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Computational Analysis of Cross Polarization on KU-Band Satellite Links over Jos, Nigeria

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Abstract

This paper presents the computational analysis of cross polarization on KU-Band satellite links. The depolarization effects on satellite links are described in terms of cross polar discrimination (XDP). The differential phase shifts mainly responsible for causing depolarization at Ku-band due to scattering by spheroidal raindrops wascomputed. Simultaneous analyses of sample data from Ku-band, EUTELSALAT (W4/W7) satellite beacon footprint at a frequency of 12.245 GHz and elevation angle of 036^0 E over Jos (9.8965^0 N, 8.8583^0 E, 1192M) were analyzed. Also the distribution of one minute rain rate obtained from Davis Vantage Vue Integrated Sensors Suites (ISS) weather station was computed. These data were applied to the ITU-R procedure in recommendation 618-12(ITU-R, 2015) to estimate the cross polarization discrimination due to rain on earth satellite path. The results shows that XPD at lowervalue imply very high incidences and cross talks are expected in the region. As such frequency re-use is difficult in Jos, Nigeria.

Keywords: Ku- band frequency, Cross polarization discrimination (XPD).
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Introduction

Satellite communication is normally thought of as a robust means of communication, not sensitive to environmental impacts. However, this perception is not completely accurate. Satellite communication can be and is affected by the environment in which it operates. Space environmental effects on satellite communication are divided into; effects on the space element (the satellite), effect on the ground element (the earth station) and effect on the signal propagating through the earth's lower and upper atmosphere. Also the propagating signal can be affected by its passage into the ionosphere (upper atmosphere) or the troposphere (lower atmosphere). These effects depend significantly on frequency (Ayantunji*et al.*,2013).Radio waves propagating through ionosphere experience different attenuation mechanisms such as absorption, reflection, refraction, scattering, polarization, group delay and fading / scintillation. In the region other than ionosphere, the troposphere, stratosphere etc, the radio wave loses its energy mainly due to absorption, cloud and rain attenuation due to snow, hail and fog. Rain is considered to be the major cause of attenuation at frequencies above 10GHz (Muhammed *et al.,* 2011). Rain attenuation is one of the most significant limitations of satellite communication link above $10GH_Z$. The amount of rain attenuation depends on rain rate, signal frequency, size, shape and the relative orientation of the rain drops (Dissanayake *et al.,* 1997). Size of the rain cell shows a strong seasonal variation which influences the rain attenuation pattern with consideration to elevation angle, season and region (Ramachandran and Kumar, 2006).

Depolarization of satellite signal results from anisotrophy of the propagation medium which can be caused by the oblateness of the raindrops and the melting layer along the earth space propagation path (Karasawa and Maekawa, 1997). According to Barclay (2003), depolarization is due to the non-spherical symmetry of the raindrops (the top and bottom are flattened), along with their tendency to have a preferred orientation. Depolarization results in cross talk between two orthogonal polarized channels, transmitted on the same path and frequency band. The depolarization effect is described in terms of cross polar discrimination. Experimental results have shown the existence of a relationship between attenuation and depolarization especially when rain depolarization is dormant, which plays major role in determining satellite signal depolarization. This has been monitored and investigated by Animesh and Arpita (2011), who reported that the differential phase due to forward scattering of raindrops is mostly responsible for the depolarization of Ku- band signal over an earth –space path. The differential phase shift at Ku- band is significant for large raindrops and hence depends on rain drop size distribution. Oguchi and Hosoya (1994) estimated the cross polarization due to different rainfall rates. Similarly, Ajewole *et al.* (1999) computed cross polarization discrimination (XPD) due to rain for four tropical types of rain by adopting the method earlier proposed by Oguchi (1994), the effects of varying the canting angle of the raindrops was also investigated by Ajewole ,*et al.* (1999) using different types of rain and rain drop sizes on cross polarization discrimination and established that cross polarization discrimination (XPD) improves by about 4-7 dB over those models having equal orientation.

Karasawa and Maekawa (1997) reported that Signal depolarization causes hindrance to the frequency re-use system that uses two orthogonal channels for radio communication. The performance of the dual polarized system in these higher frequency band of $10GH_Z$and above is affected by depolarization during precipitation and other meteorological event. Therefore, the aim of this paper is to estimate the cross polarization of millimeter wave in the Ku-band frequency of $12,245GH_Z$caused by rainfall over Jos, Nigeria. The ITU-R P.618-12 (ITU-R, 2015) recommendation for propagation data and prediction methods required for the design of earth space telecommunication systems is adopted for the purpose of computation. An attempt is made to determine the variation of the XPD with exceeded distribution frequency of percentage time, rain rate, and rain attenuation.

Materials and Methods

The measurement was taken at the Department of Physics Laboratory, University of Jos, Nigeria (9.8965^0 N, 8.8583^0 E; 1192 meters) with Maximum, Average and Minimum Temperatures of 29.8^0C, 22.8^0C and 17^0C respectively. 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 measurement of precipitation was done using the Davis Vantage Vue weather station, which logs rain rate and other meteorological parameters at one-minute integration time. The Davis weather station has an Integrated Sensor Suite (ISS), which is co-located with the outdoor unit of the beacon setup, that is, the offset parabolic antenna. Figure 1 presents the experimental set up used to concurrently measure and record rain-rate, signal loss, at Jos location. The rainfall rates were used to estimate signal loss on line of sight in Jos. Instruments used to carry out this experiment include the following:

Parabolic reflector antenna, Compass, Radio frequency power meter, Coaxial cable port connector, connecting cable (coaxial cable), Rain gauge (Davis weather station), (Durodola,2016).

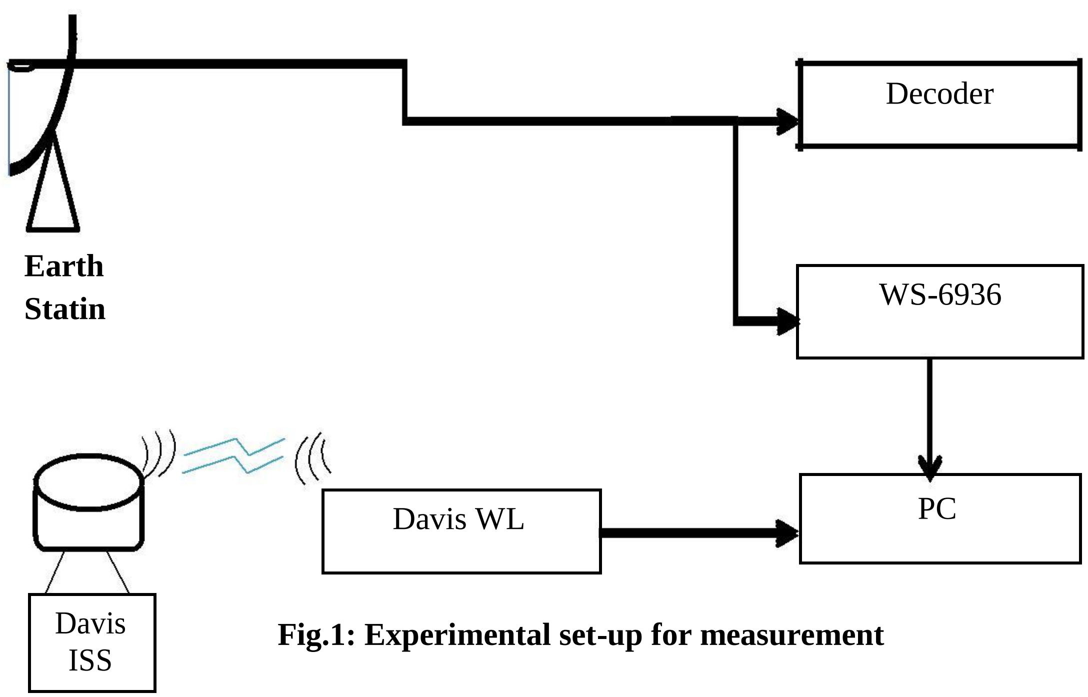

Fig.1: Experimental set-up for measurement

Plate 1: Davis Weather Station

Plate 2: Spectrum Analyzer (WS6936)

XPD Calculation Procedures (ITU-R, 2015)

Calculation of depolarization from rain attenuation statistics requires the following parameters:

A_p :rain attenuation (dB) exceeded for the required percentage of time, *p*, for the path in question, commonly called co-polar attenuation (CPA)

τ: tilt angle of the linearly polarized electric field vector with respect to the horizontal (for circular polarization use τ= 45°)

f: frequency (GHz)

θ :path elevation angle (degrees).

Step 1: Calculate the frequency-dependent term:

$C_f = 30 \log f$ for $8 \leq f \leq 35$ GHz (1)

For this work, frequency of 12,245GHz was used

Step 2: Calculate the rain attenuation dependent term:

$C_A = V(f) \log A_p$

where: $V(f) = 12.8 f^{0.19}$ for $8 \leq f \leq 20$ GHz

$V(f) = 22.6$ for $20 \leq f \leq 35$ GHz

Step 3: Calculate the polarization improvement factor:

$C\tau = -10 \log [1 - 0.484 (1 + \cos 4\tau)]$

The improvement factor $C\tau = 0$ for $\tau = 45°$ and reaches a maximum value of 15 dB for $\tau = 0°$ or 90°. In this work, $\tau = 0°$ was used.

Step 4: Calculate the elevation angle-dependent term:

$C\theta = -40 \log(\cos\theta)$ for $\theta \leq 60°$

For this work, $\theta = 37.3^0$

Step 5: Calculate the canting angle dependent term:

$C\sigma = 0.0052\,\sigma^2$

σ is the effective standard deviation of the raindrop canting angle distribution, expressed in degrees; σ takes the value 0°, 5°, 10° and 15° for 1%, 0.1%, 0.01% and 0.001% of the time, respectively. In this work, 10^0 was used. (4)

Step 6: Calculate rain XPD not exceeded for *p*% of the time:

$$XPD_{rain} = C_f - C_A + C\tau + C\theta + C\sigma \quad \text{dB} \qquad (5)$$

Results and Discussion

Figure 2 presents the cumulative distribution of one- minute rain rate over Jos (August 23rd – September 11th, 2017). It can clearly be seen that at higher rain rate is between 0.01 and 0.001% and it is during such times that maximum attenuation due to rainfall can be best estimated. Figure 3 Shows that lower value of XPD implies an increased interference (cross-talk) at the receiver station of the satellite. Figure 4, shows the variation of XPD with rain rate at 12,245GHZ. A relation was observed between the XPD and rain rate. As rain rate increases, XPD increases. Figure 5 shows the variation of the XPD and rain attenuation exceeded for the required period of time, often called the co-polar attenuation over the elevation angle at 12,245GHZ. The cross polarization discrimination degrades with increasing co-polar attenuation. This clearly shows that signal degradation as a result of XPD is more enhanced by CPA for given fade than due to XPD as the frequency decreases. Therefore differential phase shift appears to be the dominant factor in rain induced depolarization at frequency above 10GHZ and differential attenuation becomes increasingly significant at higher frequencies. These results were in agreement with observations reported by Animesh and Arpita (2011), that the differential phase due to forward scattering of raindrops is mostly responsible for the depolarization of Ku-band signal over an earth –space path. Also, Karasawa and Maekawa (1997) reported that Signal depolarization causes hindrance to the frequency re-use system that uses two orthogonal channels for radio communication.

Table 1: Exceeded Distribution Frequency of Percentage time at Various Rain Rate, Rain Attenuation and XPD

Exceeded Distribution Frequency of Percentage Time (%)	Rain Rate (mm/hr)	Rain Attenuation (dB)	Cross Polarization Discrimination (XPD_{rain}) Db
2.5292	1	217.391	-114.196
1.9993	2	209.583	-106.388
1.4328	5	198.484	-95.289
0.8516	10	181.184	-77.989
0.6177	15	170.544	-67.349
0.508	20	164.038	-60.843
0.3618	30	152.786	-49.591
0.2449	40	139.773	-36.578
0.1974	60	132.578	-29.383
0.1023	80	110.762	-7.597
0.0256	100	64.681	68.412
0.0037	120	0	103.195

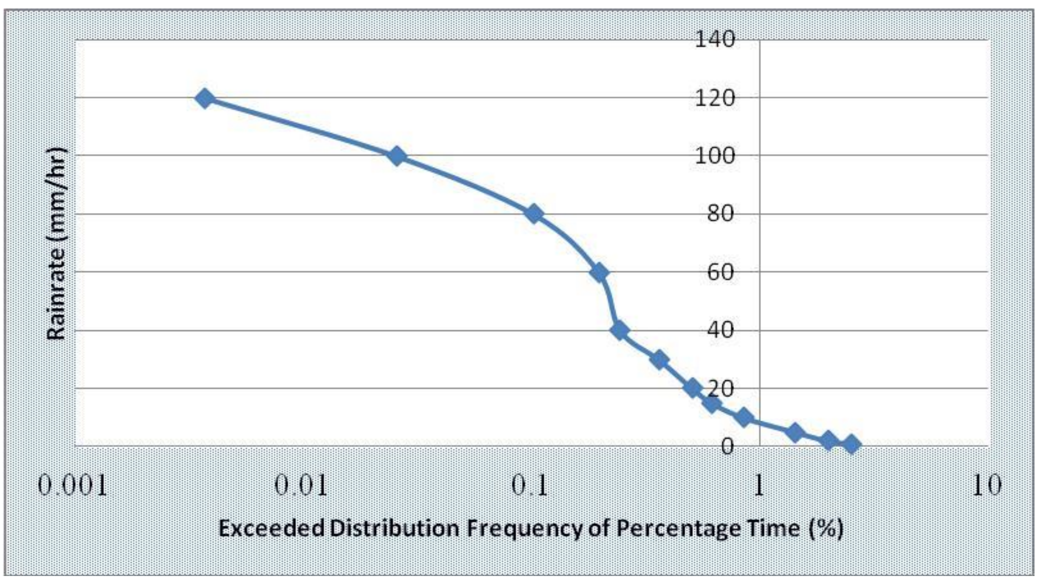

Figure 2. Variation of rain rate with exceeded distribution frequency of percentage time

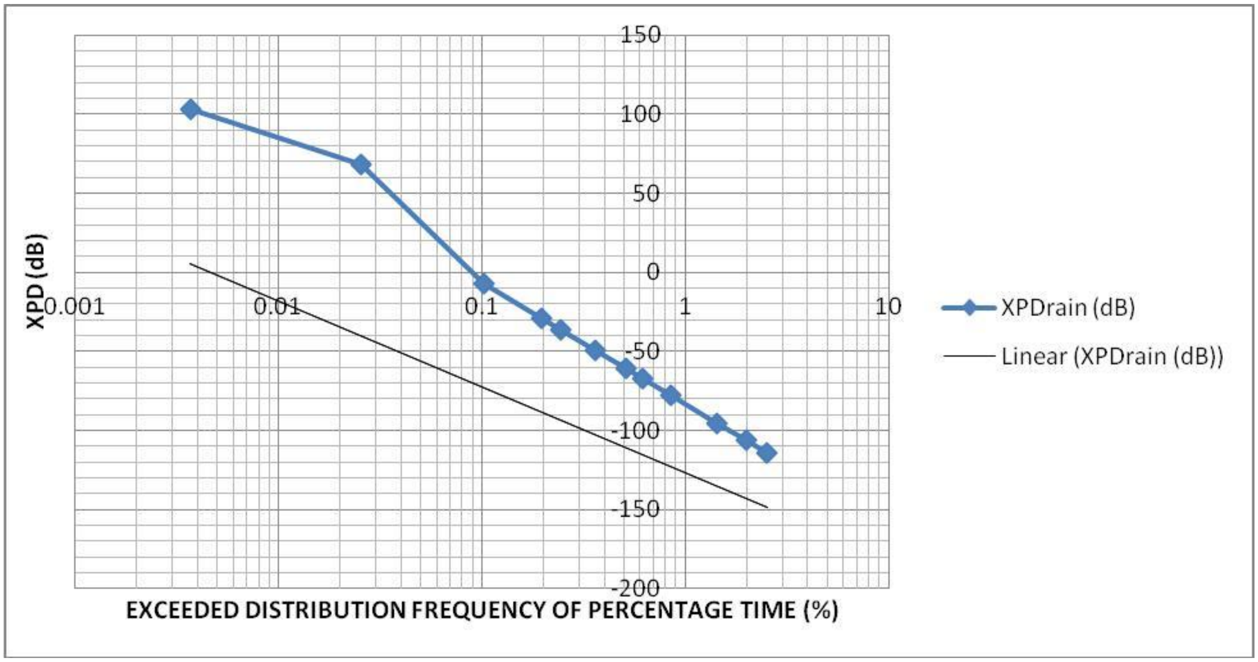

Figure 3. Cross Polarization Discrimination (XPD) variation with exceeded distribution frequency of percentage time

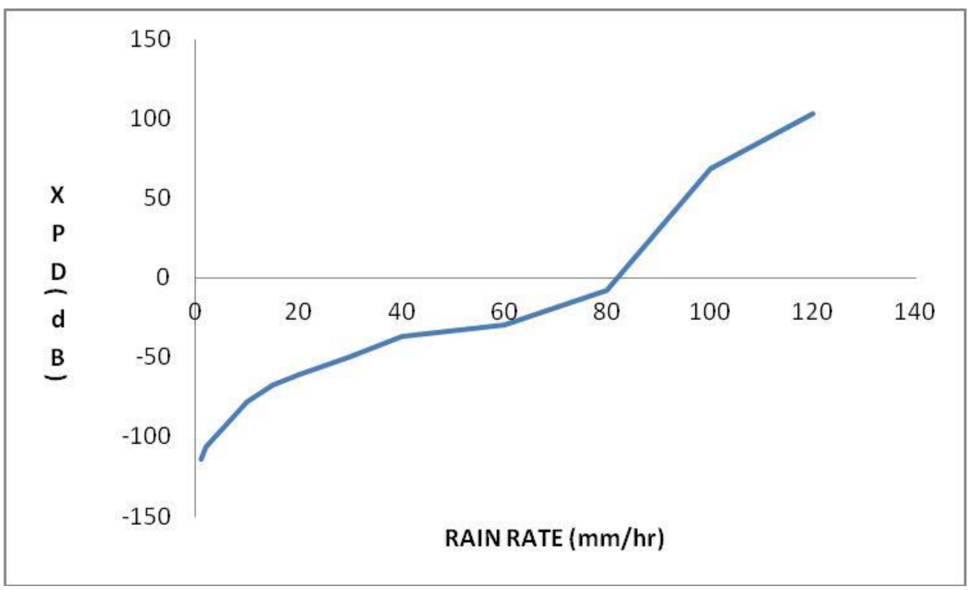

Figure 4.Cross polarization discrimination (XPD) variation against Rain rate.

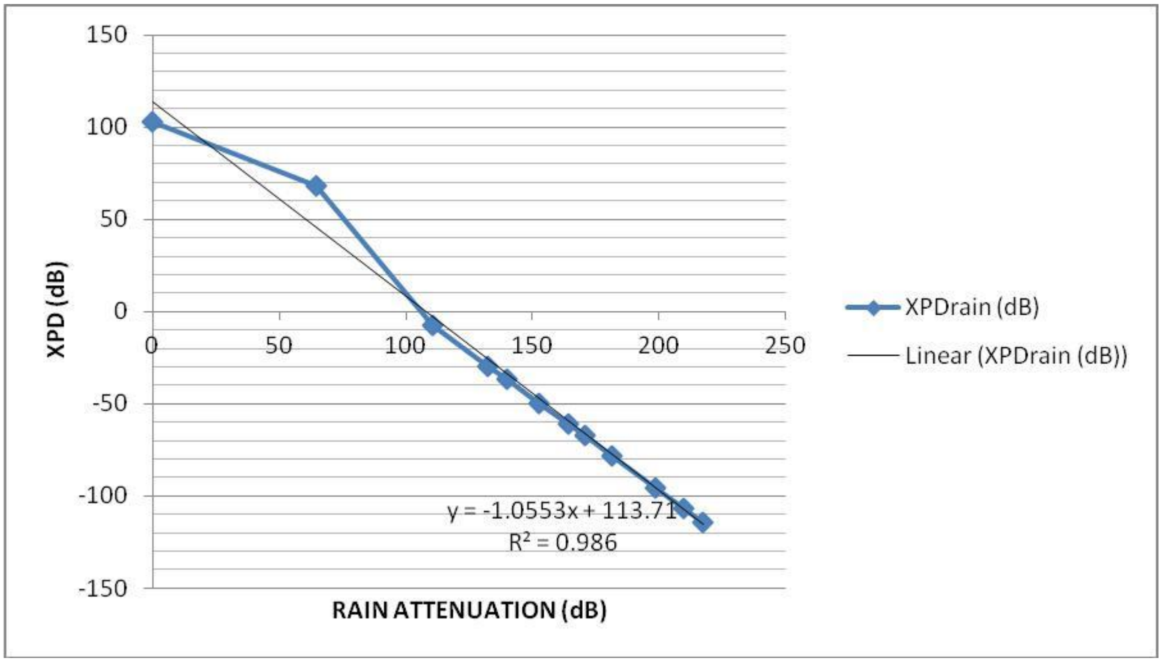

Figure 5: Show Cross Polarization Discrimination (XPD) with Rain Attenuation (C_A)Relation in Jos.

Conclusion

This paper presented some estimates of cross polarization discrimination due to rain on the earth satellite path using the ITU-R procedures in recommendation 618-12 (ITU-R, 2015). Theresults show that cross polarization discrimination degrades with increasing attenuation as shown in table 1. XPD lower value shows very high incidence and cross talk are expected in the region. Therefore, frequency re-use is difficult in the region in view. The result obtained in this paper will significantly be useful in the design of terrestrial and earth-to-satellite link in the region, which will help in determining the optimum transmitting power in which rain attenuation will have the least effect. However, degradation of XPD with respect to clear air value can be estimated with experimental arrangement that monitors the co-polar and cross- polar component of a plane polarized signal.

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