Automated and Remote Controlled Ground Station of Masat-1, the First Hungarian Satellite

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Abstract—**In 2007, a group of students at Budapest University of Technology and Economics had decided to realize the first Hungarian satellite, called Masat-1. In 2012, Masat-1 was launched from French Guyana by VEGA maiden flight (the first really own rocket of European Space Agency – ESA) to an elliptical orbit. Nowadays, Masat-1 is still working, although the planned lifetime was only 3 months. Our aim was to develop a fully automated and remote controlled ground station (ground station network) for Masat-1 to be able to receive telemetry from, and send telecommands to the satellite without supervision.**

Keywords—Masat-1, remote controlled ground station, satellite communication, ESA, VEGA-1 maiden flight

I. INTRODUCTION

Masat-1 is a 10 cm cube (1 unit cubesat) with only 1 kg mass - Fig. 1.

Fig. 1. Masat-1 – 1 U cubesat of Hungary

The surfaces of the cube are covered by solar cells as source of energy. The DC (direct current) input power from the solar panels is up to 2 W (averaged to 1 time period – 100 min).

There are several subsystems inside the cube: EPS (electrical power system) including maximal power point trackers for solar cells, accumulator conditioner for a Li accumulator (operation in dark) and limiter switches for the overcurrent protection; OBC – two independent On-Board Computers with cold redundancy; ADCS (attitude determination and control system) with a permanent magnet and two coils (electromagnets) for stabilization during orbiting; HK (housekeeping subsystem) for data collection and handling; COM (communication system) for data transmission between the Earth (GND - ground stations) and the satellite. In this satellite category, Masat-1 uniquely has more than 300 telemetry channels on-board: voltages, currents, temperatures, 3D acceleration, velocity, etc. Author 1 has been responsible for the communication subsystem and the ground station of Masat-1 – design, realization, testing.

II. COMMUNICATION SUBSYSTEM

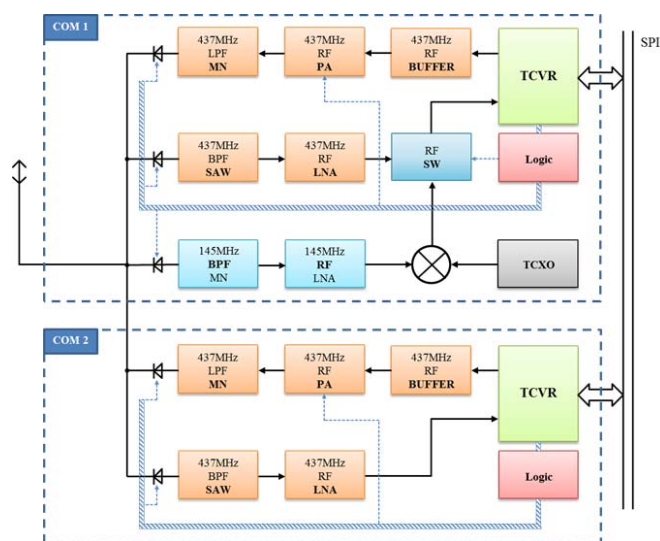The block scheme of the Masat-1 on-board communication subsystem is in Fig. 2.

Fig. 2. The communication subsystem of Masat-1: RF – radio frequency, TCVR – single chip transceiver, LPF – low pass filter, PA – power amplifier, SW – switch, SAW – surface acoustic wave filter, TCXO – temperatre compensated crystal oscillator, MN – matching network, SPI – serial pheripheral interface (digital bus with OBC) [4,5,6,7].

Because of the physical dimensions of Masat-1, the operational frequency was selected to be on the 70 cm band, so a single quarter-wavelength monopole antenna can be deployed from the cube (17 cm length steel measuring tape). The radiation pattern of which is shown in Fig. 3, [3]).
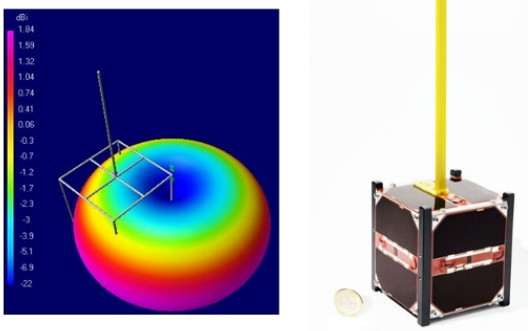
Fig. 3. Masat-1 3D on-board antenna pattern

The input DC power from the solar cells limits the RF transmit power. It is 100 or 400 mW (20 or 26 dBm switched by telecommand) with 40 % efficiency. According to the 300 / 1450 km elliptical orbit, the maximal distance between Masat-1 and the ground station is up to 4500 km at zero elevation. The free-space loss is (1) supposing LOS (line-of-sight propagation):

$$a_0 = 20 lg \frac{4\pi d}{\lambda} = 158 dB \qquad (1)$$

where d is the distance, λ is the wavelength.

If the transmit power on-board the satellite is 20 dBm with a single monopole antenna with 0 dBi antenna gain, the received power level at ground station is -138 dBm.

The antenna system at the primary ground station is shown in Fig. 4: on the left, four cross-Yagi-Uda antenna system for 70 cm band (437 MHz); on the right, two cross-Yagis for 2 m band (145 MHz) both of them with circular polarization [3].

Fig. 4. Antenna system at primary ground station of Masat-1

As shown in Fig. 2, there are two independent cold redundant transceivers on-board for transmitting telemetry data and receiving telecommands from the ground station on the 70 cm band, and there is one receiver channel on the 2 m band for the satellite-shut-down command reception. According to the coordination request of ITU and IARU, if the satellite causes any disturbances or interferences to other satellites, it has to be switched-off by telecommand on an independent radio channel.

In normal-mode, data transmission is on the 70 cm band. The Yagi antenna system gain on this band is 20 dBi. With this antenna, the received signal level is -118 dBm, which is 8 dB higher than the sensitivity of the ground station receiver (-126 dBm). So, in worst-case, the radio link is closed according to the previous simplified link budget calculation.

There are three pre-programmed data rates on-board the satellite: 625, 1250 and 5000 bit/s with 2-GFSK (Gaussian Frequency Shift Keying) [2] modulation. In case of the highest data rate, the receiver bandwidth is 7500 Hz (according to the Carson formula with 1250 Hz deviation). The noise power level estimation is the following (2):

$$N = 10 lg(kTB) = -135 dBm \qquad (2)$$

where k is the Boltzmann constant, B is the bandwidth, and T is the equivalent noise temperature at the input of the receiver chain (it is 300 K, coming from practical experiences) – so the application of higher data rates are limited by: RF power on-board, antenna gain, receiver sensitivity and receiver signal-to-noise ratio (SNR $\geq$ 11 dB) at the ground station.

The lowest data rate (625 bit/s) is necessary for those, who want to receive the satellite with antennas smaller than the primary ground station has. Lower data rate, lower bandwidth with lower antenna gain produce almost the same SNR for satellite reception. We had developed a hand-held Masat-1 receiver based on a single chip transceiver, shown in Fig. 5.
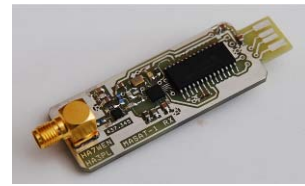

Fig. 5. Masat-1 hand-held receiver: SMA connector to e.g. 6 elements Yagi antenna, USB connector to PC (running the Ground Station Client program).

III. GROUND STATION

Our demonstrational primary ground station consists of two main parts: there is a demonstrational room for students with monitors to present satellite tracking and the functioning of Masat-1 (Fig. 6). The other part is on the roof of building E (Budapest University of Technology and Economics), where some rack-mounted hardware elements are installed, which are responsible for the remote controlled and automated satellite operation with own autonomous electrical power system (from Fig. 7).

Fig. 6. Demonstrational room of primary ground station of Masat-1

Fig. 7. Two outdoor racks near the antenna tower of primary GND contain power supplies, computers, radio tranceivers, power amplifiers, low-noise amplifiers, coaxial relays, rezonators as band-pass filter, etc.

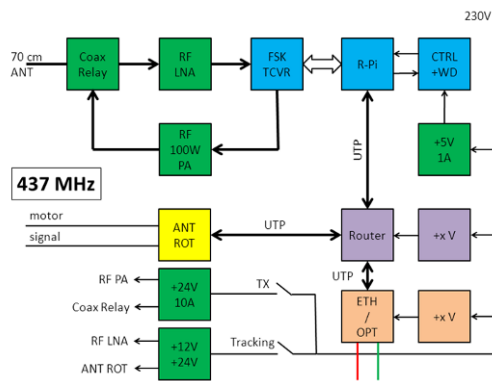The block scheme of the 70 cm band rack is in Fig. 8.

Fig. 8. The build-up of the 437 MHz rack: PA – power amplifier, TCVR – transceiver, R-Pi – Raspberry Pi as control computer, CTRL+WD – power control and watchdog unit, UTP – unshielded twisted pair as Ethernet connection, ETH/OPT – Ethernet – optical converter.

The task was to develop and realize an automated and remote controlled ground station with autonomous electrical power system (Fig. 9).

All electrical connections between the ground station and the electric networks (power and Ethernet) of the building had to be separated.

Fig. 9. Four 240 W solar panels as independent energy source

The incoming energy from the solar panels is stored in accumulators – shown in Fig. 10.

Fig. 10. Four 100 Ah 12 V accumulators with charging controller (left) and the power inverter (right) from 48 V to 230 V, mounted near the solar panels.
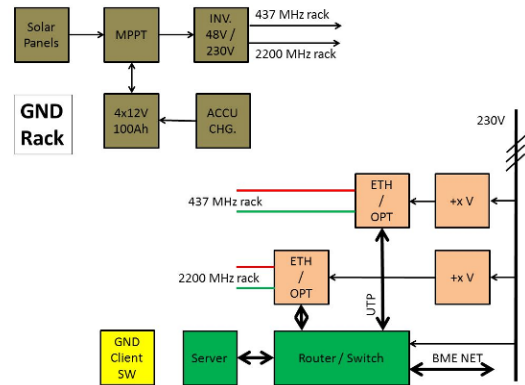

Fig. 11. Block scheme of the independent power network and the optical-isolated Ethernet communication network of GND.

Fig. 11 shows the build-up of the independent power supply system (top left); and the in-door data communication network (bottom right) connected to the other racks with optical wire because of the lightning protection.

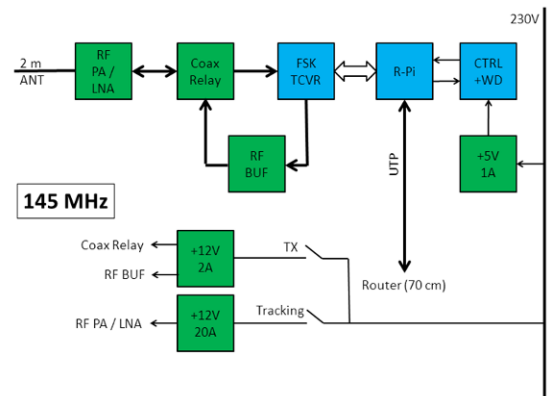For the satellite-shut-down telecommand, there is 2 m band rack – Fig. 12.

Fig. 12. Block scheme of 2 m band rack: BUF – buffer unit.

The tasks of the controller computers (Raspberry Pi – single card Linux based computer) inside the racks are [8]:

- Satellite path prediction according to the two-line-elements (TLE - Kepler data of the orbit)

- Controlling the radio transceiver: Doppler-correction. Because of the elliptical orbit, the satellite signal has approximately +/-15 kHz Doppler-shift. The receiver bandwidth is lower than 15 kHz, so the center frequency has to be tuned during path.

- Telemetry data processing: reception, demodulation, forward-error-decoding using Viterbi algorithm (the satellite-sent data is a convolutional encoded data stream for error correction with ½ code rate), data storing and Ethernet-based digital data transmission to the remote-control computer.

- Controlling the satellite according to the previous uploaded telecommands.

- Controlling the antenna rotator: the Yagi antenna system is rotated both in azimuth (0..360 degrees) and elevation (0..180 degrees) to be able to focus the main lobe of the antenna to the direction, where Masat-1 is orbiting.

IV. THE REMOTE-CONTROL PROGRAM

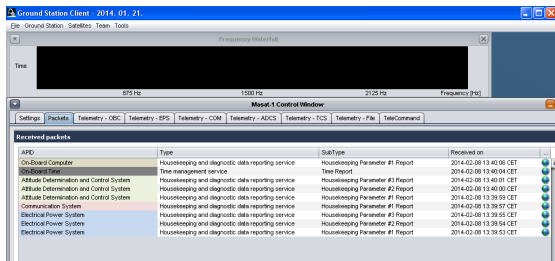The screen-shot of the remote-control program is in Fig. 13.

Fig. 13. The Ground Station Client (controller) program

Using this Java based controller program, anybody is able to receive the telemetry data from the satellite, and control the satellite with telecommands from anywhere, if there is Internet connection. If there is no human operator to track Masat-1 at a certain pass, the ground station is able to track the cubesat automatically based on the previous uploaded telecommands.

Of course, there is a possibility to track not only Masat-1 but other satellites as well. In this case, the task is only to change the two-line-elements file to another, and set the other operation frequency in the satellite prediction program.

V. FUTURE WORK

The automated and remote controlled ground station will be improved in the near future with installing a parabolic antenna (3 meters diameter) for the higher band radio transmission (1.2 GHz and 2.4 GHz band), as nowadays the number of satellites operating on these bands is increasing. The planned build-up of this microwave radio link is depicted in Fig. 14 based on software-radio equipment.
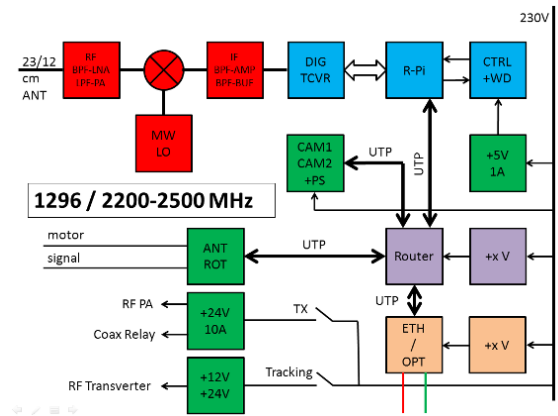

Fig. 14. The block-scheme of the planned microwave radio link: CAM – cameras observe the antennas.

VI. SUMMARY

Automated and remote controlled ground stations are developed and tested. Masat-1, the first Hungarian satellite is operated by the primary and the secondary GND (secondary is in Érd, 20 km from Budapest), which are able not only to receive telemetry, but telecommand the Masat-1 cubesat.

The amount of the downloaded data per day is four times higher with automated tracking than it was by human operated mode.

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[8] http://www.raspberrypi.org/ - Raspberry Pi Linux based card-computer.

[9] http://www.silabs.com/products/wireless/EZRadioPRO/Pages/default.aspx - digital transceiver chip: on-board the satellite and at ground station.