PHYSICAL SCIENCES

SPACIO-TEMPORAL VARIATION OF RADIO REFRACTIVITY IN LAFIA, NASARAWA STATE USING CM SAF ATOVS SATELLITE DATA

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ABSTRACT

Communications using radio waves propagates through the atmosphere and plays a major role in civilization. Vertical variation of radio refractivity in Lafia(8.492°N and 8.517°E) Nigeria,was investigated with a five-year (2010 – 2014) monthly mean atmospheric layered data from the ATOVS (Advanced TIROS (Television InfraRed Observation Satellite) Operational Vertical Sounders) instruments flying onboard the NOAA and Metop-A satellites; this data is provided by the EUMETSAT's Climate Monitoring Satellite Application Facilities (CM SAF). Using the CM SAF data, at six pressure levels (1000hPa, 850hPa, 700hPa, 500hPa, 300hPa and 200hPa), the monthly mean of radio refractivity were estimated and the results analyzed. Also, the diurnal variation of the surface radio refractivity was also investigated using the data from the automatic weather station (model no WS104) installed at the Department of Physics, Federal University Lafia.Results obtained showed that the vertical model of the radio refractivity N, in Lafia could be given as $N=N_o \exp(-h/h_o)$, where N_o, the surface radio refractivity, was found to be approximately equal to 288.1 N-units, while the scale height h_o, was found to be approximately equal to 8.40km; it was found that sub-refraction predominates in Lafia at all seasons.The diurnal range of surface radio refractivity as measured by the *in-situ* weather station was found to be between 325.0 and 365.0 N-units, with a maximum in the morning and minimum in the afternoon.

Keywords:*Atmosphere,Radio Refractivity, CM-SAF, Lafia Nigeria*

INTRODUCTION

Radio wave is a very important component of our civilization; it is used for point to point communication as well as for data exchange. Radio wave being an electromagnetic wave interacts with the space through which it propagates as it is sent to carry information from one point to the other(Adediji and Ajewole, 2008). This interaction with space generally leads to wave phenomenon such as diffraction, reflection, polarization and refraction.

Refraction is the bending of waves as it passes through different media as a result of changes in the velocity and wavelength of the wave. A measure of this bending is called refractive index (n) and is defined as

$$n = \sqrt{(\varepsilon_r)} \quad \text{...............1a}$$

$$= c/v_{\text{phase}} \quad \text{...............1b}$$

where ε_r is the dielectric constant of the atmosphere,c is the speed of light and v_{phase} is thephase velocity of thewave in the medium. The power of a medium to bend waves is called refractivity (*N*) and according to the International Telecommunication Union recommendation (ITU-R, 2009), atmospheric radio refractive index n, is related to the atmospheric radio refractivity *N*, by

$$n = 1 + N \times 10^{-6} \quad \text{...................2}$$

The interaction of radio waves with the atmosphere results in refractivity effects such as fading, which results from the bending away/towards the earth of radio waves (Adediji and Ajewole, 2008; Otasowie and Edeko, 2009; Valma *et al*., 2010).

The main atmospheric component that significantly affects radio refractivity is the water vapor and this is as a result of the polar nature of water. The International Telecommunication Union recommends Eq. 3 for the estimation of refractivity *N*,

$$N = 77.6\,{}^{P}/_{T} + 373200\,{}^{e}/_{T2} \quad \text{................3}$$

whereP is the total atmospheric pressure (hPa), e is the water vapor pressure (hPa) and T is the absolute atmospheric temperature (K). The first term of Eq. 3 is the contribution from the dry component of the atmosphere while the second term is the contribution from the wet component of the atmosphere. Eq. 3 is useful for frequencies up to 100 GHz with estimation error that is less than 0.5% (ITU-R, 2009).

The variation of refractivity with height is modelled according to Eq. 4

$$N_s = N_o \exp(-{}^{hs}/_{ho}) \quad \text{.......................4}$$

whereN_o is the average value of atmospheric refractivity extrapolated to sea level, h_o is the scale height (km) and h_s is the height above sea level (km). ITU-R (2009) recommended that N_o and h_o should be determined statistically for different climates.

A radio link designer will be much interested in the vertical refractivity gradient (G), especially at the lowest 100m from the earth's surface, because it is critical in the estimation of path clearance and propagation effects such as sub-refraction, super-refraction or ducting (Manning, 1999; ITU-R, 2009; Adediji and Ajewole, 2008; Otasowie and Edeko, 2015). Refractivity gradient (G) is defined as

$$G = \Delta N/\Delta h$$

$$= (N_s - N_1)/(h_s - h_1) \quad \text{.................... 5}$$

whereN_s is the radio refractivity at an upper height h_s and N_1 is the radio refractivity at a lower height h_1. The value of G is usually negative because the radio refractivity decreases with height. From Equation 4, radio refractivity gradient at a given height could also be written as

$$G = -N_o/h_o \exp(-{}^{hs}/_{ho}) \quad \text{.........................6}$$

Another convenient parameter that could be used to quantify the refraction effects is called the effective earth radius factor k (Manning, 1999; Grabner and Kvicera, 2011; Adedijiand Ajewole, 2011; Otasowie and Edeko, 2015) which could be defined as

$$k = 1/(1 + 0.006371G) \quad \text{........................ 7}$$

For a normal refraction, G≈ -40 *N*-units/km (k = 4/3), the radio waves will go on a straight path without bending; a sub-refraction occurs when G> -40 *N*-units/km (4/3 >k> 0), the radio waves bend away from the earth's surface resulting in fading; a super-refraction occurs when -40 >G> 156.9 *N*-units/km (∞ >k > 4/3), the radio waves bend towards the earth's surface thereby extending the radio range; for ducting, G = -157 *N*-units/km (-∞ <k< 0), the radio waves are trapped within the lower layer of the atmosphere and the surface in a wave guide manner (Battan, 1973; Hall, 1979; Bashir, 1989; Adediji and Ajewole, 2008; Zilinskas *et al*., 2012).

This research work used four years satellite data from EUMETSAT, CM SAF to study the radio refractivity over Lafia, Nigeria and hence, determine a suitable mathematical model that could be used to describe the radio refractivity and the characteristics of the propagating radio waves through the atmosphere over Lafia. The use of the newly installed automatic weather station at the Physics Department of the Federal University Lafia for the estimation and study of variation in surface radio refractivity was also demonstrated.

MATERIALS AND METHODS

The upper air data used in this work was obtained from the European Meteorological Satellite (EUMETSAT), Satellite Application Facility on Climate Monitoring (CM SAF, http://www.cmsaf.eu). The CM SAF derives its data products, among others, from the ATOVS (Advanced TIROS [Television InfraRed Observation Satellite] Operational Vertical Sounders) instruments onboard the NOAA (-15 to -19) and

Metop-A polar orbiting satellites, since 13th of May 1998. The data products were obtained as a monthly means on a cylindrical equal area projection of 90km X 90km with a global grid resolution of 0.5° X 0.5°, as a result of this grid resolution the nearest data grid (i.e., 8.250 °N; 8.750 °E) to the true geographic grid of Lafia (i.e., 8.492 °N; 8.517 °E) was used. The CM SAF operational data used in this work is the HSH (CM-138, doi: 10.5676/EUM_SAF_CM/WVT_ATOVS/V001) monthly mean data product at six (6) pressure levels, comprising of specific humidity (in g/kg) and temperature (in K); the six pressure levels are 200hPa, 300hPa, 500hPa, 700hPa, 850hPa and 1000hPa.

The *in-situ* surface measurements were done with the automatic weather station (model no WS104) installed at the Department of Physics, Federal University Lafia (see the inset of Figure 1). The weather station started operation on 1st of April, 2015. The CM SAF, ATOVS data, which was obtained in a NetCDF file format, was processed using Panoply free software while all other data analysis was done with the Microsoft Excel® Spreadsheet package.

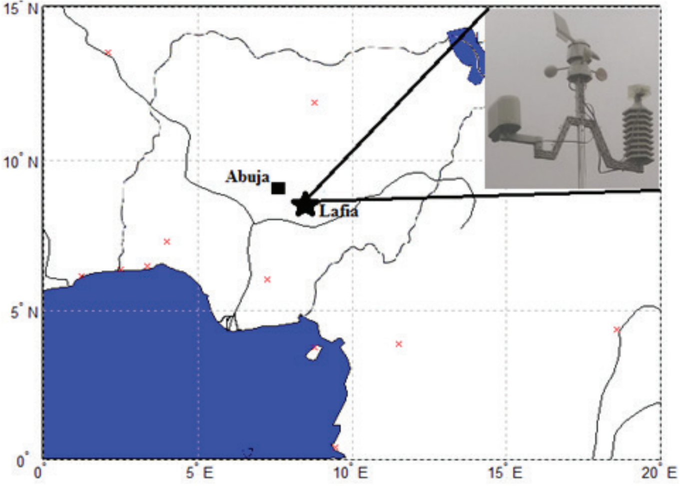


Figure 1: Geo-location of the research site (the inset shows the automatic weather station as installed at the Federal University Lafia).

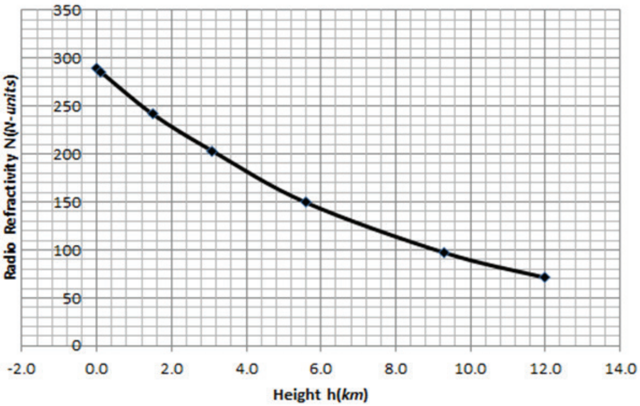
RESULTS AND DISCUSSION

The variation of radio refractivity, as measured at six different pressure levels, in Lafia is shown in Figure 2, using the average five year (2010 to 2014) data. Figure 2 shows that from the average surface radio refractivity value of ~289.2 *N*-units, the radio refractivity decays exponentially with height and at 12.0km (the top of the troposphere) it has decayed to ~70.0 *N*-units.

Following the ITU recommendation ITU-R P.453-6, an exponential fit that yielded the exponential model of Eq. 8was fitted to the data, with a coefficient of determination R2, of 0.9999. Eq. 8 could be re-written as Eq. 9, from which it could be seen that the radio refractivity scale height in Lafia is given as 8.55 km and the average surface radio refractivity in Lafia is ~289.2 *N*-units.

$$N=289.2\exp(-0.117h) \quad \ldots\ldots\ldots\ldots 8$$

$$N=289.2\exp(-h/8.55) \quad \ldots\ldots\ldots\ldots 9$$



Eq. 8 (or 9) is an all season model for Lafia and since radio refractivity strongly depends on atmospheric moisture content it would be of interest to investigate the seasonal variation of radio refractivity. Attempt at doing this yielded Eqs10 and 11 for the wet and dry seasons respectively with coefficient of determinations of 0.9999 and 0.9997.

$$N=295.9\exp(-h/8.40) \quad \ldots\ldots\ldots\ldots 10$$

$$N=283.8\exp(-h/8.62) \quad \ldots\ldots\ldots\ldots 11$$

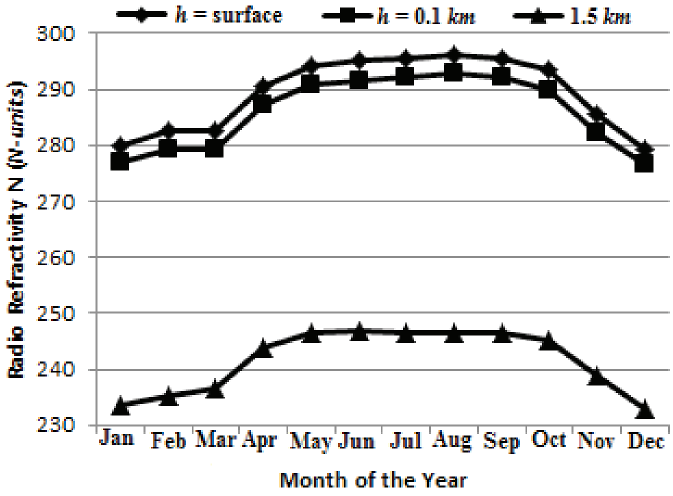
A look at Eqs.10 and 11 clearly shows greater surface refractivity during the wet season than during the dry season, besides the observed radio refractivity scale height during the seasons. The scale height during the wet season (~8.40km) could be seen to be lower than that of the dry season (~8.62km), this is as a result of the dependence of the radio refractivity on the atmospheric moisture content; scale height is inversely proportional to the mass of the atmospheric constituent. During the wet season, there is more water vapor mass hence, lower scale height and during the dry season, there is less water vapor and hence, higher scale height.

Using the monthly mean of the available five year data, the seasonal averages of the level radio refractivity is shown in Table 1. From the table, the dependence of the radio refractivity on moisture content could be easily seen as the wet season has higher radio refractivity than the dry season at all level besides the gradual decrease of radio refractivity as one climbs up from the surface to the upper atmosphere.

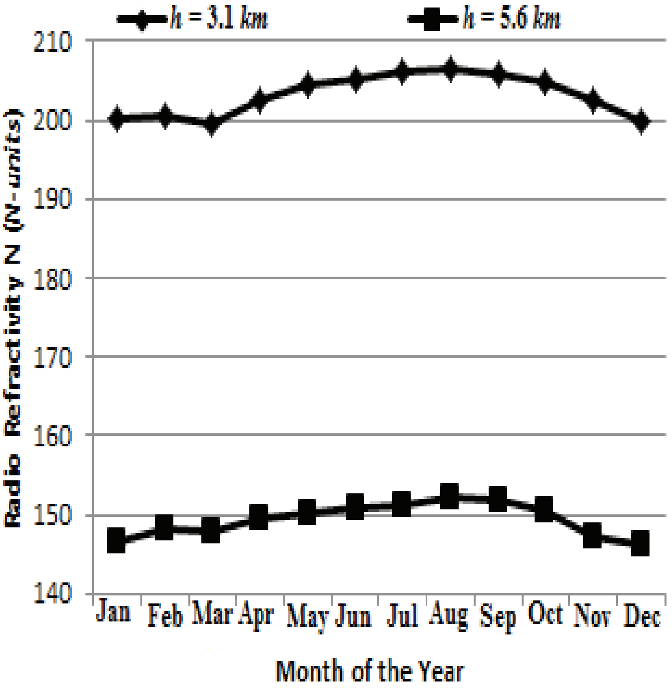
Table 1:Seasonal variation of radio refractivity at all levels in Lafia.

Height h(km)	Wet Season Average of *N* (*N*-units)	Dry Season Average of *N* (*N*-units)
0.0	294.4	282.0
0.1	290.9	278.9
1.5	245.9	235.4
3.1	204.9	200.5
5.6	150.9	147.2
9.3	97.3	97.1
12.0	71.1	71.1

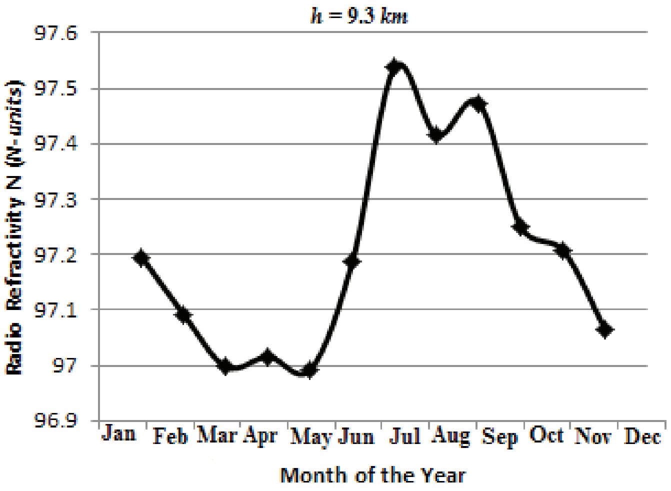
Figure 3 shows the annual variation of the radio refractivity at various atmospheric levels. The lower radio refractivity during the dry season and the higher radio refractivity during the wet season could be easily seen on Figures 3A and 3B, these two figures presents radio refractivity below the scale height of the radio refractivity in Lafia. Above the radio refractivity scale height, as presented in Figures 3C and 3D, the radio refractivity becomes somewhat "erratic", this is as a result of a very small and variable amount of moisture content at these levels.



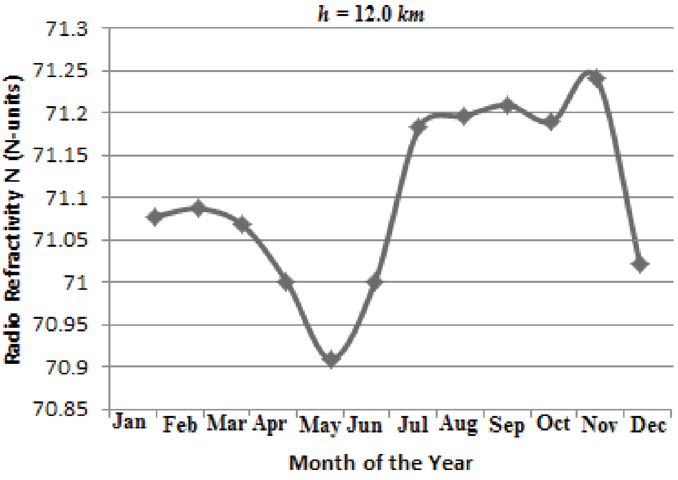
(A)



(B)



(C)



(D)

Figure 3:Annual variation of the radio refractivity at various atmospheric heights: (A) surface, 0.1km and 1.5km variation, (B) 3.1km and 5.6km variation, (C) 9.3km variation, (D) 12.0km variation.

Refractivity Gradient (G) and the effective earth radius factor k

The level refractivity gradient, as obtained from the Eq. 9 is shown in Eq. 12, it describes refractivity gradient at any height for all seasons in Lafia. Meanwhile, for both the dry and wet seasons, Eqs13 and 14 where obtained.It could be seen from Eqs13 and 14 that the refractivity gradient near the ground surface is greater during the dry season than during the wet season. The annual average refractivity gradient for the first 100m from the surface was found to be ~-33.2 *N*-units/km, while between 100m and 1.5km the average was found to be ~-31.7 *N*-units/km.

$G=-33.84\exp(-h/8.55)$ 12

$G=-35.23\exp(-h/8.40)$ 13

$G=-32.92\exp(-h/8.62)$ 14

From Table 2, it could be seen that the refractivity gradients is generally greater than -40 *N*-units/km while the effective earth radius factor k could be seen to be between 1.33 and 0. These two results show that the atmosphere over Lafia, between the surface and 1.5km, usually sub-refract radio waves.

Table 2: Monthly average of refractivity gradient at the first 100m from the surface (G1) and between 100m and 1.5km (G2) together with the effective earth radius factor k.

Month	**Refractivity Gradient G1 from surface to 100m (N-units/km)**	**k-factor for G1**	**Refractivity Gradient G2 between 100m and 1.5km (N-units/km)**	**k-factor for G2**
January	-31.8	1.25	-31.0	1.25
February	-32.4	1.26	-31.4	1.25
March	-32.4	1.26	-30.6	1.24
April	-34.2	1.28	-31.1	1.25
May	-35.0	1.29	-31.7	1.25
June	-34.8	1.28	-32.1	1.26
July	-34.8	1.28	-32.5	1.26
August	-35.0	1.29	-33.0	1.27
September	-35.0	1.29	-32.6	1.26
October	-34.6	1.28	-31.9	1.26
November	-33.0	1.27	-31.0	1.25
December	-25.4	1.19	-31.3	1.25

The diurnal variation of radio refractivity as computed from the mean of all days in August (the peak of wet season) and December (dry harmattan month) for the year 2015 is shown in Figure 4. The maximum diurnal value of the radio refractivity for the month of August was found to be ~365.5 *N*-units (occurring around 2:00Hr, local time) while the maximum diurnal value for December was found to be ~295.0 *N*-units (occurring around 16:00Hr, local time). The minimum for the month of August was found to be ~346.6 *N*-units (occurring around 16:00Hr, local time) while the minimum for December was found to be ~287.7 *N*-units (occurring around 23:00Hr, local time). The average radio refractivity for the month of August was found to be ~357.3 *N*-units while December has an average of ~291.3 *N*-units.

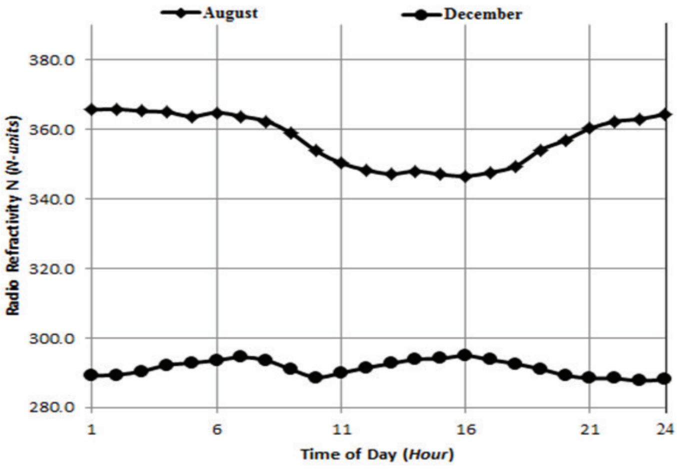


Figure 4: Daily mean of diurnal variation in radio refractivity for the months of August and December, 2015.

Due to the higher water vapor content, the wet season radio refractivity could be seen to be higher than the dry season's radio refractivity. Meanwhile the wet season's radio refractivity could be seen to be higher during the night time than the daytime radio refractivity, this results in bending away of radio waves from the earth's surface as well as considerable fading away of radio waves during the day in Lafia.

The dry harmattan month is an opposite of what happened during the wet season; the radio refractivity generally, is higher during the day than at night due to the generally low temperature during the day, observed during this period, as a result of the harmattan dust blocking the solar radiation from reaching the ground. At night the heat energy, which has been slowly absorbed during the day, is released and again blocked from radiating out thereby increasing the nighttime temperature which in turn reduces moisture and hence, reduces radio refractivity at night.

CONCLUSION

Using a five year CM SAF ATOVS' satellite data spanning the year 2010 to 2014, a model of the form $N=289.2\exp(-h/8.55)$ useful for estimating the radio refractivity at any height within the troposphere over Lafia city was derived; similar models useful during dry and wet seasons were also derived.

The radio refractivity at the surface in Lafia were found to be ~294.4 and 282.0 *N*-units for both wet and dry seasons respectively, but these decreases to ~71.1 *N*-units for both seasons at about 12.0 km above the ground surface, meanwhile the radio refractivity scale height in Lafia was found to be about 8.55 km; the wet season scale height was found to be ~8.40 km while the dry season scale height was found to be ~8.62 km.

The refractivity gradient as well as the effective earth radius factor show that within the first 1.5 km of the atmosphere in Lafia city, sub-refraction of radio waves predominates at all seasons.

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REFERENCES

Adediji, A. T. and Ajewole, M. O.(2011).Variation of Radio Refractivity Gradient and Effective Earth Radius Factor(k-factor) over Akure, South Western Nigeria.*IEEE*, 978-1-4244-5118-0/11/$26.00

Adediji, A. T. and Ajewole, M. O. (2008). Vertical profile of radio refractivity gradient in Akure South-West Nigeria.*Progress in Electromagnetic Research* C. 4, pp157 – 168.

Bashir, S.O. (1989). Three years statistics of RefractiveIndex Gradient and Effective Radius factor for the state of Bahrain: *IEE Conference Publications* 301 (ICAP 89), pp220-223.

Battan, L. J. (1973). Radio observation of theatmosphere.Univ. of Chicago Press, Chicago,pp76-78.

Grabner, M. and Kvicera, V. (2011). Atmospheric Refraction and Propagation in lower Troposphere,Electromagnetic Waves, Prof.VitaliyZhurbenko (Ed.), ISBN: 978-953-307-304-0, InTech, Available from:http://www.intechopen.com/books/electromagnetic-waves/atmospheric-refraction-and-propagation-in-lowertroposphere.

Hall, M. P. M. (1979).Effects of the Troposphere on Radio Communications. 14 - 46,445 IEEE Peter Peregrinus Ltd., London and New York.

ITU-R (2009). The Refractive Index: Its Formula and Refractivity Data.453-9.

Manning, T. (1999).Microwave Radio Transmission Guide.*British library cataloguing in the publication data*. pp 89-115.

Otasowie, P.O. and Edeko, F.O. (2009).An investigation of microwave link degradation dueto Atmospheric conditions (A case study of Akure-Owo digital microwave link).*Advances in Materials and System Technologies*, Vol. 62-64, pp 159-165.

Otasowie, P.O. and Edeko, F.O. (2015).Radio Refractivity Study InAkure-Owo Digital Microwave LinkIn South Western Nigeria. *Nigerian Journal of Technology*, 34(3), pp606 – 608, doi: http://dx.doi.org/10.4314/njt.v34i3.25

Valma, E., Tamosiunaite,M.,Tamosiunas,S.,Tamosiuniene,M. and Zilinskas,M. (2010). Determination of radio refractive index using meteorological data Electronics and Electrical Engineering – Kaunas. *Technologija,* 10(106), pp125–128.

Zilinskas M., Tamosiunaite,M.,Tamosiuniene,M.,Valma,E. and Tamosiunas,S. (2012). Gradient of Radio Refractivity in Troposphere. Progress in Electromagnetics,488 *Research Symposium Proceedings*, Moscow, Russia.