dM/dz is negative. This is the region where the curvature rays passing through atmosphere is greater than that of the earth. Hence, the energy developed in the region initially is directed towards direction parallel to the earth's surface is now trapped in this region. The energy then propagates around the curved surface of the earth in a series of hops involving successive earth reflections. This process leads to trapped energy in a duct form above the surface of the earth. This phenomenon is termed duct propagation.

The effect of duct propagation leads to a situation that when energy travels through the region of ducting, the line of sight and diffraction zone characteristics cease to be applied and the energy can now travel longer distances around the curvature of the earth without much attenuation. The duct propagation is sometimes referred to as super–refraction. The condition for the duct propagation to occur is when the transmitter antenna height is less than the height of duct region, i.e. the antenna height is required to be less than the height corresponding to the minimum in the M–curve. If the transmitting antenna is higher than the duct region, there will be relatively little effect of the presence of the duct on the signal strength either above or in the duct. On the other hand, if the transmitting antenna is within the duct, then the signal strength at a considerable distance from the transmitter (below the line of sight) varies with height as shown in Figure 1. However, the effect of the presence of duct on the signal strength at considerable farther heights above the top of the duct is not prominent even if the transmitting antenna lies within the duct. The type of ducts shown in Figure 3(a) and Figure 3(b) are ground based duct, and they usually occur over water and other large water bodies. They are also present over the ocean, especially in the trade–wind belts. At the surface of land, surface ducts or the ground based ducts are produced by radiation due to the cooling of the earth. Figure 3 described the three common duct types with straight–line segment modified refractivity (M) profiles. The evaporation duct is typified by a negative value of dM/dz adjacent to the surface (shown in Figure 3(a), (b), (c)). The height of the duct, D is given by the vertical position of the M–profile inflection point, where dM/dz changes from a negative value (or zero) to a positive value. Rays launched inside the duct, with ray directions within a few degrees of parallel with the duct boundaries, will be trapped. Precisely how small these shallow or small grazing angles need to be for trapping to occur is dependent on the wavelength of the radiation, the vertical dimension of the duct, and the strength of the duct (as gauged by the dM/dz gradient).

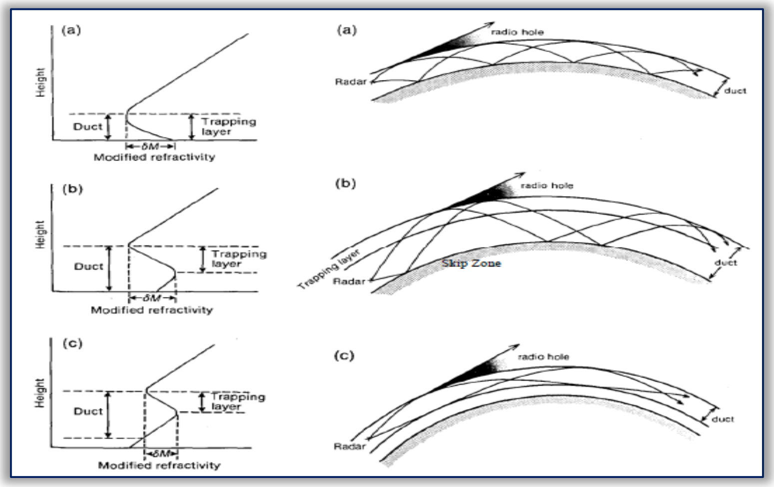

Figure 3. Examples of ducting conditions based on M gradient (left) and the typical resulting EM propagation paths (right) for a) surface duct, b) surface based duct, and c) elevated duct (after Turton, 1988)

The evaporation duct is found regularly over relatively warm bodies of water. It is generally caused by a temperature inversion near the surface (i.e., where temperature increases with height) and is accentuated by the intense relative humidity near the surface caused by water evaporation. This paper described the monthly refraction types in the coastal region of Nigeria and the effect of ducting on radio propagation of high frequency greater than 8GHz. According to Nigerian Meteorological report (2010), the seasonal northward and southward oscillatory movement of the Inter–Tropical Discontinuity (ITD) largely dictates the weather pattern of Nigeria'. The higher than normal ITD positions accounted for the high rainfall in many cities across the country, particularly in the north. The moist south–westerly winds from the South Atlantic Ocean, which is the source of moisture needed for rainfall and thunderstorms to occur, prevail over the country during the rainy season (April – October). The aim of this paper is to characterize the atmospheric refractivity of area close to sea–level in Lagos state and predict the path loss due to the ducting effect.

3. METHODOLOGY

The meteorological parameters data of pressure, minimum and maximum temperature and humidity at different height per month were collected from NIMET Nigeria for Lagos state from 2014 to 2016. These were used to determine the atmospheric refractivity for each month for the studied years and classified the refraction to Standard, Sub–refraction, Super–refraction and ducting. Evaporation duct model was used to estimate the duct height for the months where ducting occur using Paulus–Jeske (PJ) model.

Refractivity for the dry term of the radio refractivity, N_{dry} is given by:

$$N_{dry}(N-units)=77.6\frac{P_d}{T(K)} \tag{3}$$

and the wet term of the radio refractivity, N_{wet}, is:

$$N_{wet}(N-units)=72\frac{e}{T(K)}+3.75\times10^5\frac{e}{T^2} \tag{4}$$

where, P_d is dry atmospheric pressure (hPa), P is total atmospheric pressure (hPa), e is water vapour pressure (hPa), T is absolute temperature (K)

$$P=P_d+e \tag{5}$$

Since , equation (2) can be rewritten as:

$$N_{wet}(N-units)=77.6\frac{P}{T}+5.6\frac{e}{T(K)}+3.75\times10^5\frac{e}{T^2} \tag{6}$$

For ready reference, the relationship between water vapour pressure e and relative humidity is given by:

$$e_s=E\times a\times\exp\left(\frac{\left(b-t/d\right)\times t}{t+c}\right) \tag{7}$$

where
$$e=\frac{He_s}{100} \tag{8}$$

$$E_{water}=1+10^{-4}\left(7.2+P\times\left(0.00320+5.9\times10^{-7}\times t^2\right)\right) \tag{9}$$

$$E_{ice}=1+10^{-4}\left(2.2+P\times\left(0.00382+6.4\times10^{-7}\times t^2\right)\right) \tag{10}$$

where: **t**: temperature (oC), **P**: pressure (hPa), H: relative humidity (%), es: saturation vapour pressure (hPa) at the temperature t (^{0}C) and the coefficients a, b, c and d are for water, a =6.1121; b = 18.678; c = 257.14; d = 234.5 (valid between –40C to +50C) and for ice, a =6.1115, b = 23.036, c = 279.82 and d = 333.7 (valid between –80C to 0C).

Vapour pressure e is obtained from the water vapour density

$$e = \frac{\rho T}{216.7} \text{hPa} \tag{11}$$

The refractivity gradient for a medium is given as:

$$\frac{dN}{dh} = \frac{N_2 - N_1}{h_2 - h_1} \tag{12}$$

where N1, N2 h1 and h2 are the refractivity's and heights at the different pressure, temperature and humidity levels dN/dh is refractivity gradient.

4. EVAPORATION DUCT MODEL

The Paulus–Jeske (P–J) technique (Paulus, 1985) is one such popular evaporation duct model. It is based on the original Jeske method (Jeske, 1965; Jeske, 1973) that determines the height of the evaporation duct from low–altitude point measurements of air temperature, relative humidity, wind velocity, and sea temperature. In order to account for potential inaccuracies in the measurements of air temperature and sea temperature, the P–J method includes a correction that essentially approximates all highly stable atmospheric cases to either unstable or neutral cases. This adjustment often results in an underestimation of the duct height (Babin et al, 1997).The evaporation duct height is given by

$$h_d = \frac{0.06[C(e_s - e_a) + B(T_s - T_a)]}{A + 0.157} \tag{13}$$

Where, the constant A, B and C are related to the refractivity gradient through the equation

$$\frac{dN}{dh} = A\frac{dP}{dh} + B\frac{dT}{dh} + C\frac{de}{dh} \tag{14}$$

Where, N is the radio refractivity, P = the atmospheric pressure, T_a = the deck–level atmospheric temperature, T_s =the sea–surface temperature, e_a = the desk–level vapour pressure and e_s =the sea–surface vapour pressure

5. RESULTS AND DISCUSSION

In Figure 4, from December to May there is lower refractivity value ranging from 290N–units to 340 N–units while March, April and May have the least value of refractivity. From June to October there is higher refractivity value ranging from 350 N–units to 390 N–units while September and October have the highest refractivity.

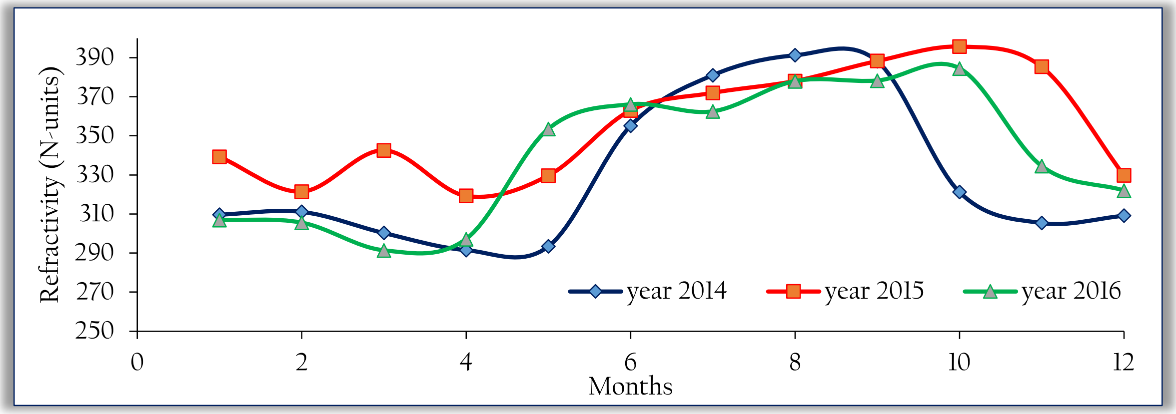

Figure 4: The Graph of Atmospheric refractivity's against months from 2014 to 2016

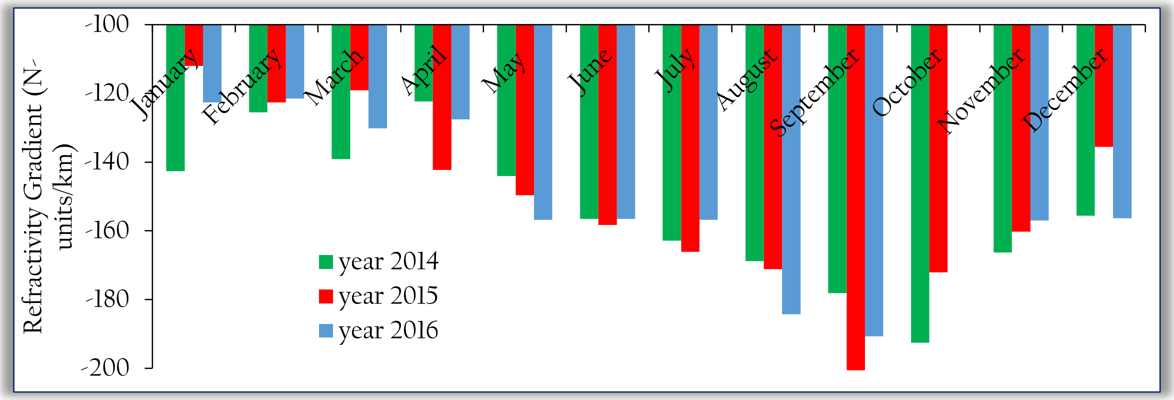

Figure 5: The Chart of Atmospheric refractivity gradient per months from 2014 to 2016

The Table 1 shows that the studied area is characterized by super refraction, critical refraction and ducting throughout the year and the refractivity gradient. The months of September recorded the peak refractivity gradient in negative value. February recorded the lowest refractivity gradient in negative value. Rainy season has highest refractivity gradient while dry season has lowest refractivity gradient in negative values. Months of July, August, September, October and November are mostly characterized by ducting. In dry season, both the early dry season (November to January) and late dry season (January to April) are characterized by super refraction and the rainy season, the months are mostly characterized by critical refraction and ducting. The months of May and June are characterized by critical refraction. Months of July, August, September, October and November are mostly characterized by ducting.

Table 1: The Atmospheric refractivity, refractivity gradients and types of refraction per month from 2014 to 2016

Months	N_{ave} (N–unit)	dN/dh (N–units/km)	Refraction	N_{ave} (N–unit)	dN/dh (N–units/km)	Refraction	N_{ave} (N–unit)	dN/dh (N–units/km)	Refraction
	2014			2015			2016		
Jan.	309.70	−142.65	super	339.27	−112.05	super	306.95	−122.65	Super
Feb.	311.14	−125.52	super	321.44	−122.67	super	305.54	−121.53	Super
Mar.	300.3	−139.13	super	342.58	−119.09	super	291.37	−13013	Siper
Apr.	291.56	−122.33	super	319.24	−142.14	super	297.14	−127.55	Super
May	293.4	−144.04	super	329.64	−149.67	super	353.47	−156.76	Critical
Jun.	355.12	−156.54	critical	363.05	−158.33	duct	366.08	−156.51	Critical
Jul.	381.04	−162.81	duct	372.04	−166.11	duct	362.46	−156.81	Critical
Aug	391.2	−168.82	duct	378.11	−171.15	duct	377.93	−184.22	Duct
Sep.	388.21	−178.12	duct	388.33	−203.85	duct	378.23	−190.68.	Duct
Oct.	321.26	−192.50	duct	395.72	−172.05	duct	384.49	−192.50	Duct
Nov	305.42	−166.28	duct	385.36	−160.28	duct	334.49	−156.68	Critical
Dec.	309.12	−155.54	super	329.824	−135.54	super	321.99	−156.34	Critical

Table 2: Statistical Analysis of evaporation duct height for the month of July and August, characterized by ducting refraction from 2014 to 2016

	July			August		
Year	2014	2015	2016	2014	2015	2016
Mean	12.02	11.95	12.01	14.3	14.43	15.1
Standard Error	0.18	0.19	0.165	0.30	0.31	0.31
Median	12.00	12.10	12.00	14.50	14.60	15.20
Mode	11.20	12.70	12.50	14.50	15.20	15.30
Standard Deviation	01.00	1.07	0.92	1.70	1.70	1.72
Range	4.30	4.00	4.10	8.00	7.10	6.50
Minimum	10.20	10.30	10.40	10.20	11.20	11.20
Maximum	14.50	14.30	14.50	18.20	18.30	17.70

Table 3: Statistical Analysis of evaporation duct height for the month of September and October characterized by ducting refraction from 2014 to 2016

	September			October		
Year	2014	2015	2016	2014	2015	2016
Mean	16.13	16.53	17.35	13.98	15.49	15.04
Standard Error	0.35	0.38	0.36	0.32	0.29	0.28
Median	15.45	16.85	17.40	13.50	15.20	15.10
Mode	15.10	15.20	15.20	15.20	15.20	15.30
Standard Deviation	1.91	2.07	1.99	1.77	1.64	1.58
Range	6.30	6.60	7.20	6.90	6.00	5.90
Minimum	12.90	13.50	13.60	11.40	13.30	12.30
Maximum	19.20	20.01	20.80	18.30	19.30	18.20

Table 2 shows the statistically analysis for evaporation duct height for the months characterized by ducting. The ducting height of July, August, September and October in the 3years ranging from 10.20–14.50m, 10.20–18.30m, 12.90–20.80m and 11.40–19.30m respectively. The mean ducting height of July, August, September and October in the 3 years are 12.01± 0.18m, 14.43±0.31m, 16.53±0.36m and 15.04±0.29 receptivity (from Table 3). The ducting height increases from July to October. Most of the days in July, August September and October have ducting height of 12.50m, 15.20m, 15.20m and 15.20m respectively.

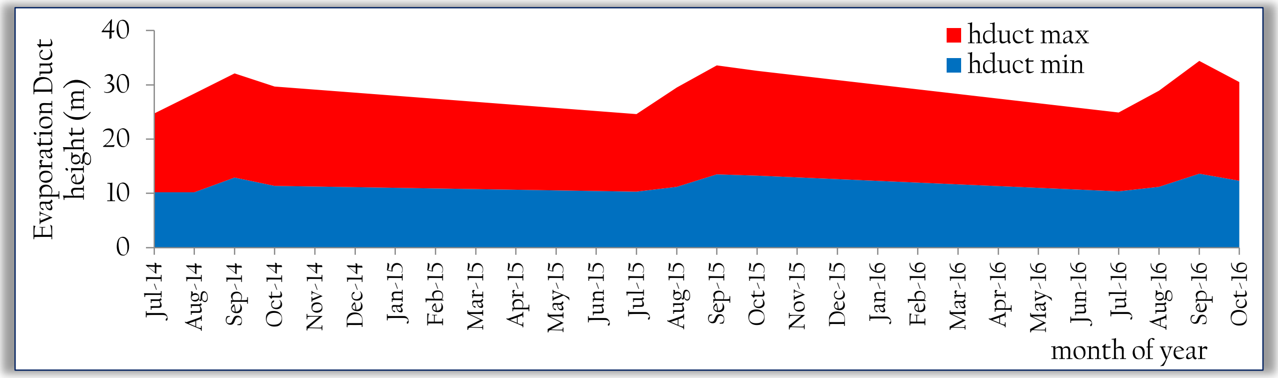

Figure 6 : The Graph of maximum and minimum evaporation ducting height per months from 2014 to 2016

September and October of each year recorded peak evaporating ducting height while July and August of each year recorded least evaporation ducting height. The minimum and maximum evaporation ducting height is around 10.00m and 32.00m respectively. The mean evaporation ducting height throughout the years is 14.52$\pm$0.52m with standard deviation of 1.80m

6. CONCLUSION

Effect of evaporation ducting from previous studies may leads to radar loss of flying target, poor line of sight for long range of communication, complete loss of signal due to refraction in shadow zone and noise in the signal. The research areas of Lagos state near ocean are characterizing by super refraction, critical refraction and evaporation ducting. Dry season of each year are characterize by super refraction while May, June and November are characterized mostly by critical refraction. July to October of every year are characterize by evaporation ducting. Refractivity values ranging from 290N–units to 390 N–units throughout the year. The mean evaporation ducting height throughout the years is 14.52$\pm$0.52m with standard deviation of 1.80m. The evaporation ducting height ranging from 10.20–20.80m and 11.40–19.30m, and the mean ducting height of July, August, September and October in the 3years are 12.01$\pm$ 0.18m, 14.43$\pm$0.31m, 16.53$\pm$0.36m and 15.04$\pm$0.29 respectively.

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, Vol. 4, pp.157–168.
[2] Falodun SE, Okeke PN (2013). Radiowave propagation measurements in Nigeria (preliminary reports). Theor. Appl. Climatol. 113:127–135
[3] Freeman R. L. (2007). Radio System Design for Telecommunications, 3rd edition. – Hoboken, New Jersey, John Wiley & Sons Inc Pb, pp 880
[4] Grabner, M. and Kvicera, V. (2008). Radio Engineering 12, No.4, pp. 50.
[5] Hughes, K. A., (1993). Radio Propagation Data from Tropical Regions: A Brief Review of a seminar on Radio Propagation in Tropical Regions, An unpublished lecture note presented at Centre for Theoretical Physics, Trieste (Italy), issue 1, pp 51 – 62.
[6] ITU–R (2012). "The radio refractivity index: its formula and refractivity data," International Telecommunication Union, Geneva. pp. 453–9.
[7] Oyedum O.D. and Gambo G.K. (1994). Surface radio refractivity in northern Nigeria. Nig. J. Phys. 6:36–41.
[8] Patterson, W.L. (1985), "Comparison of evaporation duct and path loss models," Radio Science, Vol. 20, No. 5, pp. 1061–1068.
[9] Patterson, W.L., C.P. Hattan, G.E. Lindem, R.A. Paulus, H.V. Hitney, K.D. Anderson and A.E Barrios (1994), Engineer's refractive Effects Prediction System (EREPS), Version 3.0, Technical Document 2648, Naval Command, Control and Ocean Surveillance Centre, RDT&E Division, San Diego, U.S.A.
[10] Rogers L. T., Hattan C. P., and Stapleton J. K. (2000), "Estimating evaporation duct heights from radar sea echo," Radio Science, vol. 35 (4), pp. 955–966
[11] Willoughby A. A., Aro T. O. and Owolabi I. E. (2002). Seasonal variations of radio refractivity gradients in Nigeria Journal of Atmospheric and Solar– Terrestrial Physics. Vol. 64. – P. 417–425.

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