VHF RADIOWAVE PROPAGATION MEASUREMENTS IN MINNA, NORTH CENTRAL NIGERIA

K. C. Igwe[1*], O. D. Oyedum[1], M.O. Ajewole[2] and A. A. Aibinu[3]

[1]Department of Physics, Federal University of Technology, Minna, Niger State

[2]Department of Physics, Federal University of Technology, Akure, Ondo State

[3]Department of Mechatronics Engineering, Federal University of Technology, Minna, Niger State

[1]*Corresponding author: k.igwe@futminna.edu.ng

Abstract

In designing an efficient radio communication system, the engineer is faced with the task of being able to predict the behaviour of the radio signal from the transmitter to the receiver and in doing this, preliminary calculations including the expected signal strength at the receiver has to be made. Signal strength measurement was made from a broadcasting station transmitting at a frequency of 92.3 MHz along a 14.85 Km path. The results obtained show that received signal strength (RSS) values were higher during the wet season as compared to lower values recorded during the dry season for the link. Also, the RSS was higher during the morning and evening/night hours while lower values were recorded during the afternoon time. Signal attenuation caused by atmospheric and environmental losses was calculated and for the dry season, average clear-air attenuation fluctuated between -2 dB to 2.3 dB while wet season values fluctuated between 0 dB and -2.9 dB. Also, the RSS was modeled using ITU-R P.526-12 to predict path losses due to diffraction over the earth's curvature and result obtained reveal that this model underestimated the RSS for the radio link while 206 (12.46%) enhanced field strength was recorded out of the measured 1,639 data.

Key words: Signal strength, Attenuation, Diffraction

1. Introduction

Radio waves form part of the electromagnetic spectrum that extends from the very low frequencies (3-30 kHz) to the extremely high frequencies (30-300 GHz). In the middle of these two extreme frequencies are bands of frequencies that are found in every day uses. These are audio frequencies used in systems for the reproduction of audible sounds, radio frequencies, infrared light, ultraviolet light and x-rays (Barringer and Springer, 1999). The influence of the propagating medium on electromagnetic waves determines the success of any communication.

The daily changes of water vapour in the troposphere and the ionization by the sun in the ionosphere affect radio propagation. Practical applications from the understanding of the effects of these varying conditions on radio propagation abound, from choosing frequencies for international shortwave broadcasters, designing efficient mobile telephone systems, radio navigation to radar systems operation. Radio propagation is also affected by a number of other factors determined by its path from one point to the other (Hall and Barclay, 1991). The path can be a direct line-of-sight path or over-the-horizon path aided by refraction in the atmosphere. For most communication links, the presence of the earth, the atmosphere, the ionosphere, atmospheric hydrometeors such as raindrops, snow and hail modifies the signal propagation. The natural environment has an influence on the propagation of radio waves and this influence is highly dependent on the frequency used, the directivity of the antennas involved and the proximity of the antennas to the ground. The physical nature of the intervening path may also have a significant effect on the propagation of radio waves since propagation over land is different from propagation over water, which is also different from propagation over heavy vegetation or over urbanised areas where tall buildings produce different scattering and diffraction effects (Collin, 1985). Since radio waves are a form of electromagnetic radiation, like light waves, when they travel, they interact with objects and the media in which they travel. As a result, they are affected by the phenomena of reflection, refraction, diffraction, absorption, polarisation and scattering (Paris and Hurd, 1969).

In order to achieve a reliable and efficient communication between a transmitter and a receiver, knowledge of the spatial and temporal variability of field strength is required. Where the user expects a very high quality signal, especially in broadcast applications, this assumes greater significance. Also the performance of any communication circuit depends on the models employed to calculate the coverage area and interference problems (Prasad *et al.*, 2006). At VHF and higher frequencies for which the effects of the ionosphere are generally considered negligible, the troposphere greatly influences the received signal, especially at a distant terminal. This is in addition to any influence caused by the electrical properties of the terrain over which the wave is propagated. Also, propagation conditions often changes greatly from month to month and the monthly variability can vary significantly from year to year. These statistics of signal variability is needed for spectrum planning and for predicting the performance of radio systems (Aboaba and Jegede, 2001; Middleton, 2003).

2. Relevant theory

The power flux per unit area P_a (W/m^2) at a distance r (m) from a loss free isotropic antenna radiating a power P_T (W) is given by (Freeman, 1997):

$$P_a = {P_T}/{4\pi r^2} \qquad (1)$$

where $4\pi r^2$ is the surface area of a sphere at a distance *d* (m) from the source.

The power at the receiver is given by:

$$P_R = P_T \left(\frac{\lambda}{4\pi r^2}\right)^2 \qquad (2)$$

The free space loss, L_{FSL} between transmitter and receiver antennas is defined by:

$$L_{FSL}(dB) = 10Log(\frac{P_T}{P_R}) \qquad (3)$$

Combining equations (2) and (3), the free space loss is given as:

$$L_{FSL}(dB) = 20Log(\frac{4\pi r}{\lambda}) \qquad (4)$$

Equation (4) is restated more conveniently as

$$L_{FSL}(dB) = 32.45 + 20Log(r_{km}) + 20Log(F_{MHz}) \qquad (5)$$

Or as (ITU-R, 2009):

$$L_{FSL}(dB) = 139.3 - E + 20Log(F_{MHz}) \qquad (6)$$

And the free space field strength for 1 kW e.r.p. , E_{FS} is given by:

$$E_{FS}(dB\mu V/m) = 106.9 - 20Log(r_{km}) \qquad (7)$$

For a non free-space environment, the field strength can be related to the basic free space loss by (Barringer and Springer, 1999):

$$L_{FSL}(dB) = 137 + 20Log(F_{MHz}) + P_T + G_T - E(dB\mu V/m) \qquad (8)$$

Also, field strength can be expressed as a function of received voltage, receiving antenna gain and frequency when applied to an antenna whose impedance is 50 ohms. This is given as:

$$E(dB\mu V/m) = E(dB\mu V) - G_r(dBi) + 20Log(F_{MHz}) - 29.8 \qquad (9)$$

For received voltage calculation, this equation becomes:

$$E(dB\mu V) = E(dB\mu V/m) + G_r(dBi) - 20Log(F_{MHz}) + 29.8 \quad (10)$$

where G_r is the isotropic gain of the receiving antenna

The diffraction path loss is taken as the sum of the free space loss that exists in the absence of obstacles and the diffraction loss introduced by the obstacles (Roda, 1988). The diffraction field strength, E, relative to the free-space field strength, E_0, is given by (ITU-R, 2012):

$$20\ log\frac{E}{E_0} = F(X) + G(Y_1) + G(Y_2)\ dB \quad (11)$$

where X is the normalised length of the path between the antennas at normalised heights Y_1 and Y_2.

$$X = 2.188\beta f^{1/3} a_e^{-2/3} d \quad (12a)$$

$$Y = 9.575\ X\ 10^{-3} \beta f^{2/3} a_e^{-1/3} h \quad (12b)$$

where: *d* = path length (km)

a_e = equivalent Earth's radius (km)

h = antenna height (m)

f = frequency (MHz)

β is a parameter allowing for the type of ground and for polarisation. It is related to K, the surface admittance by the following semi-empirical formula:

$$\beta = \frac{1 + 1.6\ K^2 + 0.67\ K^4}{1 + 4.5\ K^2 + 1.53\ K^4} \quad (13)$$

The distance term is given by:

$$F(X) = 11 + 10\ log(X) - 17.6\ X \quad \text{for } X \geq 1.6 \quad (14a)$$

$$F(X) = -20\ log(X) - 5.6488X^{1.425} \quad \text{for } X < 1.6 \quad (14b)$$

The height gain term G(Y) is given by the following formula:

$$G(Y) \equiv 17.6\ (B - 1.1)^{1/2} - 5log(B - 1.1) - 8 \quad \text{for } B > 2 \quad (15a)$$

$$G(Y) \equiv 20log(B + 0.1B^3) - 5log\ (B - 1.1) \quad \text{for } B \leq 2 \quad (15b)$$

where: $B = \beta Y$ (15c)

3. Methodology

Experimental Setup: The transmitter, a broadcast station is the Federal University of Technology, Minna FM station broadcasting at 92.3 MHz. It is located at the main campus of the University, Gidan Kwano, Minna. It is 14.85 Km from the receiver, which is located at the mini campus, Bosso, Minna. The climatic condition in Minna is a tropical one with two main seasons, the dry or harmattan season which occurs from November to March and the wet or rainy season which commences from April and ends in October every year. The measurement was done from January to March and from May to July, that is, three months of dry season and three months of wet season.

The instrument used for the signal strength measurement is the Geberit Digital Signal Level Meter, GE-5499 covering the signal range of 30-120 dBµV (Figure 1). Figure 2 shows the map of the transmitting and receiving stations while table 1 gives details of the parameters of the experiment.

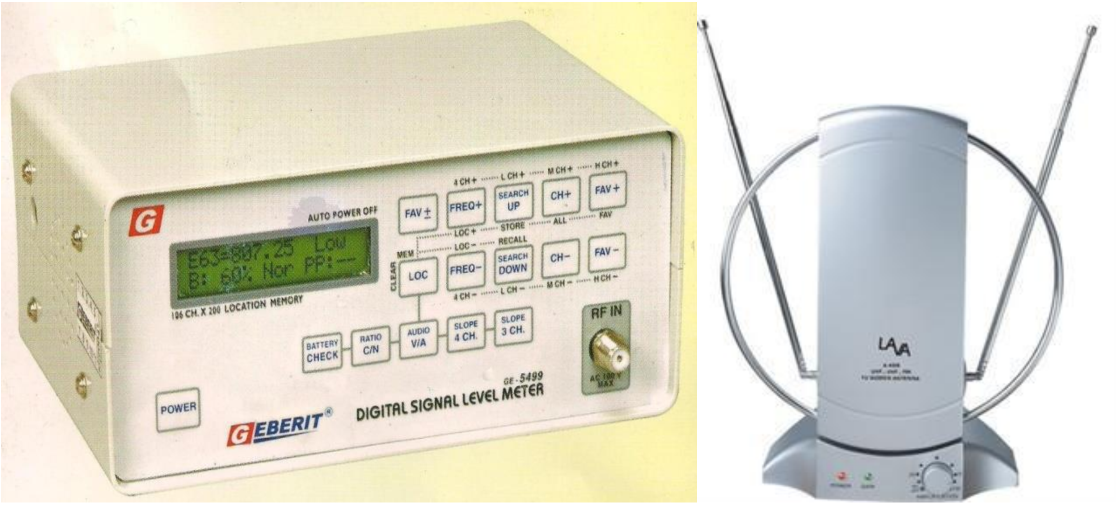

Figure 1: Geberit field strength meter and antenna

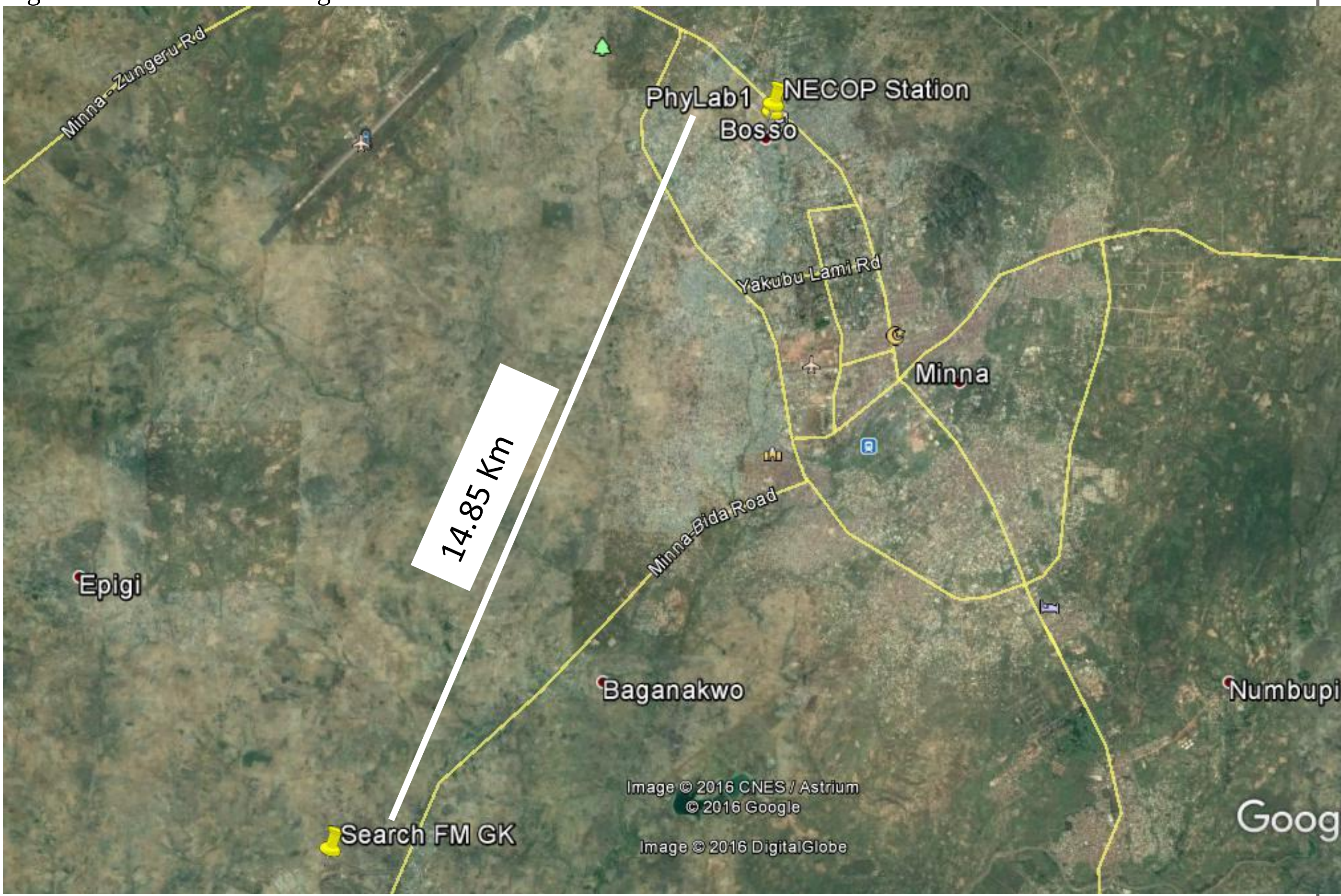

Figure 2: The transmitting station (Search FM) and the measurement site (Physics Lab 1)

Table 1: Measurement parameters

Frequency (MHz)	92.3
Tx height (m)	180
Rx height (m)	3.2
Path distance (km)	14.85

Tx Power (kW)	0.3

4. Results and Discussion

4.1 Seasonal Variation of Signal Strength

Although measurements were made for six months, only few months are shown here because of space constraints. Figures 4.1a-b show the mean monthly variation of Signal Strength for the VHF link for a typical dry season month and a typical wet season month. Using the month of March for a typical dry month, mean signal strength measured for the link varied from 72 dBµV to 93 dBµV.
Measurement made for the wet season months reveal that higher signal strength values were recorded for the link. For the month of July, a typical wet month, mean signal strength measured for the link ranged between 88 dBµV and 106 dBµV.

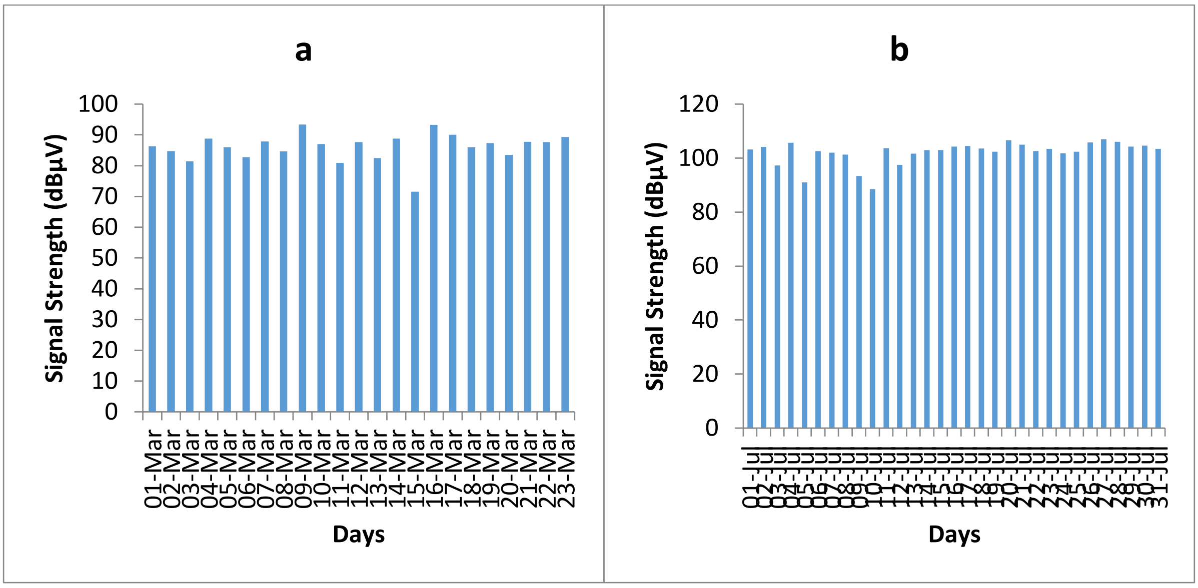

Figure 4.1a&b: Mean daily VHF Signal Strength Variation for a typical dry month (March) and a typical wet month (July)

4.2 Mean Diurnal variation of Signal Strength

Figures 4.2a-b show the mean values of diurnal variation of the received signal strength during broadcast hours. The measurement was taken from 9 am to 10 pm when the radio station ends broadcast daily. From the results, it is observed that hourly signal strength shows a noticeable diurnal trend. The received signal strength (RSS) was generally higher during the morning and evening/night hours while lower values were recorded during the afternoon time. Using the month of February as an example, a peak value of RSS of 77 dBµV was recorded around 9.00 am local time but thereafter the RSS decreases towards afternoon until a minimum value of 67 dBµV was reached by 2.00 pm. The RSS value then began an upward rise with a value of 71 dBµV from 3.00 pm until another peak value of 75 dBµV was reached by 5.00 pm. There was a slight decrease in RSS to 71 dBµV at 6 pm before another rise from 72 dBµV at 7.00 pm to a peak value of 75 dBµV by 8.00 pm which was maintained during the night. This trend of morning/night peak and midday minimum was observed in the other months.

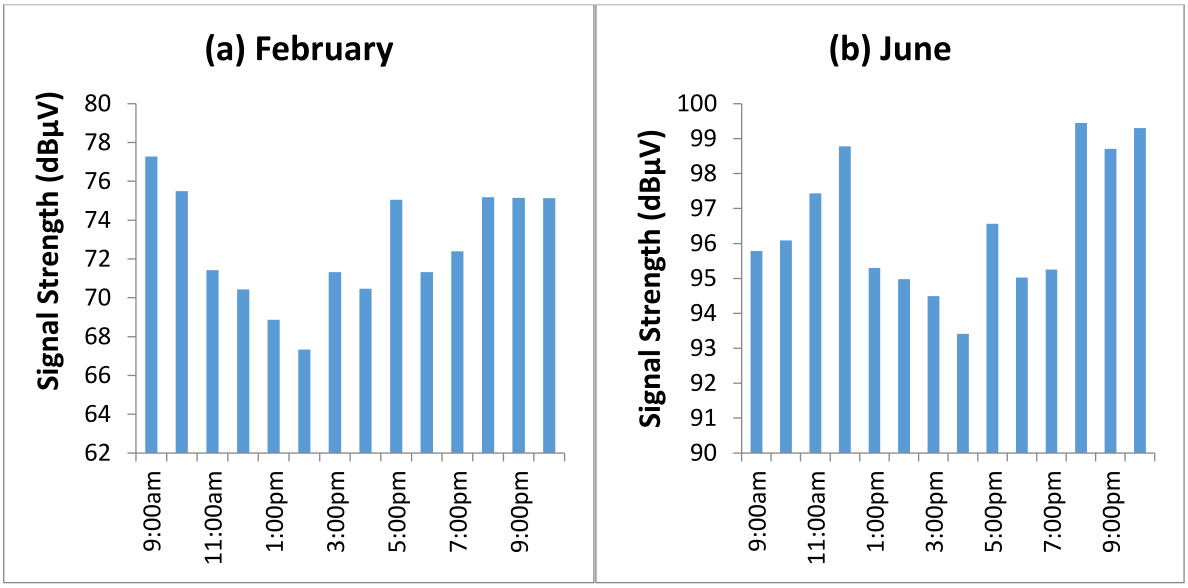

Figure 4.2a&b: Mean Diurnal Variation of Signal Strength for a typical dry month (February) and a typical wet month (June)

4.3 Cumulative Frequency Distribution of Signal Strength

The cumulative frequency distribution of the received signal strength (RSS) for the link for the entire database is presented in Figure 4.3. This curve show the fraction of the total time for which the received signal exceeded a specified power. For this link, 1,639 RSS value was recorded in the entire database. Of these values, the highest number of samples in the entire data base is 105 dBµV which occurred 313 times, corresponding to 48.38% of time of measurement while the field strength value with the lowest number of samples in the entire data base is 55 dBµV and 115 dBµV, both occurring twice during measurement and this represented 0.12% of time. Also, figure 4.3 reveals that the RSS exceed 35 dBµV in 95.5% of the measurement time.

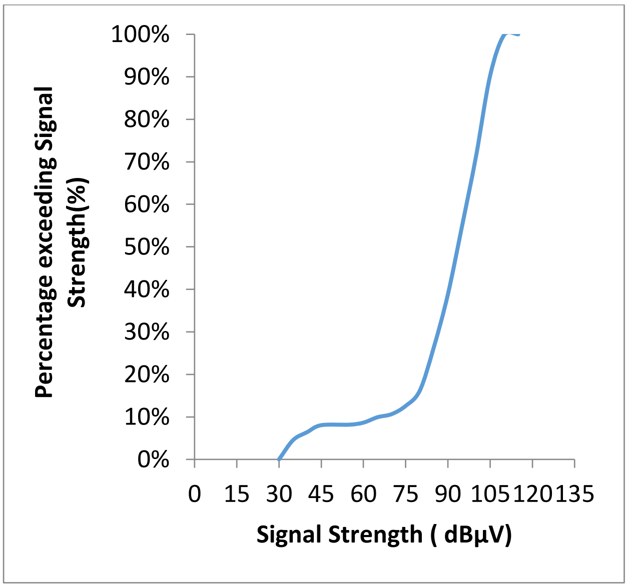

Figure 4.3: Cumulative Frequency Distribution for Search FM Minna

4.4 Attenuation of received signals

During transmission, there is a certain power expected at the receiver end of the terrestrial link. For instance the RSS expected at the receiver end is 69.3 dB when a transmitting power of 8.5 kW is used. However, the actual RSS fall below this level indicating that there is signal attenuation as a result of atmospheric or environmental losses. The attenuation of the signal level was calculated and the effect is observed in all the measured values of signal strength. Some of the results are shown in Figures 4.4a and 4.4b. Taking the month of February which is a typical dry month for an example, it is seen that the average clear-air attenuation fluctuates between -2 dB to 2.3 dB.
Considering the clear-air attenuation for a typical wet month (July), average attenuation fluctuates between 0 dB and -2.9 dB. One of the factors that contribute to this clear-air attenuation is the k-factor (effective-earth radius factor) fading. Diffraction or k-type fading in line-of-sight links result due to the variation of the effective earth radius factor which also arises because of the time-varying nature of the primary tropospheric parameters of temperature, pressure and relative humidity.

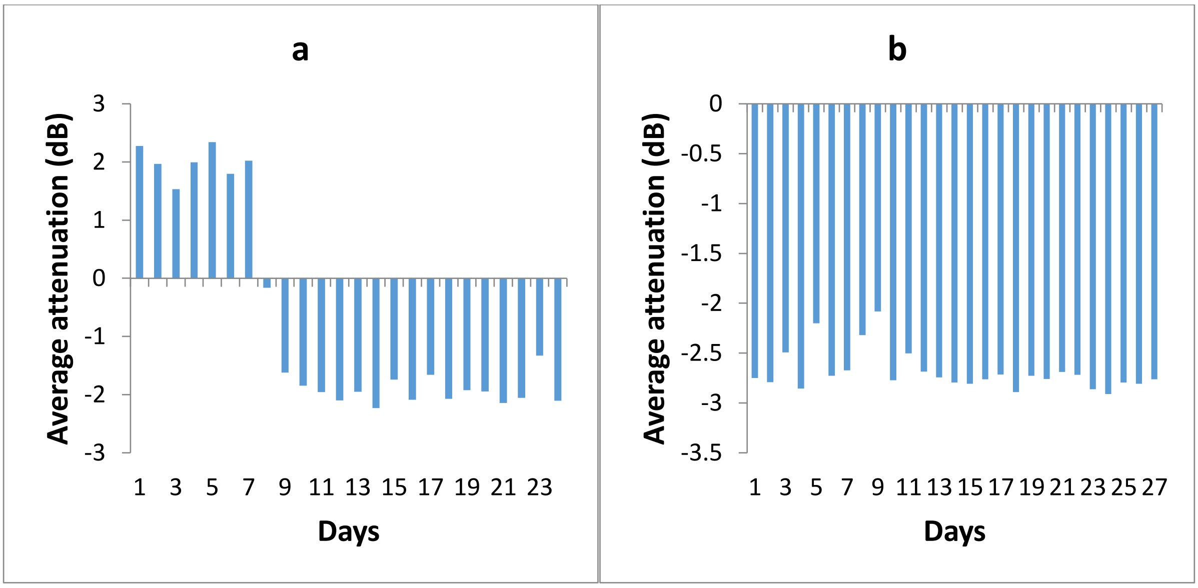

Figure 4.4: Clear air attenuation for a typical dry month (a) and a typical wet month (b)

4.5 Modelling of Field Strength using ITU-R model

The received signal strength was converted to field strength. Subsequently the diffraction values were modelled using the procedure in Recommendation ITU-R P.526-12. The step-by-step calculation of this procedure is given from equation 11-15c. This recommendation uses antenna heights and range to predict path losses due to diffraction over the earth's curvature. Free space field strength for the link was also calculated using equation 5, and assuming that free space loss along the path is classified as enhanced signals. Figure 4.5 gives comparisons between the predicted field strength, the free space field strength and the measured field strength. From the Figure, it is observed that ITU-R model underestimated the received field strength for the radio link. The differences between the predicted and the measured field strength values are notably large, hence no correlation whatsoever exists between the measured field strength and the ITU-R predicted field strength. This observation indicates that some refractive effects are prevalent all the time. Since the majority of the data lie between the free space and diffraction threshold values, this indicates that refractive effects (atmospheric effects) are able to increase the received field strength well beyond the diffraction level and this enhancement in field strength provided by the atmosphere is sufficient to reach the free space threshold as seen in some cases in the figure. For this FM link, 206 (12.46%) out of the measured 1,639 data correspond to enhanced field strength. One of the factors or type of refractive condition responsible for this type of enhanced field strength is ducting. This anomalous effect allows radio signals to reach distant receivers that would not propagate beyond the radio horizon under normal atmospheric conditions.

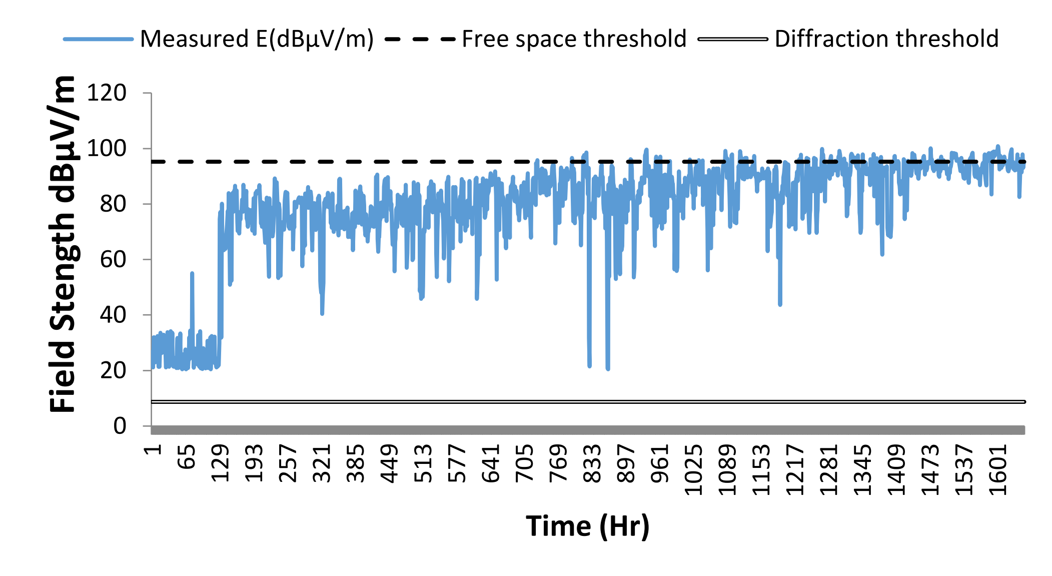

Figure 4.5: Comparison of measured Field Strength with ITU-R Models of Free-Space and diffraction values for Search FM (92.3 MHz) Link.

5. Conclusion

Very high frequency (VHF) measurements have been carried out for a point-to-area network situated in Minna. Measurement carried out reveal the effects of weather on the received signal strength (RSS) as low values were recorded during the daytime and during the dry season while peak values were recorded at night times and during the wet season. The received signal strength was converted to field strength and the field strength was modelled using the procedure in Recommendation ITU-R P.526-12. From the result, it was observed that ITU-R model underestimated the received field strength for the radio link. The experimental results obtained are required for engineers planning to design an efficient radio communication system in this part of the world since preliminary calculations including the expected signal strength at the receiver are very necessary for such design.

References

Aboaba, O. A., & Jegede O. O. (2001). Correlation studies of of VHF radiowave propagation and radiometeorological conditions. *Proc. Of the 11th International Conf. on Antennas and Propagation – ICAP2001, IEEE Conf., No. 480, Vol.1, UMIST, Manchester, UK, pp. 170-171.*

Barringer, M. H. & Springer, K. D. (1999). Radio Wave Propagation, *National Association of Broadcasters Engineering Handbook, 9th edition. Retrieved online from http://maisonthenezay.fr/Maintenance_HF/NAB.html on 2nd April, 2014*.

Collin R. E. (1985). Antennas and Radiowave Propagation. *McGraw-Hill international editions, Electrical Engineering series, Singapore, pp. 339, 402, 409.*

Freeman R. L. (1997). Radio System Design for Telecommunications. *2nd Edition, John Wiley & Sons Inc.*

Hall, M. P. M. & Barclay, L. W. (1991). Radiowave Propagation. *Peter Peregrinus Ltd., England, ISBN 0 86341 156 8, pp. 8, 75, 114, 173, 177.*

ITU-R. (2009). Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz. *Recommendation P.1546-4, ITU-R P Sers., Int. Telecomm, Union, Geneva..*

ITU-R. (2012). Propagation by Diffraction. *Recommendation P.526-12, ITU-R P Sers., Int. Telecomm, Union, Geneva.*

Middleton, J. (2003). The Propagation aspects of Broadcasting at VHF and UHF. *Propagation of Radiowaves, 2nd ed., The Institute of Electrical Engineers, London, UK, 2003, pp 253-255.*

Paris, D. T. & Hurd, F. K. (1969). Basic Electromagnetic Theory. *McGraw Hill, New York ISBN -0 048470-8.*

Prasad, M. V. S. N., Rao, R. T., Ahmad I., & Paul K.M. (2006). Investigation of VHF signals in bands I and II in southern India and model comparisons. *Indian Journ. of Radio and Space Physics, vol. 35, pp. 198-205.*

Roda, G. (1988). Troposcatter Radio Links. *Artech House Inc., Chapter 1,3,4 and 6.*