2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

AlphaSat Aldo Paraboni Experiment Q-band Receiving Station in Rome (Italy): Upgrades and Preliminary Scintillation Measurements

Augusto M. Marziani*(1)(3), Fernando Consalvi(2), Giuseppe Pierri(3), Elio R. Restuccia(3), Antonio Martellucci(4), Frank S. Marzano(1)
(1) Dipartimento di Ing. dell'Informazione, Elettronica e Telecomunicazioni, Sapienza Università di Roma,
Via Eudossiana 18, 00184 Roma (Italy) - marziani@diet.uniroma1.it, marzano@diet.uniroma1.it
(2) Fondazione Ugo Bordoni, Viale America 201, 00144 Roma (Italy) - fconsalvi@fub.it
(3) Istituto Superiore C.T.I., Ministero dello Sviluppo Economico,
Viale America 201, 00144 Roma (Italy) - giuseppe.pierri@mise.gov.it, elio.restuccia@mise.gov.it
(4) European Space Agency (ESA), ESTEC, TEC-EEP, Noordwijk, The Netherlands, antonio.martellucci@esa.int

Abstract

The Alphasat Aldo Paraboni Experiment is a radio propagation experiment in the Ka and Q bands started in 2013 with the launch of the Alphasat satellite. It consists of two CW beacons transmitted from the satellite to a large area centered on Europe. Sapienza University, in cooperation with Istituto Superiore delle Comunicazioni (ISCOM) and Fondazione Ugo Bordoni (FUB), joined this experimentation from the very beginning with the installation of two receivers, one for each band. In this article we will show the last technology upgrades made on the Q-band receiver of the Rome AlphaSat receiving station. Particular attention will be put on the custom tracking system based on ephemeris, its realization, specification and performance. A comparison between measured data before and after the installation will be given. At the end we will analyse clear air scintillation data acquired by the upgraded station to prove the quality of the whole system.

1 Introduction

Nowadays telecommunication equipments have become always more demanding, asking for higher and higher network performance in term of bit rate and quality of experience [1], [2]. To face up to these new requirements, the international community is pushed to investigate the upper part of the EM spectrum to look for new candidate bandwidths above 6 GHz. The AlphaSat Aldo Paraboni Experiment (ASAPE), is part of this context [3]. ASAPE is a European Space Agency (ESA) radio propagation experiment to investigate the Ka- and Q- bands attitude for satellite to earth communication, and in particular the effects due to atmosphere on these frequencies. The AlphaSat satellite is actually the biggest orbiting European communication satellite. It hosts on board Inmarsat communication payloads as well as Technology Demonstration Payloads (TDPs). Among these initiative, there is the TDP5. The TDP5 consists of two beacon transmitters for propagation studies, one at the frequencies of 19.701 GHz and one at 39.402 GHz, and a transceiver in the Q/V band for telecommunication studies.

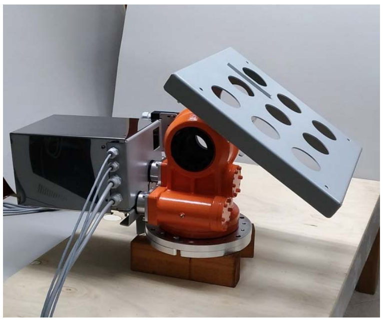
Sapienza University of Rome, in collaboration with the Instituto Superiore delle Comunicazioni (ISCOM) and Fondazione Ugo Bordoni (FUB) joined this experimentation from the beginning. Two receivers at Q-band and Ka-band were realized before the launch of the AlphaSat satellite in late 2013. Since then, data have been acquired and different studies are being carried on, focusing expecially on clear-air scintillation effects and propagation modeling. Initially the installation of the station consisted of two receiving outdoor systems without any tracking system, affecingt the received signal with an unwanted periodical oscillation of several dBs. To solve this problem, we first tried to filter the acquired data through digital signal processing but the results brought us to fold on the purchase of a tracking system for the Q-band receiver. To simplify the realization and reduce the cost, we have decided to choose an open loop ephemeris tracking system which has become operative on the 8th July 2017.

In this article we will analyze the architecture of the Q-band receiver of the Rome AlphaSat receiving station. We will take a close look at the tracking system and at the improvements introduced with this installation. After that, to give proof of the performance of the receiver, we will show a preliminary data analysis of recorded data, with particular attention on clear-air scintillation effects.

2 The Q-band receiving station in Rome

The ASAPE Rome receiving station has been realized using several refurbished components from previous stations. Each component has been characterized and assembled by Sapienza University together with the ISCOM microwave laboratories and FUB personnel. Using old components, we have succeeded to realize an high performance receiver at low cost [4]. The Q-band receiver is composed of an indoor and and an outdoor unit. The outdoor one contains all

(**a**) Receiver



(**b**) Rotating head for the tracking

Figure 1. Alphasat Q-band receiving station in Rome

the radio frequency components and the mechanical part of the tracking system. The indoor unit consists of a 70 MHz satellite beacon receiver, an acquisition system and a computer to manage and control the tracking system. The receiver architecture, from the antenna to the 70 MHz IF, is described in the simplified block diagram of Fig.2.

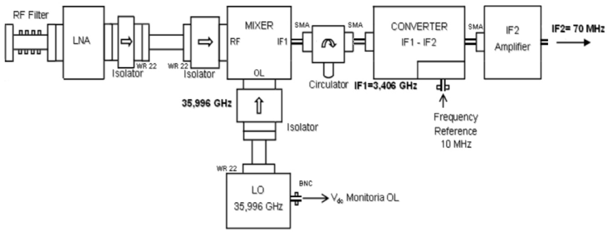


Figure 2. Q-band receiver block diagram.

The receiver at 39.402 GH, has an antenna of 40 cm of diameter with a gain of 42.7 dBi and a 3° HBW. The low noise amplifier has a Gain of 54 dB and a noise figure of 3.5 dB. The receiver has a total gain of 76 dB and a total noise figure of 3.5 dB. For what concerning the indoor unit, the satellite beacon receiver (SBR) has a PLL bandwidth of 100 Hz and is provided with an output pin wich carries an analogic DC low voltage signal proportional to the received power. This signal is sent to a PCI card of a computer where an *ad hoc* software converts and acquires the signal at a rate of 50 samples per second. The ESA TDP5 experiment imposes some specification to be met [3]. Within this there are the maximum antenna diameter of 1.5 m and the minimum carrier to noise ratio to reach for the 0.1% of the OoS (Out of Service) time equal to 5 dB. Our station outperforms this last specification giving an inlab measured C/N @0.1% of OoS time equal to 12 dB. Table 1 shows the results obtained in laboratory measurements using a RF generator set with different RF power levels as obtained from statistical propagation simulations for each OoS time.

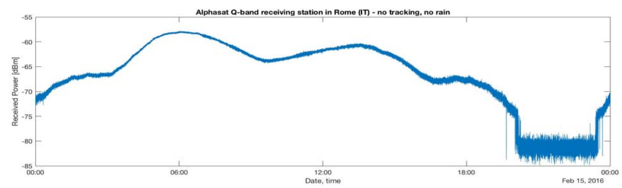
3 The Q-band tracking system

Geostationary radiopropagation experiments consist of monitoring of a radio-frequency beacon to analyze amplitude and phase change due to the surrounding environment.

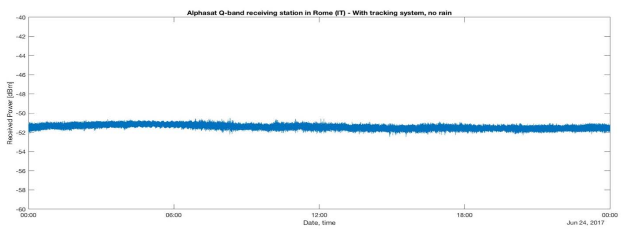
Table 1. C/N of the Q-band receiving station

Received Power	Event Probability	C/N (100Hz BW)
-114.0 dBm	90%	37 dB
-115.4 dBm	10%	36 dB
-117.7 dBm	3%	33 dB
-138.1 dBm	0.1%	12 dB

In our case we are mostly interested in fast and slow varying signals attenuation due respectively to atmosphere turbulence and weather condition like clouds and precipitation [2]. Since changes on the power level are important, each unwanted oscillation of the signal can compromise the analysis results. AlphaSat satellite has a position stability of approximately 3°and this can affects the signal to the point that the SBR can fail to detect the original signal even in absence of additional atmospheric attenuation. This is what happened before the installation of the tracking system. Effects on the signal can be seen in figure 3a. The various peaks on the graph are due to the secondary lobes of the antenna and to the satellite movements both in azimuth and elevation angles. Satellite tracking systems can be of two different types: i) closed loop, which involves a feedback check on received signal power, or ii) open loop. The tracking system used for our application is of the second type and uses ephemeris to point the receiver antenna in the proper direction. Data acquired after the installation of the tracking system in absence of precipitation can be viewed in figure 3b. It is apparent the significant differ-



(a)



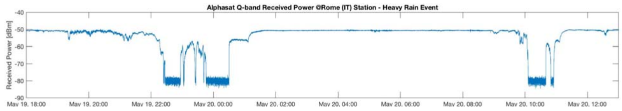
(b)

Figure 3. Data acquisition before and after the tracking system installation.

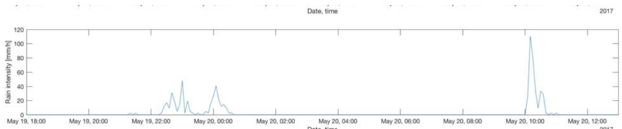
ence between the two cases. The residual oscillation in the signal is less than 1 dB and is not attributed to the tracking system functioning. Satellite ephemeris are uploaded once a week on a FTP server. The firmware of the tracking system checks every day for updated ephemeris, calculates the azimuth and elevation angles for the coordinate of our receiving station and automatically upload these data. Antenna pointing is updated every 5 minutes. The tracking system has been customized for the AlphaSat application. It is able to rotate 200° in azimuth and 180° in elevation with a maximum speed of 20°per minute with an encoders precision of 0.01°. The potential high speed of movement and high precision suggest that this tracking system could be also used in future to track non geostationary satellites for different studies. The tracking system can be seen in figure 1b.

4 Q-band Measurements

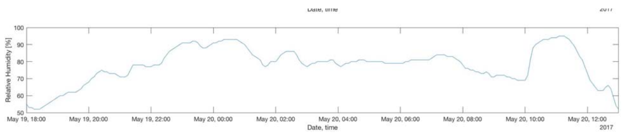
As already stated, the installation of the tracking system has significantly improved the quality of the acquired data. We investigated the residual oscillations on the signal, already viewed in figure 3b, through a spectrum analysis and this revealed that the oscillating phenomena presents a frequency really far from 5 minutes (that is the position updating frequency of the tracking system) proving the effect is most probably to attribute to air humidity . The signal stability



(a)



(b)



(c)

Figure 4. Rain event acquired by the Q-band receiver with tracking system (4a) and the in-site meteorological station (4b,4c).

gained with the installation of the tracking system, enable the possibility to make also analysis of non clear air condition with good results. An example of a rain event can be seen in figure 4 where is possible to see a side by side comparison of the received signal power against rain gauge data and relative humidity. The correlation is very strong and the effects of the raindrops on the signal received amplitude shows an high dynamic range of the receiver. In fact the PLL can withstand a supplementary attenuation up to approximately 30 dB before unlocking, corresponding to a rain rate of approximately 40 mm/h.

The main core of the AlphaSat Aldo Paraboni experiment is the scintillation data analysis. Scintillations are undesired fluctuations of the received signal due to atmospheric turbulence. The air flow through the vertical layers of atmosphere generate changes in the refractive index that, by this way, becomes an aleatory variable [5]. Changes in the refractive index generates changes in the transmitted field that affect the receiving system performance, especially in case of low-availability systems. In clear air condition scintillation effects for high elevation angles satellites are usually in the range of the tenths of dB or less [6]. Data from the AlphaSat Q-band receiving station in Rome have been used to calculate scintillations. Data acquired at 30 samples per second have been used as starting point. The first step was to calculate the mean value of the signal. For this purpose

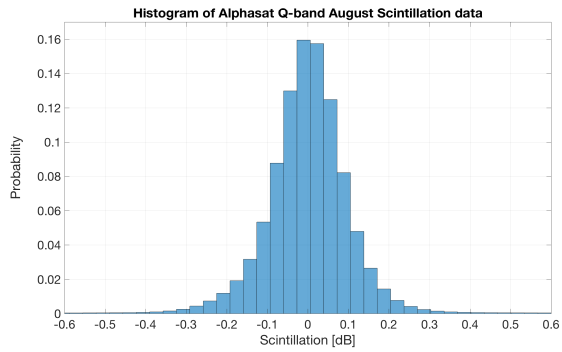


Figure 5. Q-band scintillation histogram of August 2017 data

we used a moving average filter with 1 minute window. Then the mean value is subtracted to the original signal to get oscillating values around zero. After that an high-pass filtering of the screened data allows to extract scintillation avoiding slow variations as humidity and pressure changes. The used filter is a sixth order Butterworth filter with a cut-off frequency of 0.04 Hz and a pass-band ripple of 0.01 dB. Moreover to reduce the effect due to thermal noise, before plotting data, we choose to make an average of the scintillation amplitude. For each minute we chose the sample representing the mean value assumed by the scintillation in the corresponding minute. By this way we obtained a data smoothing and decimation at the same time. In figure 5 it's possible to appreciate data histograms of August 2017. The obtained curves as expected [7] represent a good approximation of the Gaussian distribution. On the Y axes we have the probability normalized at 1 while on the X axis we have the scintillation intensity value expressed in dB.

To validate acquired data, we carried out a study in the frequency domain. Scintillation effects appear at a frequency between a few Hz to tenth of Hz. The Fourier transform has been used to calculate the Power Spectral Density ([dBm^2/Hz]) of scintillation in clear air conditions. The resulting curve can be seen in figure 6. We can appreciate the typical power spectral density curve for the scintillation, largely analyzed in literature. The spectrum follows the -8/3 slope as described by Tatarski [5]. Two peaks appear on the right part of the spectrum. These are not due to scintillation effects but depend on the architecture of the receiver. More investigation will be carried on to focus on this aspect. An-

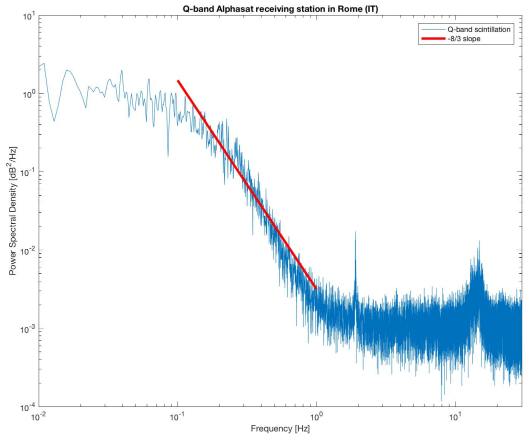


Figure 6. Q-band receiver scintillation Power Spectral Density in clear air condition.

other comparison analysis has been made with scintillation calculated from RAOB data [7]. The model in [8] has been applied to RAOB data together with the Richardson index and simulated scintillation data have been compared to the measured ones [9]. The residual spread of data around the slope one line is due to the relatively small period of acquisition (just 3 months) and to the method used to select data. Indeed,selected data are not corresponding to clear-air condition only, but to non rainy day because of the lack of joint radiometer data.

5 Conclusions

The AlphaSat receiving station in Rome has been updated with a satellite tracking system for the Q-band receiver. This customized system grants high performances and solves problems due to relative movement of the satellite both in azimuth and elevation. It is based on an open loop architecture that uses the satellite ephemeris to move the antenna toward the satellite direction, changing coordinates every 5 minutes. This does not affect the performances of the whole receiver as demonstrated by further checks. The use of actual ephemeris guarantees the tracking to keep on working during intense attenuation events such as heavy rain. Acquired data have been used to calculate scintillation spectra and variance and to derive a preliminary statistics. A good match has been found for the scintillation power spectral density, fitting the -8/3 slope, and scintillation intensity. The data collection and histograms have showed a Gaussian distribution of the log-amplitude scintillation amplitude values with the peak at approximately 0 dB. The correlation with scintillation calculated from RAOB data seems to be promising. The station upgrade has opened the possibility for further investigation on scintillation and correlation between attenuation and weather events. These data will be used to validate propagation models and to explore new scintillation parametric models to be used for slant path links.

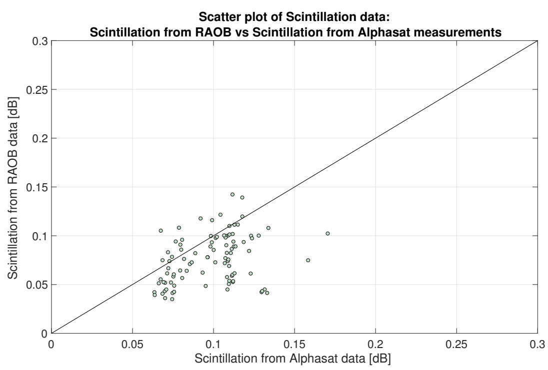


Figure 7. Scatter plot of Alphasat measured Scintillation vs Scintillation obtained using RAOB. August to December 2017, non rainy day)

References

[1] B. R. Arbesser-Rastburg and A. Paraboni, *European research on Ka-band slant path propagation*, Proc. IEEE, vol. 85, no. 6, pp. 843-852, June 1997.

[2] G. Brussaard and P.A. Watson, *Atmospheric modelling and millimetre wave propagation*, Chapman and Hall, London (UK), 1995.

[3] A. Paraboni, *Description of Alphasat TDP5 Propagation Experiment*, Proceedings of the ESA Propagation Workshop ESA WPP 298, 2008.

[4] A. M. Marziani, F. Consalvi, S. Chicarella, E. Restuccia, L. Amaduzzi and F.S. Marzano *AlphaSat Ka-band and Q-band Receiving Station in Rome: Development, status and measurements*, Antennas and Propagation (EuCAP), 2015 9th European Conference on, 2015.

[5] V. I. Tatarski, *Wave Propagation in a Turbulent Medium*, McGrawHill, New York, 1961.

[6] F. S. Marzano, C. Riva, *Evidence of Long-Term CorrelationBetween Clear-Air Attenuation and Scintillation in Microwave and Millimeter-Wave Satellite Links*, IEEE Trans. on Ant. and Prop., vol. 47, n. 12, 1999.

[7] H. Vasseur, *Prediction of Tropospheric Scintillation on Satellite Links from Radiosonde Data*, IEEE Trans. on Ant. and Prop., Vol. 47, n. 2, 1999.

[8] T. Cherubini, *Another Look at the Refractive Index Structure Function*, J. of Applied Meteorology and Climatology, Vol. 52, 2013.

[9] A. M. Marziani, C. Riva, F. Consalvi, E. Restuccia and F.S. Marzano, *Clear-air scintillation analysis of Q-band alphasat link at Spino d'Adda using radiosounding data*, Antennas and Propagation (EUCAP), 2017 11th European Conference on, 2017.