# Design of a Multi-Mission Satellite Ground Station for Education and Research

Michael Fischer and Arpad L. Scholtz
*Vienna University of Technology*
*Institute of Communications and Radio-Frequency Engineering*
*Gusshausstrasse 25/389, 1040 Wien, Austria*
*Email: michael.fischer@nt.tuwien.ac.at*

*Abstract*—**Satellite space missions need ground stations for mission control and data communication. In this paper we present a modular ground station, which will be used for nano and pico satellites. The frequency bands initially supported are VHF, UHF, and S-band around 145 MHz, 435 MHz, and 2.3 GHz, respectively. We present a flexible, layered approach, which is ideally suited for multiple missions and allows for the addition of further frequency bands and missions. Furthermore, it allows seamless inclusion of the ground station in ground station networks. The ground station is designed for research as well as education and training of students.**

*Keywords- satellite; ground station; low earth orbit; LEO; education; ground station network.*

## I. Introduction

Nano and pico satellites in a low earth orbit (LEO) offer a cheaper alternative and feature faster development cycles than traditional space missions. Such low-budget missions give access to space science for education and research at universities [1], [2]. For these small satellites often the term "CubeSat" is used because of their typical form factor. In the last years several nano and pico satellites have been launched [3]. Further recent examples can be found in [4]–[6].

A space mission consists not only of the satellite with its instruments and experiments, but also needs ground support for housekeeping and communication. At least one ground station is required. Several ground stations are favored for redundancy.

LEO satellites with altitudes between 160 km and 2000 km have the advantage of affordable launch costs, as well as relaxed power constraints on the communication link because of the shorter distance to be bridged. However, ground station antennas for LEO satellites need to track and follow the satellite on its pass over the ground station. Most of the satellites we have in mind have a polar or even a sun synchronous orbit. Since the duration of a pass of a LEO satellite over a ground station is short (e.g., some 15 minutes for an altitude of about 800 km), and the number of passes per day is some six to eight, communication duration and therefore the amount of data, which can be transfered per day is limited. Again several ground stations – spread over the globe – are favored to mitigate this constraint.

The Vienna University of Technology does not yet have its own satellite. To give the local students hands on education on space communication a multi-mission ground station is currently under construction at our institute. Multiple missions in the context of this paper mean satellite space missions, which not only differ in orbit, but particularly in their communication parameters like the frequency bands for up- and downlink, power level, modulation scheme and duplex mode.

Section II gives some background information about two space missions the ground station is intended to be used for. Section III then describes the structure and design of the ground station. Section IV gives details on the planned use of the ground station in the context of education and Section V concludes.

## II. Space Missions Considered

The ground station under construction is not dedicated to a single mission but will be able to serve different LEO satellites. The general design is kept open, modular and flexible to support future missions, but foremost, the ground station is intended to be used for BRITE-Constellation and GENSO. So in a first step, the requirements on the ground station are defined by these two projects. The compatibility to these projects is addressed in Sections III-F and III-G.

TUGSAT-1/BRITE-Austria (BRIght Target Explorer) is Austria's first satellite, a nano satellite currently being assembled at the Graz University of Technology in cooperation with the University of Vienna, the Vienna University of Technology and the University of Toronto, Space Flight Laboratory [7], [8]. Together with the satellite UniBRITE it will form the first step to the so-called BRITE-Constellation. Both satellites will perform high-precision photometry of relatively bright stars with magnitude $\leq 4$ over long observation times, one satellite in the red, the other in the blue optical spectral regime [9], [10].

The Global Educational Network for Satellite Operations (GENSO) is a network of a cluster of ground stations distributed worldwide [11], [12]. Most of them have educational research character. This project of the European Space Agency (ESA) is also supported by CSA, JAXA and NASA. The aim is to share ground stations from different space missions as well as ground stations from radio amateurs to give each space mission more access time to their respective satellite. This is possible because of the normally high idle

58

time of each ground station between two consecutive passes of their corresponding satellite.

## III. GROUND STATION STRUCTURE

Our institute has already built a satellite ground station located at the Institute for Astronomy, University of Vienna. This station serves MOST and COROT in a highly specialized manner and was not designed with further expansion in mind nor to enable educational satellite research [13]. Building on the experience gained with this ground station and with focus on the two space projects mentioned in the previous section, Figure 1 shows an overview of the structure of the new ground station to be set up at the Vienna University of Technology.

Since one of the main objectives of the ground station at our institute is the support of multiple missions, it is divided into modular subsystems. By definition of clear and open interfaces between each of the subsystems, we gain the flexibility to not only support multiple missions, but we can adapt to future missions by only adding some mission specific subsystems.

### A. Ground Station Segments

The ground station is divided into three segments, namely the segments for

- the frequency-band-specific radio frequency (RF) *front ends* including the antennas and their rotators,
- the RF *signal processing* components and converters between analog and digital domain, like transceivers, modulators, demodulators, and terminal node controllers (TNCs), and
- the *mission or experiment specific data processing components* usually realized with personal computers (PCs).

Comparing this segmentation with other work, the *front ends* and the *signal processing segment* correspond to the "Tx/Rx Pipeline" in [14], [15], while the *mission specific data processing components* subsume the "Session Group" and some portions of the "Master Group" therein.

In the following we will call a chain of components for a specific transmit or receive scenario "pipeline", adopting the notation from [14]. Different transmit or receive pipelines can be formed using different combinations of subsystems.

Between each segment and also between some of the components inside each segment, signal switches or signal splitters are necessary. Signals include for example RF signals, serial or parallel digital data, audio signals, and commands or status information. The switches and splitters allow to route signals flexibly for easy expansion of the ground station to new missions or requirements. Where possible, splitters are used instead of switches because this allows for concurrently feeding signals to several subsequent components. This enables for example parallel processing and storage of data on one hand, while monitoring signal
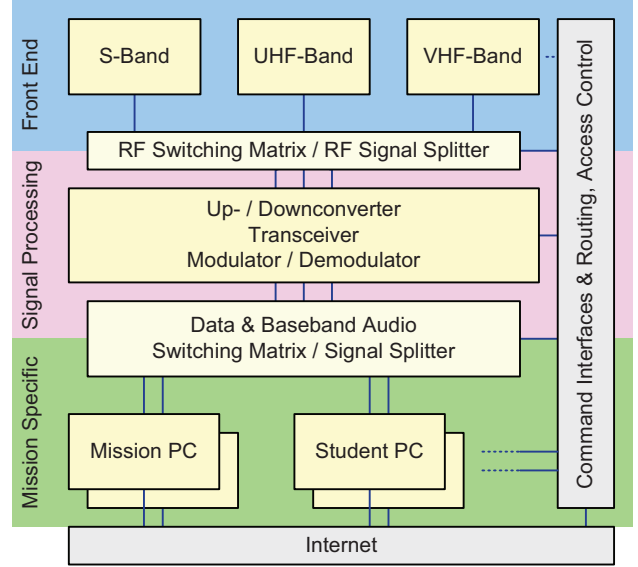


Figure 1. Overview of the proposed ground station structure. All components are divided into three segments. In this initial setup the front ends will support S-band, UHF, and VHF communication.

quality on the other hand. This also allows to compare subsystems by comparing the signals after each path.

By adding *front ends*, further frequency bands can be made accessible. Adding components to the *signal processing segment* typically adds another modulation scheme or another data representation form required for a specific mission while also making this new feature available to all other missions. Finally, support for a new mission typically calls for an additional PC in the *mission specific segment*.

### B. Virtualization and Ground Station Networks

Spanning all three segments, various *command interfaces, command routing, and access control components* are necessary. This extra block is responsible for actually setting up a transmit or receive pipeline before each satellite pass, depending on the requirements and privileges of the respective mission.

The modular and layered approach used for our ground station eases virtualization. Commands are sent by the mission PC to the components only via the *command interface* block. So this block allows for the hardware abstraction. Then – from the viewpoint of the mission PC – there is dedicated, mission specific hardware [14]. An example are the two rotator pairs, which are presented to the mission PC as a virtual single rotator system.

The flexibility gained by virtualization also enables easy inclusion of the ground station into ground station networks like GENSO or others [14], [16]–[18]. By means of virtualization the ground station network is presented with the hardware it expects.

Figure 2. S-band front end structure with VHF band interface. The structure shown is a symbolic representation. In practice the LNAs are going to be placed immediately after the feed.



Figure 3. VHF and UHF front end structures. Both front ends share the azimuth and elevation rotators. The polarization selectors correct depolarization effects caused by satellite attitude and by the ionosphere.

## C. S-Band Front End

The S-band front end uses a 3.6 m parabolic dish to receive and transmit signals in the frequency range from 2.02 GHz to 2.45 GHz. Figure 2 shows the components of the S-band front end. The parabolic dish utilizes a dual polarized feed and a polarization selector to choose between one out of two orthogonal linear or two orthogonal circular polarization states.

The frequency range from 2.02 GHz to 2.11 GHz is used for scientific space operation uplinks, the range from 2.20 GHz to 2.30 GHz is used for scientific space operation downlinks, while the range from 2.30 GHz to 2.45 GHz is devoted to amateur radio. A triplex filter will separate the frequency bands and will allow for full duplex operation in the scientific bands.

Power amplifiers (PAs) and low noise amplifiers (LNAs) are located near to the antenna feed to reduce transmission loss and to improve the noise factor. Up- and downconverters are used for the conversion of the S-band to the VHF band around 140 MHz for further signal processing.

The front end will not be able to operate in full duplex mode in amateur radio S-band. In this case, a transmit/receive switch is used in front of the PA and the LNA. However, full duplex operation is of course possible using the S-band together with the UHF or VHF front end.

The parabolic dish is mounted on an azimuth and elevation rotator pair. These rotators can point the antenna into any direction of a half sphere. They do not offer fully automatic tracking of a satellite on their own, but target angles have to be provided by the *mission specific segment*. These angles are typically calculated there using Keplerian elements or the common two line elements (TLEs) as input

parameters, together with their specific orbital models.

## D. VHF Front End and UHF Front End

The VHF front end operates in the amateur radio band from 144 MHz to 146 MHz. The UHF front end operates in the amateur radio band from 430 MHz to 440 MHz. Both are quite similar in structure and share the azimuth and elevation rotators. Again the rotators require target angles as input parameters.

Figure 3 shows the components used. The antennas are Cross-Yagi antennas with 2×7 elements and a gain of 12.15 dBi in case of the VHF antenna and 2×18 elements and a gain of 16.15 dBi in case of the UHF antenna. Again we use a polarization selector to choose between one out of four possible common polarization states.

For highly sensitive reception, LNAs for each band are located near the antenna feeds. They are bypassed during transmission by automatic transmit/receive switches. Neither the VHF nor the UHF front end allow full duplex operation on their own but only when used in combination with another front end.

The VHF/UHF front end is already realized and a photo is shown in Figure 4. The polarization selectors and the LNAs are housed in waterproof boxes. The PAs are located inside the building and are connected by some 8 m of low loss flexible coaxial cable.

## E. Signal Processing and Mission Specific Segment

The *signal processing segment* contains all further components, which can be shared among different missions. Of course, the minimal features of this segment are indicated by the particular missions. Since in a first step our ground station is intended to be used for BRITE-Constellation and GENSO, the components of the *signal processing segment* are oriented on those two missions.

Figure 5 shows the components currently planned for the *signal processing segment*. The next two sections explain

Figure 4. Photo of the VHF/UHF antenna structure at the roof of our institute. One can see the antennas and the azimuth and elevation rotators. The polarization selectors and the LNAs are visible in the middle between the antennas. The background shows the famous dome of the Karlskirche.
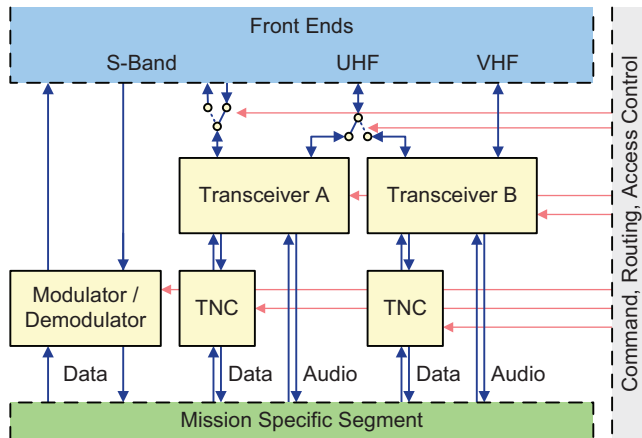


Figure 5. Components of the signal processing segment. These components are shared between different missions. Depending on the particular mission other inputs and outputs are used by the mission specific segment.

the details of these components and all further *mission specific* components necessary to form pipelines for BRITE-Constellation and the GENSO project.

### F. BRITE-Constellation Pipeline

The two satellites forming BRITE-Constellation use the same frequencies. They utilize UHF band for uplink and scientific S-band for downlink in a full duplex mode.

In the uplink path there is a *mission specific* TNC, which already includes a modulator [19]. The final upconversion to UHF is then accomplished by one of the amateur radio transceivers visible in Figure 5.

In the downlink path, after the downconversion to 140 MHz center frequency by the S-band *front end*, a commercial Datum Systems PSM-500 modem (modulator/demodulator, see Figure 5) performs the demodulation and feeds the digital data to the *mission specific* TNC.

### G. GENSO Pipelines

Since GENSO does not represent a single satellite mission, but rather a generic network of satellite ground stations, there is no predetermined configuration and several different pipelines have to be available to support potential satellites. However, typical satellites utilize the amateur radio VHF, UHF or S-band for up- and downlink. Full duplex operation is preferred, using different frequency bands for up- and downlink.

As shown in Figure 5, two transceivers A and B are available. Both are of IC910H type by ICOM. The radios have separate antenna connectors for VHF and UHF band. The VHF connector of transceiver A is used to support the S-band up- and downconverters. Either the UHF connector of transceiver A or of transceiver B is used for the UHF front end. The VHF connector of transceiver B is used for the VHF front end. This way any combination of the three frequency bands (i.e., the three front ends) can be used for up- respectively downlink in a full duplex mode.

For some satellite missions of the GENSO project, the audio connectors of the radios are then directly connected to the sound card inputs or outputs of a PC to perform the analog to digital and digital to analog conversion. This allows – for small bandwidths and low data rates (e.g., some 5 kHz and 9600 bps) – very flexible signal processing, since processing is easily definable by software on the PC. It also allows for direct storage or remote transfer of the captured data. Further processing can be performed offline and/or remotely.

For other satellite missions, the pipeline includes TNCs with modems. The TNC is then responsible for the HDLC and/or AX.25 protocol processing and relays the data to/from the PC, typically over a serial RS232 connection.

## IV. STUDENT EXPERIMENTS AND STUDENT EDUCATION

In addition to the support of the projects BRITE-Constellation and GENSO, one of the objectives of our ground station is to serve the education of students. This is facilitated by the modular structure of the ground station and by the open interface approach between the components used and especially between the segments.

In a first phase, students can experience a live, real world satellite link. They can insert a probe – e.g., a spectrum analyzer or a serial data analyzer – at any interface between two components and sample the received or transmitted signals. Attenuators or noise generators can be temporarily
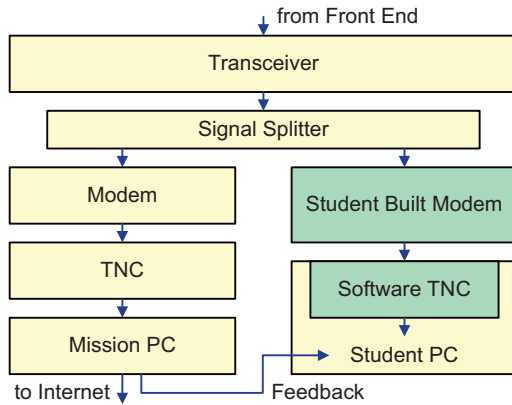
Figure 6. Example student experiment, where students compare their own modem and TNC to the existing mission's receive pipeline. The signal splitter makes sure that the two data paths do not interfere.

inserted into the pipelines to systematically degrade the overall ground station performance to demonstrate its behavior under varying conditions.

In a second phase, data recordings of satellite passes can be used in a playback scenario by students to simulate a satellite. This way operation of a ground station can be learned. The approach has similar objectives as [20].

In a third phase, students can set up a separate PC in parallel to the actual mission PCs. In this setup one can tap the receive or transmit pipeline at any given point and receive the same data as the mission PC receives or supervise the data the mission PC transmits. Figure 6 illustrates this for an example scenario, where students build their own modem and design a TNC in software. While keeping the ground station up and running, students can run their experiment without interaction with the mission. By using the mission data output as a reference, students are even able to judge their own results quantitatively.

In a further scenario, students can substitute components of the ground station – be it hardware or software – by self designed, pre-tested versions. This is more critical, but is it the only option when testing for example a new searching and tracking algorithm for a satellite, since there is only a single rotator available at most for a specific frequency band. Such experiments are only possible in missions where several ground stations are simultaneously available like in the GENSO project.

Last but not least, several students have been and will be involved in the actual construction of the ground station, e.g., in student projects or during their master's thesis.

## V. CONCLUSION AND FUTURE WORK

We are currently building at our institute a modular and flexible satellite ground station for multiple space missions. In this paper we presented its design philosophy.

This ground station design facilitates easy expansion to further frequency bands and new space missions. It is well suited for virtualization and therefore allows inclusion into ground station networks like GENSO.

One of the objectives of the ground station is the education and training of students at our university. We showed which possibilities this ground station design offers for use in student laboratories.

While the ground station is designed in a modular way to support a multitude of different space missions, we support BRITE-Constellation and GENSO in a first step. Future inclusion of further missions is planned, as well as addition of front ends for the L-band around 1.2 GHz and the X-band around 8 GHz.

## REFERENCES

[1] M. Schmidt and K. Schilling, "Small satellites for educational purposes," in *Proc. of 60th International Astronautical Congress (IAC2009)*, Daejon, Korea, Oct. 12–16, 2009.

[2] K. Schilling, "Design of pico-satellites for education in systems engineering," *IEEE Aerospace and Electronic Systems Magazin*, vol. 21, pp. 9–14, 2009.

[3] B. Klofas, "A survey of cubesat communication systems," in *5th CubeSat Developers Conference*, Cal Poly, San Luis Obispo, CA, USA, Apr. 9–11, 2008.

[4] A. Shah, K. Sarda, C. Grant, S. Eagleson, D. Kekez, and R. E. Zee, "Canadian Advanced Nanospace eXperiment 2 orbit operations: One year of pushing the nanosatellite performance envelope," in *Proc. of 60th International Astronautical Congress (IAC2009)*, Daejon, Korea, Oct. 12–16, 2009.

[5] J. Bouwmeester, G. T. Aalbers, and W. J. Ubbels, "Preliminary mission results and project evaluation of the Delfi-C3 nano-satellite," in *Proc. of Small Satellite Systems and Services*, Rhodes, Greece, May 26–30, 2008.

[6] AAUSAT-II, satellite from Aalborg University, Denmark. [Online]. Available: http://aausatii.space.aau.dk/eng/

[7] O. Koudelka, G. Egger, B. Josseck, N. Deschamp, C. Grant, D. Foisy, R. Zee, W. W. Weiss, R. Kuschnig, A. L. Scholtz, and W. Keim, "TUGSAT-1/BRITE-Austria - the first Austrian nanosatellite," *Acta Astronautica*, vol. 64, pp. 1144–1149, 2009.

[8] TUGSAT-1/BRITE-Austria, Austria's first satellite. Last accessed, March 2010. [Online]. Available: http://www.tugsat.at/

[9] R. Kuschnig and W. W. Weiss, "Brite-constellation: nano-satellites for asteroseismology," *Communications in Asteroseismology*, pp. 351–353, 2009.

[10] BRITE-Constellation. [Online]. Available: http://www.brite-constellation.at/

[11] H. Page, B. Preindl, and V. Nikolaidis, "GENSO: The global educational network for satellite operations," in *Proc. of 59th International Astronautical Congress (IAC2008)*, Glasgow, Scotland, Sept. 29–Oct. 3, 2008.

[12] Global Educational Network for Satellite Operations (GENSO). [Online]. Available: http://www.genso.org/

[13] M. Fischer, W. Keim, and A. L. Scholtz, "Low-cost Erde-funkstelle Wien: 5 Jahre Betriebserfahrung," in *Radar, Communication and Measurement RADCOM 2009*, Hamburg, Germany, Mar. 31–Apr. 1, 2009, invited, English title: 5 years of operation experience with the Vienna Ground Station.

[14] J. Cutler, "Ground station virtualization," in *Proc. of The Fifth International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operations (RCSGSO 2003)*, Pasadena, CA, USA, 2003.

[15] J. Cutler, "Ground station markup language," in *Proc. of IEEE Aerospace Conference 2004*, Mar. 6–13, 2004, pp. 3337–3343.

[16] K. Farzaneh, L. Mohamady, and A. Eidi, "Building and controlling customizable satellite GS networks," in *Proc. of International Symposium on Communications and Information Technologies (ISCIT 2007)*, 2007, pp. 774–779.

[17] M. Kasal, "Experimental satellite laboratory BUT education and research," in *Proc. of 17th International Conference on Microwaves, Radar and Wireless Communications (MIKON 2008)*, Warsaw, Poland, May 19–21, 2008, pp. 367–374.

[18] J. Cutler and A. Fox, "A framework for robust and flexible ground station networks," *Journal of Aerospace Computing, Information, and Communication*, vol. 3, Mar. 2006.

[19] T. S. Tuli, N. G. Orr, and R. E. Zee, "Low cost ground station design for nanosatellite missions," in *Proc. of 24th AMSAT North American Space Symposium*, San Francisco, CA, USA, Oct. 5–11, 2006.

[20] D. Schor, W. Kinsner, and A. Thoren, "Satellite ground station emulator: An architecture and implementation proposal," in *Proc. of Canadian Conference on Electrical and Computer Engineering (CCECE 2009)*, St. John's, Canada, 2009, pp. 868–873.