Evaluation of Signal Strength and Quality of a Ku-Band Satellite Downlink during Raining Season in Guinea Savanna Region of Nigeria

Yahaya Yunisa
Department of Electrical/Electronics Technology, Kogi State College of Education (Technical) Kabba,Kogi State, Nigeria, Email: yunisayahaya7@gmail.com
Zhimwang Jangfa Timothy
Department of Physics, Federal University Lokoja, Nigeria
Email: jangfa.zhimwang@fulokoja.edu.ng
Ogherohwo Enoh Pius
Email: enohpius@yahoo.com
Ibrahim Aminu
Email : aminuenemona@gmail.com
Shaka Oghenemega Samuel
Email: samshak4all@yahoo.com
Frank, Lagbegha-ebi Mercy
Email:lalas452000@yahoo.co.uk

ABSTRACT

This study presents the evaluation of signal strength and quality of a ku-band satellite downlink signals during raining season in Guinea Savanna region of Nigeria. Rain rate data and ku-band signal over Jos were retrieved from the Nigeria Meteorological Agency (NIMET). Rain rate data was measured using Davis Vantage Vue weather station while microwave signal were obtained using spectrum analyzer. The measured data were analyzed using Microsoft office excel. Rainfall is broadly classified into two types: stratiform (drizzle: ≤5mm/hr and widespread: >5≤25mm/hr) and convection (shower: >25≤50mm/hr and thunderstorm: >50mm/hr). Results were calculated based on ITU-Recommendations P.618-12 and P.838. The results obtained revealed that the effect of rain on signal strength and quality on a ku-band link depend on the rain type and duration of rainfall. The effect of drizzle (≤5mm/hr) on the ku-band link is not significant regardless the duration of rainfall. The results also shows that severe signal losses above 60dB were obtained under shower (>25≤50mm/hr) and thunderstorm (>50mm/hr). Also, widespread (>5≤25mm/hr) that prevailed for a longer period causes severe signal losses. This is to say that lower rain rate of about 25mm/hr that prevailed for a very long time have significant effect on Ku-band link. The results of this study will serve as crucial design parameters for communication systems engineers for providing fade margins and developing accurate fade mitigation techniques (FMTs) for the Guinea Savanna region of Nigeria. It was observed from this study that the experimental studies within the Ku-band frequency are getting over exhausted. Therefore, experimental studied in the region of higher band like K and Ka are highly recommended.

Keywords - **Ku-Band, Downlink, Signal Quality, Signal Strength and Signal Loss.**

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I. INTRODUCTION

Satellite links are used to provide communication over very large distance. This is achieved by using the satellite as a repeater. Transmitting signal like TV broadcast from one side of Earth to the other, there are three stages involved [1]. First there is the uplink where data is beamed up to the satellite from a ground station on Earth. Second, the satellite processes the data using a number of on board transponders (radio receiver, amplifiers and transmitters). This boosts the incoming signals and changes their frequency [1]. Finally, there is the downlink, where data is sent back to the ground station elsewhere on Earth. Although there is usually just a single uplink, there may be millions of downlinks, for example if many people are receiving the same satellite TV signal at once.

Ku band is the portion of the electromagnetic spectrum in the microwave range of frequencies from 10 to 18 gigahertz (HGZ). Ku band is primarily used for satellite communications, most notably for fixed and broadcast services. Ku band link is also used for back hauls and particularly for satellite from remote locations back to a television networks studio for editing and broadcasting [9; 8].

Satellite communication signals are often affected by the environment in which they operate. The effect of the environment on satellite communication can be divided into: effects on the space element, effects on the ground element and effect on the signal transmitting through the earth's lower and upper atmosphere[2].

Rain is a major challenge to Ku-band satellite communication link causing unavailability of signals most of the time. The presence of rain can have significant

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detrimental effect on the propagation of an electromagnetic signal. The rain degradation increases as the frequency increases [10]. Telecommunication links, generally (either terrestrial or satellite) are designed to meet a specific reliability of the system. Effects of rain fall on microwave communication links have been a severe concern to links have been a severe concern to link engines Ku-band is within the SHF (3-30GHZ) frequency band where there is a high density influx of users and services [12]. Unfortunately, this frequency band is prove to poor signal quality due to the presence of precipitating particles that cause high signal losses. These include ice, snow, hail, water vapour and rain. Only water vapour and rain are relevant to tropical regions like Nigeria hence the need for this work [3; 4].

Previously, [11] worked on estimation of the long term propagation losses one to Rain on Microwave satellite links over Jos, Nigeria. They reported that, the estimation of the long term propagation losses due to rain on microwave satellite links was determined based on the exceedance distribution frequency of percentage time (%) and cumulative distribution of one-minute rain rate over Jos. Their results obtained revealed that low and high intensities of rainfall over short period of time have less effect on the transmitted signals whereas low and high intensities of rain over long period of time have significant effect on the transmitted signals. This is because the amount of wat4er particles in the atmosphere becomes more concentrated when the rainfall prevailed for a longer period. There by increasing the rate of signal degradation. Also, [7] worked on analysis of satellite transmission losses due to tropospheric Irregularities in Guinea savannah Region of Nigeria. They reported that, the results on the analysis of satellite transmission losses due to tropospheric irregularities in Guinea Savanna region of Nigeria. Their analysis was based on measured rain rates data, signal strength and quality of the KU-band satellite signal during rainfall over the region. It was discovered that, low precipitation intensity below 10mm/hr has less effect on KU-band propagation while high precipitation intensity above 20mm/hr that prevail for more than 15 minutes causes high propagation loss over the region. This is because as frequency increase, the signal wavelength decreases and approaches the size of a rain drop. Therefore, giving the rain September were characterized by high intensity rain rates leading to high transmission power loss and pronounced reduction in the signal quality and strength over the Guinea savanna region of Nigeria.

II. RECEIVED SIGNAL STRENGTH

Signal strength (also referred to as field strength): refers to the transmitter power output is received by a reference antenna at a distance from the transmitting antenna [5]. High power transmissions, such as those used in broadcasting, are expressed in dB-millivolts per meter (dBmv/m). For very low power systems, such as mobile phones, signal strength is usually expressed in dB-microvolts per metre (dBuv/m) or in decibels above a reference level of one milliwatt (dBm) [5].The estimated received signal strength in active RFID tag can be estimated as follows:

$$dB_{me} = -43.0 - 40.0\log_{10}(r/R)$$

In general, you can take the path loss exponent into account[6].

$$dB_{me} = -43.0 - 10.0\gamma\log 10$$

The effective path loss depends on frequency, topography, and environmental conditions.

Actually, one could use any known signal power dB_{m0} at any distance r_0 as a reference:

$$dB_{me} = dB_{m0} - 10.0\gamma\log 10 \quad (1)$$

Number of decades

$\log_{10}\left(\frac{R}{r}\right)$ would give an estimate of the number of decades, which coincides with an average path loss or $40dB/decades$.

III. METHODOLOGY

Considering the rainfall intensity along earth path that is in-homogeneous in space, time and the raindrops have a non-spherical shape, two years (2018 and 2019) of measured data was used to evaluate signal strength and quality of a Ku-band satellite down link signal during raining season. Rain rate data and ku-band signal over Jos were retrieved from the Nigeria Meteorological Agency (NIMET). Rain rate data was obtained using Davis Vantage Vue weather station while microwave signal were obtained using spectrum analyzer. The down converted Ku-band signal is fed into the digital satellite meter and a spectrum analyzer for signal level analysis, logging and recording samples of viewed spectrum over finite periods of time on a computer system. Both satellite signal and precipitation measurements are done concurrently.

The data were collect for the period of two years (2018 and 2019). The rain rate data was measured using Davis Vantage Vue weather station which is equipped with an integrated sensor suite (ISS) and weather link data logger, and was used to measure and record one-minute rain-rates for all the days and months of the years under review. Its electronic weather link console serves as the user interface, data display and analogue to digital converter, and has capacity to log 2560 measurements. The rain gauge instrument is a self-emptying tipping spoon, with gauge resolution of 0.2 mm per tip. It is able to measure rainfall intensity from a minimum of 0.8 mm/h up to a value of 460 mm/h, with an accuracy of 0.2 mm/h. The precipitation data, with date and time is captured on the micro-chip of the wireless electronic data logger, which, when calibrated, logs on data every minute. The microchip has storage capacity of about 2563 pages, each page stands for one record, after which (i.e. after 42hours) the memory overwrites and recorded data is lost if not harvested. Technically, the data logger is connected to a Personal computer to harvest the data on a daily basis to prevent data loss. For this study, the measured rain data are classified as shown in table 1

Table 1: Rain types from rain rates

Rain Type	Range of Rain Rate (mm/h)
Drizzle	≤5
widespread	>5≤25
shower	>25≤50
Thunderstorm	>50

The drizzle is a type of rain which consists entirely of small rain drops usually of diameter less than 1 mm and commonly falls in damp weather from shallow layer clouds. It is characterized by very low rainfall rates with typical values not greater than 5 mm/h. Wide spread rainy events usually have intensity between about greater than 5mm/h to 25 mm/h and the intensity may be practically constant or change only gradually during precipitation. The shower type of rain on the other hand originates from cumuliform clouds. This type of rain is characterized majorly by high intensity values, ranging from about 25 mm/h to about 50 mm/h and raindrops with diameter greater than 2 mm. The thunderstorm rain is usually generated within the cumulonimbus cloud systems. During thunderstorm activity, the precipitation particles grow in size until they grow large to become drops of diameter greater than about 3 mm and are no longer supported by the upward currents. At this stage, they fall to the ground with values of rain rate between about 50 mm/h and 240 mm/h.

1V. PROCEDURE FOR DETERMINING THE SIGNAL LOSSES UNDER RAIN

The following parameters were used:

$R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/h)

- h_s : height above mean sea level of the earth station in km (Jos is 1.258km above sea level)
- θ : elevation angle in degrees (for this study, 45^0 was used)
- φ : latitude of the earth station in degrees (Latitude of Jos is 9.9565^0N)
- f : frequency (GHz) (for this study, 12GHz was used)
- R_e : effective radius of the Earth (8 500 km)

Step 1: Determination of the rain height, h_R, as given in Recommendation ITU-R P.839.

Step 2: For $\theta \geq 5°$ the slant-path length, L_s, below the rain height was computed from:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \quad \text{km} \tag{2}$$

For $\theta < 5°$, the following formula was used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{1/2} + \sin\theta} \quad \text{km} \tag{3}$$

Step 3: Calculation of the horizontal projection, L_G, of the slant-path length from:

$$L_G = L_S \cos\theta \quad \text{km} \tag{4}$$

Step 4: The rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min) was obtained.

Step 5: The specific attenuation, γ_R was obtained using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \quad \text{dB/km} \tag{5}$$

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\,\gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)} \tag{6}$$

Step 7: The vertical adjustment factor, $v_{0.01}$, for 0.01% of the time was calculated:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_s}{L_G\,r_{0.01}}\right) \quad \text{degrees}$$

For $\zeta > \theta$,

$$L_R = \frac{L_G\,r_{0.01}}{\cos\theta} \quad \text{km}$$

Else $L_R = \dfrac{(h_R - h_s)}{\sin\theta}$ km

If $|\varphi| < 36°$, $\chi = 36 - |\varphi|$ degrees
Else, $\chi = 0$ degrees

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\,\gamma_R}}{f^2} - 0.45\right)}$$

Step 8: The effective path length is:

$$L_E = L_R\, v_{0.01} \quad \text{km} \tag{7}$$

Step 9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R\, L_E \quad \text{dB} \tag{8}$$

Step 10: The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 5%, is determined from the attenuation to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ or $|\varphi| \geq 36°$:

$\beta = 0$

If $p < 1\%$ and $|\varphi| < 36°$ and $\theta \geq 25°$:

$\beta = -0.005(|\varphi| - 36)$

Otherwise:

$\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25\sin\theta$

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655 + 0.033\ln(p) - 0.045\ln(A_{0.01}) - \beta(1-p)}$$

For location at latitudes below 30° (North or South), the attenuation exceeded for other percentages of time p in the range 0.001% to 1% was deduced from the following power law:

$$\frac{A_p}{A_{0.01}} = 0.07\ p^{-(0.855\ +\ 0.139\ \log_{10} p)} \qquad (10)$$

$$A_p = A_{0.01} \times 0.07 \times p^{-(0.855+0.139 log_{10} p} \qquad (11)$$

Equation (11) is the signal losses under rain. Therefore, equation (2) to (11) was used to obtain the results and was repeated for all the rain types (drizzle, widespread, shower, and thunderstorm) under each month and year under review.

V. RESULTS

Results for this study were determined based on ITU-Recommendations P.618-12 and P.838. The measured rain rate data which was randomly obtained for all the days of the months under study were analyzed using Microsoft office excel statistic tool. The results were obtained by subjecting the analyzed data to equation (2) to (11)

Table 2: Computation of Signal quality, strength and losses for April 2018

RAIN TYPE	DURATION OF RAIN (MIN)	% OF TIME EXCEEDED	SIGNAL QUALITY (%)	SIGNAL STRENTH (%)	SIGNAL LOSSES (dB)
Drizzle (≤5mm/hr)	885	2.961	62	71	0.127
Widespread (>5≤25mm/hr)	296	0.912	59	68	1.942
Shower (>25≤50mm/hr)	44	0.227	57	65	6.288
Thunderstorm (>50mm/hr)	50	0.125	55	61	7.829

Table 3: Computation of Signal quality, strength and losses for May 2018

RAIN TYPE	DURATION(MIN)	% OF TIME EXCEEDED	SIGNAL QUALITY (%)	SIGNAL STRENTH (%)	SIGNAL LOSSES (dB)
Drizzle (≤5mm/hr)	703	2.553	67	64	0.146
Widespread (>5≤25mm/hr)	330	0.926	62	59	1.901
Shower (>25≤50mm/hr)	57	0.162	62	57	7.623
Thunderstorm (>50mm/hr)	13	0.030	62	56	15.632

Table 4: Computation of Signal quality, strength and losses for June 2018

RAIN TYPE	DURATION(MIN)	% OF TIME EXCEEDED	SIGNAL QUALITY (%)	SIGNAL STRENTH (%)	SIGNAL LOSSES (dB)
Drizzle (≤5mm/hr)	1110	4.338	65	51	3.304
Widespread (>5≤25mm/hr)	562	1.769	62	50	22.816
Shower (>25≤50mm/hr)	132	0.468	60	41	48.025
Thunderstorm (>50mm/hr)	40	0.162	59	41	19.607

Table 5: Computation of Signal quality, strength and losses for July 2018

RAIN TYPE	DURATION(MIN)	% OF TIME EXCEEDED	SIGNAL QUALITY (%)	SIGNAL STRENTH (%)	SIGNAL LOSSES (dB)
Drizzle (≤5mm/hr)	1906	11.704	60	55	1.79
Widespread (>5≤25mm/hr)	913	2.946	58	45	25.76
Shower (>25≤50mm/hr)	255	0.899	57	40	46.72
Thunderstorm (>50mm/hr)	106	0.327	44	38	82.48

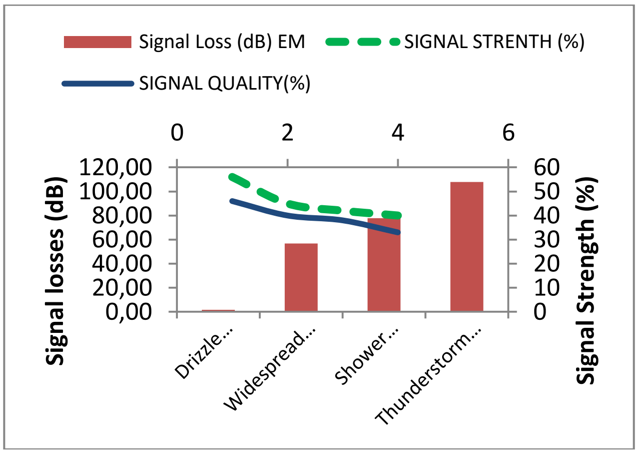

Figure 1. Variation of Rain type, signal quality, strength and losses for July 2019

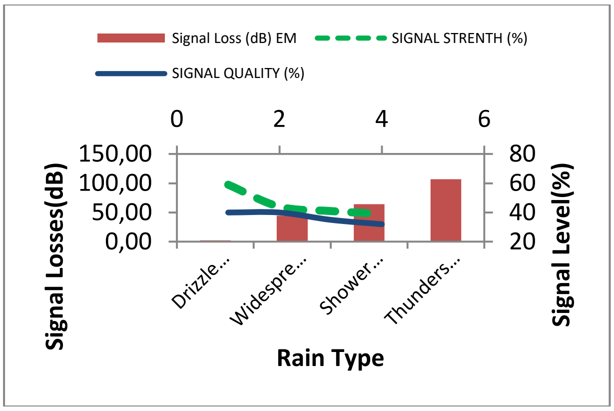

Figure 2. Variation of Rain type, signal quality, strength and losses for August 2019

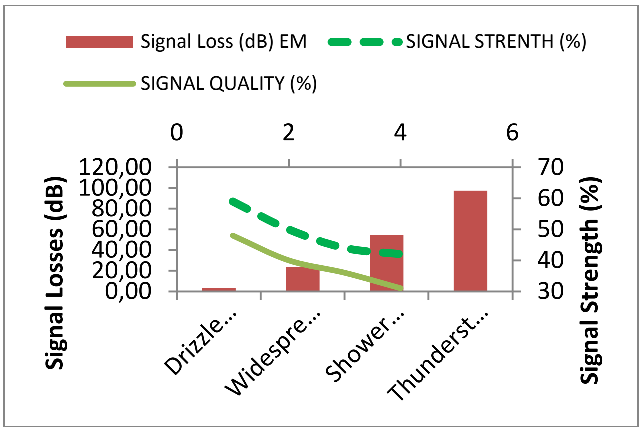

Figure 3. Variation of Rain type, signal quality, strength and losses for September 2019

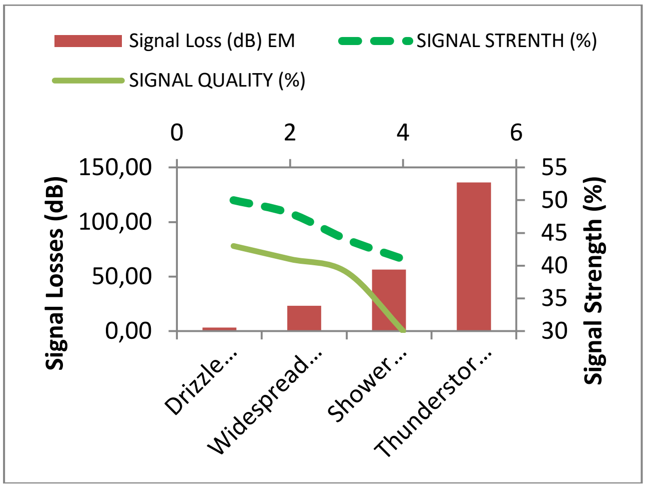

Figure 4. Variation of Rain type, signal quality, strength and losses for October 2019

VI. DISCUSSIONS

Table 2 presents the computation of Signal quality, Signal strength and Signal losses for the month of April 2018. From the result obtained, signal quality and signal strength are low under thunderstorm either 55% and 61% respectively which resulted to high signal loss of 7.829dB for the month. Table 3 presents the computation of Signal quality, Signal strength and Signal losses for the month of May 2018. From the result obtained, signal quality and signal strength are low under thunderstorm either 62% and 56% respectively which resulted for the high signal loss of 15.63dB for the month. Table 4 presented results for the month of June 2018 which revealed that signal quality and strength was drop to 60% and 46% respectively due to long duration of shower category of rain that resulted to signal loss of about 48.025dB. Table 5 presents the results for the month of July 2018. From the result obtained, drizzle, widespread, shower, and thunderstorm recorded signal losses of 1.79dB, 25.76dB, 46.72dB, and 82.48dB respectively.

Figure 1, 2, 3, and 4 shows the variation of various rain type, signal strength, signal quality, and signal losses for the months of July, August, September, and October 2019. The results show that signal losses become severe when the rain rate increases either above 40mm/hr.

VII. CONCLUSION

This study focuses on evaluating signal strength and quality of a Ku-band satellite downlink signals under rain. The results obtained revealed that the effect of rain on signal strength and quality of a ku-band link depend on the rain type and duration of rainfall. As it can be seen from the results, the effect of drizzle (≤5mm/hr) on the ku-band link is not significant regardless the duration of rainfall. The results also shows that severe signal losses above 100dB were obtained under shower (>25≤50mm/hr) and thunderstorm (>50mm/hr). The results further revealed that widespread (>5≤25mm/hr) that prevailed for a longer period also causes severe signal losses. This is to say that lower rain rate of about 25mm/hr that prevailed for a very long time have significant effect on Ku-band link. This study is able to classified rainfall within the study area into drizzle, widespread, shower and thunderstorm and their individual impact on Ku-band satellite link. The results of this study will serve as crucial design parameters for communication systems engineers for providing fade margins and developing accurate fade mitigation techniques (FMTs) for the Guinea Savanna region of Nigeria.

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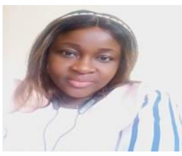
Biographies and Photographs

Yunisa Yahaya is a lecturer with Department of Electrical/Electronics Technology, Kogi State College of Education Technical, Kabba Nigeria. He holds B.Sc in Physics Electronics Technology, M.Sc in Physics, and PGDE in Education. His area of interest is electronic and Communication.

Jangfa Timothy zhimwang is a Lecturer with Department of Physics, Federal University Lokoja, Nigeria. He holds a BSc in Physics Electronics Technology, MSc in Physics (Electronics & Communication Tech.), PGD in mathematics Education, HND Pest Management Technology and presently a PhD candidate. He has previously worked under a research team sponsored by the Tertiary Education Trust Fund (TETFund) through the Department of Physics, University of Jos and productively written and published renowned articles in the field of Physics Electronics and Communication Technology.

Ibrahim Aminu is a scientific officer with Centre for Satellite Technology Development, National Space Research and Development Agency Abuja, Nigeria. He holds B.Sc in Physics Electronics Technology, M.Sc in Physics, PGDE in Education and HND Pest Management Technology. He has previously worked under a research teams sponsored by the Tertiary Education Trust Funds (TETFund) through the Department of Electrical/ Electronics, College of Education (Technical) Kogi state. His area of interest is RF and Space Physics.

Shaka, Oghenemega Samuel is a lecturer in the Option of Physics Electronics, Department of Science Laboratory Technology in the Delta State University, Abraka. He holds a BSc., SLT(Physics/Electronics Technology) and MSc. in Solid State Physics both from the Delta State University, Abraka Nigeria. He is a licensed Associate member of the Nigerian institute of Science Laboratory Technology (NISLT) and also a member of the American Physical Society (APS). His area of specialization is Electronics and communications.



Frank, Lagbegha-ebi Mercy is a Lecturer in General Studies Department, International Institute of Tourism and Hospitality, Yenagoa, Bayelsa State. She holds a B.Sc. degree in Physics and MSc. in Solid State Physics both from the Delta State University, Abraka Nigeria. She is a member of Nigeria Institute of Physics (NIP).