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PERFORMANCE AND RELIABILITY EVALUATION OF THE S-BAND VIENNA SATELLITE GROUND STATION

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ABSTRACT
A satellite ground station for participation in the Canadian project MOST (Microvariability and Oscillations of Stars) has been set up and is being successfully operated since October 2003 at the Institute for Astronomy of the University of Vienna. The location of the ground station is in a densely populated region of the town. The station has been built at costs affordable for Universities using off-the-shelf semi-professional equipment. The MOST satellite is in a polar sun synchronous orbit at a height of around 830 km. During overpass typically lasting 15 minutes the satellite has to be tracked by a 3 m dish with 0.5° precision. Since the start of the operational phase of the satellite, reliable data download is performed with the Vienna ground station contributing nearly half of the data traffic to the whole mission. This paper is an analysis of the performance and the reliability of the ground station using data collected during almost three years.

KEY WORDS
Telecommunication Technology, RF Engineering.

1 Introduction

The concept of low-cost ”microsatellites” in combination with ground stations employing semi-professional hardware forms a basis for affordable university-led space research. In this paper, we describe the performance and reliability of a satellite ground station which supports a Canadian microsatellite space telescope launched in June 2003. This telescope investigates Microvariability and Oscillations of STars (MOST) [1] - [5]. The mission's goal is to perform research on stellar structure and evolution, and to search for exoplanets. Thereby it is intended to find a lower limit for the age of the universe.

MOST has a sun synchronous polar orbit with $98.7°$ inclination at 827 km height. The orbit is designed to provide continuous observation of a certain class of stars for typical periods of several weeks. The relatively low orbit implies that there is a line of sight radio contact six to eight times per day for a total of about 70 minutes. Due to the required orbit - approximately perpendicular to the sun's direction - the satellite passes occur at dusk and dawn. The ground station antenna must track the satellite keeping a pointing accuracy of $0.5°$. A sketch of the orbit is given in [9].

In addition to the Canadian ground stations in Vancouver and Toronto, a third ground station has been set up in Vienna to increase data download capacity of the mission. The MOST satellite can be reached from Vienna at times when the satellite is below the horizon as seen from Canada. By including the Vienna ground station, the download capacity is nearly doubled. The capacity enhancement proportionally increases the scientific output.

Commands for the satellite and data download use a packet protocol closely related to X.25. Mission control is located in Toronto, with ground stations in Vancouver and Vienna connected in real time via Internet.

The Vienna ground station is located at the Institute for Astronomy of the University of Vienna, in a densely populated region of the town. Hence it is obvious that man made electromagnetical noise as well as strong mobile radio downlink signals had to be considered.

2 Ground Station Concept

The concept of the satellite ground station in Vienna is shown in Figure 1.

The ground station is optimized for best possible downlink performance. To avoid combiner loss, separate antennas are used for uplink and downlink. The antenna system of the ground station can be seen in Figure 2. For the downlink, a 3 m diameter parabolic dish is used to receive two orthogonal states of linear polarization. Receive signals at around 2232 MHz are fed into two identical low noise amplifiers with a noise figure of 0.7 dB and a gain of 30 dB directly attached to the dual linear polarized antenna feed. Filters suppress the permanently present uplink spillover. The downconverters that follow are sharing one local oscillator to preserve relative phases and have a gain

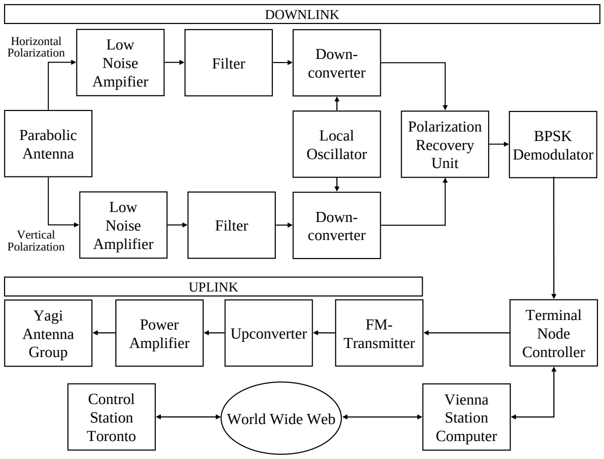

Figure 1. Block diagram of the ground station.

of 40 dB. A polarization recovery unit combines in an optimal way the 140 MHz downconverter output signals. A BPSK (Binary Phase Shift Keying) demodulator incorporating a half rate Viterbi FEC (Forward Error Correction) hardware completes the receiver.

Figure 2. Antenna system.

A separate Yagi antenna group consisting of four antennas supports the uplink. The uplink signal is generated by means of a 435 MHz FM (Frequency Modulation) transmitter and then converted to 2055 MHz. A 50 W power amplifier is placed near the antenna group to avoid cable loss.

Transmission protocols are taken care of by a terminal node controller connected to the Vienna station computer. This computer acts also as bridge to the Internet for data retrieval from Toronto.

The ground station is designed for fully automatic, unmanned operation. All important functions are autonomous. Telecommand of local operation and monitoring are implemented via TCP/IP.

3 Link Budget

The link budget compiled in Table 1 has been obtained using data provided by the designers of the MOST satellite on one hand and using properties of available high class semi-professional equipment on the other hand.

	Uplink		Downlink	
Transmit Power	47.0	dBm	27.0	dBm
Line Loss	2.5	dB	2.0	dB
Antenna Gain	25.0	dBi	0.0	dBi
EIRP	69.5	dBm	25.0	dBm
Total Propagation Loss	174.1	dB	174.9	dB
Received Isotropic Power	-104.6	dBm	-149.9	dBm
G/T_s	-33.8	dB/K	13.3	dB/K
C/N_0	60.2	dB	62.0	dB
Receive Bandwidth	50.4	dBHz	48.9	dBHz
C/N	9.8	dB	13.1	dB
min. required SNR	5.0	dB	4.9	dB
Margin	4.8	dB	8.2	dB

Table 1. Link Budget.

The uplink operates at a data rate of 9.6 kbit/s with GFSK (Gaussian Frequency Shift Keying) modulation. At the uplink we use a power amplifier with a nominal output power of 50 W. A Yagi antenna group consisting of four Yagi antennas is used for the uplink. Phase matching is done by a passive quarter-wavelength power divider. The Yagi antenna group has a gain of 25 dBi.

The downlink operates at 38.4 kbit/s with BPSK. The transmitting power of the satellite is 0.5 W and the antenna gain of the transmit antenna is 0 dBi. The total propagation loss includes the free space loss and the impairment of the link due to rain. The latter was estimated [6] using ITU recommendations and rain fall rates up to 30 mm/h. The receive antenna is a parabolic dish with a diameter of 3 m and has a gain of 35 dBi.

4 Radio Environment around the Ground Station

The ground station is located at the Institute for Astronomy of the University of Vienna, in a densely populated region of the town. Since the station is optimized for receive sensitivity elaborate filtering in the front end is not possible. Therefore we had to consider intermodulation products from the uplink carrier and mobile radio services. Also man made noise of the city has to be considered.

Investigations have shown that intermodulation products of GSM 1800 MHz (Global System for Mobile communication) and DECT (Digital Enhanced Cordless Telecommunications) base station carriers fall near but not onto the receive frequency (see Figure 3). To verify the theoretical findings the spectrum at the output of the low noise amplifiers was measured.

Figure 4 gives a screenshot of the spectrum analyzer display. GSM base station carriers near 1800 MHz and

UMTS carriers around 2100 MHz can be seen. Since overall amplifier gain at 1800 MHz is some 40 dB lower than at the MOST downlink frequency the GSM carriers appear weaker than the UMTS carriers. Intermodulations products originating from GSM and the uplink transmit signal at 2055 MHz show up from 2235 MHz upwards. They fall, as expected, near but not onto the receiving channel. Intermodulation between UMTS carriers and the uplink transmit signal also occur, but due to overall selectivity are buried in the noise.

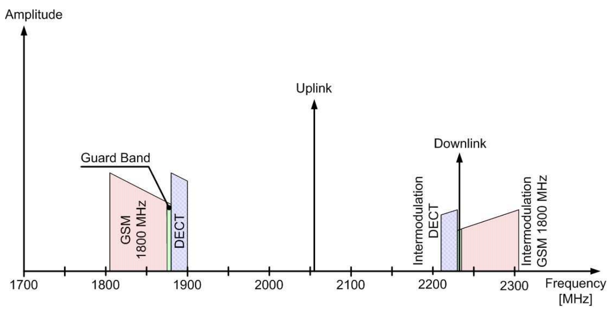

Figure 3. Possible interference through intermodulation products of the uplink carrier and mobile radio.

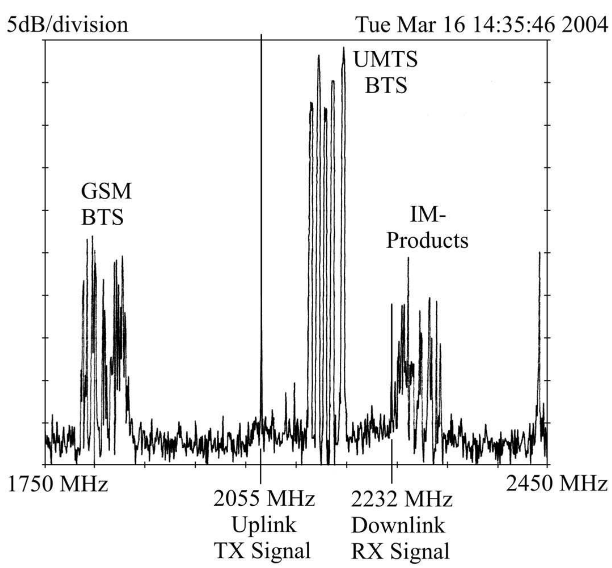

Figure 4. Intermodulation spectrum at the output of the low noise amplifier.

As shown in Figure 4 interference through intermodulation products of the uplink signal with mobile radio carriers will not occur on the receive signal. A further question was if due to the uplink carrier blocking of the low noise amplifiers will happen. For this measurement the sun was used as signal source. The noise level of the sun was measured with the transmitter turned on and the transmitter turned off. If there is blocking the noise level of the sun when the transmitter is turned on must be lower than the noise level if the transmitter is turned off. The measurement has shown that the noise level of the sun is identical in both cases. This means that there is no blocking due to the uplink carrier.

Further, man made noise of the city must be considered. Measurements have shown that the noise level is increased by 12 dB if the receive antenna is pointing to the city at an elevation of 0 degree. This is about the same value as the noise level increases if the antenna is pointing to the sun.

5 Radio Horizon

The ground station is located in a densely populated region of the town. A first interesting question was how strong the theoretical radio horizon is shifted upward due to man made noise originated in the town. For this purpose the AOS (Aquisition Of Signal) angles and the LOS (Loss Of Signal) angles were recorded for nearly all passes since March 2004. The result of the investigation is shown in Figure 5. The chain dotted line shows the theoretical radio horizon and the solid line shows the average of all recorded passes of the real radio horizon. In the direction of the densely populated part of the city (from east to south-west) the real radio horizon differs from the theoretical horizon by about three degrees. This raise of the radio horizon originates from man made noise. In the direction of the outer districts and lower populated districts of the city communication down to the theoretical horizon is possible. The shadowing in the north is caused by the dome of the optical telescope of the Institute for Astronomy.

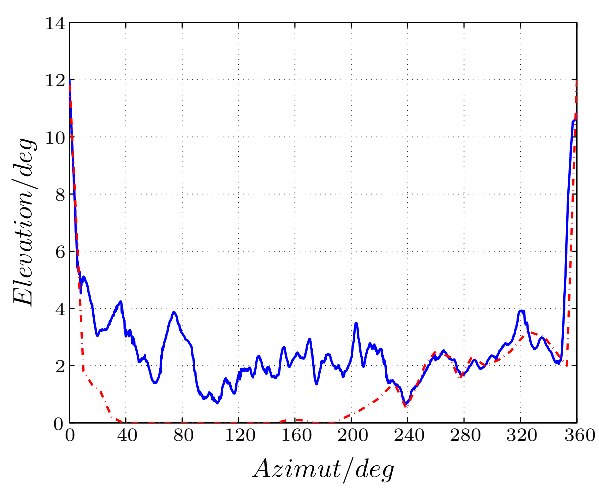

Figure 5. Comparison of theoretical radio horizon (chain dotted line) and measured radio horizon (solid line).

6 Performance

The sensitivity of the downlink is expressed as the figure of merit G/T_s. The calculated value of G/T_s=13.3 dB/K with G the antenna gain and T_s the system noise temperature. This value has been verified by the so called sun noise method. To this end, the receiver output power has been measured with the antenna pointing at a cold part of the sky, and then with the antenna pointing at the sun. The measured figure of merit was G/T_s=14.4 dB/K. This value coincides with the theoretical value within 1 dB.

To give an impression of the quality of the received signal in Figure 6 we show a screenshot taken with a spectrum analyzer. Expressed in terms of energy per bit E_b and noise power spectral density N_0 from Figure 6 one can deduce E_b/N_0 of roughly 14 dB. This leads to practically error free reception of the satellite signal.

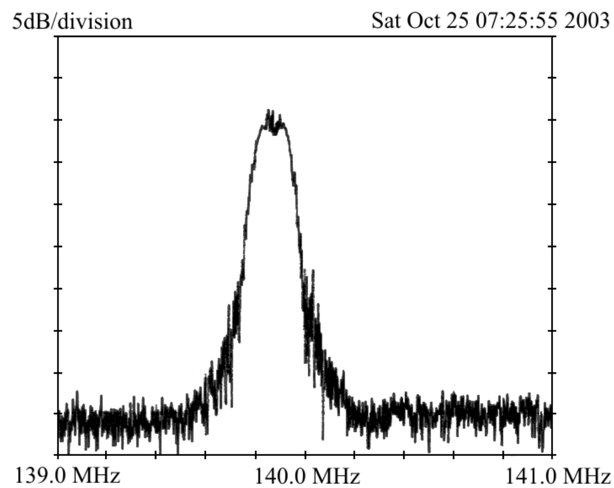

Figure 6. Receive signal spectrum.

Further E_b/N_0 in dependence of the satellite position above the ground station is of interest. The value of E_b/N_0 provided by the demodulator was recorded every two seconds for each satellite pass. The result of this measurement is shown in Figure 7 as a scatter plot. It can be seen that for nearly each position of the satellite $E_b/N_0 \geq 15$ dB. This means that also for low elevation angles a very strong receive signal is present. Since the azimuth rotator has a north stop and the satellite crosses the north line always from east to the west an area where no communication to the satellite is possible due to the rotation of the antenna can be seen in the north.

7 Reliability

The Vienna ground station started operation immediately after the commissioning phase of the satellite. Communication with the satellite is controlled from Toronto. Satellite tracking and all other housekeeping functions are implemented locally in Vienna. The local functions are fully autonomous but they also can be monitored and controlled via Internet, enabling the operator to supervise the station from any convenient location.

Since the automatic registration of the ground station communication data 4712 passes with an elevation angle greater than 3.9 degree and 913 passes with an elevation angle lower than 3.9 degree were recorded. In 92.7 per-

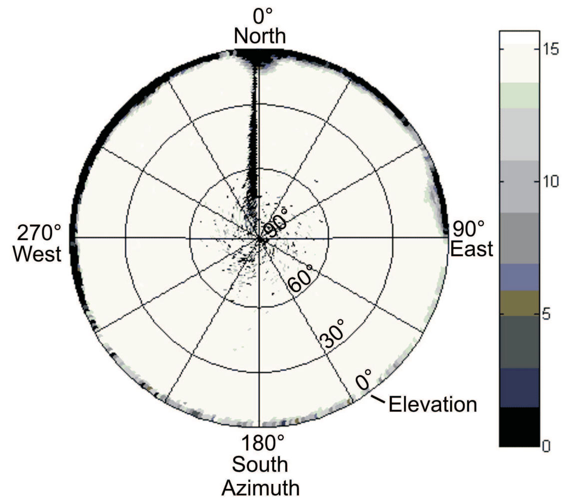

Figure 7. Scatter plot of E_b/N_0 versus antenna pointing direction.

cent of the passes with elevation angle higher 3.9 degree and in 34 percent of the passes with elevation angles below 3.9 degree successful communication to the satellite was possible. At elevation angles above 3.9 degree most of the outage of the ground station was caused by strong winds where the antenna had to be parked and thus an operation of the station was not possible. Only a small part of the outage was caused by technical malfunctions (about 2 percent). The reason of the technical problems were pointing problems due to a loss of the calibration of the rotator controller. For elevation angles below 3.9 degree the outage is caused by man made noise.

8 Conclusion

A scientific satellite ground station, which probably is affordable in cost for many university research groups, is successfully operated since October 2003. Up to now communication at more than 5000 passes was performed with a reliability of about 93%. Nearly all down times of the station were caused by strong winds where an operation of the station is not possible. Long time experience with the station shows that by man made noise from the city the radio horizon is only raised by maximally 3 degrees. In some directions communication down to the theoretical radio horizon is possible. Measurements have further shown that whenever communication to the satellite is possible a strong signal from the satellite is received. Also the download capacity fully agrees with the design.

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