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Analysis of Frequency and Polarization Scaling on Rain Attenuated Signal of a KU-Band Link in Jos, Nigeria.

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ABSTRACT

This paper presents the analysis of frequency and polarization scaling on rain attenuated signal of a KU-Band link. The study was carried out in Jos, Plateau state, Nigeria (9.8965^0 N, 8.8583^0 E; 1192 meters) with Maximum, Average and Minimum Temperatures of 29.8^{0}C, 22.8^{0}C and 17^{0}C respectively. Data were obtained for the months of May, June, July, August, September and October 2020.Davis Vantage Vue weather station was used to measured and record one-minute rain-rates 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 down converted Ku-band signal was 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 were done concurrently. Data were analyzed using Microsoft excel and results were obtained based on ITU-R model. Results obtained revealed that rain attenuated signal for vertical and horizontal polarization varies for different rain rate and months under reviewed. For the month of May 2020, rain attenuated signal is more severe from rain rate of 100mm/hr with the highest rain attenuation of 25.57dB, 30.37dB, and 39.84dB at frequencies of 12GHz, 15GHz and 18GHz respectively while the rain attenuated signal for vertical polarization is more severe from 80mm/hr with highest recorded rain attenuation of 27.96dB, 40.33dB and 45.71dB at frequencies of 12GHz, 15GHz and 18GHz respectively. For the month of July 2020, the results shows that rain attenuated signal for vertical polarization is more severe from rain rate of 80mm/hr with the highest rain attenuation of 60.57dB, 73.37dB, and 100.84dB for frequencies of 12GHz, 15GHz, and 18GHz respectively. At Horizontal polarization, signal losses are more severe from 60mm/hr. The results further proves that frequency and polarization scaling of rain attenuated signalare major factors to consider when designing a microwave link budget especially in the study area that experiences high amount of rainfall annually.

Keywords - **KU-Band, Electromagnetic Frequency, Signal Polarization, Signal Loss and Rain attenuation**

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I. INTRODUCTION

The demand for wireless communications has grown in recent years due to increase in using mobile services. Broadband services demand high data rates to meet the requirements of satellite communication applications. Advances in wireless communications have resulted into emergence of a wide range of applications. Emerging wireless networks with advanced technologies such as full-duplex (FD) communications, non-orthogonal multiple access (NOMA), multiple input and multiple output (MIMO) and millimeter wave (mmWave) require higher data rates. With provision of this higher data rate and seamless connectivity, multimedia applications, which are regarded as delay-sensitive applications, have gained a lot of attraction [16]. This requires an efficient modeling of wireless channel that can take into consideration quality of signal (QoS) [9; 4]

In satellite communication, the spectrum from 1 GHz to 300 GHz is divided in different frequency bands according to the letter band designation as explained by international telecommunication union recommendation

(ITU-R). Many satellite communication systems operate in the frequency range above 10 GHz which are Ku-, Ka-band and for experimental operation the Q/V-band. Unfortunately, major impairments of propagation happen in this frequency ranges. Signal degradation by rain represents the phenomenon that causes the most serious propagation impairments in satellite communication. Rain attenuation is one of the most significant limitations of satellite communication link above 10GHZ. Hence the amount of rain attenuation depends on rain rate, signal frequency, size, shape and the relative orientation of the rain drops [5; 15; 17]. The consequences of this rain attenuation are as follows [6].

i. Loss of signal strength at the receiver.
ii. Wastage of transmission power in a bid to overcome this form of attenuation.
iii. Total loss of signal at the receiver in extreme cases.
iv. Unavailability of the satellite link for a great percentage of the time

With the variety of satellite frequency bands that can be used, designations have been developed so that they can be referred to easily as shown in table 1. The higher frequency bands typically give access to wider bandwidths, but are also more susceptible to signal degradation due to rain fade (the absorption of radio signals by atmospheric rain, snow or ice). Because of satellites increased use, number and size, congestion has become a serious issue in the lower frequency bands. New technologies are being investigated so that higher bands can be used [4; 14].

Table 1: Satellite Communication Frequency Band

BAND NAME	FREQUENCY	APPLICATIONS
L-band	1 – 2 GHz	Used in satellite communications.
S – band	2 – 4 GHz	Used in communication satellites, weather radar, wireless LAN, multimedia applications in mobile TV & surface ship radar.
C – band	4 – 8 GHz	Used in weather radar systems, terrestrial microwave links, & 802.11a version of WiFi devices.
X – band	8 – 12.5 GHz	Used in satellites for earth exploration, in fixed and mobile satellites for communications from earth to space direction i.e. uplink & in meteorological satellites for monitoring weather conditions.
KU-band	12-18 GHz	Services are largely used for high powered satellites in digital TV to include things like news feeds, educational networks, teleconferences, sports and other backhauls, entertainment programming, and international programming.
K – band	18 – 27 GHz	Used in microwave domain for radar and satellite applications & in infrared domain for astronomical purposes.
Ka band	27-40 GHz	Is primarily used for two-way consumer broadband and military networks.

II. POLARIZATION OF ELECTROMAGNETIC WAVE

Satellite communication signal (Radio wave) is an electromagnetic waveform composed of both electric and magnetic fields. In free space, the fields are mutually perpendicular and are also perpendicular to the direction of propagation [12; 16]. The term polarization commonly refers to the electric field component of the radio wave. In microwave antennas, polarization of the radio waves is either horizontal or vertical. That is, the electric field is either horizontal or vertically orientated. The transmission characteristics of both polarizations are very similar at microwave frequencies. However, the effects of obstacles and reflections within the microwave link are more likely to degrade system performance [2; 13].

The performance of communication systems can be strongly affected by the polarization of a wave, if it is not \matched to the intended polarization. Along similar lines, propagation of a wave introduces potential changes to its polarization which will in turn affect communication system performance. Hence, it is important to understand how waves are polarized and the different polarization classification [7; 11]

i. Linear polarization is the most common form of antenna polarization. It is characterized by the fact that all of the radiation is in one plane - hence the term linear:
ii. Horizontal polarization has horizontal elements. It picks up and radiates horizontally polarized signals, i.e. electromagnetic waves with the electric field in the horizontal plane[2; 10].
iii. Vertical polarization is characterized by the vertical elements within the antenna. It could be a single vertical element. One of the reasons for using vertical polarization is that antennas comprising of a single vertical element can radiate equally around it in the horizontal plane. Typically vertically polarized antennas have what is termed a low angle of radiation enabling a large proportion of their power to be radiated at an angle close to the earth surface. Vertically polarized antennas are also very convenient for use with automobiles[2;10].
iv. Circular polarization has a number of benefits for areas such as satellite applications where it helps overcome the effects of propagation anomalies, ground reflections and the effects of the spin that occur on many satellites. Circular polarization is a little more difficult to visualize than linear polarization. However it can be imagined by visualizing a signal propagating from an RF antenna that is rotating. The tip of the electric field vector will then be seen to trace out a helix or corkscrew as it travels away from the antenna[2; 10].

III. RELATED WORKS

Abayomi et al worked on comparative analysis of terrestrial rain attenuation at Ku band in Southern Nigeria using four rain attenuation models. The study aimed at obtaining a more suitable rain attenuation prediction model for the tropical and equatorial climates in Nigeria using one year rain data. In their studies, Abdulrahman rain model was found most suitable while other tested model including ITU-R over-estimated the radio parameters. The drawback was that the data used was not restricted for temperate region only, also the study failed to recognize the fact that not all the tested models had the algorithm to process the radio parameter input for varying locations and climate [1]

Islam et al designed and simulated an improved ITU-R rain attenuation prediction model over terrestrial microwave links in tropical region. In their research, a nonlinear multiple regression and moving average techniques were employed for fitting the measured rain attenuation at different time percentages. ITU-R prediction was found to be more suitable for the Malaysian tropical climate. The drawback, model was only tested in the tropical and not tested in a semi-temperate region [8]

Ezeh et al worked on the effects of rain attenuation on satellite communication link. They stated that rain attenuation is a major challenge to microwave satellite communication especially at frequencies above 10 GHz, causing unavailability of signals most of the time. Rain attenuation is caused as a result of absorption of part or all of the signal's radiation power by the raindrop. This absorption is as a result of scattering effect (diffraction and refraction) of the rain drop to the signal. At a particular frequency, rain attenuation increases exponentially with increasing rain rate values because, the higher the rainfall rate, the higher the rain drop size (rain drop diameter) [6]

Fikih et al also worked on the Computation of rain attenuation in tropical region with multiple scattering and multiple absorption effects using exponential drop size distribution. Their worked revealed that rain attenuation causes scattering and absorption of electromagnetic waves and could be a significant problem in radio propagation, especially in tropical region which has high rainfall rate. In their paper, raindrop was modeled using exponential raindrop size distribution and computed with multiple scattering and multiple absorption effect previously derived. It was assumed that raindrop shape is spherical and has dielectric constant following the Double Debye Model. Based on the analysis, rain attenuation effects become significant for frequencies above 10 GHz and reach the peak at about 125 GHz [7]

IV. MATERIALS AND METHODS

The study was carried out in Jos, Plateau state,Nigeria (9.8965^0 N, 8.8583^0 E; 1192 meters) with Maximum, Average and Minimum Temperatures of 29.8^{0}C, 22.8^{0}C and 17^{0}C respectively. Theequipment used includes the following: Davis weather station, USB data logger, computer system, Compass, Radio frequency power meter, Coaxial cable port connector and connecting cable (coaxial cable). Data were obtained for the months of May, June, July, August, September and October 2020. The Davis Vantage Vue weather station is an equipped with an integrated sensor suite (ISS) and weather link data logger, and was used to measure and record one-minute rain-rates. 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 down converted Ku-band signal was 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 were done concurrently.

V. DETERMINATION OF CUMULATIVE DISTRIBUTION FUNCTION (CDF) USING RAINFALL RATE

The long-term behavior of rain fall rate is described by a cumulative probability distribution or by a cumulative distribution function (CDF). The CDF for rainfall rate is commonly referred to as an exceedance curve. This gives a percentage of time (usually the percent of 1 year) that the rain fall rate exceeds a given value. Rain accumulation can vary significantly from year-to-year. The CDF using rainfall rate was obtained using the following steps [3]:

1. The frequency of each rain rate (mm/hr) recorded at one minute integration time for each of the month under review was obtained
2. The cumulative frequency (N) was calculated from the rain rate frequency
3. The cumulative distribution function (CDF) for each of the month was calculated using
   $CDF = \frac{N\times100\%}{30\times24\times60}$, (for months with 30days) (1a)
   $CDF = \frac{N\times100\%}{31\times24\times60}$, (for months with 31days) (1b)

VI. DETERMINATION OF FREQUENCY AND POLARIZATION SCALING FOR RAIN ATTENUATED SIGNAL

The following parameters and procedures listed below were used to determine the frequency and polarization scaling :

$R_{0.01}$: 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 1.19km 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 9.8965^0 N)

f : frequency (GHz) (for this study, 12GHz, 15GHz, and 18GHz was used)

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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 θ ≥ 5° the slant-path length, L_S, below the rain height was computed from:

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

For θ < 5°, the following formula was used:

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

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

$L_G = L_S \cos\theta$ km

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:

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

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

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

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 ζ>θ, $L_R = \frac{L_G\, r_{0.01}}{\cos\theta}$ km

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

If | φ | < 36°, χ = 36 – | φ | degrees
Else χ = 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:

$L_E = L_R\, v_{0.01}$ km

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

$A_{0.01} = \gamma_R\, L_E$ dB

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 | φ | ≥ 36°: β= 0

If $p < 1\%$ and | φ | < 36° and θ≥ 25°: β= –0.005(| φ | – 36)

(42)

Otherwise:

β= –0.005(| φ | – 36) + 1.8 – 4.25 sin θ

(43)

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655 + 0.033\ln(p) - 0.045\ln(A_{0.01}) - \beta(1-p)\sin\theta)} \quad \text{dB} \qquad (49)$$

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:

(44)

$$\frac{A_p}{A_{0.01}} = 0.07\,p^{-(0.855 + 0.139\log_{10} p)} \qquad (50)$$

$$A_p = A_{0.01} \times 0.07 \times p^{-(0.855 + 0.139 log_{10} p} \qquad (51)$$

The values of rain attenuated signal A_p(dB) at frequencies; 12GHz, 15GHz and 18GHz for both horizontal and vertical polarization were calculated from step one to step ten and presented in Table 2, Table 3, and Table 4.

(45)

(46)

VII. RESULTS AND DISCUSSIONS

Rainfall intensity along the earth path is in-homogeneous in space and time. Therefore, results were determined on monthly basis. This is because the rain intensity experienced in the month of May is different from that experienced in June or October.

Table 2: Computation of rain attenuated signal (A_p) at frequencies of 12GHz, 15GHz and 18GHz for May 2020

Polarization	Rain rate (mm/hr)	CDF (%)	A_p(dB) at 12GHz	A_p(dB) at 15GHz	A_p(dB) at 18GHz
Vertical	20	0.479	4.58	6.61	6.61
	40	0.282	4.35	12.04	16.57
	60	0.176	6.04	14.62	25.29
	80	0.076	10.48	23.87	31.39
	100	0.042	15.12	26.23	37.49
	150	0.016	25.57	30.37	39.84
Horizontal	20	0.479	3.86	6.23	6.61
	40	0.282	4.31	11.22	30.79
	60	0.176	6.24	14.49	31.82
	80	0.076	11.04	24.38	39.51
	100	0.042	16.16	34.61	47.39
	150	0.016	27.96	40.33	45.71

(47)

(48)

Table 3: Computation of rain attenuated signal (A_p) at frequencies of 12GHz, 15GHz and 18GHz for June 2020

Polarization	Rain rate (mm/hr)	CDF (%)	A_p(dB) at 12GHz	A_p(dB) at 15GHz	A_p(dB) at 18GHz
Vertical	20	1.698	2.28	3.29	3.29
	40	1.084	2.14	5.94	21.00
	60	0.511	3.83	9.26	22.34
	80	0.204	7.63	17.39	37.45
	100	0.060	11.90	26.17	50.14
	150	0.027	18.53	38.69	59.10
Horizontal	20	1.698	1.92	3.10	3.29
	40	1.084	2.13	5.54	15.19
	60	0.511	3.95	9.17	20.14
	80	0.204	8.04	17.76	36.07
	100	0.060	12.72	27.25	53.06
	150	0.027	20.27	41.56	76.63

Results in Table 3 shows that rain attenuated signal for both vertical and horizontal polarization become severe from 80mm/hr and must severe signal losses for vertical polarization are 18.53dB, 38.69dB, 59.10dB for 12GHz, 15GHz, 18GHz frequencies respectively while that of horizontal polarization are 20.27dB, 41.56dB, 76.63dB for 12GHz, 15GHz, 18GHz frequencies respectively. This clearly revealed that signal losses are more pronounce at higher frequency and Horizontal polarization.

Table 4: Computation of rain attenuated signal (A_p) at frequencies of 12GHz, 15GHz and 18GHz for July 2020

Polarization	Rain rate (mm/hr)	CDF (%)	A_p(dB) at 12GHz	A_p(dB) at 15GHz	A_p(dB) at 18GHz
Vertical	20	0.986	2.55	3.68	3.68
	40	0.560	2.61	7.24	25.58
	60	0.255	4.72	11.42	27.57
	80	0.095	29.28	21.15	45.54
	100	0.037	65.97	68.10	76.28
	150	0.011	60.57	73.37	100.84
Horizontal	20	0.986	2.15	3.47	3.68
	40	0.560	2.59	6.74	18.50
	60	0.255	4.87	21.32	37.86
	80	0.095	39.78	51.60	43.87
	100	0.037	67.07	72.55	81.18
	150	0.011	77.96	84.33	105.71

Table 4 presents the Computation of rain attenuated signal at frequencies of 12GHz, 15GHz and 18GHz for the month of July 2020. The results shows that rain attenuated signal for vertical polarization is more severe from rain rate of 80mm/hr with the highest rain attenuation of 60.57dB, 73.37dB, and 100.84dB for frequencies of 12GHz, 15GHz, and 18GHz respectively. At Horizontal polarization, signal losses is more severe from 60mm/hr.

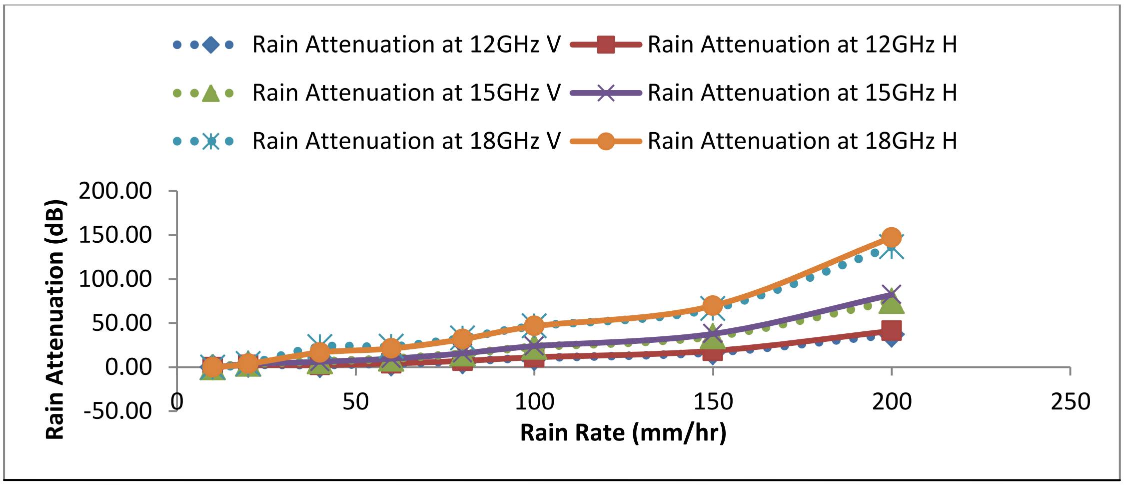

Figure 1: comparison of rain attenuated signal at different frequencies and polarization for the month of August 2020

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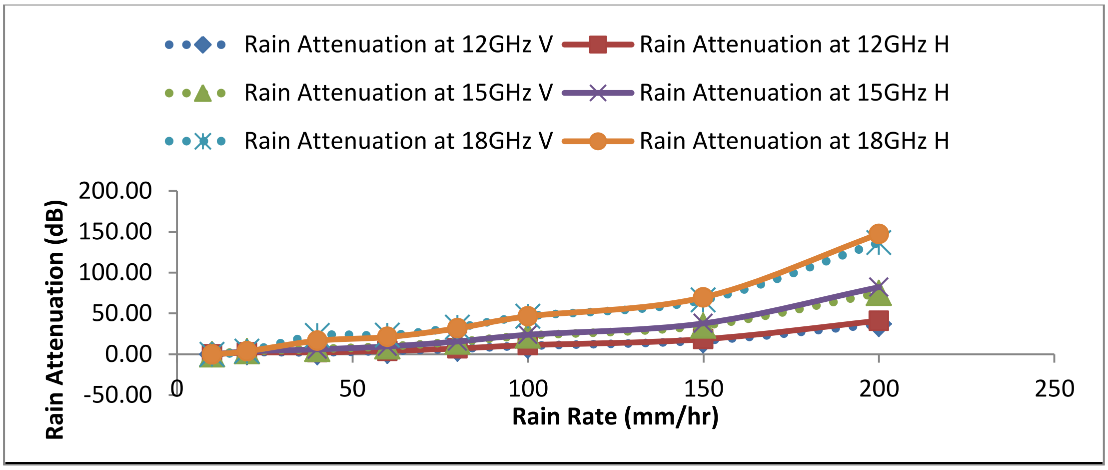

Figure 2: comparison of rain attenuated signal at different frequencies and polarization for the month September 2020

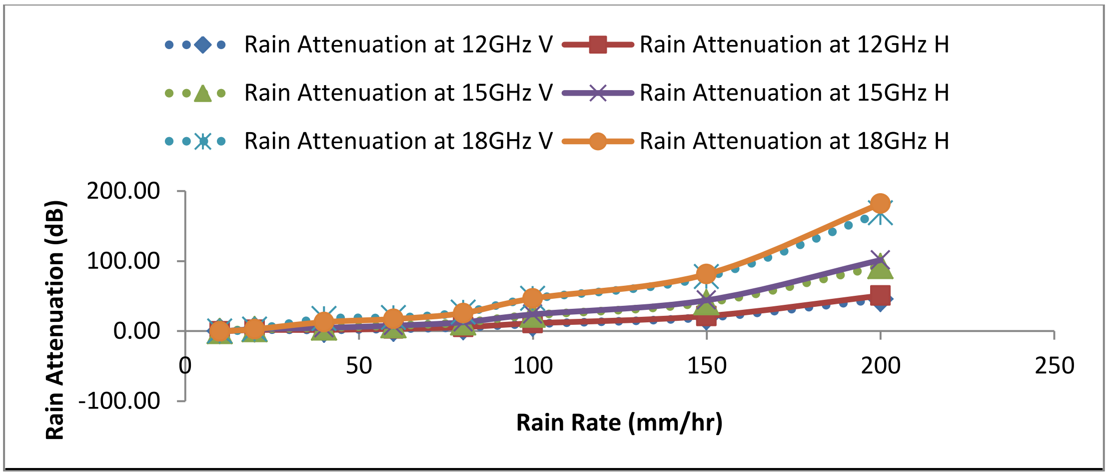

Figure 3: comparison of rain attenuated signal at different frequencies and polarization for the month of October 2020

Figure 1, 2 and 3 presents the comparison of rain attenuated signal at different frequencies and polarization for the months of August, September and October 2020. As it can be clearly seen from the results, rain attenuated signal at 18GHz recorded the highest losses and 12GHz recorded the lowest losses.

VIII. CONCLUSION

Rain is the major variable in the design of microwave link budgets. Attenuation due to rain depends on frequency and the rainfall intensity. This study measured and analyzed frequency and polarization scaling on rain attenuated signal of a KU-Band. Results obtained revealed that rain attenuated signal for vertical and horizontal polarization varies for different rain rate and months under reviewed. For the month of May 2020, rain attenuated signal is more severe from rain rate of 100mm/hr with the highest rain attenuation of 25.57dB, 30.37dB, and 39.84dB at frequencies of 12GHz, 15GHz and 18GHz respectively while the rain attenuated signal for vertical polarization is more severe from 80mm/hr with highest recorded rain attenuation of 27.96dB, 40.33dB and 45.71dB at frequencies of 12GHz, 15GHz and 18GHz respectively. For the month of July 2020, the results shows that rain attenuated signal for vertical polarization is more severe from rain rate of 80mm/hr with the highest rain attenuation of 60.57dB, 73.37dB, and 100.84dB for frequencies of 12GHz, 15GHz, and 18GHz respectively. At Horizontal polarization, signal losses are more severe from 60mm/hr. These results further proves that frequency and polarization scaling of rain attenuated signalare major factors to consider when designing a microwave link budget especially in the study area that experiences high amount of rainfall annually.

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