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Comparative Analysis Of Rain Attenuation In Satellite Communication Link For Different Polarization Options

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Abstract— **In this paper, comparative analysis of rain attenuation in satellite communication link for different polarization options, namely, horizontal, vertical and circular polarization is presented. The satellite link look angle and slant range are first computed and then, the analysis of the rain attenuation was performed using the International Telecommunication Union (ITU) rain attenuation model. The case study satellite link consist of NIGCOMSAT-1R satellite at orbital slot with longitude of 42.5°E and a ground station at Imo State University located at latitude of 5.503728 °N and longitude of 7.043795 °E . The results of the look angle computation showed that the satellite link has elevation angle of 48.421°, azimuth angle of 97.7° and slant range (distance) of 37,180.745 km. The rain attenuation computation was done for frequency range of 1 GHz to 100 GHz, for link rain outage probability (p) of 1 %, 0.1%, 0.01% and 0.001% and for rain rate of 10 mm.hr, 45 mm.hr and 95 mm.hr. The results show that for the case study link, the horizontal polarization suffers the highest rain attenuation while the vertical attenuation has the lowest rain attenuation among the three options. As such, if there is a choice in the link design , the vertical polarization should be chosen as it will require less power to transmit over the given link slant range when compare to the horizontal and circular polarizations. Furthermore, the results show that the rain attenuation increases as outage probability (p) decreases. Notably, P indicates rain outage probability and the inverse of p is the link availability. Hence, the results can be state that if the link availability is increased, then the expected rain attenuation will increase. Also, the results show that rain attenuation increases with the rain rate and frequency.**

Keywords— Rain Rate, Rain Attenuation, Rain Height, Vertical Polarization, Satellite Link, Horizontal Polarization, Rain Outage Probability, Circular Polarization

1. INTRODUCTION

Like every wireless communication systems, satellite links suffer losses due to several factors that include environmental, atmospheric and climatic factors, among others [1,2,3,4,5,6]. Particularly, rain attenuation is one of the prominent sources of degradation in the received signal strength for high frequency signals [7,8,9,10,11]. Consequent, accurate estimation of rain attenuation is essential for the deployment of satellite links which mainly operate in the high frequency microwave bands [12,13,14,15,16,17,18].

In this paper, the International Telecommunication Union (ITU) rain attenuation model is used to estimate the rain attenuation for satellite link for frequencies ranging from 1 GHz to 100 GHz [19,20,21,22,23]. Research has shown that rain attenuation depends on the signal polarization [24,25,26,27,28,29,30]. As such, in this paper, the study evaluated the rain attenuation for three different polarization options, namely, horizontal, vertical and circular polarization. A case study NIGCOMSAT-1R satellite at orbital slot with longitude of 42.5°E [30,31] was used for numerical example where the earth station is located in Imo State , Nigeria. The study also considered the impact of rain rate, rain outage probability and frequency on the rain attenuation. In all, the paper presented relevant information for satellite link designers on how to determine the rain attenuation for different rain rate and different signal polarization.

II. METHODOLOGY

The rain attenuation (A_{rn}) suffered by a satellite communication link has been modeled by ITU as follows;

$$A_{rn} = k\left(R_p\right)^{\alpha}(L_e) \quad (1)$$

Where R_p is the rain rate (in mm/hr) at p% exceeded time per year. ITU provided the values of R_p in chart tabular form for about 15 different rain zones .

K and α are constants that depend on frequency and polarization. ITU provided the values of k and α for different frequencies for the vertical and horizontal polarization. For circular polarization, the values of k and α for different frequencies can be determined from those of the vertical and horizontal polarization as follow;

$$k_c = 0.5\ (k_h + k_v\ ) \quad (1)$$

$$\alpha_c = \frac{(k_h)(\alpha_h) + (k_v)(\alpha_v)}{2(k_c)} \quad (2)$$

Where h, v and c subscripts in Eq 1and Eq 2 indicates the horizontal, vertical and circular polarizations.

L_e is the effective path length (in km) affected by the rain. The value of L_e is determined from the values of the elevation angle (θ_{el}) of the satellite –earth station link, the latitude (φ_{es}) of the earth station, the rain height (H_{rn}) and the altitude (H_{es}) of the earth station. The value of L_e is computed as follows;

$$L_e = \frac{L_0}{1+\left(\frac{L_0(R_p-6.2)}{2636}\right)} \quad (3)$$

$$L_0 = \frac{H_{rn}-H_{es}}{\sin(\theta_{el})} \quad (4)$$

$$H_{rn} = \begin{cases} 4.8 & for\ \varphi_{es} < 30° \\ 7.8 - 0.1(\varphi_{es}) & for\ \varphi_{es} \geq 30° \end{cases} \quad (5)$$

Where H_{rn}, H_{es} , L_0 and L_e are all in km and R_p is in mm/hr.

The rain attenuation $A_{o.01}$ in dB computed at p = 0.01 % can be converted to rain attenuation A_p in other exceedence values, p as follows;

$$A_p = \begin{cases} A_{0,01}\left(0.12p^{-(0.546+0.043(Log(p))}\right) & for\ \varphi_{es} \geq 30° \\ A_{0,01}\left(0.07p^{-(0.855+0.139(Log(p))}\right) & for\ \varphi_{es} < 30° \end{cases} \quad (6)$$

Specifically, in this paper, the effective rain path length and rain attenuation for the vertical, horizontal and circular polarization are computed for some selected frequencies (f) and percentage of time (p) exceeded. The results obtained are discussed as they pertain to impacting on the performance of the satellite communication link. The basic data of the case study NIGCOMSAT-1R satellite and the ground station location at Imo State University (IMSU) Owerri, are as follows;

i) NIGCOMSAT-1R satellite Longitude is 42.5°E
ii) IMSU latitude is 5.503728 °N
iii) IMSU longitude is 7.043795 °E
iv) $R_{0.01\%} = 95\ mm.hr$

Then, the computed look angle and slant range for the satellite link are;

i) Elevation angle is 48.421
ii) Azimuth angle is 97.7
iii) Slant range , d is 37,180.745 km

III. RESULTS AND DISCUSSION

In this paper, the rain attenuation computation was done for frequency range 1 GHz to 100 GHz , for link rain outage probability (p) of 1 %, 0.1%, 0.01% and 0.001% and for rain rate of 10 mm.hr, 45 mm.hr and 95 mm.hr . The results of the computation for rain attenuation for p = 0.01% and Rain rate = 95 mm.hr for the horizontal , vertical and circular polarizations are show that the horizontal polarization suffers the highest rain attenuation while the vertical attenuation has the lowest rain attenuation among the three options. As such, if there is a choice in the link design , the vertical polarization should be chosen as it will require less power to transmit over the given link slant range when compare to the other two options (namely, horizontal and circular polarizations).

The results of the computation of the rain (dB) attenuation for Rain rate = 95 $mm.hr$ and for the horizontal polarization, p = 1 %, 0.1%, 0.01% and 0.001% show that for the horizontal polarization the rain attenuation increases as p decreases. Notably, P indicates rain outage probability. As such, if the link rain outage probability (p) decreases, the expected rain attenuation increases. Conversely, the inverse of p is the link availability. Hence, the results can be state that if the link availability is increased in the face of rain attenuation , then the expected rain attenuation will increase.

The results of the computation of the rain (dB) attenuation for p = 0.01 and the horizontal polarization for Rain rate = 10 mm.hr, 45 mm.hr and 95 mm.hr are shown in Table 3 and Figure 3. The results show that the higher the rain rate , the higher the rain attenuation. As such, areas with higher rain rate will suffer higher rain attenuation than those areas with little rain fall incidence. Finally, it is also noted that in all the cases, the rain attenuation increases with increase in frequency.

Table 1 Rain (dB) attenuation for p=0.01% and Rain rate = 95 $mm.hr$ for the horizontal , vertical and circular polarization

Frequency (GHz)	Arain (dB) for p=0.01 % and horizontal pol.)	Arain (dB) for p=0.01 % and vertical pol.	Arain (dB) for p=0.01 % and circular pol	Frequency (GHz)	Arain (dB) for p=0.01 % and horizontal pol.)	Arain (dB) for p=0.01 % and vertical pol.	Arain (dB) for p=0.01 % and circular pol	Frequency (GHz)	Arain (dB) for p=0.01 % and horizontal pol.)	Arain (dB) for p=0.01 % and vertical pol.	Arain (dB) for p=0.01 % and circular pol
1	0.013	0.009	0.011	31	96.66	78.97	87.55	66	149.69	139.09	144.31
1.5	0.024	0.018	0.02	32	99.59	81.95	90.53	67	150.20	139.87	144.96
2	0.057	0.039	0.046	33	102.36	84.84	93.37	68	150.75	140.62	145.61
2.5	0.113	0.075	0.091	34	105.06	87.66	96.14	69	151.22	141.36	146.22
3	0.197	0.131	0.153	35	107.69	90.34	98.81	70	151.67	142.09	146.82
3.5	0.385	0.218	0.248	36	110.18	92.97	101.37	71	152.04	142.82	147.37
4	0.813	0.374	0.437	37	112.59	95.51	103.86	72	152.47	143.46	147.91
4.5	1.562	0.711	0.911	38	114.95	97.93	106.25	73	152.82	144.11	148.41

5	2.542	1.348	1.814	39	117.14	100.32	108.55	74	153.18	144.75	148.91
5.5	3.716	2.239	2.949	40	119.28	102.58	110.75	75	153.53	145.33	149.38
6	5.107	3.264	4.183	41	121.28	104.72	112.82	76	153.88	145.90	149.84
7	8.433	6.092	7.262	42	123.21	106.84	114.85	77	154.19	146.48	150.29
8	12	9.578	10.786	43	125.12	108.81	116.79	78	154.49	147.01	150.71
9	15.616	12.319	13.943	44	126.85	110.77	118.64	79	154.73	147.56	151.11
10	19.332	14.846	17.013	45	128.59	112.64	120.44	80	154.98	148.03	151.47
11	23.132	17.808	20.326	46	130.16	114.42	122.12	81	155.26	148.46	151.83
12	26.985	21.041	23.783	47	131.70	116.15	123.77	82	155.47	148.91	152.16
13	30.846	24.251	27.216	48	133.16	117.83	125.34	83	155.64	149.37	152.48
14	34.773	27.278	30.577	49	134.49	119.39	126.79	84	155.83	149.80	152.79
15	38.703	30.144	33.868	50	135.87	120.92	128.24	85	156.05	150.17	153.09
16	42.667	32.907	37.146	51	137.06	122.40	129.58	86	156.22	150.57	153.37
17	46.644	35.639	40.446	52	138.27	123.87	130.93	87	156.41	150.92	153.64
18	50.606	38.406	43.788	53	139.42	125.24	132.19	88	156.56	151.30	153.91
19	54.551	41.237	47.182	54	140.46	126.53	133.37	89	156.74	151.65	154.17
20	58.47	44.16	50.63	55	141.48	127.80	134.52	90	156.88	151.95	154.40
21	62.316	47.18	54.105	56	142.44	129.00	135.60	91	156.98	152.28	154.62
22	66.094	50.277	57.594	57	143.39	130.20	136.67	92	157.12	152.58	154.83
23	69.836	53.445	61.099	58	144.20	131.34	137.66	93	157.23	152.85	155.02
24	73.503	56.632	64.579	59	145.03	132.43	138.62	94	157.37	153.08	155.21
25	77.075	59.895	68.044	60	145.79	133.51	139.55	95	157.48	153.36	155.40
26	80.558	63.163	71.464	61	146.57	134.49	140.43	96	157.55	153.59	155.56
27	83.963	66.399	74.821	62	147.26	135.49	141.28	97	157.67	153.87	155.76
28	87.296	69.609	78.126	63	147.89	136.45	142.08	98	157.75	154.05	155.89
29	90.487	72.786	81.337	64	148.53	137.32	142.84	99	157.81	154.27	156.03
30	93.63	75.907	84.491	65	149.10	138.21	143.57	100	157.91	154.46	156.17

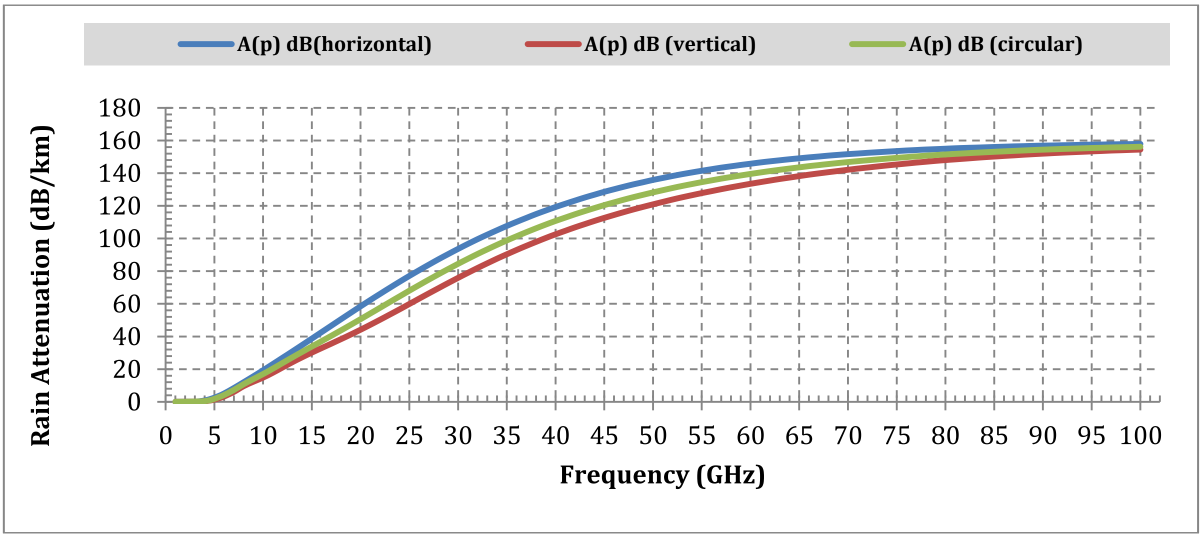

Figure 1 Rain (dB) attenuation for p=0.01 % and Rain rate = 95 mm. hr for the horizontal , vertical and circular polarization

Table 2 Rain (dB) attenuation for Rain rate = 95 mm. hr and the horizontal polarization for p = 1 %, 0.1%, 0.01% and 0.001%

Frequency (GHz)	Arain (dB) for p=1% and horizontal pol.)	Arain (dB) for p=0.1% and horizontal pol.)	Arain (dB) for p=0.01% and horizontal pol.)	Arain (dB) for p=0.001% and horizontal pol.)	Frequency (GHz)	Arain (dB) for p=1% and horizontal pol.)	Arain (dB) for p=0.1% and horizontal pol.)	Arain (dB) for p=0.01% and horizontal pol.)	Arain (dB) for p=0.001% and horizontal pol.)
1	0.001	0.005	0.013	0.018	66	10.48	54.49	149.69	215.92
1.5	0.002	0.009	0.024	0.034	67	10.51	54.67	150.20	216.65
2	0.004	0.021	0.056	0.081	68	10.55	54.87	150.75	217.45
2.5	0.008	0.041	0.113	0.163	69	10.59	55.05	151.22	218.13
3	0.014	0.072	0.197	0.284	70	10.62	55.21	151.67	218.77
3.5	0.027	0.140	0.385	0.555	71	10.64	55.34	152.04	219.31
4	0.057	0.296	0.813	1.173	72	10.67	55.50	152.47	219.93
4.5	0.109	0.569	1.562	2.253	73	10.70	55.63	152.82	220.43
5	0.178	0.925	2.542	3.667	74	10.72	55.76	153.18	220.95
5.5	0.260	1.352	3.715	5.359	75	10.75	55.88	153.53	221.46
6	0.357	1.859	5.107	7.367	76	10.77	56.01	153.88	221.97
7	0.590	3.069	8.433	12.164	77	10.79	56.12	154.19	222.41
8	0.840	4.368	12.000	17.309	78	10.81	56.23	154.49	222.84
9	1.093	5.684	15.616	22.525	79	10.83	56.32	154.73	223.19
10	1.353	7.037	19.332	27.885	80	10.85	56.41	154.98	223.55
11	1.619	8.420	23.132	33.366	81	10.87	56.51	155.26	223.95
12	1.889	9.822	26.985	38.924	82	10.88	56.59	155.47	224.26
13	2.159	11.228	30.846	44.493	83	10.89	56.65	155.64	224.50
14	2.434	12.657	34.773	50.158	84	10.91	56.72	155.83	224.77
15	2.709	14.088	38.703	55.827	85	10.92	56.80	156.05	225.09
16	2.987	15.531	42.667	61.545	86	10.94	56.86	156.22	225.34
17	3.265	16.978	46.644	67.281	87	10.95	56.93	156.41	225.61
18	3.542	18.420	50.606	72.996	88	10.96	56.99	156.56	225.82
19	3.819	19.856	54.551	78.686	89	10.97	57.05	156.74	226.08
20	4.093	21.283	58.470	84.340	90	10.98	57.10	156.88	226.29
21	4.362	22.683	62.316	89.887	91	10.99	57.14	156.98	226.44
22	4.627	24.058	66.094	95.337	92	11.00	57.19	157.12	226.64
23	4.889	25.420	69.836	100.734	93	11.01	57.23	157.23	226.79
24	5.145	26.755	73.503	106.024	94	11.02	57.28	157.37	227.00
25	5.395	28.055	77.075	111.176	95	11.02	57.32	157.48	227.15
26	5.639	29.323	80.558	116.201	96	11.03	57.35	157.55	227.26
27	5.877	30.562	83.963	121.111	97	11.04	57.39	157.67	227.42
28	6.111	31.776	87.296	125.920	98	11.04	57.42	157.75	227.55
29	6.334	32.937	90.487	130.522	99	11.05	57.44	157.81	227.63
30	6.554	34.081	93.630	135.056	100	11.05	57.48	157.91	227.78

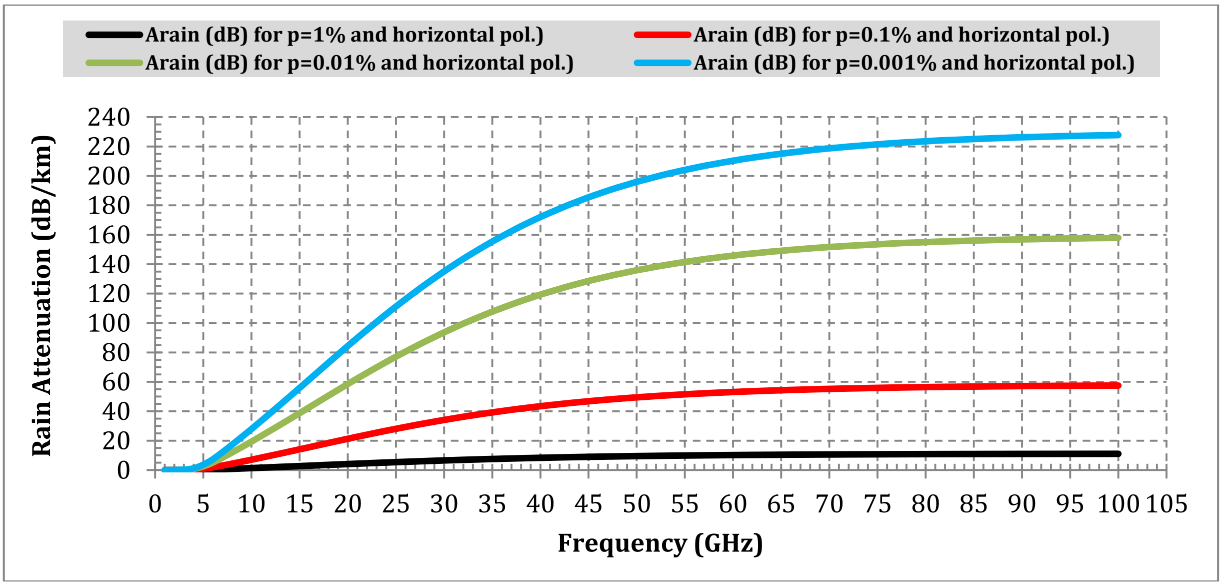

Figure 2 Rain (dB) attenuation for Rain rate = 95 mm.hr and the horizontal polarization for p = 1 %, 0.1%, 0.01% and 0.001%

Table 3 Rain (dB) attenuation for p = 0.01 and the horizontal polarization for % Rain rate = 10 mm.hr, 45 mm.hr and 95 mm.hr

Frequency(GHz)	Arain (dB) for p=1% , R0.01 = 95 mm/hr and horizontal pol.)	Arain (dB) for p=1% , R0.01 = 45 mm/hr and horizontal pol.)	Arain (dB) for p=1% , R0.01 = 10 mm/hr and horizontal pol.)	Frequency(GHz)	Arain (dB) for p=1% , R0.01 = 95 mm/hr and horizontal pol.)	Arain (dB) for p=1% , R0.01 = 45 mm/hr and horizontal pol.)	Arain (dB) for p=1% , R0.01 = 10 mm/hr and horizontal pol.)	Frequency(GHz)	Arain (dB) for p=1% , R0.01 = 95 mm/hr and horizontal pol.)	Arain (dB) for p=1% , R0.01 = 45 mm/hr and horizontal pol.)	Arain (dB) for p=1% , R0.01 = 10 mm/hr and horizontal pol.)
1	0.0009	0.0007	0.0002	31	6.766	3.720	0.981	66	10.48	6.66	2.35
1.5	0.0017	0.0009	0.0002	32	6.971	3.858	1.031	67	10.51	6.69	2.37
2	0.0040	0.0020	0.0004	33	7.165	3.992	1.081	68	10.55	6.73	2.40
2.5	0.0079	0.0038	0.0008	34	7.354	4.124	1.131	69	10.59	6.77	2.42
3	0.0138	0.0061	0.0010	35	7.538	4.253	1.181	70	10.62	6.80	2.44
3.5	0.0269	0.0104	0.0013	36	7.713	4.377	1.230	71	10.64	6.83	2.46
4	0.0569	0.0191	0.0019	37	7.882	4.499	1.279	72	10.67	6.86	2.48
4.5	0.1094	0.0342	0.0029	38	8.047	4.618	1.328	73	10.70	6.89	2.50
5	0.1780	0.0555	0.0047	39	8.200	4.732	1.375	74	10.72	6.92	2.52
5.5	0.2601	0.0841	0.0076	40	8.350	4.844	1.423	75	10.75	6.95	2.54
6	0.3575	0.1209	0.0120	41	8.490	4.950	1.469	76	10.77	6.98	2.56
7	0.5903	0.2165	0.0253	42	8.625	5.054	1.515	77	10.79	7.00	2.58
8	0.8400	0.3296	0.0441	43	8.758	5.156	1.560	78	10.81	7.03	2.59
9	1.0931	0.4537	0.0679	44	8.879	5.252	1.604	79	10.83	7.05	2.61
10	1.3532	0.5867	0.0959	45	9.001	5.347	1.648	80	10.85	7.07	2.63
11	1.6192	0.7250	0.1264	46	9.111	5.436	1.690	81	10.87	7.09	2.64
12	1.8889	0.8659	0.1583	47	9.219	5.524	1.731	82	10.88	7.11	2.66
13	2.1592	1.0076	0.1910	48	9.321	5.607	1.772	83	10.89	7.13	2.67
14	2.4341	1.1521	0.2247	49	9.415	5.686	1.811	84	10.91	7.15	2.68

15	2.7092	1.2980	0.2594	50	9.511	5.766	1.851	85	10.92	7.17	2.70
16	2.9867	1.4468	0.2956	51	9.594	5.838	1.888	86	10.94	7.19	2.71
17	3.2651	1.5979	0.3333	52	9.679	5.910	1.925	87	10.95	7.20	2.73
18	3.5424	1.7507	0.3724	53	9.759	5.980	1.961	88	10.96	7.22	2.74
19	3.8186	1.9052	0.4131	54	9.833	6.045	1.996	89	10.97	7.23	2.75
20	4.0929	2.0609	0.4552	55	9.904	6.108	2.030	90	10.98	7.25	2.76
21	4.3621	2.2164	0.4986	56	9.971	6.169	2.063	91	10.99	7.26	2.77
22	4.6266	2.3716	0.5430	57	10.037	6.229	2.095	92	11.00	7.28	2.78
23	4.8885	2.5275	0.5888	58	10.094	6.283	2.126	93	11.01	7.29	2.79
24	5.1452	2.6828	0.6357	59	10.152	6.337	2.157	94	11.02	7.30	2.81
25	5.3952	2.8363	0.6833	60	10.206	6.388	2.187	95	11.02	7.31	2.82
26	5.6391	2.9883	0.7316	61	10.260	6.439	2.216	96	11.03	7.32	2.83
27	5.8774	3.1389	0.7806	62	10.308	6.486	2.244	97	11.04	7.34	2.84
28	6.1107	3.2883	0.8303	63	10.352	6.530	2.270	98	11.04	7.35	2.84
29	6.3341	3.4337	0.8800	64	10.397	6.574	2.297	99	11.05	7.36	2.85
30	6.5541	3.5783	0.9303	65	10.437	6.615	2.322	100	11.05	7.37	2.86

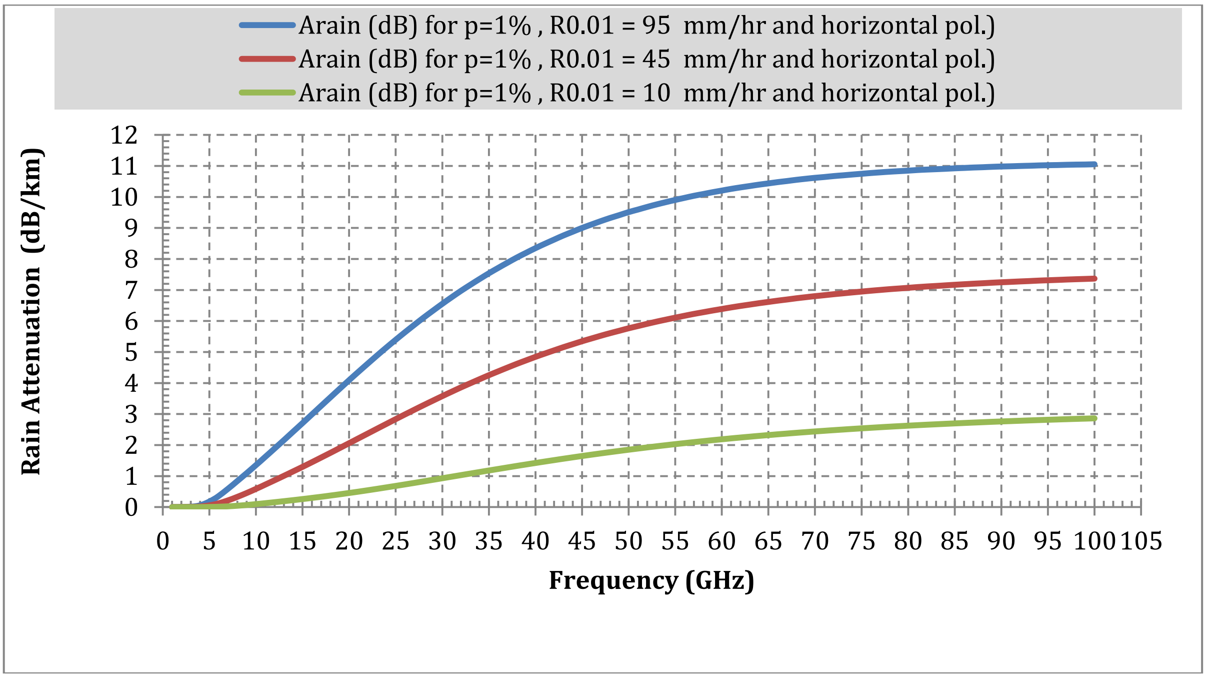

Figure 3 Rain (dB) attenuation for p = 0.01 and the horizontal polarization for %
$R_{0.01\%} = 10$ mm. hr, 45 mm. hr and 95 mm. hr

IV . CONCLUSION

The rain attenuation that can be experienced by signal in a satellite communication link is evaluated for three different polarization options, namely, horizontal, vertical and circular polarization. The analysis utilized the International Telecommunication Union (ITU) rain attenuation model and associated parameters to determine the rain attenuation. A case study NIGCOMSAT-1R satellite and ground station at Imo State University was used as the case study for numerical computation sample. The results showed that the horizontal polarization suffered the highest rain attenuation. Also, rain attenuation increases with rain rate, increases with increase in required link availability and also increases with increase in frequency.

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