New Model for Tropospheric Scintillation Flauctuations and Intensity in the V-band for the Earth-Satellite Links

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ABSTRACT

In this paper, we have obtained a model for the prediction of long-term scintillation fade depth, scintillation enhancement, and cumulative distribution of its intensity, in the 40/50 GHz band. Based on the frequency dependence analysis for the experimental results of the scintillation collected at Spino d'Adda, Italy, a model for scintillation variance is presented and then, according to the mesasurments at Madrid, Spain, using the Italsat beacon at 49.5 GHz, and a regression analysis of these data, we have extracted models for the scintillation. Moreover, the prediction accuracy of the new proposed model evaluated using the experimental results from Spino d'Adda, Italy.

Keywords: earth-satellite link, radiowave propagation, tropospheric scintillation, fade

1 INTRODUCTION

In order to satisfy the growing demand for the long distance communications, during the last decades, the exploitation of satellites for communication purposes has increased considerably. As the C-band (4/6 GHz) is already congested, and the Ku-band (12/14 GHz) is filling up rapidly, recently, interest focused on the utilization of higher bands, e.g. Ka (20/30 GHz) and V (40/50 GHz) bands [1].

The performance of the satellite systems operating in the Ka and V bands essentially depends on the propagation characteristics of the transmission medium, i.e. troposphere. Some of the most important tropospheric propagation effects are attenuation due to rain, depolarization, gas absorption and scintillation due to atmospheric turbulance[2].

In general, the impact of rain on communication systems is predominant. Scintillation, however, becomes important for low-margin systems that operating at high frequencies and low elevation angles. It has been observed that, at high frequencies and for low elevation angles, scintillation may contribute as much as rain, or more, to the total fade measured. This is especially true for low margin systems[3]. Therefore, it is necessary to characterize the scintillation phenomena in the earth-satellite links.

This paper has been organized as follows; first, a review of the tropospheric scintillation theory is presented. Then, current existing models already proposed for the prediction of tropospheric scintillation are introduced. Finally, according to the available experimental data, and applying a regression method, new models for scintillation fade, enhancement and intensity, are extracted, and the performance of the new model is compared to the current existing models, using the measurements data collected at eleswhere site.

2 THEORY

The tropospheric turbulence yields time-varying modifications of the refractive index and thus affect propagation of radiowaves on earth-space paths by generating random amplitude, phase and angle of arrival fluctuations, called scintillation [3,4]. It is generally assumed that the fluctuations of signal level due to scintillation for short-term periods (i.e. up to several minutes) is stationary and follows a guassian distribution around the mean signal level[5-7]. Therefore, scintillation is often characterised only by the variance or standard deviation of its probablity distribution, called scintillation intensity. However, for longer time periods, meteorological parameters are not constant and the variance of fluctuations varies and follows its own pdf. Two distribution for long-term standard deviation or variance of scintillation is proposed. The first, is gamma distribution and is appropriate for severe scintillation intensities [8,9]. The second, is log-normal distribution and is proper for moderate scintillation intensities [6,10]. Most of the models try to relate the parameters of these distributions to the link and meteorological parameters (e.g. beacon frequency, elevation angle, humidity, temperature).

3 CURRENT MODELS

In this section, the current existing models proposed for the prediction of tropospheric scintillation are introdoced. The general formulation used by most of the authors is as following :

$$\sigma_x^2 = Q(\mathrm{Meteo.Factor}).f^{\alpha}.\sin(\theta)^{-\beta}.g^2(D_e) \tag{1}$$

where, f is the beacon frequency in GHz, α is the frequency exponent, θ is the elevation angle, β is the elevation angle exponent, and $g(D_e)$ is the antenna avereaging factor, generally given by [14]:

$$\begin{aligned} g(D_e) &= \sqrt{3.8637(x^2+1)^{11/12}\sin[\frac{11}{6}\arctan\frac{1}{x}] - 7.0835x^{5/6}} \\ &\approx \sqrt{1-7.0835x^{5/6}} \quad \text{for } x \ll 1 \end{aligned} \tag{2}$$

in which, $x = 0.0584kD_e^2/z$, and D_e is the effective antenna diameter and given by :

$$D_e = D\sqrt{\eta} \tag{3}$$

where, D is the geometrical antenna diameter and η is the radiation efficiency of the antenna. $Q(\mathrm{Meteo.Factor})$, is the metorological dependence factor and often is expressed in the terms of the wet term of refractivity index at the ground level, called N_{wet}. Table I summarized the current existing models.

	Estimated Parameter	Frequency Exponent	Elev. Angle Exponent	Meteorological Factor
ITU-R[11]	σ_x	7/6	2.4	$(3.6\times10^{-3}+1.03\times10^{-4}.N_{wet})^2$
Karasawa[5]	σ_x	0.9	2.6	$(0.15+5.2\times10^{-3}N_{wet})^2$
Ortgies-T[13]	μ	1.21	2.4	$-12.5+0.0865.T$
Ortgies-N[12]	μ	1.21	2.4	$-13.45+0.0462.N_{wet}$
Otung[9]	σ_x	7/6	11/6	$(3.6\times10^{-3}+1.03\times10^{-4}.N_{wet})^2$

Table I. A summary of the current exsiting models for scintillation prediction

Note : For time and sheet saving, the above model's cumulative distribution are not expressed here and interested reader can see them at the corresponding references.

4 EXTRACT THE NEW MODEL

4.1 Prediction model for the scintillation variance

The general equation (1) was used for the scintillation variance and the meteorological term is considered as $(a+bN_{wet})^2$. By the frequency dependence analysis of the measurement results at Spino d'Adda, Italy, Van de Kamp found the long-term frequency exponent of the scintillation variance equal to 1.41, in the 40/50 GHz band[15]. For the elevation angle dependency, the theoretical term,i.e. $\sin(\theta)^{-11/12}$, is used[16]. By using the data of [17] and [18] (these data are in graphs, specified as fig.1 and fig.14 and have been extracted by scanning enlarged paper copies by hand), and applying the reverse ITU-R model, monthly-averaged variance and N_{wet} at each site obtained. Then, the data of monthly-averaged scintillation variance over a year was plotted versus the corresponding data of N_{wet} at both sites and fit a curve between them in the form of $(x+yN_{wet})^2$. Now, by equalizing the resulting fit coefficients to the (1), the meteorological term at each site was obtained. Finally, in order to increase the coverage range of the model, the corresponding coefficients of the meteorological terms at two sites, were averaged. So, the model obtained for the prediction of scintillation variance is expressed as bellow:

$$\sigma_x^2 = (0.0021 + 1.1914\times10^{-4}.N_{wet})^2.f^{1.41}.\sin(\theta)^{-11/6}.g^2(D_e) \qquad (4)$$

where, $g(D_e)$, is given by (2).

Table II shows the measured and predicted values of the scintillation variance at Spino-d'Adda and Madrid sites (good performance of the new model is clearly seen).

	Spino d'Adda	Madrid
Experimental Data	0.0135	0.022
Proposed model	0.0145	0.0205
ITU-R model	0.0098	0.0094

Table II. Measured and predicted values of scintillation variance

4.2 Scintillation fade and enhancement on the long-term basis

The fade and enhancement terms refered to the negative and positive fluctuations around the mean signal level,respectively. The data used in this section, was extracted from [19](these data are in graphs, specifeid as fig.2 and extracted similar to the previous section). We have used the expression $\sigma_{pre}\,\eta(p)$ for the formulation of curve fitting in which σ_{pre} is the predicted scintillation intensity and $\eta(p)$ is a cubic polynomial in $\log(p)$. **Fig. 1** shows the measurment results of the scintillation fades and enhancements distributions.

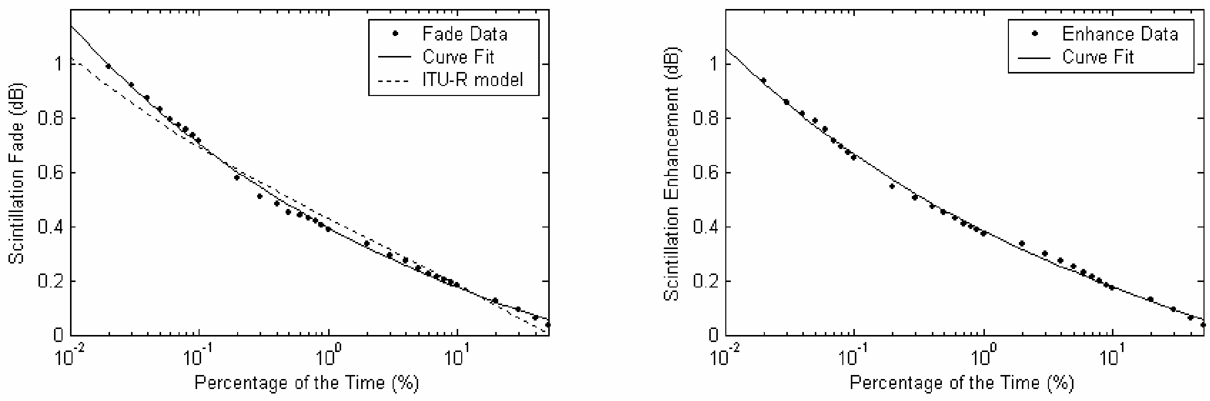

Fig. 1. Scintillation fade data, its best fitting curve and ITU-R model (left side) and the scintillation enhancement data, its best fitting curve (right side)

The best fitting curves and the ITU-R model are also plotted in the **Fig. 1**(left). Now, the coefficients of the fitting curves are determined and we have the following expression for the distribution of the long-term scintillation fade:

$$X_{-a} = \sigma_{pre}(-0.037\log(p)^3 + 0.317\log(p)^2 - 1.824\log(p) + 2.763) \qquad (5)$$

And, the long-term scintillation enhancement is obtained as:

$$X_{+a} = \sigma_{pre}(-0.0462 og(p)^3 + 0.258 og(p)^2 - 1.664\log(p) + 2.685) \qquad (6)$$

where ‘a’ indicates the annual and p is the percent time absicca exceeded. The correlation coefficient and rms error of the above regression process are shown in Table III.

	Correlation Coefficient	Standard Error
Fade Data Fit Process	0.9992	0.01352
Enhance Data Fit Process	0.9991	0.01294

Table III. Quality factors of the regression process for the fade and anhancement data

4.3 Annual and worst-month cdf of the scintillation standard deviation

The worst month distribution is the synthetic peak envelope of the monthly cumulative distribution obtained by selecting at each time percentage the maximum value of the scintillation intensity exceeded in 12 month. In order to obtain the cumulative distribution of these quantities, again, we use the data of [19] (specified by fig.1 and fig.3). **Fig. 2** shows the data of the annual scintillation standard deviation and its worst-month distribution at Madrid site, at the 49.5 GHz. The best fitting curve are also plotted in **Fig. 2**.

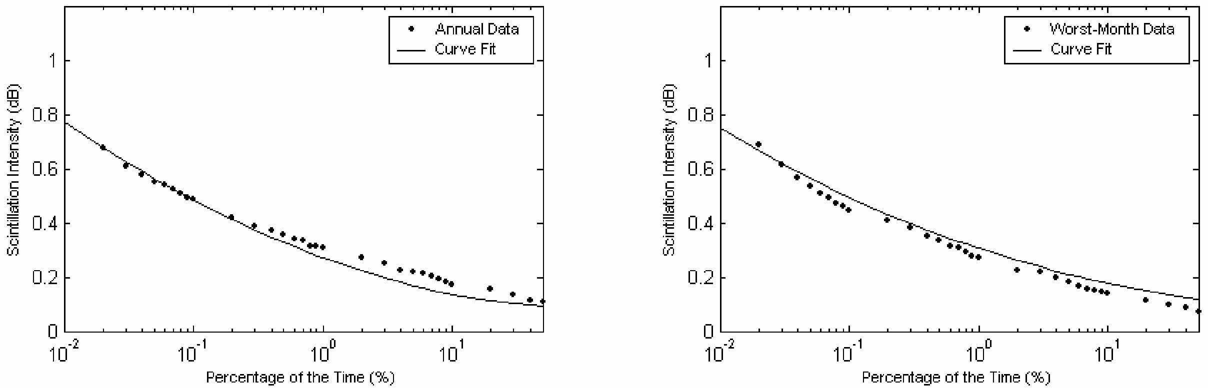

Fig. 2. Annual scintillation intensity data, and its best fitting curve (left hand), and worst-month scintillation intensity, and its best fitting curve(right hand)

Therefore, the cumulative distribution of the annual scintillation intensity is expressed as the following:

$$\sigma_a = \sigma_{pre}(-0.00921\log(p)^3 + 0.2063 og(p)^2 - 1.088\log(p) + 2.159) \qquad (7)$$

Similarly, the expression for the worst month cumulative distribution is obtained as:

$$\sigma_{wm} = \sigma_{pre}(0.00522\log(p)^3 + 0.2772\log(p)^2 - 1.217\log(p) + 1.898) \qquad (8)$$

in which, ‘wm’ indicates the worst month. The quality parameters of regression analysis in this case, including correlation coefficient and rms error, are shown in Table IV.

	Correlation Coefficient	Standard Error
Annual Data Fit Process	0.9977	0.01343
WM Data Fit Process	0.9935	0.02512

Table IV. Quality factors of the regression process for the annual and worst-month data

5 COMPARISION

In this section, we will compare the proposed model for the scintillation fade depth with the current existing models and available elsewhere experimental data obtained at Spini d'Adda, Italy, using the Italsat beacon at 39.6. These data were extracted from [20] by the same method described before in section (4.1). The elevation angle of the slant path is 37.8^0, and the diameter of the receiving antenna is 3.5 m and its radiation efficiency is 0.64. **Fig. 3** (left-side) shows the experimental fade data at 39.6 GHz, for the summer period , the predicted fade obtained from proposed model and currernt existing models. Meanwhile, in order to have a more obvious observation, **Fig. 3** (right-side) shows a zoom window of the left-side figure (for the practical range of time percentages).

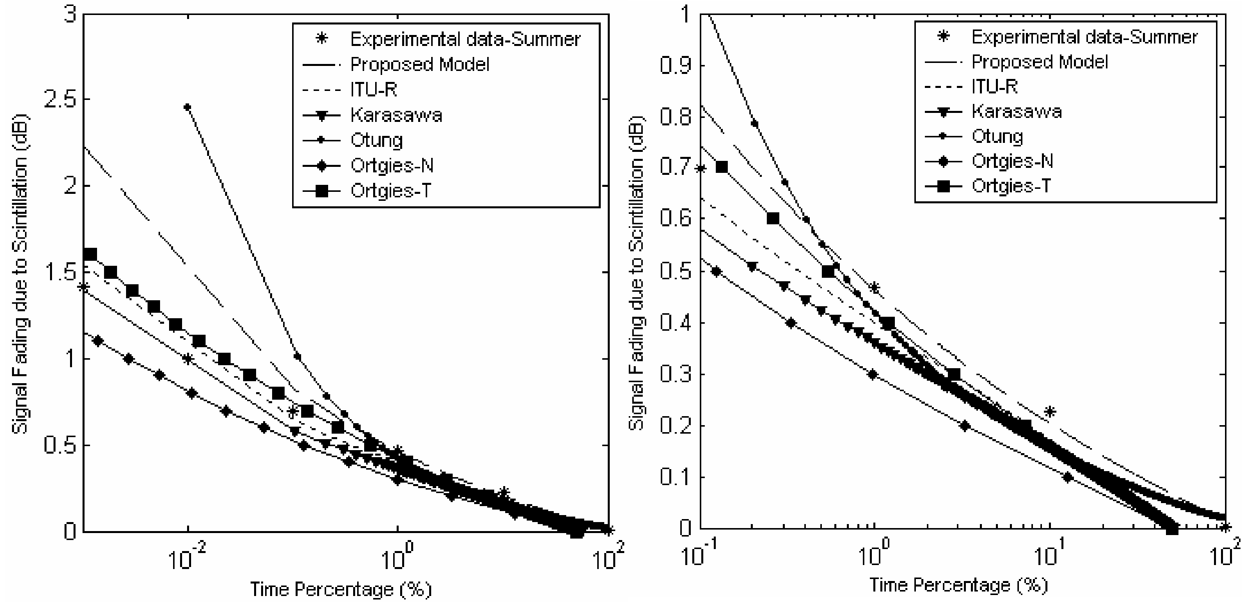

Fig. 3. Comparision between proposed model, current existing models, and experimental data at 40 GHz (left-side), and a window of the left-side figure for more obvious view(right-side)

Fig. 4 shows the same comparision, but for annual measurements at Spini d'Adda. Similar to the previous comparision, a window of **Fig. 4** is also shown.

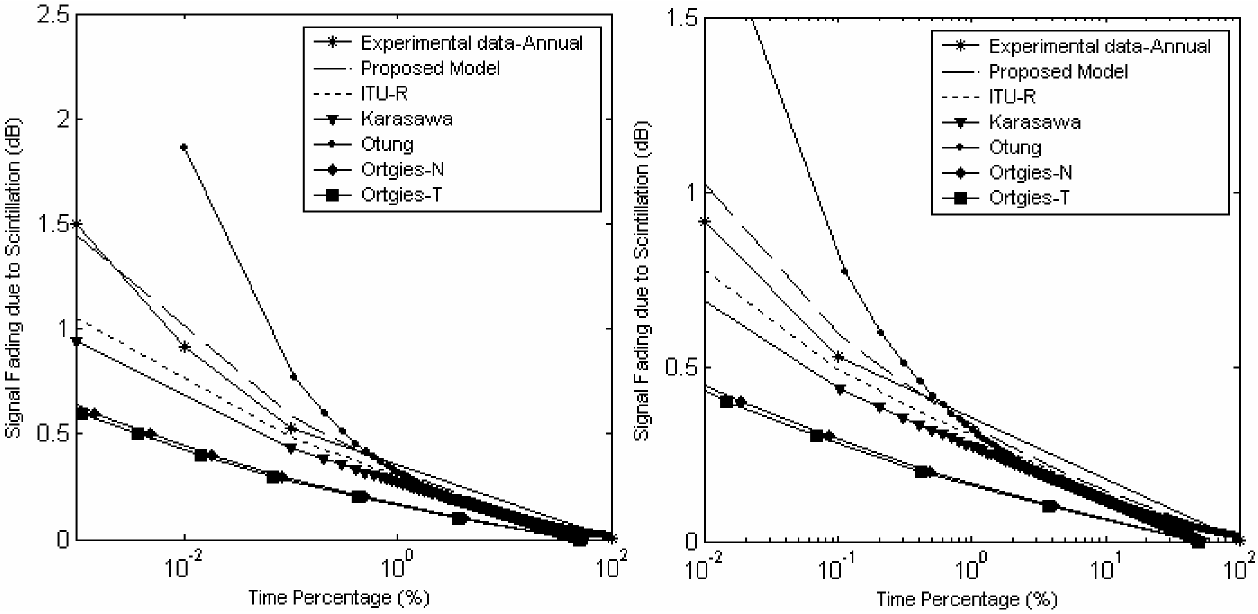

Fig. 4. Similar to **Fig. 3**, but for annual data (left-side), and a window of **Fig. 4** (right-hand)

Fig. 3 and **Fig. 4** verified that the proposed model has the best performance in predicting the scintillation fade, both in summer(seasonal) and annual periods. Note that this good behaviour is valid for practical range of time percentages (the range which is important in link design, i.e. between about 0.1% to 100%). Moreover, among the current existing models, for summer period, Ortgies-T has a better behaviour than other models, but for annual period, ITU-R model is the best. Since the Ortgies-T model is based on the temperature, while, another models based on the wet term of refractivity index, therefore, for the summer period, in which the temperature is the dominant meteorological factor affecting the scintillation, Ortgies-T is the best. But, for annual period, which covers the whole year and N_{wet} is predominant meteorological factor, the models based on the N_{wet}, have better performance than Ortgies-T model, which clearly seen in **Fig. 4**

Table VI shows the accuracy of the proposed model and current existing models in terms of the relative error (%) and the correlation coefficient, for seasonal period.

	Relative Error(%)	Correlation coefficient
Proposed model (fade)	3.4	0.993
ITU-R	79.6	0.998
Karasawa	81.6	0.998
Otung	21.1	0.940
Ortgies-N	48	0.986
Ortgies-T	10	0.988

Table VI.

6 CONCLUSION

New models for the prediction of long-term cumulative distribution of signal fluctuations due to scintillation in the V-band (40/50 GHz), were presented. We obtained models for the annual cdf of scintillaion fadings, enhancements, and intensity. Meanwhile, worst month cdf of scintillation intensity was also obtained.

In order to show the accuracy of the proposed model, we compared our model with the measurements data at 40 GHz (for the annual and seasonal period), and its good performance in compariosion with other current models was observed. For the practical range of time percentages, i.e. higher than about 0.1%, most of the the current existing models understimated the experimental fade data. For summer period, Ortgies-T model had a better performance than others, while, for annual period, other models based on N_{wet} were found to be better than Ortgies-T. Therefore, at higher frequency bands, it is recommanded to utilize the new proposed model for the prediction of scintillation fade in the budget design of satellite links.

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REFERENCES

[1] M. M. J. L. van de Kamp, “Climatic radiowave propagation models for the design of satellite communication systems,” *Ph.D. dissertation, Technical University Eindhoven, The Netherlands*, 1999.

[2] C. E. Mayer, B. E. Jaeger, R. K. Crane, and X. Wang, “Ka-band scintillations: Measurements and model predictions,” *Proc. IEEE*, vol.85, pp. 936–945, June 1997.

[3] Vanhoenacker, D., G. Brussard, F. Haidara, G. Ortgies, A. Paraboni, T. Pratt, C.Riva, J.Tervonen, S. Touw, H.Vasseur. “Chapter V Atmospheric Scintillation,” *OPEX Second Workshop of the OLYMPUS Propagation Experimenters, European Space Agency, Noordwijk Netherlands*, pp. 49-64, November 1994.

[4] B. R. Arbesser-Rastburg and A. Paraboni, “European research on Ka-band slant-path propagation,” *Proc. IEEE*, vol. 85, pp. 843–852, June 1997.

[5] Karasawa, Y., M. Yamada and J. E. Allnutt, “A New Prediction Method for Tropospheric Scintillation on Earth-Space Paths*”, IEEE Trans. Antennas Propagat.*, pp. 1608-1614, 1988.

[6] Moulsley, T. J. and E. Vilar, “Experimental and Theoretical Statistics of Microwave Amplitude Scintillations on Satellite Down-Links”, *IEEE Trans. Antennas Propagat.*, pp. 1099-1106, 1982.

[7] Otung, I. E. and B. G. Evans, “Short term distribution of amplitude scintillation on a satellite link”, *Electron. Lett.*, pp. 1328-1329, 1995.

[8] Karasawa, Y., K. Yasukawa and M. Yamada , “Tropospheric Scintillation in the 11/14-GHz Bands on Earth-Space Paths with Low Elevation Angles*”, IEEE Trans. Antennas Propagat.*, pp. 563-569, 1988.

[9] I.E. Otung, “Prediction of Tropospheric Amplitude Scintillation on a Satellite Link”, *IEEE trans. on Antennas & Propagation*, Vol. 44, No. 12, pp. 1600-1608, December 1996.

[10] G. Ortgies, “Probability density function of amplitude scintillations”, *Electron. Lett.*, pp. 141-142, 1985.

[11] ITU-R, Rec. PN. 618-3, “Propagation data and prediction methods required for earth-space telecommunications systems” *PN Series* Vol., pp. 329-343, 1994.

[12] G. Ortgies, “Prediction of Slant-Path Amplitude Scintillations from Meteorological Parameters”, *Proceedings of 1993 International Symposium on Radio Propagation*, Beijing, pp. 218-221, 1993.

[13] G. Ortgies, “Frequency dependence of slant-path amplitude scintillations”, *Proc. of the 20th Meeting of Italsat propagation experiment (OPEX), Darmstadt (Germany)*, pp. 156-164, 1993.

[14] Haddon, J. and E. Vilar, “Scattering Induced Microwave Scintillations from Clear Air and Rain on Earth Space Paths and the Influence of Antenna Aperture”, *IEEE Trans.Antennas Propagat.*, pp. 646-657, 1986.

[15] Van de Kamp, et al, “Frequency Dependence of Amplitude Scintillation”, *IEEE Trans. Antennas Propagat.*, pp. 77-85, 1999.

[16] V.I.Tatarskii, “Wave propagation in a turbulent Medium”, (translated by R.A.Silverman), New York:McGraw-Hill, 1961.

[17] F.S.Marzano, et al, “Model-Based Prediction of Amplitude Scintillation Variance in the 10-50 GHz Band: Compariosion with Italsat Satellite Measurements”, *First International Workshop on Radiowave Propagation Modelling for SatCom Services at Ku-band and above*, October 1998.

[18] C.E.Mayer, et al, “Ka-Band Scintillations: Measurements and Model Predictions”, *Proceeding of IEEE*, VOL. 85, NO.6, pp. 936-945, June 1997.

[19] P.Garcia, J.M.Riera, A.Benarroch, “Statistics of dry and wet scintillation in Madrid using Italsat 50 GHz beacon”, *PM3-013, International Workshop, COST Action 280*, July 2002.

[20] C.N.Kassaianidas, I.E.Otung, “ Dynamic model of tropospheric scintillation on earth-space paths”, *IEE Proc. Microw Propag.*, Vol. 150,No.2, pp. 97-103, April 2003.