Q/V band ground station for Alphasat TDP5 Telecommunication experiment – Design and verification

Michael Schmidt[1] (michael.schmidt@joanneum.at), +43 316 876-1311
Harald Schlemmer[1] (harald.schlemmer@joanneum.at), +43 316 876-1308
Johannes Ebert[1] (johannes.ebert@joanneum.at), +43 316/ 876-1303
M. Kückelheim[2] (mkueckelheim@vertexant.de) +49 2066 20960
Juan Rivera Castro[3] (Juan.Rivera.Castro@esa.int), +31 71 565-3397
[1]JOANNEUM RESEARCH (Austria), Steyrergasse 17, 8010 Graz, Austria
[2] Vertex Antennentechnik GmbH, Baumstraße 50, 47198 Duisburg, Germany
[3] ESA-ESTEC Keplerlaan 1, 2201 AZ Noordwijk, The Nederlands

ABSTRACT

The new Alphasat satellite hosts several TDP (Technology Demonstration Program) payloads. TDP#5 includes a Q/V band transponder with 3 spot beams and was named Aldo Paraboni payload. Two of these spot beams point towards Italy and one is planned to point towards Austria. The beams can be operated in loop-back and beam interconnection mode. JOANNEUM RESEARCH was invited by the Italian Space Agency (ASI) to join the experiments for this payload and to set up and operate a ground station in Graz (Austria). This paper presents the ground station design, implementation and testing.
The paper will first address the design of all the subsystems composing the ground station, starting from the 3m dual reflector antenna designed by Vertex, passing through the front end with high power amplification section in V-band and the LNA section in Q-band, down the up- and down-conversion to L-band. Due to the high gain of the antenna and its stringent requirements in terms of pointing, the possible tracking options will be discussed and the selected one described in more details.
The second part of the paper will address installation, integration and testing of the station, including subsystem characterisation up to system level tests.

1. Introduction

The ground station in Graz is placed on top of a 35m historical tower called Hilmwarte. Because of the small antenna 3dB beam-width of only 0.17° there was the concern that the movement of the tower caused by wind and temperature could generate additional pointing error to the system. This error was compensated by using a tilt-meter which measures the x/y movements of the tower and is integrated in the tracking and pointing system of the Antenna Control Unit.
Starting with the transmit path, the test data is generated in the self-designed packet generator and sent to the transmit port of the EL470 Newtec DVB-S2 modem. Please note that in figure 1 the DVB-S2 transmitter and receiver of the DVB-S2 modem are split into two different modules but in reality they are contained in one modem. The modem sends the L- band modulated signal to the up-converter from Miteq, which provides a fixed conversion into the 48GHz band. The output power of the up-converter can be adjusted within a 30dB range which helps to compensate cable losses from the control room to the shelter behind the antenna, which is about 15m of cable length. The HPA supplied from CPI provides a nominal power of 50W (400Wpeak) with an EIK (Extended Interaction Klystron).
The V-Band up-converter is connected via a WR22 waveguide flange to the HPA. In addition the HPA provides a monitor output which is connected to a test translator (48/38GHz). The amplified signal from the HPA can either be switched to a dummy load for measurement purpose or sent to the diplexer. This module provides an isolation of 100dB between the TX and RX port. A motor controlled polarisation adjustment is the final module before the signal is transmitted.
The receive part operates on the air-interface from 37,9 to 39,4 GHz. The signal passes the diplexer and arrives at the LNA (50dB, 270K). The down-converter can now select between the satellite signal from the LNA or the signal from the HPA via the test translator. In this respect, all waveguide switches are controlled by the control and monitoring program via an Ethernet to I/O controller. The down-converter from Miteq allows adjustment of the drive output level.
The received signal contains the modulated carrier (38GHz) and the beacon signal sent from Alphasat @39,4GHz, which is used for the tracking system. It is fed into the DVB-S2 receiver (1-2GHz) via a power splitter and into the tracking receiver via a separate 2,5 to 1,5 GHz down-converter because the tracking receiver can only operate at L-band. The tracking receiver measures the power of the beacon and feeds it into

the antenna control system, which controls the pointing/ tracking of the antenna. The beacon is transmitted from Alphasat with a polarisation of 45degrees from vertical but will only be received at vertical polarisation (signal of the data carrier). The thereby caused loss of 3dB is covered in the link budget.
The 10 MHz reference is a GPS-disciplined rubidium frequency standard source with an integrated NTP-Server. All devices will be synchronized to UTC with an average accuracy of 1ms. A self-designed packet generator and analyser software is executed on a PC. The packet generator loads the carrier with defined traffic pattern. The packet analyser finally measures the packet error rate (PER). In cross link mode to the Italian GS in Tito, the analyzer forwards the results - together with a SNR measurement - to the transmit station.

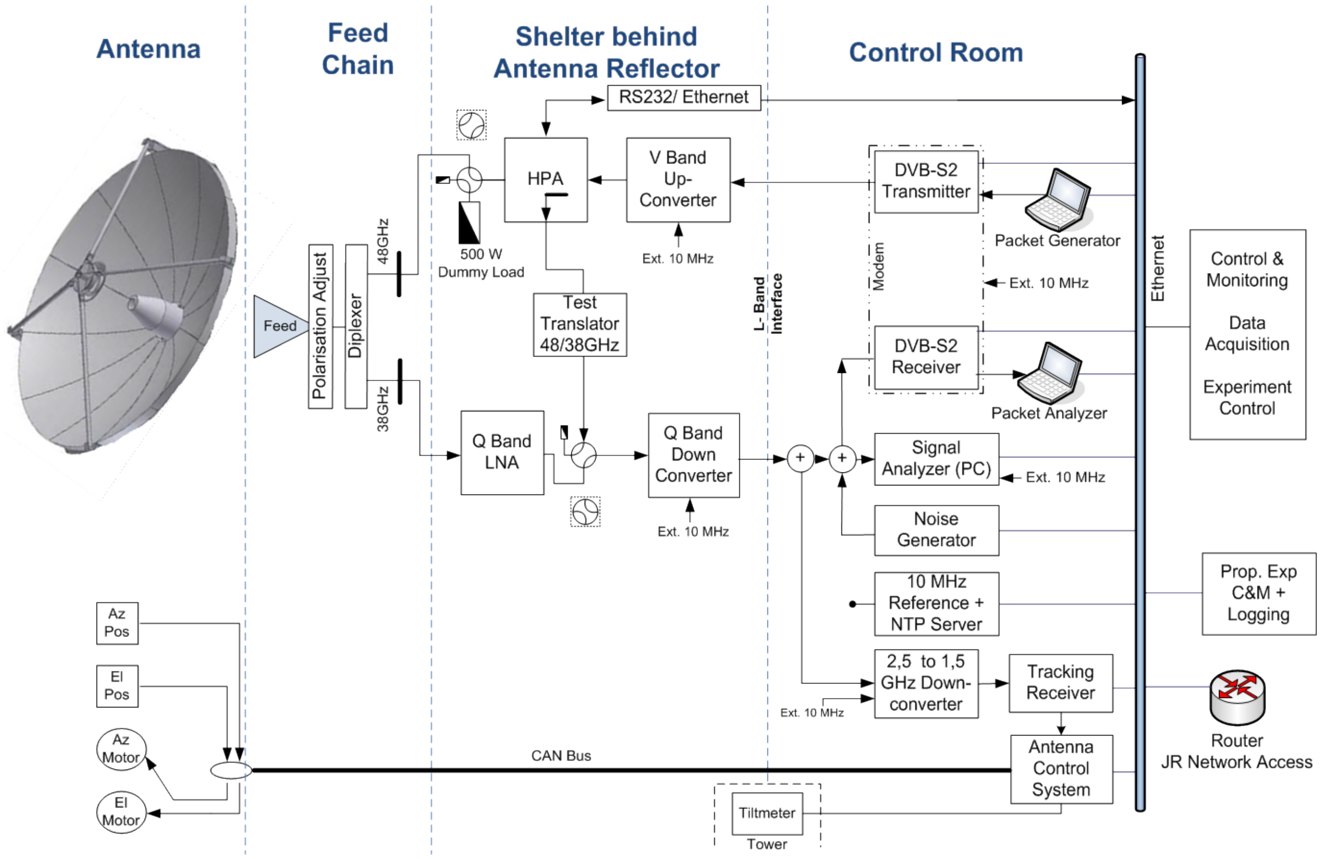


Figure 1: Architectural Design of the Q/V band GS Graz

The function of the signal analyser is to measure the SNR and to track the MODCOD of the Physical Layer Frames (PL-Frame) of the DVB-S2 generic-stream. An accurate SNR measurement is essential for the analysis and development of Adaptive Coding and Modulation (ACM) algorithms, which can be selected as data-aided or non-data-aided approaches. To this end, we have developed a solution, which offers the possibility to test and optimize various SNR algorithms by means of software. The signal analyzer is based on the GNU radio platform with the Ettus Research HW. The HW provides a L-band interface with a down-converter and an AD converter with 100MHz. All relevant sample operations are processed with FPGA technologies and the symbol based signals are processed on the attached PC platform. The DVB-S2 modem provides a built-in SNR measurement tool, but there is no possibility to influence the computation/algorithm of this tool, which is not sufficient for the development of enhanced ACM algorithms. The DVB-S2 modem is the Newtec EL470, which has a built-in linear pre-distortion. This will be used to compensate the non-linearity along the path. MODCOD switching is possible via RMCP. For efficient testing and artificially reducing the SNR value, a noise generator can be added in the receive path.

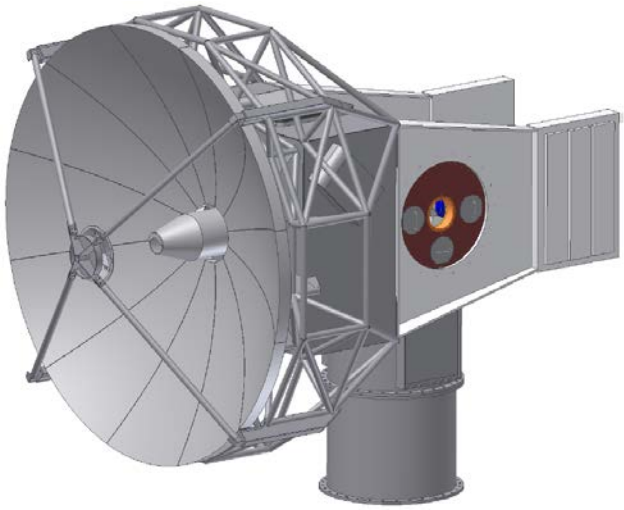
The Data Acquisition and Pre-processing System collects the data from signal and packet-analyser as well as meteorological data and results from the propagation experiment and writes these data in logging files. The experiment control module will allow configuring the various devices of the ground station and the monitoring of error events. Local and remote access is provided by the graphical user interface (GUI), which is attached to the data acquisition and pre-processing system as well as to the experiment control system. In addition, it will be possible to perform post processing of the collected data within the GUI. The propagation experiment is a separate ESA project which operates in parallel to the communication experiment. This experiment uses a separate antenna located next to the communication antenna. Details of the station and the first results can be found in [4][5][6].

2. Subsystem design

2.1. Antenna

Presently the satellite payload is defined with an E.I.R.P. of 39 dBm which requires a ground station antenna with a reflector in the range of 3 m. The satellite beacon might have scintillations in the order of 2 dB which has to be considered in the design of the antenna tracking system.

The design of the ground station antenna system comprises the full motion antenna with Q/V-band feed, servo & drive subsystem and control system with antenna control unit, RF equipment in form of some inter-facility components as waveguides inside the reflector hub, signal cables and a dehydrator for the feed and waveguides. The full motion antenna combines the pedestal and the 3 m reflector with Q/V- band feed in the secondary focus. The pedestal is an elevation over azimuth axes design; bias torqued drives in both axes guarantee precise pointing and tracking. The antenna axes travel ranges and speeds / accelerations allow for tracking of inclined satellites.



Freq. Pol.	Tx	47,85 – 48,15GHz
	Rx	37,85 – 38,15GHz
	Beacon	39,4GHz, 45deg
Sidelobes	ITU 732, ITU-R S580	
Feed	2 port feed linear polarised	
G/T	@38GHz, elev. 20°, LNA 230K	33,8 dB/K
Gain	@ 48/38GHz	61,18dBi/ 59,08dBi
Pattern BW	-3dB @38GHz	0,17°
	-3dB @48GHz	0,14°
Power	< 50W operation, 250W (max)	

Figure 3: CAD drawing of the 3m Q/V Band antenna © Vertex Antennentechnik GmbH and right the specifications of the antenna

The antenna drive cabinet was installed inside an operating room close to the antenna which is available at the site Hilmwarte. At Hilmwarte the antenna is installed on top of the operating room which itself is on top of a 35 m high tower. The antenna is designed for operational wind speeds up to 100 km/h and capable to survive winds up to 200 km/h.

The struts scattering mainly influences the radiation pattern in the strut planes. Figure 3 shows the radiation pattern at 38.15 GHz with the struts contribution.

The configuration of the feed is capable of receiving signals in the frequency ranges from 37.850 up to 38.150 GHz in linear vertical polarization (VLP). This wide RX range is determined to include the beacon frequency at 39.400 GHz, with deg 45° polarization angle.

In the TX range between 47.850 – 48.150 GHz the feed is able to transmit with nominal power of 50W and maximum power of 200-250W. The feed system consists of a corrugated horn including one mode launcher, one polarizer system, one WG to Coax transition, one diplexer unit and one WG flange.

WR 22 is the flange type for RX as well as for the TX division. Inside the feed system WR 28 is designed in order to reduce the insertion losses of the RX part of the feed system. TX flange is determined to WR-22.

The polarizer itself consists of two rotary joints and one phase shifter in between. This subsystem will be controlled via ACU. The consequence of this design is, that the feed horn will be fixed inside the tubus and only the small phase shifter is turn-able which is easier to handle.

To minimize the noise temperature in the receive chain, the LNA is directly mounted to the diplexer Rx flange.

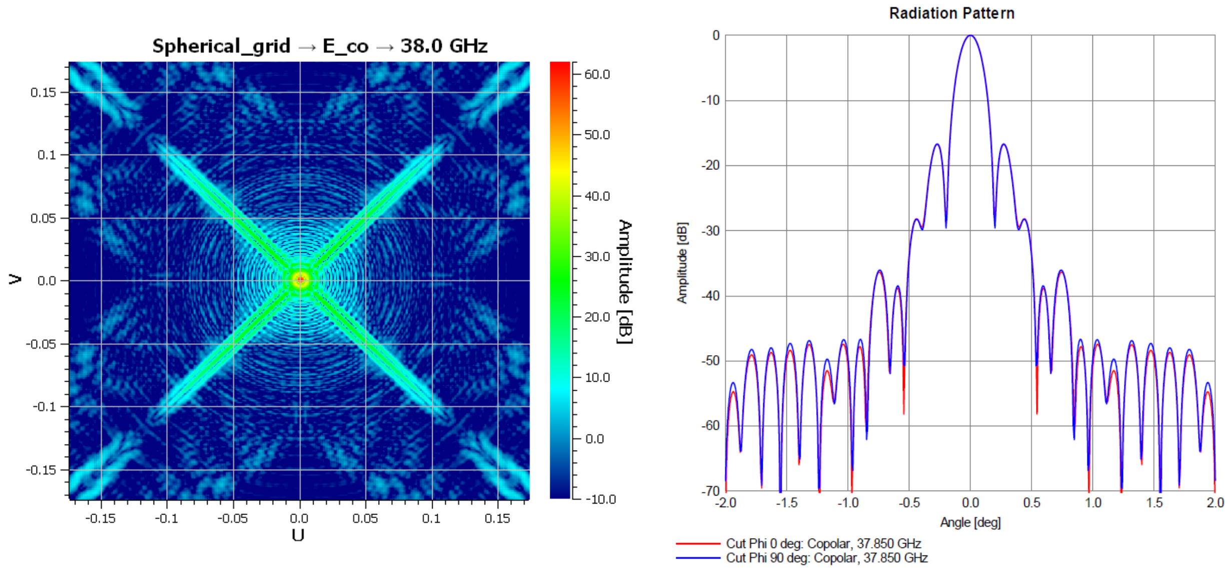


Figure 4: 3D Radiation pattern with struts influence@38GHz and right the RX antenna pattern.
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2.2. Tracking System

Antenna Controller
The antenna controller Type ACU 8119 from Vertex Antennentechnik GmbH commands the Q/V-Band Antenna System. The major tasks of the Antenna Control Unit (ACU) are:
- control of operating modes
- readout of antenna position (encoder interface)
- interface to superior station computer
- control of position and velocity loops (drive control)
- correction of azimuth and elevation angles depending on actual tilting position (using tilt algorithms, optional)
- operator interface locally at ACU
- remote control from station computer

Tracking Modes

The following tracking modes are implemented in the ACU 8119: STOP, RESET, RATE, OPT, BORESIGHT, STEP TRACK, INTEL11, STOW POSITION, SECTOR SCAN, PROGRAM TRACK, AUX MODE AZ/ EL

Tracking Concepts

Step-Track
The ACU provides a basic step track mode which uses a beacon signal in the receive frequency band. Fully automatic tracking of the inclined orbit satellites is accomplished with the step track algorithm, which generates AZ and EL pointing data. The step size and interval are adjustable. If the strength of the beacon signal is varying a threshold can be defined; if the signal strength is below this threshold the ACU switches to a defined mode.

OPT
The Orbit Prediction Mode (OPT) is an intelligent step track which uses measured satellite inclinations and calculates a model out of this data over several hours. From this model the ACU can easily determine the direction of the next look angle (AZ and EL) step with a very high accuracy.
In this manner, an optimum level of antenna drive system activity is achieved and sufficient motion is provided to maintain accurate pointing without causing excessive drive component wear. In particular under rough environmental conditions this tracking mode is the first and most efficient choice to keep tracking the satellite if a valid OPT model is available.
Tracking Accuracy
Step Track mode:
Better than 10% of receive 3 dB beam width, RMS

OPT mode (independent of orbit inclination):
Nominally 5% of receive 3 dB beam width, RMS, with valid OPT model.

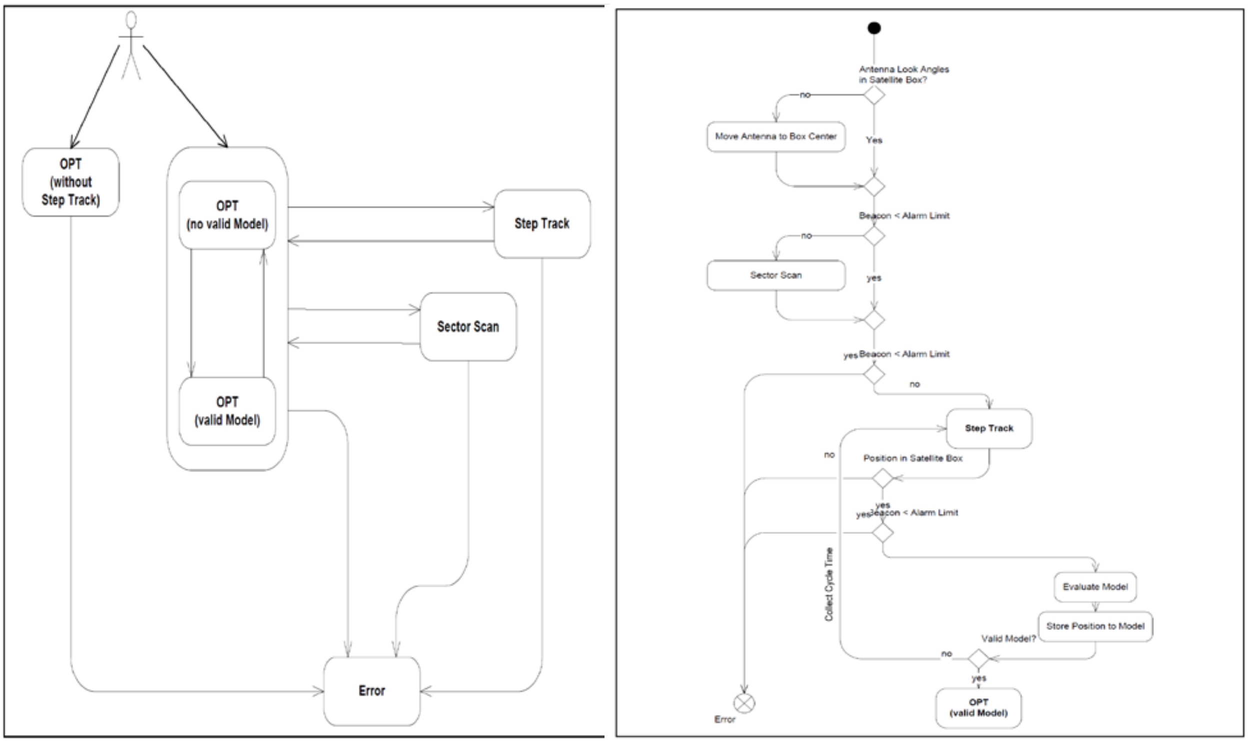

Figure 5: Overview OPT modes and right the OPT state diagram

<u>Conclusion for the tracking system</u>
The OPT Mode is the preferred / optimal mode to track the 3m Q/V-Band antenna on this dedicated frequency band with high volatile atmospheric path losses and additional scintillation effects.

For a better understanding please find the state models of the implemented OPT-Modes *Figure 5*

2.3. HPA

The HPA is an Extended Interaction Klystron (EIK) and was delivered by CPI.

Connector RF Input	2.4 mm coax, female
Input Frequency Range	47.9 GHz $\pm$ 10 MHz, 48.1 GHz $\pm$ 10 MHz
Connector RF Output	flange/waveguide WR22 squared
RF output monitor	2.4 mm coax, female
Nominal power (high-linearity operation):	50W
Rated power (i.e. maximum usable RF power):	at least 200W
Gain at rated power on both channels (with input attenuator set to minimum)	70 dB min.
RF level adjust	0 to 20 dB, with resolution equal or better than ±1.0 dB
Primary Power:	190-264 VAC; 47-63 Hz

Figure 6: HPA from CPI © CPI and right the specifications

2.4. LNA

The LNA was delivered by SPACEK and has the following specifications:

Input Interface

Connector RF	WR 22 In / V female Out
Gain	50 dB min / 54 dB typical
Gain Flatness	+/- 1.5 dB max
NF	2,4dB typ / 3dB max
VSWR	2:1
Frequency Range	37.89 GHz – 39.41 GHz
Operating Temp	-40 to + 60 degC
Spec Temp	25 degC

Connector RF Output	K-Type Coax (2.4 mm) (F)
P-1 dB	10 dBm typical / 8 dBm min
VSWR	2:1
Power Interface	Bias: 210mA @+8 - +12VDC

Figure 7: Left: Input Interface; Right: Output Interface of the LNA

3. Installation

The antenna was the most difficult part of the installation. The transport via a small forest road, followed by the lifting on top of the tower was at the limit of the transport vehicle and the lifting crane.

Figure 8: Antenna installed on top of the "Hilmwarte" tower

4. Test of the antenna

Verification of the antenna gain/ pattern in transmit and receive has been undertaken by bore-sight tower measurements. A local mountain was chosen as the bore-sight tower, in a distance of 12,3 km and an elevation of 4,5°.

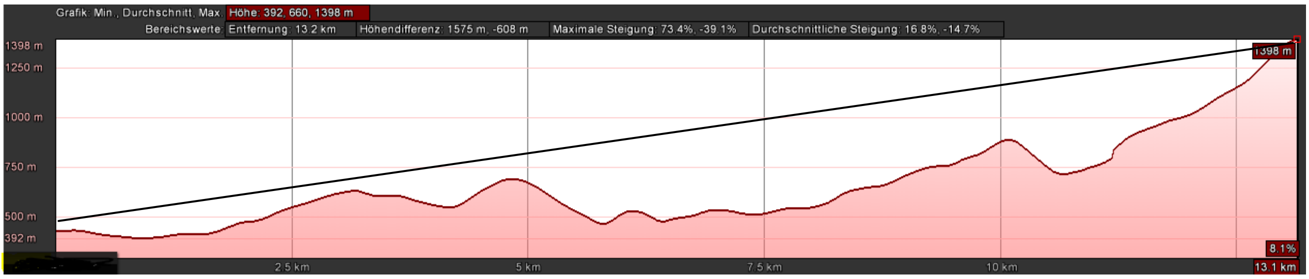

Figure 9: Vertical profile of the test range. Left side is the Hilmwarte Tower and right the Schöckel mountain

On the mountain we had a horn antenna with 24/ 26dB gain (@38/48GHz) which was connected to a signal generator for the RX pattern measurement and to a spectrum analyser for the TX measurements. Please keep

in mind that the accuracy of the tools is less important because it is a relative measurement, but what is indeed very important is the stability of the instruments during the measurement.
With this setup the pattern measurements have been performed. To this end, the antenna has been moved with a constant velocity of 0.02°/s and a spectrum analyser has been setup with a sweep time of 100s. This means that one single sweep of the spectrum analyser covers 2°. The results for pattern cuts in elevation and azimuth are shown in Fig.12 and Fig.13 respectively.

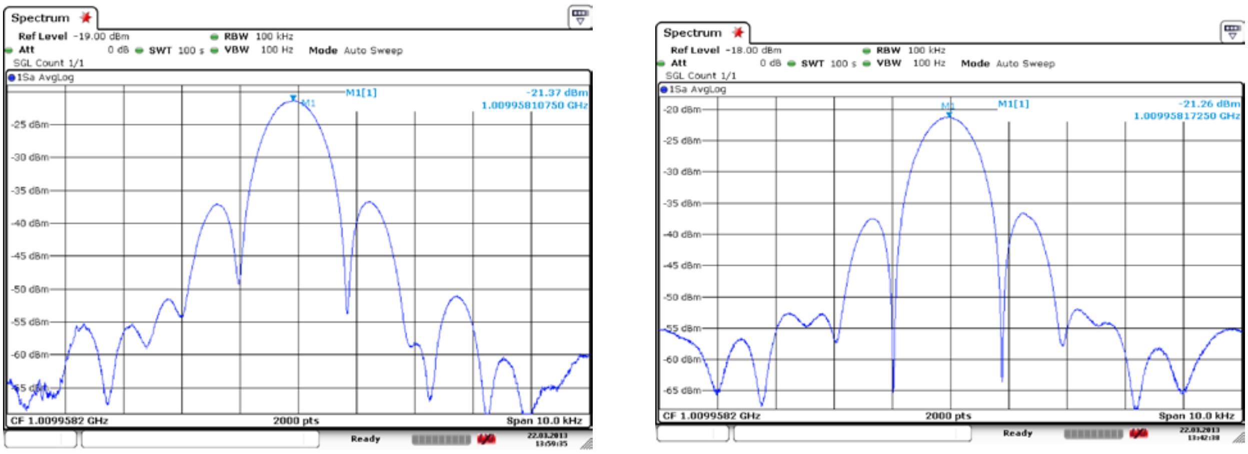

Figure 10: Left: Elevation pattern taken from the Schöckl mountain, 4.06°…6.06°, rate=0.02°/s ;
Right: Azimuth pattern taken from the Schöckl mountain, 3.75° … 5.75°, rate=0.02°/s

The directivity of the antenna in the transmit and receive frequencies, which are 48 and 38GHz respectively, has been done with the 3/10dB method [1], [2]. This method works as follows:
The operator has to point the antenna to the maximum signal strength of the beacon signal.

- Move the antenna upwards, until signal strength is less than 3dB (less) and then downwards until signal strength is 3dB. Note the angle between the 3dB "up" and "down" elevations as El_3.
- Do the same for 10dB and note the angle as El_{10}
- Repeat the procedure for CW and CCW in azimuth, which gives the angles Az_3 and Az_{10}.

Now the directivity D can be calculated by using the following formulas:

$$D_3 = \frac{31000}{Az_3 * El_3} \quad (1)$$

$$D_{10} = \frac{91000}{Az_{10} * El_{10}} \quad (2)$$

$$D = 10 \cdot \log\left(\frac{D_3 + D_{10}}{2}\right) \quad (3)$$

Correction of the azimuth angle displacement was not necessary. Subtracting the feed insertion loss and the RMS loss from that calculates the gain. For the RMS loss RMS_{loss} the following formula has been used:

$$RMS_{loss} = 4.92299867 \cdot (RMS \cdot f)^2 \quad (4)$$

The feed insertion loss has been determined to be 0.92dB. This is based on simulations undertaken by Mirad, the feed supplier.

The measurements have been done twice on different days. The result was practically identical on both days. The obtained antenna gains are 59.3dB for 38GHz and 61.3dB for 48GHz which are by 0.1dB close to the specified values in both cases.

5. SUMMARY AND NEXT STEPS

The ground station in Graz was designed by Joanneum Research and successfully installed at the location Hilmwarte. The gain of the antenna was verified by a boreside tower measurement from a local mountain. The Ground station has been in operation since autumn 2013 and the communication experiment works as planned. The station was also used successfully for the In-Orbit-Test (IOT) of the Q/V band transponder on

Alphasat [3]. It is planned to gather statistical data and experience in operation of the GS for the next 2 years. Further publication will follow to report about the results from the communication experiment.

6. ACKNOWLEDGES

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7. REFERENCES

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