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RAIN INDUCED DEPOLARIZATION SCALING PARAMETERS FOR LINEARLY POLARIZED SHF WAVES COMMUNICATION ON EARTH-SPACE PATHS IN NIGERIA

M. O. AJEWOLE AND B. O. AFOLAYAN

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ABSTRACT

On Earth-space propagation paths, propagation effect such as depolarization caused by deformed raindrops (such as oblate spheroids) is of prime importance to telecommunication systems designers. This is because rain induced depolarization results in cross talk between orthogonal channels (or frequency re-use systems) transmitted on the same path and at the same frequency. This study presents the results of numerical computation of cross polarization discrimination (XPD) arising from transmission of linearly polarized super high frequency (SHF) signals through three rain types, namely; widespread, shower, and thunderstorm on Earth-space path in Nigeria. Two methods of computing XPD are employed; one uses a standard expression while the other uses a scaling relation based on the existence of a correlation between depolarization and attenuation. This latter method has been studied extensively in the temperate region. Its parameters are computed in this study and then substituted in the scaling relation to compute XPD at elevation angles of 23^0 and 55^0 to the satellite in Nigeria. Comparison of horizontal and vertical XPD shows that the vertical XPD is poorer than the horizontal XPD at all frequencies studied. In addition, we compare the results of the two methods of computing XPD in terms of the percentage difference between them. It was found that at frequencies lower or equal to 30 GHz and for horizontally polarized signal, the maximum percentage difference between the two methods is $\pm 3\%$, while the maximum percentage difference for vertical polarization is $\pm 12\%$. At higher frequencies, it is $\pm 30\%$ for horizontal polarization and $\pm 21\%$ for vertical polarization. The scaling expression, though less accurate at frequencies higher than 30 GHz gives a quicker estimate of XPD. Many of the present day satellite services use frequencies lower than about 20 GHz. The next generation of satellite communication systems are favoured to use the higher Ka and Q frequency bands. Therefore, the results presented in this study will be useful in quick field estimation of cross polarization discrimination to assess the quality of the channels on communication satellites during rainy conditions in Nigeria.

INTRODUCTION

Telecommunication satellites continue to play important roles in the provision of telecommunication infrastructure such as in audio and video broadcast/multicast, provision of point-to-point services for data and personal communication among others. Telecommunication satellites compared to terrestrial systems have the advantage of wider coverage ability, high flexibility, quality assurance and ease of deployment. The C- and Ku frequency bands are used presently for terrestrial, radar and for satellite telecommunication. However, the congestion in these bands and the shortage of available orbital slots to place new satellites has necessitated the need to look for a solution. The technique of using the same frequency more than once within the same satellite system so that the total capacity is increased without increasing the allocated bandwidth has been adopted as solution. Other solution methods include the use of higher frequencies and site diversity. Currently, attention is on the Ka (20-30 GHz) and the Q (40-50 GHz) frequency bands (Castanet et al, 2003). The major constraint in the use of these frequency bands however remains the effect of hydrometeors particularly rain on radio propagation. As the frequency of the communication system increases, raindrops sizes become comparable to the wavelength of the signal thereby causing attenuation and scattering of the signal. In Nigeria, the prevalence of large raindrop sizes during rainfall is a major cause of signal degradation when frequencies higher than 10 GHz are used. In particular, rain attenuation could be large enough to lead to complete system outage. In addition, when a satellite system transmits orthogonal polarizations in this region simultaneously, poor cross polarization discrimination between the channels will result in reduction of XPD thereby increasing co-channel interference. To ensure minimum outage duration during service delivery, it might be important to investigate the levels of cross polarization discrimination that will result in severe channel degradation.

Cross polarization discrimination can be defined simply as the dB level of a signal that starts out as one polarization but finishes up as the opposite polarization due to atmospheric effects such as rain. The transmitted polarization is called the wanted (co-polarized) signal, while the opposite received polarization is called the unwanted polarization (cross-polarized) signal. Since poor cross polarization discrimination levels could lead to severe degradation of the channels, it is therefore important to be able to differentiate between the wanted channel and the unwanted channel introduced by the propagation medium in order to stem channel degradation to acceptable levels.

This study investigates cross polarization discrimination (XPD) on Earth-space paths when linearly polarized radio waves in the frequency range 4-50GHz propagates through tropical widespread, shower and thunderstorm rain types. This study considers two elevation angles 23^0 and 55^0 widely used for satellite communication in Nigeria. Cross polarization discrimination is computed in terms of the differential propagation constant, the elevation angle, canting angle distribution of the non-spherical raindrops along the path and the polarization tilt angle. This approach is called the standard method in this study. However, when the CPA statistics along a propagation path is known experimentally or otherwise, XPD can be calculated for the link in terms of the CPA statistics using a scaling relation whose fitting parameters are known. These frequency and polarization dependent fitting parameters are calculated for the three rain types investigated in this study. Thus in this study, the above two approaches are employed to compute XPD. The results of the standard method of computing XPD are compared with the scaling method by finding the percentage difference between the two

M. O. Ajewole, Department of Physic, Federal University of Technology, Akure, Nigeria.
B. O. Afolayan, Department of Science Technology, Federal Polytechnic, Ado-Ekiti, Nigeria.

methods of estimating XPD.

Theoretical Formulation

Whenever a radio wave passes through a rain medium, the electric field vector $\overline{E}$ of the radio wave acquires a component whose polarization is orthogonal to that of the transmitted signal. As an example, if the incident electric field vector is linear and horizontally polarized ($\overline{E}_H$), after passing through the rain medium, a vertically polarized field vector ($\overline{E}_V$) will be detectable in addition to the wanted $\overline{E}_H$ component at the receiver. Thus, cross polarization discrimination is the ratio of the cross-polarized (unwanted) power to that of the co-polarized (unwanted) power and is expressed in decibels as

$$XPD = -20 \log_{10} \frac{\overline{E}_{cross}}{\overline{E}_{co}} \qquad (1)$$

$\overline{E}_{cross}$ is the cross-polarized electric field vector, while $\overline{E}_{co}$ is the copolarized electric field vector.

Oguchi (1977) proposed a method of calculating XPD based on the dependence of XPD on differential attenuation, differential phase shift and a distribution of canting angle for non-spherical raindrops on the propagation path. This is expressed as

$$XPD = \frac{20 \log e^{-jk_l l_s} \cos^2(\theta - \tau) + e^{-jk_l l_s} \sin^2(\theta - \tau)}{(e^{+jk_l l_s} - e^{-jk_l l_s})(\sin\theta - \tau) - \cos(\theta - \tau))} \qquad (2)$$

where k is the propagation constant of the medium, l_s is the slant path length through uniform rain, l_s is 1km for horizontal propagation, that is for elevation angle of $\theta = 0^0$, and τ the polarization tilt angle. τ is 0° for horizontal polarization and π/2 for vertical polarization. Olsen (1981) proposed an improvement to equation (2) by assuming that the propagation constants k_1 and k_2 associated with two characteristic polarizations propagated through a rain medium are almost equal. The improved approximate equation for XPD takes the form

$$XPD \cong -20 \log(l_s \cos^2 \theta |\Delta k| e^{-2\sigma^2} \sin|\phi - \tau| / 2) \qquad (3)$$

ϕ is the effective canting angle distribution of raindrops along the path and σ is their effective standard deviation while Δk is the differential propagation constant which is expressed as

$$\Delta k = (\Delta A^2 + \Delta \beta^2)^{\frac{1}{2}} \qquad (4)$$

ΔA is the differential attenuation measured in nepers while $\Delta \beta$ is the differential phase shift measured in radians per km. The values of ΔA and $\Delta \beta$ for the rain types at the frequencies investigated are available from Ajewole et al. (1999a). The path length l_s is expressed for elevation angles greater or equal to 5° (ITU-R, P. 618-8, 2003) as

$$l_s = \frac{h_R - h_S}{\sin \theta} \qquad (5)$$

h_R is the rain height at the location and this is 4.86 km in Nigeria and h_S is the height of the location above sea level. It is 0.4 km for Akure in South Western Nigeria. The satellite elevation angles considered are 23° and 55° for satellites seen in the western and eastern look directions in Nigeria. Ajewole et al., (1999b) employed equation (3) to compute XPD on terrestrial propagation path in Nigeria. They obtained results that show an improvement of 7 dB in XPD over those calculated using the constant canting angle method (Ajewole et al., 1999a).

Until now, XPD studies carried out in Nigeria have been limited to the terrestrial path (Ajayi, 1985, Ajayi et al., 1987, Ajose et al., 1995). In Nigeria and indeed on many tropical propagation paths, detailed prediction or measurement of XPD are not available particularly for application on Earth-space paths. Usually on propagation paths, a rough estimate of the unconditional distribution of XPD can be computed in terms of the co-polarized attenuation (CPA) using the equi-probability relation between XPD and CPA (ITU-R P. 618-8, 2003). Many authors (Nowland et al., 1977, Olsen and Nowland, 1977, Dissanayake et al., 1980 and Chu, 1982, Fukuchi et al., 1984, Bostian et al, 1986, van de Kamp, 2001) have earlier on examined the use of this equi-probability relationship of rain depolarization on temperate propagation paths. The result of their studies formed the basis of the ITU-R equi-probability relation. This equi-probability relation is expressed as

$$XPD = u - v \log CPA \qquad (6)$$

u and v are frequency and polarization dependent scaling parameters which are determined by regression analysis. The values of u and v are available for temperate propagation paths and for terrestrial path in Nigeria (Ajayi et al, 1987), but are unavailable for earth-space paths in Nigeria. Therefore, in this study these regression parameters are computed for earth-space propagation paths in Nigeria. XPD computed using equation (3) and the CPA on the path is used in the regression analysis to determine u and v for Nigeria. The CPA was computed from the power law relation expressed in terms of the rain rate R (mm/h) as

$$CPA = aR^b l_s \qquad (7)$$

Ajewole et al (1999a) have previously calculated the parameters 'a' and 'b', for widespread, shower and thunderstorm rain types. These values of 'a' and 'b' are used to compute CPA for the three rain types in the frequency range 4-50 GHz. Rain rates ranging between 0.25-50 mm/h are considered for widespread rain, 0.25-150 mm/h for shower rain and 0.25-180 mm/h for thunderstorm rain.

Using equation (3) as the standard, the percentage difference between the two estimates of XPD was calculated from

$$\%\ \text{Difference} = \frac{\text{XPD (standard)} - \text{XPD (scaling)}}{\text{XPD (standard)}} \qquad (8)$$

The computed percentage difference will be a useful parameter for judging the reliability or otherwise of applying the scaling relation to compute XPD.

RESULTS AND DISCUSSION

Figures 1 and 2 show examples of the frequency characteristics of XPD at some rain rates in the three rain types investigated for satellite elevation angles of 23° and 55°. These satellite look angles correspond to satellite positions in the western and eastern hemispheres, which are for International satellites (INTELSATs) located over the Atlantic and Indian Oceans as seen from Nigeria. Generally, on the slant path, XPD decreases with increasing frequency and rain rate and is worse for vertical polarization compared with the horizontal. However, XPD improves with increasing elevation angle as could be seen from Figure 2 when compared with Figure 1. This may be because at the elevation angle of 55°, the signal travels through a shorter path length of 5.45 km in the rain region compared to a path length of 11.41 km at the elevation angle of 23°. Thus at the lower elevation angle, the signal path length through rain is nearly twice as much as that at the higher elevation angle implying that the co-polarized attenuation of the wanted signal is more severe at the lower elevation. Figure 3 shows an example of the variation of co-polarized attenuation with frequency in thunderstorm rain of intensity of 150 mm/h and elevation angles of 23° and 55°

respectively. The orthogonal polarized signal introduced by the rain medium is stronger than the wanted signal such that cross polarization discrimination is poor at lower elevation angles to the satellite. Therefore, the problem of cross talk will be severe for communication using the Westerly satellites at lower elevation angle and frequencies higher than 10 GHz in Nigeria. Figure 2 further shows that while cross polarization is poor for vertically polarized signal propagation through widespread rain at frequencies higher than 20 GHz and elevation angle of 55^0, it is poorer for vertically polarized signal communication through convective shower and thunderstorm rain types even at low frequencies. Figure 2 shows that total signal outage may occur due to strong signal attenuation at frequencies higher than 10 GHz and poor cross polarization discrimination at lower elevation angles whatever the signal frequency and polarization.

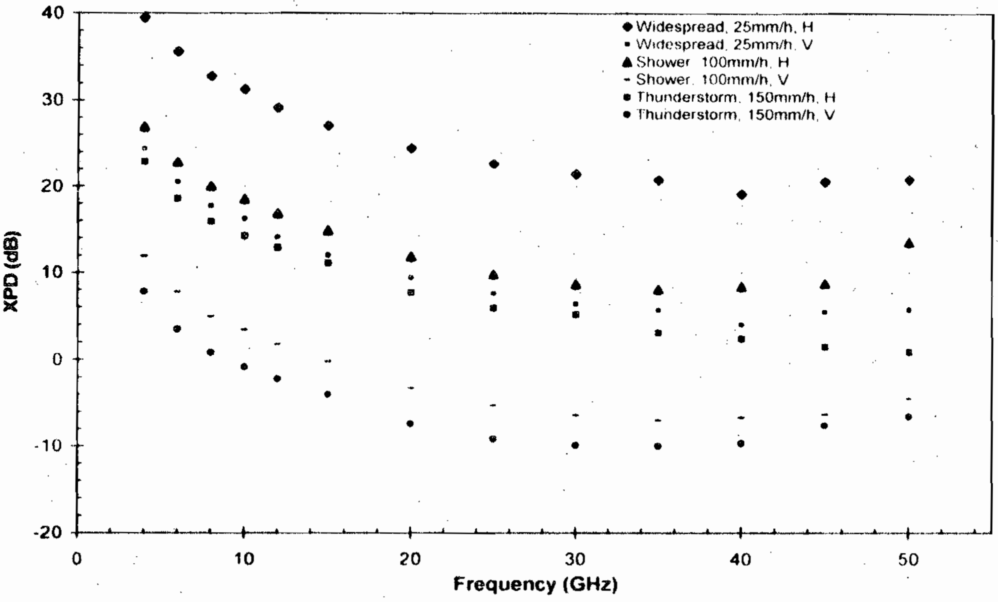

Figure 1: Frequency characteristics of XPD at some rainfall rates for elevation angle of 23 degrees. H and V refers to horizontal and vertical polarization

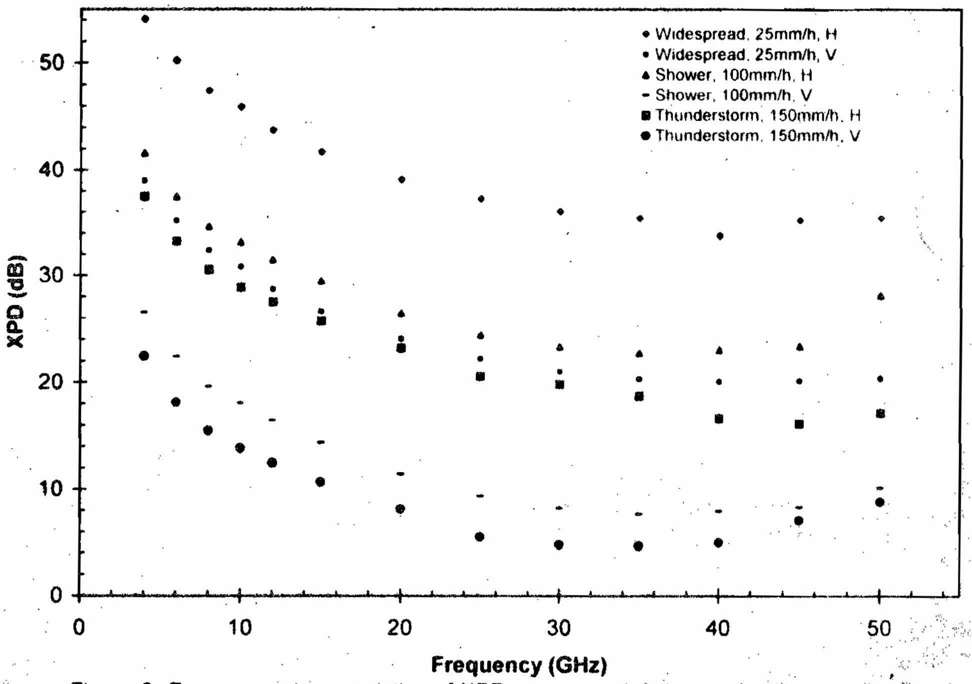

Figure 2: Frequency characteristics of XPD at some rainfall rates for elevation angle of 55 degrees. H and V refers to horizontal and vertical polarization

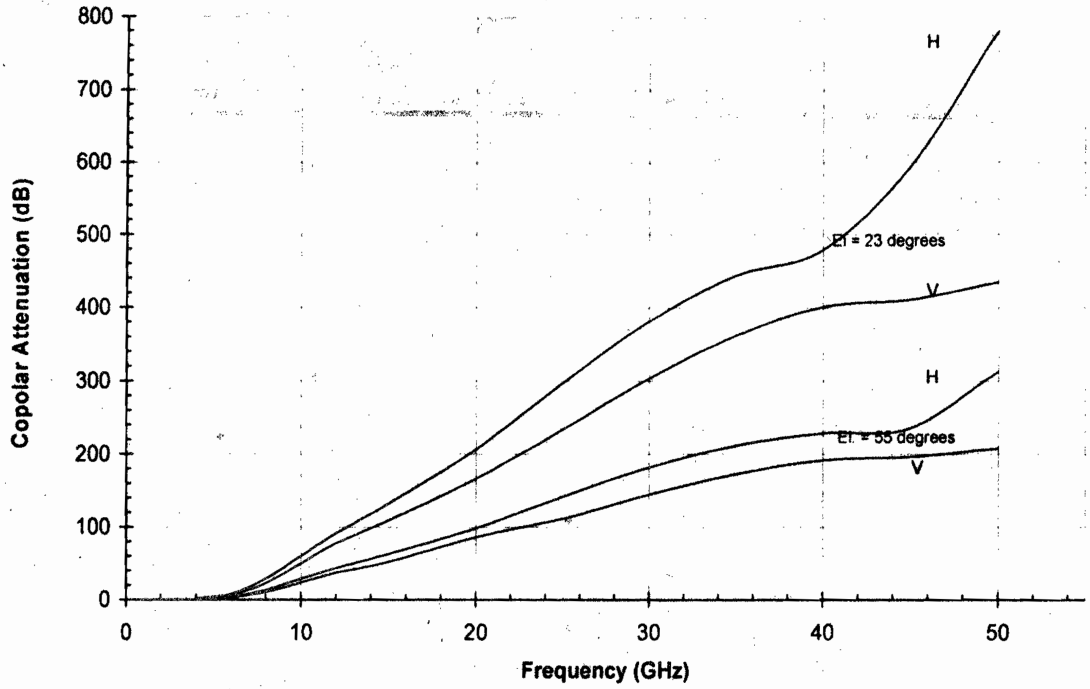

Figure 3: An example of the frequency characteristics of the copolar attenuation due to thunderstorm rain at elevation angles of 23 and 55 degrees and rain rate of 150 mm/h

The XPD computed using equation (3) was combined with the CPA computed using equation (7) to compute the regression parameters u and v of equation (6) for scaling XPD. The results of u and v parameters obtained for the rain types are shown in Tables 1-3 for elevation angles of 23^0 and 55^0 and for horizontal and vertical polarizations. The values of u and v for terrestrial application (0^0) are also included in Tables 1-3. The results show that for a given frequency, the horizontal component of v is constant irrespective of the elevation angle. For example, in widespread rainfall and at a frequency of 6 GHz, the horizontal component of v at 0^0 is equal to its value at 23^0 and at 55^0 and this is equal to 19.09. Similarly, the vertical component of v is constant at these elevation angles and is equal to 18.61. Therefore, in Tables 1-3, the second and third columns show the horizontal and vertical components of v, while the rest columns show the corresponding horizontal and vertical components of u. These values of u and v are used to calculate XPD and ultimately the percentage difference between XPD obtained from equation (3) – standard, and the scaling estimates of XPD from equation (6). The results of the percentage difference are summarised in Table 4 for the rain types. A marked difference is observed in the percentage difference between the XPD calculated using the two methods for frequencies lower than 30 GHz and for frequencies in the range of 30-50 GHz. For frequencies less or equal to 30 GHz, the maximum percentage difference for horizontal polarization is $\pm 3\%$, while it is $\pm 12\%$ for the vertical polarization. At frequencies higher than 30 GHz, the maximum percentage difference for horizontal polarization is $\pm 30\%$, while it is $\pm 21\%$ for the vertical polarization. The scaling expression is more accurate at low frequencies, while the standard method is more accurate at higher frequencies.

Table 1: Regression coefficients v and u for computing XPD due to widespread rain

Elevation	$0^0, 23^0, 55^0$		0^0		23^0		55^0	
Freq (GHz)	v_H	v_V	u_H	u_V	u_H	u_V	u_H	u_V
4	21.87	22.97	26.91	10.06	25.76	7.4	33.37	14.65
6	19.09	18.61	32.84	17.04	35.54	20.4	44.05	29.07
8	16.77	17.2	36.86	20.92	42.75	26.24	52.01	35.35
10	16.68	16.09	40.06	23.92	46.09	30.76	55.37	40.23
12	17.48	17.77	43.15	27.41	48.07	31.93	57.1	40.87
15	18.48	18.86	47.17	31.63	50.7	34.64	59.41	43.23
20	19.2	19.75	50.76	35.61	53.31	37.41	61.79	45.7
25	19.06	19.64	51.72	36.73	54.46	38.66	62.98	46.99
30	18.68	19.2	51.82	36.77	55.08	39.31	63.72	47.78
35	18.35	18.77	51.91	36.73	55.63	39.87	64.38	48.48
40	18.96	19.3	51.49	35.35	54.37	37.76	62.91	46.2
45	17.88	18.11	52.43	36.97	56.8	41.02	65.7	49.84
50	17.76	17.92	52.88	37.32	57.42	41.64	66.36	50.53

Table 2: Regression coefficients u and v for computing XPD due to shower rain

Elevation	$0^0, 23^0, 55^0$		0^0		23^0		55^0	
Freq (GHz)	v_H	v_V	u_H	u_V	u_H	u_V	u_H	u_V
4	20.82	21.12	25.7	8.92	26	8.81	33.95	16.66
6	19.89	20.12	33.6	16.48	35.2	18.12	43.45	26.3
8	18.87	19.08	38.83	22.43	41.84	25.14	50.42	33.65
10	18.31	18.42	42.07	25.89	46.26	29.91	54.98	38.6
12	18.37	18.42	44.77	28.6	48.46	32.22	57.2	40.95
15	19.16	19.22	48.74	32.62	51.34	35.14	59.83	43.61
20	20.32	20.58	53.68	37.86	54.67	38.49	62.78	46.52
25	20.25	20.63	54.97	39.37	56.06	39.94	64.19	47.95
30	19.63	19.98	54.38	38.78	56.33	40.25	64.67	48.47
35	19.05	19.33	53.58	37.91	56.34	40.28	64.86	48.72
40	18.41	18.58	52.57	36.77	56.21	40.17	64.94	48.85
45	17.97	18.07	51.91	36.05	56.15	40.15	65.022	48.99
50	19.52	18.44	54.06	29.52	56.08	42.83	64.09	48.93

Table 3: Regression coefficients u and v for computing XPD due to thunderstorm rain

Elevation	$0^0, 23^0, 55^0$		0^0		23^0		55^0	
Freq (GHz)	v_H	v_V	u_H	u_V	u_H	u_V	u_H	u_V
4	20.32	20.53	25.6	8.55	26.63	9.31	34.75	17.36
6	19.67	19.86	34.64	17.57	36.51	19.19	44.83	27.45
8	18.75	18.92	40.18	23.6	43.21	26.42	51.83	34.99
10	18.41	18.47	43.52	27.12	46.99	30.52	55.71	39.23
12	18.64	18.66	46.2	29.87	49.38	33.02	58.03	41.67
15	19.26	19.33	49.52	33.08	51.9	35.38	60.35	43.81
20	20.38	20.68	53.83	37.86	54.79	38.44	55.34	32.03
25	20.22	20.57	54.81	38.94	55.97	39.65	64.12	47.68
30	19.82	20.11	54.89	38.97	56.56	40.26	64.84	48.44
35	19.41	19.61	54.71	38.68	56.9	40.62	65.31	48.97
40	19.19	19.31	54.89	38.81	57.36	41.13	65.84	49.57
45	20.24	20.44	55.66	39.75	56.79	40.64	64.93	48.71
50	22.49	24.77	59.68	47.81	57.94	43.16	65.35	49.85

Table 4: Summary of Percentage difference in estimating XPD using the standard and scaling methods

Rain Type	Widespread				Shower				Thunderstorm			
Elevation Angle	23^0		55^0		23^0		55^0		23^0		55^0	
Polarization	H	V	H	V	H	V	H	V	H	V	H	V
$f \le 30$ GHz	±3%	±11%	±2%	±4%	±3%	±10%	±3%	±12%	±3%	±9%	±0%	±4%
$30 \le f \le 50$ GHz	±10 %	±17%	±5%	±11 %	±30 %	±21%	±8%	±14%	±15%	±12%	±8%	±17%

CONCLUSION

This study has presented an investigation of cross polarization discrimination on Earth-space propagation paths for two elevation angles in Nigeria. A standard and an equi-probable relation has been used to compute cross polarization discrimination at frequencies ranging from 4-50 GHz. General XPD results for vertically polarized signal is poorer than the XPD for horizontally polarized signals on the paths. Our results also show that XPD decreases rapidly with decreasing elevation angle to the satellite because of the larger attenuation due to the longer distance the signal travels at low elevation angles. A significant result of this study is the computation of the parameters u and v of the scaling relation between XPD and CPA. Some results are presented for elevation angles of 0^0, 23^0, and 55^0. Comparison of the results of the two methods of computing XPD show that the scaling method gives very good results for frequencies in the range 4-30 GHz, while the standard method is better at higher frequencies.

REFERENCES

Ajayi, G. O., 1985. Characteristics of rain induced attenuation and phase shift at centimetre and millimetre wavelengths using a tropical raindrop size distribution model, Int. J. Infrared and Millimeter Waves, 6: 771-806.

Ajayi, G. O., Owolabi, I. E., and Adimula, I. A., 1987. Rain induced depolarization from 1 GHz to 300 GHz in a tropical environment, Int. J. Infrared Millimeter Waves, 8(2): 177-197.

Ajose, S. O., Sadiku, M. N. O., and Goni, U., 1995. Computation of attenuation, phase rotation, and cross polarization of radio waves due to rainfall in tropical regions, IEEE Trans. on Antennas and Propagat., 43: 1-5.

Ajewole, M. O, Kolawole, L. B and Ajayi, G.O., 1999a. Theoretical study of the effect of different types of tropical rainfall on microwave and millimetre-wave propagation. Radio Sci., 34(5): 1103-1124.

Ajewole, M. O, Kolawole, L. B and Ajayi, G.O., 1999b. Cross polarization on line-of-sight links in a tropical location: effects of variation in canting angle and rain dropsize distributions, IEEE Trans. Antennas and Propag., 47(8): 154-1259.

Bostian, C. W., Pratt, T. and Stutzman, W. L., 1986. Results of three-year 11.6 GHz low-angle propagation experiment using the SIRIO satellite, IEEE Trans. on Antenna and Propagat., AP-30(4): 720-725.

Castanet, L., Bolea-Alamanac, A., and Bousquet, M., 2003. Interference and fade mitigation techniques for Ka and Q-V band satellite communication systems, Proc. Second International Workshop of Action 280 joint with COST 272, ESTEC, Hoodwink, Holland, 26-28 May, PM5-002.

Chu, T. S., 1982. A semi-empirical formula for microwave depolarization versus rain attenuation on earth-space paths, IEEE Trans. On Commun., COM-30, 2550-2554.

Dissanayake, A.W., Haworth, D.P. and Watson, P.A., 1980. Analytical models for cross polarization on Earth- - Space radio paths for frequency range 9 – 30GHz, Annales des Telecomm., 35(16): 398 – 404.

Fukuchi, H., Awaka, J., and Oguchi, T., 1984. Improved theoretical formula for the relationship between rain attenuation and depolarization, Electron. Letts, 20(21): 859-860.

International Telecommunication Union-Radiocommunication, ITU-R P. 618-8, 2003. Propagation data and prediction methods required for the design of Earth-space telecommunication systems.

Nowland, W. L., Olsen, R. L. and Sharkofsky, I.P., 1977. Theoretical relationship between rain depolarisation and attenuation. Electronic Letters, 13: 676 – 678.

Oguchi T., 1977. Scattering properties of oblate raindrops and cross polarization of radio waves due to rain. Calculation at 19.3 and 34.8GHz. Radio Res. Lab. Japan, 20(102): 79-118.

Olsen, R.L., 1981. Cross Polarization during precipitation on Terrestrial Links: A review. Radio Sci., 16(5): 761-779

Olsen R.L. and Nowland L., 1977. Theoretical relationship between rain depolarization and attenuation. Electronic letters 13(22): 676-678

Van de Kamp M. M. J. L., 2001. Depolarization due to rain: International J. Satell. Comms., 19(3): 285-301