RAIN INTERFERENCE BETWEEN EARTH-TO-SPACE AND TERRESTRIAL LINKS

Dario TARDUCCI

CSELT - Centro Studi e Laboratori Telecomunicazioni S.p.A.
Via G. Reiss Romoli, 274 - 10148 TORINO (Italy)

1. INTRODUCTION

In the recent past a number of papers have been presented [1], [2], [3], [4], [5], dealing with interference due to rain between earth to space and terrestrial links sharing the same frequency band.
In these works, the scattering volume, defined by the intersection of the rain cell with the beams of the antennas, is usually computed for some particular geometrical configurations. Moreover, according to the mean value theorem for definite integrals, a constant value is considered for the integrating function, evaluated at a suitable point within the volume. The goal of this paper is to present a more general and accurate method for computing the interference contributions, as a function of the intervening geometrical parameters (i.e., position and orientation of the antennas, position of the rain cells) and meteorological parameters (i.e., rainfall intensity, cell sizes). Without any loss of generality, sample computations have been performed within the 19 GHz band, allocated to both terrestrial and satellite services.

2. GEOMETRY OF THE PROBLEM

The integration volume used is defined, as in Fig. 1, by the intersection of a cylindrical rain cell with the beam of the transmitting ground station antenna T, for which operating elevation angles above about 30° are considered, typical of mid-latitude ground stations.
In these conditions it is easy to prove, in the hypothesis of a limit cell height of about 5 km [6], at the frequency under consideration and for the usual antenna gains, that the whole rain cell lies within the "near field" zone of the antenna. In fact, for an antenna T diameter value above about 14 m (used in our interference computations) the "near field" zone ranges up to about 6 km from the aperture. In this case the transmitting antenna beam (the T beam) may be represented as a cylinder, and the scattering volume is given by the intersection of two cylinders. Furthermore, if we suppose a receiving antenna R (see Fig. 1) with a main lobe (R-beam) embedded in a cone of small aperture (≤ 3°) and if the cone intersects the scattering volume V in the receiving antenna far-field zone, we shall have to restrict V to the inner-cone zone. As a conclusion, the effective scattering volume will be defined by the intersection of three solids: the cylindrical rain cell, the cylindrical T-beam and the conical R-main lobe.

3. ANALYTICAL FORMULATION

The average normalized power scattered contribution δP_R received by R is given, for general polarizations of the two antennas, by [7]:

$$(\delta P_R/P_T) = c_R \left\{ \int_V \frac{1}{r_R^2} c_T \, [p_R \, (\hat{k}_R)] \cdot [Ap(\hat{k}_R, \ell_R)]_R \cdot [Fs(\hat{k}_R, \hat{k}_T)] \cdot [Ap(\hat{k}_T, \ell_T)]_T \cdot [St]_T \, (\underline{p}_T) \, dP \right\} \qquad (1)$$

where:
- P_T is the T-transmitted power;

- $r_R(P)$ is the distance between a generical point P in the scattering volume and the antenna R (see Fig. 2);
- $\hat{k}_R(P)$, $\hat{k}_T(P)$ are the unit vectors along scatter and incidence directions (see Fig. 2);
- $[St]_T$ ($\underline{p}_T$) is the radiation function of the antenna T expressed according to Stokes formalism [7] (in order to retain polarization informations);
- $[p_R(\hat{k}_R)]$ is a 4 column vector representing the normalized receive pattern of the antenna R;
- $[Ap(\hat{k}_R, \ell_R)]_R$, $[Ap(\hat{k}_T, \ell_T)]_T$ are coherent field propagation 4 x 4 matrices for the scattered and incident waves, referred to point P;
- $[Fs(\hat{k}_R, \hat{k}_T)]$ is the unit volume average scattering matrix at P;
- ℓ_R and ℓ_T are the rain lengths along the scattered and the incident rays.

c_R and c_T are radiation factors for the two antennas given respectively, by:

$$c_T = (\lambda^2/4\pi) \cdot (G_T/A_{eT})$$
$$c_R = (\lambda^2/4\pi) \cdot G_R \qquad (2)$$

where G_T and G_R are the maximum gains, λ is the wavelength and A_{eT} the T antenna equivalent area.

4. SAMPLE COMPUTATIONS

In this paragraph some results of the expected interference contribution at 18.5 GHz are shown. The geometrical configuration considered is the same as the actual configuration adopted for the interference measurements carried out at Fucino [2], using the SIRIO I satellite.
With reference to Fig. 2, the elevation angle is θ_{Tz} = 56.5°, the relative height is z_{RT} = -11 m and the rain-cell size R_c was related to the rain rate R by means of the Misme formula [6]. An uniform illumination for the T aperture has been considered, with an aperture radius (the radius of the equivalent antenna T area) a_T = 7 m. As far as the receive antenna pattern is considered, the CCIR sidelobe envelope was assumed [8], for an antenna of 0.81 m diameter. Moreover, raindrops have been supposed equi-oriented, with canting angle (see Fig. 2) θ_{az} = 0°.
The remaining parameters (both geometrical and meteorological) were allowed to vary, in order to obtain parametric curves of the received normalized scattered power $\delta P_R/(P_T\ c_R\ c_T)$.
In Fig. 3 plots of the normalized received scattered power versus rain-cell position co-ordinate y_c (Fig. 1) are shown for 5 different azimuth orientation angles φ_{Rz} of R antenna (Fig. 2), covering the 0°-180° range with a 45° step. A constant rain-cell co-ordinate x_c = 0 (Fig. 1) has been taken, so the cell axis moves through the T beam vertical symmetry plane yz. The other parameters, namely R antenna position and elevation, and rain rate, were given fixed values: d_{RT} = 6.614 km, φ_R = -33.975°, θ_{Rz} = 86.3° (see Figs. 1, 2), R = 40 mm/h. This rain rate has been chosen because it has been found to correspond to the maximum scattering "efficiency" for the rain-cell co-ordinate x_c = 0. Finally, both antennas were supposed operating in linear vertical polarizations.
In Fig. 4 two examples of $\delta P_R/P_T$ curves versus R (mm/h) are shown: in the former both antennas were considered vertically polarized; in the latter the polarization of the T antenna is horizontal, while the R antenna polarization is still vertical. In the same figure the curve corresponding to the T antenna in circular polarization and the R antenna in linear vertical polarization is also presented. The curve is about 3 dB below the curve corresponding to the case of both antennas vertically polarized.
The values used for the other intervening parameters are the same as Fig. 3, except for φ_{Rz}, y_c. In this case the receiving antenna R has been supposed oriented towards the scattering volume, in order to maximize its sensitivity, with an azimuth angle φ_{Rz} = 143°, corresponding to a rain cell position x_c = 0 km, y_c = .58 km.
Moreover, in Fig. 4 experimental data collected during interference measurements carried out at Fucino [2] (with the T antenna in circular polarization and the R antenna in linear vertical polarization) are reported, allowing a quick comparison with computed values (dashed curve).

5. CONCLUSIONS

Bearing in mind the previous assumptions, some conclusions can be pointed out. As Fig. 3 shows, interference variation with y_c position co-ordinate (representing the interference pattern for a rain cell moving through the T antenna beam) is stronger when the R antenna is oriented towards the scattering volume (φ_{Rz} > 120°÷130°). This shows that the directivity pattern of the R antenna is by far the most important factor in determining the interference power received in these conditions, while the scattering volume directivity pattern plays only a secondary role.

On the other hand, the interference variation with x_c position co-ordinate depends strongly on rain attenuation contribution on the scattered rays, which depends essentially on the path length within the rain cell. From this point of view, the assumption of a co-ordinate $x_c = 0$ causes scattered rays to cover an average rain length, giving rise to an average attenuation contribution.

Looking at Fig. 4, a comparison between the computed curve (dashed line) and the experimental results shows that the predicted interference, using such average value for the attenuation contribution, overestimates measured data at any rain rate.

As already pointed out in [2], this could indicate that multiple cells, here ignored, may play an important role on incident and scattered rays attenuation. In the same figure the noticeable improvement due to polarization decoupling can be noted; the configuration corresponding to the situation of cross-polarized antennas gives rise to much lower interference values than the co-polarization case.

REFERENCES

[1] Awaka J. (1978), Estimation of rain scatter interference in the case of medium scale broadcasting satellite for experimental purposes (BSE), J. of Radio Res. Lab. (Tokyo), March 1978, pp. 23-49

[2] Barbaliscia F., Maggiori D., Migliorini, Paraboni A. (1981), Rainfall Scatter Interference Between Terrestrial and Satellite Radio Links, Ann. Télécom., Vol. 36, No. 1-2, Jan.-Feb. 1981, pp. 166-170

[3] Awaka J. (1979), Angular dependence of rain scattering at frequencies below 30 GHz, Trans. Inst. Electr. Commun. Eng. Jpn., Part E, 62(7), 462-465

[4] Awaka J., Oguchi T. (1982), Bistatic radar reflectivities of Pruppacher-and-Pitter form raindrops at 34.8 GHz, Radio Science, Vol. 17, Number 1, pages 269-278, Jan.-Feb. 1982

[5] Crane R.K. (1974), Bistatic scatter from rain, IEEE Trans. Antennas Prop., AP-22(2), 312-320

[6] Misme P., Fimbel J., Détermination Théorique et Experimentale de l'Affaiblissement dû à la pluie sur un Trajet Radioélectrique, Ann. Télécomm., Vol. 30 (5-6), 1976, 149-158

[7] Van de Hulst H.C., Light Scattering by Small Particles, John Wiley, New York, 1957

[8] CCIR Report 614-1, 1978

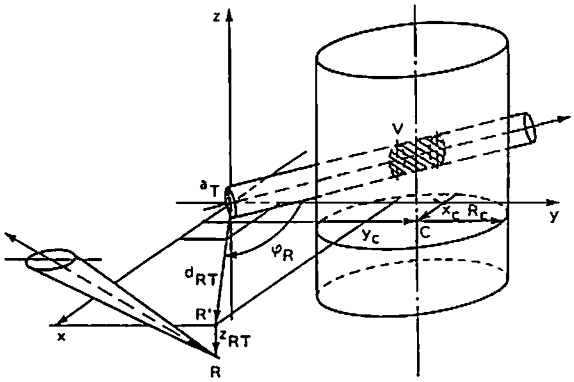

Fig. 1 - Geometrical configuration of the scattering problem with: Rain Cell, T cilindrical beam (with a_T radius), R receive main lobe included in a cone

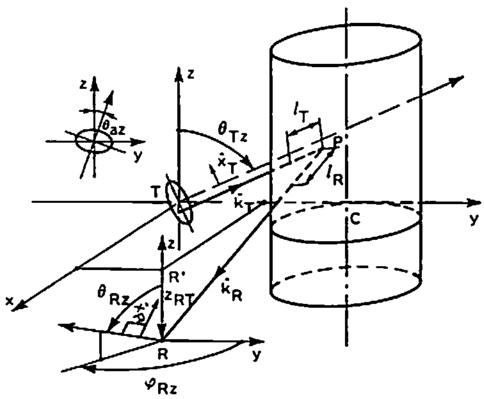

Fig. 2 - Geometrical parameters related to R and T antennas and to a generical scattering point P

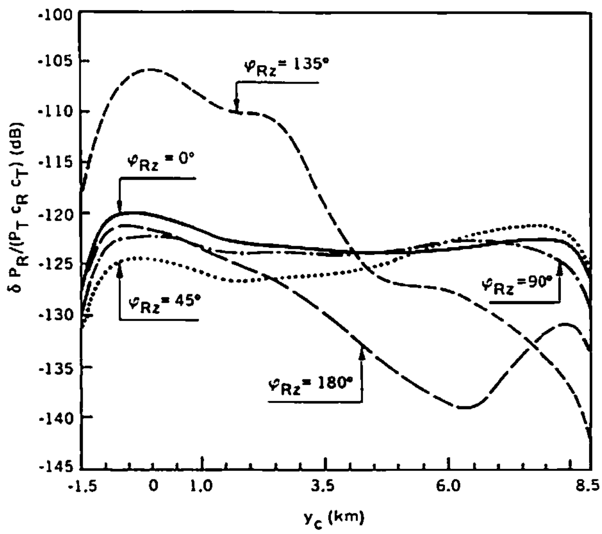

Fig. 3 - Received normalized interference power $\delta P_R/(P_T\ c_R\ c_T)$ versus y_c rain cell position coordinate, for different R antenna azimuth orientation angles φ_{Rz}

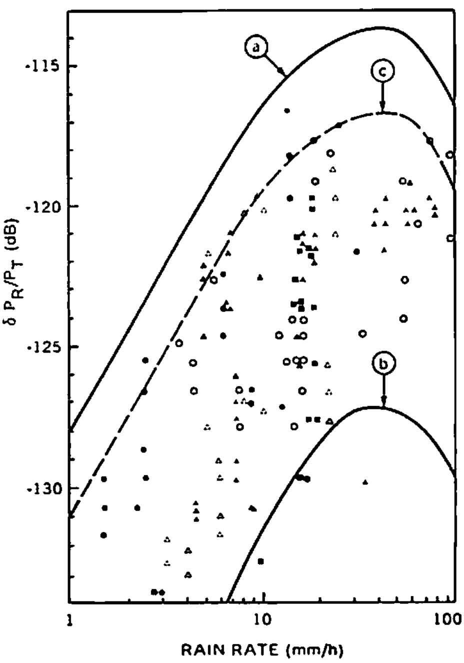

Fig. 4 - Curves of $\delta P_R/P_T$ versus rain rate for different transmitted polarizations and experimental results [2].

(a) Theoretical curve (Tx: Vert., Rx: Vert.)

(b) Theoretical curve (Tx: Horiz.; Rx: Vert.)

(c) Theoretical curve (Tx: Circular; Rx: Vert.)

●○▲△■ experimental points for 5 events [2] (Tx: Circular; Rx: Vert.)