HYDROMETEOR SCATTER INTERFERENCE SIMULATED USING DUAL-POLARISATION RADAR DATA

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1.Introduction

Scattering of microwave energy from hydrometeors is widely recognized as a cause of mutual interference between terrestrial and satellite communication systems operating at the same frequency.For coordination purposes, the CCIR model [1] evaluates the cumulative statistics of transmission loss for a given path geometry, rain intensity and average melting layer height.It assumes a cylindrical rain cell with a fixed location and an empirical correlation between the rainfall rate at the scattering point and the attenuation along the interference path.

In this paper we examine one aspect of the CCIR model, namely the difference in transmission loss between forward and back scatter statistics. This difference is due to the difference in path length, and hence attenuation, inside the raincell, and increases in importance for higher rain rates.

The predicted asymmetry is examined by simulating hydrometeor scatter events using data obtained from the 3GHz dual-polarisation radar at Chilbolton in Hampshire,UK [2]. The narrow beam (15') of the radar allows good resolution of rain structure, an important consideration when 2 dimensions of the common volume in the simulated interference situation are defined by a narrow earth-station beam. Of equal importance is the additional measurement of differential reflectivity, Z_{dr}, which makes it possible to reliably distinguish between water and ice hydrometeors as well as determine the statistical distribution of drop sizes in rain. This enables the path attenuation to be accurately quantified [3]. The other factor involved in the transmission loss, namely the reflectivity, can be scaled directly from the radar frequency.The results are compared with the predictions at a frequency of 18GHz, where attenuation due to rain should be considerable, and for a station separation of 60km.

2.Simulation of Hydrometeor Scatter

For the simulation of hydrometeor scatter we use a variation of the general bistatic radar equation (as in (4)), with the narrow-beam approximation (5,6).When the beam-pattern of the ES antenna is approximated to a Gaussian function, the scattered power becomes:

$$P_r = \int_{\Psi} \frac{P_t \, \lambda^2 \, G_2(\Psi) \;\; \eta(\Psi) \;\; A(\Psi) \; G_1^{max} \; \theta_3^2}{64 \, \pi^2 \; r_2 \; \mathrm{Sin}\, \alpha_s \;\; ln\, 2} \; d\Psi \qquad (1)$$

where $\mathbf{P_t}$ is the transmitted power, λ the wavelength, $\mathbf{G_1}$ and $\mathbf{G_2}$ the respective antenna gains of ES and TS, η the reflectivity per unit volume, $\mathbf{G_1^{max}}$ the maximum gain, θ_3 the half beamwidth and **A** is the attenuation along the two paths. α_s is the scattering angle and Ψ is the angle off the bore-sight of the TS antenna.

Simulations are made on data in vertical plane scans (RHIs) collected on a statistical basis during a 2-year data collection program which commenced in September 1987. The observational cycle, repeated once every 10 minutes 24 hours a day, includes three RHI scans with a maximum elevation of 15^o and separated by 10^o in azimuth. Data are collected over ranges between 4.8km and 158km.

Since real satellite elevations do not permit 0^o or 180^o scatter, a comparison is made between the 30/150 deg scatter. The scattering angle was changed by altering the elevation of the ES-CV path on the plane of the data (as in fig. 1). A number of simulations with identical geometry were performed within each scan by varying the position of the CV relative to the radar. However, as shown in fig. 1, the CVs were chosen to lie between ranges of 30 and 70 km in each scan. The minimum range of 30km provides data up to 7.5km in height at the maximum elevation of 15 degrees. Choosing the maximum range to be 70km ensures that the radar resolution across the beam stays commensurate with the resolution of 300m in range.

Equation (1), in principle, should be integrated over all Ψ, but if we assume a Gaussian shaped beam for the TS antenna, it becomes sufficient to limit the integration to three times the half power beamwidth. A TS antenna gain of 42dB with a corresponding beamwidth of 1.3^o was used. The elevation is fixed at 0^o with the result that the lower half of the beam is cut off.

3.Simulation Results

The forward/back asymmetry is expected to be most significant when the scattering medium is predominantly intense rain. The data from July 1988 generally met this condition and were therefore selected for this study. Not only was it by far the wettest month encountered since the start of the data collection program, but also the freezing level was generally at least 1.5km above ground,while the CV height ranges from 200m at the boresight to 900m at the -3dB point. Thus the CV almost always contains rain rather than ice.

The cumulative distribution of transmission loss (P_t/P_r) is given in figure 2. Curves (b) refer to the normal transmission loss values, obtained by evaluating equation (1). Curves (a) are similar but neglect path attenuation. In this case, the scattered power is determined solely by the reflectivity within the CV, and hence it is not surprising that the forward and back scatter cases produce similar curves.

Curves (b) clearly show the effect of the rain attenuation. As predicted by the CCIR model, the two curves begin to deviate at low time percentages, the back scatter producing the lower transmission loss of the two (ie higher signal). The differences are quantified in Table 1 (ΔL = Loss[Backward] - Loss[Forward]) and compared with the corresponding predictions from Report 569-3. To be consistent with the simulation results, the rainfall statistics for July 1988 were used as input to the model. A freezing level height of 2.6km was used for the model calculations, obtained from an average of the radar values.

The simulation results do indeed confirm the model prediction that there is a difference between forward and backscatter transmission loss in rain.However, such agreement would not necessarily be found if annual statistics were under consideration. The reason for this is that a much wider distribution of freezing level heights would occur when winter months were also included, and ice scatter would contribute significantly to the transmission loss statistics. Ice scatter cannot be expected to exhibit significant forward-backward asymmetry, because of its negligible attenuation at the frequency considered here. Furthermore, because the total path attenuation in the case of ice scatter is low, the overall statistics of transmission loss may well be dominated by ice scatter in the low time percentage/low transmission loss end of the distribution. Statistically, therefore, we would expect only a small difference, at most, between forward and backward transmission loss derived on an annual basis. In its present form, the CCIR model requires the mean freezing level height (in rain conditions) as input, but for the reason given above, this may overpredict the effect of attenuation and the asymmetry between forward and back scatter.

Further information on this topic will be gleaned when the full two years of radar data are analysed, but it is worth noting that an unpublished study of some earlier Chilbolton radar data, collected during the summer and autumn months of 1981 and 1982, showed no significant asymmetry. However, a further complication to the interpretation of that result is that those data were collected on 30° elevated slant planes, and this in itself may reduce the expected asymmetry because the effective path length through the cylindrical rain cell for the forward scatter reduces gradually as the inclination of the interference plane decreases from 90° to 0°. The plane elevation,therefore, is also an important factor in determining the magnitude of the attenuation differences.

4.Conclusions

Simulation results using RHI data show differences in forward and back scatter transmission loss statistics when the scattering medium is almost entirely rain. The magnitude of these differences are similar to the CCIR predicted values. However, these differences are likely to be reduced if (a) the elevation of the interference plane is reduced and (b) the freezing level heights show a wide distribution (as would be the case on an annual basis).

5.References

1. CCIR, 1986, Recommendations and Reports of the CCIR Vol 5, Report 569-3, ITU, Geneva.
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5. Crane R.K.,1974, "Bistatic scatter from rain", IEEE Trans.,AP 22, pp312-320.
6. Awaka J., Nakamura K. and Inomatu H., 1983, "Bistatic rain-scatter experiment at 34.8 GHz", IEEE Trans., AP 31, pp693-698.

Table 1 - Difference in transmission loss between forward and backward scatter from simulation results and CCIR predictions.

	ΔL (in dB) from	
Time %	Simulation	Report 569
1.0	0.1	0.1
0.3	0.4	0.4
0.1	0.5	0.9
0.03	1.1	1.9
0.01	1.9	3.3

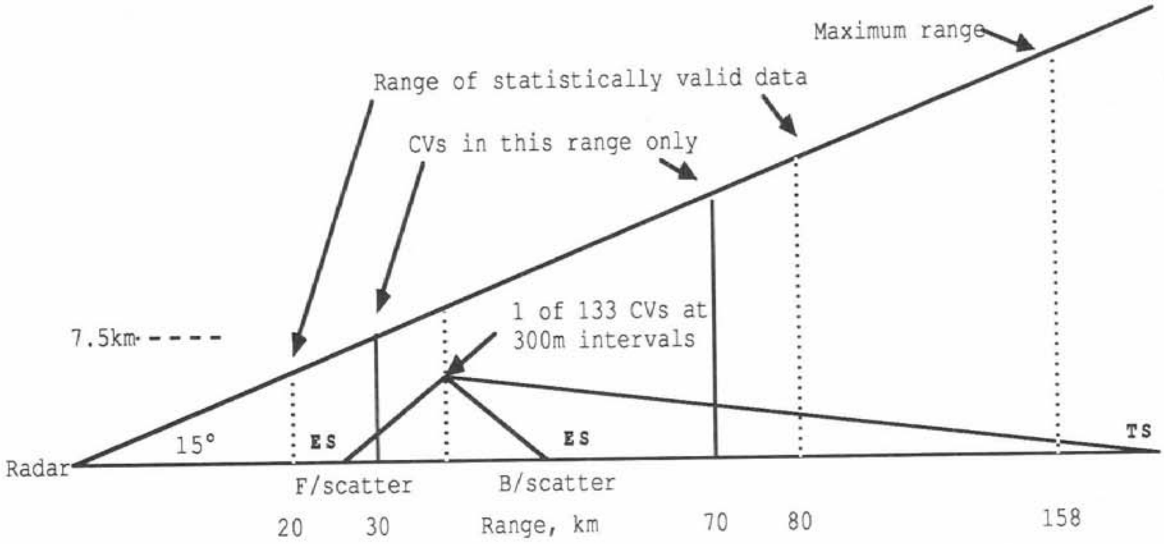

Figure 1 RHI geometry indicating simulated bistatic configurations

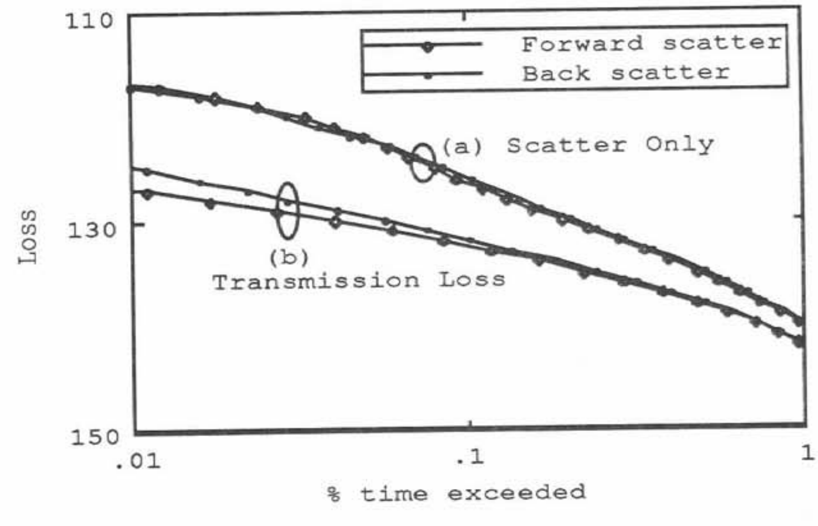

Figure 2 : Statistics of forward and backward scatter at 60km station separation, with and without attenuation.