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# TROPOSPHERIC EFFECTS ON ETS-II MILLIMETER WAVE PROPAGATION

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INTRODUCTION: An Engineering Test Satellite Type II(ETS-II) was stationed at 130°E of the geostationary orbit on March 5, 1977. An elevation angle from Kashima earth station of the Radio Research Laboratories is about 47°. Propagation experiments are carried out since early May of 1977 at the Kashima station receiving three frequencies of 1.7, 11.5, and 34.5 GHz emitted by ETS-II. This paper describes attenuation and cross-polarization characteristics due to precipitation at 11.5 and 34.5 GHz signals.

RAIN ATTENUATION: In Fig. 1, the dashed line shows cumulative distribution of 34.5 GHz attenuation based on the data during the period of May to November, 1977. The attenuations exceeded 10, 1, and 0.1 % of the total observation of 4095 hours are 3, 6, and 18 dB, respectively. Usually, more than half of the whole rain around year is recorded in these 7 months in Japan. A rainy season exists over early June to middle July. In addition, heavy rains are accompanied with thunderstorms in summer season and typhoons in summer and autumn seasons. The cumulative distribution of 34.5 GHz attenuation at each month is also shown in Fig. 1. This figure shows the tendency that the percent of time of deep attenuations in June and July are small compared with the other months. This fact suggests that in a rainy season of Japan, light rain is predominant and many rain events do not affect severely a millimeter wave which are being used for earth-to-space communication link. On the other hand, August is the worst month in these 7 months being observed. Fig. 2 shows cumulative distributions of 11.5 and 34.5 GHz attenuations in this worst month. The 34.5 GHz(11.5 GHz) attenuation is found to be 9(2), 24(5), 32(8) dB for 1, 0.1, and 0.01 % of time, respectively.

Duration time of attenuation is the other important parameter in evaluating a communication link. Fig. 3 shows cumulative distribution of the duration time for the 34.5 GHz attenuation of 5, 10, 15, 20, and 25 dB levels summarized for the data over May to November. The duration time of deep attenuation is much shorter than that of a small fade.
This corresponds that a heavy rain which causes severe attenuations does not continue during long period and light rain may continue during long period of time

C band rain radar which is installed at the Kashima station has many capabilities for measuring rain cell structure. We can measure rain rate along the earth-to-space path by using this radar. Rain rate R(mm/h) is derived from the radar reflectivity Z($mm^6/m^3$) through the following empirical formula;

$$Z = 200\ R^{1.6} \qquad (1)$$

Fig. 4 shows the scattergram of attenuation versus integrated rain rate along the path up to bright band for the data obtained during 5:00-9:00LT, August 14, 1977. Solid lines with letters A and B show the best fit curves by means of the least-mean-square error method based on the rain rate and the attenuation.

These can be represented by the following formula;

$$A_m = \alpha \cdot R_{integ}^{\beta} \qquad (2)$$

where $A_m$ is a measured attenuation and $R_{integ}$ is an integrated rain rate. The coefficients $\alpha$ and $\beta$ for 34.5 and 11.5 GHz are listed in Table 1. On the other hand, the theoretical relations between attenuation A(dB/km) and rain rate R for the spherical raindrops can be written as follows [1],

$$A = 0.2369\ R^{1.022} \quad \text{for 34.5 GHz} \qquad (3)$$

$$A = 0.0185\ R^{1.1678} \quad \text{for 11.5 GHz} \qquad (4)$$

where Marshall and Palmer raindrop size distribution is assumed. The best fit curves for 34.5 GHz are almost similar to those derived from the theory, while the best fit curves for 11.5 GHz are different from the theory. This difference in 11.5 GHz, especially in the case of being based on the attenuation, comes from rough quantization levels of 1 dB.

CROSS-POLARIZATION EFFECTS: In ETS-II project, cross-polarization components of 11.5 and 34.5 GHz signals are recorded with values of phase difference between co- and cross-polarization components. But, the cross-polarization discrimination(XPD) of the transmitting system is not so good that correction on the received data is made to obtain degradation of XPD due to the propagation medium. The formula for correction is written as follows [1],

$$XPD = 20\ \mathrm{Log}_{10}\left( \left|\frac{E_L}{E_R}\right|^2 + \left|\frac{E_{L_0}}{E_{R_0}}\right|^2 - 2\cdot\left|\frac{E_L}{E_R}\right|\cdot\left|\frac{E_{L_0}}{E_{R_0}}\right| \cos(\Delta\phi)\right)^{1/2} \qquad (5)$$

where $E_{R_0}$ and $E_{L_0}$ are the field strength of the right and left circularly polarized components on a clear day, respectively; $E_R$ and $E_L$ are those on a rainy day; and $\Delta\phi$ is the variation of phase difference between co- and cross-polarization components due to rain relative to the value on a clear day. Using (5), XPD influenced by the precipitation medium can be obtained with reference to the value on a clear day. Fig. 5 shows the cumulative distributions of XPD of the 11.5 and 34.5 GHz computed in the data for the period of August. For a "worst month" of August, degradation of XPD for 34.5 GHz(11.5 GHz) was found to be 26.4(30), 21(27), and 16(x) dB for 1, 0.1, and 0.01 % of time, respectively. XPD versus co-polar attenuation(CPA) for the period is shown in Fig. 6. Solid lines show the theoretical results from Oguchi et al., [2]. In the case of large CPA, the data points are almost correlated with the theoretical value of $\sigma$ =30°($\sigma$ is a standard deviation of canting angle), while XPD is observed to be small compared with the theoretical values in the case of small CPA. This may result from the depolarization due to ice crystals [3].

CONCLUSION: The following results were obtained.
1) For the period over May to November, 1977, the 34.5 GHz attenuation was found to be 3, 6, and 18 dB for 10, 1, and 0.1 % of time, respectively, and fading duration time was summarized in Fig. 3.
2) For a "worst month" of August, 1977, 34.5 GHz(11.5 GHz) attenuation was found to be 9(2), 24(5), and 32(8) dB for 1, 0.1, and 0.01 % of time, respectively. The degradation of XPD for 34.5GHz(11.5 GHz) was found to be 26.4(30), 21(27), and 16(x) dB for 1, 0.1, and 0.01 % of time, respectively.

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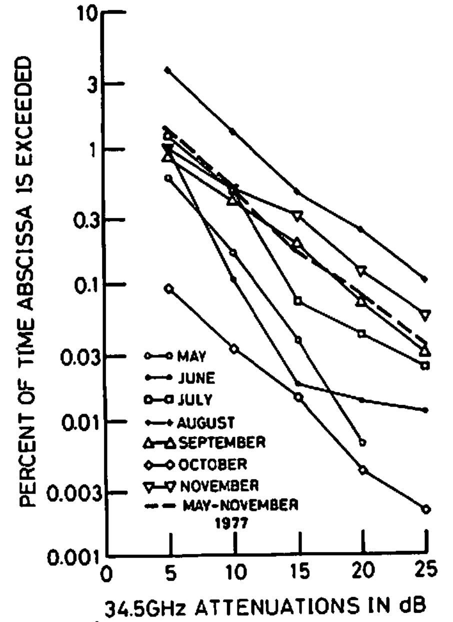


Fig. 1 Cumulative distributions of the 34.5 GHz attenuation for the period over May to November, 1977.

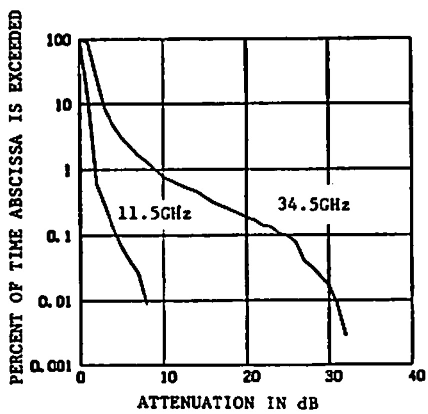


Fig. 2 Cumulative distributions of the 11.5 and 34.5 GHz attenuations for August, 1977.

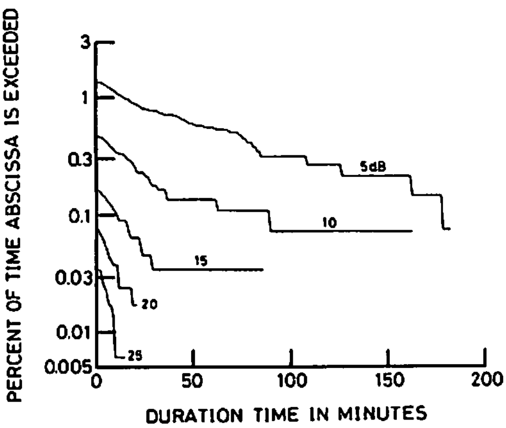


Fig. 3 Cumulative distributions of the duration time of the 34.5 GHz attenuation for the period over May to November, 1977.

Table 1 Coefficients $\alpha$ and $\beta$ of best fit curves for the relations between attenuations and integrated rain rate based on the data during 5:00-9:00LT August 14, 1977.

| | | $\alpha$ | $\beta$ |
|---|---|---|---|
| 34.5 GHz | A | 0.3264 | 1.0478 |
| | B | 0.2346 | 1.1336 |
| 11.5 GHz | A | 0.00576 | 1.14173 |
| | B | $2.6 \cdot 10^{-7}$ | 4.6441 |

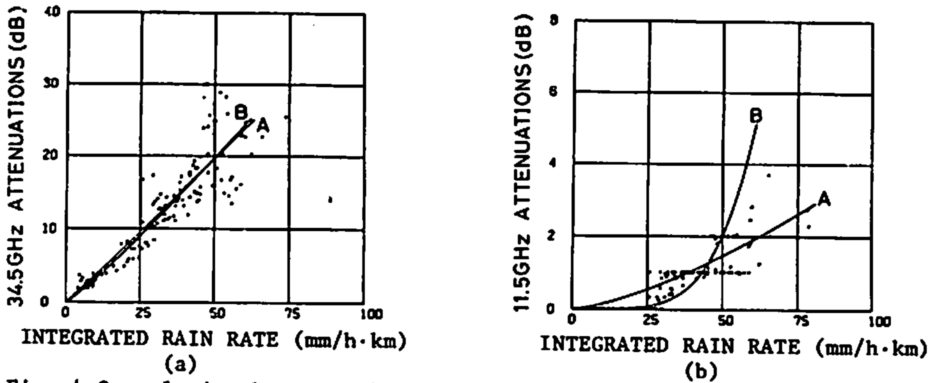


Fig. 4 Correlation between the attenuation and the integrated rain rate along the path up to bright band for the data during 5:00-9:00LT August 14, 1977. The rain rate along the path was derived from rain radar data. (a) 34.5 GHz, (b) 11.5 GHz

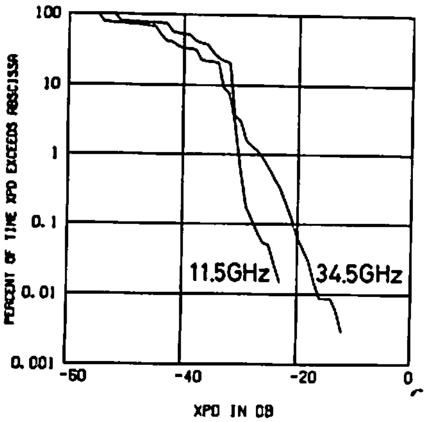


Fig. 5 Cumulative distribution of the cross-polarization discriminations for 11.5 and 34.5 GHz in August, 1977.

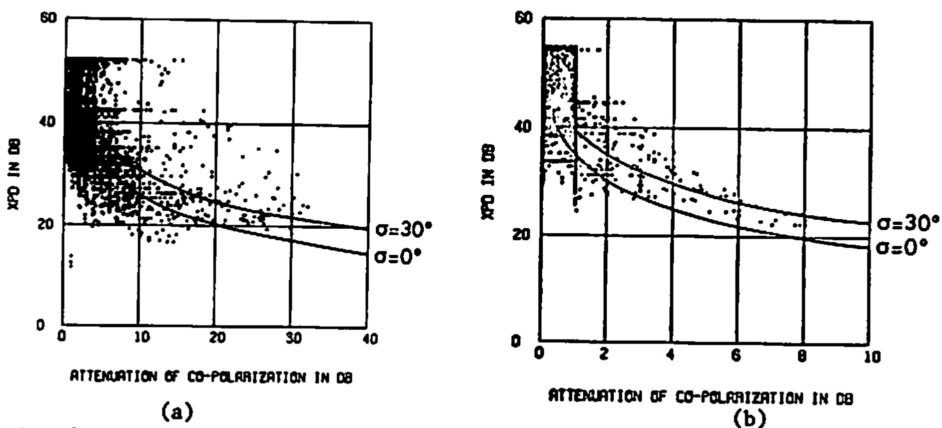


Fig. 6 Cross-polarization discrimination versus co-polar attenuation for the period of August, 1977. Solid lines show the the theoretical results from Oguchi et al. The parameter show the standard deviation of canting angle. (a) 34.5 GHz, (b) 11.5 GHz