PREDICTION OF DEPOLARIZATION DISTRIBUTION ON EARTH-SPACE PATH

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1. Introduction

For a reliable dual-polarization space communication system design, it is necessary to establish a method of predicting cross-polarization discrimination (XPD) statistics for earth-space path. Theoretical relationships between rain-attenuation and XPD based on the deformed raindrop model have been reported[1]. Using the theoretical relation and a cumulative distribution of attenuation, a cumulative distribution of XPD can be predicted. In the case of earth-space path, however, it is found that there is poor correlation between measured attenuation and XPD because of the so-called anomalous depolarization[2]. This fact implies that predicted XPD value for earth-space path includes an error if the theoretical relationship between rain-attenuation and XPD is used.

In this paper, a new method of predicting cumulative distribution of XPD is proposed, in which the effects of the anomalous depolarization are taken into consideration by using a factor "anomalous XPD ratio". After the details of the proposed method are presented, the model prediction is compared with the experimental data.

2. Anomalous XPD ratio and correction factor

According to the propagation experiments conducted along earth-space path, it is found that the measured attenuation and XPD are distributed two-dimensionally on the attenuation-XPD plane[3]. A shaded area in Fig. 1 shows an example of area in which the measured data exist. A factor "anomalous XPD ratio" ρ is defined as follows[4]:

$$\rho = \frac{P(XPD<x|A<a_x)}{P(XPD<x)} \times 100\ (\%) \qquad (1)$$

where, $P(XPD<x|A<a_x)$: percentage of time that XPD and attenuation are less than x and a_x, respectively,
$P(XPD<x)$: percentage of time that XPD is less than x,
a_x : theoretical attenuation which corresponds to XPD, x.

On the assumption that Eq.(2) holds, a correction to the predicted cumulative time percentage of XPD cumulative distribution can be made. For example, if ρ is 50% at $A=a_x$, cumulative time percentage that XPD is less than x, $P(XPD<x)$, is derived by multiplying time percentage that attenuation is larger than a_x, $P(A>a_x)$, by 2.

$$P(XPD>x|A>a_x) = 0 \qquad (2)$$

A correction factor δ is defined as the multiplication factor to the time percentage. The correction procedure is expressed by Eqs(3,4).

$$P(XPD<x) = \delta \cdot P(A>a_x) \qquad (3)$$

$$\delta = \frac{100}{100-\rho} \qquad (4)$$

3. Rainfall rate and rainfall type dependence of correction factor

In the centimeter wave propagation experiments using a beacon signal (19.5GHz, circular polarization) of Japanese geostationary satellite CS[4], the dependence of correction factor on the attenuation can be approximated as

Fig.2. The correction factor δ remains almost constant δ_0 at attenuation below A_1 and the factor decreases as the attenuation increases. At the attenuation larger than A_2, the factor is almost equal to 1, which means the effects of anomalous XPD can be neglected in this region.

The characteristic attenuations A_1 and A_2 are derived to be about 10 and 40dB, respectively, in the CS experiment. The attenuation values can be converted to effective rainfall rates R_1 and R_2, which are 20 and 80mm/h, respectively, by using the propagation parameters. Then, the variation of correction factor can be characterized by R_1 and R_2.

In the CS experiment, rainfall events are classified into three types, "stratus", "cumulus", and "others" by using the spatial characteristics of the radar reflectivity factor along the satellite-to-earth path. The stratus events are characterized by the apparent existence of melting layer in the cloud structure. It is found that the anomalous XPD events mainly occur in the stratus rainfall events. Then, a stratus rain ratio, α, is defined as the ratio of rain amounts between stratus rainfall events and total rainfall events. Using the monthly variation of α and ρ_0 during 6 years, the α - ρ_0 relation can be derived as shown in Fig.3. The anomalous XPD ratio ρ_0 corresponds to the correction factor δ_0 in Fig.2. The α - ρ_0 relation can be approximated by Eq.(5) and the approximated results are shown by broken line in Fig.3. If the stratus rain ratio α at the location of concern is given, the correction factor δ can be obtained by using Eqs(4, 5) and Fig.2.

$$\rho_0 = 50 (1 + \alpha) \tag{5}$$

4. Prediction of XPD distribution

In this XPD prediction method, the following items are needed:

(i) cumulative distribution of attenuation
(ii) stratus rain ratio α and geographic latitude of the location
(iii) propagation parameter(frequency, elevation angle, etc.)

The prediction procedure is as follows(See Fig.4):

(i) The slant-path length ℓ is obtained from the geographic latitude and elevation angle, according to the procedure of CCIR[5].
(ii) The parameters U and V in Eq.(6) are obtained by using the propagation parameters[1]. In deriving the parameters, Marshall-and-Palmer type raindrop-size distribution is assumed and the standard deviation of raindrop canting angle is assumed to be 30°.

$$XPD = U - V \log A \tag{6}$$

(iii) The characteristic attenuations A_1 and A_2 are obtained from:

$$A_{1,2} = a R_{1,2}^{b} \ell \tag{7}$$

where, R_1 and R_2 are the characteristic rainfall rates and they are assumed to be 20 and 80mm/h, respectively, in this prediction method. The parameters a and b can be obtained from Olsen et al.'s paper[6], for example.
(iv) The correction factor δ is obtained from the stratus rain ratio of the location and the anomalous depolarization ratio by using Eqs.(4, 5).
(v) The attenuation dependence of δ is obtained as shown in Fig.2.
(vi) The distribution of XPD due to deformed raindrops is predicted from the attenuation distribution and Eq.(6). This procedure is the conventional XPD prediction method and the results are shown by a solid line in Fig.4.
(vii) The XPD distribution predicted in step(vi) is corrected by using the attenuation dependence of the correction factor. Finally the XPD

distribution, taking the anomalous depolarization into account, is predicted and the results are shown by dotted line in Fig.4.

5. Comparison to measured data

Fig.5 shows the cumulative distributions of XPD at 11.5(circular polarization), 11.7(vertical polarization with tilt angle of about 6°) and 19.5 GHz(circular polarization), which were measured at Kashima in the ETS-II[7], BS[4] and CS[4] wave propagation experiments, respectively. The solid lines in Fig.5 show the measured distributions and the broken lines show the distributions predicted by the proposed method. In the prediction procedure, the stratus rain ratio of yearly averaged value, which is about 0.8, is used.

It is quite reasonable that the agreement between measured and predicted results at 19.5GHz is good because this prediction method is established by considering the measured results at 19.5 GHz. It is noticed that the agreements at 11.5 and 11.7 GHz are also good for the time percentage above 0.01%. It is expected that the precise prediction of XPD distribution on earth-space path at other locations can be made if the location dependence of the stratus rain ratio is obtained.

6. Conclusion

The new XPD prediction method, taking the anomalous depolarization into account, is proposed. The effects of the anomalous depolarization is characterized by the anomalous XPD ratio which is used to obtain the correction factor to the predicted time percentage. This prediction method is applied to the measured results obtained in the ETS-II, BS and CS wave propagation experiments. Agreements between measured and predicted XPD distribution are very good.

References

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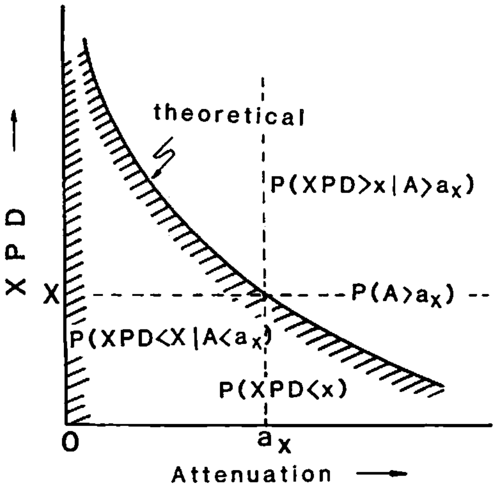

Fig.1 Attenuation-XPD plane showing the area in which the measured data exist.

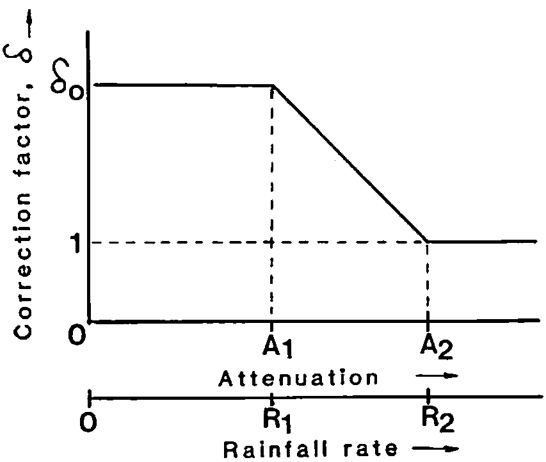

Fig.2 Attenuation and rainfall rate dependence of the correction factor δ .

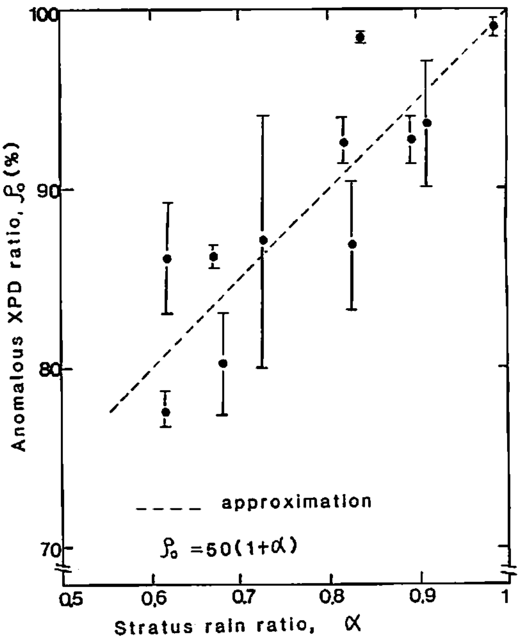

Fig.3 Anomalous XPD ratio ρ_0 as a function of the stratus rain ratio α .

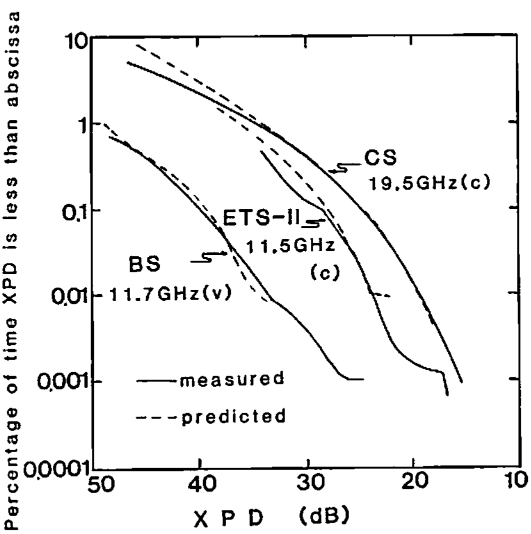

Fig.5 Prediction of XPD distribution using the ETS-II, BS, and CS wave propagation experiments.

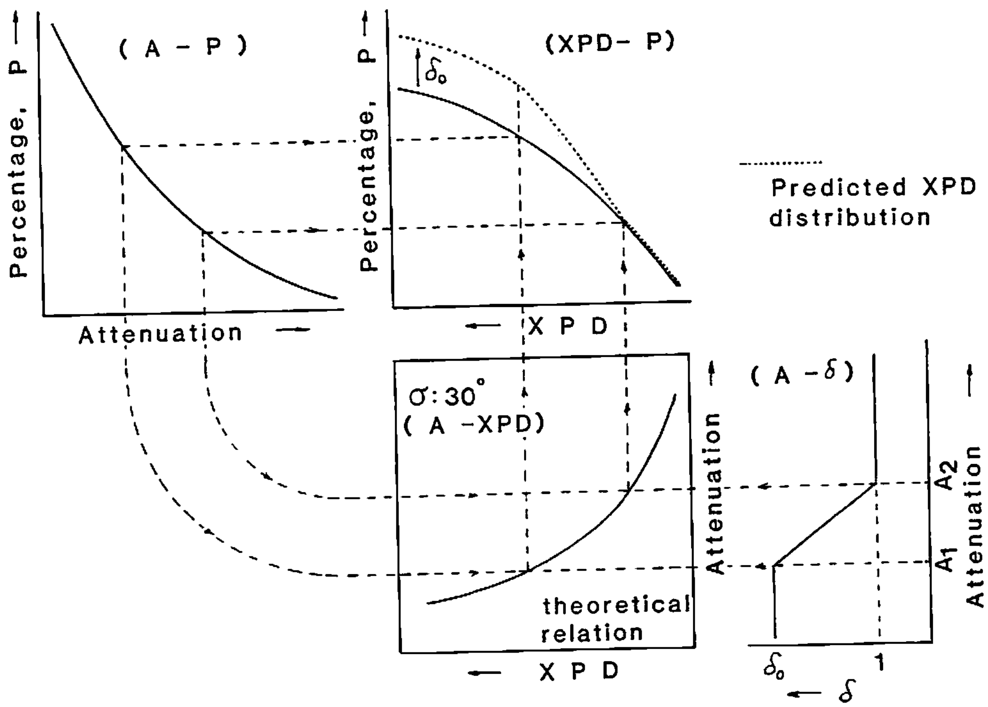

Fig.4 Schematic diagram showing the procedure of XPD distribution prediction.