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Impact of Elevation Angle on Cross Polarization Discrimination for Telecommunication Application in Warri, Delta State, Nigeria

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ABSTRACT
This study explores the impact of elevation angle on Cross Polarization Discrimination (XPD) in telecommunication systems, as evidenced by data collected under varying rain conditions. The study examines XPD values at elevation angles of 40^0 and 60^0 degrees across different rain classifications and intensities. Analysis of the data reveals that increasing the elevation angle generally leads to improvements in XPD, indicating enhanced discrimination against cross-polarized interference and improved signal quality. Notably, significant improvements in XPD are observed in conditions of widespread rain at higher elevation angles. However, the effectiveness of elevating antennas in mitigating interference diminishes as rain intensity increases, particularly in extreme cloudburst scenarios. The findings underscore the importance of considering elevation angle in antenna placement and system design to optimize XPD and ensure reliable communication performance, especially in adverse weather conditions. This research contributes to a deeper understanding of the complex relationship between elevation angle and XPD, offering valuable insights for the design and optimization of telecommunication networks.

Keywords - **Elevation angle, Cross Polarization Discrimination (XPD), Telecommunication systems, Signal quality, Interference mitigation and rain rate.**

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I. INTRODUCTION

Improving signal quality, reducing interference, and optimizing system performance are continuously evolving goals in the field of telecommunications. Among the numerous factors that affect the effectiveness of communication systems, the angle of elevation and cross-polarization discrimination (XPD) stand out as essential components in the quest for reliable and efficient transmission. In a wireless communication system that uses polarized antennas, polarization refers to the orientation of the electromagnetic waves emitted or received by the antennas [1] [2]. Typically, antennas are designed to have a specific polarization, such as vertical or horizontal. However, in some cases, the received signal may experience a change in polarization due to factors like signal reflection or scattering. Telecommunication networks, whether terrestrial or satellite-based, rely on the precise alignment of antennas and the discrimination of polarized signals to ensure the accurate transmission of information across vast distances. The angle of elevation, which represents the inclination of antennas relative to the horizontal plane, plays a fundamental role in determining the trajectory of communication beams and the establishment of line-of-sight connections [3]. Conversely, cross-polarization discrimination serves as a measure of the antenna system's ability to mitigate interference arising from unintended polarization states, thereby safeguarding signal integrity and fidelity. The dynamic interplay between these two concepts exerts a profound influence on the performance and reliability of telecommunication systems in various scenarios and environments. Understanding the nuanced distinctions of how elevation angle impacts cross-polarization discrimination is paramount for telecommunications engineers, researchers, and industry stakeholders alike as they endeavor to design, deploy, and optimize communication infrastructures to meet the burgeoning demands of an interconnected world [4] [5].

Elevation angle, often referred to as the angle of elevation or simply elevation, denotes the angle between the horizontal plane and the line of sight from a ground-based transmitter or receiver to a satellite or distant point of interest [6]. This angular parameter assumes paramount importance in satellite communication, terrestrial microwave links, and radio propagation studies, guiding the precise alignment of antennas for optimal signal reception and transmission. Concurrently, cross polarization discrimination (XPD) emerges as a crucial metric in assessing the efficacy of antenna systems in suppressing interference stemming from orthogonal polarization states. Expressed in decibels (dB), XPD quantifies the attenuation between co-polarized and cross-polarized signals, providing insights into the antenna's ability to discriminate against undesired polarization components. In telecommunication applications, a high XPD signifies robust isolation between polarizations, thereby enhancing signal quality and minimizing the deleterious effects of polarization mismatch [7] [8].

II. FACTORS INFLUENCING XPD

Signal Propagation Effects: Changes in elevation angle affect the propagation path of electromagnetic waves, leading to variations in signal attenuation, reflection, and scattering. These propagation effects can influence the polarization state of the transmitted signal and, consequently, the level of cross-polarized interference experienced by the receiving antenna [7] [9].

Atmospheric Conditions: Atmospheric phenomena such as rain, snow, fog, and atmospheric turbulence can introduce additional polarization effects and attenuate signal strength. The elevation angle influences the path length through the atmosphere, thereby affecting the degree of polarization distortion and cross-polarization interference [10] [11].

Antenna Characteristics: The design and orientation of antennas significantly impact their ability to discriminate against cross-polarized signals. Antennas with higher XPD values exhibit superior performance in rejecting unwanted polarization components. The elevation angle may affect the antenna's radiation pattern and polarization characteristics, thus influencing XPD.

Terrain and Obstructions: The surrounding terrain and obstacles can obstruct the line of sight between transmitting and receiving antennas, leading to signal blockage and multipath propagation. The elevation angle determines the clearance required to maintain an unobstructed communication path, thereby affecting XPD and signal quality [10] [12] [13].

III. CROSS POLARIZATION DISCRIMINATION (XPD)

Parameters needed to calculate XPD due to rain statistics include [8] [14] [15]:

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 using $\tau = 45^0$

f : frequency (GHz) = 10 GHz

θ: path elevation angle (degrees).

Step 1: Calculating the frequency-dependent term:

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

For this work, frequency of 12 GHz was used

Step 2: Calculate the rain attenuation dependent term [16]:

$C_A = V(f) \log A_p$ (2)

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:

$C_\tau = -10 \log [1 - 0.484 (1 + \cos 4\tau)]$ (3)

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

Step 4: Calculate the elevation angle-dependent term:

$C_\theta = -40 \log (\cos \theta)$ for $\theta \leq 60^0$ (4)

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

Step 5: Calculate the canting angle dependent term [16]:

$C_\sigma = 0.0052\sigma^2$ (5)

σ is the effective standard deviation of the raindrop canting angle distribution, expressed in degrees; σ takes the value 0^0, 5^0, 10^0 and 15^0 for 1%, 0.1%, 0.01% and 0.001% of the time, respectively. For this study 10^0 will be used.

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

$XPDrain = C_F - C_A + C_\tau + C_\theta + C_\sigma$ dB (6)

IV. RESULT

Table 1: Impact of Elevation Angle on XPD for April, 2021 and 2022 in Warri

Year	Rain Classification	Rain intensity Range (mm/hr)	XPD(dB) at 40^0 Elevation Angle	XPD(dB) at 60^0 elevation Angle
2021	Widespread	>5≤25	3.611	23.315
	Shower	>25≤50	10.874	21.943
	Cloudburst	>50≤100	8.650	18.855
	Extreme Cloudburst	>100	2.927	13.345
2022	Widespread	>5≤25	4.134	33.064
	Shower	>25≤50	15.438	26.822
	Cloudburst	>50≤100	12.040	22.277
	Extreme Cloudburst	>100	4.347	14.690

Table 2: Impact of Elevation Angle on XPD for June, 2021 and 2022 in Warri

Year	Rain Classification	Rain intensity Range (mm/hr)	XPD(dB) at 40^0 Elevation Angle	XPD(dB) at 60^0 elevation Angle
2021	Widespread	>5≤25	16.800	49.449
	Shower	>25≤50	20.532	32.629
	Cloudburst	>50≤100	14.787	25.177
	Extreme Cloudburst	>100	5.733	16.020
2022	Widespread	>5≤25	4.876	34.013
	Shower	>25≤50	14.186	25.451
	Cloudburst	>50≤100	9.156	19.356
	Extreme Cloudburst	>100	2.608	13.045

Table 3: Impact of Elevation Angle on XPD for July, 2021 and 2022 in Warri

Year	Rain Classification	Rain intensity Range (mm/hr)	XPD(dB) at 40^0 Elevation Angle	XPD(dB) at 60^0 elevation Angle
2021	Widespread	>5≤25	6.134	35.624
	Shower	>25≤50	17.411	29.030
	Cloudburst	>50≤100	15.354	25.792
	Extreme Cloudburst	>100	8.433	18.666
2022	Widespread	>5≤25	29.017	65.485
	Shower	>25≤50	26.714	40.047
	Cloudburst	>50≤100	18.547	29.341
	Extreme Cloudburst	>100	4.789	15.112

Table 4: Impact of Elevation Angle on XPD for August, 2021 and 2022 in Warri

Year	Rain Classification	Rain intensity Range (mm/hr)	XPD(dB) at 40^0 Elevation Angle	XPD(dB) at 60^0 elevation Angle
2021	Widespread	>5≤25	16.460	49.006
	Shower	>25≤50	19.874	31.861
	Cloudburst	>50≤100	14.347	24.705
	Extreme Cloudburst	>100	6.002	16.281
2022	Widespread	>5≤25	37.973	77.313
	Shower	>25≤50	31.786	46.326
	Cloudburst	>50≤100	23.514	35.127
	Extreme Cloudburst	>100	10.211	20.456

Table 5: Impact of Elevation Angle on XPD for September, 2021 and 2022 in Warri

Year	Rain Classification	Rain intensity Range (mm/hr)	XPD(dB) at 40^0 Elevation Angle	XPD(dB) at 60^0 elevation Angle
2021	Widespread	>5≤25	11.515	42.570
	Shower	>25≤50	18.638	30.430
	Cloudburst	>50≤100	13.512	23.816
	Extreme Cloudburst	>100	5.329	15.631
2022	Widespread	>5≤25	4.796	33.910
	Shower	>25≤50	17.446	29.070
	Cloudburst	>50≤100	15.158	25.579
	Extreme Cloudburst	>100	7.772	18.011

V. DISCUSSION

Table 1 shows the effect of elevation angle on XPD for April 2021 and 2022 at 40^0 and 60^0 elevation angles. In 2021, when the rain rate exceeded 100 mm/hr, an XPD of 2.927 dB was observed at a 40^0 elevation angle, while a 60^0 elevation angle recorded 13.345 dB. In 2022, at a rain rate greater than 100 mm/hr, a 40^0 elevation angle yielded 4.347 dB of XPD, while a 60^0 elevation angle recorded 14.690 dB. Similarly, Table 2, Table 3, Table 4, and Table 5 present the effect of elevation angle on XPD for June, July, August, and September respectively. These findings demonstrate that the elevation angle influences XPD in telecommunication links. As a result, the system seems to have a reasonable ability to reject cross-polarization interference caused by rain at higher elevation angles. A higher XPD value indicates a greater ability to mitigate the impact of rain-induced polarization changes. Comparing the results from 2021 and 2022, it is clear that, even with the same rain type and elevation angle, the recorded XPD values differ between the two years. This confirms that atmospheric parameters, especially rainfall, vary over time, leading to differences in their impact on telecommunication links.

VI. CONCLUSION

The study highlights how the elevation angle affects Cross Polarization Discrimination (XPD) in telecommunication systems, particularly in different rain conditions. The relationship between elevation angle and XPD varies across various rain classifications and intensities, indicating the complex interaction between environmental factors and antenna performance. In general, increasing the elevation angle improves XPD, leading to better discrimination against cross-polarized interference and enhancing signal quality. This improvement is most notable in widespread rainy conditions, where the XPD significantly increases at higher elevation angles, demonstrating the effectiveness of elevating antennas in reducing interference. However, as rain intensity increases, the impact of elevation angle on XPD diminishes. In extreme cloudburst scenarios, the improvement in XPD at higher elevation angles becomes less significant, indicating challenges in maintaining effective discrimination against cross-polarized interference during intense rainfall.

Despite the observed variations, the study emphasizes the importance of considering elevation angle in antenna placement and system design to optimize XPD and ensure reliable communication performance, especially in environments prone to adverse weather conditions. By understanding the relationship between elevation angle and XPD, telecommunications engineers can make informed decisions to enhance signal quality, minimize interference, and improve the resilience of telecommunication networks.

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