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Radio Refractivity Measurement at 150m Altitude on TV Tower in Akure, South-West Nigeria

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Abstract: In the design and frequency planning of microwave networks, propagation related parameters are used. During the ''clear sky'' conditions, atmospheric refractive index is the important parameter that influences the propagation of radio waves. This study presents the results of the measurement of the basic physical parameters for the determination of radio refractivity. Meteorological sensors (Integrated Sensor Suite, ISS) are positioned at the ground surface and 150m above ground level for the measurements. From the result therefore, propagation conditions in this region are then classified as sub-refractive, normal, super-refractive and ducting.

Key words: Refractivity, super-refraction, ducting, refractivity gradient, K-factor

INTRODUCTION

It is often necessary to know in detail the structure of the radio refractive index of the lower atmosphere in the design of microwave communication. Performance and reliability of microwave link depends essentially on the quality of the propagation of electromagnetic waves between the transmitter and receiver (Grabner and Kvicera, 2003). Worse propagation conditions lead to decreasing input/output power level and to increasing signal distortion. Absorption and interference can cause fades on microwave links. The absorption fades are mostly due to hydrometeors (rain, snow, fog, hail, etc), while the interference fades are related to multipath propagation and the bending of electromagnetic waves in the atmosphere.

For radio communication, every path between two points (except communications between satellites) passes through the troposphere which affects propagation. The continuous movement of the atmosphere implies changes of the geometry of the path between a transmitter and receiver. The troposphere is the region of the atmosphere extending from the surface of the earth up to a height of 8-10km at polar latitudes, 10-12km at moderate latitudes and up to 16-18km at the equator. In this region of the atmosphere, the temperature generally decreases with height and, as a result, it is thermodynamically unstable and always in a situation of turbulent mixing. The radio refractive index of the troposphere is due to the molecular constituents of the air: Principally nitrogen, oxygen, carbon dioxide and water vapour. This study focuses on the effect of the troposphere on radio wave propagation in Nigeria; specifically the study of refractivity of microwave radio signals. It reports the results of refractivity at 150metre altitude based on the measurements taken in Akure (7.15°N, 5.12°E) headquarters of Ondo State, Nigeria between the month of December 2006 and April 2007.

Propagation in the troposphere: One reason for multipath of e-m waves/fading is bending due to variation in the refractive index distribution along the ground layer of the atmosphere. The refractive index of a medium is defined as the ratio of the speed of propagation of radio energy in vacuum to the speed in the medium. Microwave propagation in the troposphere is determined by changes in the refractive index of air. Because it is very close to unity (about 1.0003), the refractive index of air is measured by a quantity called the radio refractivity N, which is related to refractive index, n as (ITU-R, 2003):

$$n = 1 + N \times 10^{6} \quad (1)$$

In terms of meteorological quantities, the refractivity N, can be expressed as:

$$N = 77.6\frac{p}{T} + 3.73 \times 10^{5}\frac{e}{T^{2}} = N_{dry} + N_{wet} \quad (2)$$

with the dry term, $N_{dry,}$ of radio refractivity given by:

$$N_{dry} = 77.6\frac{p}{T} \quad (3)$$

and the wet term, N_{wet}, by:

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$$N_{wet} = 3.73\times10^5 \frac{e}{T} \quad (4)$$

Where:
p = Atmospheric pressure (hPa)
e = Water vapour pressure (hPa)
T = Absolute temperature (K)

The dry term N_{dry} contributes about 70% to the total value of refractivity while the wet term N_{wet} is mainly responsible for its variability. Equation 2 may be used for all radio frequencies; for frequencies up to 100GHz (Babin *et al*., 1997). The error is less than 0.5% (ITU-R, 2003).

The water vapour pressure e, can be calculated from the relative humidity and saturated water vapour, given by:

$$e = \frac{He_s}{100} \quad (5)$$

with

$$e_s = 6.1121\exp\left(\frac{17.502t}{t+240.97}\right) \quad (6)$$

Putting (6) into (5) gives;

$$e = H\times\frac{6.1121\exp\left(\frac{17.502t}{t+240.97}\right)}{100} \quad (7)$$

Where:
H = Relative humidity (%)
t = Celsius temperature (°C)
e_s = Saturation vapour pressure (hPa) at the temperature t (°C)

Gradual variations in the refractive index result in a bending of the paths taken by radio waves, so that they can follow the curvature of the earth. Thus, the troposphere affects the propagation of ground waves and can promote communication over large ranges.

Refractivity gradient, dN/dh and effective earth radius factor, K: For tropospheric propagation, it is not only the absolute value of refractivity that is important but also its vertical gradient often referred to as modified refractivity. Modified refractivity is a mathematical formulation of refractivity such that the curvature of the earth is taken into consideration, that is, when the slope of modified refractivity over altitude is zero; the earth is effectively flat with regards to radio wave propagation (Falodun and Ajewole, 2006). Therefore, for accurate predictions of microwave propagation, knowledge of height profiles of radio refractivity is required (Dockery, 1988).

The slope of refractivity with altitude determines how microwaves propagate and it is used to characterize microwave propagation as sub-refraction, normal refraction, super-refraction or ducting. To determine these conditions, one must take into account the curvature of the earth's surface. This is accomplished by using the modified refractivity M, given as (Bech *et al*., 2002);

$$M = N + \frac{z}{10^{-6} r_e} \approx N + 0.157z \quad (8)$$

Where r_e is the earth's radius in meters and z is the altitude above sea level in meters.

In sub-refractive conditions, often referred to as worse-than- normal propagation;

$$\frac{\partial N}{\partial h} > -40 \text{ or } \frac{\partial M}{\partial h} > 117$$

Refractivity N increases with height and in this case, the radio wave moves away from the earth's surface and the line of sight range and the range of propagation decrease accordingly. Sub-refraction in the troposphere is generally thought to be a rare occurrence, but can happen when conditions exist to support upward bending of Electromagnetic waves (EM) (Bech *et al*., 2001). In normal refraction, that is, standard atmosphere;

$$\frac{\partial N}{\partial h} \approx -40 \text{or} \frac{\partial M}{\partial h} \approx -117$$

Radio signals travel on a straight line path along the earth's surface and go out to space. With super-refraction also referred to as better-than- normal propagation;

$$\frac{\partial N}{\partial h} < -40 \text{ or } \frac{\partial M}{\partial h} < 117$$

The radius of curvature of the ray path is smaller than the earth's radius and the rays leaving the transmitting aerial at small angles of elevation will undergo total internal reflection in the troposphere and return to the earth at some distance from the transmitter. On reaching the earth's surface and being reflected from it, the waves can skip large distances, thereby giving abnormally large ranges beyond the line of sight due to multiple reflections. When a super-refraction condition is present, EM waves are bent downward towards Earth. The degree of bending depends upon the strength of the super-refractive condition. In ducting conditions;

$$\frac{\partial N}{\partial h} < -157 \text{ or } \frac{\partial M}{\partial h} < 0$$

The waves bend downwards with a curvature greater than that of the earth. Radio energy can become trapped between a boundary or layer in the troposphere and the surface of the earth or sea (surface duct) or between two boundaries in the troposphere (elevated duct). In this wave guide-like propagation, very high signal strengths can be obtained at very long range (far beyond line-of-sight) and signal strength may exceed its free-space value.

In estimating the effects of the atmosphere on the refraction of radio waves, the concept of an effective earth radius a_e which is greater than the actual value, a, by K times is often adopted, That is;

$$a_e = Ka \quad (9)$$

This approach simplifies the calculation of propagation problems by assuming that the radio refractivity gradient, dN/dh, is constant within the first kilometre (Willoughby *et al*., 2002). This allows radio waves to be propagated as straight rays over the hypothetical earth rather than curved rays over an earth with true radius. Thus, K is expressed as; (Afullo*et al*., 1999):

$$K = \left[1 + a\frac{dN}{dh} \times 10^{-6}\right]^{-1} \quad (10)$$

Where a is in kilometres. The significance of the parameter K is that it permits the simplification of practical problems encountered in tropospheric communications and radio engineering. Furthermore, the prediction of radio field strengths at a location is easily facilitated with this approach.

MATERIALS AND METHODS

The instrument used in this work for the measurement of the parameters for the computation of refractivity is the Davis 6162 wireless Vantage Pro2 Plus which is equipped with Integrated Sensor Suite (ISS), a solar panel with an alternative battery source and wireless console which serves as the receiver from the ISS and provide the user interface data display. The ISS houses the external sensors for measurements of temperature, pressure, relative humidity, UV index, rainfall rate, solar radiation etc. A datalogger is attached to the console for storing the data transmitted via radio from the ISS from where the data are retrieved through a computer connected to it.

The fixed measuring method by a high tower is employed for the measurement with the ISS positioned at the ground level for surface measurement and 150 m on the tower for continuous measurement of the atmospheric pressure, air temperature and relative humidity. The

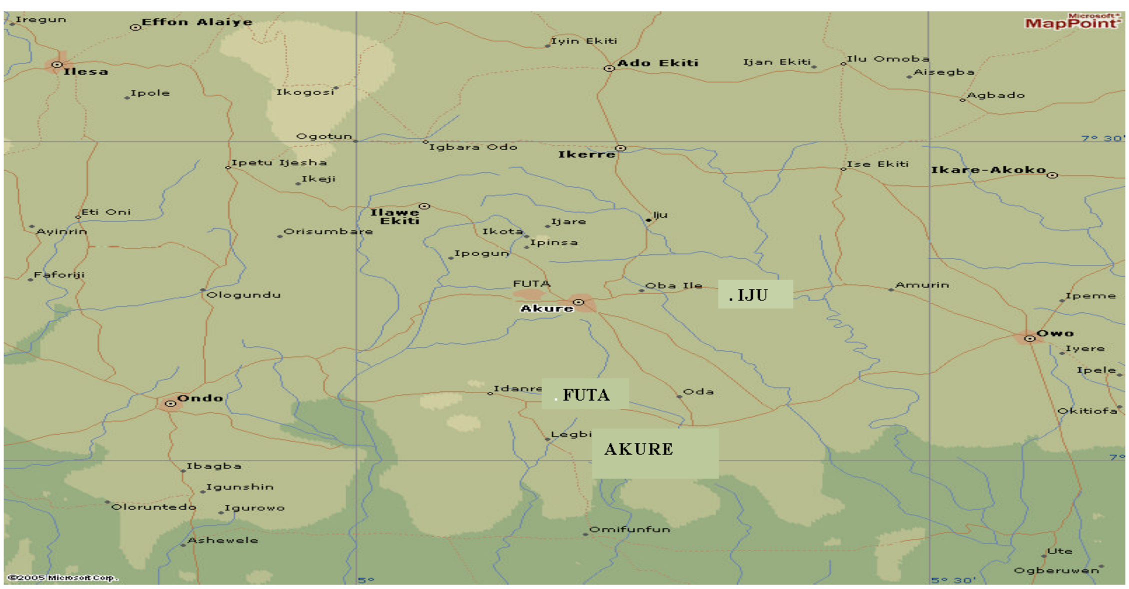

Fig. 1: Map of the experimental site in Ondo state, Nigeria

Fig. 2: Communication Mast on which the ISS is placed

tower/mast (Fig. 1) is 212m high and it is located at the old premises of the Nigerian Television Authority (NTA) at Iju in Akure North local government area of Ondo state, about 25km away from the campus of the Federal University of tower/mast Technology, Akure (FUTA) and about 11.5 Km on line of sight from Akure with coordinates, (7.15°N, 5.12°E) (Fig. 2). This site is chosen because of the availability of the NTA mast/tower, which is currently not in use for transmission purposes by NTA due to their relocation. The measurements cover 24 h each day beginning from 00 hours Local Time (LT) and for a time interval of 30 min.

RESULTS AND DISCUSSION

Refractivity and refractivity gradient: Data used for this work were from in-situ measurements of meteorological parameters made from December 2006 to April 2007. The measurement covered both the Harmattan seasons and the early rainy seasons occurring in Akure every year. The Harmattan period is usually from December to February while the rainy season months are usually from March to October every year. The Akure climate is basically tropical; it is a zone where warm, moist air from the Atlantic converges with hot, dry and often dust-laden air from sahara called the 'harmattan'. The data were collected from the sensors placed at the ground level for surface measurement and 150m on the tower. The records cover 24 h daily from 00-2300h local time and measured at a time interval of 30 min. The parameters extracted from the daily records are; the Pressure, P (hpa), temperature, T (°C) and the Relative Humidity, RH (%).

The values of the relative humidity were converted to water vapour pressure, e (hpa) by using Eq. 5-7. The data were used to compute the refractivity using Eq. 2 at the ground level and 150 m altitude. From the calculated

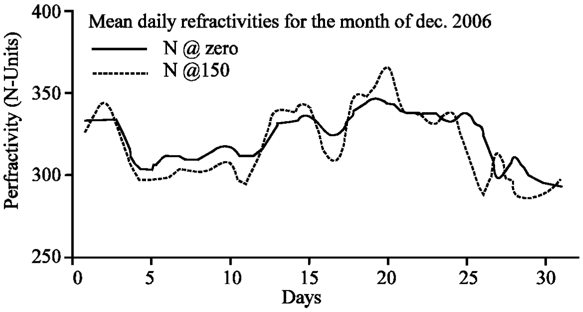

Fig.3: Mean daily variation of refractivity for the month of Dec., 2006

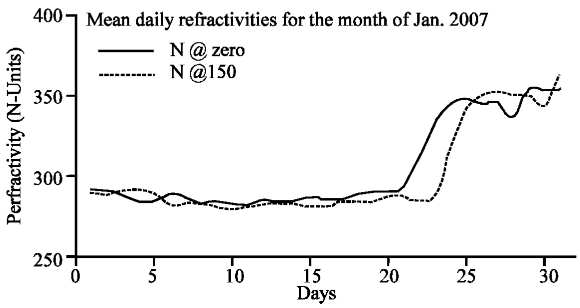

Fig. 4: Mean daily variation of refractivity for the month of Jan., 2007

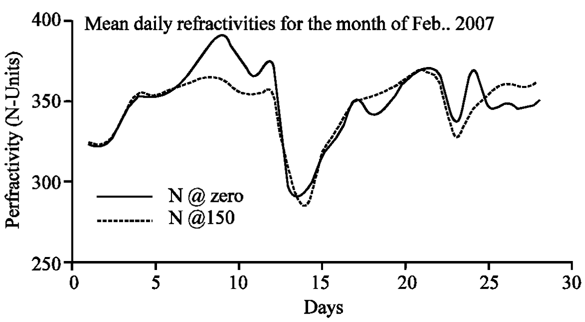

Fig. 5: Mean daily variation of refractivity for the month of Feb., 2007

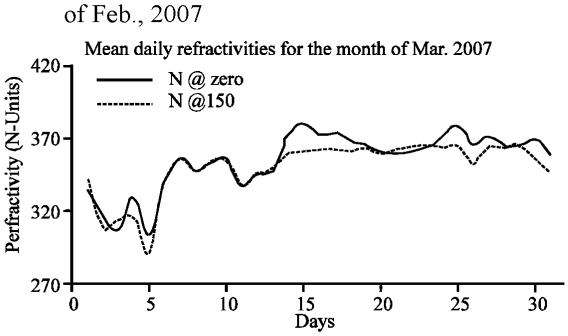

Fig. 6: Mean daily variation o refractivity for the month of Mar., 2007

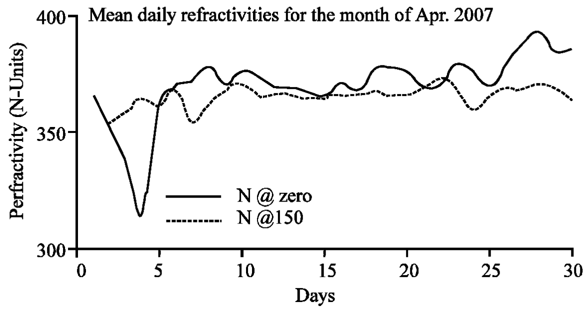

Fig. 7: Mean daily variation of refractivity for the month of Apr., 2007

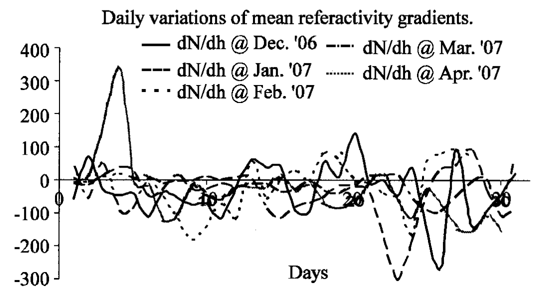

Fig. 8: Mean daily variation of fractivity gradients for the period of study

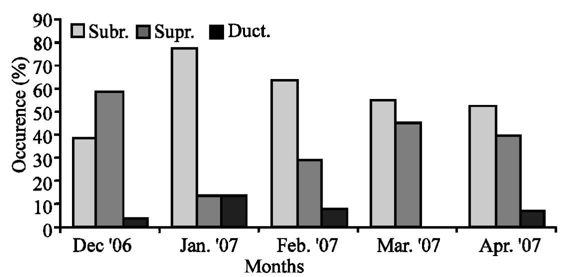

Fig. 9: Summary of occurrence of Sub-refraction, Super-refraction and Ducting

values of the refractivities, refractivity gradient at 150m are then determined. Examples of the results obtained for the average daily records are presented in Fig. 3-7. The values were observed to be generally high during the beginning of the rainy season (March-April). In this period, the values vary between about 302 and 393 N-units. The high values are due to high air humidity (very close to 100%) observed in this part of the globe during this period because the city (Akure) is under the influence of a large quantity of moisture laden tropical maritime air resulting from continuous migration of inter-tropical discontinuity with the sun.

Generally, when the dry and dust-laden north-west winds become dominant in December, the dry harmattan season sets in, this can be attributed to the low values of

Table 1: Mean values of the effective earth's radius, K

Month	Effective earths radius factor, K
Dec. '06	1.9912
Jan. '07	0.5893
Feb. '07	0.9593
Mar. '07	1.5525
Apr. '07	1.9998

refractivity observed in January-February (278-360N-units). This is mostly due to high temperatures for the commencement of the rainy season in March. Figure 8 shows the vertical gradient of refractivity calculated on the basis of the mean daily statistical distribution of N_{150} and $N_{surface}$. It shows that the daily variation has some minima points corresponding to the end of the dry season and some peaks with highest peak in April corresponding to the period of rainy season. There are observed some days in the dry harmattan season of intensive temperature inversion especially in the morning hours. Figure 9 shows the monthly statistics of the occurrence of propagation conditions (Sub-refraction, Super-refraction and ducting) over the period of the study. The statistics shows that the propagation conditions have varying degree of occurrence but prevalently sub-refraction conditions take the lead followed by super-refraction and some low percentage of ducting conditions. During the months when sub-refractive conditions are present, stations in this region of the globe will have reduced radio horizon and are also open to severe interference from distant stations due to the combined effect of super-refraction and ducting. This effect may lead to frequent signal outage from the stations.

Effective earth radius factor K: Table 1 shows the monthly mean of the effective earth's radius factor K. From the result, it was observed that the values were low for dry seasons; January to February (about 0.5-0.9) and continue to increase from the beginning of the rainy season; March to April (about 1.5-1.9).

CONCLUSION

The results of the present research constitute the initial report of our experimental work in making systematic In-situ measurements for the study of microwave propagation in the lower atmosphere in this part of the globe. The measurement is continuing and more sensors shall be positioned at other lower levels at 25, 50 and 100m altitudes respectively for the vertical distribution of radio-refractivity in Akure.

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