Phase C

Swisscube RF communications description and ICD

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RECORD OF REVISIONS

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1/0	07/12/2007		Ted Choueiri
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INTRODUCTION

This document describes the interfaces between the COM board and the Ground Stations for the main RF data uplink, the main RF data downlink and the beacon downlink.

National and international frequency coordination has been achieved through the OFCOM (Federal Office of Communications) and the USKA (Union of Swiss Short Wave Amateurs) for national frequency coordination and through the ITU (International Telecommunications Union) and the IARU (International Amateur Radio Union) for international coordination.

The assigned frequencies are 145 MHz for the uplink and 437.505 MHz for the downlink.

1 REFERENCES

1.1 Normative references

[N1]

1.2 Informative references

[R1] Enrique Rivera, *Phase C Performance Evaluation and Optimization of the RF Circuits for a Satellite Communication System*, 20/12/2007.
[R2] Nicolas Stempfel and Lorenzo Prati, *Phase B Beacon*, 01/07/2007.
[R3] Marc Jacquat, Nicolas Raemy, Angelo Auderset, *Swisscube Ground Station Fribourg*, January 2008.
[R4] S3-B-C- COM-1-0-Beacon Design.
[R5] S3-B-C-ADS-2-3-Antenna Deployment System.

2 TERMS, DEFINITIONS AND ABBREVIATED TERMS

2.1 Abbreviated terms

3 DESCRIPTION OF THE END-TO-END COM SYSTEM.

3.1 Overview of the system.

The communication system is composed of two main parts: the Swisscube Spacecraft and the Ground segment.

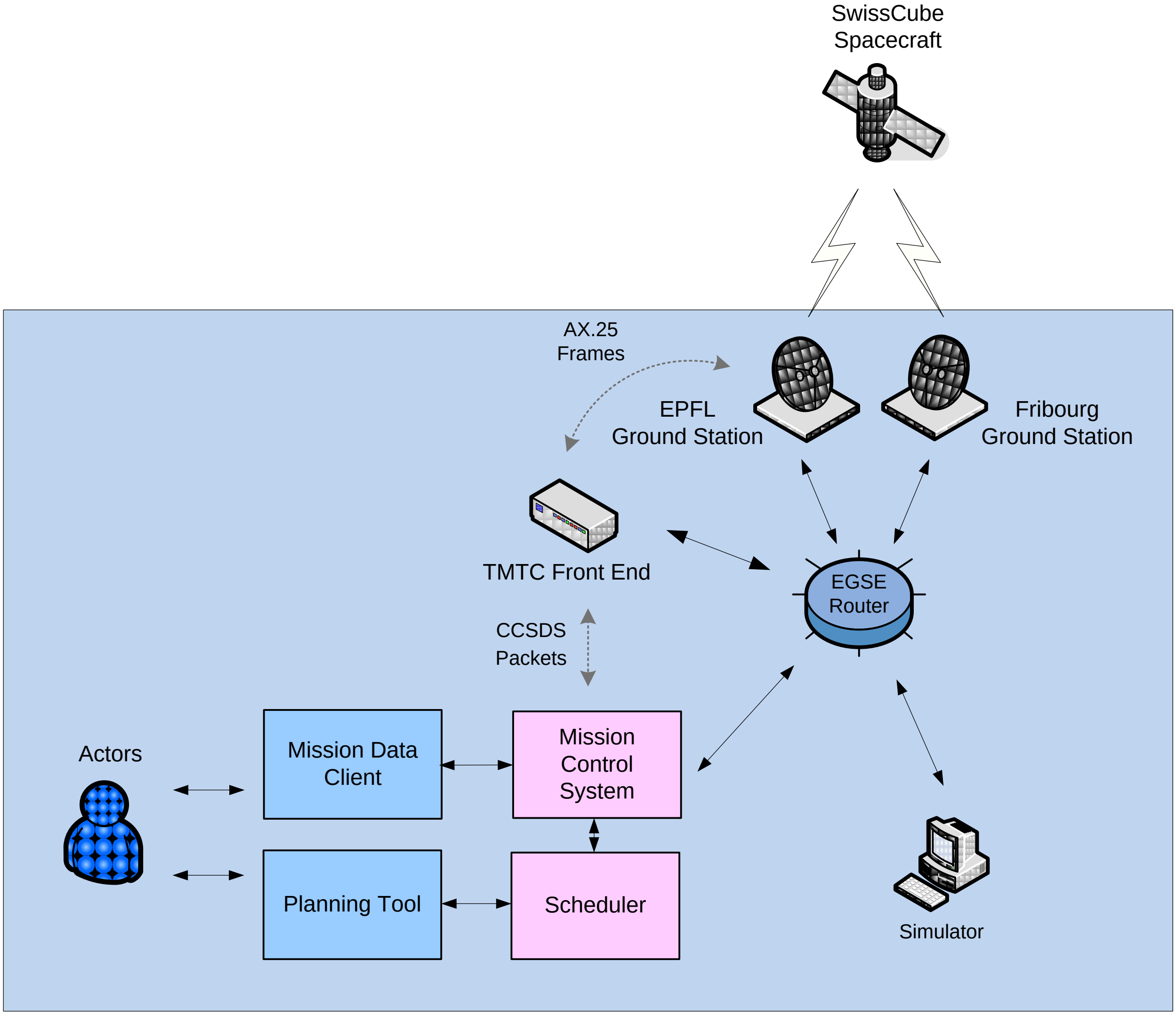


Figure 1: System Block Diagram.

The ground segment is composed of an EGSE router, a TMTC Front End, a Mission Control System, a Scheduler, a Mission Data Client and a Planning Tool. Its purpose is to manage the data that is sent to and received from the Swisscube satellite.

The mission operators interact with the Mission Data Client and the Planning Tool. These two blocks allow for the visualisation of the telemetry received from the satellite and the planning of scenarios that will be played out during the communication windows.

The Mission Control System manages the CCSDS PUS packet format. It encapsulates telecommands in CCSDS PUS packets and decapsulates the telemetry. It communicates with the TMTC Front End through the EGSE router.

The TMTC Front End manages the AX.25 protocol, and encapsulates telecommands and decapsulates telemetry into AX.25 transfer frames. These frames are sent to and received from the Ground Station(s) through the EGSE Router.

The Swisscube satellite has two main communication links.

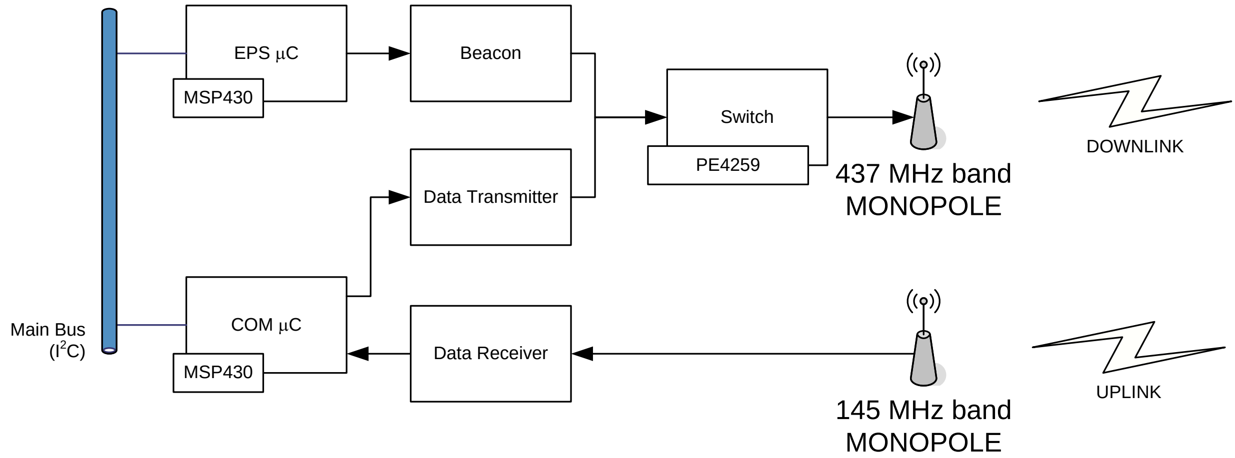


Figure 2: Simple block diagram of the Swisscube communication system.

The first link is the main data RF link. It is the high powered and high data rate RF link, and is composed of a downlink signal and an uplink signal. These two signals are handled on the satellite by the COM board.

The second link is the low powered link. It is a beacon signal in Morse code, generated by the EPS board and transmitted by the Beacon board.

These two communication links are handled on Earth by the Ground Station. An overview of the system is given in the diagram below.

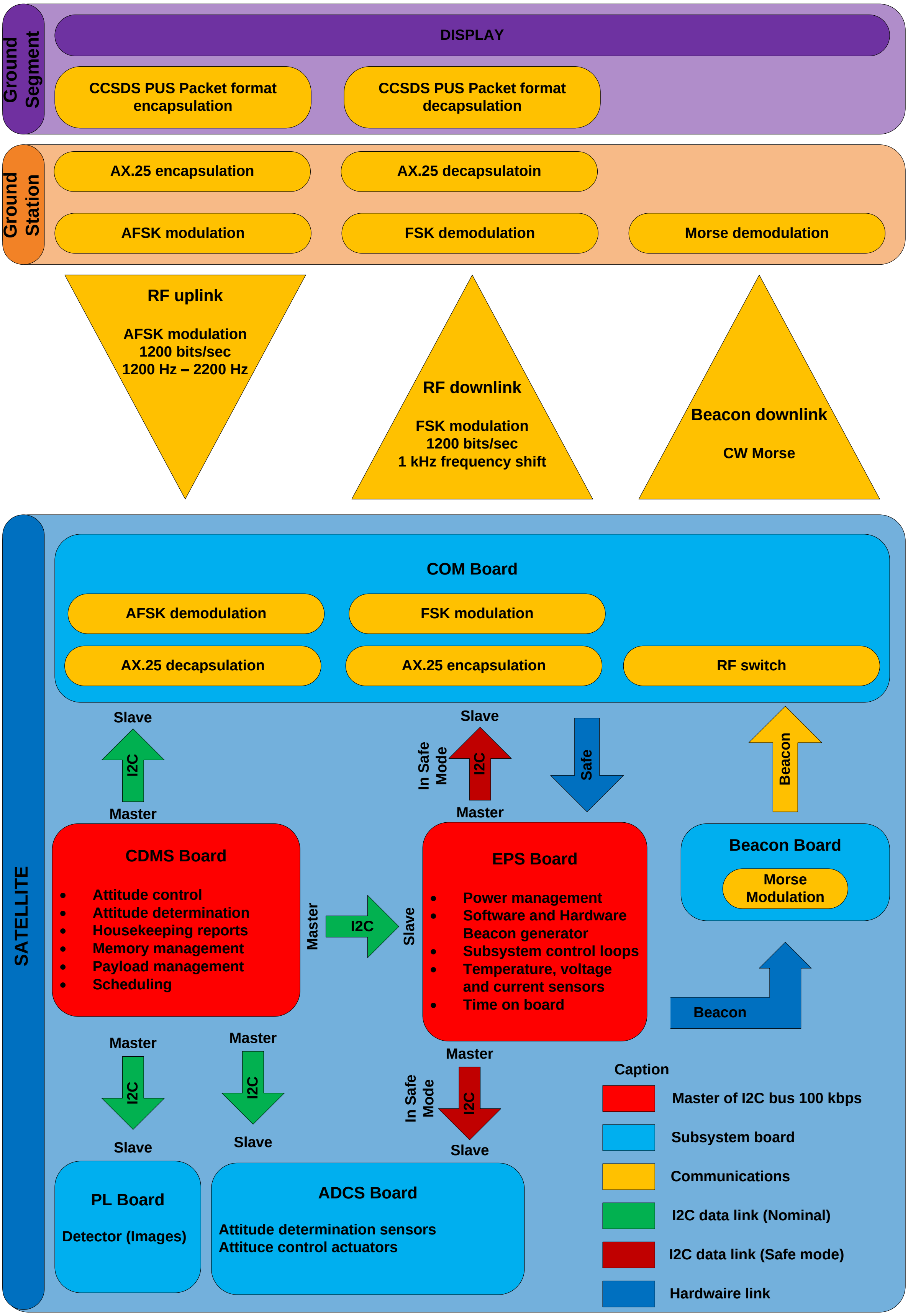


Figure 3: Simple diagram of the communication system.

It should be noted that the Ground Station handles the RF links, i.e. it modulates and/or demodulates the data, and manages the start/end flags of the AX.25 frames along with the bit stuffing. The rest of the Ax.25 protocol, along with the PUS protocol, are handled by the Ground Segment.

3.2 Description of the COM board.

The COM board manages the uplink and downlink signals. As such, it can demodulate the AFSK uplink signal, modulate the FSK downlink signal and can encapsulate and decapsulate AX.25 frames.

A block diagram of the COM board is given in the schematic below.

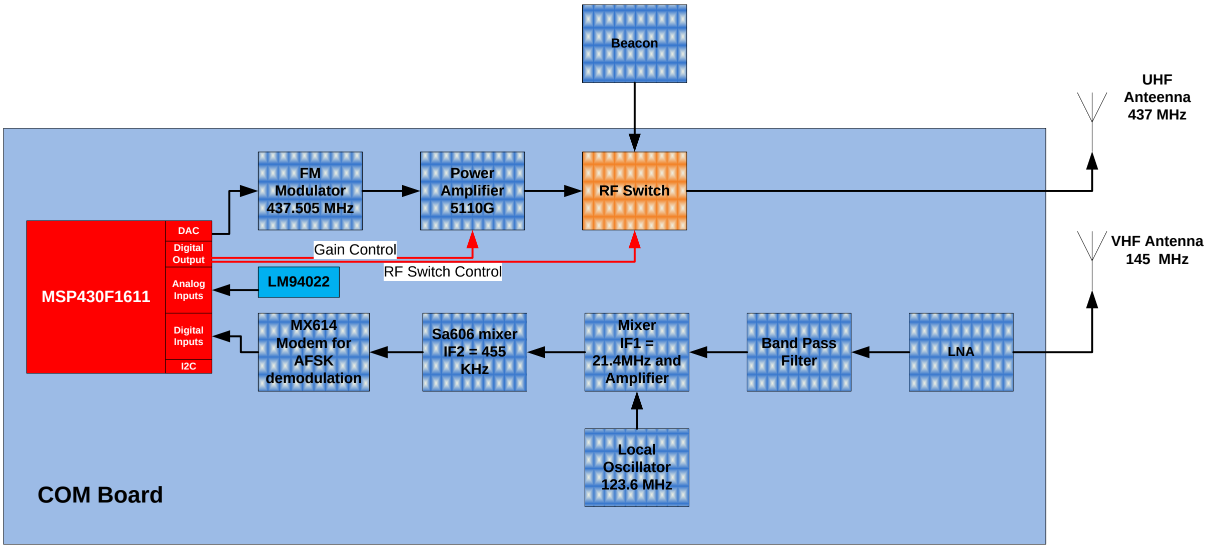


Figure 4: Block diagram of the COM board.

Both the beacon signal and the main data downlink signal are connected to a RF switch for transmission to the TX antenna.

<u>Receiver architecture:</u>

The receiver design is based on a dual-conversion receiver architecture, which in a nutshell means the received frequency is down-converted twice before demodulating the message signal from the carrier.

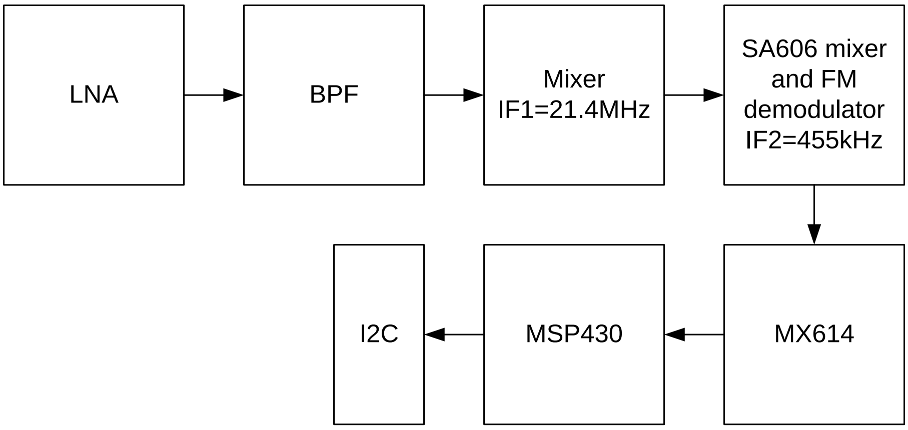


Figure 5: Block diagram of the receiver architecture.

Figure 5 shows the block diagram representation of the receiver. The major building blocks of receiver are a low noise amplifier, band pass filter, 1st mixer and final 2nd mixer /demodulator (SA606).

The incoming carrier frequency is in the 145 MHz band, it is passed through a LNA to boost the signal power while removing noise from the incoming signal. The amplified signal is then passed through a passive band pass filter. After which it is down converted to the 1st intermediate frequency (IF1) of 21.4 MHz using 1st mixer and local oscillator.

Finally, the message is passed through a SA606 chip, which is a single IC that includes the 2nd Mixer, IF amplifier and the quadrature FM demodulator. The mixer in SA606 converts the incoming signal to 455 KHz (IF2) before being demodulated by the quadrature detector. The MX614 modem then proceeds to the demodulation of the AFSK signal.

Block	Details and specifications
LNA	The Low Noise Amplifier is assembled using discrete components. The maximum gain that is achieved is 17.26 dB with a Noise Figure of 2 dB.
Band Pass Filter	Assembled using discrete components. This filter has a negligible insertion loss.
Mixer, amplifier and Local Oscillator	These two blocks ensure that the 145.98 MHz signal is multiplied with the oscillator frequency in order to have an output signal at 21.4 MHz. The amplifier has a gain of 23 dB.
SA606 mixer	IC chip from NXP. It's output is a signal at 455 KHz.
MX614 Modem	FSK modem chip from MX COM. Used to demodulate the AFSK signal.

Table 1: Details and characteristics of the receiver blocks in Figure 4.

Transcritter architecture:

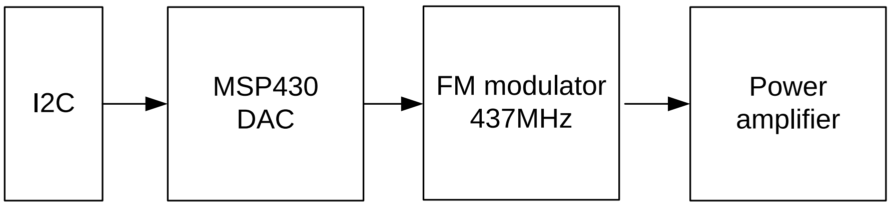


Figure 6: Block diagram of the transmitter architecture.

The architecture used for transmission is shown in Figure 6. The modulation is FSK. The data is used to drive the FM modulator through the microcontroller's DAC. The generated FM signal is then passed through a power amplifier. The power amplifier is capable of transmitting 30dBm (1W). This is required to satisfy the link budget requirements for BER<10^{-4}. The power amplifier used is RF5110G manufactured by RF micro devices.

Block	Details and specifications
FM Modulator	This module's goal is to receive the data rate signal in base band and make up the conversion directly to the frequencies used. The modulation is FSK with a frequency deviation of 500Hz around a carrier at 437.505 MHz.
Power Amplifier	5110G chip from RFMD. The achieved efficiency is 43% with an output power of 29 dBm.
RF Switch	The RF switch is used to select which signal is connected to the UHF antenna (main data COM or Beacon). The reference is PE4259 from Peregrine.

Table 2: Details and characteristics of the transmitter blocks in Figure 4.

3.3 Description of the Beacon board.

The Beacon board receives the beacon signal generated by the EPS board, and modulates this signal in Morse code. It then amplifies and transmits the beacon signal to the RF switch on the COM board.

The architecture of the beacon subsystem is shown in Figure 7. When the beacon is turned on, the oscillator provides continuously the carrier frequency, in our case the same frequency as the main COM. Then the signal is modulated in amplitude (OOK) and finally amplified. The desired bit rate is 10 bits/s.

A block diagram of the Beacon board is given below.

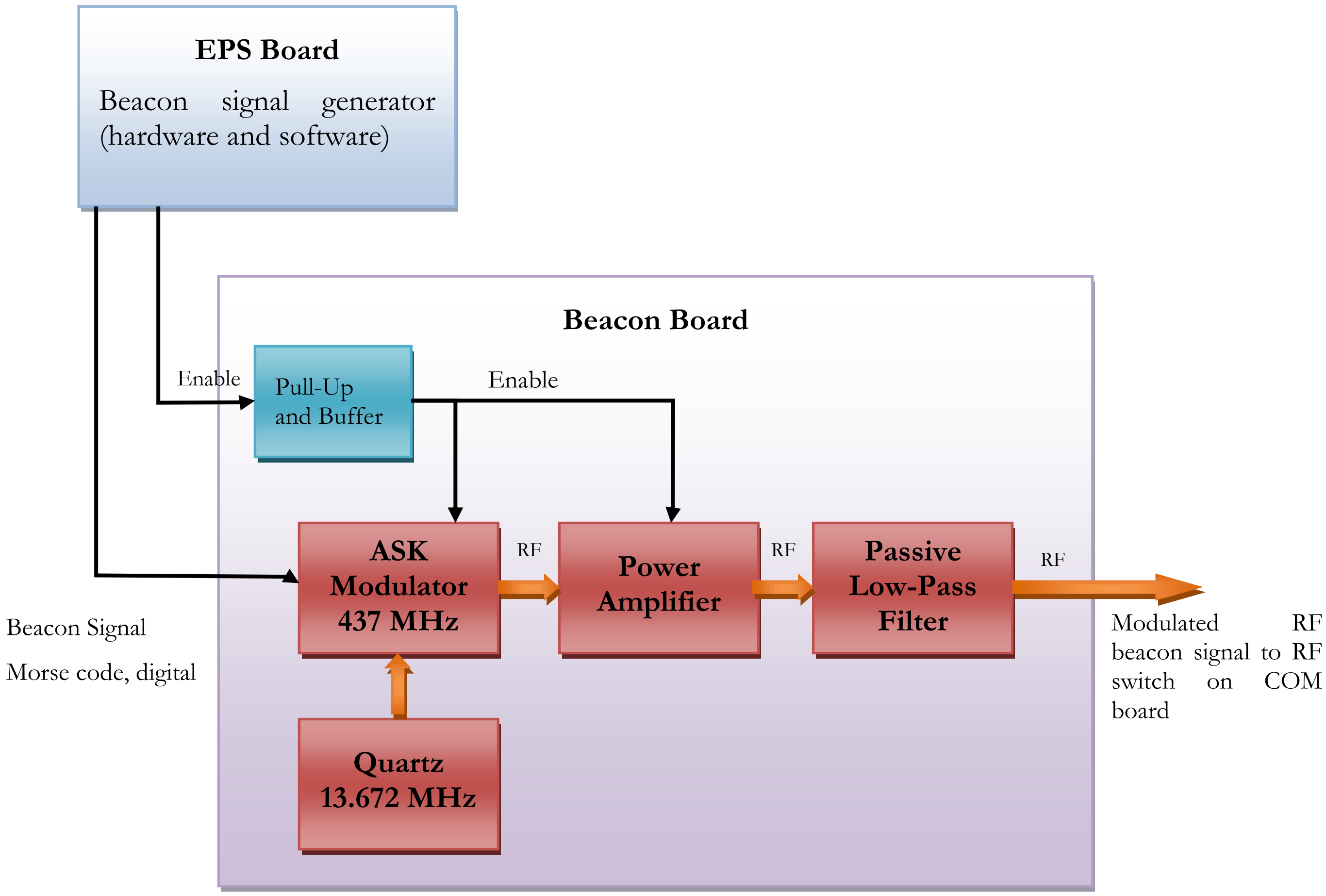


Figure 7: Block diagram of the Beacon board.

Block	Component(s)	Details and specifications
Pull-Up and Buffer	10 kΩ resistor for the pull-up and NC7SZ125 chip for the buffer	This block activates the beacon if the enable signal from EPS fails during transmission (small glitch in the signal).
ASK Modulator	RF2516 Modulator from RFMD	This block generates the carrier frequency at 437.5 MHz (32x 13.672 MHz) and allows the ASK/OOK modulation of the sinusoidal carrier with the Morse signal.
Quartz	13.672 MHz 49USMX from Euroquartz	This quartz is responsible for the generation of the carrier frequency. • Frequency: 13.672 MHz. • Electrical configuration: series resonance. • Calibration tolerance at 25°C: ±20 ppm. • Temperature stability: ±20 ppm. • Operating temperature range: -40°C to 85°C. • Operating mode: AT-Cut Fundamental.
Power Amplifier	RF2172 from RFMD	High efficiency linear amplifier, with an input power of about 0 dBm and with an output power of 20 dBm. At Vcc=3.3V, and with a supply current of 123.8mA, the measured output power is 118mW (20.72 dBm) with a 28.9% efficiency.
Passive Low-Pass filter	Made of capacitors and inductances.	The main purpose of this filter is to remove the unwanted higher harmonics of the output signal.

Table 3: Details and characteristics of the blocks in Figure 5.

3.4 Description of the SwissCube antennas.

Modeling of the antennas length, satellite backplane material and position on the satellite panel was performed and several solutions were analyzed.

In convergence with the Antenna Deployment System design, the chosen antenna configurations include a quarter-wavelength monopole antenna for 145.8 MHz and another one for 437.5 MHz. Figure 8 shows the antenna layout and Figure 9 the radiation patterns for SwissCube. Both antennas are made of beryllium copper.

Several tests were performed on the antenna deployment system and on the effect of the bending of the antennas on the RF pattern.

The VHF antenna is 610 mm long when the antenna is in straight ideal position. The maximal gain is about 2.25 dBi and the return loss (S11) goes from -15.3 dB in the first case to -14 dB in the second (3 % of power is reflected and therefore 97 % is transferred to the antenna).

The UHF antenna of 176 mm when the antenna is in straight ideal position and 181 mm when in bent position. The gain is 3.15 dBi for the first case and 3.65 dBi for the second case whereas the S11 parameter is -16.44 dB and, respectively, of -14.5 dB (3 – 5 % of power is reflected and 95 – 97% is transferred to the antenna). The final design features a length of 176 mm.

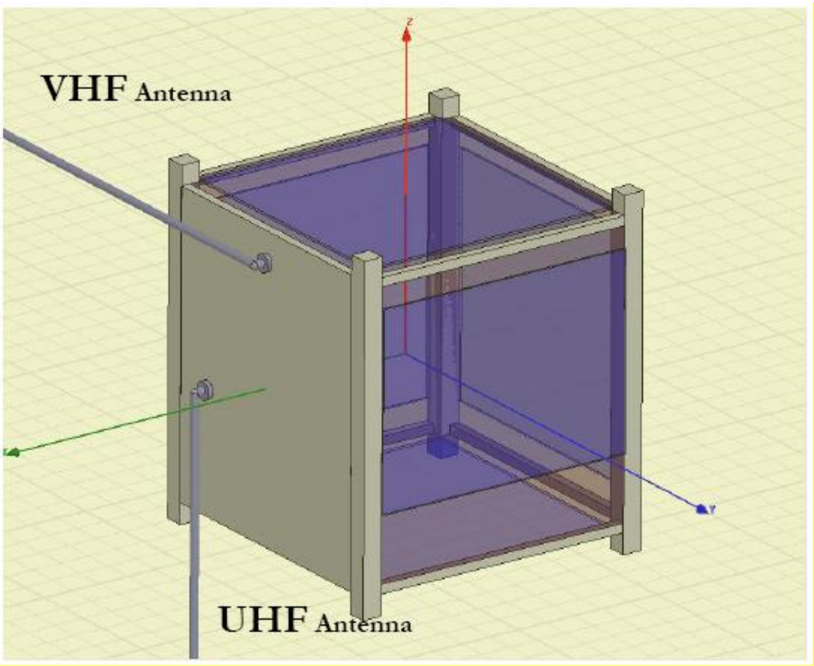
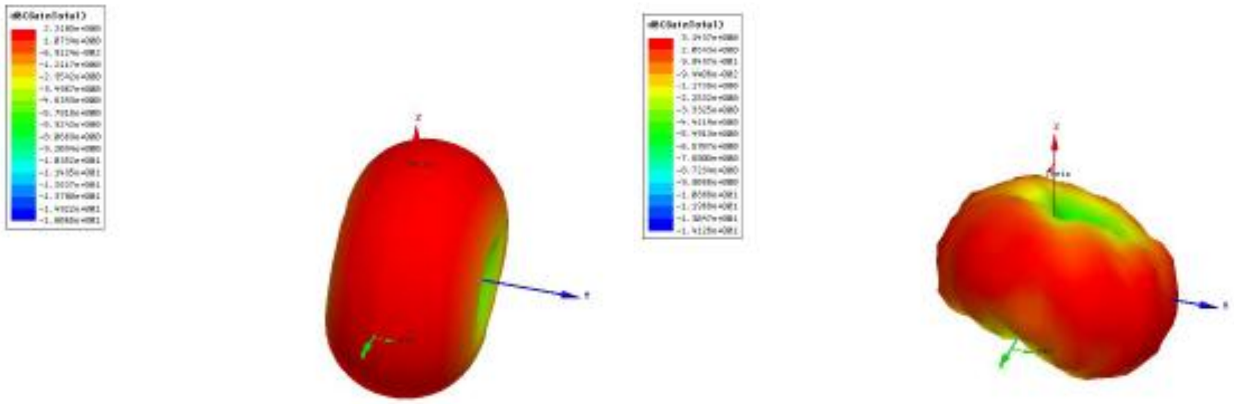


Figure 8: SwissCube antenna layout.



VHF 3D Polar Antenna Gain UHF Polar Antenna Gain

Figure 9: Radiation pattern for the antenna baseline design.

For further information please refer to:

- SwissCube RF Beacon Design: [R4].
- Antenna Deployment System [R5].

3.5 Description of the Ground Station at EPFL.

This is a brief description of the Ground Station at EPFL. It is an example of a compatible ground station that can be used to communicate with the Swisscube. Ground stations with different designs can also be used, as long as they are able to send and receive the RF signals described in chapter 4 correctly.

The ground-station will be built on the roof of the EL building of the EPFL. One part, the antenna system, will be installed outside on a mast. The other part, the control electronics, will be located in a storage room on the last floor of the building.

The design was proposed by radioamateurs from the RAV club (Club des radioamateurs vaudois) and was approved by the system engineering team.

Figure 10 shows the system Block Diagram for the Ground Station. It shows all connections and devices. Table 4 also shows the planned manufacturer and model of the devices.

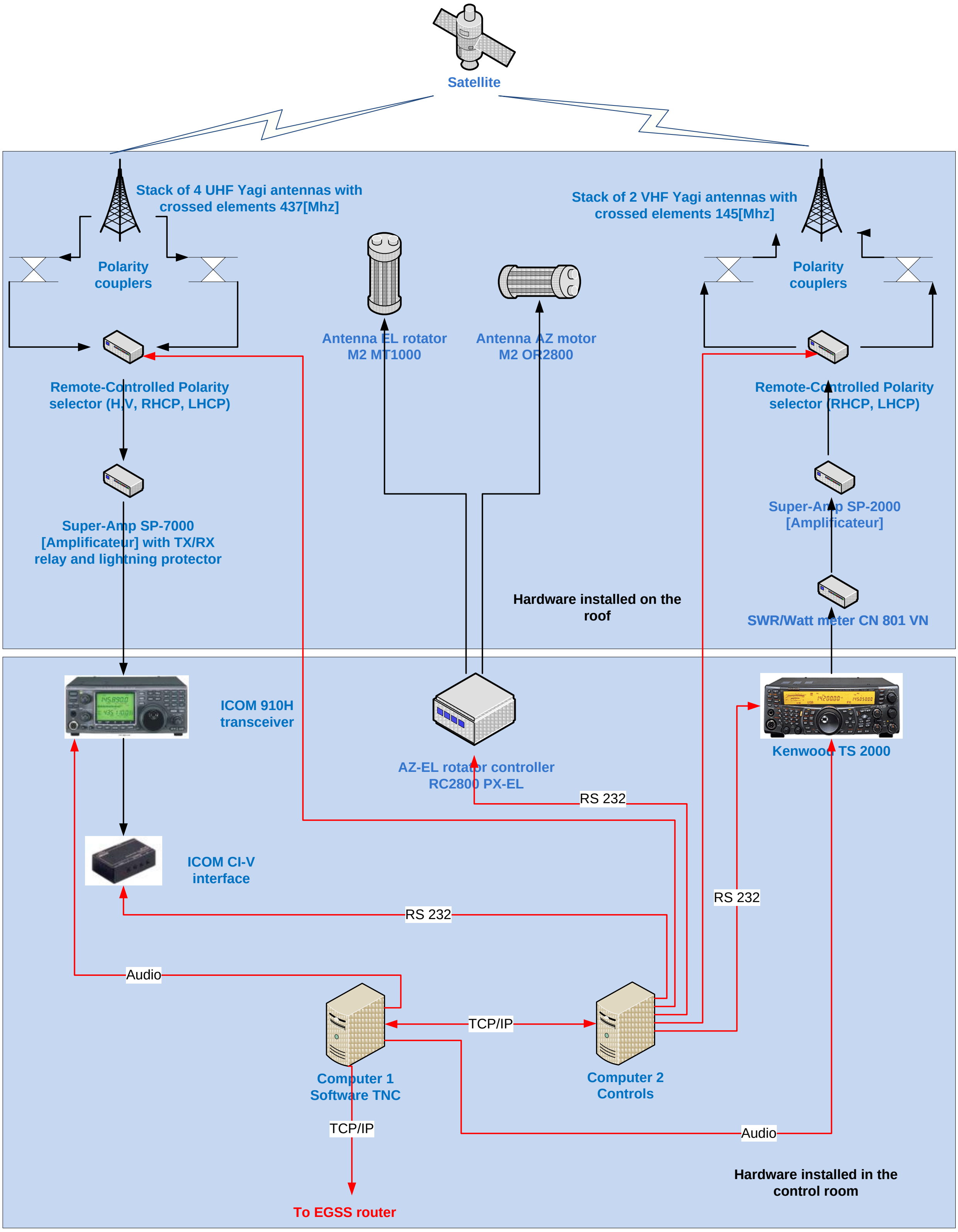


Figure 10: EPFL Ground Station block diagram.

The telecom data protocol between the ground and the space systems is the AX.25 protocol and was chosen for its wide-spread use in the Amateur Radio community.

Element	Model	Function	Choice Rationale	Purchased
Control electronics				
Transceivers	Kenwood TS-2000 ICOM 910H	Kenwood for transmission ICOM for reception	See Note 1.	Yes
TNC	Software TNC developed at EPFL with help from the radioamateurs	AX.25 packet FSK/AFSK modem	Allows for custom-made signal processing	Is being developed.
Controller PCs	1) 486 IBM PC 2) DELL Optiplex 755 MT	1) Control the antenna positioning motors for tracking of the satellite and Doppler compensation, controls the transceivers and the polarity selectors. 2) software TNC	1) Available and free. 2) Powerful enough for comfortable software signal processing.	Yes
Rotator controller	RC2800 PX-EL Controller	Command the rotator's position		Yes
SWR meter	CN-801VN	Check the quality of the match between the antenna and the transmission line		Yes
Power supply	GSV-3000			Yes
Antenna System				
Tx Preamp	SSB-Elektronik SP-7000	Low noise amplifier	Recommended by radio amateurs	Yes
Rx Preamp	SSB-Elektronik SP-2000	Low noise amplifier	Recommended by radio amateurs	Yes
Lightning protection	Lynics 20310-3	Protect from lightning damage		No
Polarity couplers				yes
AZ-EL rotator	EL: M2 MT1000 AZ: M2 OR2800	Antenna rotators		yes
Uplink Antennas 2-m	2 CP: 2MXP20 Yagis		Good G/T Optimized for stacking	yes
Downlink Ant. 70-cm	4 CP: 436CP42 Yagis		Gain and F/B are excellent	yes
Mast			Donated by radio amateur	yes
Additional clamping, beams and mounting HW				In process.

Table 4: EPFL Ground Station hardware.

Note 1: The criteria for the choice of the transceivers were:

- Band of frequencies adapted to the frequencies of the CubeSat radio amateurs (145 MHz for upload and 437.5 MHz for download).
- The transceiver must be able to recognize all the modes used for satellite radio amateur operations: FM, USB, LSB, CW, AM, AFSK, 9600 bauds packet, 1200 bauds packet.
- Possibility of controlling the transceiver by PC.

- Good compensation of the Doppler Effect: the step of the synthesizer must be to the maximum of 1 kHz.
- Full Duplex: broadcast on a band and reception on the other one (VHF > UHF or UHF> VHF). The full duplex mode is currently not a requirement for the SwissCube but it is or might be for other satellites.
- Software support.
- There are 2 transceivers. One Kenwood TS-2000 for the uplink and one ICOM IC-910 for the downlink. There are several reasons for having two transceivers:
    a. Experience has shown that the ICOM 910 receiver has better performances than the Kenwood TS-2000 receiver.
    b. Both transceivers handle duplex communications. As such, one transceiver can handle all the communications with the satellite if the other transceiver fails.
    c. Interfacing the transceivers in simplex mode with the computer and the TNC (be it software or hardware) is simpler than in duplex mode.

Figure 11 shows the existing antenna mast on the EL Building. The mast and antennas have been removed.

Figure 11: Current installation on the roof of the EL building.

The EPFL Ground Station has a stack of 4 Yagi UHF antennas for the downlink signal and a stack of 2 Yagi VHF antennas for the uplink.

Figure 12 shows the baseline layout of the ground-station with two circularly polarized 2m Crossed-Yagi antennas for the uplink and four 70cm antennas for the downlink. Figure 13 shows the radiation patterns of available Yagi antennas for 2m and 70 cm.

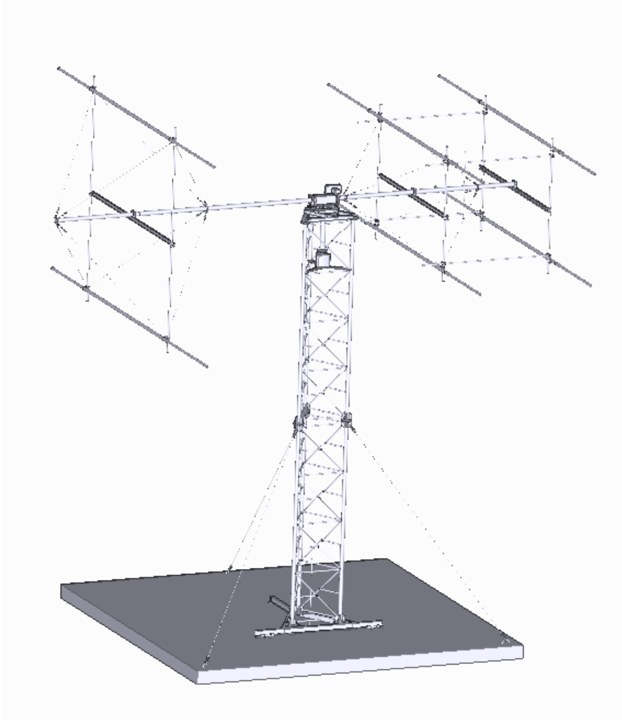


Figure 12: Antennas layout.

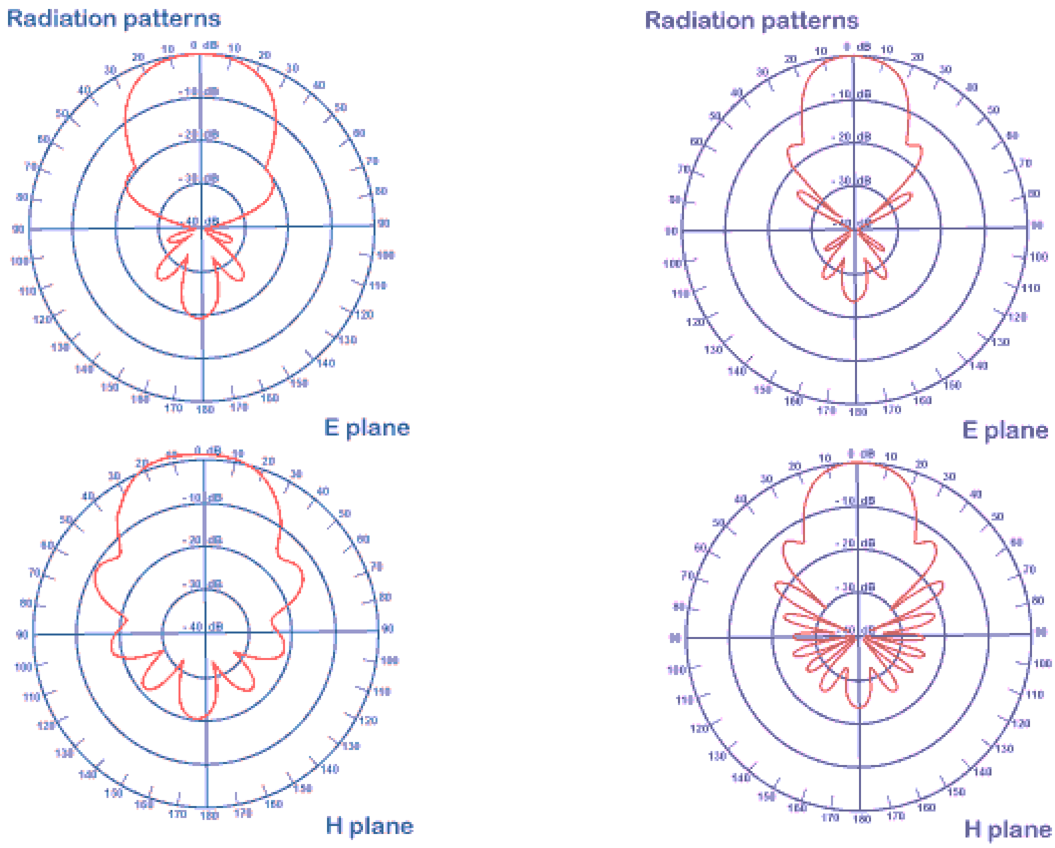


Figure 13: Radiation pattern of a 2m and 70cm Yagi Antenna

Specifications	Antennas uplink 145.98 MHz		Antennas downlink 437.505 MHz	
	Single antenna	Stack of 2 antennas	Single Antenna	Stack of 4 antennas
Model Number	2MCP22	2MCP22	436CP42UG	436CP42UG
Frequency range	144 to 146 MHz	144 to 146 MHz	430 to 438 MHz	430 to 438 MHz
Gain	10.11 dBi	13 dBi	14.66 dBi	20.46 dBi
Beamwidth	38 degrees	19 degrees	21 degrees	10 degrees
Polarity	RHCP or LHCP		RHCP or LHCP	
Front to Back	25 dB typical		25 dB typical	
VSWR	1.4:Max		1.5:1 & Better	
Feed Impedance	50 Ohm Unbal.		50 Ohm Unbal.	
Connector	N Female		N Female	
Elements	2*11	2*2*11	21H and 21V	4*2*21

Table 5: Specifications of the EPFL ground station antennas.

Software.

Two computers are used for the Ground Station. The first one (Computer 1) runs a software TNC that will be developed at EPFL. This software will have the following functionalities:

- Software demodulator: the software will read the audio signal delivered by the receiver and demodulate it to extract the AX.25 frames. It will send these frames to the TMTC Front End through the EGSE router.
- Software modulator: the software will receive AX.25 frames from the EGSE router, and will modulate it into an audio signal that will be sent to the transmitter.
- Signal analyser: the software demodulator will also analyse the signal received (S/N ratio, frequency drift, frequency deviation, etc.). These parameters determine the corrections that are needed to the receiver parameters. The software will transmit these corrections to the second computer.

Meanwhile, the MixW32 software will be used for tests. A hardware TNC may also be used.

The second computer (Computer 2) runs 6 separate programs that interact together:

- Two programs (may be grouped into one single software) to control the two transceivers.
- One program to control the two rotors.
- One program to track the satellite. Orbitron or Nova. This software will give commands to the software mentioned above to correct the position of the two rotors.
- One program to manually input corrections to the transceivers' parameters or to the rotors' control. This software will also accept commands from the tracking software and the software TNC.
- One program to control the polarity selectors.

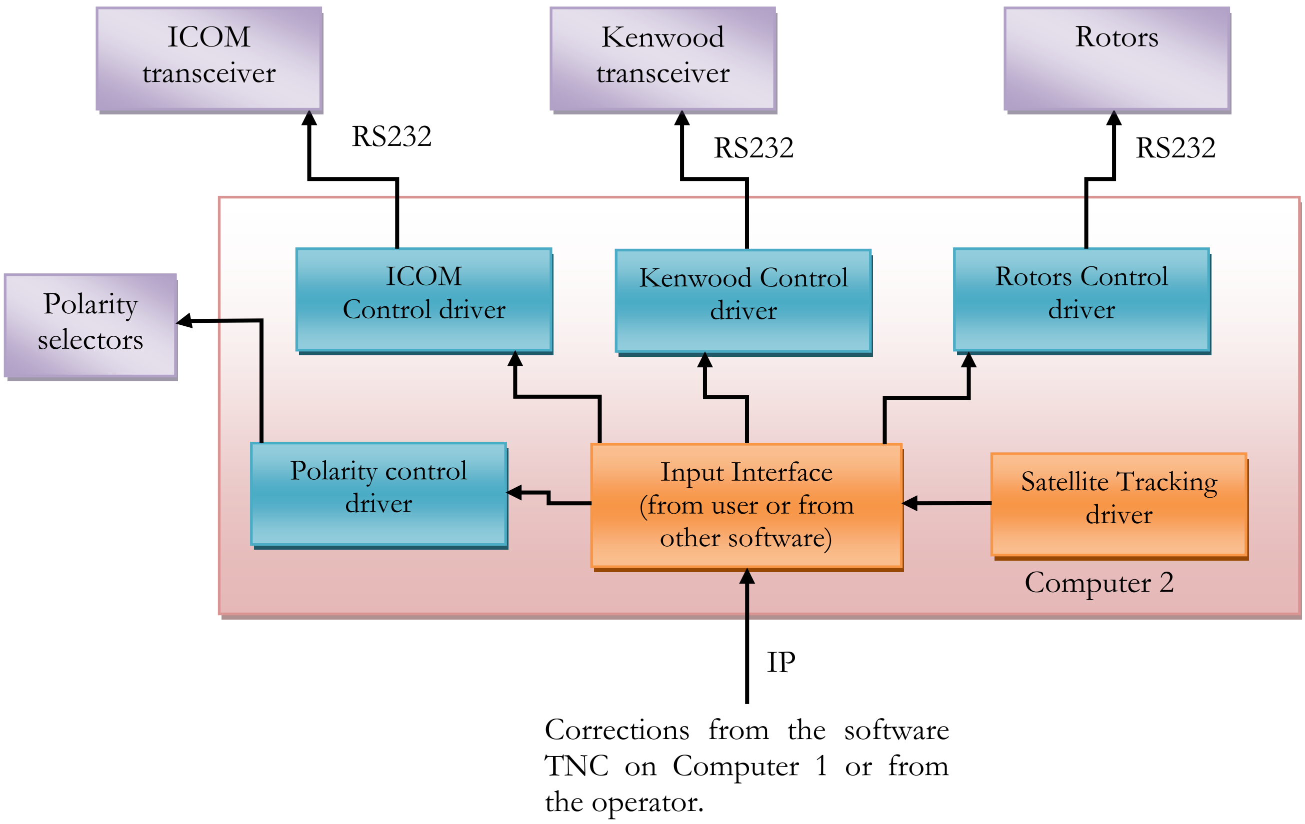


Figure 14 : Software and interfaces for Computer 2 of the EPFL Ground Station.

3.6 Description of the Ground Station in HES-SO Fribourg.

A simple diagram of the HES-SO Fribourg Ground Station is given in Figure 15.

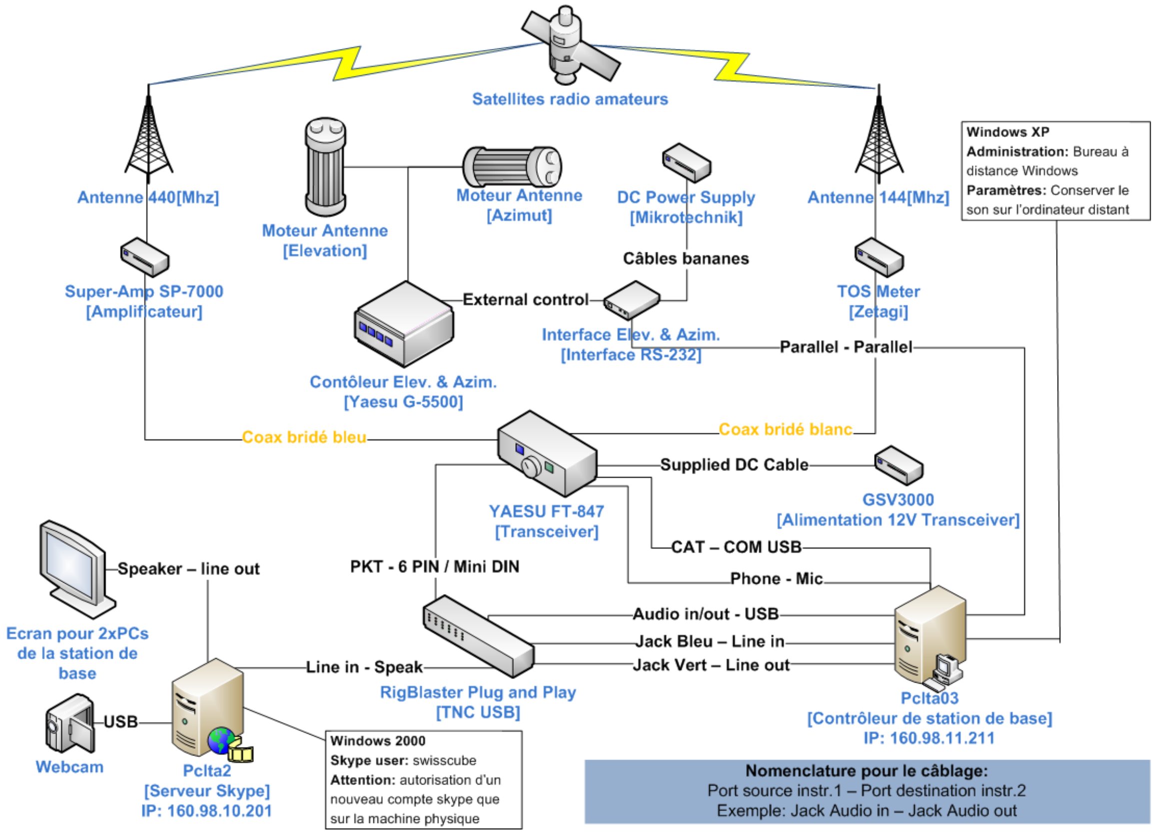


Figure 15: Block diagram of the Ground Station in HES-SO Fribourg.

The ground station in Fribourg was used a few years ago for Radio Amateur and educational purposes. The ground station at HES-SO Fribourg has been refurbished and is now fully functional. Several successful tests have been done to communicate with existing amateur radio satellites.

The data collected from reports of past semester and diploma projects written by students and from spec-sheets is summarized below.

1) Uplink

11.4 dB of antenna-gain (crossed 9-element yagi)

17 dBW transmitter power-level (Yaesu FT-847, no external power-amplifier so far)

0.066 dB/m of attenuation for 26.4 m of coaxial-cable (Huber–Suhner S_07212BD)

2) Downlink

14.5 dB of antenna gain (crossed 17-element yagi)

0.125 μV of receiver sensitivity for 10 dB S/N at SSB/CW (2.2 kHz of bandwidth) (Yaesu FT-847, no preamplifier so far)

	2m Antenna 144-146 MHz Uplink	***70cm Antenna 430-438 MHz Downlink***
	HES-FB	*HES-FB*
Transmitter power	17 dBW	
Antenna type	1 CP Yagis	1 CP Yagis
Antenna Gain	11.4 dBi	14.5 dBi
Beamwith	41 degrees	30 degrees
Elements	1*2*9	1*2*17
Feed impedance/Conn	50 Ohm / N	50 Ohm / N
Transmission line losses	2.3 dB	1.1 dB
Ground station EIRP	26.1 dBW	

Table 6: Summary of HES-SO Fribourg ground station performances.

4 RF INTERFACES BETWEEN THE SWISSCUBE AND THE GROUND STATION(S).

4.1 Assumptions

Several assumptions were made to determine the Isotropic Signal Level at the Ground Station. It was assumed that the satellite follows the following orbit:

- Circular sun synchronous orbit with 1000km radius,
- 98.61° inclination,
- argument of Perigee 180 degree,
- R.A.A.N 7.13 decrees,
- elevation angle of 5 degrees.

4.2 Main data uplink.

Main data uplink specifications	
Frequency	145 MHz
Admissible frequency deviation	4 kHz (i.e. ± 2kHz)
Data rate	1200 bits/s
Modulation	AFSK
Mark frequency (binary 1)	2200 Hz
Space frequency (binary 0)	1200 Hz
Bandwidth	14.3 KHz

Table 7: Main data uplink specifications.

4.3 Main data downlink.

Main data downlink specifications	
Frequency	437.505 MHz
Admissible frequency deviation	4 kHz (i.e. ± 2kHz)
Data rate	1200 bits/s
Modulation	FSK
Frequency deviation	500 Hz
Bandwidth B = 1.6*D+2*Δf	2.920 kHz
Isotropic Signal Level at GS EPFL	-161.8 dBW

Table 8: Main data downlink specifications.

This signal must be received as an AFSK signal using SSB.

4.4 Beacon downlink.

Beacon downlink specifications	
Frequency	437.505 MHz
Admissible frequency deviation	4 kHz (i.e. ± 2kHz)
Data rate	14 bits/s
Modulation	ASK/OOK CW
Bandwidth	22.4 Hz (1.6*data rate)
Isotropic Signal Level at GS EPFL	-171.8 dBW

Table 9: Beacon downlink specifications.

5 LINK BUDGETS FOR THE EPFL GROUND STATION.

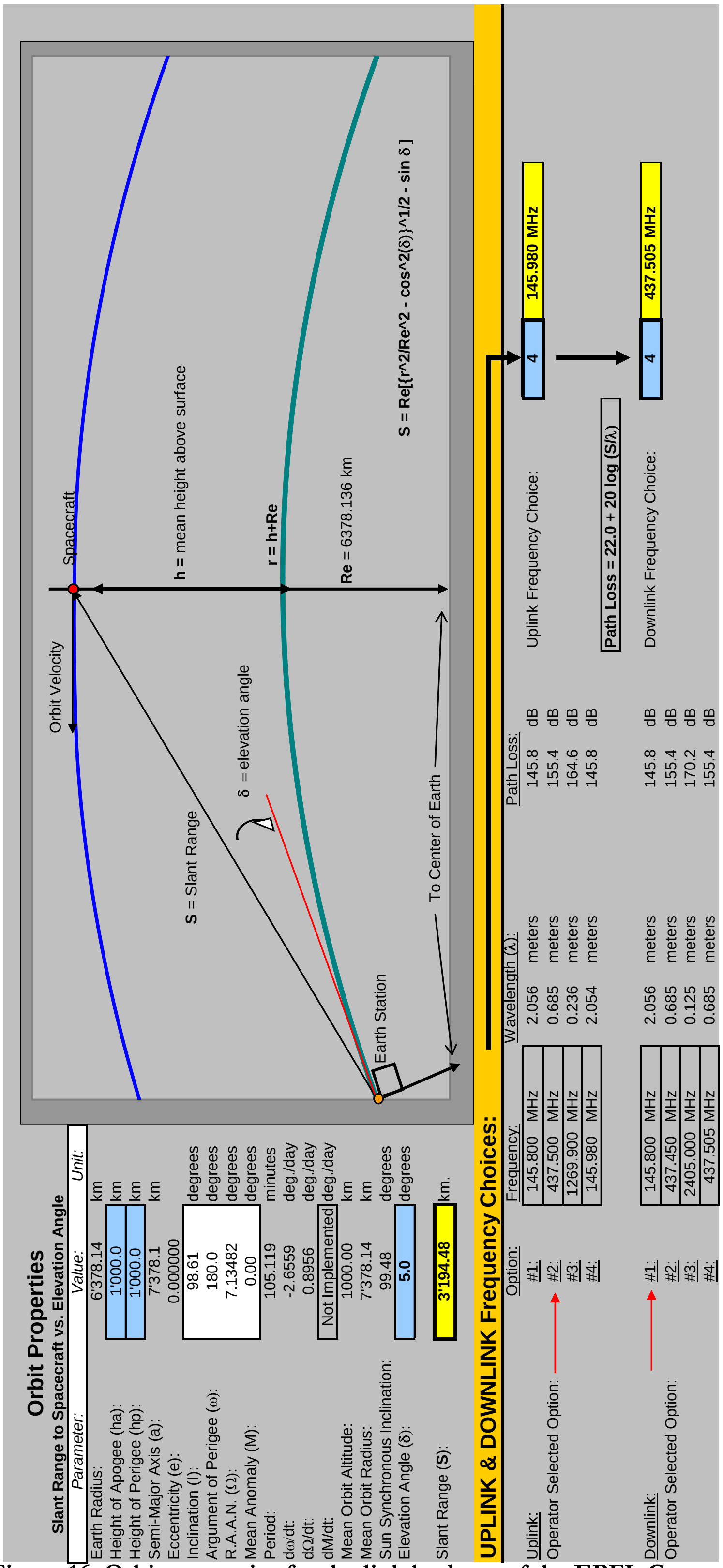


Figure 16: Orbit properties for the link budgets of the EPFL Ground Station.

5.1 Link budget for the main data uplink.

SwissCube Project Uplink Command Budget	NOTE:	
Parameter:	*Value:*	*Units:*
Ground Station:		
Ground Station Transmitter Power Output:	20.0	watts
In dBW:	13.0	dBW
In dBm:	43.0	dBm
Ground Stn. Total Transmission Line Losses:	2.7	dB
Antenna Gain:	13.0	dBi
Ground Station EIRP:	23.3	dBW
Uplink Path:		
Ground Station Antenna Pointing Loss:	0.5	dB
Gnd-to-S/C Antenna Polarization Losses:	3.0	dB
Path Loss:	145.8	dB
Atmospheric Losses:	2.1	dB
Ionospheric Losses:	0.7	dB
Rain Losses:	0.0	dB
Isotropic Signal Level at Spacecraft:	-128.9	dBW
Spacecraft (Eb/No Method):		
------- Eb/No Method -------		
Spacecraft Antenna Pointing Loss:	3.0	dB
Spacecraft Antenna Gain:	2.2	dBi
Spacecraft Total Transmission Line Losses:	3.1	dB
Spacecraft Effective Noise Temperature:	357	K
Spacecraft Figure of Merrit (G/T):	-26.4	dB/K
S/C Signal-to-Noise Power Density (S/No):	76.3	dBHz
System Desired Data Rate:	1200	bps
In dBHz:	30.8	dBHz
Command System Eb/No:	45.6	dB
Demodulation Method Seleted:	AFSK/FM	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	0.0	dB
Telemetry System Required Eb/No:	23.2	dB
Eb/No Threshold:	23.2	dB
System Link Margin:	**22.4**	dB
Spacecraft Alternative Signal Analysis Method (SNR Computation):		
---------- SNR Method -----------		
Spacecraft Antenna Pointing Loss:	3.0	dB
Spacecraft Antenna Gain:	2.2	dBi
Spacecraft Total Transmission Line Losses:	3.1	dB
Spacecraft Effective Noise Temperature:	357	K
Spacecraft Figure of Merrit (G/T):	-26.4	dB/K
Signal Power at Spacecraft LNA Input:	-132.7	dBW
Spacecraft Receiver Bandwidth:	10'000	Hz
Spacecraft Receiver Noise Power (Pn = kTB)	-163.1	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	30.3	dB
Analog or Digital System Required S/N:	15.8	dB
System Link Margin	**14.5**	dB

Figure 17: Link budget for the main data uplink for the EPFL Ground Station.

5.2 Link budget for the main data downlink.

SwissCube Project Downlink Telemetry Budget		
Parameter:	*Value:*	*Units:*
Spacecraft:		
Spacecraft Transmitter Power Output:	1.0	watts
In dBW:	0.0	dBW
In dBm:	30.0	dBm
Spacecraft Total Transmission Line Losses:	1.1	dB
Spacecraft Antenna Gain:	3.2	dBi
Spacecraft EIRP:	2.0	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	3.0	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	155.4	dB
Atmospheric Loss:	2.1	dB
Ionospheric Loss:	0.4	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-161.8	dBW
Ground Station (EbNo Method): ***------- Eb/No Method -------***		
Ground Station Antenna Pointing Loss:	3.0	dB
Ground Station Antenna Gain:	20.5	dBi
Ground Station Total Transmission Line Losses:	2.4	dB
Ground Station Effective Noise Temperature:	477	K
Ground Station Figure of Merrit (G/T):	-8.8	dB/K
G.S. Signal-to-Noise Power Density (S/No):	55.0	dBHz
System Desired Data Rate:	1200	bps
In dBHz:	30.8	dBHz
Telemetry System Eb/No for the Downlink:	24.2	dB
Demodulation Method Seleted:	Non-Coherent FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1	dB
Telemetry System Required Eb/No:	13.8	dB
Eb/No Threshold:	14.8	dB
System Link Margin:	**9.4**	dB
Ground Station Alternative Signal Analysis Method (SNR Computation): ***---------- SNR Method ------------***		
Ground Station Antenna Pointing Loss:	3.0	dB
Ground Station Antenna Gain:	20.5	dBi
Ground Station Total Transmission Line Losses:	2.4	dB
Ground Station Effective Noise Temperature:	477	K
Ground Station Figure of Merrit (G/T):	-8.8	dB/K
Signal Power at Ground Station LNA Input:	-146.8	dBW
Ground Station Receiver Bandwidth (B):	2'500	Hz
G.S. Receiver Noise Power (Pn = kTB)	-167.8	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	21.0	dB
Analog or Digital System Required S/N:	14.8	dB
System Link Margin	**6.2**	dB

Figure 18: Link budget for the main data downlink for the EPFL Ground Station.

5.3 Link budget for the beacon downlink.

SwissCube Project Beacon Downlink Telemetry Budget		
Parameter:	*Value:*	*Units:*
Spacecraft:		
Spacecraft Transmitter Power Output:	0.1	watts
In dBW:	-10.0	dBW
In dBm:	20.0	dBm
Spacecraft Total Transmission Line Losses:	1.1	dB
Spacecraft Antenna Gain:	3.2	dBi
Spacecraft EIRP:	-8.0	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	3.0	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	155.4	dB
Atmospheric Loss:	2.1	dB
Ionospheric Loss:	0.4	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-171.8	dBW
Ground Station (EbNo Method): ***------- Eb/No Method -------***		
Ground Station Antenna Pointing Loss:	3.0	dB
Ground Station Antenna Gain:	20.5	dBi
Ground Station Total Transmission Line Losses:	2.4	dB
Ground Station Effective Noise Temperature:	477	K
Ground Station Figure of Merrit (G/T):	-8.8	dB/K
G.S. Signal-to-Noise Power Density (S/No):	45.0	dBHz
System Desired Data Rate:	14	bps
In dBHz:	11.5	dBHz
Telemetry System Eb/No for the Downlink:	33.5	dB
Demodulation Method Seleted:	Morse Code	
Forward Error Correction Coding Used:	Morse	
System Allowed or Specified Bit-Error-Rate:	1.0E-02	
Demodulator Implementation Loss:	0	dB
Telemetry System Required Eb/No:	10	dB
Eb/No Threshold:	10	dB
System Link Margin:	**23.5**	dB
Ground Station Alternative Signal Analysis Method (SNR Computation): ***---------- SNR Method ------------***		
Ground Station Antenna Pointing Loss:	3.0	dB
Ground Station Antenna Gain:	20.5	dBi
Ground Station Total Transmission Line Losses:	2.4	dB
Ground Station Effective Noise Temperature:	477	K
Ground Station Figure of Merrit (G/T):	-8.8	dB/K
Signal Power at Ground Station LNA Input:	-156.8	dBW
Ground Station Receiver Bandwidth (B):	150	Hz
G.S. Receiver Noise Power (Pn = kTB)	-180.1	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	23.2	dB
Analog or Digital System Required S/N:	10.0	dB
System Link Margin	**13.2**	dB

Figure 19: Link budget for the beacon downlink at EPFL Ground Station.

6 Link Budgets for the HES-SO Fribourg Ground Station.

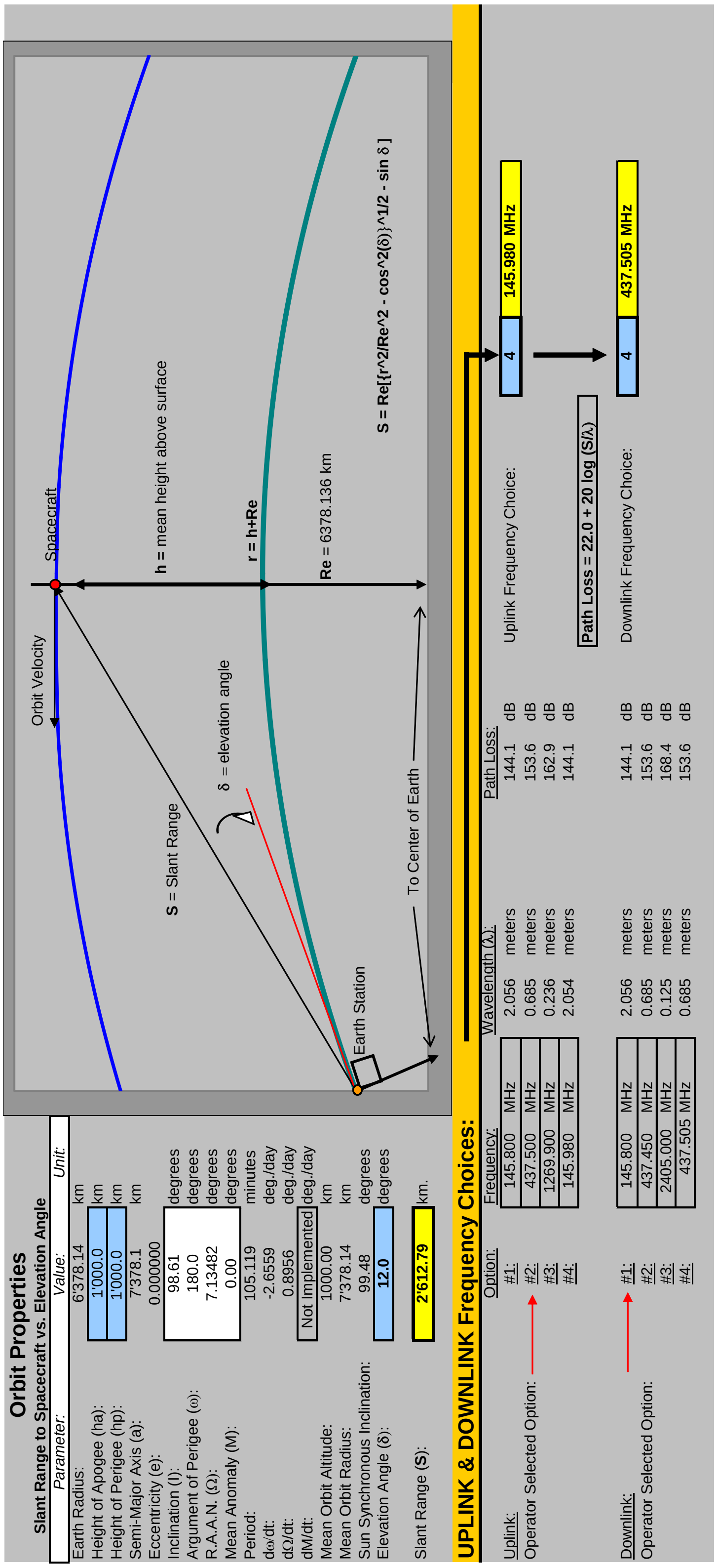


Figure 20: Orbit properties for the link budgets of the HES-SO Fribourg Ground Station.

6.1 Link budget for the main data uplink.

SwissCube Project Uplink Command Budget	NOTE:	
Parameter:	*Value:*	*Units:*
Ground Station:		
Ground Station Transmitter Power Output:	50.0	watts
In dBW:	17.0	dBW
In dBm:	47.0	dBm
Ground Stn. Total Transmission Line Losses:	2.3	dB
Antenna Gain:	11.4	dBi
Ground Station EIRP:	26.1	dBW
Uplink Path:		
Ground Station Antenna Pointing Loss:	0.2	dB
Gnd-to-S/C Antenna Polarization Losses:	3.0	dB
Path Loss:	144.1	dB
Atmospheric Losses:	1.1	dB
Ionospheric Losses:	0.7	dB
Rain Losses:	0.0	dB
Isotropic Signal Level at Spacecraft:	-122.9	dBW
Spacecraft Alternative Signal Analysis Method (SNR Computation):		
---------- SNR Method ------------		
Spacecraft Antenna Pointing Loss:	3.0	dB
Spacecraft Antenna Gain:	2.2	dBi
Spacecraft Total Transmission Line Losses:	3.1	dB
Spacecraft Effective Noise Temperature:	357	K
Spacecraft Figure of Merrit (G/T):	-26.4	dB/K
Signal Power at Spacecraft LNA Input:	-126.8	dBW
Spacecraft Receiver Bandwidth:	10'000	Hz
Spacecraft Receiver Noise Power (Pn = kTB)	-163.1	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	36.3	dB
Analog or Digital System Required S/N:	23.2	dB
System Link Margin	**13.1**	dB

Figure 21: Link budget for the main data uplink for the HES-SO Fribourg Ground Station.

6.2 Link budget for the main data downlink.

SwissCube Project Downlink Telemetry Budget		
Parameter:	*Value:*	*Units:*
Spacecraft:		
Spacecraft Transmitter Power Output:	1.0	watts
In dBW:	0.0	dBW
In dBm:	30.0	dBm
Spacecraft Total Transmission Line Losses:	1.1	dB
Spacecraft Antenna Gain:	3.2	dBi
Spacecraft EIRP:	2.0	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	3.0	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	153.6	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.4	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-159.1	dBW
Ground Station (EbNo Method):		
------- Eb/No Method -------		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	14.5	dBi
Ground Station Total Transmission Line Losses:	1.1	dB
Ground Station Effective Noise Temperature:	760	K
Ground Station Figure of Merrit (G/T):	-15.5	dB/K
G.S. Signal-to-Noise Power Density (S/No):	53.7	dBHz
System Desired Data Rate:	1200	bps
In dBHz:	30.8	dBHz
Telemetry System Eb/No for the Downlink:	22.9	dB
Demodulation Method Seleted:	Non-Coherent FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1	dB
Telemetry System Required Eb/No:	13.8	dB
Eb/No Threshold:	14.8	dB
System Link Margin:	**8.1**	dB
Ground Station Alternative Signal Analysis Method (SNR Computation):		
---------- SNR Method ------------		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	14.5	dBi
Ground Station Total Transmission Line Losses:	1.1	dB
Ground Station Effective Noise Temperature:	760	K
Ground Station Figure of Merrit (G/T):	-15.5	dB/K
Signal Power at Ground Station LNA Input:	-146.1	dBW
Ground Station Receiver Bandwidth (B):	2'500	Hz
G.S. Receiver Noise Power (Pn = kTB)	-165.8	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	19.8	dB
Analog or Digital System Required S/N:	14.8	dB
System Link Margin	**5.0**	dB

Figure 22: Link budget for the main data downlink for the HES-SO Fribourg Ground Station.

6.3 Link budget for the beacon downlink.

SwissCube Project
Beacon Downlink Telemetry Budget

Parameter:	Value:	Units:
Spacecraft:		
Spacecraft Transmitter Power Output:	0.1	watts
In dBW:	-10.0	dBW
In dBm:	20.0	dBm
Spacecraft Total Transmission Line Losses:	1.2	dB
Spacecraft Antenna Gain:	3.2	dBi
Spacecraft EIRP:	-8.0	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	3.0	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	153.6	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.4	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-169.1	dBW
Ground Station (EbNo Method):		
------- Eb/No Method -------		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	14.5	dBi
Ground Station Total Transmission Line Losses:	1.1	dB
Ground Station Effective Noise Temperature:	760	K
Ground Station Figure of Merrit (G/T):	-15.5	dB/K
G.S. Signal-to-Noise Power Density (S/No):	43.7	dBHz
System Desired Data Rate:	14	bps
In dBHz:	11.5	dBHz
Telemetry System Eb/No for the Downlink:	32.2	dB
Demodulation Method Seleted:	Morse Code	
Forward Error Correction Coding Used:	Morse	
System Allowed or Specified Bit-Error-Rate:	1.0E-02	
Demodulator Implementation Loss:	0	dB
Telemetry System Required Eb/No:	10	dB
Eb/No Threshold:	10	dB
System Link Margin:	**22.2**	dB
Ground Station Alternative Signal Analysis Method (SNR Computation):		
---------- SNR Method ------------		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	14.5	dBi
Ground Station Total Transmission Line Losses:	1.1	dB
Ground Station Effective Noise Temperature:	760	K
Ground Station Figure of Merrit (G/T):	-15.5	dB/K
Signal Power at Ground Station LNA Input:	-156.1	dBW
Ground Station Receiver Bandwidth (B):	150	Hz
G.S. Receiver Noise Power (Pn = kTB)	-178.0	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	21.9	dB
Analog or Digital System Required S/N:	10.0	dB
System Link Margin	**11.9**	dB

Figure 23: Link budget for the beacon downlink at HES-SO Ground Station.