SSRG International Journal of Electronics and Communication Engineering (SSRG-IJECE) – Volume 6 Issue –9 Sep 2019

Investigation of Soil Effect on VHF Surface Wave Propagation of RF Signal in Kogi State, Nigeria

Farouq E. Shaibu[1], Evans C. Ashigwuike[2], Muhammad Uthman[2]

[1]Senior Engineer, Engineering Department, Federal Radio Corporation of Nigeria, F.C.T, Abuja, Nigeria
[2]Senior Lecturer, Department of Electrical/Electronics Engineering, University of Abuja, F.C.T, Nigeria

Abstract — *This research work adopted an improved Friis-space path loss model for both regular and irregular terrain in Kogi State to investigate the effect of soil on VHF surface wave propagation. With a digital signal strength meter, the signal strength of the transmitted signal were taken along two different routes of Kogi Central; Kogi East, and Kogi West at ten different locations from the transmitting station. The corresponding distances were measured using Global Positioning System (GPS). A Sony 12 Bands Stereo Receiver was buried in the ground of different soil types and its phono output port was connected to a personal computer in order to analyze its received signal strength by virtue of signal analyzing software. Three different types of soil were considered within the coverage area of the propagation of RF signal. Measurements of received signal strength taken along two different routes were compared against predictions made by the improved Friis Free Space model for the path loss. The results obtained show that the central part of the state, which is predominantly enriched with sandy soil experiences low signal strength. This implies that RF signal induces more current in sandy soil with respect to its reflected signal from the ground.*

Index Terms — *Surface wave, Soil, Path loss, Signal strength.*

I. INTRODUCTION

In surface wave propagation, path loss due to soil is a particularly important element in the design of any radio communication system where earth surface plays the major role on the signal propagation [1].

For setting up VHF radio broadcasting system over surface wave propagation, propagation model and investigation of soil impact are important to predict the path loss and determine the behaviors of the propagating signal. The attenuation of surface waves increases very rapidly with increase in frequency. The maximum range of coverage depends on the transmitted power and frequency.

Prediction of path loss is a significant element of system, which usually use as a model to design any communication system. Path loss may be due to certain propagation mechanism. In general, radio wave propagation consists of three main attributes; reflection, diffraction, and scattering [1,2].

These also constitute the basic propagation mechanisms, which are listed below;

1) Reflection
2) Diffraction
3) Refraction
4) Gain
5) Return loss
6) Voltage Standing Wave Ratio (VSWR)
7) Scattering
8) Absorption

Reflection occurs when a propagating electromagnetic wave impinges upon an object i.e. when radio wave propagating in one medium impinges upon another medium with different electromagnetic properties. When an RF signal bounces off of a smooth, no absorptive surface, changing the direction of the FM signal, it is said to reflect. Figure 1 illustrates the concept. FM signals also reflect off objects that are larger than the waves that carry the signals. The amplitude and phase of the reflected wave are strongly related to the medium's intrinsic impedance, incident angle, and electric field polarization.

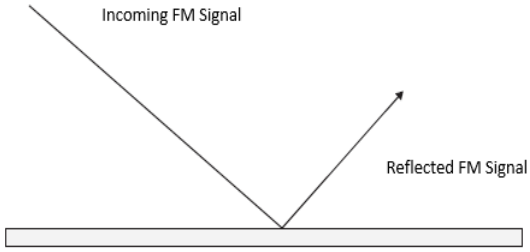

Figure 1: FM Signal Reflection

Diffraction is a phenomenon by which propagating radio waves bend or deviate in the neighborhood of obstacles. It results from the propagation of wave into a shadowy region caused by obstructions such as walls, buildings, mountains, and so on [2].

Scattering occurs when a radio signal hits a rough surface or rough object having a size smaller than or on the order of the signal wavelength. This causes the signal energy to spread out in all direction. Scattering occurs when an FM signal strikes an uneven surface, causing the signal to be scattered instead of absorbed so that the resulting signals are less significant than the original signal [2]. This can be illustrated in figure 2.

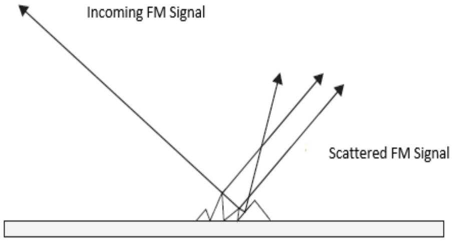

Figure 2: FM Signal Scattering

This phenomenon can be viewed at the receiver as another radio wave source. Typical scattering objects are furniture, street signs, and foliage. The object is of dimensions that are small compared to the wavelength, or the number of obstacles per unit volume is large. [3]

Absorption is the conversion of the FM signals energy into heat. Thisresultbecause the molecules in the medium through which the FM signal is passing cannot move fast enough to “keep up” with the FM waves. Different materials have different absorption rates. When performing a site survey, one should certainly consider the effects of materials. An FM signal can experience scattering effect, reflection effect, and diffraction effect during same pattern of radiation, as seen in figure 3.

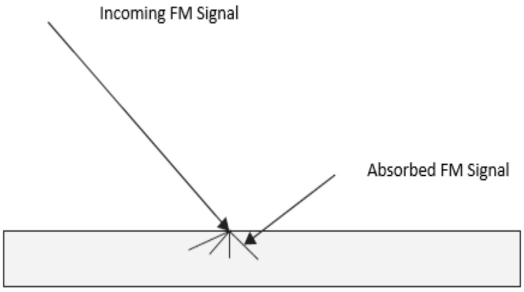

Figure 3: FM Signal Absorption

Refraction occurs when an FM signal charges speed and is bent while moving between media of different densities. Different mediums, such as drywall, wood, or plastic, will have different refraction index. The refraction index helps in determining how much refraction will occur. Figure 1.4 shows an FM signal being refracted. When refraction occurs with FM signals, some of the signals will be reflected and some will be refracted as it passes through the medium. Of course, some of the signal will be absorbed as well.

For this reason, refraction is not usually an issue within a building, but it may introduce problems in wireless site-to-site links outdoors [3,4].

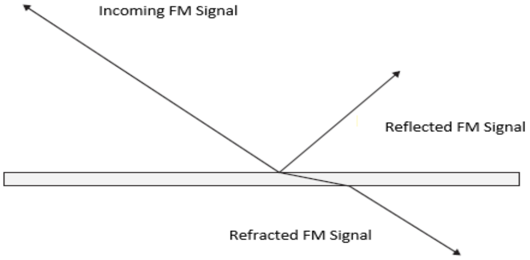

Figure 4: FM Signal Refraction

The effects of reflections on the radio channel are very important in propagation studies. Let’s look at the case of a reflection from a smooth flat surface of infinite extent. This is one of those cases that do not really exist, but as long as the surface is large compared to the size of the Fresnel zone, it will behave in the same way.

The phase and amplitude of the reflected wave is found from the reflection coefficient, ρ. The value of ρ is different when the E-plane or the H-plane is parallel to the reflecting plane. The reason the expressions are different is because the surface has different properties for E and H fields, one governed by the permittivity, the other by the permeability.[4]

$$\rho_E = \frac{sin\theta - \sqrt{\left(\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega \acute{\varepsilon}}\right) - (cos\,2\theta+1)/2}}{sin\theta + \sqrt{\left(\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega \acute{\varepsilon}}\right) - (cos\,2\theta+1)/2}}$$

(1)

$$\rho_H = \frac{\left(\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega\varepsilon_0}\right)sin\theta - \sqrt{\left(\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega\varepsilon_0}\right) - (cos\,2\theta+1)/2}}{\left(\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega\varepsilon_0}\right)sin\theta + \sqrt{\left(\frac{\varepsilon}{\acute{\varepsilon}} - \frac{j\sigma}{\omega\varepsilon_0}\right) - (cos\,2\theta+1)/2}}$$

(2)

Where ε is the permittivity, σ is the conductivity, ω is the angular frequency, and έ is the permittivity of free space. Generally, ρ is complex and both amplitude and phase change on reflection. Frequently, substitutions are made for relative permittivity and relative permeability.

The relative permittivity, $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$

For conductivity, we use parameter; $x = {}^{\sigma}/_{\omega\varepsilon_o}$

Table 1: Some typical values of conductivity and dielectric of materials

Surface	Conductivity (Siemens)	Relative Dielectric Constant
Dry ground	0.001	4.7
Average ground	0.005	15
Wet ground	0.02	25-30
Sea Water	5	81
Fresh water	0.01	81

The equation for ρ becomes;

$$\rho_E = \frac{sin\theta - \sqrt{(\varepsilon_r - jx) - (cos\,2\theta+1)/2}}{sin\theta + \sqrt{(\varepsilon_r - jx) - (cos\,2\theta+1)/2}}$$

(3)

$$\rho_H = \frac{(\varepsilon_r - jx)sin\theta - \sqrt{(\varepsilon_r - jx) - (cos2\theta + 1)/2}}{(\varepsilon_r - jx)sin\theta + \sqrt{(\varepsilon_r - jx) - (cos2\theta + 1)/2}} \quad (4)$$

For small angles, the reflection coefficient, ρ is -1, as there is 180^0 phase change on reflection. This is important as on terrestrial path we can often get two signals arriving at around the same amplitude, the direct wave and one via a ground reflection. Depending on the relative phase shift and the relative path lengths the two signals can add together constructively or subtract from each other destructively. We call this phenomenon "Multipath" [5].

For the signals to cancel, the phase shift of the reflected path needs to be a complete wavelength. The reflection gives 180^0 phase change.

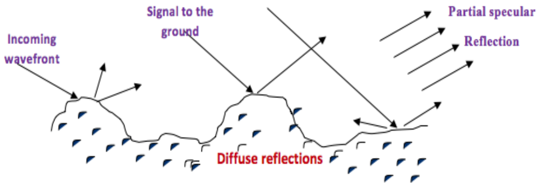

Figure 5: Effect of an FM signal on Surfaces

There is no hard transition from rough to smooth, it is a gradual process but that is not good enough for broadcast Engineers. Some surfaces absorb much of signals that glide through, compare to others. This entails how the signal induces current in the surface that leads to the attenuation of the signal. [6]

The soil is a dielectric material, characterized by a dielectric constant. The propagation of EM waves is directly related to the dielectric constant of the material. A smaller value of the dielectric constant basically implies better conditions for the propagation of EM waves. The soil medium behaves as a dielectric material composed of air, bound water, free water, and bulk soil. If the soil presents small density and high porosity, the performance of the propagation of EM waves is better due to the high quantity of air [7].

The Friis free space equation shows that the received power within the radio coverage falls off as the square of the separation distance between the transmitter and receiver. It's given as;

$$P_r = \frac{P_t G_t G_r \lambda^2}{16(\pi d)^2} \quad (5)$$

The illustration of this geometry for direct and ground reflected waves is shown in fig. 7.

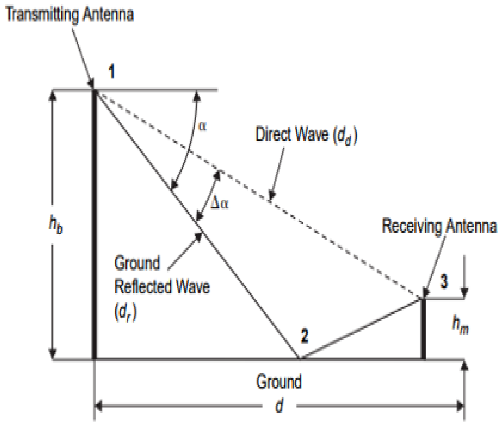

Figure 6: Geometry for direct and ground reflected waves

For isotropic antennas which are capable of transmitting the signal in all direction equally, i.e linear gain = 1

So, the power density, PD, for the isotropic antenna is given by the power transmitted, p_t upon the surface area of the sphere, $4\pi d^2$.

i.e $PD = \frac{P_t}{4\pi d^2}$ (Isotropic Antenna)

P_t = Transmitted Power

$4\pi d^2$ = Area of Sphere

For directive antenna, capable of transmitting the signal in one direction;

Gain, G is introduced because of its directivity in nature

Hence,

$$P_r = \frac{P_t \lambda^2}{(4\pi d)^2} \quad (6)$$

$$PATH\ LOSS = 20log\left(\frac{4\pi d}{\lambda}\right) \quad (7)$$

For VHF surface wave propagation, ground has a strong influence on the propagation of the signal. A wave induces current in the ground over which it passes, and it is attenuated as a result of absorption of energy by the earth. The absorption rate depends on the impact that soil contributes to the surface wave propagation of the signal. This impact depends on the soil type, which is verified during this research [8].

The radiation pattern from the transmitting antenna has direct ray to the receiving antenna through line of sight and diffused component to the earth surface. The ability of the ground to reflect this signal depends on its dielectric property, which is based on the Peplinski Semi-empirical soil dielectric model [8,9]. Sandy soil, clay soil, and silt were considered during this research work. This can be illustrated in the figure below;

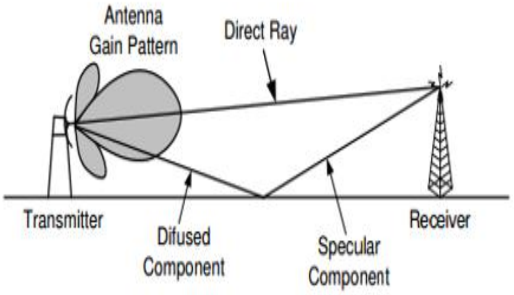

Figure 7: Signal Characteristics on different paths

However, antenna gain is the ratio of maximum radiation intensity in the same direction produced by an isotropic radiator antenna. The parameters like return losses, gain and VSWR can also be calculated when investigating the influence of soil on VHF signal propagation. [9]

METHODOLOGY

A. Equipment and Software

The equipment and the software used in the acquisition of data and results are;

i. Digital Signal Strength Meter
ii. BE20S Transmitter
iii. A GPS (Global Positioning System) Receiver
iv. MatLab software
v. Sony 12 Bands Stereo Receiver
vi. Mixcraft Pro Studio Spectrum Analyzer Software

B. Methods

The study area was limited to Kogi central, Kogi East, and Kogi West of Nigeria.

Figure 8: Study Area

a) Measurement of RF Signal Strength in Soil

Apersonal Computer was placed on soil surface with an installed mixcraft pro studio spectrum analyzer, while a Sony 12 Bands Stereo Receiver was buried in the ground.

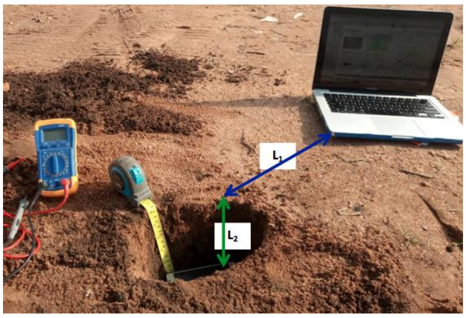

Figure 9: Soil sample test

The position depth of the stereo receiver with reference to its soil surface is designated as l_1, which represents the distance between the position of the receiver and the soil surface in centimeter.

The distance between the Laptop to that of the surface, directly to the stereo receiver is designated as $L_2, in\ meter.$

The output of the stereo receiver was connected to the PC, where mixcraft pro studio spectrum analyzer revealed the strength of the received signal to the stereo receiver.

This measurement was repeated on varyingL_1 from 0 to 10cm with a step of 2cm whilekeeping L_2 to be constant (2m) for better observation.

This soil absorption test was done on sandy soil, clay soil, and silt within the coverage area ofthe VHF radio wave.

Figure 10: Pro Studio Spectrum Analyzing Platform

b) Measurement of Received Field Strength on Line-of-Sight

Since RF travels away from the transmitter over surface wave propagation, the strength of the wave keeps on decreasing.

The received field strength is a simple conversion of the effective isotropical radiated power, EIRP, in $Volts/meter$. This is given as;

$$E_r = \frac{\sqrt{30P_T G_T}}{D} \quad (8)$$

Where;

P_T: The transmitted power.

G_T: The transmitter antenna gain.

D : The distance between transmitter and receiver.

E_r: The received field strength.

In the case of the transmitter used during the acquisition of data;

$$P_T = 7000W$$
$$G_T = 8.2\ dB$$

c) Measurement of Path Loss

Considering the surface wave propagation of RF wave as it glides over the earth surface, additional path loss was included in Friis equation due to this loss by soil medium [6].

This comprises of attenuation loss due to the wavelength in soil and that in free space.

$$l_p = l_\beta + l_\alpha$$
$$l_p = 6.4 + 20\log(D) + 20\log(\beta_s) \quad (9)$$

Where l_p: The total path loss

D: The distance between the transmitter and the receiver.

β_s: Phase constant.

The phase constant, β_s in soil is a function of the average relative dielectric constant of dry ground and the wavelength of propagation in free space. This is written as;

$$\beta_s = \frac{2\pi\varepsilon_r^2}{\lambda_f} \quad (10)$$

Where;

β_s: The phase constant in soil.

ε_r: The average relative dielectric constant of dry ground.

λ_f: The wavelength of propagation in free space.

An interval of 5 Km was taken up to 70Km from the transmitting source to each measured point of the receiver.

II. RESULT AND DISCUSSION

Table 2a: sandy soil absorption test, varying L_1 while keeping L_2 constant

$L_1(cm)$	$L_2(m)$	Strength, S (dB_m)
0.0	2.0	-17.2
2.0	2.0	-22.4
4.0	2.0	-25.3
6.0	2.0	-28.5
8.0	2.0	-33.2
10.0	2.0	-38.3

Table 2b: clay soil absorption test, varying L_1 while keeping L_2constant

$L_1(cm)$	$L_2(m)$	Strength, S (dB_m)
0.0	2.0	-31.0
2.0	2.0	-36.2
4.0	2.0	-42.4
6.0	2.0	-46.1
8.0	2.0	-49.4
10.0	2.0	-54.2

In table 2(a and b), soil impact on RF signal was investigated and the result shows that the signal induces current in the ground during surface wave propagation. Hence, the RF signal looses its strength to the soil by absorption. The level of this absorption depends on the nature of the soil, which had been investigated. Sandy soil tends to act as transparent medium to the RF signal, thereby absorbing high percentage of the signal strength compare to clay and silt, leaving very low level to be reflected (see fig. 11)

Table 2c: Silt soil absorption test, varying L_1 while keeping L_2constant

$L_1(cm)$	$L_2(m)$	Strength, S (dB)
0.0	2.0	-27.4
2.0	2.0	-32.6
4.0	2.0	-36.2
6.0	2.0	-39.3
8.0	2.0	-42.2
10.0	2.0	-46.0

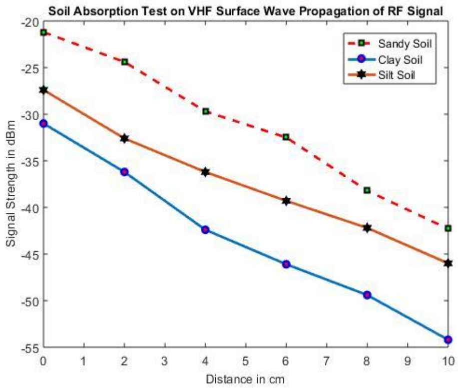

Figure 11:Result of soil absorption strength test

Silt soil also absorbs more of the transmitted electromagnetic wave compare to the reflected part but not as much in the case of sandy soil. Clay soil tends to reflect more of the signal when an electromagnetic wave glides over its surface during surface wave propagation. Rural/Urban environments that are predominantly with clay soil are expected to experience strong received signal strength (RSS) of an FM signal compare to those areas with either sandy or silt soil.

Table 3: Average Received Signal Strength (RSS) in dBμV/m V/S Distance in Km

S/N	Distance (Km)	Distance (m)	FIELD STRENGTH in dBμV/m			Average Relative Error, E_{R1}	Average Relative Error, E_{R2}
			Predicted Value	Measured value (route 1)	Measured value (route 2)		
1	0	0	125.40	114.56	117.42	1.00	1.00
2	5	5000	108.31	105.43	103.51	0.03	0.05
3	10	10000	102.36	99.25	98.42	0.03	0.04
4	15	15000	98.84	96.70	94.55	0.02	0.05
5	20	20000	96.34	94.84	95.12	0.02	0.01
6	25	25000	94.40	93.36	98.27	0.01	0.04
7	30	30000	92.82	85.32	84.34	0.08	0.10
8	35	35000	91.48	81.41	79.82	0.17	0.24
9	40	40000	90.32	77.45	73.40	0.02	0.08
10	45	45000	89.30	79.35	75.32	0.02	0.16
11	50	50000	88.38	76.98	74.25	0.07	0.19
12	55	55000	87.55	74.62	72.47	0.17	0.21
13	60	60000	86.80	71.83	68.15	0.21	0.27
14	65	65000	86.10	73.35	63.65	0.17	0.35
15	70	70000	85.46	69.42	57.74	0.23	0.48

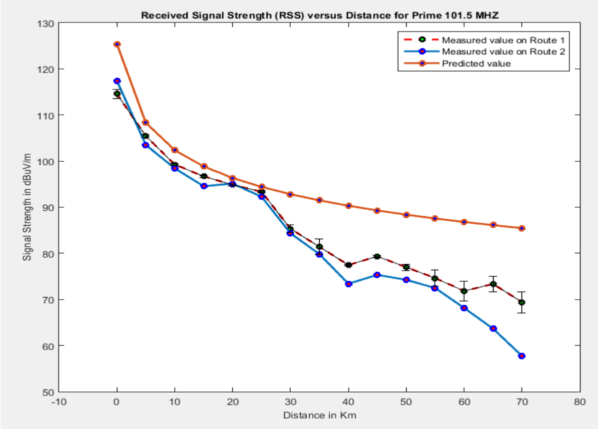

Figure 12: Field signal strength along the two routes

Table 4: Path Loss in dB V/S Distance in KM

S/N	Distance (Km)	Distance (m)	Predicted Path Loss, P_r (dB)	Measured Path Loss, P_m (dB)	$\frac{(P_m - P_r)^2}{N}$	Average Relative Error, ε_r	% Absolute Relative Error
1	0	0	74.48	85.37	7.91	0.13	13.00
2	5	5000	109.16	116.34	3.44	0.06	6.00
3	10	10000	112.45	122.37	6.56	0.08	8.00
4	15	15000	118.34	125.89	3.80	0.06	6.00
5	20	20000	121.23	128.39	3.42	0.06	6.00
6	25	25000	125.41	130.32	1.61	0.04	4.00
7	30	30000	127.55	131.91	1.27	0.03	3.00
8	35	35000	131.36	133.25	0.24	0.01	1.00
9	40	40000	131.83	134.41	0.44	0.02	2.00
10	45	45000	132.72	131.43	0.11	0.01	1.00
11	50	50000	134.37	136.34	0.26	0.02	2.00
12	55	55000	134.93	137.17	0.34	0.02	2.00
13	60	60000	135.84	137.92	0.29	0.02	2.00
14	65	65000	137.25	136.62	0.03	0.01	1.00
15	70	70000	137.76	138.27	0.02	0.01	1.00

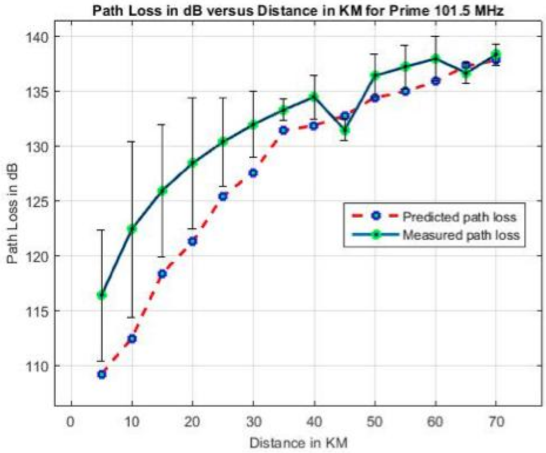

Figure 13: Comparison results between predicted and measured path loss at 101.5 MHz

III. CONCLUSION

The performance of this improved Friis free-space model to investigate soil effect on VHF surface wave propagation on RF signals has revealed its suitability for the path loss prediction of a typical RF signal in Central part of Nigeria. This model can be useful to improve the services of upcoming FM radio stations for better signal coverage. With the analysis of the results obtained, surface wave propagation of RF signal should be focus on the region that's predominantly clay soil for the sake of maximum received signal strength (RSS) within the coverage area.

ACKNOWLEDGEMENT

A very special gratitude goes out to Dr. Evans C. Ashigwuike and Dr. Muhammad Uthman for taking time out from their busy schedule to guide me to the success of this research.

REFERENCES

[1] M. T. Prof, Path Loss, New York: UTD, 2002.
[2] M. M. Radmanesh, Radio Frequency and Microwave Electronics, New York: Pearson Education Asia Edition, 2001.

[3] Peterson, A.F, Ray, S.L., Mittra .R, Computational Methods of Electromagnetics, New York: Wiley-IEEE Press, 1998.
[4] B. Hoffman, Wellenhof, H. Litchenegger, GPS-Theory and Practice, New York: Springer, 2001.
[5] M. Can Vuran, Agnelo .R Silva, "Communication Through Soil in Wireless Underground Sensor Networks-Theory and Practice," IEEE Transactions on Geoscience and Remote Sensing, vol. 03, no. 12, pp. 309 - 318, 2010.
[6] Evans C. Ashigwuike, Ale Felix. Farouq E. Shaibu, "The Impact of Soil Texture on Path Loss Modelling of an FM Signal Using Diffraction Technique - A Case Study of Prime FM Radio Nigeria," EJERS, European Journal of Engineering Research and Science, vol. 04, no.4, pp.58-62, 2019.
[7] Zhe Geng, Hai Deng, "Wireless Signal Propagation Path Loss Estimation," IEEE Transactions on Antennas andPropagations, vol. 02, no. 04, pp. 953-954, 2014.
[8] Sayali S. Pawar, Jagadish B. Jadhav, “Design of Multiband Slot Antenna for WLAN,” SSRG International Journal of Electronics and Communication Engineering (SSRG – IJECE), vol. 06, no. 01, pp.08-10,2019.
[9] Er. Richa Arora, Dr. Suyeb Alikhari, Er. Parwinder Kaur, “Design and Analysis of L-Shaped fractual Antenna Using Microstrip Line feed and Inset Cut Line Feed Technique,” SSRG International Journal of Electronics and Communication Engineering (SSRG – IJECE), vol. 06, no. 08, pp. 12-14, 2019