SIMULATION OF RAIN ATTENUATION ON SIMPLE AND DIVERSITY SATELLITE LINKS

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INTRODUCTION

Satellite earth stations have to use antennas with enough gain to overcome the occasional rain attenuations to comply with service requirements. At frequencies above 10GHz this is usually accomplished either by using larger antennas or by setting up diversity stations, based on the assumption that heavy rain is less probable on two spaced paths if they are separated by more than the average diameters of raincells. A 6dB "diversity gain" for instance, makes it possible to use two spaced smaller antennas instead of one larger antenna of double diameter.

Many methods have been proposed to estimate the yearly rain-attenuation statistics for a site, given rain statistics (see [Rogers, 1985] or CCIR-564). However, it seems quite difficult to estimate diversity gain, unless radar measurements are used [Goldhirsh, 1984]. Formulas estimating diversity gain, given single-path attenuations, were developed empirically [Allnut et al, 1982; Hodge, 1982].
Recently, Capsoni et al [1987] have proposed a more physical model of "exponential-rainrate" raincells, based on radar measurements of many raincells. From this model rain statistics and also attenuation statistics are derived, which makes it possible to convert from known rain c.d.f (cumulative distribution function) to attenuation c.d.f. Also Crane's [1982] two-component model is based on radar-derived raincell structure. Both models make it quite difficult to estimate diversity performance.

We have used a simpler approach, similar to Fimbel's [1975], relating rain-attenuation c.d.f to the rain-rate c.d.f by assuming cylindrical homogeneous cells. Fimbel and also Misme et al [1980] use a fixed relationship between rain-rate and cell diameter which excludes the estimation of diversity effects. The method developed at COMSAT [Mass, 1987] uses a log-normal distribution of raincell diameters thus enabling investigation of diversity performance. The universal parameters of the distribution were taken from radar data, adjusted to experimental results available.

The simulation method will first be reviewed and then applied to a generic estimation of the influence of elevation angle and of diversity separation for different cases.

REVIEW OF SIMULATION METHOD

Raincells are assumed to be cylindrical with constant rainrate. Diameters are between 1 and 40Km log-normally distributed. Cell heights are assumed equally distributed between 4 heights depending on rain type (rain-rate). Also the median diameters depend on rain type. The parameters used are repeated here. They describe a typical structure of raincells as function of rain-rate, after adjustment to fit experimental data, and assumed to be applicable anywhere:

R[mm/h]	D_m[Km]	h[Km]	σ[ln(D)]
>50	1.2	1, 2, 3, 4	1.1
30-50	2.0	1, 2, 3, 4	1.1
20-30	4.0	1, 2, 3, 4	1.1
14-20	8.0	2, 2.7, 3.3, 4	1.1
8-14	12.0	3, 3.7, 4.3, 5	1.1
0-8	20.0	4, 4.3, 4.7, 5	1.1

The known cdf of rain-rate is arbitrarily divided into 13 time-percentage intervals. For each, 160 raincells are assumed (40 diameters x 4 heights) tagged with their probability. For each of the 13x160=2,080 cells a ratio is calculated between the locus area for the centers to create a given attenuation and the locus area to create a given rain-rate at a point. This gives after addition of all contributions, properly weighted, the ratio of occurrence of a certain attenuation (or larger) to the occurrence of a certain rain-rate (or larger) at a point. Thus, one gets the overall c.d.f of attenuation from the known c.d.f of rain-rate. A homogeneous planar distribution of raincells must be assumed but the density of cells (per unit area) is not required.

The simulation method was tested on 10 experimental results for diversity and 13 for single-path attenuation, for various frequencies above 10GHz, elevation angles, separation distances and for different rain-climates. Discrepancies are in most cases smaller than 1dB and with rare exceptions less than 2dB. The model parameters might be improved using recent experimental data.

Fig. 1 gives sample simulated results for yearly attenuation c.d.f at 20 and 11GHz, single and diversity at 10,20 and 30Km, for a medium rain-climate (see below).

The program was recently rewritten (in Pascal) for a IBM-AT p.c. and takes about 10 minutes to run, using 8087 math. coprocessor - for single and diversity-path attenuation c.d.f, given rain data, frequency, elevation angle, diversity separation and also baseline orientation.

ELEVATION-ANGLE DEPENDENCE

The simulation method was used for 4 frequencies and 3 typical rain-climates as defined using M (mm/year) and thunderstorm ratio β as given by Rice et al [1973]:

Low-rain-climate	M= 700mm	β=0.05	Typical of N. Europe
Medium-rain-climate	M= 990mm	β=0.11	Typical US East Coast
High-rain-climate	M=1,500mm	β=0.25	Typical Japan & others

It appears from Fig. 2 that the attenuation values for the 0.01% of-the-year and the 0.1% of-the-year criteria follow closely a cosec(E) function except for E<30°, where simulated results give slightly smaller values, up to 20% less (in dB) at E=10° (4.5dB at 20GHz for 0.1%). Similar results were obtained for the other rain-climates.

Attenuation values for 45GHz are higher than 14dB for 0.01% of-the-year in all 3 rain-climates. However, for the 1% of-the-year value, relevant to some service requirements, an interesting feature is observed (Fig. 3). While for the low-rain climate the elevation-angle dependence is below the cosec line (by 1dB at E=20°) it is higher than the cosec line for the high-rain climate (by about 2.5dB at E=20°).

For diversity attenuations, a good fit was found to a cosec(E) law at elevation angles down to 30°. At E=10° to 20° the diversity attenuation is often about 1dB below the cosec line.

DEPENDENCE ON DIVERSITY SEPARATION

Several empirical formulas are available to estimate "diversity gain" in dB over a single-path attenuation. Allnut & Rogers [1983] use the single-path attenuation c.d.f to determine a "knee-point" and an offset of the diversity gain vs. single-path attenuation. They show that systematic errors could be expected due to differences in elevation angle and convective-rain ratio (β). Hodge [1982] developed empirical formulas best-fit to 34 experimental data sets available. Diversity gain is estimated from single-site attenuation, frequency, elevation angle and baseline orientation. The overall RMS error was 0.73dB.

The simulation method makes it possible to obtain diversity performance and gain directly, taking into account all relevant factors. Fig. 4 shows diversity gain at 0.1% and 0.01% of-the-year of 20GHz, as a function of diversity separation (Km) at a medium rain-climate, for elevation angles of 40° and 60°. It is evident that the asymptotic gain (for large separations) is higher for lower elevations and lower percentages. Also, diversity gain increases faster with separation at the lower percentages. Similar results are obtained for the other rain-climates.

BASELINE ORIENTATION

Simulation results show no appreciable effect of baseline orientation, as has been pointed out previously [Mass, 1980]. On Fig. 4 it can be seen that the transverse orientation (baseline perpendicular to line-of-sight) gives slightly better or slightly worse diversity gain than the longitudinal orientation (by less than 0.5dB) in different cases.

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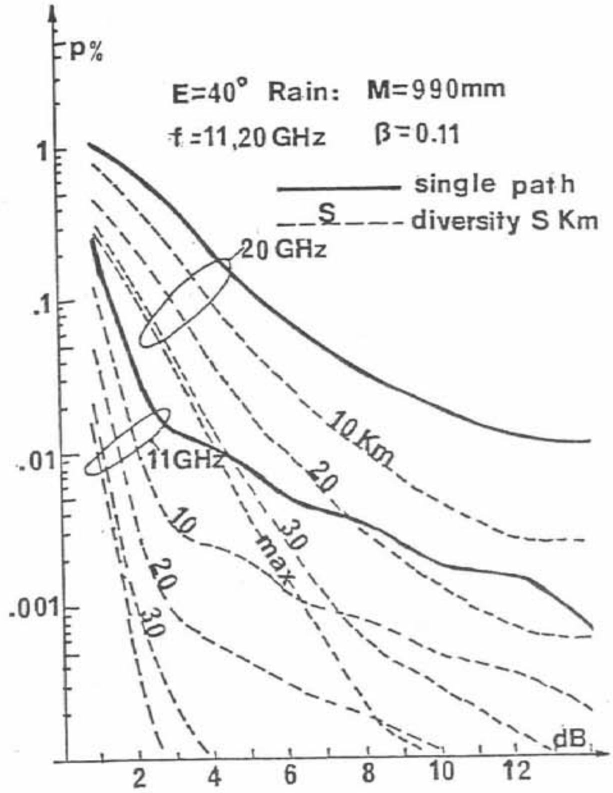

Fig. 1: Simulated rain-attenuation at 11 and 20GHz, including diversity.

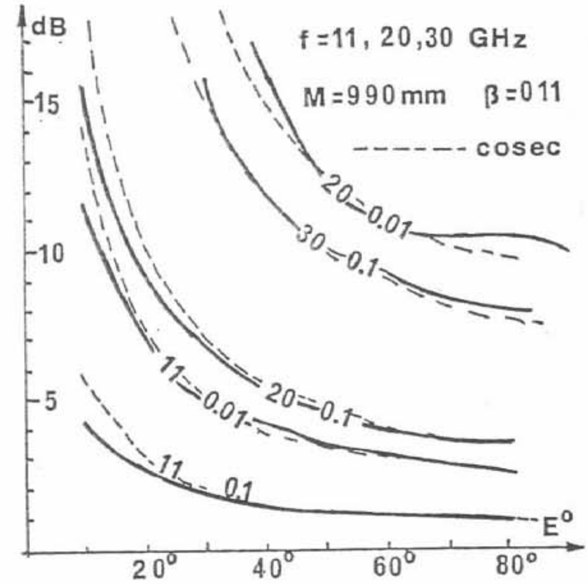

Fig. 2: Attenuation vs. elevation angle at 0.1% and 0.01% of-the-year.

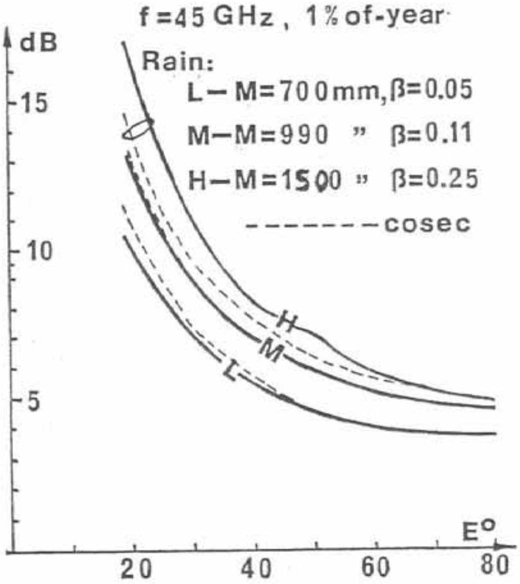

Fig. 3: Rain-attenuation vs. elevation angle for 3 rain climates.

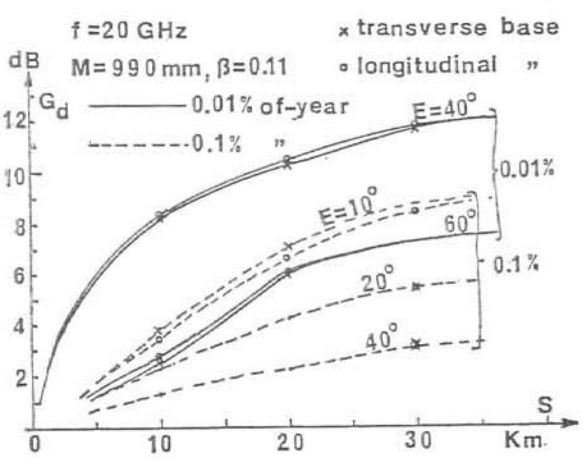

Fig. 4: Diversity gain vs. site separation (parameters: elevation, %-of-year).