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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

This research investigates the effects of temperature and relative humidity on UHF 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 significant effect on measured path loss while a positive correlation coefficient was obtained between temperature and measured path loss. 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 (P_L = 37.920 + 2.796T + 0.290R + 3.733) was obtained using multiple regression analysis and we believe that the obtained result will be useful to radio engineers for UHF signal propagation in the study terrain.

Keywords: UHF signals; radio waves; temperature; relative humidity; path loss.

1. INTRODUCTION

Ultra-High Frequency (UHF) is the International Telecommunications Union (ITU) designation for radio frequencies between 300 megahertz (MHz) and 3 gigahertz (GHz), also known as the decimetre band because its wavelength ranges between one decimetre to one metre [1-5]. They propagate at 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

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the earth's curvature and are easily obstructed. They can, however, be concentrated into narrow and highly directional signal beams. These characteristics make UHF suitable for line-of-sight applications that require high accuracy. UHF radio waves 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. They typically carry television signals on channels 14 through 83 [8,9].

Study has it that adverse atmospheric conditions absorb, reflect, refract, diffract, depolarize and scatter communication signals [5,10-23] and these results to substantial path loss and severe degradation in signal coverage and quality of service [24-44]. Atmospheric induced attenuation and impairment is the prominent source of signal degradation in radio wave communication channels; however, they depend on the transmission frequency, transmission links and particularly, the location from which the signal is transmitted [45].

In designing and deploying meaningful communication systems, several attenuation effects owing to different atmospheric conditions need are examined [46,47]. The knowledge of specific attenuation influenced by different atmospheric variables is essential for efficient fade management [48]. 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 [49]. As such, wireless network designers are concerned about the nature of the atmosphere through which the signal propagates from the transmitter to the receiver [50].

The effect of atmospheric factors on UHF radio signals have been previously explored [51-62]. The authors in [56] investigated the effects of relative humidity on received signal strength for sunny and rainy days and statistical analysis was used to determine the relationship between both variables. The following results for rainy and sunny days at various frequencies were obtained (r_r=correlation on rainy day, r_s= correlation on sunny day): For frequency 382.5 MHz (r_r =-0.423, r_s=-0.382), while for frequency 945 MHz (r_r =-0.512, r_s=-0.631), frequency 1867.5 MHz (r_r =-0.588, r_s=-0.669) and frequency 2160 MHz (r_r = -0.509 r_s=-0.805).

For the authors in [55], the effect of temperature on UHF signals was investigated. Computed result shows that temperature had no significant effect on UHF signal strength. In [59], the effects of temperature and relative humidity on UHF radio waves was investigated. It was concluded that an increase in temperature and relative humidity led to a decrease in UHF signal strength and vice versa. In [62] the effects of temperature and relative humidity on signals emanating from a mobile network operating at a frequency band of 900MHz was studied. A rise in relative humidity led to a decrease in UHF signal strength while temperature rise was accompanied by an increase in received signal strength and vice versa.

In [61], the authors studied the effects of temperature and humidity on radio signal strength in outdoor wireless sensor networks. Experimental measurements were performed using Atmel ZigBit 2.4GHz wireless modules, both in summer and wintertime. They employed all the radio channels specified by IEEE 802.15.4 for 2.4GHz ISM frequency band with two transmit power levels. The results show that changes in weather conditions affect received signal strength. As temperature rises, there was a reduction in signal strength and vice versa. Also, as relative humidity rises there was a rise in signal strength and vice versa.

With the conflicting results and conclusions, 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 UHF signals transmitted 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 signals in the study area.

2. METHODOLOGY

2.1 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 hygrometer 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 were taken in twelve locations, based on the peculiarity of the location.

2.2 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.

2.3 Data Analysis

Measured data were grouped according to routes and the average values were used for the analysis. Collected data of received signal strength, temperature and relative humidity were averaged for each location. Line of sight (LOS) distance of each measurement point was calculated, taking the base station as the reference point. Path loss of the measured signals were calculated, various graphs were plotted and correlation coefficients were obtained 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.

3. RESULTS AND DISCUSSION

3.1 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

$$P_L = P_T - P_R \tag{1}$$

Where, P_T = 56.0206dBm

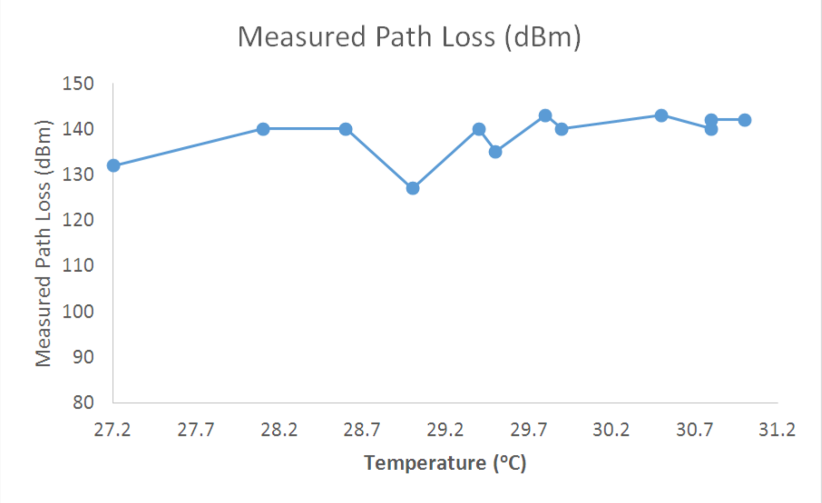

Fig. 1. Graph of Measured Path loss against Temperature

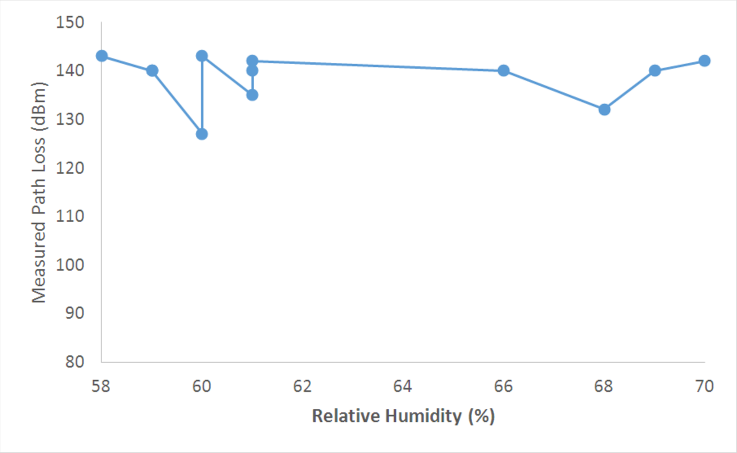

Fig. 2. Graph of Measured Path loss against Relative Humidity

From the measured and calculated data, a graph of measured path loss against temperature/relative humidity, as shown in Fig. 1 and Fig. 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. From the available literature, this work agrees with results earlier obtained by the authors in [59], where an increase in temperature led to a decrease in received signal strength.

3.2 Path Loss Model for Study Area Using Multiple Regression Analysis

In this section, multiple regression analysis was used in developing a 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 and based on the assumption that temperature and relative humidity influenced radio wave transmission from the transmitter to the receiver. In multiple regression analysis,

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

Where, Y = P = calculated path loss, 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, β_o = 37.920, β_1= 2.796, β_2= 0.290 and μ = 3.733

Therefore, regression model becomes

$$P_L = 37.920 + 2.796T + 0.290R + 3.733 \quad (3)$$

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 Fig. 3 and Fig. 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 2.796dBm increase in path loss and a unit increase in relative humidity resulted to 0.290dBm increase in path loss.

3.3 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 [63] 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 Fig. 5 and Fig. 6.

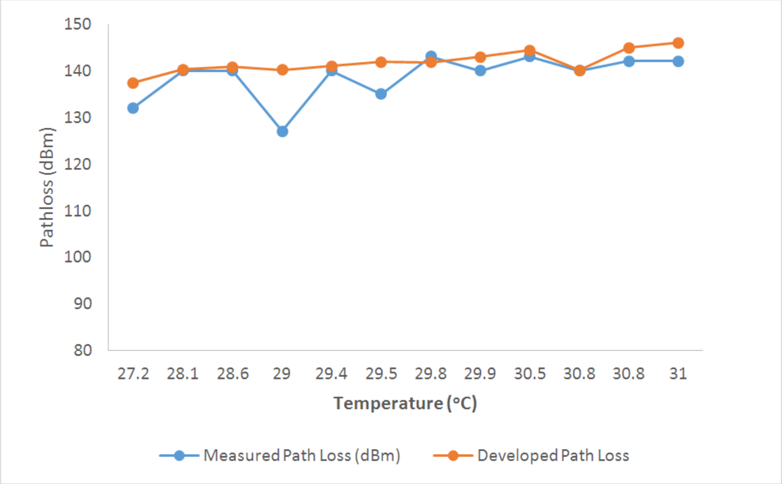

Fig. 3. Graph of Measured Path loss/Developed Path Loss against Temperature

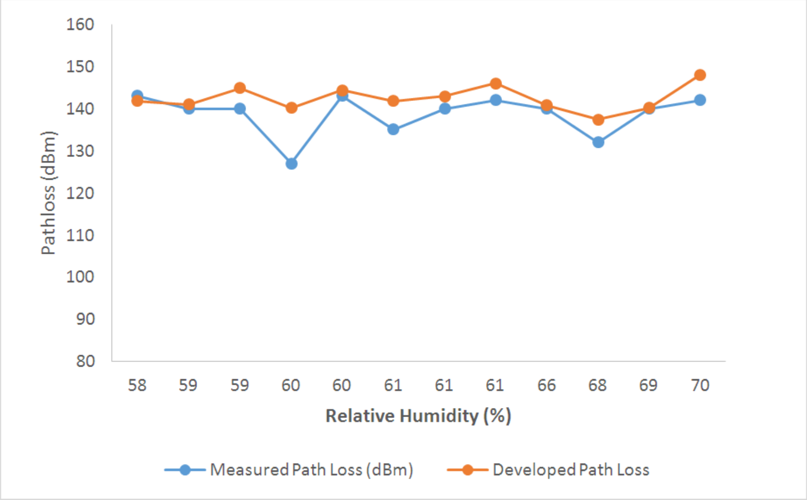

Fig. 4. Graph of Measured Path loss/Developed Path Loss against Relative Humidity

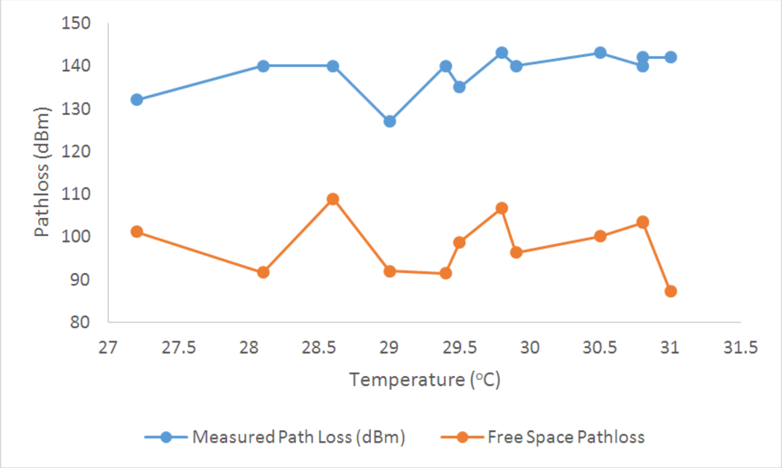

Fig. 5. Graph of Measured/Free Space Path Loss against Temperature

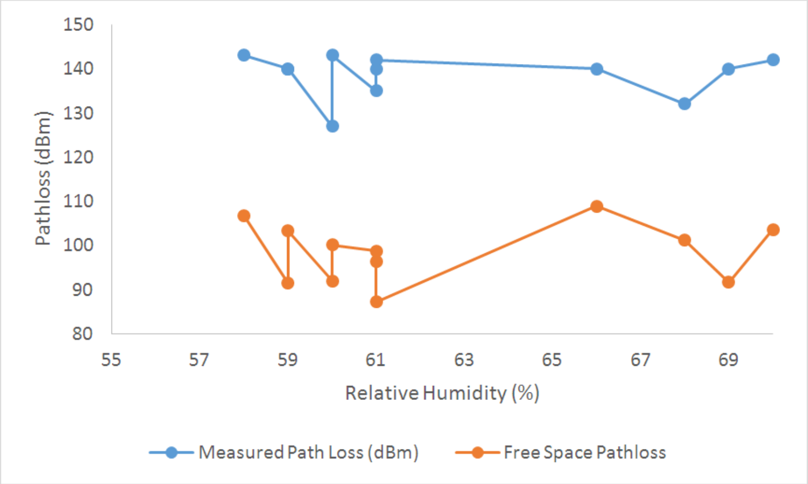

Fig. 6. Graph of Measured/Free Space Path Loss against Relative Humidity

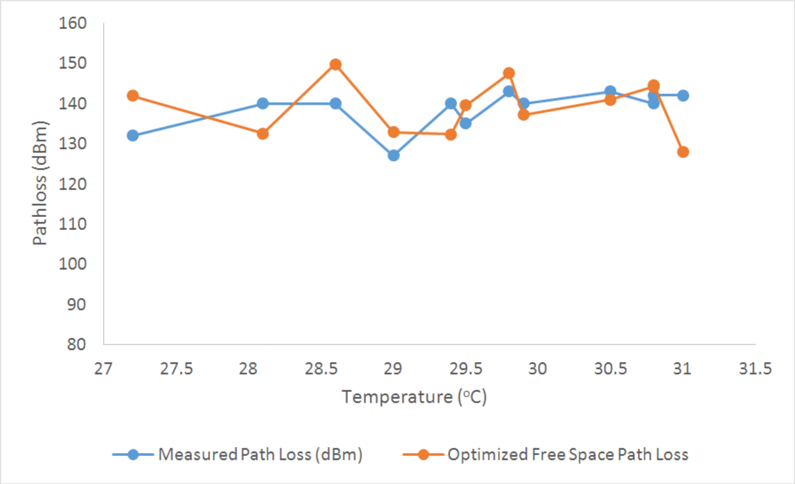

Fig. 7. Graph of measured/optimized free space path loss against temperature

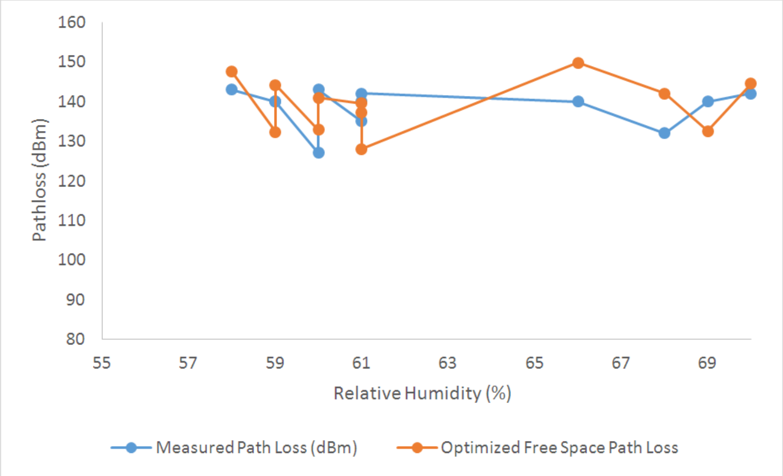

Fig. 8. Graph of measured/optimized free space path loss against relative humidity

As observed in Figs. 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.

3.4 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,

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

And

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

Where, C = 53.7dBm

Therefore,

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

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

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.

4. CONCLUSION

The effects of meteorological variables on UHF signals have been studied, taking temperature and relative humidity as the meteorological variables of importance. Results obtained shows that a rise in temperature led to a rise in received signal strength for UHF signals while relative humidity has no significant effect on UHF signals. The suitability of the free space propagation model for the study terrain failed, as calculated results showed that this model underestimated 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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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