DEPOLARIZATION OF CIRCULARLY POLARIZED MILLIMETRE WAVES BY PRECIPITATION IN NIGERIA

BY

H.O.David

(PHY/98/1887)

A Thesis submitted to the Department of Physics, Federal university of Technology, Akure in partial fulfillment of the requirement for the award of degree of Master of Technology (M. TECH) in Communication Physics.

2003.

Certification page

I certify that H.O. David obtained the results contained in this thesis for the purpose of the award of the degree of Master of Technology (M TECH) in Communication Physics in the Department of Physics, Federal University of Technology Akure.

4/2/04

M .O Ajewole B.Sc., M.Sc, PhD
Department of Physics
Federal University of Technology,
Akure

ACKNOWLEDGEMENT

I honorably acknowledged YOU, my creator, For it is by YOUR GRACE that I am what I am today , I am grateful on to you my LORD JESUS CHRIST for making this my M.TECH. programme a reality.

I am sincerely grateful to my supervisor, Dr M.O. Ajewole for his contribution to my academic development and for taking time to supervise this work .You indeed led me into your wealth of academic experience. Thank you sir and May the Lord Jesus Christ shower you with His abundant blessings (Amen).

I also acknowledge the contribution of Dr. M.T. Babalola, co-coordinator/ Postgraduate students' adviser in the department. Thanks for your fatherly advice and concern towards the success of this programme. I also wish to express my appreciation to Dr (Mrs.) I.A. Fuwape for her concern and contributions toward the completion of my M.Tech. programme. I am also grateful to the following people for their interest in my success and contributions both in kind and cash. They are my dear brothers: Mr. Adekola Remi, Mr. Adedayo Kayode, and my colleagues Messrs 'Kunle Adediji, Ayodele Odo and Ojo Oladotun.

Chief Durotimi, (Deputy Rector, Federal Polytechnic, Offa Kwara state) Sir, your immense support, advice and guidance contributed greatly to what I am today. I most appreciate you sir. I am also grateful to Mr. Olatona, The Registrar, and Dr. R. Bello, The Rector, both of Federal Polytechnic Offa for their love and advice at all times.

I indeed enjoyed the support of my loved one and my children in ensuring that this study is successfully completed. I thank you sincerely for all your support.

Dedication

This report is dedicated to my family

Table of Contents

CHAPTER ONE

CHAPTER TWO

2.0 THEORETICAL BACKGROUND

CHAPTER THREE

RESULTS AND DISCUSSION

CHAPTER FOUR

CONCLUSION AND RECOMMENDATIONS

ABSTRACT

Rain induced depolarization due to distorted rain drops may be a serious problem to satellite communication at short wavelengths when dual – polarized signals are employed. This study investigates the effects of rain induced depolarization on circularly polarized millimeter and centimeter wave propagation in a tropical location (Nigeria). Propagation along the Earth-space path is considered. Cross-polarization discrimination (XPD) and copolar attenuation (CPA) are calculated for an effective raindrop canting angle of 10^0 with standard deviation of 19^0 and for varying elevation angles. Three tropical rain types classified as widespread, shower and thunderstorm are assumed. The frequency range of the study covers the band 4-100GHz. The study presents results for the variation of XPD with frequency, path length to the rain region, XPD as a function of fade depths (CPA) and so on. The study found that for convective rain types (shower and thunderstorm) cross polarization discrimination becomes very poor as elevation angle decreases and frequency and rain rate increases. For instance as elevation angle becomes low (e.g. 23^0), because the path length to the rain region becomes longer, XPD falls rapidly with increasing rain rate. Copolar attenuation on the other hand increases with increasing rain rate and frequency. The study also found that depolarization of circularly polarized waves is more severe when signal transmission is through convective rain type.

CHAPTER ONE

INTRODUCTION

The first generation telecommunication systems made use of low frequency bands but it was later found to be inadequate to cope with the demands for more telecommunication services. This led into research on the use of higher frequency bands. This consequently led into the use of millimeter and microwave frequencies, which was found to be highly valuable for telecommunication services especially for long distance link because of the fairly good bandwidth. Hall, (1991) show the classification of a part of the electromagnetic spectrum relevant to radio propagation as described in Table 1.

Hydrometeor is a general term referring to the products of condensed water vapour in the atmosphere usually observed as rain, ice, fog, snow, or cloud. The interaction of hydrometeors with radio signal at millimeter and microwave frequencies do exist in the medium containing the hydrometeors and which significantly degrade the quality of communication (Oguchi, 1983).Some of the effects of hydrometeors on microwave propagation as pointed by Ippolito (1981) are:

(a) Attenuation caused by dissipation of radio waves energy as heat

(b) Scattering results in energy loss in the desired direction and consequently causing interference to other systems

(c) Depolarization due to non spherical nature of rain drops

(d) Bandwidth coherence reduction especially in digital systems involving carriers spanning over large channel bandwidths.

Table 1: Electromagnetic spectrum relevant to radio propagation.

Frequency Band	Wavelength	Descriptive designation
30-300Hz	10000-1000km	- ELF
3-30 KHz	100-10km	Myriametric waves VLF
30-300KHz	10-1km	kilometric waves LF
300-3000KHz	1000-100m	Hectometric waves MF
3-30MHz	100-10m	Decametric waves HF
30-300MHz	10-1m	Metric waves VHF
300 – 3000 mhz	100 – 10 cm	Decimetric waves UHF
3 – 30 GHz	10 – 1 cm	centrimetric waves SHF
30 – 300 GHz	10 – 1 mm	Millimetric waves EHF
300 – 3000GHz	1 – 0.1 mm	Sub – millimetric waves -

It has long been discovered that rain is a major cause of signal degradation for communication systems operating at millimeter and centimeter waves and particularly in the tropical environment that is characterized by high rainfall intensity and presence of large rain drops when compared with the temperate region (Ajayi, 1994).

The increasing demand for high capacity radio channel has led to the use of orthogonal polarization in order to increase channel capacity without increasing bandwidth. Communication systems are designed to use dual polarization channel in which two separate frequency channels are transmitted over the same terrestrial or earth -space communication link.

As a result of imperfection in the separation of the orthogonal channels and interaction of waves with hydrometeor, there is always an amount of cross talk between channels, which limit the use and performance of communication system using orthogonal polarization (Ajewole, 1998). The constraint in the use of microwaves and millimeter waves band for communication on both the terrestrial and earth -space links depend largely on the interaction between radio waves and rain as wavelength of waves approach the size of rain drops. The strong interaction of waves with rain often lead to degradation effects such as signal attenuation, rain induced depolarization and so on. Rain Attenuation is a factor to be considered when designing both terrestrial and earth- space radio links particularly at frequencies above 5 GHz in the tropical environment. Initially, it was believed that depolarization is caused by the imperfection of communication system until later when it was discovered that rain is also a major depolarizing agent (Semplak, 1974). Depolarization also depends on the wavelength of waves, rain drop size, rain drop shape, rain intensity and orientation of rain drop along the propagation path.

The non-spherical shape of rain drops result in differential attenuation and differential phase shift, thus causing depolarization. Depolarization limits the use of orthogonal communication channels.

By definition, depolarization is the decibel difference between the polarized and cross polarized signals. Rain induced attenuation and phase shift are important parameters in evaluating depolarization. These parameters are also dependent on scattering amplitude and raindrop size distribution. The occurrence of heavy tropical rain over the propagation path limit the reliability of communication systems performance since rain induces cross polarization interference which tend to reduce the cross polarization isolation between orthogonal channels along the propagation path as rain attenuation is a polarization dependent (Ajewole et al., 1999)

Most of the work done till date on depolarization of radio waves in the tropical environment has been on linearly polarized wave. This study intends to evaluate depolarization statistics for circularly polarized centimeter-millimeter wave signals in the tropical environment using the existing tropical rain drop size distribution to evaluate the specific attenuation and phase shift statistics. Canted rain drops with the shape of oblate spheroid are assumed for different tropical rain types in this study. In most cases, raindrops are not spherical in shape because of wind gusts, air turbulence and rain drop vibration. If rain drops were not canted, a horizontally polarized wave would produce only horizontally polarized scattered waves along the propagation path, hence there will be no cross polarization discrimination (XPD) but a canted rain drop will cause a difference in attenuation of vertically and horizontally polarized wave thus causing rotation of the direction of polarization (XPD) along the path.

The drop size distribution of Adimula and Ajayi (1996) which classified tropical rain into drizzle, widespread, shower and thunderstorm will be used to evaluate the depolarization of circularly polarized signal. This study will concentrate on rain induced depolarization of circularly polarized waves.

CHAPTER TWO

THEORETICAL BACKGROUND

This study is on tropical rainfall depolarization of radio signals propagating through non spherical rain drops. Theoretical approaches to the formulation of the problem of rain induced depolarization are considered.

2.1 POLARIZATION OF SIGNALS

When an electromagnetic wave emanating from a source is viewed at a long distance from the source, the waves arriving appears as plane waves. In the waves, the magnetic and electric fields contained in the plane normal to propagation direction are orthogonal to each other in such plane waves.

Polarization therefore, is the state of electromagnetic radiation when transverse vibrations take place in some regular manner, for example; all in one plane, in a circle, in an ellipse or in some other definite curve. Radiation may become polarized because of the nature of its emitting source as in the case of some types of radar antennae or because of some processes to which it is subjected after leaving the source as that which results from the scattering of solar radiation as it passes through the earths atmosphere. There are two major classes of polarization; the linear and circular polarization.

In linear polarization, the electric vector has a fixed orientation, while the electric vector rotates about the axis of propagation in the case of circular polarization. The rotation is set up by first splitting a linear polarization vector into two equal vectors at 45^0 Circularly polarized electric field vector can be further resolved into right hand and left hand circular polarizations, E_R and E_L. The linearly polarized waves are also resolved into horizontal and vertical linear polarization, E_H and E_V

As a result of imperfection in isolation of signals there is always a residual amplitude in the orthogonal polarization sense. Cross polarization discrimination (XPD) is a measure of purity of the polarization and is defined for a circularly polarized wave as

$$XPD = 20Log\frac{E_L}{E_R} \tag{2.1}$$

For linear polarization, it is defined as

$$XPD = 20Log\,\frac{E_V}{E_H} \tag{2.2}$$

According to Wait and Rahmat Samil (1989) the choice of polarization depends on the following:

- severity of propagation impairment applicable to the carrier frequency selected
- antenna characteristics
- axial alignment in system design.

However propagation impairment is less severe on linear polarization than on circular polarization. Wait and Rahmat Samil (1989)

2.2 Depolarization due to rain

Depolarization is a phenomenon by which the power of a radio wave transmitted with defined polarization may no longer have a defined polarization after propagation through the atmosphere (ITU – R, 1995). That is depolarization is any process (reflection, refraction, scattering, etc) by which the polarization of the incident wave is altered , for example, circularly polarized wave becomes elliptical or the plane of polarization of a plane wave is turned. In particular, the component polarized perpendicular to the incident wave is called crossed polarized component. Depolarization can occur when scattering or reflection is multiple or when the individual scatterers are anisotropic and or non spherical.

For linear polarization, rain induced depolarization is due to differential attenuation and differential phase shift between two polarization states as well as the slight tilt of the symmetry axis of the rain drops from the vertical (Saunders, 1971) . Due to non spherical nature of rain drops, attenuation by rain have different characteristics depending on the orientation of the polarization of the incident plane wave. The difference in attenuation and difference in phase shift between major and minor axis of orientation of raindrops are called differential attenuation and differential phase shift respectively.

When a single polarization is transmitted, there is no problem of differential attenuation and differential phase shift due to rain but there will be problem of depolarization by the rain medium. However, in dual polarized communication system, differential attenuation and differential phase shift will result in degradation of the wanted channel (Ajayi, 1994)

Due to differential phase shift and differential attenuation, a circularly polarized wave would be transformed into elliptically polarized wave thereby resulting into generation of cross polarized components which have opposite sense of rotation. Cross polarization discrimination is a measure of polarization purity. .

Depolarization effect is maximum when cross polarization is minimum. Circularly polarized wave will be affected in much the same way by differential phase and amplitude effect as linearly polarized wave. The differential amplitude effect will cause polarized wave to exit the rain medium with different amplitude but if the wave align with the principal axis of the rain- drops, no depolarization will occur as there will be no rotation away from the original orientation.

As the incident polarized signal moves away from the axis of symmetry of the rain drops the magnitude of the orthogonal resolved components of the incident wave increases to a maximum value when this wave is at 45^0 with respect to the principal axes of symmetry of the rain drop. This shows that depolarization effect of a linearly polarized signal will always be less than that of circularly polarized signal except at angle 45^0 with respect to the axes of symmetry of rain drop. The amount of differential attenuation and differential phase shift experienced by signal passing through non-spherical rain drop depends upon frequency, rain rate and alignment of rain drop axis, among others. The use of dual-polarization at the same frequency over the same path is constrained by co-channel cross coupling due to depolarization of the incident waves by rain and other hydrometeors. A dual polarized system therefore need to be designed to have adequate depolarization margin and fading for it to attain good system reliability. David (1971) suggested that unacceptable XPD level will occur only under condition of severe copolar signal fading. Shutie and Allnutt (1976) conducted a study on depolarization at 30GHz and the result shows that severe degradation can occur on earth -space link even in the absence of significant copolar fading.

2.3. Attenuation

Attenuation of a radio wave is defined as the difference in decibel between the power received at a given time and the power received under ideal propagation condition. Decibel is a measure of relative power or the relative values of two flux densities especially of sound intensities, radio intensities or radar power densities. The difference in n decibels between flux densities I_2 and I_1 is given by the relation

$$n = 10\log_{10}\left(\frac{I_2}{I_1}\right)$$

Attenuation of radio waves is made up of two components: absorption and scattering. Absorption takes place when the incident wave energy is transformed into mechanical energy thereby heating up the absorbing material. This energy can re-radiate if temperature of the material is above that of surrounding.

Scattering occurs when radio wave energy is redirected without loss of energy to the scattering particle. This scattered energy could be in any direction. Back-scattering occurs when the redirected energy retraces its path. This mechanism is used in radars. Side scatter occurs when the redirected energy moves out of the transmission path and this mechanism gives rise to interference to other systems. Forward scatter on the other hand takes place when the redirected energy moves back into the original propagation direction after one or more scattering. The proportion of differential attenuation to differential phase shift is significantly affected by the rain fall types, the raindrops size distribution and the rain rate. Differential attenuation is a critical factor of cross talk problem between orthogonal polarization channels (Mackawa et al., 1992).

2.4 Shape of raindrop

The shape of rain drop at any time depends on the surface tension and aerodynamic forces acting on the drop as they fall to the ground (Wait and Rahmat Samil, 1989). Surface tension is gradually overcome by aerodynamic forces as rain drop is falling. Surface tension keeps the shape of small rain drop spherical but the shape gets distorted as the rain drop becomes larger and fall faster to the ground.

For small drops less or equal to 170μm in diameter, the shape is exactly spherical and surface tension dominates other forces. Between 170 to 500μ m in diameter the rain drops become elliptical. Between 500 to 2000μ m in diameter the drops become flattened at the base. The base is hollowed out (Pruppacher -Pitter shape) when the drop is above 2000μm in diameter (Pruppacher and Pitter, 1971)

In general, the rain drops range in size from small to fairly large ones which may not be bigger than 4mm in radius since raindrops greater than 4mm are hydro-dynamically unstable and break up however raindrops of about 6mm have been estimated at Ile - Ife.

The rain drop oscillates between oblate and prolate spheroid once it is distorted as it becomes unstable. The spheroidal shape is formed by rotating the ellipse about the shortest axis. The shortest or minor axis is vertical for oblate shape but horizontal for prolate spheroidal shape. It has been shown that the natural frequency of a rain drop oscillating between oblate and prolate shape is expressed as (Battan, 1973)

$$f = 11.7d^{-1.47} \tag{2.3}$$

where d is diameter of rain drop in centimeter.

2.5 Falling velocity of raindrops.

Investigation has shown that the fall velocity of rain drop increases as the drop size increases until about 2.5mm in radius and then remains fairly constant (Table2.1) . Investigations carried out by many researchers like Best (1950) were done in the temperate region. Such measurements till date have not been carried out anywhere in the tropical environment. The values proposed by Best (1950) are assumed for the tropical environment since the fall mechanisms are taken to be independent of geographical region (Ajewole, 1997)

The fall velocity of raindrops is an important parameter in estimating rain fall intensity. In this study, an oblate spheroidal rain drop shape is assumed.

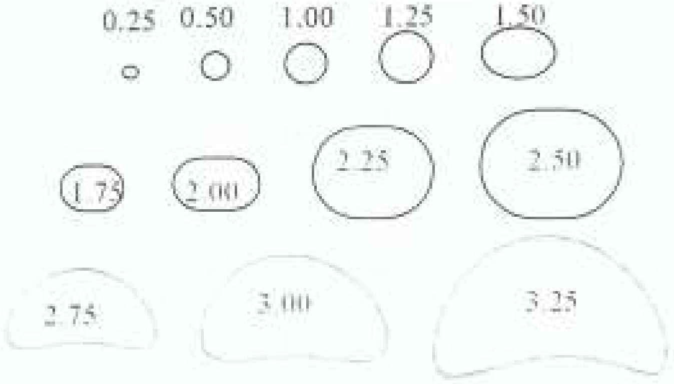


Fig. 2.1: Shape of raindrops of different types measured in millimetres.

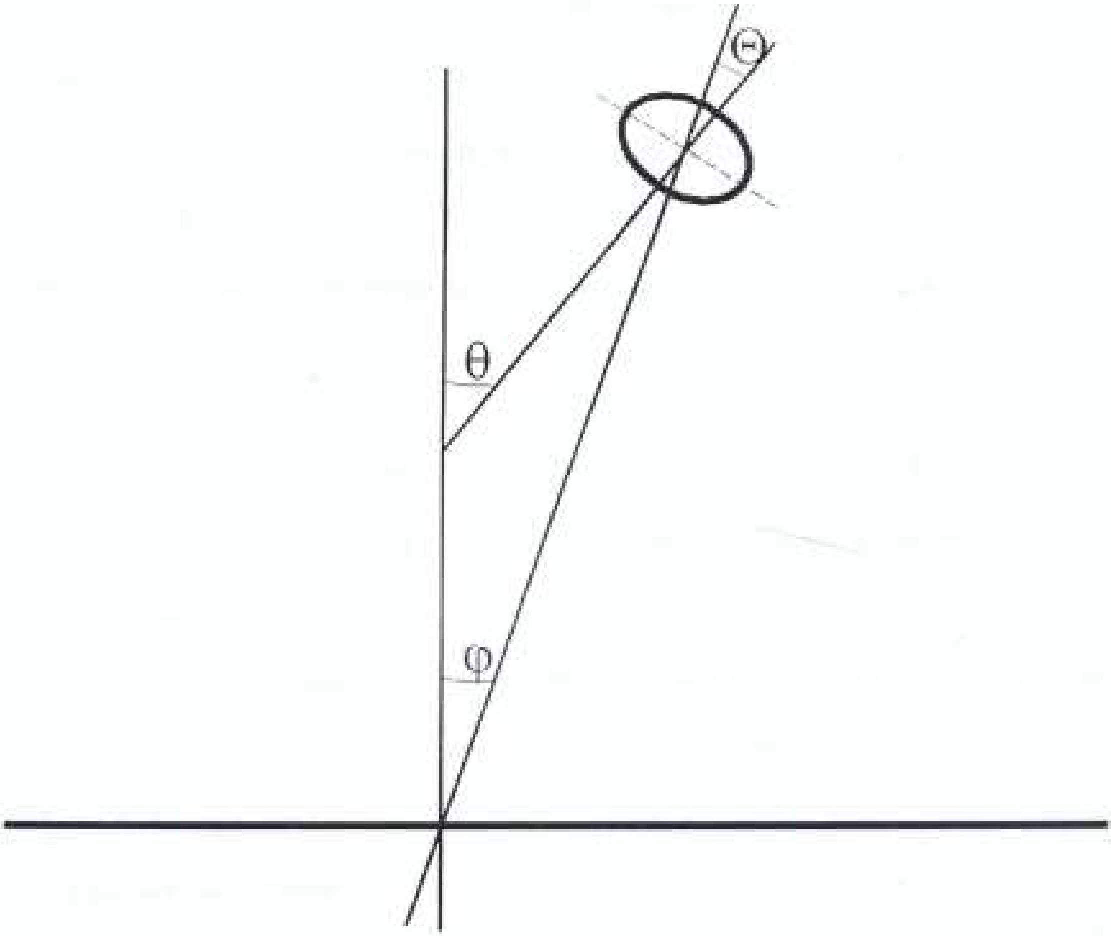
Table 2.1: Terminal velocity of some spherical rain drop, (Medhurst ,1965)

Radius(mm)	Velocity(m/s)
0.25	2.1
0.50	3.9
0.75	5.3
1.00	6.4
1.25	7.3
1.50	7.9
1.75	8.4
2.00	8.7
2.25	9.0
2.50	9.2
2.75	9.2
3.00	9.2
3.25	9.2

2.6 Canting angle of rain drops

The non spherical rain drops in the atmosphere tend to cant away from the vertical direction as they fall due to the aerodynamic forces acting on them. The measured canting angle of rain drops differs with rain drops size and they form an angle distribution. The mean angle is nearly vertical. Brussard (1976) calculated the canting angle of rain drop with radius 1.5mm at a height of 10m above the ground and found it to be 10^0 at a wind speed of 15m/s. He also showed that the larger the distance from the ground the smaller the canting angle and that the canting angle increases with increasing drop size. It is generally accepted that rain drops fall as oblate spheroid with increasing flattened base. (Watson and Evans, 1974)

Canting angle is an important parameter in estimating depolarization in dual-polarized systems operating independently at the same frequency. Canting angles may be assumed constant for all rain drops on a path. This is called the deterministic model. The Stochastic model assumes that canting angles are distributed uniformly with a mean and standard deviation along a propagation path. In this study, the stochastic model is assumed.



Θ is the angle between the trace of fall and the drop axis

Φ is the angle between the vertical axis and the trace of fall

Θ is the canting angle

Fig. 2.2: A model of drop canting angle

2.7 Rain rate

Rain rate is the rate at which rain water reaches the ground per unit time. Battan (1973) estimate rain rate from $R_0 = M_i(w_i - w_u)$

M_i is the mass of individual rain particle, w_i is the terminal velocity of the drop while w_u is the updraft rate.

If the rain cell consists of raindrops all of the same size, the rain rate is expressed as

$$R = \frac{4}{3}\pi\rho a^3 N(w - w_u) \tag{2.4}$$

where a is radius of rain drop and N is the concentration per unit volume of water. Measurement of rain rate for radio communication has been made at Ile-Ife in Nigeria using a rain gauge or distrometer. The duration analysis showed that high rain rate of 100mm/h can be continuously exceeded for periods of the order of minutes. The high rain rate can cause signal outage on communication system operating above 10 GHz (Ajayi 1994).

2.8. Classification of rain

Tropical rain fall is usually characterized by large size raindrops and high frequency of occurrence, thus having severe effect on radio communication at millimeter or microwave frequencies. Nigeria is located in the high rain fall region (ITU–R, 1995). Rain is classified into stratiform and convective rain. Stratiform rain occurs fairly steadily and can cover a wide area for a long period. The rain rate for this type of rain is generally low. Convective rain on the other hand occurs with high rain rate for short periods of time. It also covers a small area. The stratiform rain type is further classified as drizzle and widespread, while the convective rain is further classified as shower and thunderstorm.

The drizzle is a low intensity rainfall of about 5mm/h. It is associated with drops of diameter of the order of 1.0mm. They may be generated by the Stratus cloud.

The widespread rain consists of raindrops with diameter in the range 1.0-3.5mm. It occurs fairly steadily and uniform over relatively large area. The duration is usually long (greater than an hour) and has a maximum intensity of 50mm/h. The Nimbo Stratus clouds are usually responsible for this rain type.

Shower rainfall is often called warm rain and consists of extremely few raindrops above 2.0mm diameter. It occurs suddenly with small duration of between 10 – 15 minutes. It originates very well from below the 0^0 isotherm height and so they do not involve the ice phase. It is characterised by high rainfall intensity of about 150mm/hr and are generated within the Cumulus cloud.

The thunderstorm rain is generated within the Cumulonimbus cloud (high rising clouds). Thunderstorm rain is characterized by high rainfall intensity of about 210mm/hr with relative high concentration of large drops typically greater than 3.0mm. Thunderstorm rain is sometimes accompanied by thunderstorm activities especially in the tropics.

For the purpose of study of radio communication in Nigeria, rainfall has also been classified as drizzle, widespread, shower and thunderstorm with rainfall intensities ranging from drizzle with a maximum of 5mm/h to thunderstorm with a maximum of 210mm/h (Ajayi et al., 1987). The drizzle and widespread rain types are composed mostly of small drops while thunderstorm is characterized with large drop size with high concentration (Oguchi, 1983).

2.9. Rain drop Size distribution model

Rain drop size distribution (DSD) is a measure of the number of rain drops of a given size in unit volume of rain. For now, most raindrops size distribution models are region specific. For example, the lognormal distribution is most suitable for tropical Nigeria (Adimula and Ajayi, 1996). For the temperate region, the Laws and Parsons, and the negative exponential distribution models are suitable. The Marshall and Palmer (1948) is particularly suitable for continental Europe. Detailed review of these models is available from Ajewole (1997). In what follows, a brief description of lognormal models is given.

2.9.1 Lognormal distribution

The tropical raindrop size distribution proposed by Ajayi and Olsen (1985) can be represented by the lognormal distribution given by;

$$N(D)=\frac{N_T}{\sigma D\sqrt{2\pi}}Exp\left[-\frac{1}{2}\left\{\frac{\ln(D)-\mu}{\sigma}\right\}^2\right] \tag{2.5}$$

where N (D) is the number of raindrops per unit volume per diameter interval and μ is the mean of ln (D), σ is the standard deviation and N_T is the total number of raindrops of all sizes.

The parameters σ, μ and N_T depend on climate, geographic location of measurement of rainfall types. Ajayi and Olsen (1985) analyzed the results of raindrop size distribution measurement made at Ile-Ife over rain rate of about 0.25 to150mm/h for four rain types; drizzle, shower, widespread and thunderstorm rains. Lognormal distribution function fitted by method of moment regression was employed to produce good theoretical fit to the measured data at Ile-Ife, Nigeria. In equation (2.5), N_T is obtained from zero moment, and using the second and third moments, Ajayi and Olsen (1985) further obtained the following:

$$N_T = 108R^{0.363}$$

$$\mu = -0.195 + 0.199\ln R$$

$$\sigma^2 = 0.137-0.013\ln R$$

Adimula and Ajayi (1996) extended the results further by making measurements for a period of three years at two more locations in Nigeria. They obtained the values for σ^2, μ and N_T for the four rain types which could be applied to tropical rain types using the expressions;

$$N_T = a_0 R^{b_0}$$

$$\mu = A_\mu + B_\mu \ln R \tag{2.6}$$

$$\sigma^2 = A_\sigma + B_\sigma \ln R$$

Table 2.2 shows the values of the propagation parameters obtained by Ajayi and Adimula (1996). Ajewole (1997) made use of Ajayi and Adimula parameters of lognormal distribution in the computation of forward scattering amplitude for the four rain types.

Table 2.2: Parameters of the lognormal distribution obtained by Ajayi and Adimula (1996).

Rain type	N_T		μ		σ^2	
	a_o	b_o	A_μ	B_μ	A_σ	B_σ
Drizzle	718	0.399	-0.505	0.128	0.038	0.013
Widespread	264	-0.232	-0.473	0.174	0.161	0.018
Shower	137	0.370	-0.414	0.234	0.223	-0.034
Thunderstorm	63	0.491	-0.178	0.195	0.209	-0.030

2.10 Computational method

In practice, wave may not be perfectly polarized and thus will have component in the orthogonal sense. The energy in the wanted sense of polarization is called co-polarized component while energy in the orthogonal sense *(the unwanted energy) is called the cross –* polarized component .The measure of purity of polarization is the cross polarization discrimination (XPD) .When propagating through a rain medium, a perfectly polarized signal will exit the rain medium with the original polarization in addition to an orthogonal component with opposite *polarization in the communication system.*

Rain depolarization severely limit the full utilization of dual –polarization systems in the tropical region as a result of high occurrence of heavy rainfall over the propagation path.(Ajewole and Kolawole, 1999) . Depolarization effect can be evaluated in terms of the cross-polarization discrimination (XPD) ratio.

Cross-polarization discrimination (XPD) is dependent on differential attenuation and differential phase shift. Using small argument approximations based on an assumption by Oguchi (1977) that propagation constants associated with the two characteristics polarization propagated through rain medium without depolarization are approximately equal. Olsen (1981) simplified the semi empirical model of XPD prediction from which the theory is derived.

For linear polarization, cross-polarization discrimination XPD and co-polar attenuation CPA are approximated thus;

$$XPD = -20\log\left(L Cos^2\varepsilon \left|\Delta k\right| e^{-2\sigma^2} Sin\left(\frac{\phi-\tau}{2}\right)\right) \tag{2.7}$$

$$CPA = \left(A_H + A_V + \left(A_H - A_V\right) Cos^2\varepsilon e^{-2\sigma^2} Cos2(\phi-\tau)\right) \times \frac{L}{2} \tag{2.8}$$

ere A_H and A_V are specific attenuation associated with the principal plane of the rain p axes *(major and minor axes of rain drops)* . The parameter Δk defined in equation) is expressed as

$$= \left[(A_H - A_V)^2 + (P_H - P_V)^2 \right]^{\frac{1}{2}} \quad (2.9)$$

e A_H -A_V is the differential attenuation and P_H -P_V is the differential phase shift, resent the effective canting angle, τ is the polarization tilt angle, σ is the effective ard deviation of the canting angle distribution, ε is the path elevation angle (ε =0 for strial propagation path) and L is the path length expressed as (Olsen et al., 1977);

$$\left[7.41 \times 10^{-3} R^{0.766} + \left(0.232 - 1.80 \times 10^{-4} R \right) Sin\varepsilon \right]^{-1} \quad (2.10)$$

e R is the rain rate. For circular polarization, which is the thrust of the present study, xpression for linear polarization is modified by

$$= 45^0 = \frac{\pi}{4} \quad (2.11)$$

uation (2.11) is substituted in equations (2.7) and (2.8), then,

$$) = -20 \log \left[L Cos^2 \varepsilon \left| \Delta k \right| e^{-2\sigma^2} \times 0.383 \right] \quad (2.12)$$

$$= (A_H + A_V) \frac{L}{2} \quad (2.13)$$

vious studies of Ajewole (1997) evaluated rain depolarization for horizontal and cal polarization in the tropical environment but the present study will investigate rain larization of circularly polarized incident signal using data from Nigeria.

is study adopted the specific attenuation and phase shift computed by Ajewole (1997) hich the forward scattering amplitude functions were computed by least squares method for oblate spheroid raindrop. This study will also adopt uniform distribution of canting angle on the propagation path and the raindrop size distribution model of Adimula and Ajayi (1996).

XPD and CPA are computed for circular polarization for an effective canting angle of 10^0 with standard deviation of 19^0 over a varying propagation path at elevation angles ranging from 10^0 to 55^0 and frequency range of 4 to 100 GHz and for three tropical rain types with rain rate ranging from 5mm/h to 150mm/h.

CHAPTER THREE

RESULTS AND DISCUSSION.

Computation of results was done using equations 2.10 to 2.13 for three rain types namely; widespread, shower and thunderstorm. Rain rates of 5, 10, 20, and 30mm/h were considered for widespread rain type. Rain rates 20, 50, and 150mm/hr were selected for shower rain type while rain rates 20, 50, 100, and 150mm/h for thunderstorm rain type at elevation angles of 10^0 , 15^0 ,23^0, 30^0, 40^0, 50^0, and 55^0 and the effective canting angle of 10^0 with the effective standard deviation of the canting angle distribution of 19^0 were used for evaluation of XPD and CPA over the frequency range of 4-100GHz. In order to determine depolarization effect and copolar fading on the satellite communication path, XPD and CPA were computed.

Emphases are laid on the result of XPD and CPA at elevation angles of 23^0 and 55^0 because of its importance to satellite communication in the tropics particularly in Nigeria. Elevation angles of 23^0 and 55^0 represent the look angle of INTELSAT over the Indian Ocean Region (IOR) satellite and the Atlantic Ocean Region (AOR) respectively.

3.1 Variation Of XPD With Rain Rate

Figures 3.1 to 3.5 shows the results of variation of XPD with rain rate for the rain types and at some frequencies. The results represent in general a decrease in XPD as the rain rate increases. XPD become poorer as the frequency increases. It decreases to negative values at high rain rates. XPD becomes poorer as frequency increases and elevation angle decreases. Generally, XPD at the elevation angle of 55^0 is better than at elevation angle of 23^0 as the rain rate increases. This is because the path length through rain is longer at elevation angle of 23^0, so deterioration is much.

The XPD for widespread stratiform is better compared to the convective rain types. This is due to the predominance of small size spherical rain drops in the rain structure. XDP is better for shower rain than for thunderstorm rain at the two elevation angles (23^0 and 55^0).

XPD is worst for thunderstorm at all frequencies as rain rate increases. This result is due to the large distorted rain drops and the high rainfall intensity. Depolarization effect will be insignificant for widespread rain types while the effect is significant for other rain types with the worst effect for thunderstorm rain particularly at high rain rates and high frequencies. At frequencies higher than 25 GHz, and for thunderstorm rain type, XPD decreases to levels well below the 20-30 dB margin allowed on most communication equipment. This clearly shows how deleterious thunderstorm rain can be to satellite communication in tropical regions irrespective of the elevation angle.

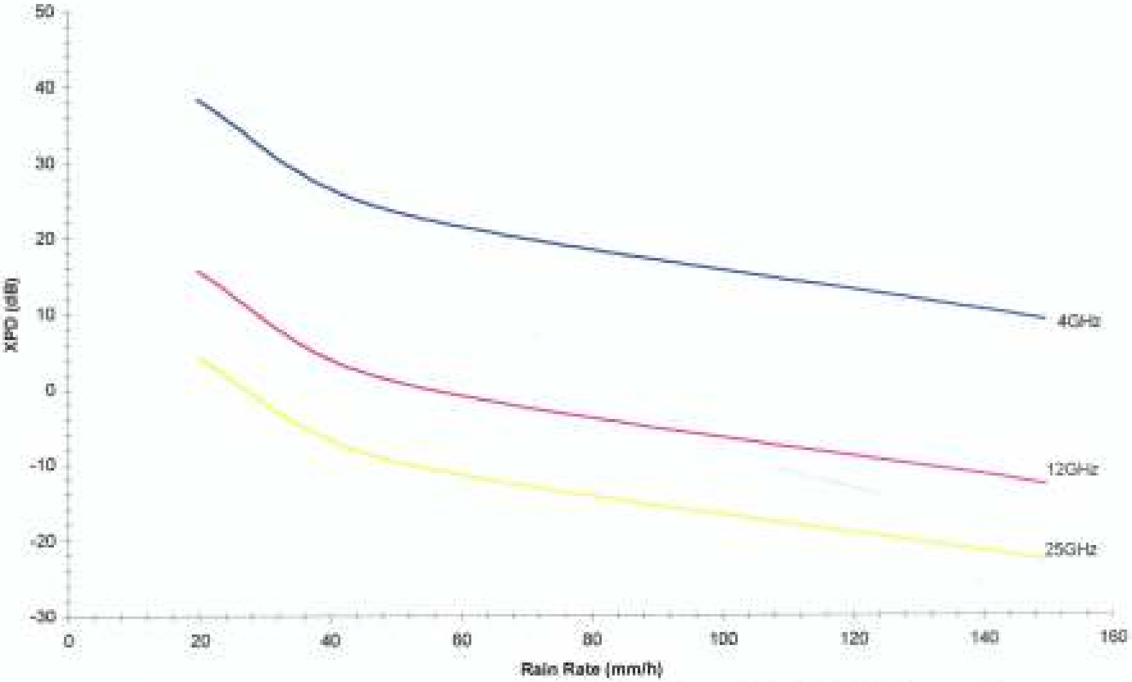


Fig 3.1:Variation of XPD with rain rate at elevation angle of 23 and frequencies 4 ,12,25,GHz for shower rain.

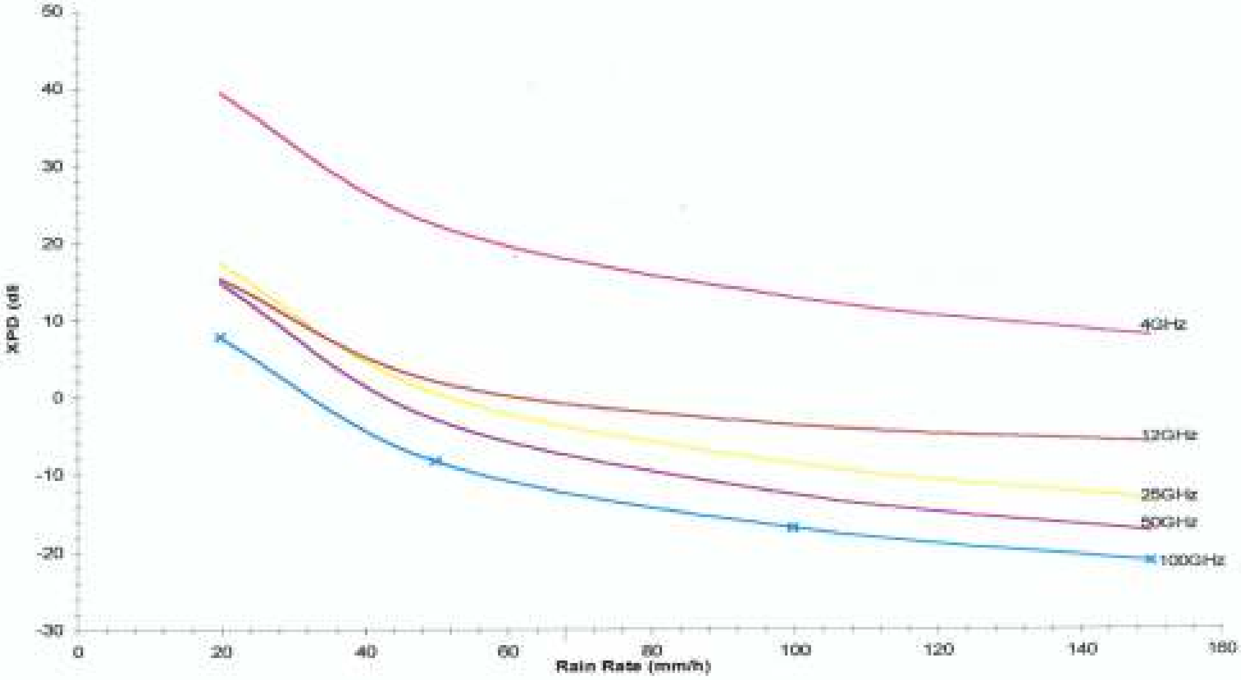


Fig 3.2:Variation of XPD with rain rate at elevation angle of 23 and \frequencies 4,12, 25,50,100GHz for thunderstorm rain.

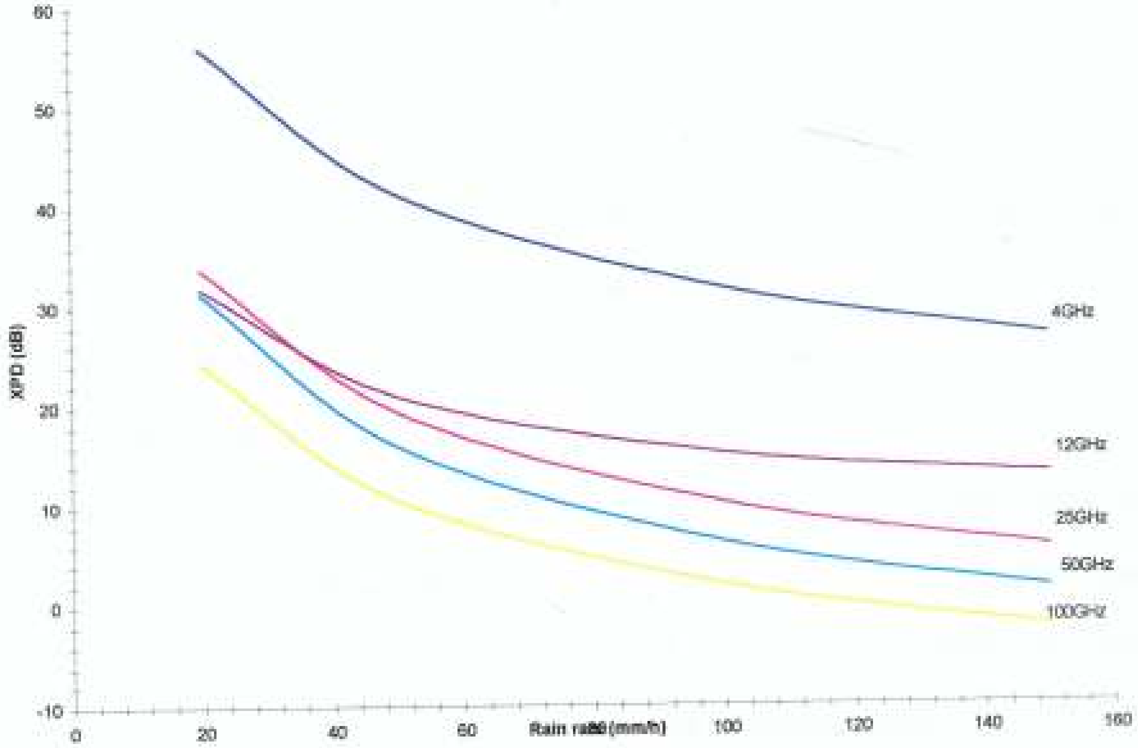


Fig3.5: Variation of XPD with rain rate at elevation angle of 55 and frequencies 4,12,25,50,100 GHz for thunderstorm rain.

3.2 Variation Of CPA With Rain rate

Figs 3.6 to 3.9 shows the variation of copolar fade as the rain rate varies at elevation angle of 23^0 and 55^0 and at some frequencies for the three rain types.

The results show that copolar attenuation (CPA) increases as rain rate and frequency increases. Generally CPA varies almost linearly with increasing rain rate. CPA for the widespread is better than the other rain types due to the predominance of small size rain drops which attenuate less particularly at the low frequencies. CPA is higher at elevation angle of 23^0 than at elevation angle of 55^0. Attenuation of circularly polarized signal is better generally for widespread rain and worst for thunderstorm and shower rain. Attenuation could be as high as 80 dB during shower rain, and at signal elevation angle of 55^0 at 100GHz. This is by far much higher than the 30-35 dB margin allowed in most satellite telecommunication systems. This high value of attenuation at frequency greater than 10GHZ will have significant effect on quality of communication signal. In effect, the satellite signal may be totally unavailable under these conditions. This result is in agreement with the results of many researchers such as Ajewole, et al., (1999), Oguchi, (1983), Ajayi et al., (1998) for terrestrial communication. Therefore whether slant path or terrestrial link, and irrespective of the polarization of the satellite signal, CPA will be high on tropical propagation paths during rainfall. The higher the rain rate the greater the attenuation of the signal and the worse is the fade level of the signal. This result also shows that attenuation effect or fading will be high on single polarized signal.

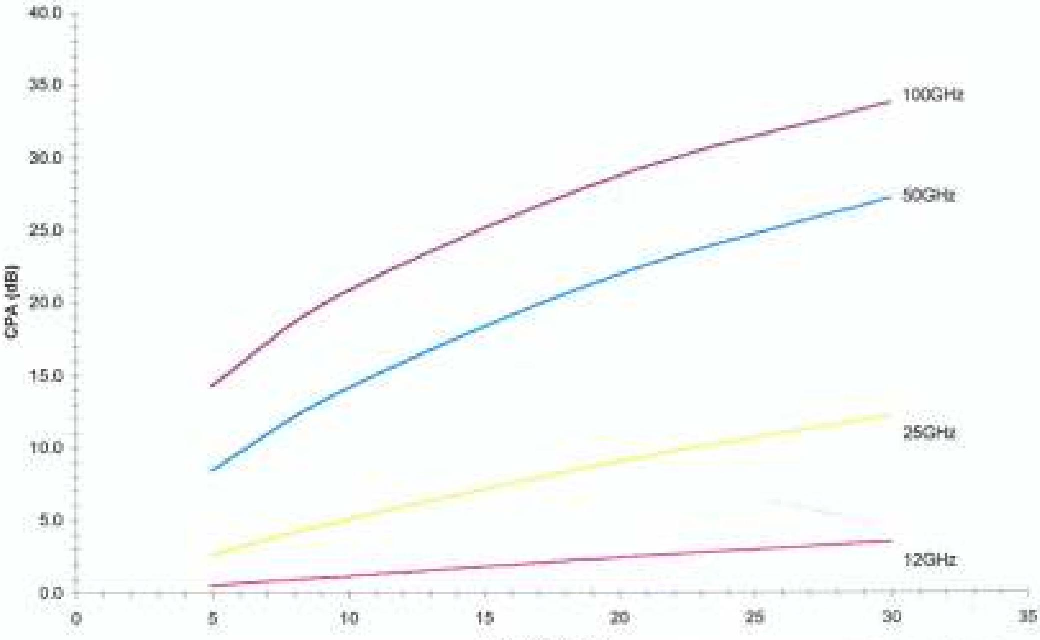


Fig 3.6: Variation of CPA with rain rate at elevation angle of 23 and frequencies 12,25,50,100GHz for widespread rain.

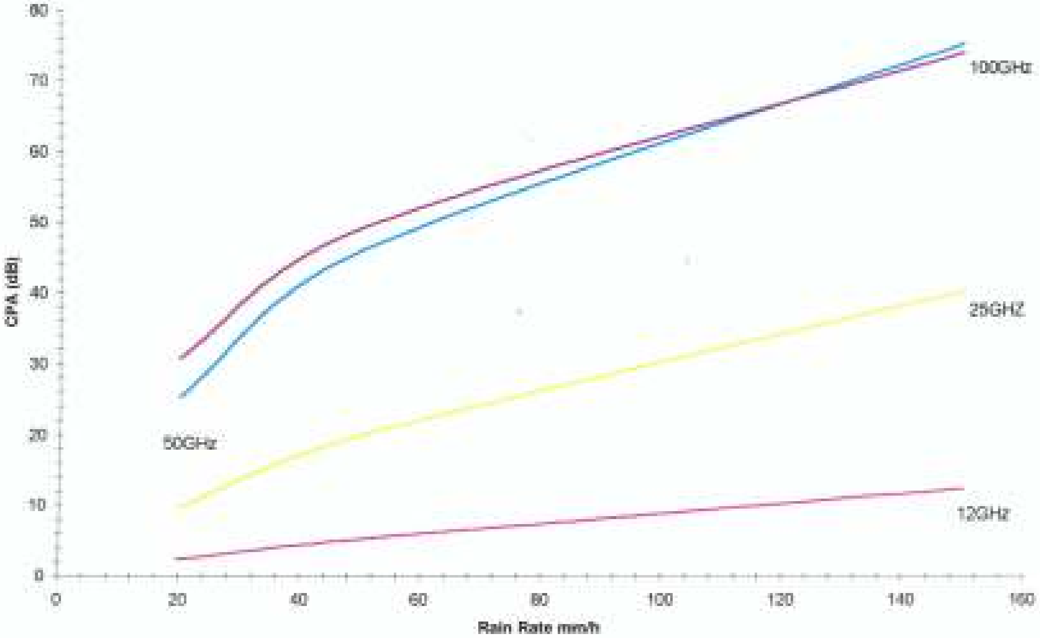


Fig 3.7: Variation of CPA with rain rate at elevation angle of 23 and frequencies 12,25,50,100GHz for shower rain.

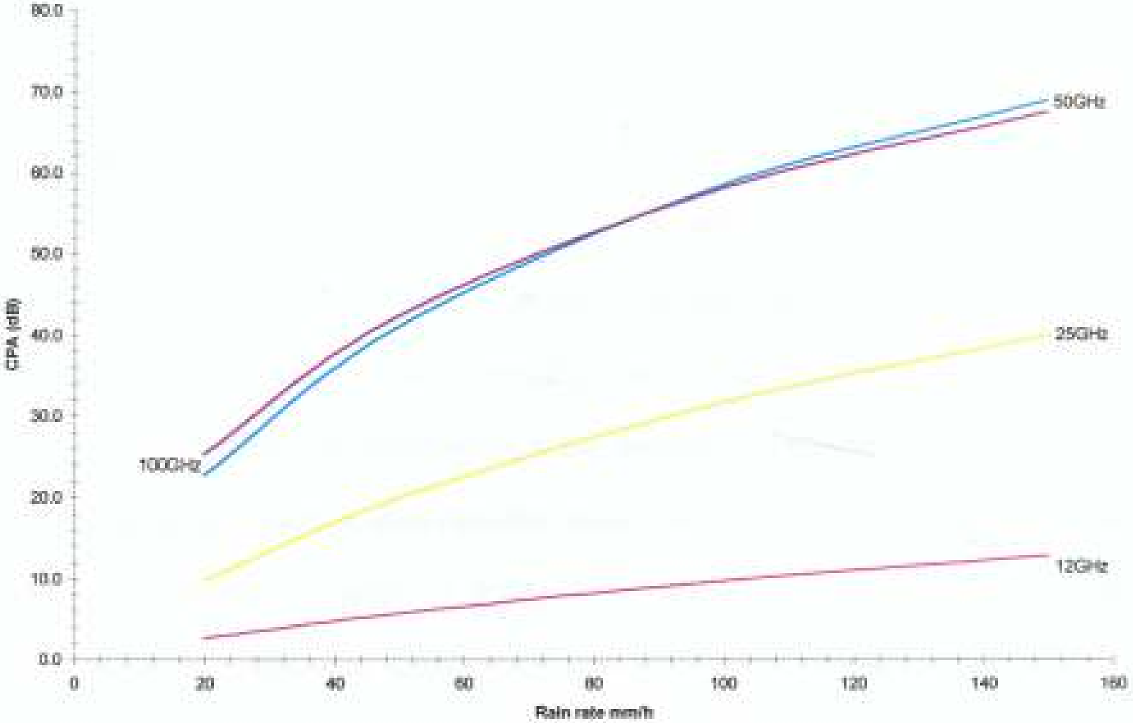


Fig 3.8:Variation of CPA with rain rate at elevation angle of 23 and frequencies 12,25,50,100GHz for thunderstorm rain.

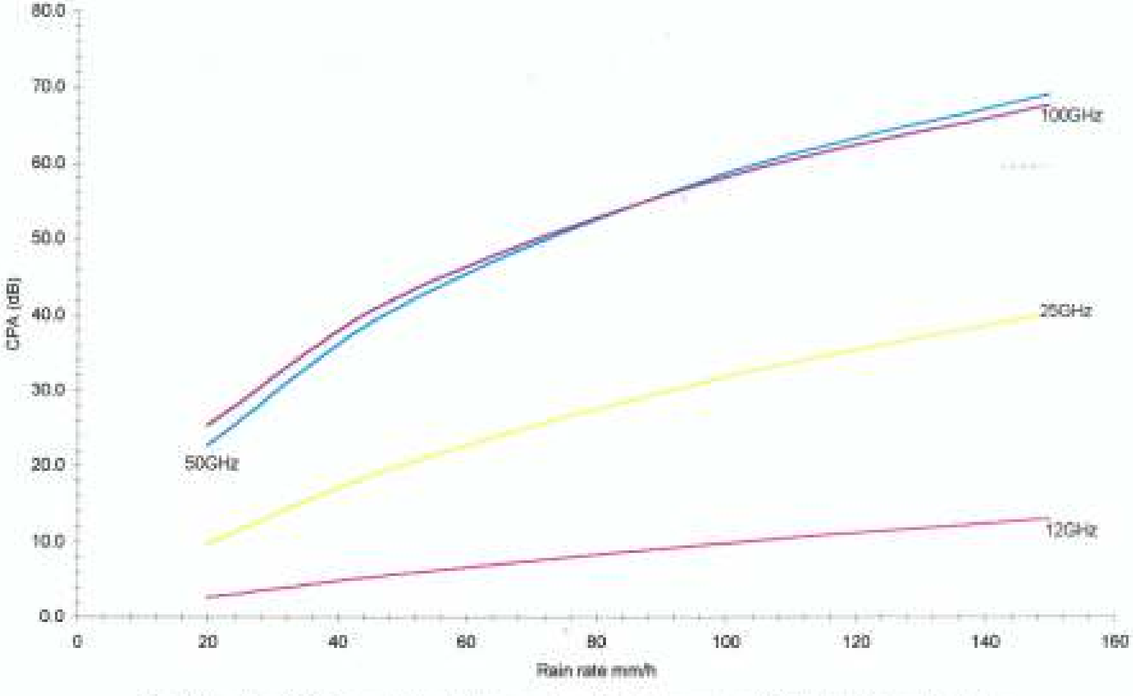


Fig 3.9:Variation of CPA with rain rate at elevation angle of 55 and frequencies 12,25,50,100GHz for thunderstorm rain.

3.3 Variation Of XPD With Elevation Angle

Figs 3.10 to 3.12 show the values of XPD as the elevation angle is varied. Generally, XPD improves with increasing elevation angle and decreasing frequency particularly at low frequencies. XPD is low at small elevation angle and highest at elevation angle of 55^0 for all rain types. Depolarization effect is worst for shower and thunderstorm rain where values become negative at low elevation angles. Low rain rate and small size raindrops in widespread rain cause low depolarization effect on circularly polarized waves. The result of the variation of XPD with elevation angle has therefore shown that it is better to transmit circularly polarized signal at high elevation angles than at low elevation angles for good quality and reliability of signal in dual-polarized communication system operating in tropical regions. At elevation angle of 10^0 and rain rate of 150mm/h and frequency of 25GHz, XPD becomes as low as -28dB during thunderstorm rain. This implies complete and total signal outage at the receiver. At low frequency depolarization has insignificant effect on communication signal.

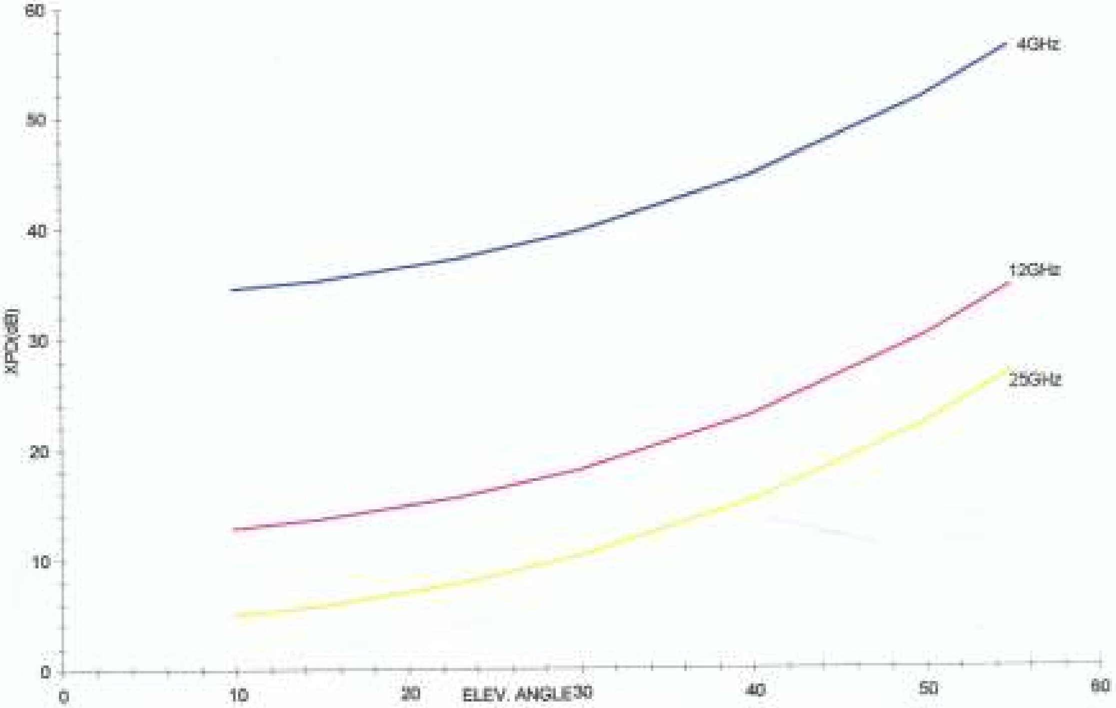


Fig 3.10 : varition of XPDwith elevation angle at rain rate 20mm/h and frequenccies 4,12,25 GHz for widespread rain

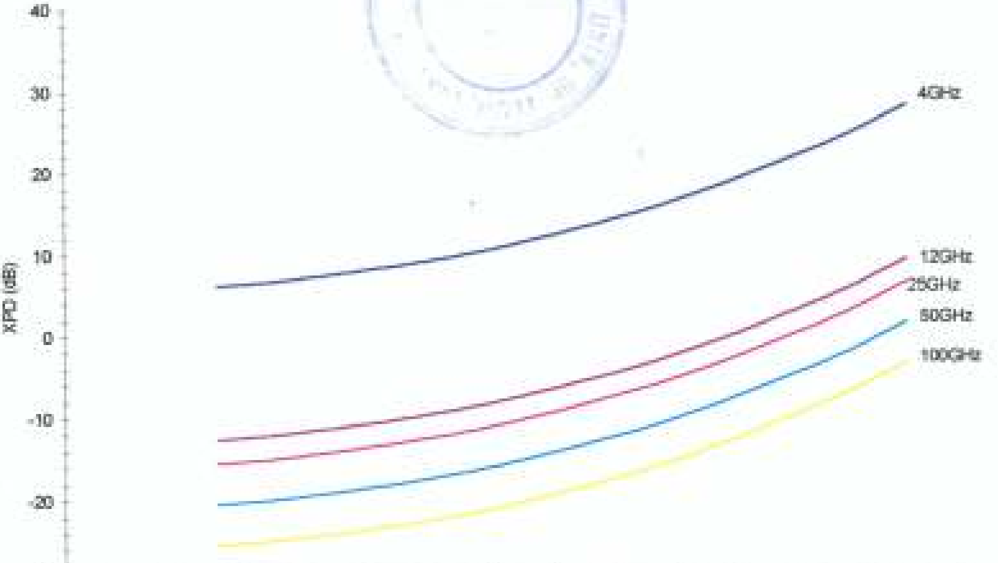


fig.3.11: variation of XPD with elevation anlge at rain rate of 150mm/h and frequencies 4,12,25,50,100 GHz for shower rain

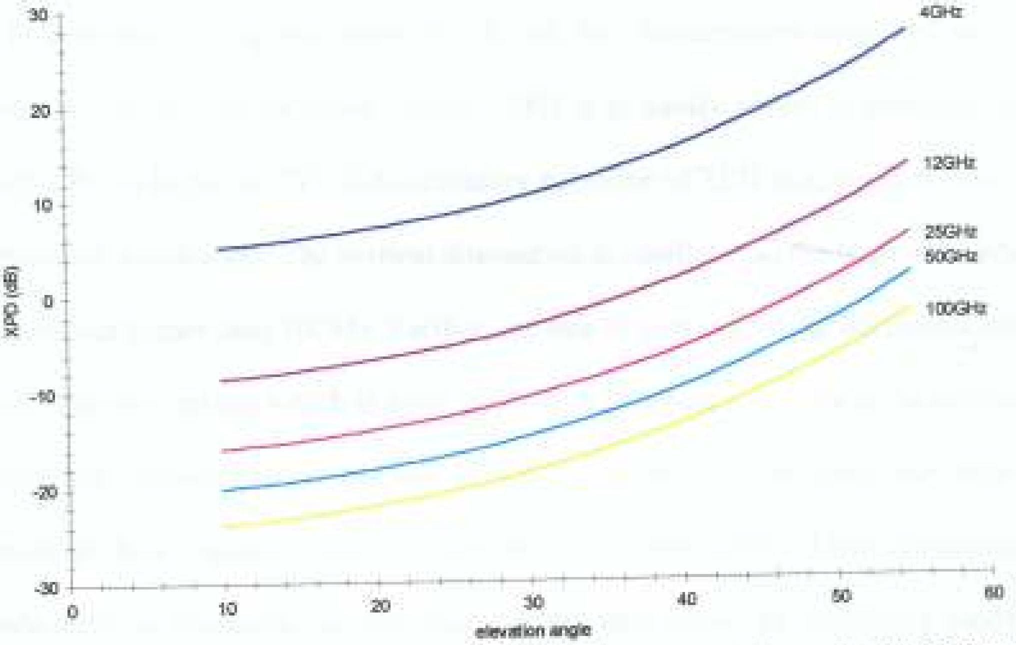


fig 3.12: variation of XPD with elevation angle at rain rate of 150mm/h at frequencies 4,12,25,50,100 GHz for thunderstorm rain

3.4 Variation of XPD with CPA at some frequencies.

Figs 3.13 to 3.18 shows the variation of XPD with CPA at elevation angle of 23^0 and 55^0 for some rain rates and frequencies .The results show that XPD decreases linearly with CPA up to 10dB level for widespread rain. The XPD also decreases with increasing rain rate. Depolarization and attenuation are better for wide spread rain than for other rain types. XPD decreases to negative value for shower and thunderstorm rain. The results are also compared for the two elevation angles. XPD is generally poorer at elevation angle of 23^0 while CPA is higher at 23^0. The oscillatory behavior of XPD is as result of the variation in differential attenuation. The vertical attenuation is smaller than the horizontal attenuation at frequencies higher than 10GHz. Further, the rate of decrease of the horizontal attenuation is faster than the vertical which is more gradual. A consequence of these variations is that the differential attenuation per decibel of vertical attenuation becomes oscillatory. Typical results of these variations are available from Ajewole (1997). Thus calculating the XPD particularly at frequencies greater than 30GHz then shows an oscillatory tendency. Also, the validity of the Olsen's (1981) approximate formula used is questionable at frequencies higher than 30GHz. These oscillations featured prominently in all situations investigated. This result shows that attenuation and depolarization become more significant as rain rate increases for circularly polarized waves, which is similar to a linearly polarized wave when compared with result of Ajewole et al., (1999). It is better to transmit circularly polarized signals at elevation angle of 55^0 than at any other lower elevation angle.

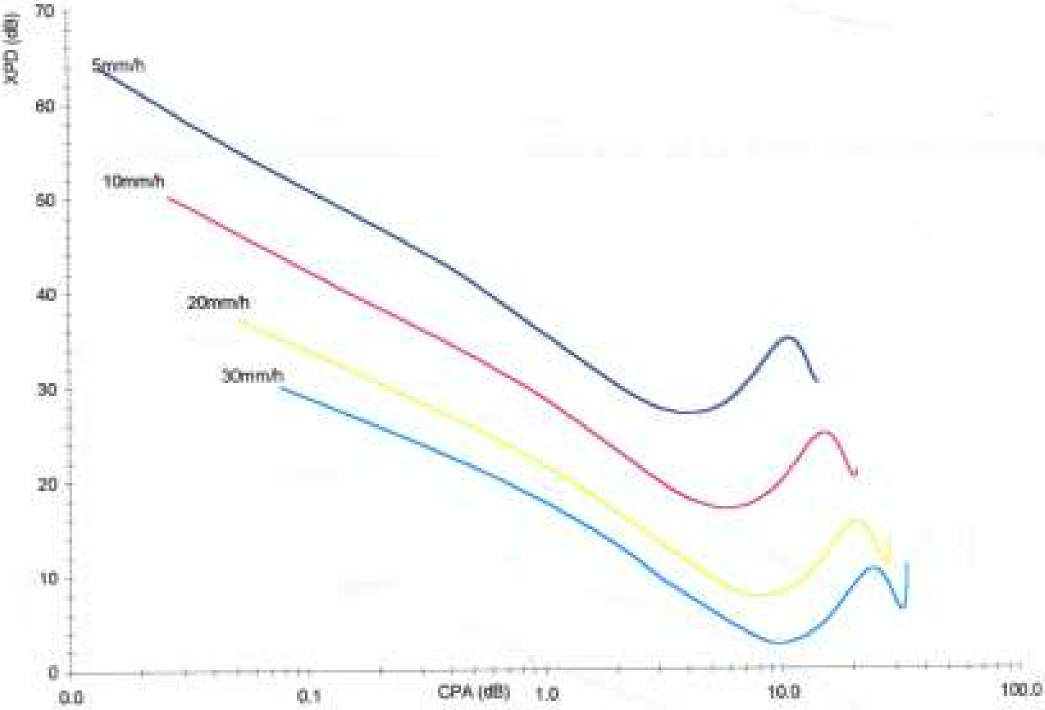


Fig 3.13 :Variation of XPD with CPA at rain rate of 5,10, 20,30mm/h and elevation angle of 23 for widespread rain,for frequency range of 4-100GHz.

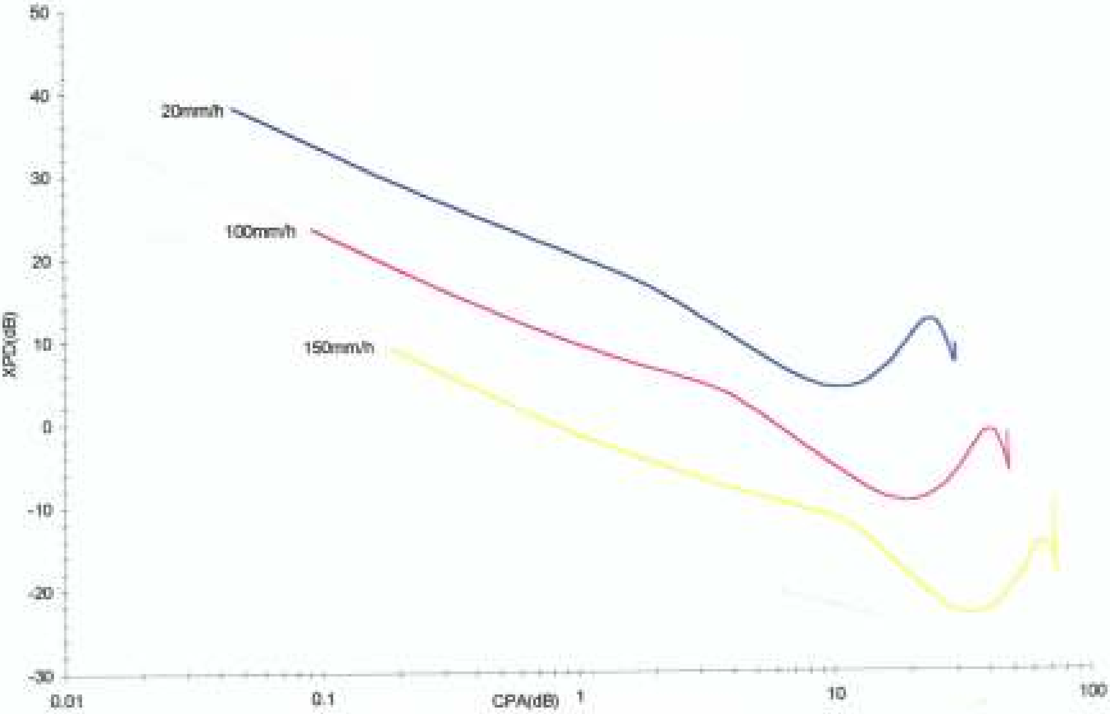


Fig 3.14:Variation of XPD with CPA at rain rate of 20,100,150mm/h and elevation angle of 20 for shower rain,for frequency range 4-100GHz.

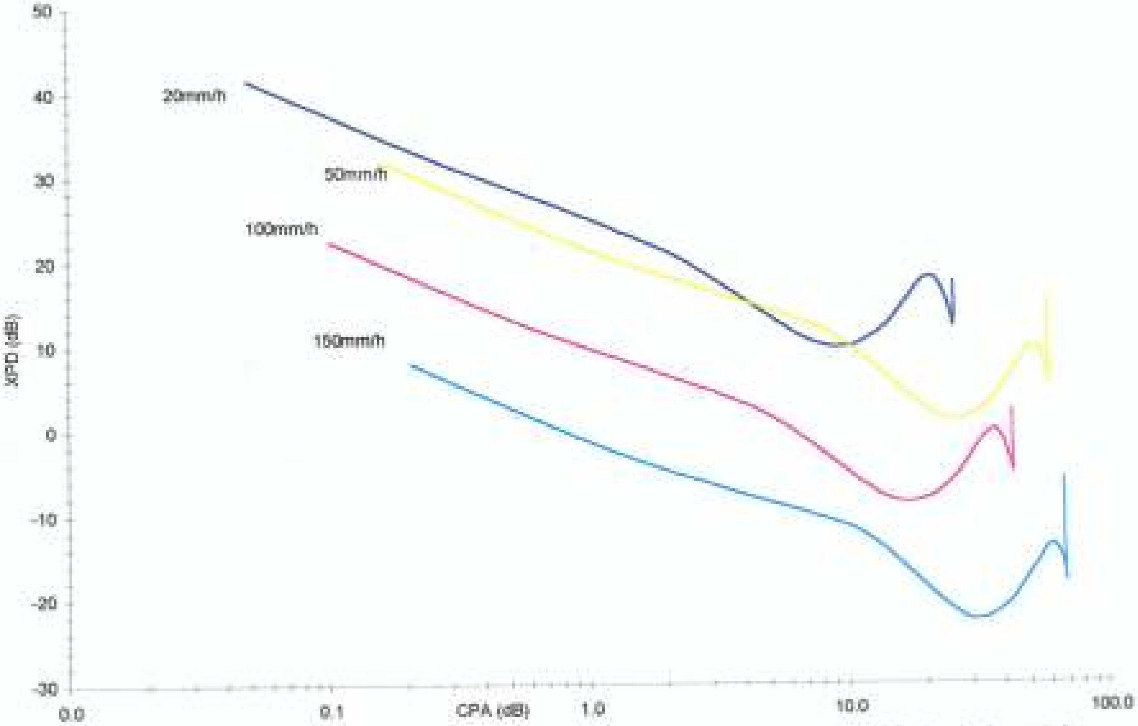


Fig 3.15:Variation of XPD with CPA at rain rate of 20,50,100,150mm/h and elevation angle of 23 for thunderstorm rain,for frequency range 4-100GHz.

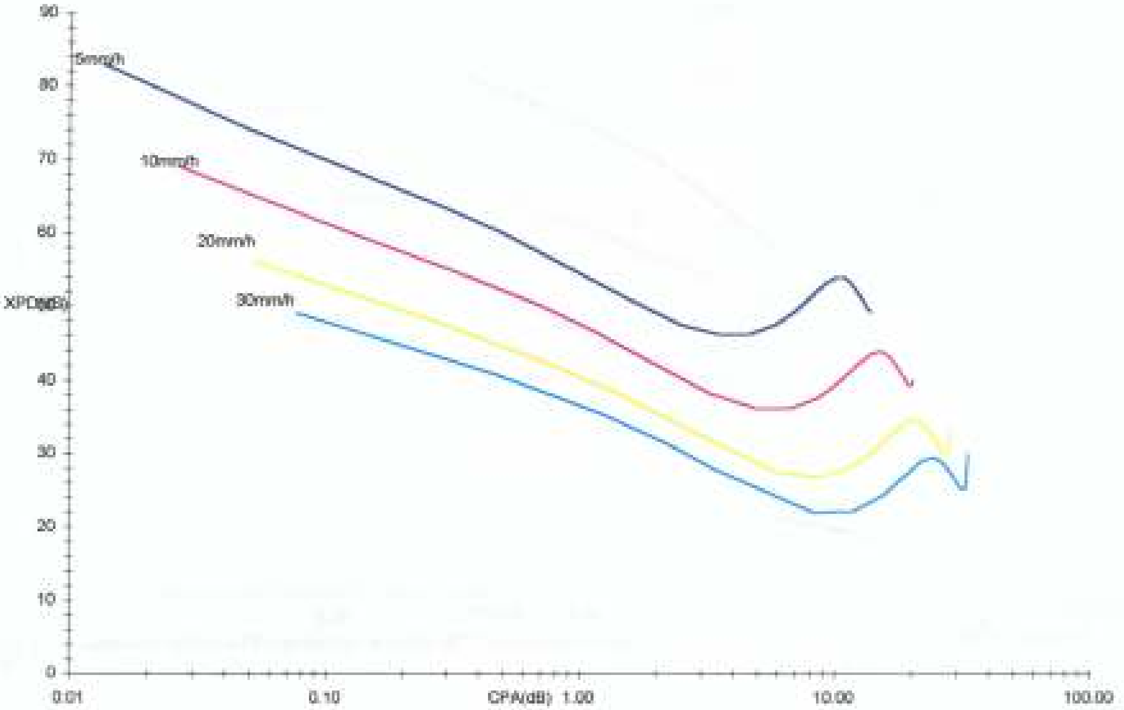


Fig 3.16 : variation of XPD with CPA at rain rate 5,10,20,30mm/h and elevation angle 55 for widespread rain for frequency range 4-100GHz

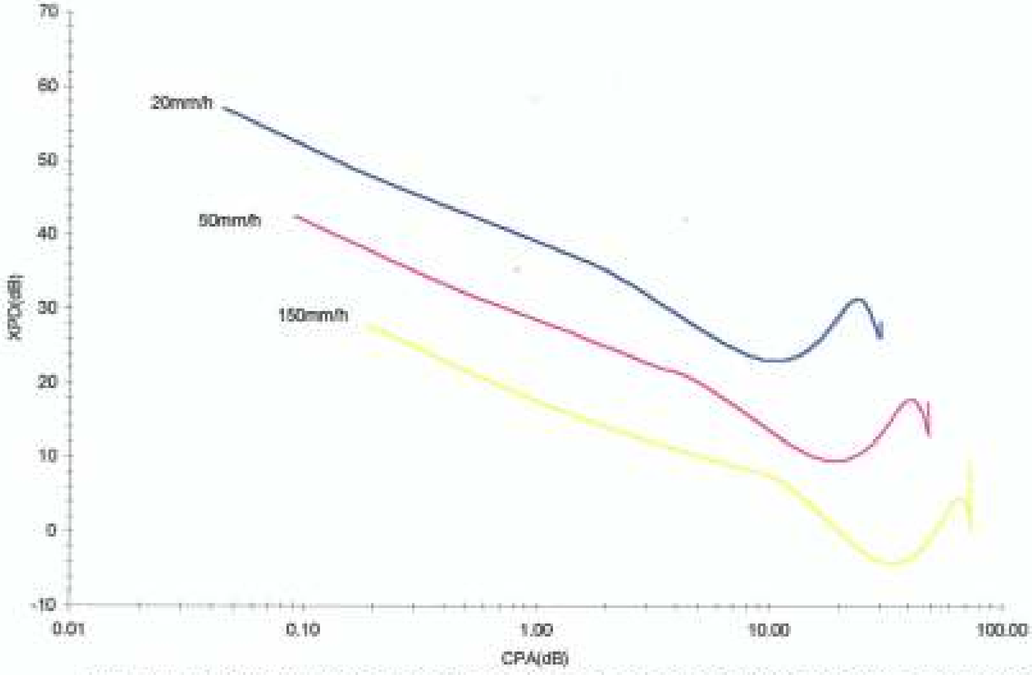


Fig 3.17 : variation of XPD with CPA at rainrate of 20,50 150 and elevation angle of 55 for shower rain, for frequency range of 4-100GHz

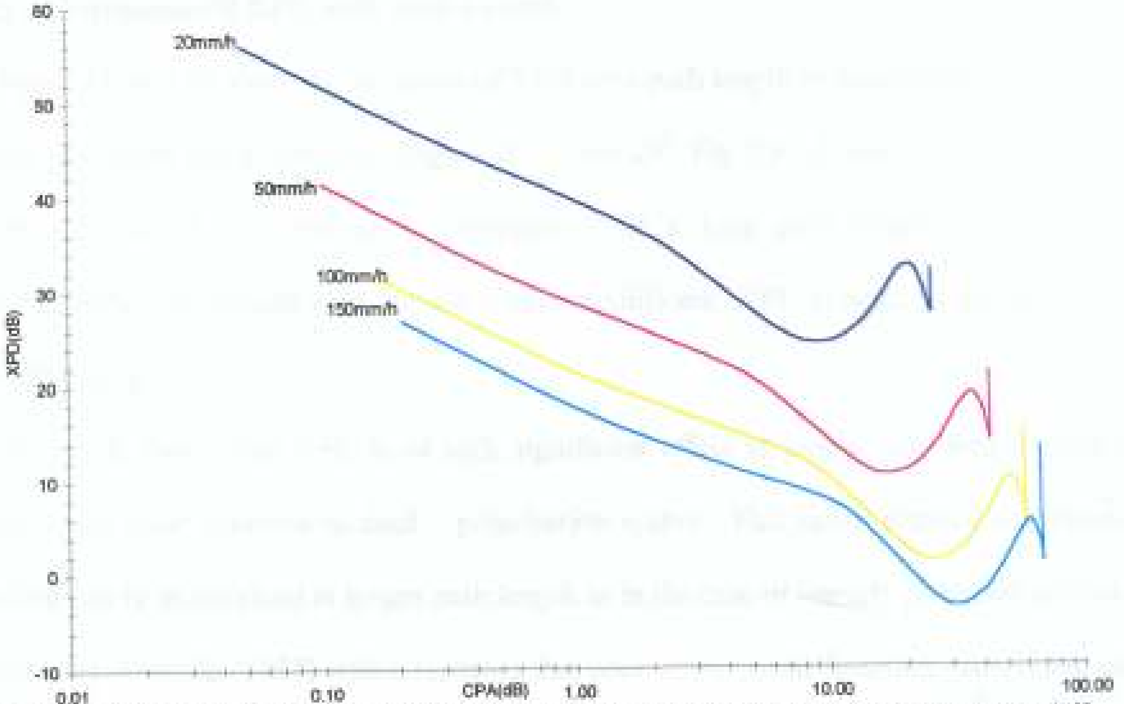


Fig 3.18 : variation of XPD with CPA at rain rate of 20,50,100,150mm/h and elevation angle of 55 for thunderstorm rain for frequency range 4-100 GHz

3.5 Variation Of XPD with Path Length

Figs 3.19 to 3.24 show the variation of XPD with path length at some frequencies for the three rain types and at elevation angles of 55^0 and 23^0. Fig 3.33 shows that XPD decreases with path length with increasing frequency. .At a long path length of about 4km, depolarization of circular polarization is more significant .XPD is better at elevation angle of 55^0 than at 23^0.

The result shows that XPD is of high significant effect at longer path length implying poor cross polar isolation in dual – polarization system .This result implied that repeater station can be maintained at longer path length as in the case of linearly polarized system as shown by Ajewole (1997) which reported that poor cross –polar isolation occurred at path length longer than 2km.

XPD is generally poor for thunderstorm and shower rain at the selected frequencies.

3.6 Variation Of CPA With Path Length

Figs 3.25 to 3.29 show variation of CPA with path length at elevation angles of 23^0 and 55^0 for the three rain types .The results show that CPA increases with increasing path length . At higher path length CPA will be serious at all frequencies. CPA at lower path length is generally low with increasing frequency. Copolar attenuation is worst at the highest path length. The variation of CPA for all rain types increase almost linearly with increasing path length. Circularly polarized communication signals used for orthogonal channel will highly depolarized at longer path length Attenuation is at its highest value for the longest path length for all rain types with the worst attenuation at elevation angle of 55 for thunderstorm and shower rain. XPD improves with increasing elevation angle to the satellite. Poor copolar isolation of signal is due mainly to depolarization. This result agrees with result of Ajewole (1997) and Ajewole (1998).

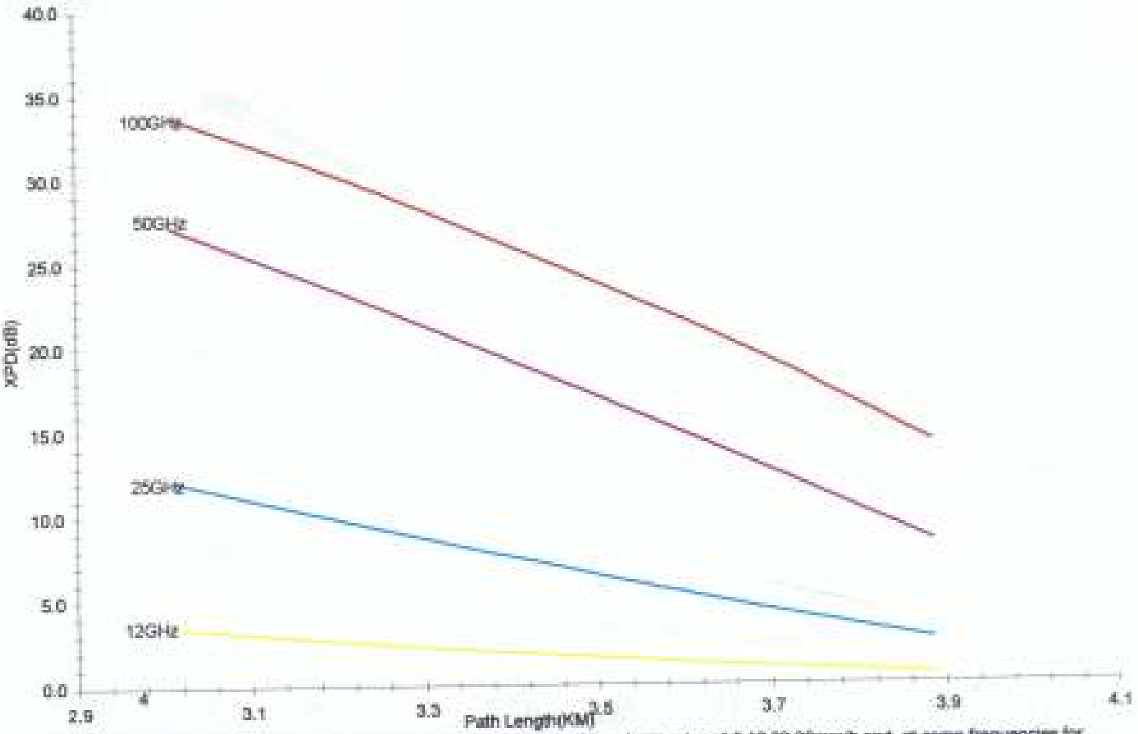


Fig 3.19:Variation of XPD with path length at elevation angle of23 and rain rates of 5,10,20,30mm/h and at some frequencies for widespread rain.

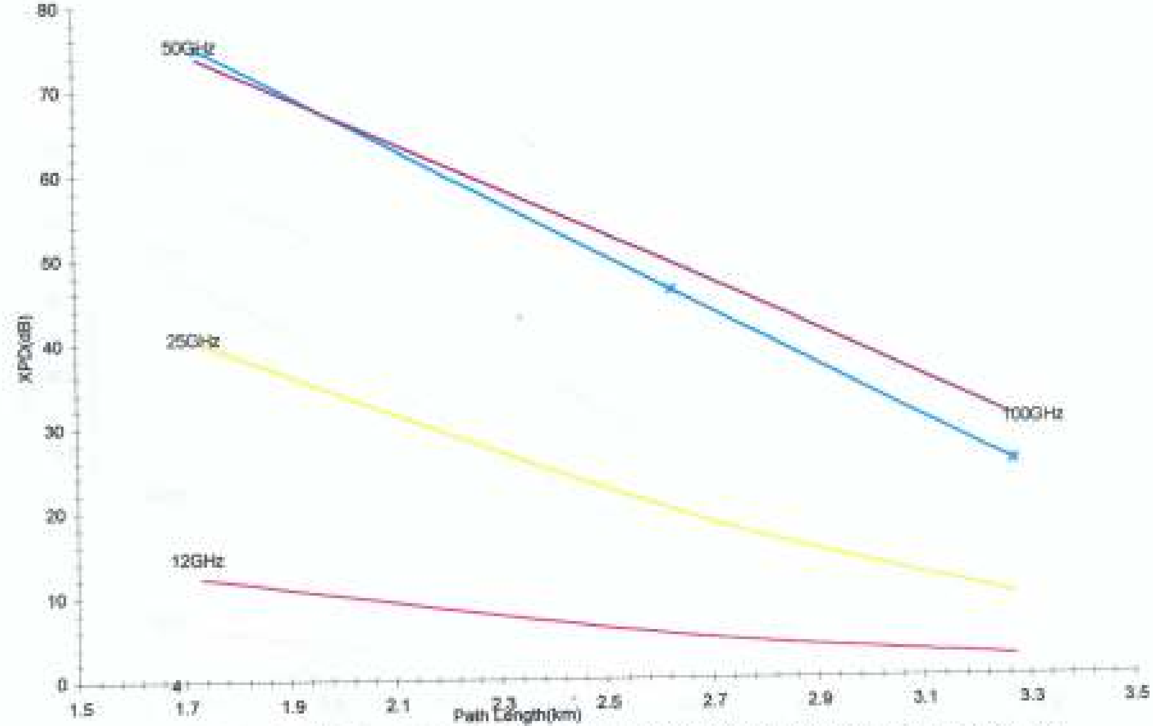


Fig 3.20:Variation of XPD with path length at elevation angle of 23 and rain rates of 20,50,150mm/h at some frequencies forshower rain.

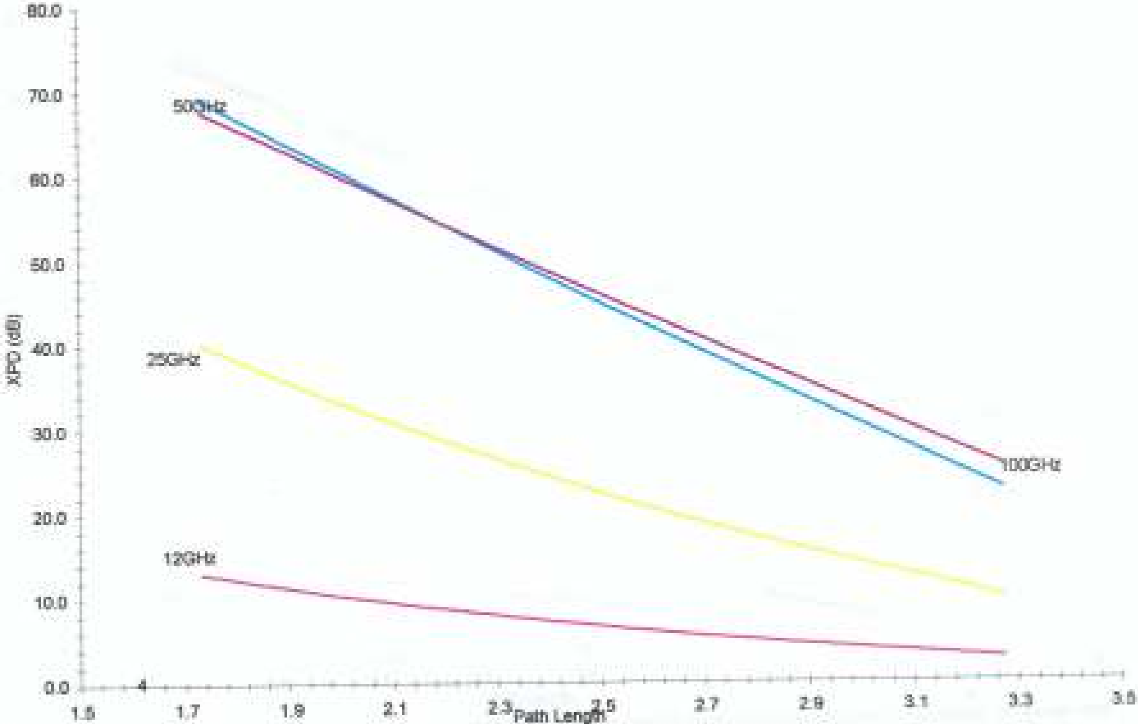


Fig 3.21:Variation of XPD with path length at elevation angle of 23 and rain rates of 20,50,100,150mm/h and some frequencies for thunderstorm rain.

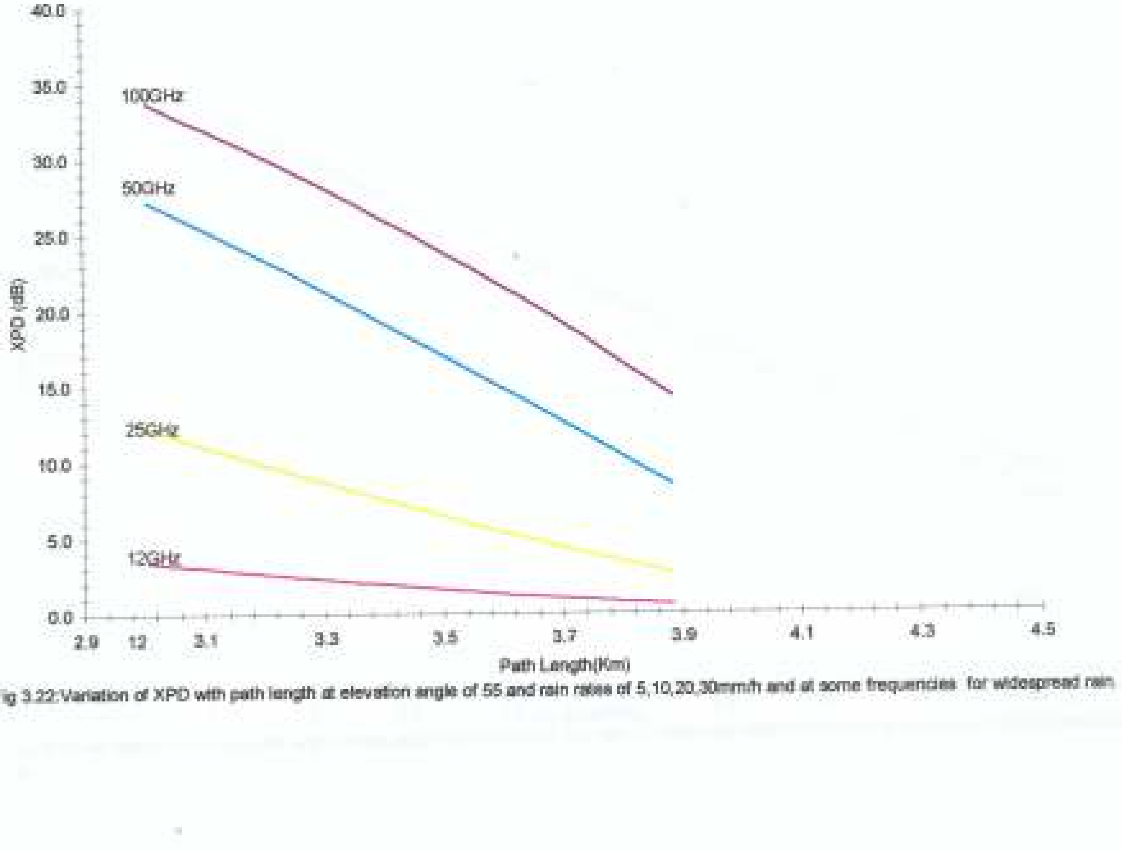


Fig 3.22:Variation of XPD with path length at elevation angle of 55 and rain rates of 5,10,20,30mm/h and at some frequencies for widespread rain.

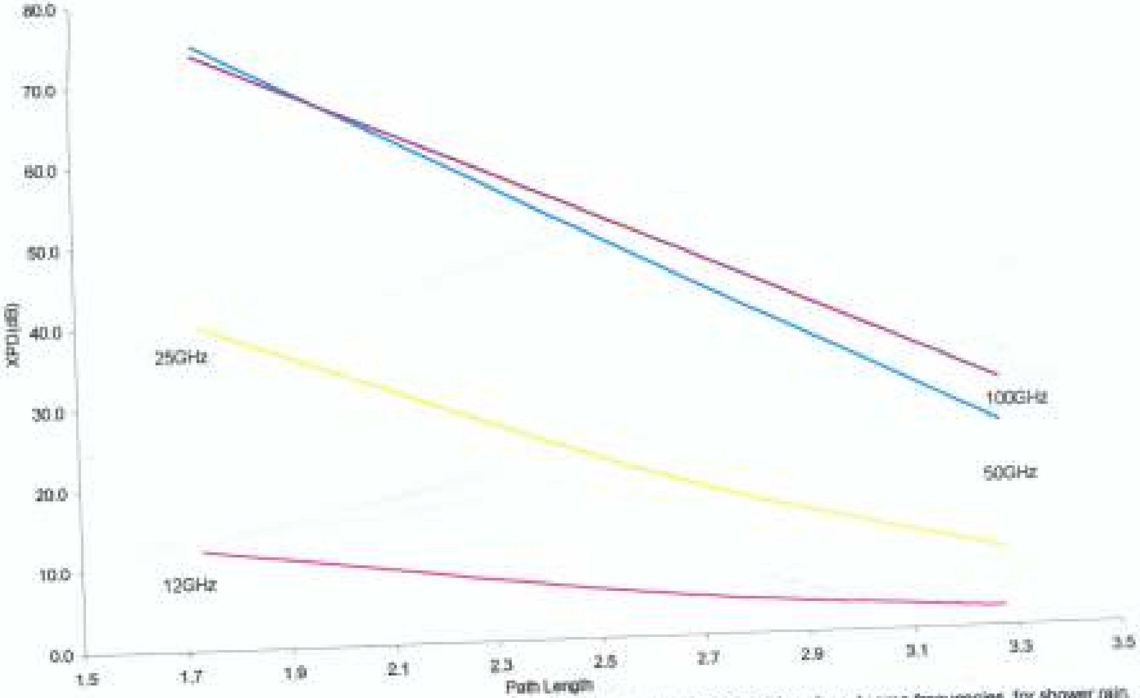


Fig 3.23:Variation of XPD with path length at elevation angle of 55 and rain rates of 20,50,150mm/h and some frequencies for shower rain.

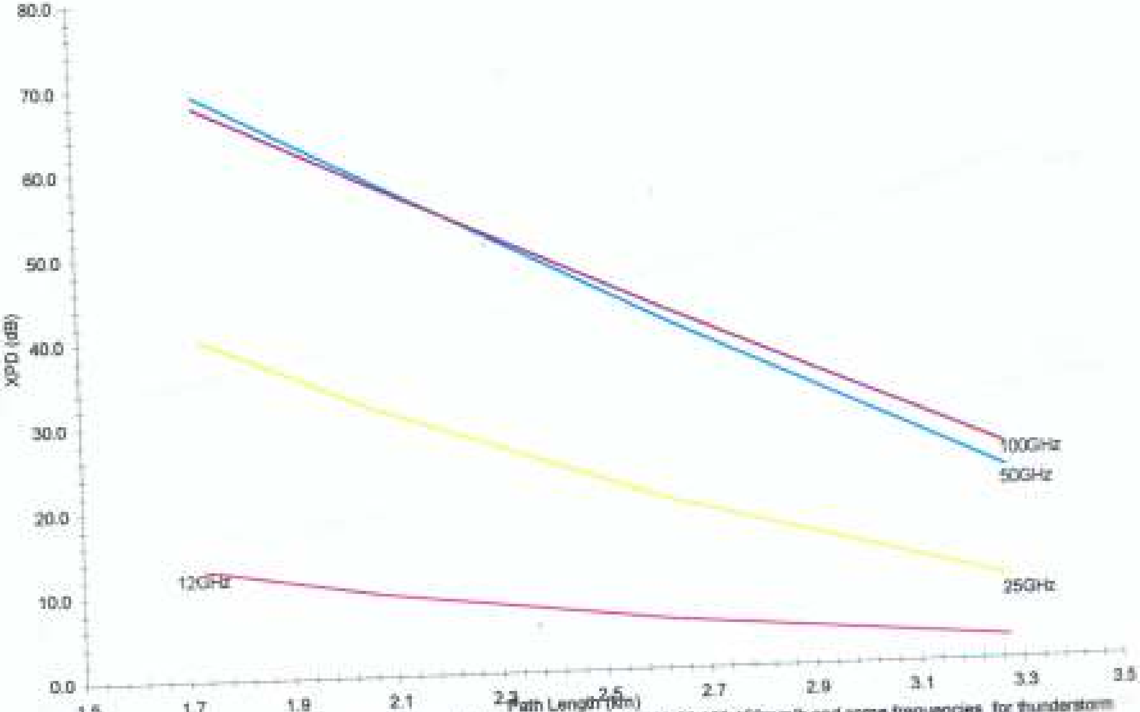


Fig 3.24:Variation of XPD with path length at elevation angle of 55 and rain rates of 20,50,100,150mm/h and some frequencies for thunderstorm rain.

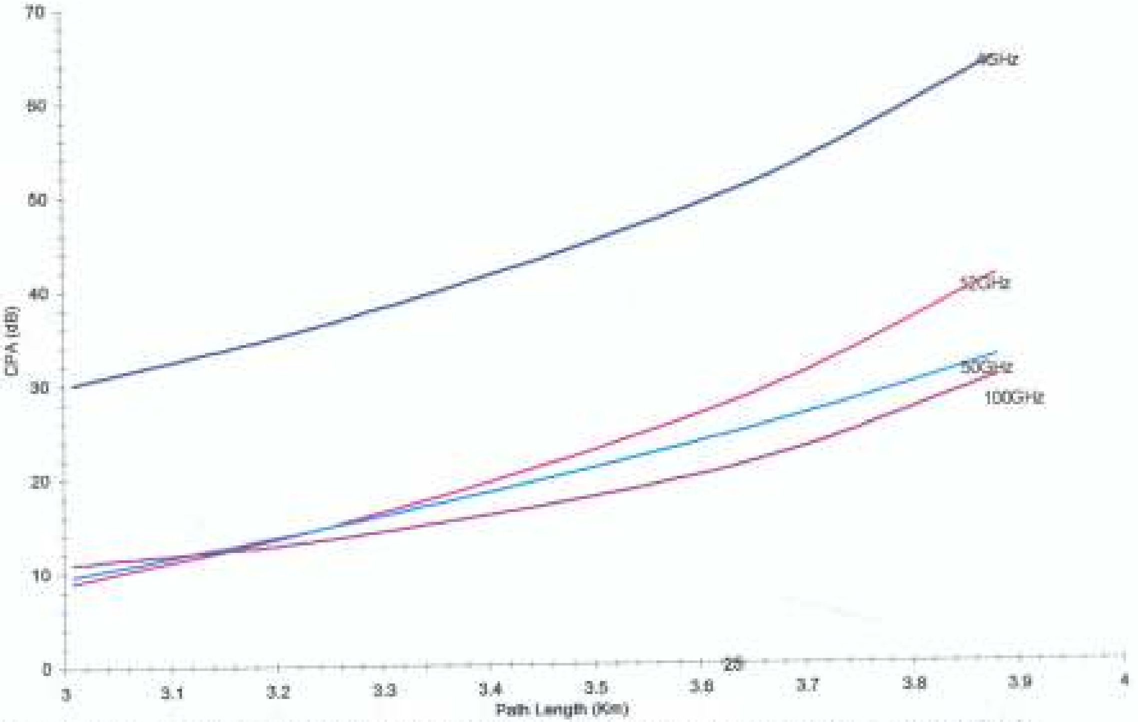


Fig 3.25:Variation of CPA with path length at elevation angle of 23 and rain rate 5,10,20,30mm/h and frequencies 4,12,50,100GHz for widespread rain.

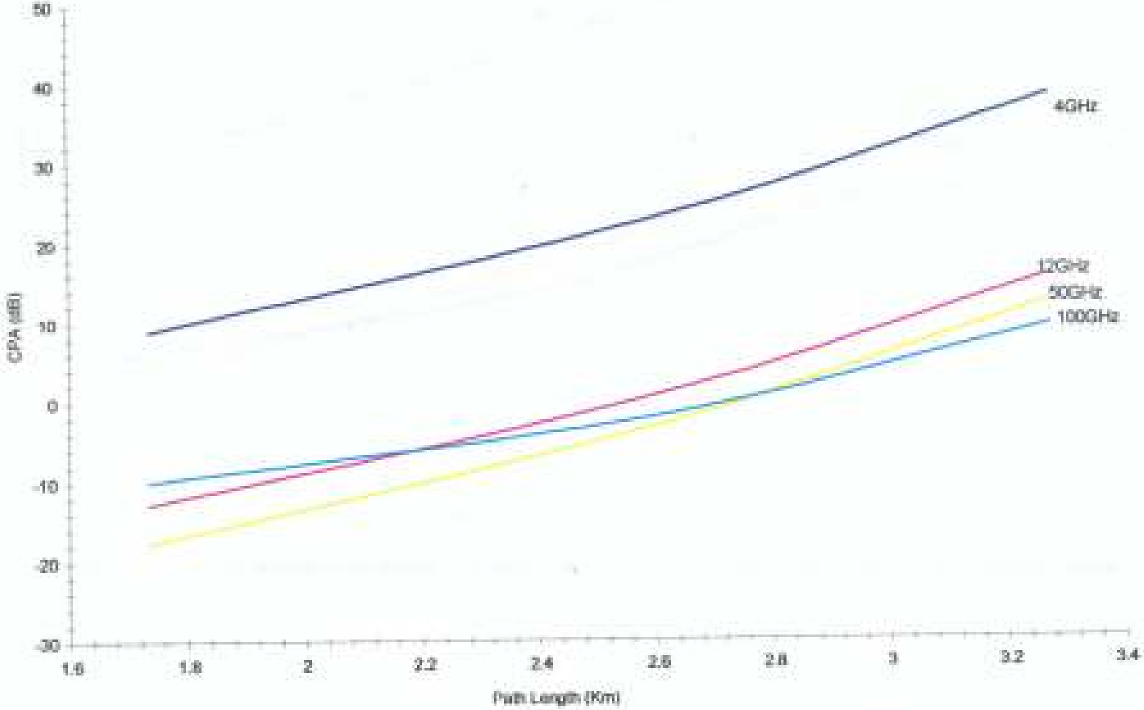


Fig 3.26:Variation of CPA with path length at elevation angle of 23 and rain rate 20,50,150mm/h and some frequencies for shower rain.

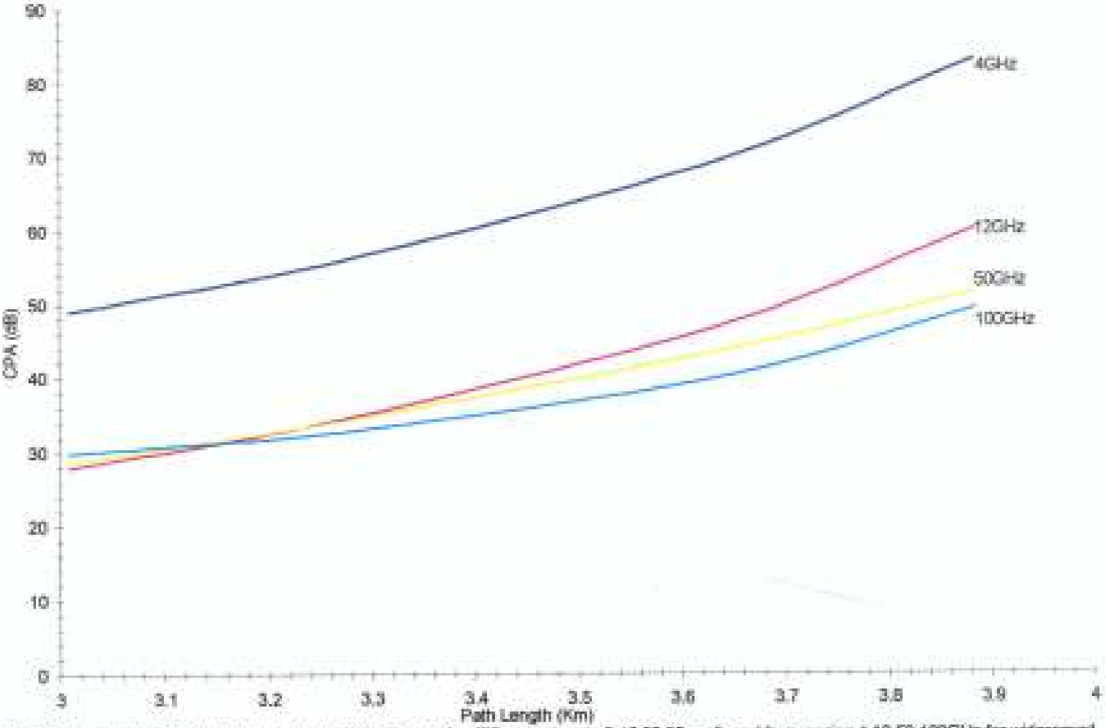


Fig 3.27 Variation of CPA with path length at elevation angle of55 and rain rate 5,10,20,30mm/h and frequencies 4,12,50,100GHz for widespread rain.

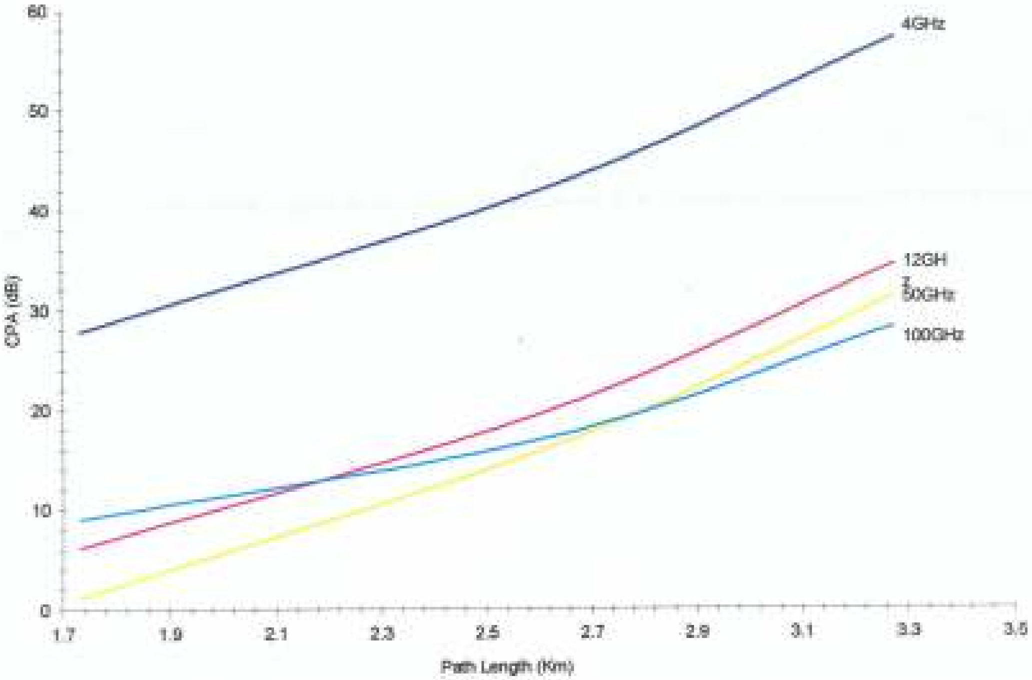


Fig 3.28 Variation of CPA with path length at elevation angle of 55 and rain rate 20,50,150mm/h and frequencies 4,12,50,100GHz for shower rain.

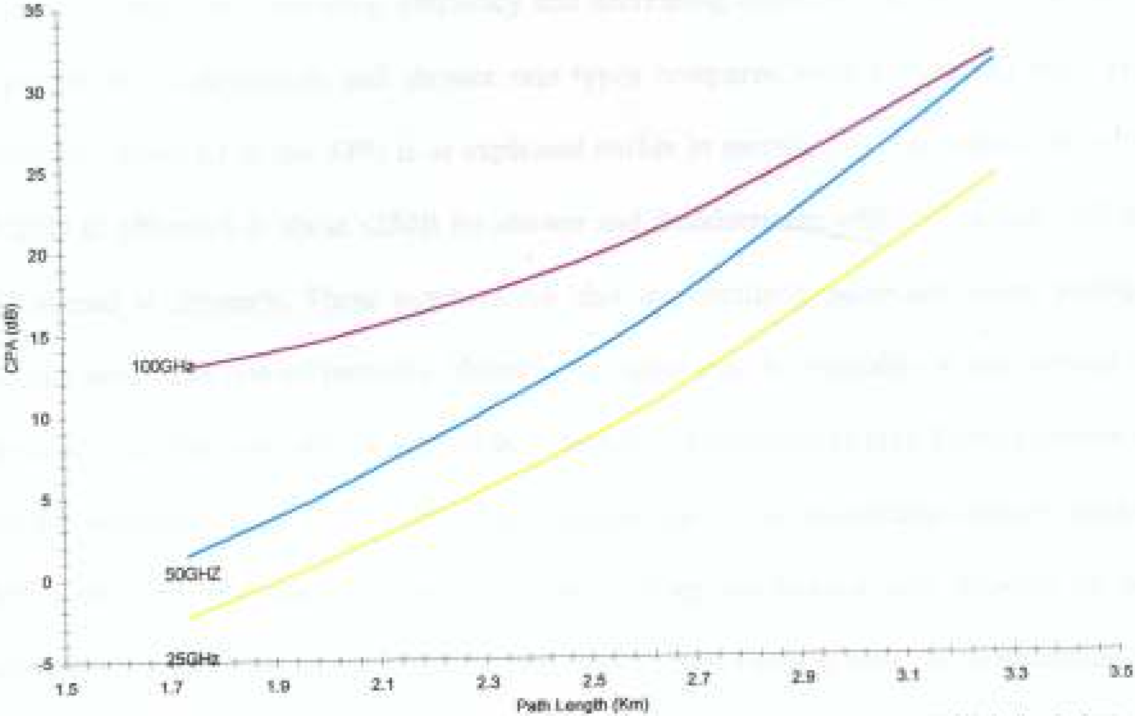


Fig 3.29:Variation of CPA with path length at elevation angle of 55 and rain rate 20,50,150mm/h and frequencies 25,50,100GHz for thunderstorm rain.

3.7 Variation Of XPD With Frequency

Figs. 3.30 to 3.38 show the frequency characteristics of XPD at some rain rates and elevation angles ranging between 10^0 to 55^0 , Figs. 3.30 to 3.33 show that XPD decreases almost linearly with increasing frequency up to about 40GHz and then rise and fall in regular pattern over the frequency interval of about 20GHz. This implies that XPD becomes poorer with increasing frequency and decreasing receiver elevation angle. XPD is poorer for thunderstorm and shower rain types compared with widespread rain. The oscillatory behavior of the XPD is as explained earlier in section 3.4. The minimum value of XPD at 150mm/h is about -28dB for shower and thunderstorm while it is about 5dB for widespread at 20mm/h. These results show that for circularly polarized signal passage through stratiform rain of intensity 20mm/h, no signal may be available at the receiver at this rain rate. The same will be true of high intensity thunderstorm rain. Depolarization is worst at elevation angle of 23^0 and at high frequencies. Cross polarization discrimination (XPD) of circularly polarized signal is better during widespread rain because of the spherical shape of most of the raindrops in the rain type. There is little or no distortion of the shape from spherical. This result agrees well with the result of Oguchi (1983) for linearly polarized signal. Ajewole et al., (1999) and Ajewole (1998) also obtained similar results for linearly polarized signal passage through tropical rain.

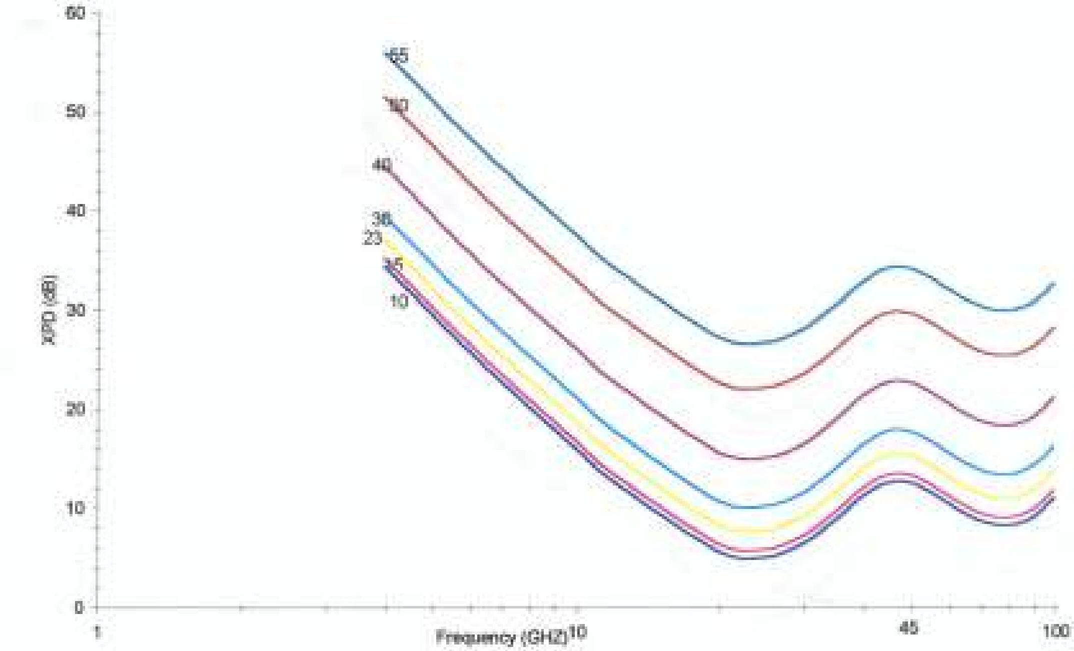


Fig 3.30 Frequency Characteristic of XPD at Rain rate 20 mm/h and elevation angle of 10-55 degree for Widespread Rain type

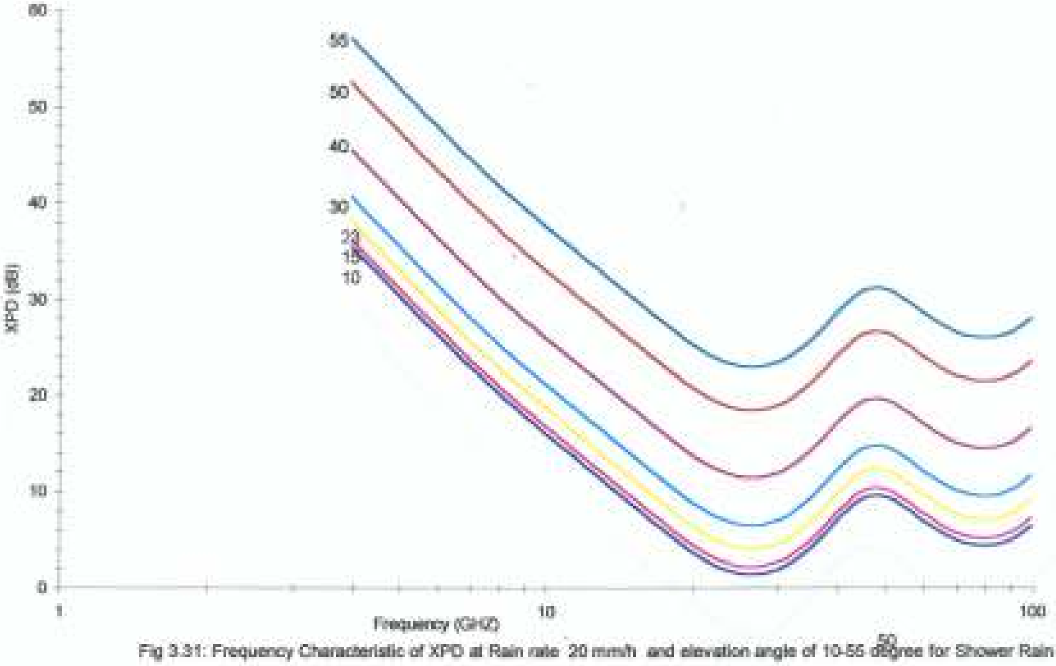


Fig 3.31: Frequency Characteristic of XPD at Rain rate 20 mm/h and elevation angle of 10-55 degree for Shower Rain type

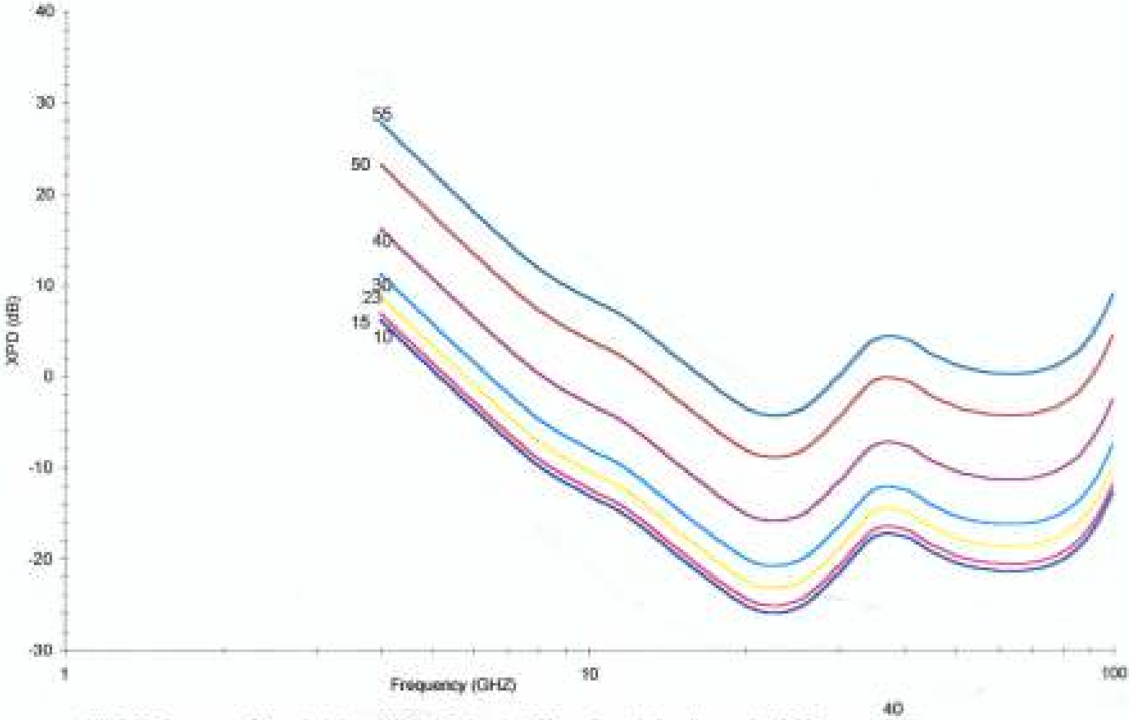


Fig 3.32: Frequency Characteristics of XPD at Rain rate 150 mm/h and elevation angle 10-55 degree for Shower Rain type

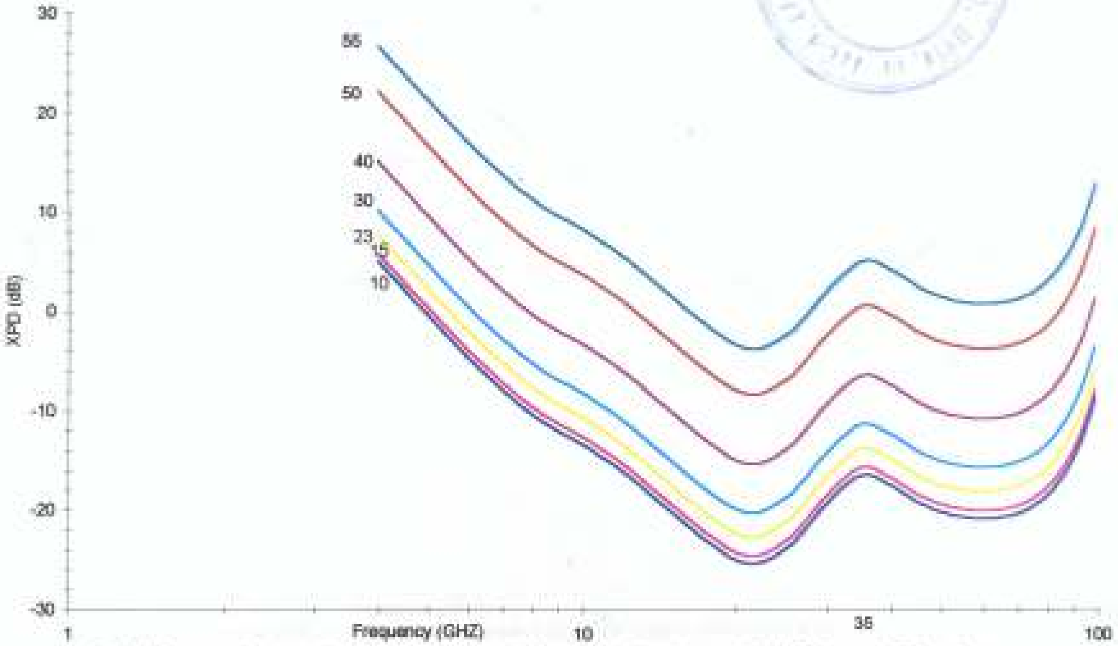


Fig 3.33 Frequency Characteristics of XPD at Rain rate 150 mm/h and elevation angle of 10-55 degree for Thumderstorm Rain type

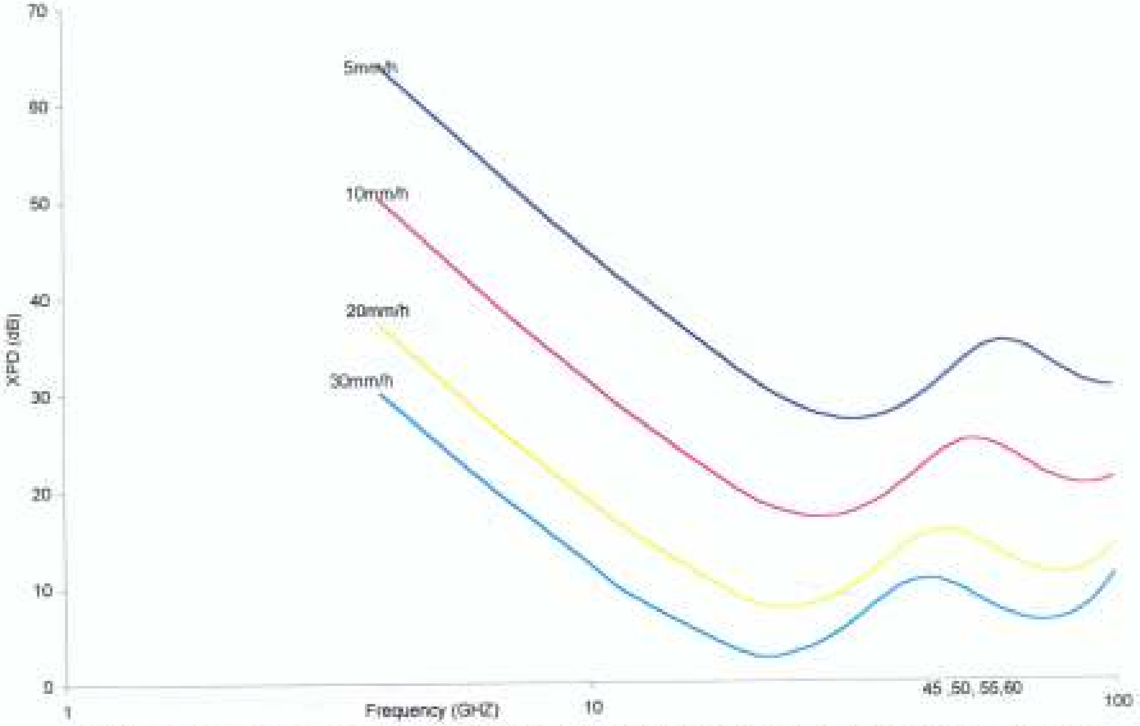


Fig 3.34 : Frequency Characteristics of XPD at Rain rate 5,10,20 and 30 mm/h and elevation angle of 23 for Widespread Rain type

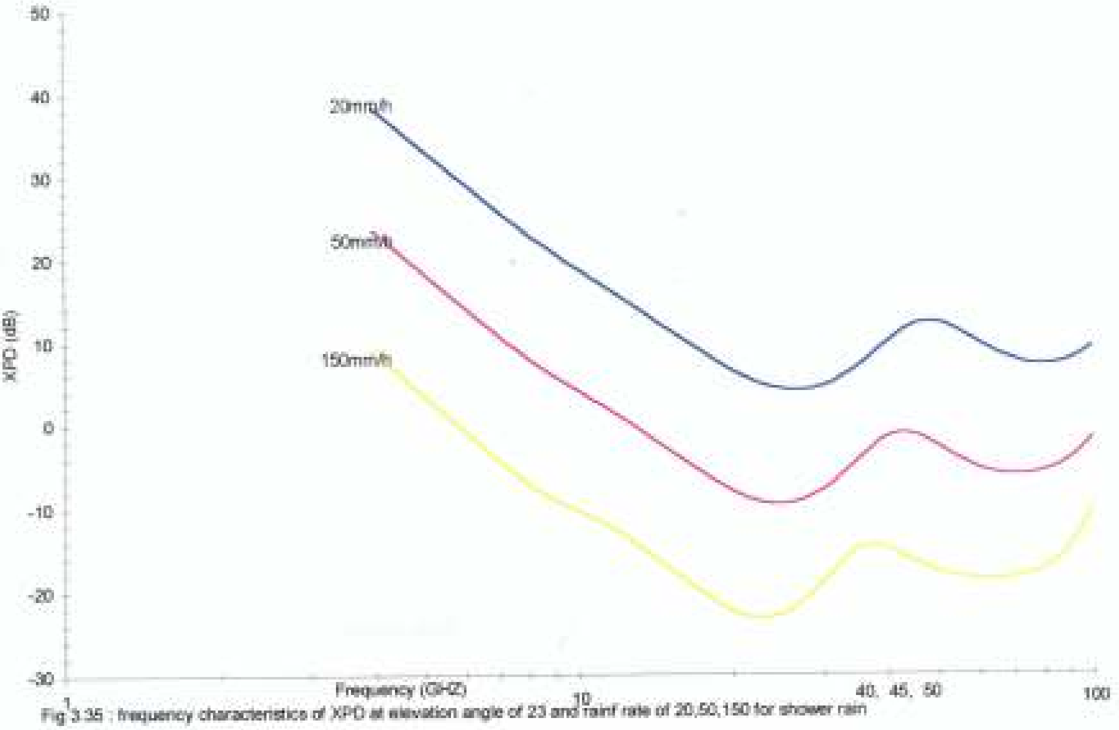


Fig 3.35 : frequency characteristics of XPD at elevation angle of 23 and rainf rate of 20,50,150 for shower rain

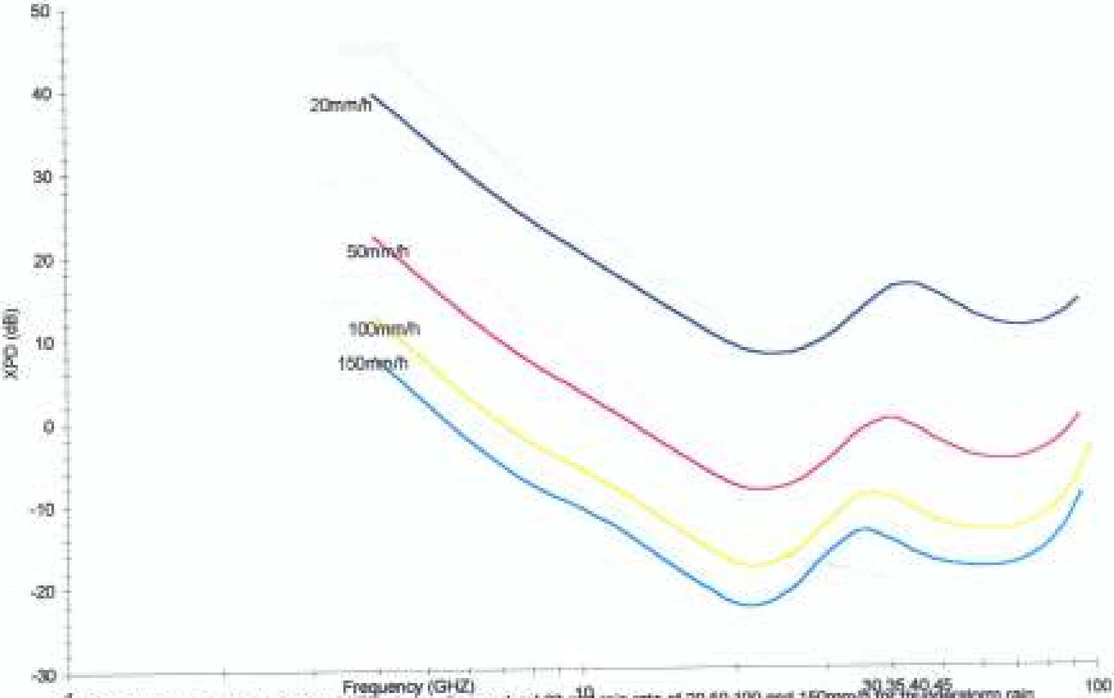


Fig 3.36 : frequency characteristics of XPD at elevation angle of 23 and rain rate of 20,50,100 and 150mm/h for thunderstorm rain

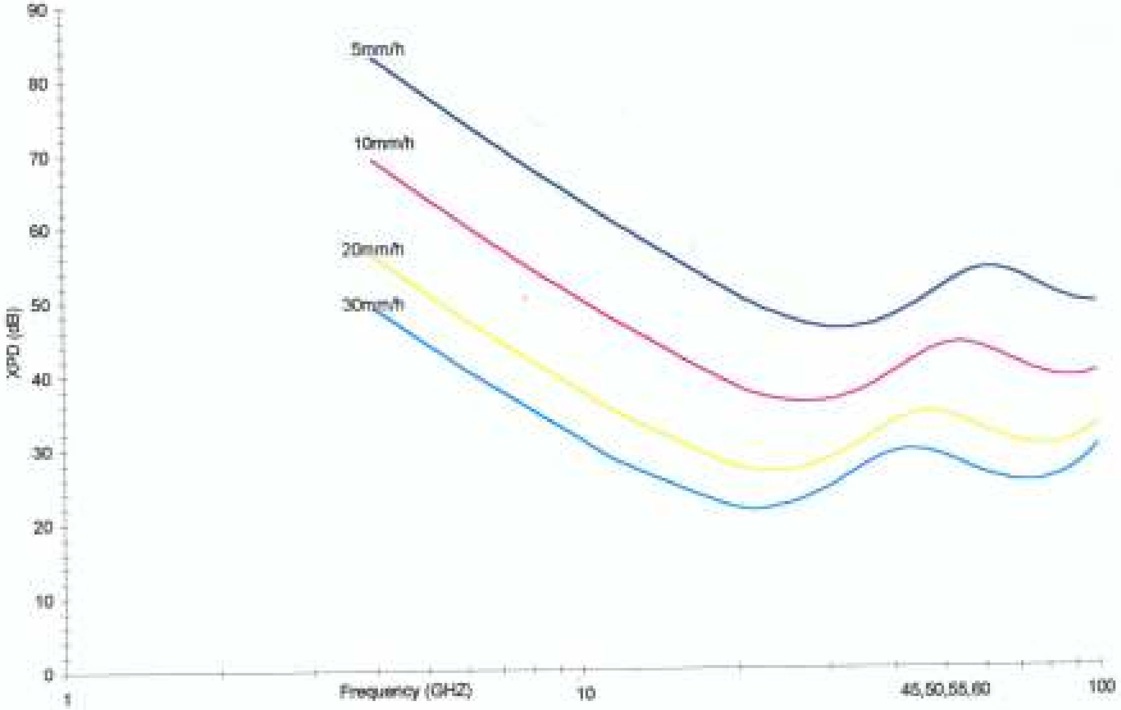


Fig 3.37 Frequency Characteristics of Xpd at Rain rate 5,10,20 and 30 mm/h for Widespread Rain type at

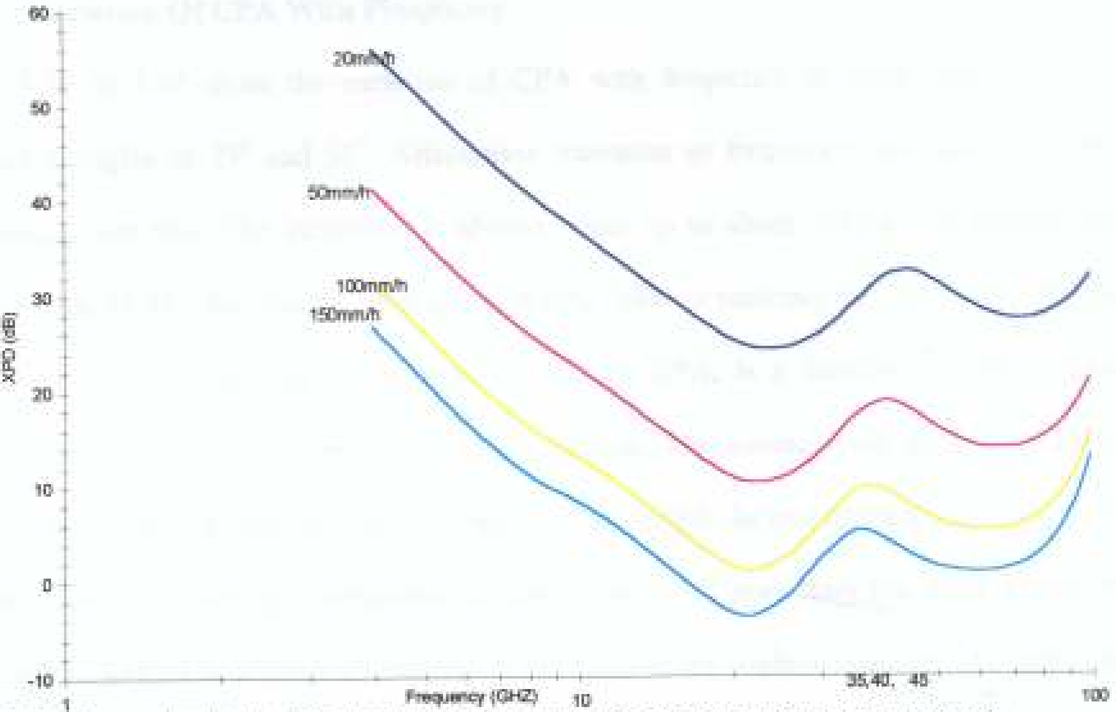


Fig 3.38 : frequency characteristics of XPD at elevation angle of 55 degree and rainrate of 20,50,100,150mm/h for thunderstorm rain

3.8 Variation Of CPA With Frequency

Figs 3.39 to 3.44 show the variation of CPA with frequency at some rain rates and elevation angles of 23^0 and 55^0. Attenuation increases as frequency increases and with increasing rain rate. The increment is almost linear up to about 50GHz. At frequencies higher than 30GHz, the copolar attenuation (CPA) shows a tendency for saturation. This is due largely to the fact that in equation (2.13), the CPA, is a function of the average attenuation in the horizontal and vertical polarizations. This average path attenuation plays a more dominant role than the rain rate and elevation angle factors characterizing the path length. Thus, this average attenuation influences the CPA more than the other factors in equation (2.13). The highest attenuation is obtained at the highest rain rate. At high rain rates, the signal will be highly attenuated thus creating a serious problem for the receiving communication system. This result is also similar to the findings of Ajewole (1998), and Adimula and Ajayi (1996) for linearly polarized signal. At low frequencies, attenuation is low. For this reason, the transmission and reception quality of signals at the C-band (6/4GHz) is better in tropical regions such as Nigeria compared to the high attenuation at the Ku band (14/12 GHz) and other higher frequencies, where rain size drops are comparable to the signal wavelength.

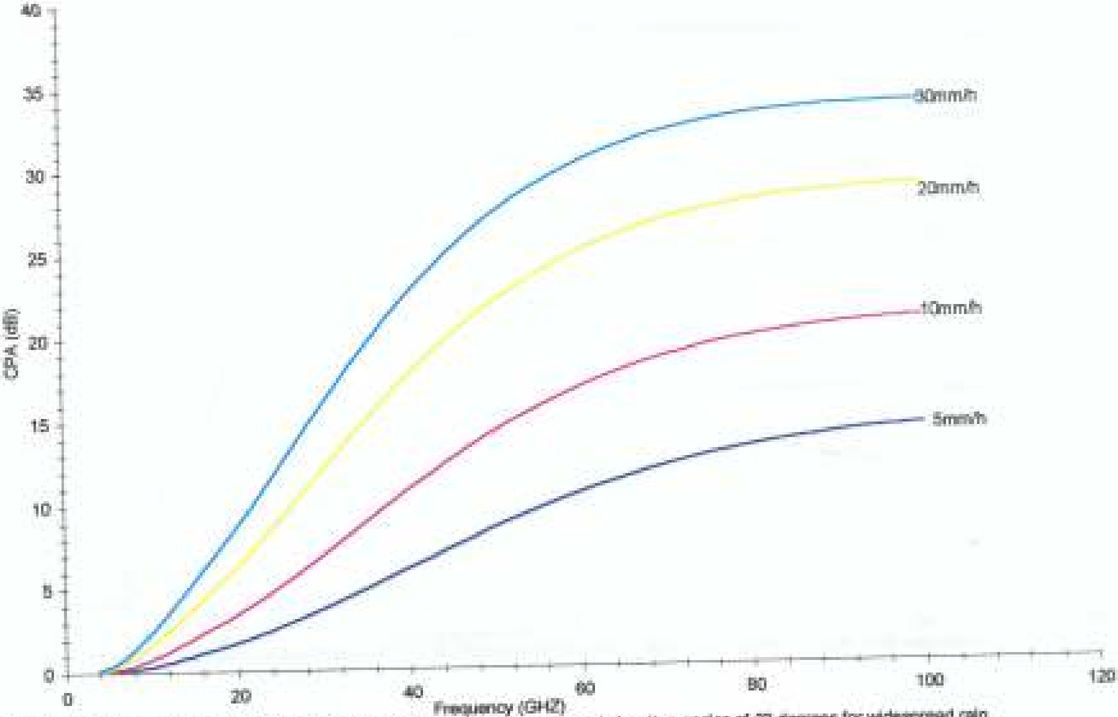


Fig 3.39 : Frequency characteristics of CPA at rain rates of 5,10,20,30mm/h and elevation angles of 23 degrees for widespread rain

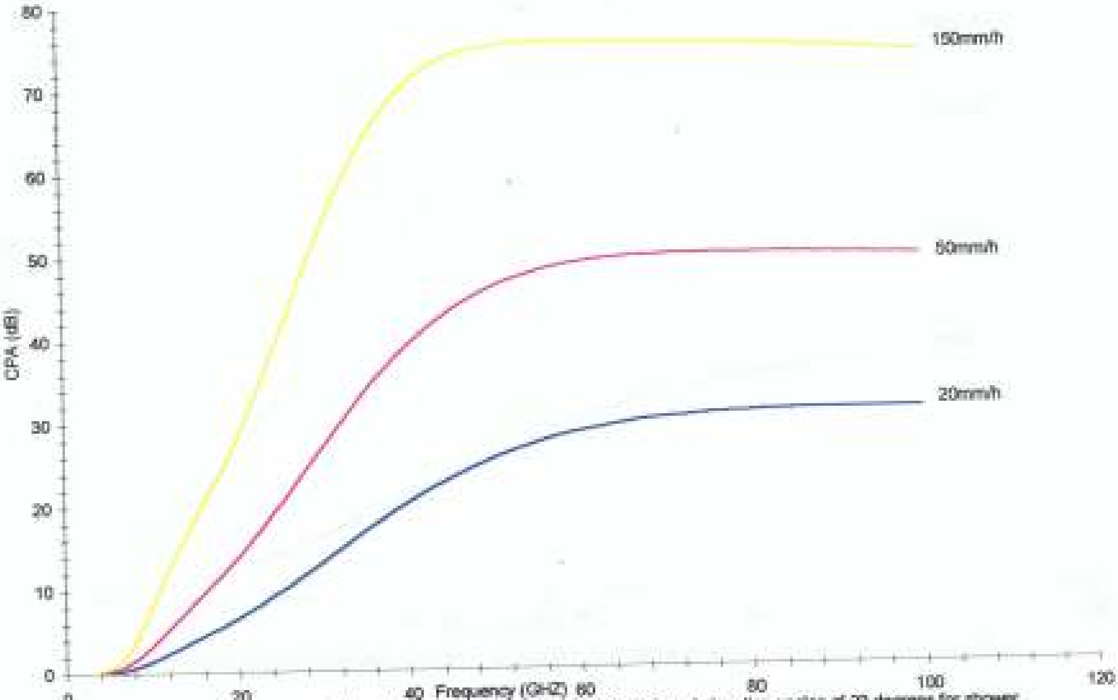


Fig 3.40: Frequency characteristics of CPA at rain rates of20,50,150mm/h and elevation angles of 23 degrees for shower rain

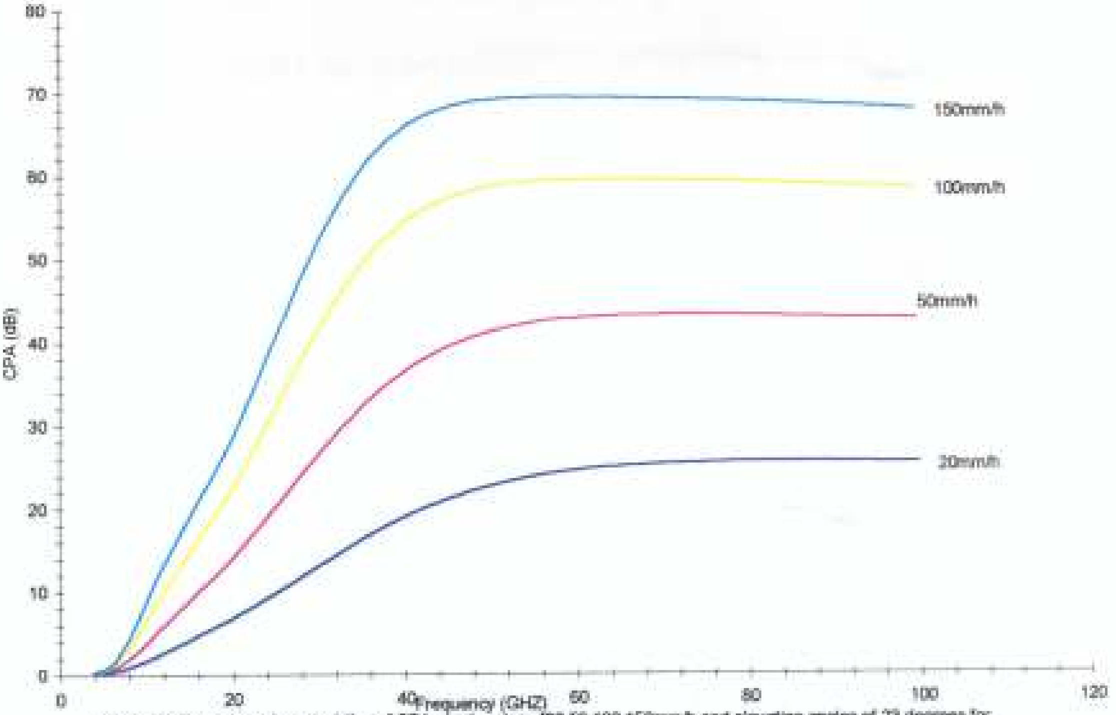


Fig 3.41 : Frequency characteristics of CPA at rain rates of20,50,100,150mm/h and elevation angles of 23 degrees for thunderstorm rain.

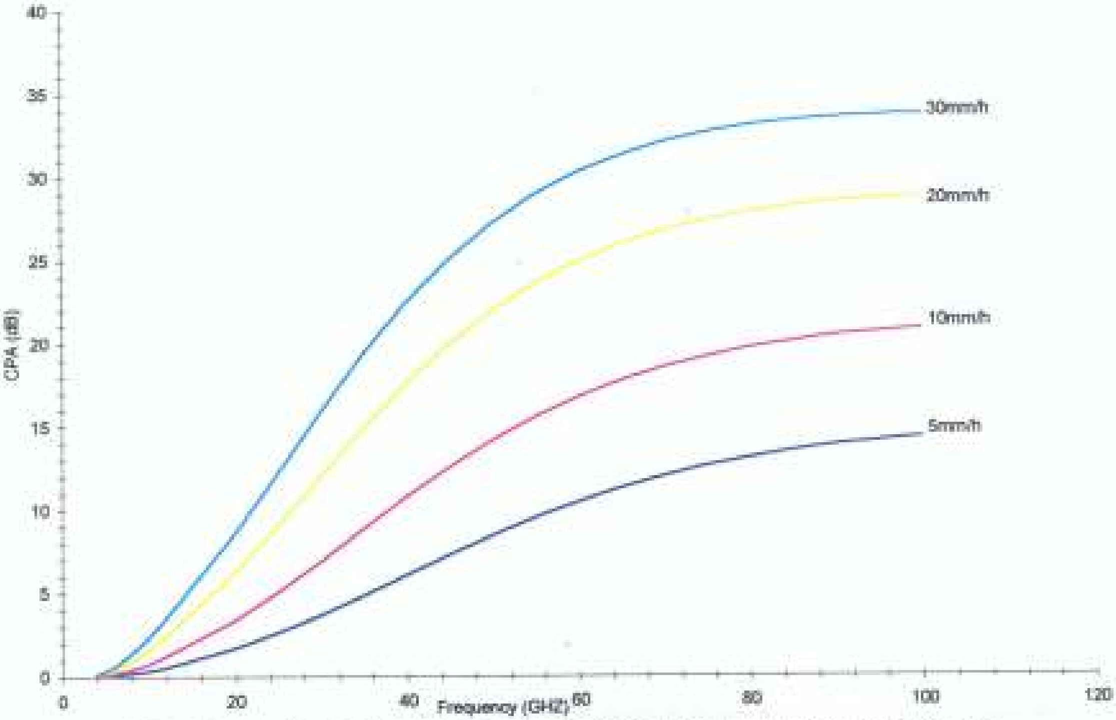


Fig. 3.42: Frequency characteristics of CPA at rain rates of 5,10,20,30 mm/h and elevation angles of 55 degrees for

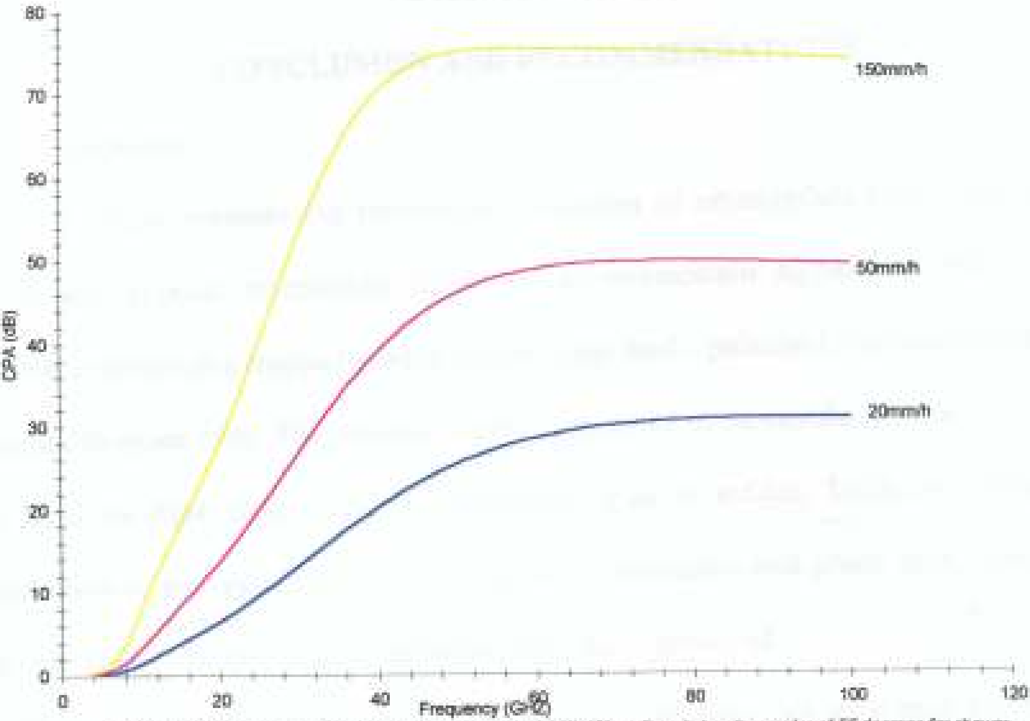


Fig 3.43:Frequency characteristics of CPA at rain rates of20,50,150mm/h and elevation angles of 55 degrees for shower

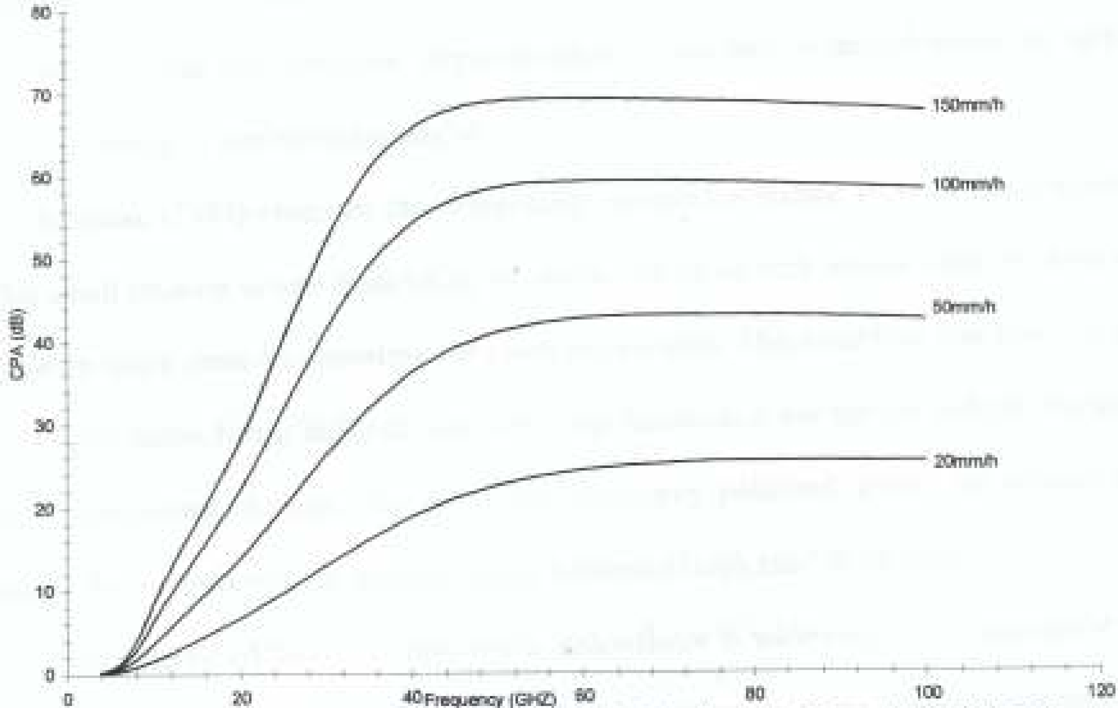


Fig 3.44 : Frequency characteristics of CPA at rain rates of20,50,100,150mm/h and elevation angles of 55 degrees fo thunderstorm rain.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This report presents the theoretical evaluation of cross-polarization discrimination (XPD) and copolar attenuation (CPA) of communication signals at millimeter and centimeter waves in a tropical rainfall region using dual – polarized communication system along earth-space path. The received signal is assumed to be circularly polarized. Either a left hand or right hand circularly polarized signal is suffice. Uniform canting angle distribution is assumed. The values of specific attenuation and phase shift computed by Ajewole (1997) for rain in the tropical location were employed.

The results obtained show that widespread rain does not give rise to significant depolarization unlike the other rain types in which depolarization is severe as rain intensity increases. The result also shows that cross – polarization discrimination decreases with frequency as rain rate increases. Depolarization of circularly polarized waves by rain is worst generally at low elevation angles

Semplak (1974) observed that when large attenuation occurs, there is small rotation. This small rotation comes from tilting of oblate rain drops with almost equal positive and negative angle there by canceling the cross components. This condition can exist even in the largest drops during high rain intensity. Depolarization is due mainly to high rotation of cross component. Results, also show that circularity polarized waves are subjected to severe depolarization in the tropical region because of high rainfall intensity.

The variation of XPD with rain rate is insignificant in widespread rain because the rain intensity is low and rain drop size is small and spherical in shape which yields very low differential attenuation. Other rain types have significant effect on XPD at high rain rates.

Attenuation is high at high rain rates hence XPD is very poor at elevation angle of 23^0 and long path length at low elevation angles.

At high rain rates and high frequencies, communication in the tropical regions using circularly polarized signal (right or left hand) in orthogonal channels will be degraded because significant amount of energy will be transferred from one channel to another channel of the same frequency thus making degree of isolation between channels to be poor. This could lead to outage for some time depending on the duration and intensity of rainfall. Attenuation is a dominant factor in signal degradation for wide spread rain because depolarization is insignificant when a circularly polarized signal is transmitted orthogonally. If cross coupling is to be reduced, circularly polarized signal should be transmitted at the highest elevation angle on earth-space path in Nigeria. At such satellite look angles, attenuation is low. A communication system is said to be reliable if good quality signal is available for at least 99.9% of time Ajewole (1998). Ajewole (1998) noted that it is difficult to meet this condition in the tropical region because of degradation problem as a result of high rainfall and non spherical shape of large tropical rain drops. Using compensating networks the unwanted signal can be cancelled and so the problem of depolarization by rain can be reduced. This is however beyond the scope of this present study.

4.2 Recommendations

This report recommends that if good signal reliability is sought for, circularly polarized signals will give better signal quality at the transmit and receive ends on tropical paths such as Nigeria. Short slant propagation paths are recommended, that is the use of high elevation angles. In area where depolarization effect is high, communication station could be installed with compensating network in order to maintain orthogonality between the channels. It is also recommended that further studies be carried out on microwave signal depolarization due to rain in the tropical environments using other drop size distribution model and another canting angle distribution model within the same frequency range of 4 – 100 GHz and rain rates

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