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Effect of Rain Depolarization on Circularly Polarized Millimeter Waves Propagation in Selected Stations in Nigeria

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Abstract-The effects of rain-induced depolarization on circularly polarized millimeter wave propagation on the earth–space path was investigated in this work. Cross Polarization Discrimination (XPD) and Co-Polar Attenuation (CPA) are evaluated for frequencies between 30-50GHz at three locations, namely Ikeja (South West), Akure (South West) and Ilorin (Middle Belt) in Nigeria. Ilorin with the lowest amount of attenuation experiences the least cross talk when compared with the other stations, while Ikeja located in Coastal area has the highest signal depolarization. XPDs were evaluated using ITU-R depolarization model and the Fukuchi model. The ITU-R predictions values are higher than the Fukuchi model. Between 30-50GHz the ITU-R and Fukuchi models reached minimum values of 5.3dB and 4.4dB in Ikeja, 6.8dB and 5.7dB in Akure, 6.9dB and 5.8dB in Ilorin respectively. The results of the ITU-R model peaked at 40GHz in the three stations beyond which there was a continuous decrease in XPD while the results of the Fukuchi model continued to increase with frequency until 36GHz in all the three stations. It is observed from the results that the Fukuchi Model characterizes the relationship between Co-Polar Attenuation and Cross Polarization Discrimination better than the ITU-R model in the selected stations. This may be attributed to the dependence of tilt and elevation term of the Fukuchi et al model on the effective path length through rain across the location.

Keywords; Cross Polarization, Earth–space path, mm Waves, Rain Attenuation, XPD.

1 Introduction

There is an increase in bandwidth demand due to the rapid growth in satellite services pushing up the frequency for satellite communication and leading to more complex systems involving freqency reuse scheme with cross-polarized channels. The actual performance of a millimeter wave link depends on various factors: the distance between radio nodes, the link margin of the radios, and the diversity of redundant paths. (Adhikari 2008) The adverse effects of rain impairment increases with frequency and varies with regional locations. It is therefore important to make an accurate rain attenuation prediction on propagation path when planning system links both in terrestrial and microwave line of sight. (Ojo, Ajewole and Sarkar 2008).

In radio-communications systems depolarization of a signal is a crucial topic. For example, depolarization due to raindrops may increase the cross-polarization in satellite communication links. This leads to an increasing interference between two orthogonal channels as a result of multiple scattering effects in a propagation medium arising from random discrete scatterers (Talhi, et al. 2002). The principal limitation of the millimeter-wave link availability is precipitation(rain-fall) while the hardware designer cannot account for rain effect or the link;the major duty of network planner is to incorporate a sufficient margin into the link design (Owolawi, Afullo and Malinga 2009). It has been revealed by several studies that cross polarization takes place because of differential attenuation and differential phase shift between two orthogonal polarizations. These two factors are due to the changing in raindrop shape from spherical to oblate during its fall (J. S. Ojo 2012).

The depolarization of signal prevents the frequency re-use in system that uses two orthogonal channels for radio communication. The separation between the two communication channels with orthogonal polarization is indicated by the cross polarization discrimination (XPD) (Omotosho and Oluwafemi 2009). In this paper, the cross polarization discrimination (XPD) for three stations (Ikeja, Akure, Ilorin) in Nigeria were evaluated using two models (Fukuchi and ITU-R models). The results of both models are compared to know which one better characterizes cross polarization discrimination of millimeter waves due to rain fall in those stations. This is to contribute to the available empirical data for link budget planning for millimeter waves propagation in Nigeria.

2 Methodology

2.1 Rain Rate

Monthly rain accumulations for 2011 and 2012 were used for the Ikeja and Ilorin respectively; while those of June 2010-September 2011 were used for Akure.

The rain rate at 0.01% was calculated using the Chebil-Rahman model as

$$R_{0.01} = \alpha M^{\beta} \qquad (1.1)$$

where M is the total rain fall in mm measured for a year and rain rate($R_{0.01}$) is measured in mm/h, α and β are regression coefficients defined as; α = 12.2903; and β = 0.2973. `

The rain rate for the selected stations was calculated for 0.01% of time (of a year) and the ITU-R P618-10 model (ITU 2009) was used to calculate the amount of attenuation experienced by the signal at these stations at different frequencies (30-50) GHz. The rain attenuation at 0.01% of time ($A_{0.01}$) also called co-polar attenuation was used for the calculation of XPDrain at 0.01%.

2.2 Rain Depolarization

Rain induced depolarization on a link is quantified by the cross polarization experienced by the signal. Depolarization can be predicted by direct measurement or the use of prediction models. While there are different prediction models, they all have the form of

$$XPD = U - V \log A \qquad (1.2)$$

Where U is the sum of the frequency, tilt, elevation angle and canting angle dependent terms of the models

V is a frequency dependent constant.

A is the Co polar Attenuation

Depolarization is most evident for fixed linear polarization with tilt angles of +/- 45^0 and for circular polarization. Rain dominates cross polarization discrimination (XPD) statistics for percentage lower than 0.1% of time for circular polarization.

The ITU-R depolarization model (ITU 2009) and the Fukuchi model are (Fukuchi 2008) based on the XPD empirical relationship in equation 1.2 differing only in the functions used to represent U and V depending on site and system parameters.

Since the models are based on the relationship between attenuation and XPD, the attenuation along the path is needed to calculate the XPD.

3 Discussion

Figures 1.1a-c shows the variation of XPD with frequency at, 0.01%, 0.1% and 1% of time. The variation of XPD with frequency shows that as the frequency increases there is a decrease in XPD initially for the ITU-R model between 30-36GHz whereas beyond 36GHz it increases and then decreases again after 40GHz with increase in frequency for the three stations. While for the Fukuchi model, XPD decreases with increase in frequency for all the three locations for frequency ranges considered.

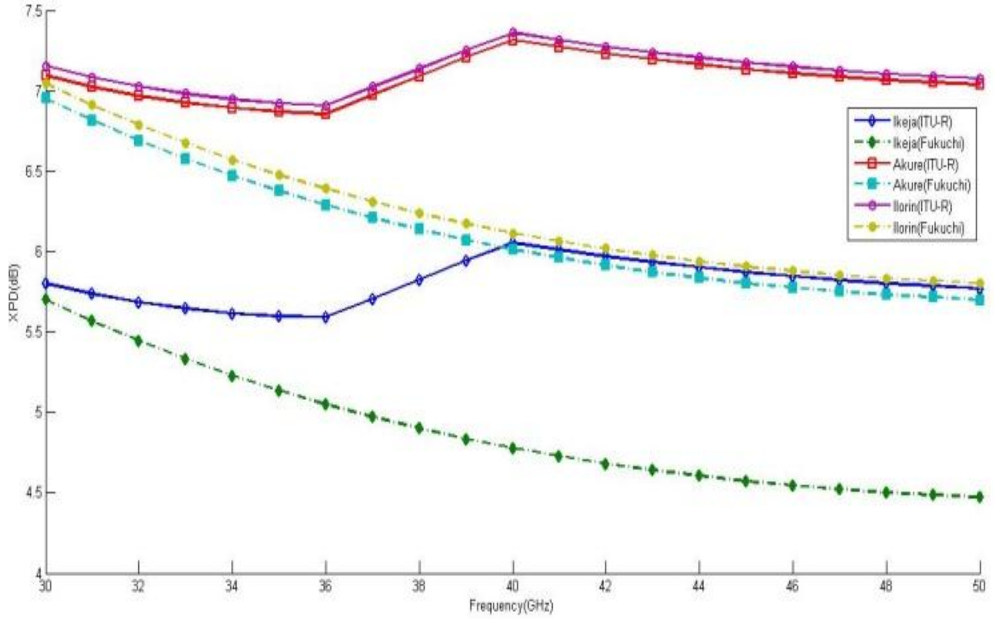

Fig.1.1a:Variation of XPD with Frequency at 0.01% of time

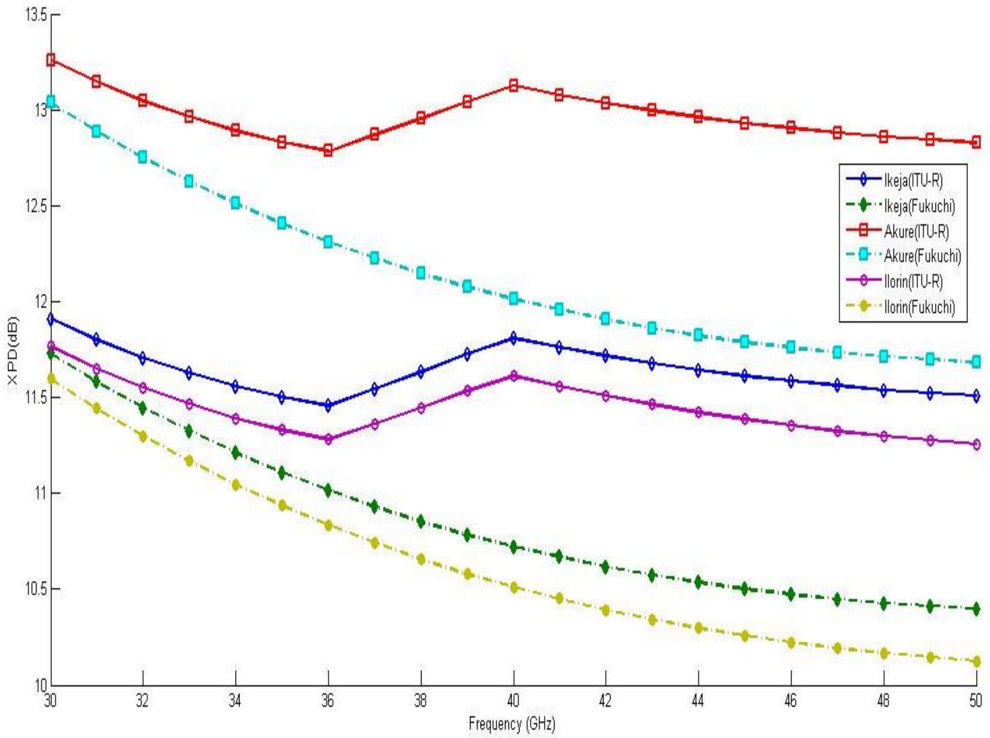

Fig.1.1b:Variation of XPD with Frequency at 0.1% of time

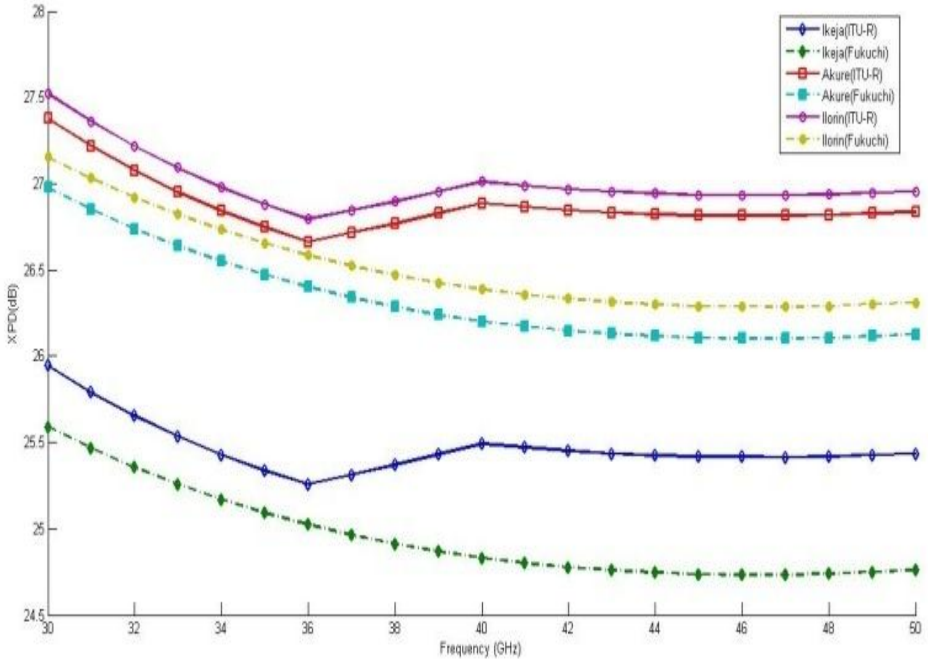

Fig.1.1c:Variation of XPD with Frequency at 1% of time

Generally, XPD decreases with increasing frequency, however for the three stations, the XPD predicted by the ITU-R model decreases to a minimum of 5.5dB in Ikeja,6.8dB in Akure and 6.9dB in Ilorin between the frequency band 30-36GHz and a maximum of 6.1dB,7.3dB and 7.4dB respectively between the frequency band 37-40GHz. The XPDs predicted for all frequencies by Fukuchi et al model is lower for all locations than the XPD predicted using the ITU-R model at all corresponding frequencies. The higher the percentage of time, the higher the XPD values with the two models. There is decrease in XPD with increase in frequency also at 0.1% and 1% of time for the Fukuchi model while the ITU-R model follows the same trend as the 0.01% of time (. i.e. increasing between 36-40GHz before continuing its descent as frequency increases).

Figures 1.2a-c show the variation of XPD with Co-polar attenuation(CPA) at 30,40 and 50GHz at different percentages of time. These figures show that as CPA increases XPD decreases. At high rainfall rates and frequencies there is a high level of attenuation of signal as there is more absorption, hence an increased level of cross talk (increased interference at the satellite receiver between two orthogonal signal) (Sen, Geetha and Uma 2007), (J. S. Ojo 2012), (Mandeep 2008).

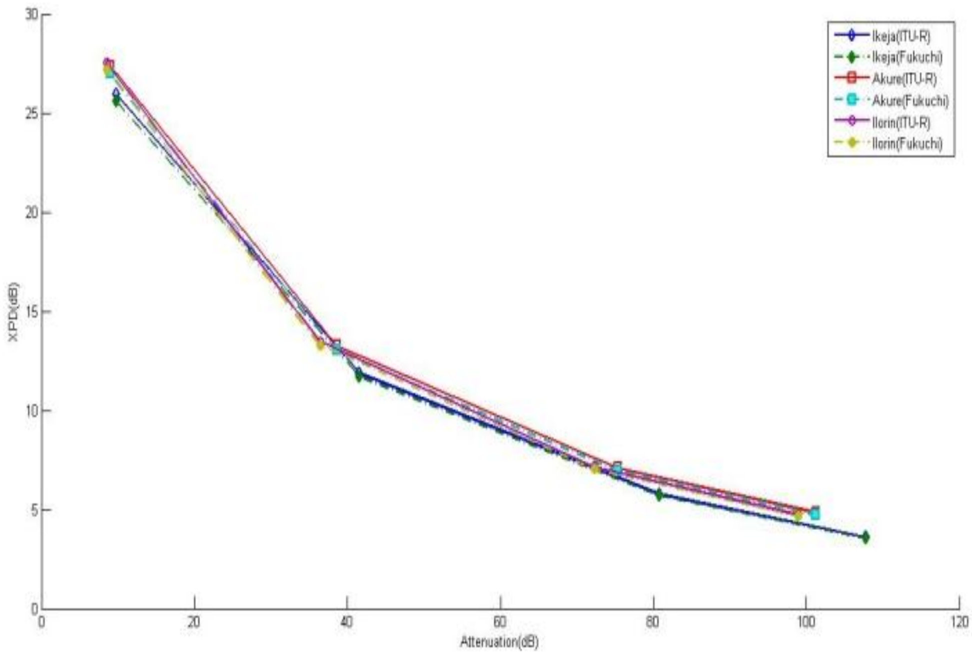

Fig.1.2a: Variation of XPD with Attenuation at 30GHz

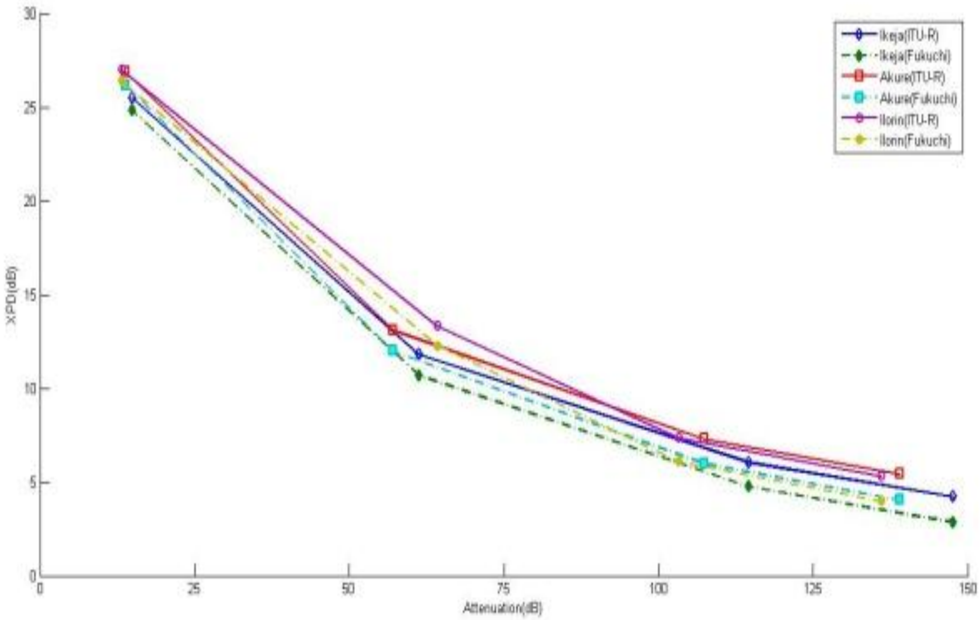

Fig. 1.2b: Variation of XPD with Attenuation at 40GHz

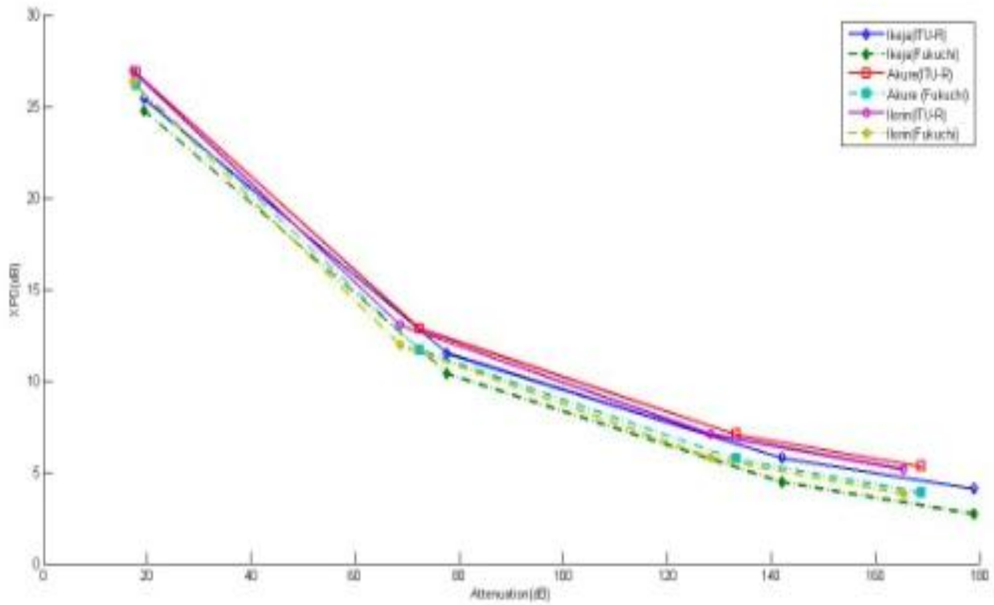

Fig. 1.2c: Variation of XPD with Attenaution at 50GHz

As CPA increases XPD decreases as shown in figures 1.2a-c for all frequency band considered for both the ITU-R and Fukuchi et al models for the three stations. This corresponds to increase in frequency since at high frequency there is higher absorption of signals, which would result in increased interference between two orthogonal signals. This is consistent with the findings of (Sen, Geetha and Uma 2007) whose study stopped at 35GHz. An exception to this is between 36GHz and 40GHz where there was an increase in XPD with increase in CPA in the ITU-R model, while for the Fukuchi model XPD decreased with increase in CPA for all frequency band at the three Locations. At all the locations, there is a significant change in XPD with attenuation as the frequency changes. Ikeja has the lowest values of XPD for both models, which is due to the higher rainfall rate and as a result recorded higher attenuation since signal absorption is more due to its location in Coastal region. Ilorin has the highest values of XPD for both models due to a lower rainfall rate when compared with the other two locations, which has resulted in lower rain attenuation. However, at 50GHz it seen that the XPD and attenuation values of Akure and Ilorin were very close for both rain depolarization models.

While planning the link budget for orthogonal propagation in the three stations considered, the there is need for a higher link margin for the links in Ikeja when compared to Akure and Ilorin to cater for the low cross polarization discrimination experienced in Ikeja. In the empirical evaluation of cross polarization discrimination, it is observed that the Fukuchi model gives the expected characteristics of XPD with attenuation and frequency while with the ITU-R model there is a slight deviation. An adapted ITU-R model is needed to take cater of this observed deviation.

4. Conclusion

The Co-Polar attention for the three stations were evaluated. Ikeja had more attenuation than the other two locations (Akure and Ilorin) at any particular frequency therefore it recorded the lowest XPD of the three locations in both models. The higher the rain rate and the lower the elevation angle the higher the slant path attenuation and consequently the higher the cross talk experienced at the receiving station. While these parameters affect the XPD values at a particular station, the values of the coefficients U and V of the XPD-attenuation relation for both models influenced the values of XPD. The rain rate, elevation angle and attenuation at a particular frequency were constant for both models, which however produced different values of XPD for each location. The U term of the Fukuchi model takes into account the effective path length through the rain of the signal while the ITU-R model is independent of the effective path length through the rain. This has resulted in decreasing values of U for all frequencies when compared with the ITU-R model. Invariably contributed to the lower values of the XPD predicted for the Fukuchi model at all location for frequency range 30-50GHz. Ilorin has the least cross talk of the three locations for both models while Ikeja has the most cross talk.

The amount of link margin needed for each station differs. If using the ITU-R model, the link margin would be slightly lower than what would ensure low signal outage. While the link margin using the data from the Fukuchi model would, more accurately depict the situation on the ground given the fact that the Fukuchi model takes into consideration the effective path length through the rain. While the results of this empirical study is in agreement with expected general behaviour of depolarized signals by rain, more study is needed to specifically characterize circularly polarized signal depolarized by rain in more locations in the country. Earth receiving stations can be set up to measure the effect of rain depolarization on signals to further validate the data from the empirical study of XPD. **References**

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