Prediction of scintillation intensity from sky-noise temperature in Earth-satellite links

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Further evidence of the strong correlation between sky-noise temperature and scintillation intensity at 12.5GHz is revealed. Predictions from an measurement derived linear regression fit are compared with CCIR predictions and show a net improvement in the accuracy of the scintillation levels. Extrapolation to 30GHz also gives reasonably accurate intensities.

Introduction: Accurate prediction of scintillation intensity in Earth-satellite links is important when evaluating link budgets in low fade margin systems, particularly for systems operating in the Ku frequency band and above, where scintillation intensity is relatively high. Some of the currently available tools for estimating the reference scintillation intensity [1 – 3] only take into account meteorological parameters measured at the ground for estimating the reference intensity. The ground information is then used to infer air refractive index changes in the thin layer where the path is assumed to experience the actual turbulence that leads to scintillation. This study is concerned with deriving an accurate expression for the reference scintillation intensity from measurements of sky-noise temperature along the path length, combined with the ground meteorological information. The reference intensity then enters into the computation of the predicted intensity levels given the particulars of the propagation path.

Experiment and results: Beacon signal magnitude measurements at 12.5GHz with an elevation angle of 27.5° and a receive antenna aperture of 1.2m using ESA's Olympus satellite were performed between December 1989 and May 1991. Sky-noise temperatures were measured in parallel using a radiometer operating at 12.85GHz [4]. The radiometer and the receive system antennas were distinct but were both pointing in the same direction. Routine air temperature and relative humidity measurements were also conducted at the receiver site. All measurements were made with a sampling rate of 2Hz.

The scintillation intensity, σ, was calculated for each valid day of the 18 months from the time series of signal magnitude. These were the days where no spurious spikes of technical origin were detected, or when sky-noise temperature did not exceed 70K. Higher temperatures would generally be connected to rain periods and should be treated differently from clear-sky conditions because of the overlapping effects of rain and turbulence induced scintillation, both phenomenon having different statistical characteristics [6]. The scintillation intensity was evaluated by estimating the standard deviation of the measured signal magnitude (decibels) over 1min periods after a 10mHz cutoff frequency highpass filter was applied to the data. The filter was intended to remove the contribution of the low frequency components from the signal, generally associated with rain fades or due to satellite motion [7], without affecting the contribution of turbulence to scintillation. The 1min intensities were then averaged over 1h periods and the mean hourly intensities for each particular month were then estimated. The data was therefore reduced from its original size to a representative one sample of scintillation intensity per hour per month.

In the CCIR prediction model [1], the most commonly used practical model, the reference scintillation intensity σ_{REF} depends only upon the wet component of the ground refractive index, N_w, according to

$$\sigma_{ref} = 1.03 \times 10^{-4} N_w + 3.6 \times 10^{-3} \qquad (1)$$

where N_w is estimated from air temperature and relative humidity.

For the study period, it was found that the correlation between measured and predicted scintillation intensity improved when sky-noise temperature T_S(°C) was taken into account. It was also found that the short term prediction level over periods of the order of one day to one month were better correlated with the ambient temperature T (°C), that they were with N_w. The combination of ambient air temperature and sky-noise temperature provided the most accurate predictions given only one or two input variables. To test the effectiveness of the prediction from measured T_S and T, the coefficients of a linear regression function were computed over the first 12 months, i.e. over a full seasonal cycle. The following expression for σ_{REF} (in decibels) was derived:

$$\sigma_{ref} = 2.1 \times 10^{-4} T + 1.2 \times 10^{-4} T_s + 2.5 \times 10^{-3} \qquad (2)$$

For the given link parameters and receiving system characteristics, σ_{REF} was then used to infer σ from

$$\sigma = \sigma_{ref} f^{7/12} \frac{\sqrt{G(D)}}{\sin^{1.2}\theta} \qquad (3)$$

where f is the frequency (GHz), $G(D)$ is the aperture averaging factor [1] and θ is the elevation angle. A height of 1000m was assumed for the turbulent layer. Eqn. 2 was then used to infer the scintillation intensity levels for the last 6 months of the experimental period. Fig. 1*a* shows the monthly mean scintillation intensity as predicted from eqn. 2 and from [1]. Although the latter model seems to provide a reliable prediction for the first 12 months, its accuracy becomes questionable for the last 6 months where the prediction error reaches as much as 40% (Fig. 1*b*). Predictions using eqn. 2 however, remain, close to the measured values not only for the first 12 months, as we would expect, but also during the 6 months where no measured data were used to derive the coefficients of eqn. 2. The prediction error remains < ~12% throughout the 18 months. The RMS scatter was estimated and found to be 0.008dB for the predictions derived from eqn. 2 and 0.017dB for CCIR predictions, an improvement which emphasises the relevance of the selected combination of parameters.

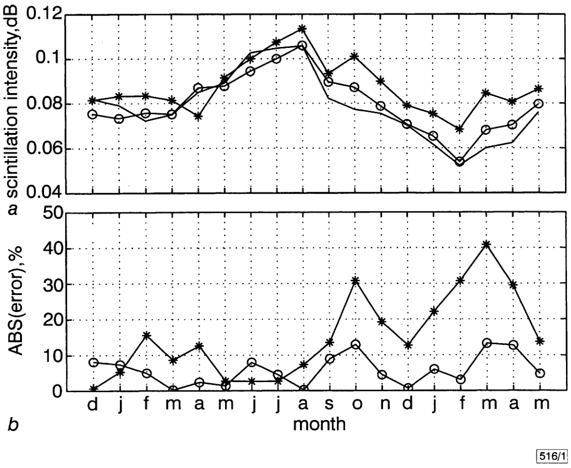

Fig. 1 *12GHz beacon*

a Comparison between monthly mean predicted scintillation intensity from CCIR model and from eqn. 2
b Error between measurements and intensity predicted from CCIR and from eqn. 2
✻ CCIR model
○ eqn. 2

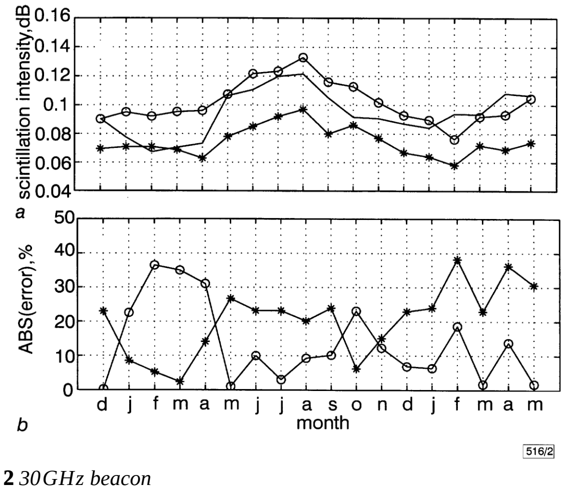

Fig. 2 *30GHz beacon*

a Comparison between monthly mean predicted scintillation intensity from CCIR model and from eqn. 2
b Error between measurements and intensity predicted from CCIR and from eqn. 2
✻ CCIR model
○ eqn. 2

Application to Ka-band scintillation intensity prediction: The availability of simultaneous 29.7GHz beacon signal magnitude measurements at the experimental site, together with sky-noise temperature radiometer measurements at 30GHz, provided a unique opportunity to assess the accuracy of the scintillation intensities predicted from eqn. 2 and to determine whether the coefficients of this expression remained valid at other frequencies. The resulting predictions were, once again, compared to the CCIR predictions. Fig. 2*a* shows the monthly mean scintillation intensity as derived from eqn. 2, and the intensity as estimated from the CCIR model. There is clear evidence from the Figure that eqn. 2 improves the prediction accuracy. The error is seen to be reduced, on average, by a factor of 2 throughout the period, except for the first three or four months of 1990 where quite low scintillation intensities were measured despite normal seasonal temperatures. It would also be fair to note that the CCIR model was originally designed from measurements carried out at frequencies of up to 14GHz [1] and that predictions at higher frequencies using this model should be used with care. It is suspected that some factors, linked to the nonlinear nature of atmospheric turbulence, might account for part of the observed discrepancies during January–April 1990.

Conclusions: It was shown that the inclusion of sky-noise temperature improved the accuracy of the predicted scintillation intensity at 12.5GHz. A new expression for the reference scintillation intensity σ_{REF} incorporating T_S, is suggested. The validity of the expression was tested against six months of data and showed a net improvement in prediction accuracy compared to the more traditional models [1]. The underlying error level of < 12% observed during the study period is attributed to the existence of nonlinear effects between scintillation intensity and some meteorological parameters. Extrapolation of the 12.5GHz linear correlation coefficients to imply the scintillation intensity at 30GHz has proved very promising, with an average 50% improvement over CCIR predictions for most of the experimental period.

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