Original Research Article

Tropospheric Influence on Ultra-High Frequency (UHF) Radio Waves

Abstract

This research investigates the effects of temperature and relative humidity on UHF radio wave signals. A spectrum analyzer was used in measuring UHF signals while a digital thermometer and hygrometer was used in measuring temperature and relative humidity, respectively. From results obtained, relative humidity had no effect on UHF signal strengths while temperature had a positive correlation effect on path losses in UHF radio waves. This implies that an increase in temperature will lead to a decrease in received signal strength of UHF signals. Furthermore, a path loss propagation model for Calabar was obtained using multiple regression analysis and we believe that the result obtained in this study will be useful to radio engineers, for UHF signal propagation in the study terrain.

Keywords: UHF Signals, Radio Waves, Temperature, Relative Humidity, Path Loss

Introduction

Ultra-High Frequency (UHF) is the International Telecommunications Union (ITU) designation for radio frequencies in the range between 300 megahertz (MHz) and 3 gigahertz (GHz), also known as the decimetre band, because its wavelength ranges between one meter to one decimeter [1-5]. They propagate on line-of-sight and are easily blocked by obstacles [6-9].

Waves in the decimetre band are weakly reflected by ionized layers of the upper atmosphere and as a result, they bend around the earth's curvature and are easily obstructed. They can, however, be concentrated into a narrow and highly directional signal beams. These characteristics make UHF suitable for line-of-sight applications that require high accuracy. They are used in many facets of life including ship and aircraft navigation systems, satellite communication, GPS, Wi-Fi, bluetooth, walkie-talkies, cordless phones, cell phones and television broadcasting. UHF waves typically carry television signals on channels 14 through 83 [8, 9].

Adverse atmospheric conditions absorb, reflect, refract, diffract, depolarize and scatter communication signals [5, 10-23], resulting in substantial path loss and severe degradation in signal coverage and quality of service [24-42]. Atmospheric induced attenuation is the prominent source of signal degradation in radio wave communication channels. However, the signals' attenuation and impairment effects from various natural atmospheric phenomena depend on the transmission frequency, transmission links, and particularly, the location at which the signal is transmitted [43].

In designing and deploying meaningful communication systems, several attenuation effects owing to different atmospheric conditions need are examined [44, 45]. The knowledge of specific attenuation influenced by different atmospheric variables is essential for efficient fade management [46].

Based on this premise, studies on atmospheric effects on radio signals have become imperative for radio engineers and scientists for the proper planning of reliable radio links, power budget and coverage areas [47]. As such, the wireless network designers are concerned about the nature of the atmosphere through which the signal propagates from the transmitter to the receiver [48].

How atmospheric factors affect the strength of UHF radio signals have been previously explored, with conflicting results and conclusions [49-57].

Therefore, there is a need to study the effect of temperature and relative humidity on UHF signals in order to ease its deployment for signal transmission. Based on this need, this paper aims at determining how temperature and relative humidity affects UHF radio waves, using signals generated at 512.25MHz. Furthermore, the obtained result will be used to develop a propagation model for the study area and make comparison with the free space propagation model. This is done to check the suitability of the free space propagation model for transmission of signal in the study area.

Methodology

Equipment used for data collection

A digital spectrum analyzer (GW-INSTEK) GSP-730 with frequency range of 150 MHz - 3GHz was used in measuring signal strength while a digital thermometer and relative humidity meter (model Htc) was used in measuring temperature and relative humidity. A hand-held GPS (GARMIN 78S) was used for the measurement of latitude and longitude. This research was carried out in the city of Calabar, Cross River State. Measurements of received signal strength, geographical coordinates (elevation, longitude and latitude) and meteorological variables were simultaneously taken. Measurements was taken in twelve locations, based on the peculiarity of the location.

Data Collection

Signals transmitted from the base station of Cross River Broadcasting Corporation at a frequency of 519.25MHz was measured at Line-of-Sight (LOS) distance at 12 different routes with the base station as reference point. The received signal strength were obtained at the receiver antenna at a height of 3.0 m. During the measurement campaign, latitude and longitude at the various points of data collection were measured using the GPS, which equally measured the elevation. Concurrently, temperature and relative humidity was measured.

Data Analysis

Measured data were grouped according to routes and the average values were used for the analysis. The data for received signal strength, temperature and relative humidity were averaged for each location. Line of sight (LOS) distance of each measurement point were calculated, taking the base station as the reference point. Path loss of the measured signal was calculated, various graphs were plotted and correlation analysis were calculated for a proper understanding of the effects of temperature and relative humidity on UHF signals. A path loss model to suit with the terrain of the study area was obtained using multiple regression analysis. Finally, free space path loss was calculated using the free space path loss equation and the calculated values were compared with the measured path loss model. This was done to ascertain its suitability for transmission of UHF signals in the study terrain. Where the free space path loss model does not suit with the terrain, an optimized free space path loss model was developed.

Results and Discussion

Effect of Temperature and Relative Humidity on UHF Radio Waves

In this section, how temperature and relative humidity affects UHF signal strengths was studied. Average values of temperature and relative humidity at each study route was compared with the measured path losses at each study route. To compute the path losses,

Let transmitted power = P_T
Received power = P_R
Loss in power = P_L

$$P_L = P_T - P_R \quad (1)$$

Where P_T = 56.0206dBm

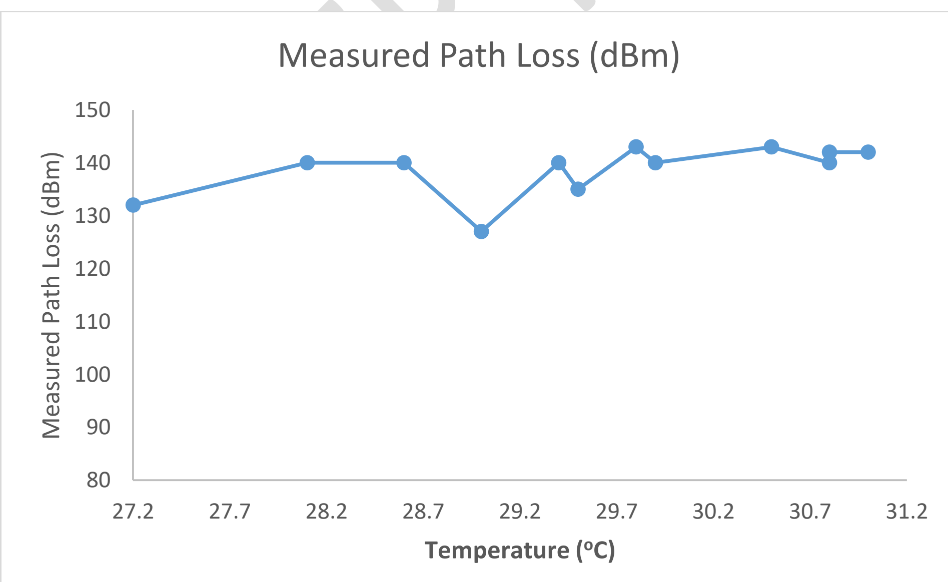

Figure 1: Graph of Measured Path loss against Temperature

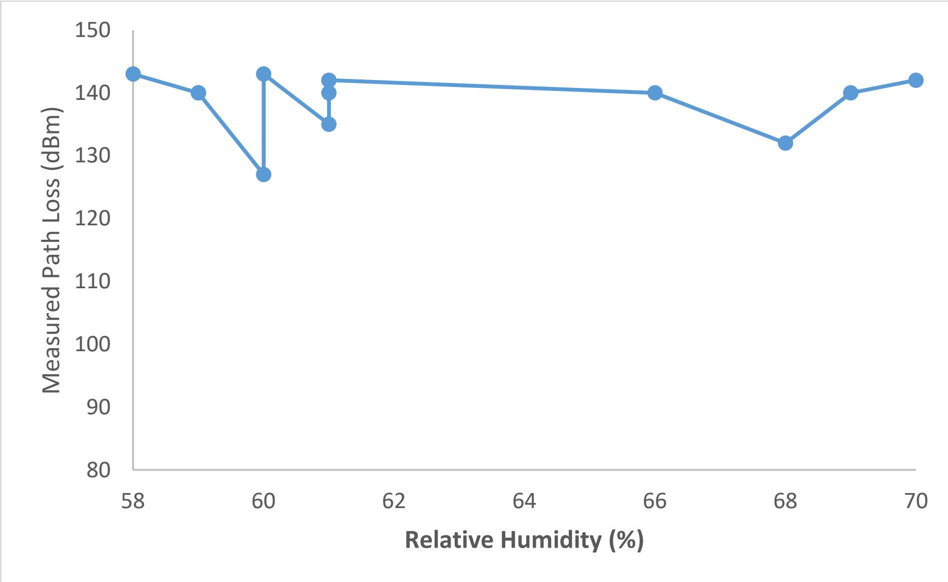

Figure 2: Graph of Measured Path loss against Relative Humidity

From the measured and calculated data, a graph of measured path loss against temperature/relative humidity, as shown in figure 1 and figure 2, with correlation coefficients of 0.56 for temperature and -0.04 for relative humidity, respectively. The low negative correlation coefficient for relative humidity implies that relative humidity does not account for the path losses in the study area and therefore, does not affect UHF signal strength. Also, an increase in temperature led to an increase in path losses, hence, as temperature increases, UHF signal strength decreased.

Path Loss Model for Study Area using Multiple Regression Analysis

In this section, multiple regression analysis was used in developing path loss model for the study area. In this model, path loss was considered the dependent variable while temperature and relative humidity were the independent variable. Based on the assumption that temperature and relative humidity influenced radio waves transmission from the transmitter to the receiver. In multiple regression analysis,

$$Y = \beta_o + \beta_1 T + \beta_2 R + \mu \qquad (2)$$

Where, Y = calculated path loss = P, β_o = constant, β_1= predictor variable for temperature, β_2= predictor variable for relative humidity, μ = prediction error, T = temperature and R= relative humidity

Here, $\beta_o = 37.920$, $\beta_1 = 2.796$, $\beta_2 = 0.290$ and $\mu = 3.733$

Therefore, regression model becomes

$$P = 37.920 + 2.796T + 0.290R + 3.733 \qquad (3)$$

Equation (3) becomes the developed path loss model for the study area. From the developed path loss, values of relative humidity and temperature were substituted and the developed path loss in each route was obtained. The values, as shown in figure 3 and figure 4, underestimated and overestimated the measured path losses. However, the low prediction error of 3.733, indicates a better fit for the regression model. It was also discovered that a unit increase in temperature resulted to 2.796dB increase in path loss and a unit increase in relative humidity resulted to 0.290dB increase in path loss.

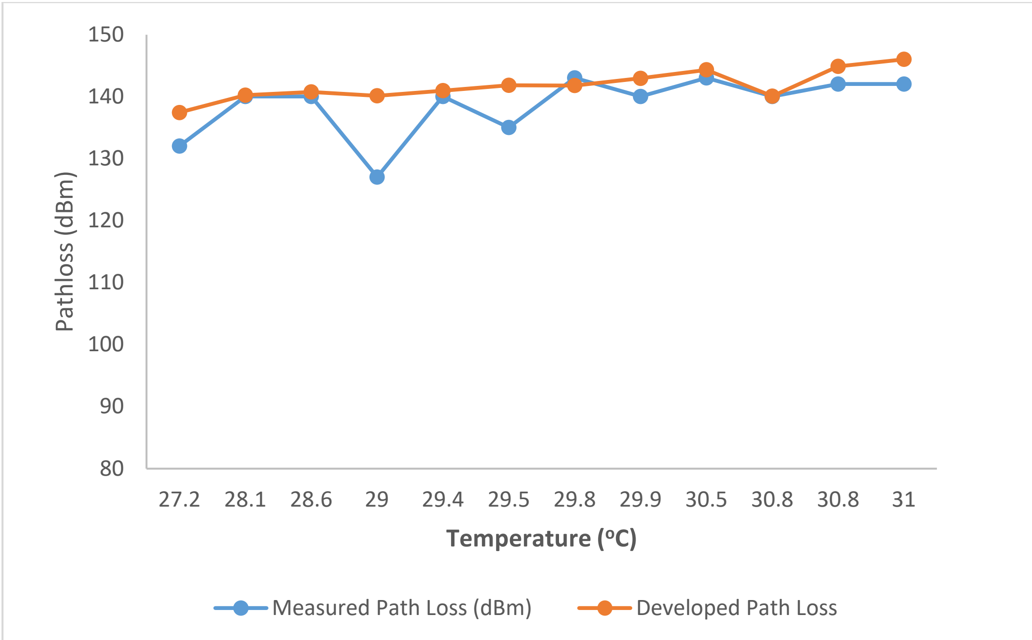

Figure 3: Graph of Measured Path loss/Developed Path Loss against Temperature

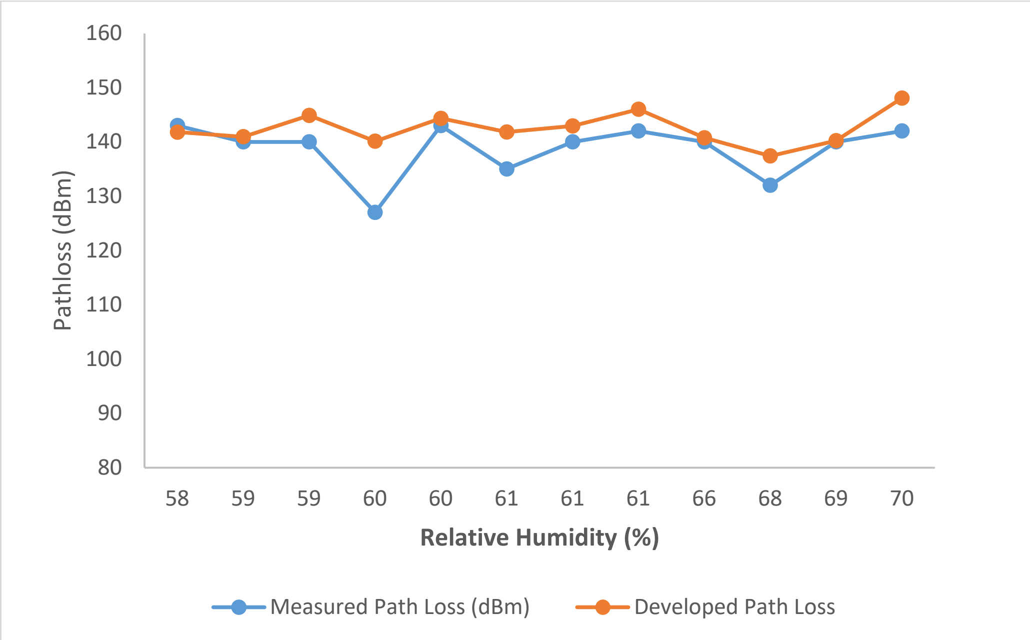

Figure 4: Graph of Measured Path loss/Developed Path Loss against Relative Humidity

Analysis of Free Space Propagation Model

In this section, the longitudes and latitudes of each measured route and that of the base station, which serves as the reference point, is used to calculate the LOS distance of each location from the base station. The calculated LOS distance is then substituted into the free space propagation equation, given by [58] as

$$L_{FS} = 32.5 + 20 \log d + 20 \log f \quad (4)$$

Where f is in megahertz (MHz) and d in kilometers (km).

Solving for locations the 12 locations and comparing it with the measured path loss model, we obtain figure 5 and figure 6.

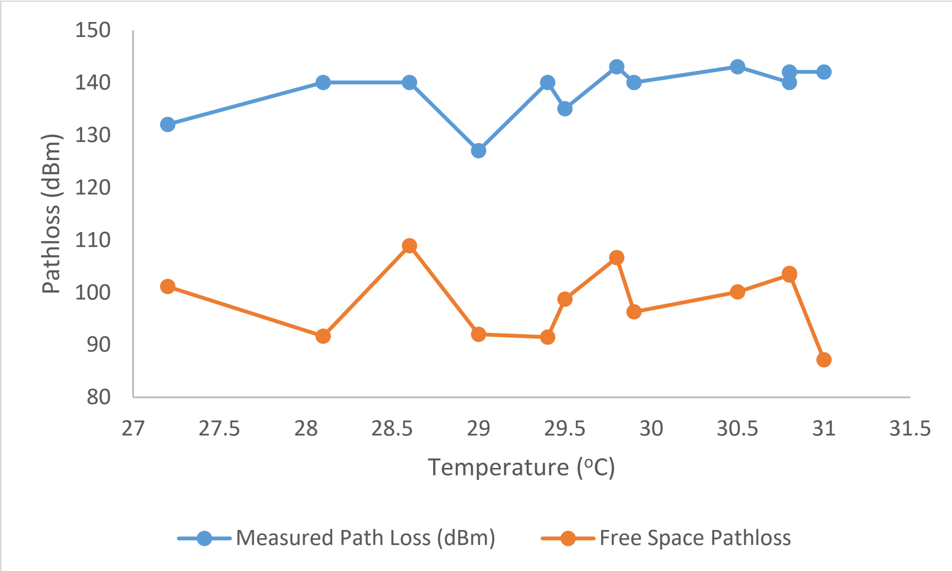

Figure 5: Graph of Measured/Free Space Path Loss against Temperature

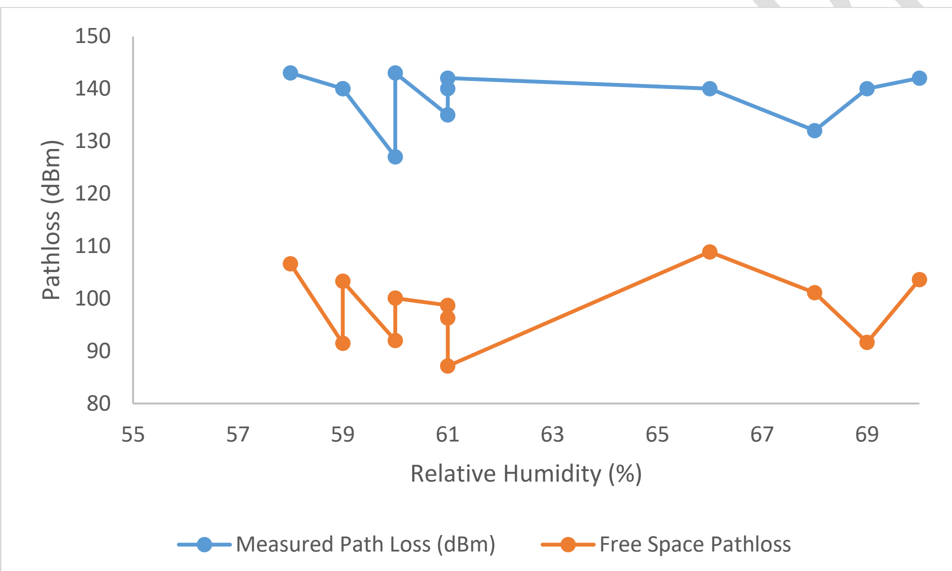

Figure 6: Graph of Measured/Free Space Path Loss against Relative Humidity

As observed in figures 5 and 6, the free space path loss underestimated pathlosses in the study area and therefore, it is not suitable for signal propagation in the study area.

Optimization of Free Space Propagation Model

The unsuitability of the free space path loss model for signal propagation in the study area has given rise for a need for an adjustment to be made for its suitability for signal transmission in the study area.

Recall, in equation (4), free space path loss model is given as

$L_{FS} = 32.5 + 20 \log d + 20 \log f$

To optimize the model for its suitability in the study area, we introduce a prediction error C. Therefore,

$$L_{FS} = 32.5 + 20 \log d + 20 \log f + C \qquad (5)$$

And

$$C = \sqrt[2]{\frac{(P_m - P_{FS})^2}{N}} \qquad (6)$$

Where C = 53.7dBm

Therefore,

$$L_{FS} = 32.5 + 20 \log d + 20 \log f + 53.7 \qquad (7)$$

Substituting the values of d and f into (7) and plotting it against temperature/relative humidity, we obtain figures 7 and 8.

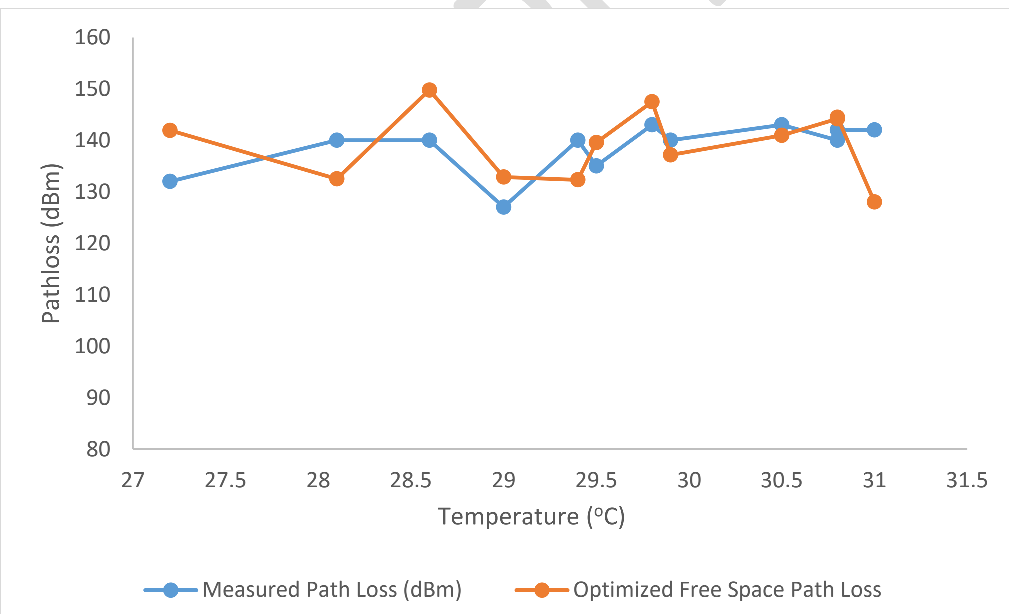

Figure 7: Graph of Measured/Optimized Free Space Path Loss against Temperature

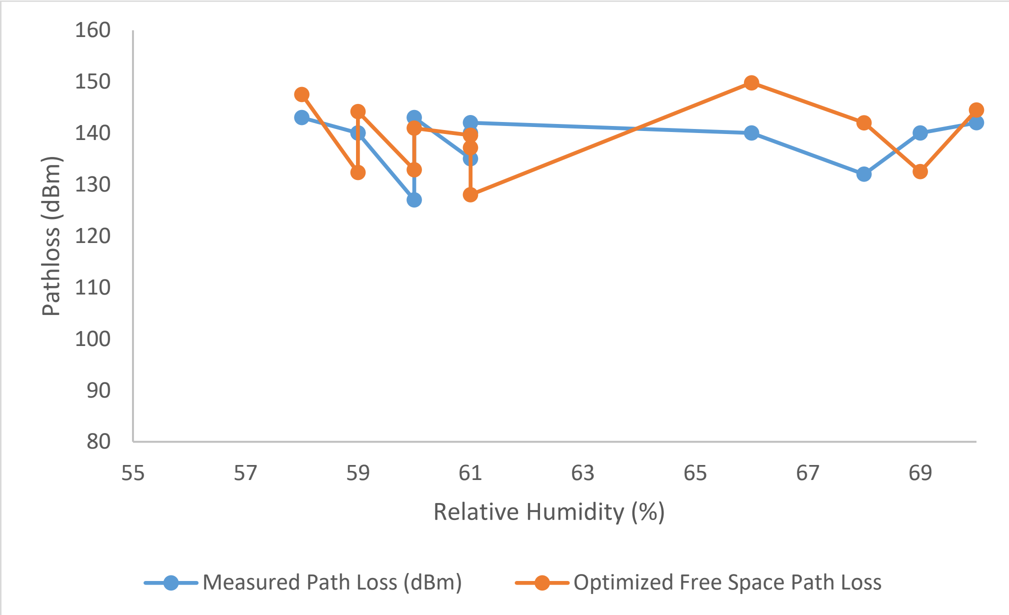

Figure 8: Graph of Measured/Optimized Free Space Path Loss against Relative Humidity

From the plotted graphs, it is observed that the optimized path loss model underestimated and underestimated the measured path losses at each measurement route. In addition to this, since the prediction error was above the recommended threshold of at most 6dBm [41], it is justifiable to say that the optimized free space path loss will not be fit for signal propagation in the area under investigation.

Conclusion

The effects of meteorological variables on low-band VHF signals have been studied, taking temperature and relative humidity as the meteorological variables of importance. Results obtained shows that temperature and relative humidity has no effect on VHF signals. The suitability of the free space propagation model for the study terrain failed, as calculated results showed that this model under-estimated path losses in the study area. Multiple regression analysis has been used to obtain a suitable path loss model for the study terrain.

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