An Automated Data Processing System for Satellite Propagation Beacon Measurements

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***Abstract*—The paper describes an automated data processing system of propagation measurements from satellite beacon in the microwave spectral range. The software has been developed in the framework of the ESA contract "Data Collection and Processing System for the Alphasat TDP5 Ka/Q Band Propagation Experiment" with the purpose to offer a common data processing approach for the Alphasat TDP5 beacon data collected among different experimenters in Europe. The main advantage in using a common data processing system provides homogeneous results to fill in the gap of propagation models. On the other hand, the automated procedure has strong limitations due to non-ideal status of the received signal. The main issue is related with the definition of the propagation events. On one side, the standard data processing software requires a visual inspection from the experimenter. The PDPS procedure extracts information from independent systems such as microwave radiometers or surface meteorological stations and no human interface is expected. This automated approach allows a fastest data processing but there is no possibility to verify the correspondence between the events detector and the beacon signal. Knowing these limitations, the PDPS offers a unique opportunity to the experimenters to expedite the data processing in order to have a preliminary result. Potential issues encountered during the automated processing are reported to the experimenter, which has the possibility to validate the result.**

***Keywords*—signal propagation; Earth-satellite link; data processing; atmospheric attenuation;**

I. INTRODUCTION

The trend for enhancing satellite services is heading in the direction of Ka, Q and V bands. At these frequencies, the detailed link budget computation is mandatory for the development of future space missions, proving high performance services. For this reason, a careful analysis of the tropospheric effects at these frequencies as well as dedicated satellite propagation experiments are required.

Some telecommunication satellites with Ka-band beacon transponder (20 GHz) are already flying, providing important inputs for propagation campaigns. Since summer 2013, the launch of the Alphasat mission with the TDP5 (Technology Demonstrator Payload) Aldo Paraboni Payload [1] offers a unique opportunity to the scientific community to gather additional Ka and Q band propagation data at 19.701 GHz and 39.402 GHz, respectively. Purpose of the propagation campaign is to develop, to improve and to test prediction models and more specifically to fill the gap of missing data for the new fade mitigation techniques.

Since the launch of Alphasat, several research institutions started to collect accurate propagation measurements from various locations in Europe, collecting daily copolar signal at one or both frequencies.

In general, a typical propagation campaign consists in a space segment, a ground segment and the experimenter segment. The space segment is the beacon transponder on board a satellite, typically beacons are onboard geosynchronous telecommunication satellites transmitting a signal at a selected frequency. The ground segment is represented by the operator of the satellite which could provide ancillary data on the status of the spacecraft (S/C) and the payload. Finally, the experimenter segment is a beacon receiving station. It includes a receiving beacon terminal (BRX) and a series of ancillary meteorological instruments. The ancillary instruments provide additional information on the status of the atmosphere, which will be used for an accurate data processing. Typical ancillary instruments are microwave radiometers (MWRs) and high-accurate meteorological stations (MET) including rain gauges and disdrometers.

In order to update and enhance the propagation models in a coherent way, a common data processing is required. The data processing is the crucial activity to extract the propagation information from the received data. In particular, the data processing removes all the non-idealities of both the emitter on-board and the receiver on the ground as well as the satellite orbital maneuvers and instabilities. Finally, the main tropospheric impairments are extracted: gases, rain, clouds and scintillation.

The typical data processing output is represented by statistical attenuation curves expressed in terms of Complementary Cumulative Distribution Function (CCDF) of copolar attenuation at the beacon frequencies.

In order to provide updated CCDF curves a common data processing procedure is required among all the propagation terminals. For this purpose, the ESA Contract ESTEC 4000109353/13/NL/NR "Data Collection and Processing System for the Alphasat TDP5 Ka/Q Band Propagation Experiment" [2], aims to develop a Propagation Data Processing System (PDPS) to standardize the data processing and to offer a valid support to the scientific community to process their received data.

II. Equipments of a Propagation Campaign

As introduced, the experimenter segment of a propagation campaign includes a series of different equipment providing propagation and ancillary data for the estimation of the propagation quantities.

A. *Beacon Receiver (propagation terminal)*

The beacon receiver (BRX) is intended to be the main instrument in a propagation campaign. It measures the beacon signals transmitted from the satellite at known frequencies. It could have different architectures and capabilities, like receiving both co-polar and cross-polar signal levels at the beacon transmitted signal frequencies. In general, it measures the electric field received by the ground antenna, and it can measure the complex components (in-phase and quadrature or amplitude and phase) of the received electric field, using a certain base for the polarization of the field (e.g. linear with respect to the spacecraft reference, circular or elliptical). The original polarization transmitted by the spacecraft is defined as co-polar while its orthogonal polarization is defined as cross-polar.

B. *Surface Meteorological Station*

The ground meteorological station (MET) represents a series of sensors to measure the atmospheric meteorological parameters. The station is expected to be compliant with WMO standards for meteorological stations [3]. In a propagation campaign, the meteorological station is supposed to measure also precipitation parameters. It can be required for radio wave propagation modelling with particular regard to the rainfall rate (mm/hr) at 1 min integration time (as currently needed by ITU-R P recommendations).

C. *Ground-based Microwave radiometer*

The microwave radiometer (MWR) is the instrument capable to measure the radiation emitted by the atmosphere towards the earth surface at certain frequencies. This instrument is used for atmospheric remote sensing of integrated water vapour (IWV), integrated liquid water (ILW), air temperature in the upper layers of the atmosphere and for the measurement of total atmospheric attenuation. Based on dedicated retrieval algorithms, independently from the beacon, the MWR could estimate the attenuation of the atmosphere at the beacon frequencies.

III. Propagation Data Processing System

The PDPS is an automated data processing software aimed to support the experimenter in the processing phase of the beacon data. The PDPS is structured in the implemented data processing routine extracts the time series of the main atmospheric propagation parameters: attenuation due to rain, clouds, gases, scintillation. Thanks to the ancillary data it is possible to extract also the time series of rain rate, IWV, ILW and the main surface meteorological parameters. The daily time series will be used for the computation of the monthly statistics of the corresponding parameters.

The users of the PDPS are the experimenters of propagation campaigns, which feed the system with their collected data. In general, the PDPS receives data from propagation experiment sites and it processes them with an automated procedure, which provides the processed daily time series and the monthly CCDF statistics.

The overview of the PDPS is reported in Figure 1, where all the data levels are shown together with the interactions between the experimenters and the system itself.

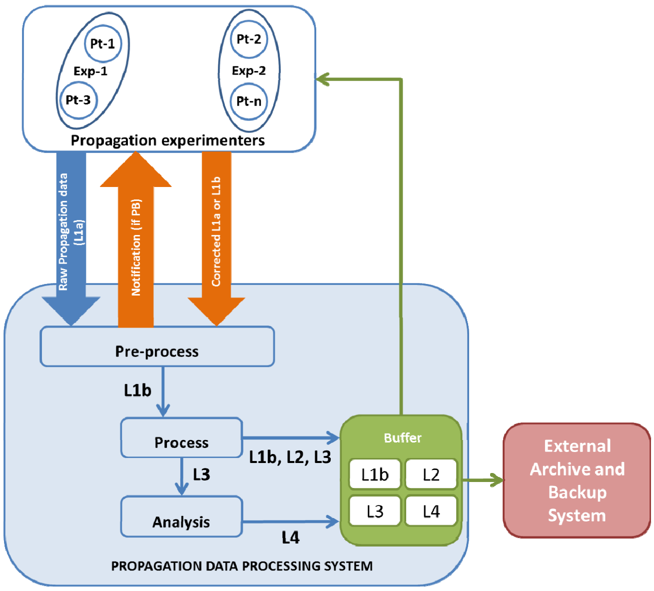

Fig. 1. High-level overview of the Propagation Data Processing System

Based on the equipment availability, the experimenter's sites have been organized in four configurations:

- Case 1: Beacon receiver with microwave radiometer and rain gauge
- Case 2: Beacon receiver with Microwave Radiometer
- Case 3: Beacon receiver with rain gauge
- Case 4: Beacon receiver only

In order to ensure homogeneity of the data processing, a standard input exchange format has been developed and data processing levels have been defined. The input format has been based on the GNSS IGS RINEX exchange format, while the processed data levels are based on the Earth Observation data level processing approach. This means that the level 0 data are the instrumental raw data and the level 4 data are the output CCDF statistics. The data levels are organized as follows:

- Level 0 are the Instrumental Raw Data as provided by the instruments, not processed in the PDPS
- Level 1a are Raw Propagation Data provided by the experimenter. This is the only allowed input of the PDPS. Experimenters could apply their own preprocessing procedure before submitting the data
- Level 1b are Raw Propagation Data after preprocessing (correction of the spikes, removal of the diurnal variation, …)
- Level 2 are Intermediate Propagation Data, before the radiometric correction of the beacon for retrieval of the 0 dB level
- Level 3 are the Validated Time Series of the tropospheric effects (attenuation, scintillation, …)
- Level 4 are the Analyzed Experimental Statistics (monthly, seasonal, yearly, …)

The data are processed in a three steps procedure named: pre-processing, processing and statistics. The pre-processing phase aims to first read and convert the input data. The input data are checked, validated and then a series of quality checks are performed, like: physical validity, spike detection and outlier removal, time frame validity.

The processing phase is the core part of the system. It is based on the data processing technique described in [4], [5]. In this phase, the input data are combined to extract the time series of the parameter of interest, copolar attenuation, Integrated Water Vapor (IWV), Liquid Water Content (LWC) and rain events. The processing provides two outputs: the intermediate level 2 (L2) data with the corrected beacon time series and some ancillary time series like IWV and LWC, and the final level 3 (L3) data with the copolar attenuation time series. During the processing phase, a crucial phase is the rain events detection, described in the next section.

The station cases are crucial also to identify the typical L3 output. If the station is in Case 1 or Case 2, the typical L3 output is the total attenuation, obtained by the determination of the zero dB level. On the other hand, if the station is in Case 3 or Case 4, the computed output is the excess attenuation, which represents attenuation in exceedance without having information on the zero-dB level.

The L3 attenuation time series generated as output of the processing system will be used as input for the statistical phase of the PDPS process. The standard output of the statistical module are the level 4 (L4) monthly CCDF statistics of the parameters computed in the processing phase.

As already mentioned, the main feature of the PDPS is its automation. The experimenters' data are automatically sent each day to the PDPS and when the daily file has arrived, the pre-processing starts automatically. If errors are encountered (for example, missing data or incomplete files for example), a notification is sent to the experimenter to allow resubmission of missing or incomplete data. Otherwise, after the pre-processing, the processing phase is performed and the daily-validated time series are generated. Once per month, the propagation statistics are released. Experimenters could perform conditional statistics based on the available processed data, e.g. statistics for the month of January of different years, or seasonal statistics considering the corresponding three months.

A. *Validity Flags*

Due to the automatic nature of PDPS system, the preprocessing tests are fixed and not all the cases could be solved automatically. Since visual inspection is not foreseen in the system, there is no automatic possibility for the PDPS to correct particular cases. For this reason, the experimenter could perform preliminary visual inspections and flag the data accordingly. For this purpose, flags are a crucial aspect of PDPS and allows the experimenter to guide the automatic processing.

The PDPS foresees two different kinds of flags: observation flags and event flags: the observation and the event flags.

The observation flags are referred to each single observable and to provide a quality factor. The event flags are referred to the epoch and their value will affect all the observables of the single epoch.

The two flags are independent and their invalidity results in a different management of the data. As an example, it could occur that, during a rain event, all the observation flags could be valid, even if the epoch flags are invalid. In this case, all the observables are not considered for the creation of the filtered signal time series, but then will be considered for the computation of the attenuation. On the other hand, in clear sky condition the epoch flags are valid, but if one of the channel fails its observable flags are invalid. In this case, the flagged observable are discarded and they are not taken into consideration for the whole data processing.

B. *Rain Events Detection*

The detection of the events is one of the most crucial phases of PDPS, since the periods of propagation events (mostly rain) should be excluded in the definition of the reference signal.

In general, the most common data processing software detects propagation events with user's visual inspection or semiautomated procedures. The main advantage of PDPS is the evaluation of the presence of propagation events using information of 5 potential indexes: (1) ILW, (2) epoch flags, (3) Sky Status Indicator (SSI), (4) rain rate or (5) radiometric attenuation.

The ILW detection is based on the definition of a threshold of liquid content, if the value is passed, the event is flagged. This detection is possible only for the station cases which includes the MWR. The epoch flag detection is based on the exact setup of the epoch flags from the experimenter. This detection method could be performed in all station cases and it is the only possibility for station cases 4. The detection with SSI is based on the parameter defined in [6]. The experimenter should define the SSI thresholds (clear sky and rainy) for its own station and when the instantaneous SSI crosses the threshold the event is detected. Since the SSI is based on comparison of Brightness Temperature measurements (TB), this technique is possible only if the MWR is available, station cases 1 and 2. The rain rate detection is based on the independent measurement of a rain gauge or a disdrometer. This technique is possible for all the station cases with the exclusion of Case 4. Finally, the radiometric attenuation threshold is a similar approach of ILW and SSI with the only exception that the parameter used for comparison is the attenuation at the beacon frequencies derived from MWR measurements. As for ILW and SSI methods, this detection method is applicable only if the MWR is present.

The implemented event detection techniques requires independent inputs from ancillary data or from experimenters. This detection methods have some limitations such as the different field of view of the ancillary instrument. For this reason an further parameter should be defined, the so-called Extent Event Interval, EEI. This term includes a buffer period before and after the detected event in order to compensate some potential issue in the detection process. The use of this further interval corresponds to a potential conservative approach in the detection of events.

Each of these indexes are independent measurement of the atmospheric status with respect to the beacon measurements. The main disadvantage is due to the not verified correspondence between the beacon measurement and the detected events. For this reason a final validation of the results is recommended.

C. Excess Attenuation Computation

The computation of the excess attenuation is obtained by processing the signal level in order to remove the attenuation due to atmospheric events. The mathematical model behind the excess attenuation computation is reported in Fig. 2, where the correspondence with the PDPS at levels are reported.

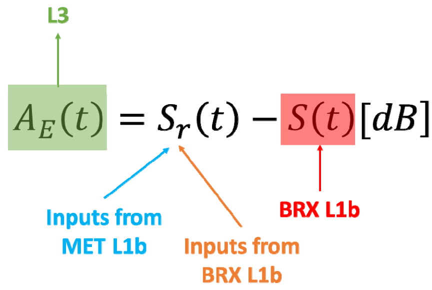

Fig. 2. Excess Attenuation Algorithm

Where:

S(t) is the input signal level [dB]

$S_r(t)$ is the reference signal [dB]

$A_E(t)$ is the excess attenuation [dB]

t is the time [s]

The crucial aspect of the algorithm in Fig.2 is the computation of the reference signal. Which is derived from the received signal with the exception of the propagation event periods. The reference signal is computed with a Fast Fourier Transform (FFT) by considering only the first 4 harmonics in order to remove all the high frequency contributions.

In general, the excess attenuation is centered to zero with peaks due to propagation events.

D. Total Attenuation Computation

The algorithm reported in Fig. 3 describes the computation of the total attenuation.

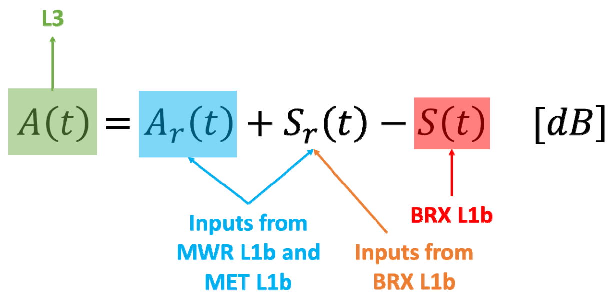

Fig. 3. Total Attenuation Algorithm

Where:

A(t) is the total attenuation

$A_r(t)$ is the radiometric attenuation

The reference level of this equation is the so-called 0-dB level, which is defined as the sum the radiometric attenuation and the reference signal. The total attenuation includes also the effects of the gases, since the radiometric attenuation is obtained with MWR measurements. On the other hand, the computation of the reference signal follows the same approach of the previous case.

E. Propagation Mission Ancillary Data

Even if the main purpose of the PDPS is the data processing, it includes, in parallel, a subsystem to collect ancillary information concerning the propagation mission. In the first version of the PDPS, the processed data doesn't interact with the ancillary mission data, but they are accessible for the experimenters for offline analysis and comparison.

As far as the Alpahsat mission is concerned, the TDP ESA Coordination Office (TECO) provides the mission ancillary data. This allows the experimenters to access the precise azimuth and elevation information derived from the INMARSAT OEM (Orbital Ephemeris Message) data, the TDP5 and satellite communication subsystem telemetry and the mission information messages which will include housekeeping maneuvers, eclipse and out-of-order periods.

IV. DATA PROCESSING EXAMPLES

This section reports some results of two different data sets available:

- The first example refers to Graz, Austria [7]. This station is equipped with a dual frequency beacon receiver, the ESA ATPROP MWR [8] and a meteorological station with rain gauge and distrometer. According to the station equipment, it is considered as station Case 1 and the L3 output is the total attenuation.
- The second example is based on the data collected at the University of Technology, Malaysia of Johor Bahur, Malaysia. This station is equipped only with a beacon receiver and a meteorological station including a rain gauge. The propagation campaign in this case is with the Syracuse 3A satellite at 20.245 GHz. According to the PDPS standards, this is a station Case 3.

A. Data Processing of Case 1

The following Fig. 4 depicts an example of processed data, the blue curve is the preprocessed input signal level (L1). Then it is filtered (cyan curve) to remove the effects of scintillation and the filtered signal is summed to the radiometric attenuation to obtain the zero-dB level (black curve). The total attenuation is reported in green and it is the difference between the L1 and the zero-dB level. The red line represents the event flags which are not present in this case.

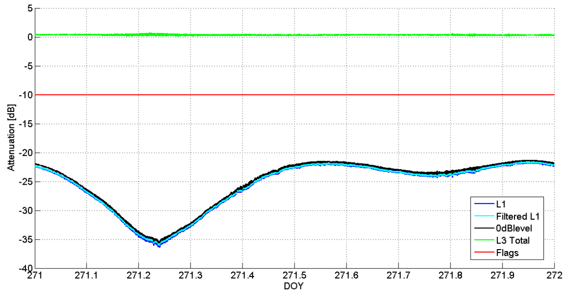

Fig. 4. Example of processed data in Graz, Austria

Fig.5 reports total attenuation estimated for both the Ka-band signal (blue curve) and the Q-band signal (green curve).

By comparing Fig 5 and Fig. 6 it is visible the capability of the PDPS to remove the daily fluctuations of the signal due to the spacecraft orbit. Since there are no flag events detected at the two frequencies, the estimated output is the measure of a clear sky day.

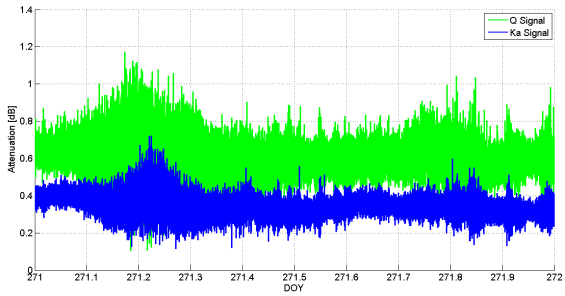

Fig. 5. Total attenuation at Ka band (blue) and Q band (green) in Graz, Austria

In case of an event, the PDPS is capable to isolate it. With the same conventions used in Fig. 5, Fig. 7 depicts the result of a rainy event day.

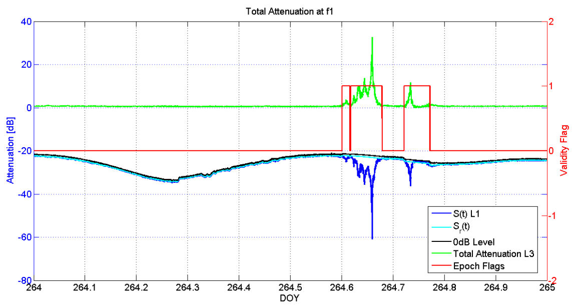

Fig. 6. Example of processed data in Graz, Austria

The corresponding detected ILW is reported in Fig. 7 where the limit is reported.

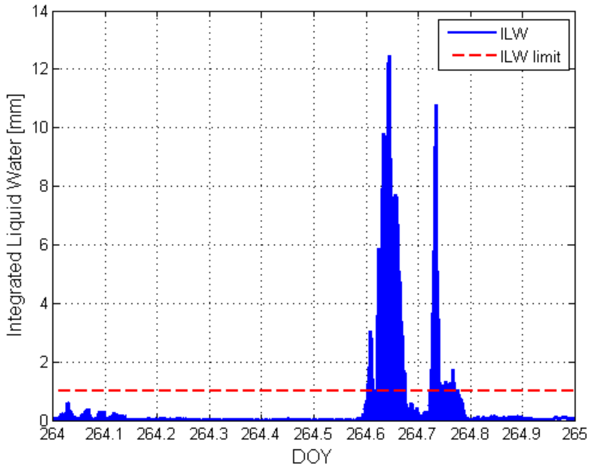

Fig. 7. IlW time series and threshold

In this case, the total attenuation is computed and the event is extracted. A close up of the total attenuation in the event period in reported in Fig. 8.

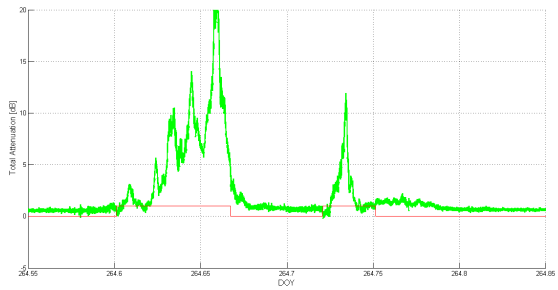

Fig. 8. ILW time series and corresponding flags

B. *Data Processing of Case 3*

In this second example, a day with a rain event is presented.

Fig. 9 depicts an example of processed data where the received signal and the reference signal are reported.

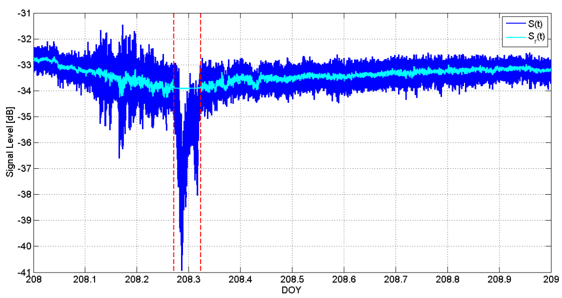

Fig. 9. Signal level received (blue) and referece signal computed (light blue) at Ka band at UTM, Malaysia

The estimated excess attenuation is reported in Fig. 10. In this case, the attenuation is centered to zero with a significant event reported within the two red thresholds.

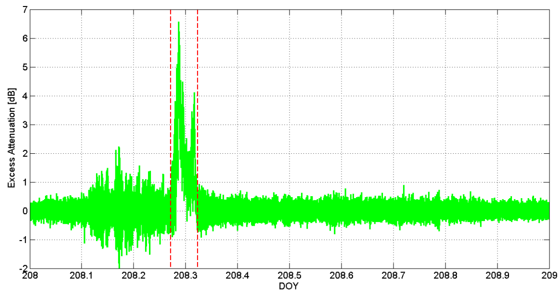

Fig. 10. Excess attenuation at Ka band at UTM, Malaysia

In this case, the satellite of the propagation campaign has smaller diurnal fluctuations that are easily corrected.

V. CONCLUSIONS

The PDPS is an automated system for data processing of satellite propagation measurements, which offer a unique opportunity to have a homogeneity process of data of different stations. The system is capable to process the data sent by different experimenter and to extract the propagation statistics.

The main limitation is represented by the not verified correspondence between the detected propagation events and the received beacon signal. This limit requires an offline review of the results from the experimenter. On the other hand, even if some processed days could require a review, the majority are processed and ready to correctly contributo in the computation of the monthly statistics.

It should be pointed out that this system is modular and it could include further features to further provide reliable results.

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REFERENCES

[1] A. Paraboni, C. Riva, C. Capsoni, G. Codispoti, L. Zuliani, S. Falzini, A. Martellucci, E. Colzi, “The plans for a new satellite-based scientific experiments (TDP#5 Alphasat) to assess the effectiveness of the future large capacity communication systems operating in the Ka and Q/V (40/50) GHz bands”, 6th Broadsky workshop, Ka and broadband communications conference. 24th – 26th September 2008.

[2] ESA study n°4000109353, “Data Collection and Processing System for the Alphasat TDP5 Ka/Q Band Propagation Experiment”, UCL, Joanneum Research, Aethis.

[3] World Meteorological Organization “Guide to meteorological Instruments and Methods of observation”, WMO No.8 2008.

[4] ESA study n°4000107135/12/NL/LvH : "Development of High Order Propagation Models for Multimedia Satellite Communication Systems", ONERA, PoliMi, UPM, Univesity of Aveiro and Joanneum Research.

[5] COST Action IC0802, Handbook on measurements, 2012

[6] A.V. Bosisio, P. Ciotti, E. Fionda, and A. Martellucci, "A sky status indicator to detect rain-affected atmospheric thermal emissions observed at ground," IEEE Trans. Geosci. Remote Sens, vol. 51, no. 9, pp. 4643–4649, Sep. 2013.

[7] Schmidt M., M. Schönhuber, J. Ebert, H. Schlemmer, F. Teschl, "Austrian satellite ground station for the Alphasat Q/V band experiments", Elektrotechnik und Informationstechnik (2014), September 2014, Volume 131, Issue 6, pp 150-154

[8] D. Norenberg, S. Crewell, U. Lohnert, Th. Rose and A. Martellucci, "A novel ground-based microwave radiometer for high precision atmospheric observations between 10 and 90 GHz", IEEE IGARSS, Boston, MA, USA, 2008, DOI: 10.1109/IGARSS.2008.4779500