Radio communications systems for small satellites based on Polish experience

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Abstract—**This paper presents the current image of Polish participation in small satellites project which involved many education and research entities from Poland since 2000 with focus on communication systems design. It describes problems and achievements in such research area, as well it shows the future development paths for small satellites communication systems.**

Keywords: satellite, cubesat, communication

INTRODUCTION

Since 2000 Poland takes part in projects of building small satellites. Small satellite is an object which dimensions start from 10x10x10cm and weights from 1kg (so called picosatellite, cubesat), through 20x20x20cm and 10kg (nanosatellite) ending on 100x100x100cm and 100kg (microsatellite). This is much less than typical satellite which is as big as 5x5x10m and weights abort 10 tons. Investing in small satellites is related to the minimization of costs associated with the high cost of the launch of each kilogram, and technologies used (small satellites usually do not make use of advanced technology and expensive electronics resistant to cosmic radiation, instead apply the elements used in the industry). Another element of reducing costs is utilization of amateur radio bands for communication, which can be used (with some restrictions) for free. Additionally, for amateur band is available cheap (by the standards of space), high-quality communication equipment.

I. RADIO AMATEUR BAND LIMITATIONS.

For small satellites communication the most often used bands are: VHF (145.800-146.000MHz), UHF (435.000-438.000MHz) and S-band (2.400-2.450GHz). The communication channel can be encrypted but it cannot be used commercial purposes. There is a strong recommendation to use modulations which are popular among radioamateurs and to add services for radioamateur usage on satellites.

The most common digital mode is AFSK 1200bps with use of Packet Radio protocol (AX.25). AFSK modulation was created in order to send digital signal through audio channel of transceiver. The audio signal is modulated with two tones (typically 1200Hz and 2200Hz) according to input bit stream and then such modulated signal is fed to the audio input of FM transceiver. The disadvantages of this modulation [1] is the minimum Eb/No level at 21 dB for bit error rate (BER) less than 1E-4.

Another common modulation is FSK G3RUH 9600bps. This modulation is a form of FSK modulation, but the bit-stream is passed through a filter/scrambler that provides the possibility to adapt the signal to amateur radio transceivers. This modulation requires Eb/No≥17dB to achieve BER≤1E-4.

The next popular modulation is CW (carrier keying with Morse code). This modulation is popular due to simplicity of generation and decoding and low energetic requirements (Eb/No≥6dB) for proper decoding. The disadvantages include low throughput (typically about 8bps) and big problems with automatic reception (CW is tailored to decode from hearing by the operator - computers are doing this task poorly).

With the consecutive space missions (mainly cubesats) and technological development, mentioned modulations were being replaced with fully digital ones such as FSK (Eb/No≥13dB), GMSK (Eb/No≥9dB), BPSK (Eb/No≥9dB) or QPSK (Eb/No≥10dB) and for demodulation there were used demodulators and modems implemented as computer programs.

As previously written, the most widely used communication protocol is AX.25 Packet Radio [2]. It is an adaptation of X25 protocol used on the network such as Ethernet. The disadvantage of this protocol is that to validate the transmitted frame it uses only a 16-bit checksum (CRC), which allows to detect transmission distortion but does not allow the correction of the packet and its retransmission is required. There was proposed extension of the protocol to the FX25 [3] by adding coding allowing the repair of the package (Forward Correction) but this solution was not adopted. Sometimes it is managed to repair damaged packages by attempting to find a damaged sequentially changing all bits in the packet and re-check the checksum, but this solution is also not very popular.

II. SSETI EXPRESS

The first small satellite project in which Poland took part was SSETI Express satellite [4]. The aim of satellite was Earth observation and testing of newly designed components. The satellite was launched into orbit in 2005 and consisted of components developed for satellite SSETI ESEO (which is still being designed). For communication there was used UHF band module with G3RUH FSK AX.25 modulation and 9600bps speed (3W transmission power) working as an uplink and downlink. Additionally, the system has included the S-Band module with similar modulation but speed of 38400bps (3W transmission power), which worked as a downlink. The satellite also allowed to control it using DTMF tones. Communication modules were developed by English radioamateurs. The team from the Wrocław University of Technology developed S-band antenna for this satellite and team from Warsaw University of Technology created management and operation team. Unfortunately, due to failure of the power module satellite was operational for about 8 hours (until the battery was exhausted). It was managed to control the satellite using UHF module, but S-Band module was never utilized.

III. YES2

YES2 mission [5] has been developed by the Dutch company Delta UTEC on behalf of ESA Edu Office as an experiment on the Russian Foton satellite, which relies on deorbitation and safe landing of a small lander by means of special Dyneema wire 30km in length. During the mission, the individual components used a communication in the UHF band (satellite - lander, lander - ground station) using FSK modulation and a simple single-chip transceiver from Chipcon CC1000 series. It is not known whether the communication systems were operative in space. It is only known that it has failed to establish communication between the lander and the mobile earth station awaiting in the Kazakh steppe. Lander itself was never found. Simulations indicate that the lander had landed 5000 km from the mobile ground station, being completely beyond the reach of the station (lander was meant to turn on the transmitter in the final stage of landing). In this mission many teams from Warsaw Technical University have taken part, among others developers and operators of mobile ground station. The mobile ground station used the complex set of rotating antennas, which allowed for easy assembly and disassembly, and transportation by means of public transportation [Figure 1.].

Figure 1. Mobile ground station for YES2 project.

IV. PW-Sat

PW-Sat [9] is a mission developed by the Technical University of Warsaw, and realized in cooperation with the Space Research Centre. Its scientific objective is to test the deorbitation system by increasing aerodynamic resistance in the residual atmosphere of the satellite. To achieve this satellite will open a special tail. The second scientific objective is to examination of new flexible photovoltaic cells under conditions of space. These cells are mounted on a folding tail. In the initial phase of the project it was planned to use (appropriately adapted to the space) radioamateur handheld transceiver Yaesu VX2 controlled with ATMEL ATmega128 microcontroller. It was intended to use UHF band communications with 1200 bps AFSK modulation and AX.25 protocol. In addition, higher communication protocol had to be APRS [6]. The project was realized for many years and has evolved. In the meantime, another project was created (1stSTEP [7]) also by Warsaw University of Technology. This project was not as an alternative to the project of PW-Sat. The satellite was intended to work in the same way as PW-Sat also offering BEACON UHF CW. The difference was entirely new communication module [8] using Chipcon CC1000 modules and power amplifiers AH117 and M68710H. At the next stage of the project PW-Sat decided to combine both projects, and thus the configuration shown in the diagram below has been created [Figure 2.].

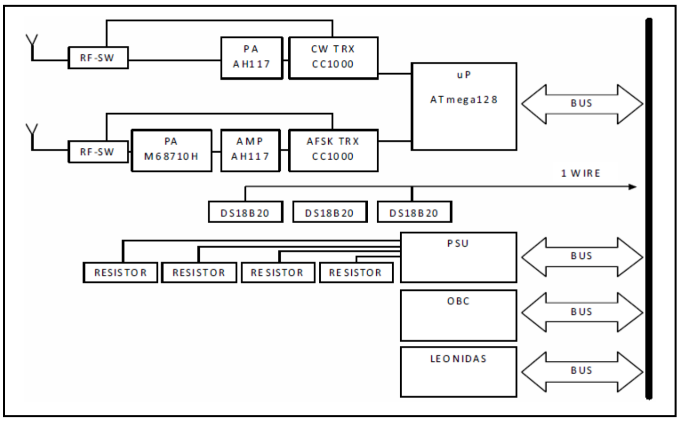

Figure 2. PW-Sat configuration diagram.

The new configuration has been implemented at the level of the engineering model of the satellite and there have never been built a more advanced model. Finally, in 2011 it was decided to conduct a review of the project and to use partially of ready-made components on the market. As the communication module ISIS_TRXUV transceiver is used [10]. In this module [Figure 3.] the receiving part operates in the UHF band with AFSK AX.25 modulation with 1200bps speed. Transmitter operates in the VHF band with BPSK AX.25 modulation with 1200bps speed. Satellite transmission power is about 150 mW. In addition, PW-Sat can transmit switch to CW mode and offers FM-DSB crossband repeater. The repeater receives FM audio signal and feeds it on BPSK modulator which retransmit it as DSB signal (Double Side Band with suppressed carrier). Antennas are created by two dipoles made from elastic metal tape which are developed from antenna containers (antennas are perpendicular to each other).

Communications module is a well designed solution. AFSK modulation used in the uplink is not very sensitive to channel pitch shift which is caused by the Doppler effect. A small modulation efficiency can be easily compensated at ground station by increasing transmission power. Downlink is implemented using BPSK modulation which effectively uses low transmission power of satellite. This modulation is very sensitive to channel pitch shift, but fine-tune in the ground station is performed by observing the received broadband spectrum. In addition, ground station stores the received broadband signal so that subsequent demodulation is possible (with the tuning to the signal) using the techniques of SDR (Software Defined Radio).

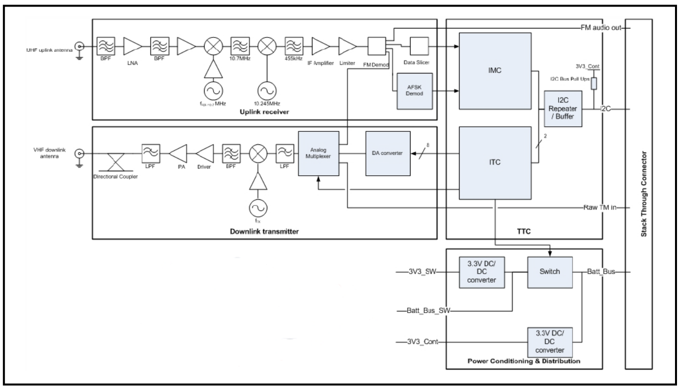

Figure 3. PW-Sat communication module - final configuration diagram.

To receive and decode telemetry of PW-Sat a ground station at the Nicolaus Copernicus Astronomical Centre of PAN is used which antenna gain is 15 dBi. The satellite is being received well in SQ5FNQ station where antenna system has gain of 5 dBi and by many radio amateurs around the world.

V. BRITE-PL

Project BRITE-PL [11] assumes launching two satellites BRITE-PL-1-Lem and BRITE-PL-2-Heweliusz. Whole BRITE constellation will consist of 6 satellites (2 Polish, 2 Austrian and 2 Canadian).

Each satellite contains an optical telescope to observe the variability of bright stars, the orientation system (sun sensors, magnetometer, startracker), stabilization (flywheels, magnetic coils) and a communication system and power system. The satellites are built by a team working in the Space Research Centre (SRC) and the Nicolaus Copernicus Astronomical Centre (CAMK). The project is financed from the funds of the Ministry of Science and Higher Education. Satellite communication module BRITE-PL-1 receives telecommands in the UHF GMSK 4kbps channel [Figure 4.] and transmits telemetry in S-Band BPSK/QPSK 8-256kbps channel (transmission power 350 mW) [Figure 5.]. Used S-band frequency is outside the amateur radio band. In addition on the second satellite BRITE-PL-2 there will be installed Beacon operating on amateur S-Band frequency. BRITE satellites use their own transmission protocol. UHF and S-band modules are produced by the University of Toronto UTIAS/SFL and are evolution of solutions which are used in satellites such as MOST [12]. BEACON is being developed by a team of CBK and CAMK.

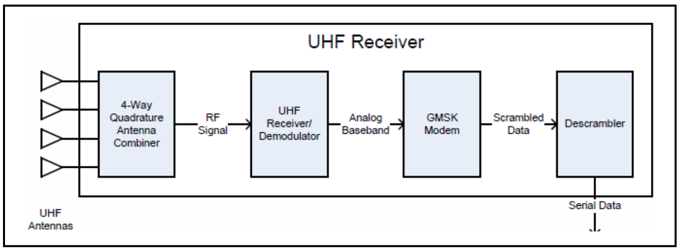

Figure 4. BRITE-PL receiver.

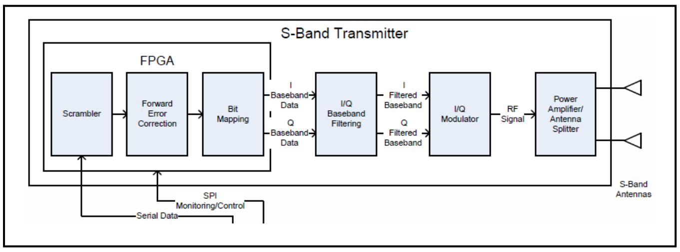

Figure 5. BRITE-PL transmiter.

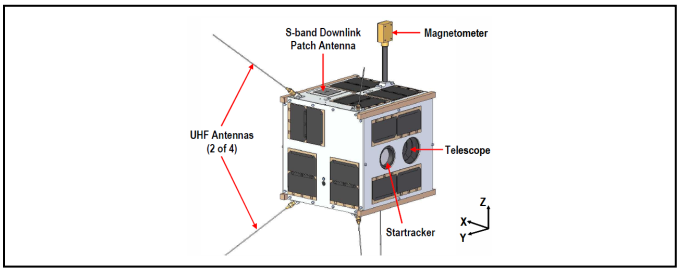

Figure 6. BRITE-PL antenna configuration.

Satellites are using for reception a system of four monopoles which are connected with the signal combiner located in the receiver module [Figure 6.]. For transmission the system uses two patch antennas located on opposite sides of the satellite. BEACON will be connected to monopole antenna, but its location has not yet been determined. Antenna systems are designed in such way to provide satellite communications regardless of its orientation.

For purposes of communication with BRITE satellites a Ground Station and Mission Control Center has been built at CAMK. This station consists of a three-meter parabolic antenna receiving the S-band signals and 4 cross-Yagi antennas operating as a transmitting system. Antenna structure is mounted on the rotator specially developed for the project by SPID Elektronik from Żyrardów. The signal from the receiving antenna [Figure 7.] is converted to the VHF band, and then demodulated in the Datum Systems PSM-500 satellite receiver. The demodulated digital data is sent from receiver to the TNC (Terminal Node Controller) module and then are transferred to the PC software. This software also creates telecommands which are then sent to the TNC. This module generates the GMSK signal which is then modulated by the amateur radio transceiver. Next signal is amplified sent to the antenna system.

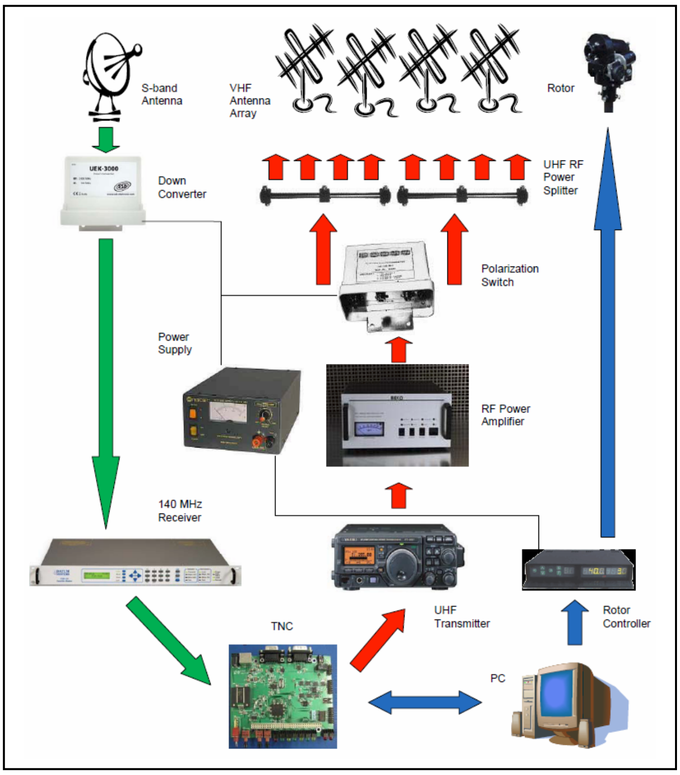

Figure 7. BRITE-PL ground station configuration.

VI. FUTURE EXPERIMENTS

The team consisting of employees SRC, CAMK, and PW is also working on developing the new satellite communications systems . The first project involves using an active feedback loop to the satellite for real-time link quality analysis and such control of the channel that by consuming link margin one can maximize bandwidth satellite link throughput.

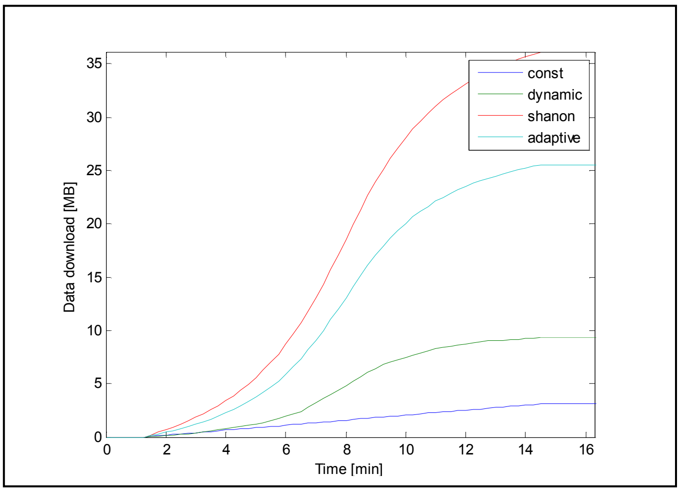

Figure 8. BRITE-PL adaptive radio channel data downlink simulation.

In Figure 8 are presented simulations of amount of received data for the satellite BRITE-PL during a single window of communication. The lowest line reflects the situation when the satellite continuously broadcast with constant speed of 32 kbps. The total amount of received data is about 2 MB. The next line is a simulation when the satellite transmission speed varies depending on the level of the received signal at the ground station (dependent on variable distance satellite - ground station). The result obtained is 10 MB. Another simulation involves a dynamic channel change of speed resulting from the actual quality of the channel. The result obtained is 25 MB. Last simulation is the limit the channel throughput (Shannon), which gives a 35 MB.

Another technique developed by the team is to use distributed ground station utilizing unused fifteen-meter radio telescope dish as a receiving antenna. Such dish is located in Centre of Astronomy of Nicolaus Copernicus University in Piwnice near Torun. The use of such dish is burdened with many problems such as slow rotation of the construction, or the inability to set the telescope in any direction. Because of these limitations reception of the signal should be carried using both a standard 3-meter dish as a ground station and a 15-meter radio telescope dish as support for low elevation angles.

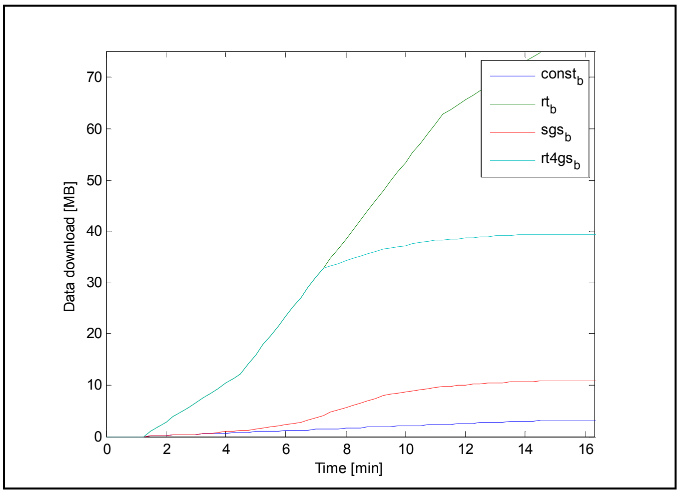

Figure 9. BRITE-PL distributed ground station data downlink simulation.

Figure 9 presents simulations of data amount received from the BRITE satellite using such a distributed system during a single window of communication. The lowest line is the reference when the satellite telemetry is received with a constant speed of 32 kbps. The resulting amount of data received is 2 MB. Variable speed transmission with use of 3-meter receiving antenna can pick up about 10 MB of data. The use of a distributed ground station allows to receive approximately 40MB of data. Utilizing a professional 15m antenna in ground station could allow to receive 75 MB of data.

VII. SUMMARY

The article presented the latest small satellite missions in which teams from the Poland took an active part. The focus is on describing the communication systems used in correlation to the limitations and restrictions on amateur radio bands as well of satellite platforms themselves. In more detail the communication systems of the mission carried out as entirely Polish satellite were described (PW-Sat, BRITE-PL). Finally the future directions of work that will be implemented in projects related to the Polish satellites. These researches shows that the Polish satellite projects are not just consumers of technologies developed by foreign research teams, but there are new proposals to develop this segment of the study.

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