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TEST OF METHODS ELIMINATING REGULAR SIGNAL LEVEL VARIATIONS DUE TO SPATIAL ALPHASAT SATELLITE MOTION

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ABSTRACT

Many countries receive the Alphasat satellite signal in both Ka and Q bands in order to analyze the random atmospheric attenuation. The received signal from the Alphasat satellite is influenced not only by the atmosphere but also by the quasi regular satellite motion causing the "cosinusoidal" signal level fluctuations of about 24 hour period. In this contribution we describe mathematical methods eliminating this fluctuation and perform tests of the suitability of particular methods. To test these methods we developed and used the signal level software simulator as we must know the "true" attenuation values while the simulated values are the "true" ones from our testing viewpoint. The tests showed that we should recommend the MY method developed at the Institute of Atmospheric Physics Prague but the differences among tested methods are low and all described methods are acceptable.

Keywords: Satellite communication, Atmospheric attenuation, Satellite space motion elimination

INTRODUCTION

The Alphasat signal measurement (see receivers in Fig. 1) is running at the Institute of Atmospheric Physics Prague (IAP) on both Ka and Q bands (19 and 39 GHz) and the TDP#5 "Aldo Paraboni propagation experiment" continues. Our receivers are described in (Fiser et. al., 2017). The IAP cooperates within the ASAPE and ASALASCA groups.

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The primary activity is the long term signal level monitoring completed by the important experimental meteorological data measurement (rain intensity, temperature, humidity, air pressure, sky noise etc.). From signal level we derive the atmospheric attenuation - this procedure is not easy as we do not have the antenna tracking after OEM coordinates. The usual procedures will be described and tested in next chapters of this contribution. Our simple tracking system works namely autonomously searching for the maximum signal level each 10 minutes. The antenna moves in elevation only.

Fig.1. The 19 GHz and 39 GHz Alphasat satellite signal receivers of the Institute of Atmospheric Physics in Prague, Czech Republic

As we have derived the atmospheric attenuation, we analysed step by step:

- Long term attenuation statistics including second order statistics and attenuation event analysis with respect to meteorological situation
- Test of prediction models of atmospheric attenuation
- Frequency scaling and scintillation analyses

First results were published in (Ventouras et. al., 2016; Ventouras et. al., 2017; Vilhar et. al., 2016; Pek et. al., 2016a and Pek & Fiser, 2017).

Signal fluctuation due to satellite motion and methods of its elimination

A big problem to extract attenuation information from the signal level record is caused by the space satellite fluctuation - see the primary quasi regular (nearly cosinusoidal) signal fluctuation due to this motion in Fig.2. We have described the satellite space motion in (Pek et. al., 2016b).

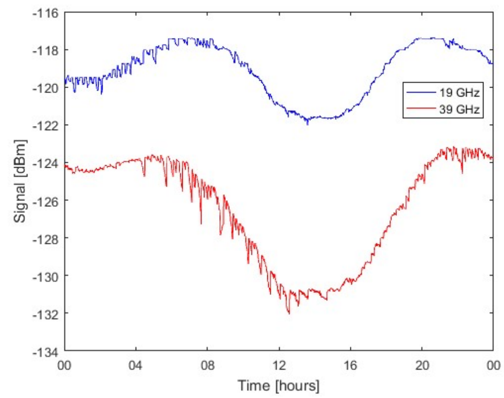

Fig.2. Example of 24h recorded signal level fluctuation due to satellite space motion which is the source for signal template (Prague, 6.1.2017)

The actual atmospheric attenuation must be derived due to the difference (substracting) between 1. actual signal level and 2. modelled regular signal level fluctuation (called "template"). This template corresponds to the signal level which would be in the case of zero atmospheric attenuation (clear air weather). The template is constructed for 24 hours because this is the period of satellite motion (Pek et. al., 2016b). A template example is shown in Fig. 3.

Let us mention some methods constructing the signal template (Fiser et. al., 2016): a, template +1 or –1 one day in the case there was no atmospheric attenuation b, cosine function c, FFT/IFFT while the signal template $S_0(t)$ consists of first 4 terms of the Fourier expansion (Boulanger et. al., 2015) while t represents time and a_n; b_n are the Fourier expansion coefficients:

$$S_0(t) \approx \frac{a_0}{2} + \sum_{n=1}^{4} [a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t)] \quad (1)$$

d, polynomial (order of the polynomial is adopted to the signal behaviour, here is order of 7 as an example only)

$$S_o(t) \approx a_7 \cdot t^7 + a_6 \cdot t^6 + \ldots a_1 \cdot t^1 + a_0 \quad (2)$$

e, "MY" method as combination of methods "a," "c," and "d," having been developed at the IAP in Prague. This method will be explained in next chapter.

It is clear, that the methods “b,” “c” and “d” are of the “spline” character.

Description of MY method

The MY method is based on FFT/IFFT method (Boulanger et. al., 2015) but we added a small improvement. The original method is suggesting the replacement of the signal level course (containing the atmospheric attenuation drop) linearly, see Fig.3, yellow line (in fact, in this instructive figure there is no attenuation drop). When reconstructing the signal template by this manner, the FFT smooth approximation (black line) does not have the disposition like actual template (blue curve) and it oscillates out of right template. Therefore we decided to construct the template polynom in order to replace the curve section of “twisting” or of a signal drop due to atmospheric attenuation (bottom part of blue curve in Fig. 3) by the template course from previous or following day (only if the atmospheric attenuation was not occurring - in such cases we replace it by +2 or -2 day etc.).

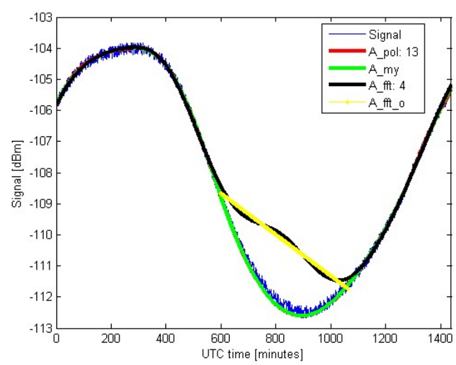

Fig.3. Example of good and worse template (FFT/IFFT method failed in this case)

Example of the MY method application is explained in Fig. 4. The “this day” signal level is represented by black colour, no atmospheric attenuation observed. In previous day (blue colour, “-1 day”) some attenuation drops are expressive ones (attenuation about 9 dB) while in the next day (brown curve, “+1 day”) only small attenuation (2 dB) is obvious. Red sections represents the input points for the polynomial template construction (via Matlab function “polyfit”) which was used for previous as well as for following day to derive the atmospheric attenuation due to the polynomial template construction. Resulting polynomial template is shown (red colour) in Fig. 5.

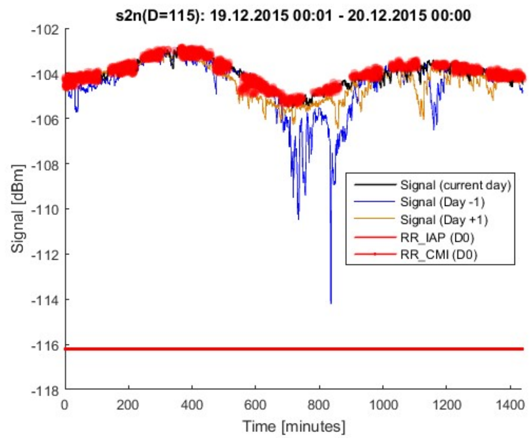

Fig.4. An example of polynomial template construction as one step of MY method (actual signal level data from December 2015)

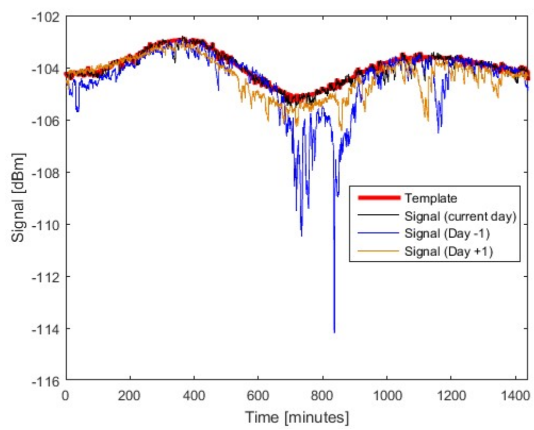

Fig.5. Resulting polynomial template (red colour)

Next figure 6 is the final example of the template construction while the actual signal level represents black curve. The concurrent rain rates are plotted, too. The good correlation between the attenuation and rain intensity (red curve below) is obvious. As input points for polynomial template of the 11th order polynom type were used values illustrated as “bold” while the previous and next day signal level curves were considered as well. Finally, the points from this polynom were used as input parameters for FFT/IFFT template construction and resulting FFT/IFFT template (red curve) you can find in Fig. 7.

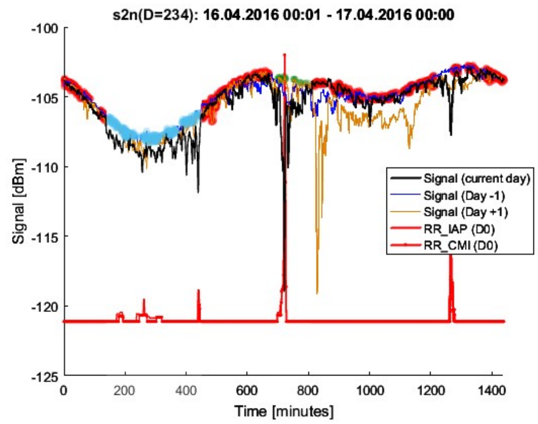

Fig.6. On template construction (see text), rain rate RR is in mm/h

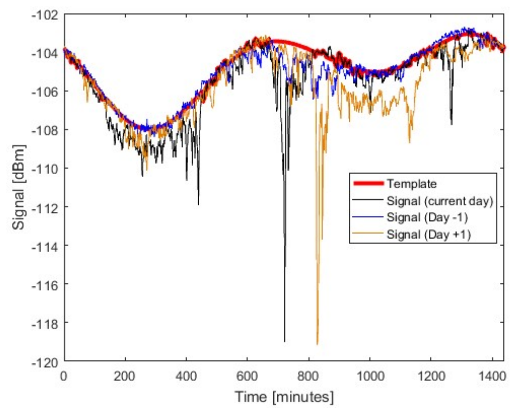

Fig.7. Constructed final template (red colour) after both polynomial and FFT/IFFT procedures applications (i.e. the MY method)

Method testing and attenuation time series SW simulator

Our existing software simulator of rain rate time series (Fiser & Kvicera, 2009 and Fiser & Wilfert, 2009) was converted to the satellite path atmospheric attenuation time series generator. As the time series of rain is similar to the time series of atmospheric attenuation, only the amplitude of the output value was converted to the expected attenuation values. Our simulator respects: 1, random rain rate peaks between 0.2 and 200 mm/h 2, random duration between two peaks 3, random rain event duration between a few seconds to tens hours 4, random inter-event (NO RAIN period) duration between seconds to a few days.

The advantage of this simulator is based on the fact that the "true" or "reference" values are known while the probable values from the actual rain rate measurement are strongly dependent on the processing technique and are not known precisely. That's why the simulated rain rates (and consequently atmospheric attenuation) are preferred to the actual ones to test mentioned methods deriving the actual atmospheric attenuation course from the measured and recorded satellite signal level influenced by the satellite space motion causing the regular signal level variations. The simulator consists of the Matlab random number functions ”rand” and generates numerical components of rain rate values step by step. i.e.: units, tens, hundreds and thousands. The output random rain rate value is created through the linear combination (summing) of these numerical components, while the sign (+ or -) in the summing process is also randomly generated. A time increment is assigned to the next random rain rate value. This time increment is also randomly generated while the lower rain rate values have higher probability of longer duration. The rain rate course between two generated rain rate values, as explained above, is obtained through the linear interpolation of the one second resolution. Respecting the realities of the weather, the duration between two rain events is also randomly generated. Special decision function monitors the reality of these rain rate series. Fig. 8 (upper part) shows the example of the generated attenuation time series while below there is the modelled signal level measurement (an actual template was added to the simulated attenuation series). So we know the attenuation and we see what would the satellite receiver measured in the case of satellite space motion. Ideal for testing purposes.

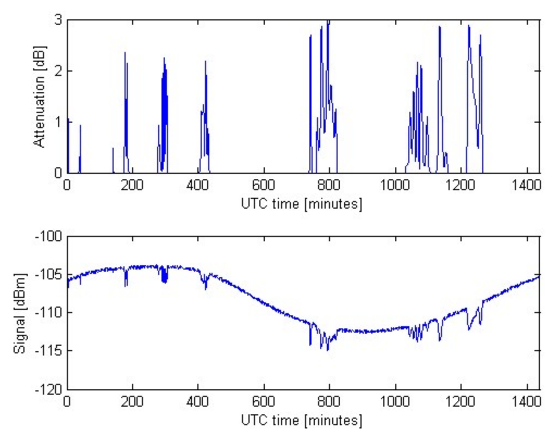

Fig.8. Example of simulated atmospheric attenuation time course (upper) and signal level course (below) respecting the fluctuations of received signal due to the space instability of the Alphasat satellite

TEST RESULTS

In Fig. 9 we do compare three methods constructing the template. Blue colour represents the actual signal level measurements. The template after FFT/IFFT method (black), polynom (red) and MY method (green) is plotted.

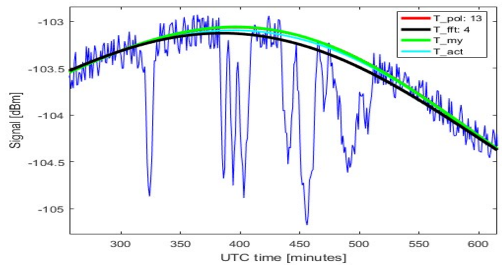

Fig.9. Comparison of templates after three different methods

Other test comes from simulated signal level from Fig. 10. After all mentioned methods application we derived and compared the atmospheric attenuation course in Fig. 11 resulting that the differences are small.

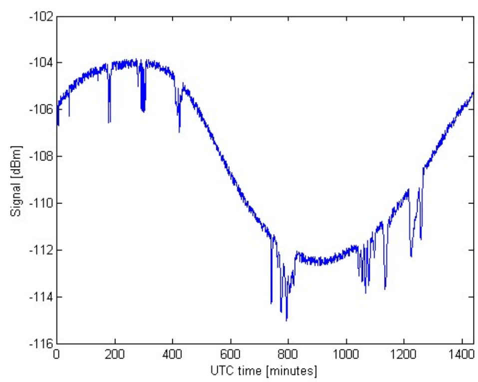

Fig.10. Other example of simulated signal level time course

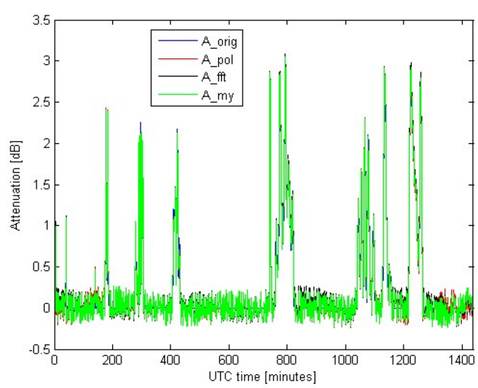

Fig.11. Atmospheric attenuation after application of all methods in charge while the inspiration default signal level course from Fig. 10 is used

To compare different methods of the template creation and application we performed many tests based on traditional statistical testing. Firstly we used 21 templates from actual data.

Using the attenuation time course simulator we prepared 21 events of modelled 24 hours signal level courses. All 21 courses looked like the actual signal level course but we knew the actual attenuation values (even if they are simulated). Also a “noise” of a random value +/- 0.2 dB (uniform distribution) was added. As a next step we applied three described standard methods, i.e.:

a) polynomial method
b) FFT/IFFT method
c) “MY” method

Finally we computed the difference between estimated attenuation and “actual” (even if simulated) attenuation and evaluated the statistics of these differences. The results we summarize in Table 1.

This table is divided in two parts. In first one we used the fixed order of polynom (i.e. 11) as well as fixed number of applied terms of the inverse Fourier transform (i.e. 5). In the second part of this table the polynomial order was changing from 10 to 16 in order to find out the minimum of the difference between “true” and “prediction.” Similarly the number of Fourier expansion terms was optimized using values between 4 and 11 while the best fit results were putted into this table. As expected, the “best fit parameters” are of better prediction accuracy.

Table 1 is showing 8 statistical parameters describing the difference between simulated “actual” attenuation and derived attenuation through described methods. RMSE is standard parameter, “*d*” is the difference between estimated attenuation and true attenuation, *d*+ (*d*-) is the positive (negative) difference, *N d*+ (*N d*-) is the average number of relevant positive (negative) differences in our population.

Best fit (minimum difference) is emphasized by green colour while worst fit is indicating by red colour. After RMSE testing the best method is the MY one. One the other hand, the polynomial method is the best method in the variable (best fit) parameter case. In average, the FFT/IFFT method is relatively worse. We must mention that the differences among methods under test are very small and all method are usable.

CONCLUSION

It seems that the comparisons of estimated attenuation values from Table 1 shows small differences among tested methods. The simulator generated quite small number of attenuation events of longer duration which could show greater differences among tested methods. Based on our practical experiences, the FFT/IFFT method is not very acceptable. It is more practical to use the fixed parameters for polynomial order (i.e. 11) or FFT/IFFT method of 5 terms of Fourier expansion. But for practical cases the “MY” method can be recommended as it supports the continuity between consequent days and is slightly more accurate.

ACKNOWLEDGEMENT

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Table1. Results of statistical test comparing described methods

degree	metoda	RMSE [dB]	max d+	mean d+	N d+	max d-	mean d-	N d-	mean(|d+|+|d-|)
11	pol	0,1259	0,3712	0,1038	726,1429	-1,1003	-0,1019	713,8571	0,7357
5	fft	0,1265	0,3553	0,1063	747,8095	-1,0752	-0,0997	692,1905	0,7152
pol+fft(11,5)	my	0,1241	0,3521	0,1031	724,7619	-1,0682	-0,1009	715,2381	0,7101
best	pol	0,1219	0,3153	0,1010	727,8571	-1,1002	-0,1000	712,1429	0,7078
best	fft	0,1258	0,3482	0,1059	747,3333	-1,0733	-0,0991	692,6667	0,7107
pol+fft(best)	my	0,1223	0,3336	0,1016	725,8571	-1,0754	-0,1000	714,1429	0,7045

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