A QUICK OVERVIEW OF A NEW SCINTILLATION DATABASE

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Abstract – This paper explores a new Ka and Q-band dry scintillation database and ancillary meteorological data collected at Aveiro, Portugal in two converging Earth-satellite propagation paths. The measurement equipment, the parameters of both links and the processing procedure of the database are described first. The dependencies of the hourly averaged scintillation standard deviation with respect to several meteorological parameters, measured at the ground level, and with respect to the wet refractive index are analyzed. The diurnal variation of the hourly averaged scintillation standard deviation, on a monthly and yearly basis, is explored. The yearly amplitude distributions, fades and enhancements, are presented and compared against some available models. The scatter plot of the concurrent hourly averaged scintillation standard deviation is analyzed and a frequency scaling factor is tentatively derived.

Keywords – Diurnal variability, modeling, scintillation

1. INTRODUCTION

A microwave signal crossing the atmosphere is subjected to several impairments such as attenuation, depolarization and scintillation. The scintillation is caused by the scattering of atmospheric refractive index irregularities in turbulent layers that evolve over time and drift through the propagation path carried by the wind. The phase and amplitude distorted wave front is integrated by the receiving antenna aperture giving rise to the observed signal amplitude fluctuations (phase fluctuations are more difficult to measure) around a mean value computed typically in 1 minute to 5 minutes.

The modeling of scintillation is important because it can disturb the fade mitigation systems and the scintillation fades can impact the availability of terminals with very small fade margins.

Scintillation long term data at Q-band and databases collected with concurrent satellite links are yet relatively scarce in the literature.

2. EXPERIMENTAL SCENARIO

Two propagation experiments have been active at our site: one using the Ka-Sat satellite Ka-band beacon at 19.68 GHz and the other with the Alphasat satellite Q-band beacon at 39.402 GHz. The receivers use FFT techniques for signal detection whose samples are stored, in both cases, at a rate of 8S/s. More information can be found in [1]. The receivers are fully independent; they do not share any hardware.

The general characteristics of the links are given in the following table: where the $CNR_0$ (dB-Hz) is the carrier to noise spectral density ratio in clear sky.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ka-Band</th>
<th>Q-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna diameter (m)</td>
<td>1.50</td>
<td>0.62</td>
</tr>
<tr>
<td>Elevation (º)</td>
<td>39.63</td>
<td>31.9</td>
</tr>
<tr>
<td>Azimuth (º)</td>
<td>153.95</td>
<td>134.6</td>
</tr>
<tr>
<td>$CNR_0$ (dB-Hz)</td>
<td>53.0</td>
<td>57.7</td>
</tr>
<tr>
<td>Polarization quasi-V (º); tilt angle</td>
<td>19.5</td>
<td>12.3</td>
</tr>
<tr>
<td>Sampling rate (S/s)</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

The site coordinates are 40° 37’ N and 8° 39’ W being the Q-band receiver about 3 m below the Ka-band receiver (in an office below the roof). The angular aperture between the two links is about 17º. Recently the K-band receiver front-end was refurbished and the $CNR_0$ has been improved by about 4 dB. A small meteorological station is also co-sited and measures temperature, relative humidity, rain rate, wind speed and atmospheric pressure at the ground level.

Q-band data are logged by a MATLAB application into a set of files and the Ka-band beacon and meteorological data are logged by a Labview application into another set of files. The beacon data copolar amplitude time series is stored at a sampling rate of 8 S/s.
3. DATA ANALYSIS

The raw experimental data is loaded together and preprocessed by a dedicated tool to perform the preprocessing [2]. This step aims to check the quality of the data and to derive the attenuation by using the measured copolar levels and the estimated copolar levels that would be observed in the absence of attenuation. All preprocessed time series are stored in a single daily file.

For the scintillation analysis, first, the preprocessed data files are loaded and the scintillation time series is obtained by using a high pass filter, based on raised cosine with a 0.025 Hz cut-off frequency. Then, the wet refractivity, \( N_{\text{wet}} \), is calculated using the temperature, \( T(\text{°C}) \), relative humidity, \( H(\%) \), and pressure, \( P(\text{hPa}) \), all integrated with a 10 minutes integration time, according to [3]:

\[
N_{\text{wet}} = 72 \frac{e}{T+273} + 3.75 \times 10^5 \frac{e}{(T+273)^2} \quad (1)
\]

The water vapor pressure, \( e(\text{hPa}) \), is related with \( H \) by

\[
e = \frac{e_0 H}{100} (\text{hPa}) \quad (2)
\]

The water vapor saturation pressure, \( e_s \), can be calculated from the temperature and the pressure but the equations also found at [3], are omitted here for brevity.

The scintillation variance is calculated in one-minute non-overlapping time windows. Finally, the scintillation time series and the processed meteorological data are stored in a new file. Statistical data on scintillation parameters is derived by dedicated tools that have been developed in MATLAB.

It must be pointed out that, due to the finite \( \text{CNR}_0 \), the Gaussian noise introduces a bias on the scintillation variance, given by [4]:

\[
\sigma_n^2 = 75.44 \times 10^{-\frac{\text{CNR}-10\log_{10}(f_s)}{10}} (\text{dB}^2) \quad (3)
\]

where \( f_s = 8 \) Hz is the sampling bandwidth. The calculations, using the values in Table 1, gives respectively, 1.0E-3 and 3.0E-3 dB2 for the Q and Ka bands.

The measured variance, \( \sigma_m^2 \), is related to the atmospheric induced variance, \( \sigma_{\text{atm}}^2 \), by the equation:

\[
\sigma_m^2 = \sigma_{\text{atm}}^2 + \sigma_n^2 (\text{dB}^2) \quad (4)
\]

The variance (or standard deviation) presented throughout the paper, is \( \sigma_m^2 \). The accurate removal of the noise contribution must yet be carefully addressed due to CNR variations along the time; however, its contribution to the variance is small.

4. RESULTS AND ANALYSIS

The scintillation is usually characterized by the distribution of the amplitude, \( \chi (\text{dB}) \), or by the standard deviation, \( \sigma_\chi \), computed in 1-minute time windows. This last one is often calculated only for dry periods, therefore, the periods with attenuation larger than 0.5 dB at Ka-band and 1 dB at Q-band were excluded from the statistical calculations. The annual and monthly statistics here presented correspond to a full year, from June 2017 to May 2018.

4.1 Meteorological dependencies

The joint distributions of the hourly averaged scintillation standard deviation and meteorological parameters were calculated.

Fig. 1 presents the Q-band scintillation standard deviation versus the atmospheric pressure. The higher the pressure the lower the scintillation variance. High pressure means usually clear sky, dry and stable weather: conditions that are not prone to atmospheric instability. As we can see the higher the scintillation standard deviation is, the more sensitive to the pressure. The scintillation variance is higher than the minimum expected value due to measurement noise (see Section 3), therefore, a residual scintillation is always present. The hourly correlation between the two-time series is already not negligible. A similar plot is obtained for the Ka-band.

![Histogram for AlphaSat from 06/01/2017 to 05/31/2018](image-url)
Fig. 2 shows the scintillation standard deviation at Ka-band versus $N_{\text{wet}}$. As we can see, there is also a clear correlation with $N_{\text{wet}}$; the higher the wet refractivity the higher the scintillation standard deviation. The $N_{\text{wet}}$ parameter, averaged on a long term basis, has been used to model the distribution of the scintillation standard deviation[5]–[7].

Fig. 3 depicts the scintillation standard deviation at the Q-band versus temperature. There is a clear trend that shows the effect of the temperature; the higher the temperature the higher the scintillation standard deviation. That is, higher temperatures are associated with increased atmospheric instability. Exactly the same trend is observed at Ka-band (not depicted).

Table 2 – Correlation between scintillation standard deviation and meteorological parameters

<table>
<thead>
<tr>
<th>Meteorological parameter</th>
<th>Correlation Ka-band</th>
<th>Correlation Q-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (mB)</td>
<td>$-0.31$</td>
<td>$-0.29$</td>
</tr>
<tr>
<td>$N_{\text{wet}}$</td>
<td>0.33</td>
<td>0.34</td>
</tr>
<tr>
<td>Temperature (ºC)</td>
<td>0.34</td>
<td>0.36</td>
</tr>
<tr>
<td>Water vapor (g/m$^3$)</td>
<td>0.33</td>
<td>0.35</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>0.14</td>
<td>0.12</td>
</tr>
</tbody>
</table>

The most uncorrelated variable is the relative humidity. The variables $N_{\text{wet}}$, temperature and water vapor content have similar correlations being the corresponding correlations at Q-band slightly higher. The models usually use meteorological parameters averaged on longer periods as input data, however, a noticeable correlation is observed with hourly data. The Ortgies-T [8] and Marzano [9] models seem to deserve attention as the correlation of the standard deviation with temperature is similar to that of the usually used $N_{\text{wet}}$ as a modeling parameter.

4.2 Diurnal variation

The diurnal variation of the standard deviation (the time is given in UTC) has been calculated on a monthly and yearly basis. The trend is the same along all months with somewhat more striking diurnal variations during the months with average higher temperatures.

The most scintillating periods of the day are from 10 am to 8 pm as can be observed in Fig. 4; this latter hour occurs a little bit earlier during winter.
Often, higher scintillation periods, however not as intense as those of the afternoon, also occur close to midnight, usually after, as can be observed in Fig. 5. The lowest scintillation periods occur from 5 am to 9 am and 10 pm to 11 pm. Some turbulent processes must be occurring in the atmosphere between the more quite end of the day and the early morning. The day variations are very similar at both frequencies as can be easily observed.

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4.3 Distribution of fades and enhancements

The monthly distribution of the scintillation amplitude enhancements, $\chi^+$ (dB), and fade depth, $\chi^-$, for a full year are depicted, respectively, in Fig. 6 and Fig. 7 for the Q-band.

As discussed in [4] for the same probability the fades are, in general, deeper than the enhancements. However, in spite of being true along an average year, the difference is very small and it is not verified for all the months.

There is a significant variability of the cumulative distributions from month to month but there is no clear distinction between late spring, summer and early fall from the other periods. Higher temperatures but clear sky and higher pressures are balanced by lower temperature but often cloudier conditions during the other periods.
4.4 Concurrent standard deviation at the two bands

As described above the two converging links have an angular difference of about $17^\circ$ and the distance between the points where the links cross a plane at 1000 m altitude is several hundreds of meters. Nevertheless, a very high correlation between the scintillation variance at the two frequencies has been always observed. This means that the spatial stationarity of the turbulence is of the same order of the distance between the points where the links cross the turbulence.

Fig. 8 depicts the high correlation mentioned above, with the peculiarity that the Ka-band receiver has been upgraded during this month; for the last 10 days of the month a higher $CN_{R_0}$ was already available. It is notorious that the presence of two data sets being the lower set collected already with the better $CN_{R_0}$ estimated to be about 6.5 dB wrt to the actual performance of the receiver (the receiver NF had a fast CNR degradation during the last two months of operation).

The annual scatter plot results presented in Fig. 9 show the high correlation between the two variances that were, nevertheless, expected from the diurnal variation discussion in section 11. The obtained annual correlation was 0.772 and is quite similar throughout all the months.

5. SCINTILLATION MODELS

A few essays of some available scintillation models have been performed, such as, the scintillation fades and enhancements using the Otung [7], ITU [10] (only for fades), van de Kamp [11] and the Karasawa [5] models. Fig. 11 and Fig. 12 were obtained for the Ka-band using the yearly average measured $N_{wet} =51.5$, the antenna variance averaging factors of about 0.86 and 0.95 (respectively for the Ka and Q-band) computed for a turbulent layer height of 1 km (ITU and Otung models) and 2 km (for the Karasawa model) and,
finally, assuming the antennas efficiency of 60%.
The long term average water content $W_{hc}$ of heavy
clouds, used in the van de Kamp model, was roughly
estimated as 1 kg/m² from [12].

The correlation of the hourly averaged scintillation
standard deviation and local meteorological data
has been analyzed. A positive correlation was found
with ambient temperature and the water vapor
density and a negative one with the atmospheric
pressure.

The diurnal variation is more observable during the
summer months and the scintillation is more
intense from 10 am to 8 am. The monthly fade and
enhancements distributions show a significant
variability. There is a high correlation between the
hourly scintillation variance at the two frequencies
in spite of the angular separation of the two links.
The variance frequency scaling seems to be well
described by the theory. The best fade and
enhancements model to describe the experimental
data seems to be the Otung one.

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range.

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