Roman Wawrzaszek; Marcin Stolarski; Maciej Kalarus; Agata Wielgosz[1)]
Grzegorz Woźniak; Grzegorz Marciniszyn[2)]
Marcin Waraksa[3)]
Jerzy Żurek[4)]
Manuela Unterberger; Patrick Romano[5)]

Kraków, 27-29 czerwca 2016

[1)]Space Research Centre PAS
Bartycka 18A
00-716 Warsaw
Poland
{wawrzasz; mstolars; kalma; awielgosz}@cbk.waw.pl

[2)]Nicolaus Copernicus Astronomical Centre PAS
Bartycka 18
00-716 Warsaw
Poland
{gwozniak; gmarciniszyn}@camk.edu.pl

[3)]Gdynia Maritime University
Morska 81-87
81-225 Gdynia
Poland
m.waraksa@we.am.gdynia.pl

[4)]National Institute of Telecommunications
Szachowa 1
04-894 Warsaw
Poland
j.zurek@itl.waw.pl

[5)]Technical University of Graz
Rechbauerstr. 12
8010 Graz
Austria
{manuela.unterberger; patrick.romano}@tugraz.at

Właściwości i charakterystyka interfejsu radiowego UHF satelitów BRITE-PL

Properties and main characteristics of the UHF radio channel for communication with BRITE-PL satellites

Abstract**: Communication states a basis of utilization of a Space through scientific and technological satellite missions. Nevertheless even nowadays it is a challenging task which need advanced equipment and precise analysis of the problem. After a successful launch of three satellites Polish engineers and scientists are getting experience in that field. In the following paper authors are presenting a communication system used in a frame of the BRITE-PL project. Additionally a theoretical analysis and on-board satellite measurements of the satellite radio link parameters will be presented and compared.**

Keywords**: Low Earth Orbit satellites, radio link budget, satellite communication, BRITE-PL**

1. Introduction

Despite of already long history of artificial satellite technology development a direct operation of the spacecraft stays not very common experience. Since 2012 Poland is a part of international community of countries which have its satellites on orbit. After a launch of PW-Sat1, the satellite which was the first Polish satellite located on orbit, two more satellites named Lem (Fig.1a) and Heweliusz (Fig.1b) has been launched in 2013 and 2014 respectively. In a frame of cooperation with 3 other satellites: UniBRITE, TUGSAT-1 and BRITE Toronto, Lem and Heweliusz are a part of BRITE (BRIght Target Explorer)[1][2].

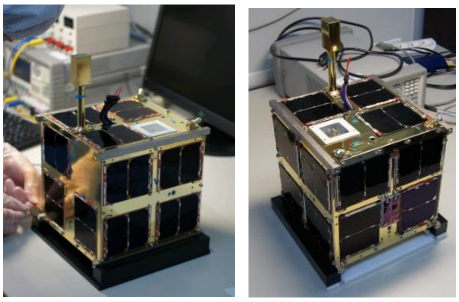

Fig. 1. BRITE-PL satellites: Lem (a) and Heweliusz (b).

The main scientific goal of those small fleet of spacecrafts is performing observations of brightest stars visible on the Earth's sky. It appears that such stars are very often out of scope of interest of large observatories which extremely sensitive equipment with, typically, large aperture telescopes are not the most suitable equipment to perform such research. Utilizing of this niche the BRITE project starts generating a significant scientific output[3][4]. It is worth to mention, that light curves of some of bright stars being carefully observed by BRITE satellites nowadays has not been analysed with comparable accuracy and completeness since 60's of last century.

Except scientific aspect of the BRITE mission, projects which were conducted in Poland and Austria gives to Polish and Austrian engineers and scientists possibility to be involved in the satellite development, integration and as last but not least managing and direct operation of spacecraft for the first time. What is more - to face in practice all problems which are often far from an academic routine. Considerable share in development of this knowledge and skills has been provided by engineers from Space Flight Laboratory at University of Toronto who are providers of satellites design and developers of some key technologies related to the project.

One of typical need related to managing and operation of satellite is establishing of radio communication link to it and to adopt to some specific aspects of this activity. If satellite is not located on the geostationary orbit than typically communication with it is limited to some periodic sessions when satellite rise above the horizon, increasing its elevation and in the same moment getting closer to ground station, than starts to decrease elevation moving farer from the ground station and sets. What is more, distance between satellite and ground station vary and for Low Earth Orbit (LEO) it can change from a few thousands to a few hundred kilometres during a single pass. Also relative velocity of the LEO satellite with respect to ground station antenna may change by up to 7.5km/s what results in not negligible Doppler shifts.

In the article, using real BRITE-PL Heweliusz data collected during a several communication sessions the authors analyse data communication uplink properties. Communication systems of both Lem and Heweliusz satellites were carefully investigated during the functional tests in anechoic chamber in facilities of the Military University of Technology in Warsaw in a frame of test campaigns before launch. The work presents the very first attempts of analysing received signal strength level data collected on board of the BRITE-PL satellites during a communication sessions with ground station localized at Nicolaus Copernicus Astronomic Centre (NCAC) to the theoretical simulations.

2. BRITE-PL: Space and ground segment

2.1. Satellites description

Lem and Heweliusz were integrated, tested and launched in a supervision of Space Research Centre PAS (SRC PAS) while operation phase is conducting by Nicolaus Copernicus Astronomical Centre PAS (NCAC) through a dedicated ground station and mission control centre at NCAC premises in Warsaw.

Satellites itself are 20cm x 20cm x 20cm cubic in shape with a solar panels on each side. Internally, the satellite consists of two trays which contains a complete satellite avionics including complete 3 axis stabilization system. Between the trays there is a payload bay which is used to accommodate scientific payload in a form of small telescope and as also a startracker sensor for fine guiding of the satellite based on images of the sky [5].

For the communication purposes satellite is equipped with four λ/4 monopoles (UHF band - uplink) and two patch antennas (S band – downlink) situated on the opposite side of the satellite. Assignment of antennas and communication system main properties are presented in Tab.1.

Tab. 1. Main properties of communication system of BRITE-PL satellites.

Component	*Parameter*	*Value*
UHF	Frequency	437.365MHz
	Bandwidth	60kHz
	modulation	GFSK
	polarization	linear
UHF antennas	Length	λ/4
	Number	4
S-Band	Frequency	2234.4MHz
	Bandwidth	500kHz
	modulation	BPSK/QPSK
	polarization	Linear
S-Band antennas	Type	Patch
	Number	2

As it is easy to conclude an idea of the satellite designers was to not favour any specific direction for communication and resulted satellites characteristics should be at the first approximation omnidirectional. Gathered in a frame of test campaign data clearly shows that these characteristics may have some directions with a higher gain [Fig. 2].

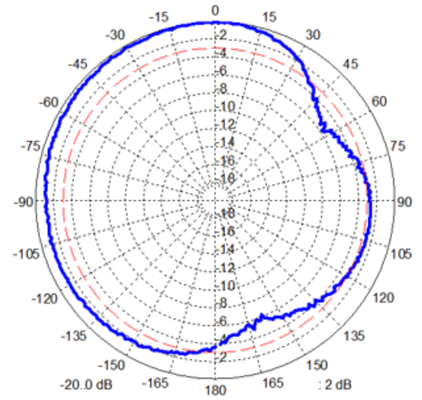

Fig. 2. Measured, resultant radio characteristics of the satellite (UHF band)

2.2. Impact of orbit characteristics on communication routines.

Satellites has been injected on Low Earth Sun Synchronous Orbits (SSO). The main parameters of LEM and Heweliusz orbits are presented in Tab.2.

Tab. 2. Properties of orbits of BRITE-PL satellites

Satellite	*Orbital param.*	*Value*
Lem	Min/max attitude	613km/893km
	Inclination	97.68°
	Period	99.53min
Heweliusz	Min/max attitude	607km/644km
	Inclination	97.713°
	Period	99.55min

By choosing high inclination SSO type orbits the satellites executes 5-8 passes per day over the horizon for observer placed at geographical latitude of Warsaw. Each pass takes 10-13min and the sum of time during which the satellite is theoretically visible from Warsaw is about 60-

70 minutes per day in total. In practice effective communication time is limited due to exclusion from operation of low elevation passes, obstructions by natural obstacles, margins due to urban area etc. As a result accumulative time of communication with satellites is about 30-40 minutes per day. It is obvious that using a high antenna gain for the communication it is needed to follow the actual position of the satellite with the main beam of the antenna during each pass of the satellite. This procedure requires implementation of a satellite tracking system which is able to predict location of the satellite and to control appropriately an antenna and rotator.

Except careful preparation and control of antenna system on the ground some improvements in communication effectiveness can be introduced by reorientation of the satellite antenna system with respect to the direction to the ground station. In a case of BRITE-PL satellites this type of procedure has been introduced. While all antennas at BRITE-PL satellites are fixed, the procedure basis on reorientation of the whole satellite before the pass over ground station to get more profitable orientation of satellite with respect to the antenna on the ground during a communication session. To implement this strategy a special mode of operation of the satellite has been used in which its orientation is defined and set with respect to so called orbital reference frame. This reference frame is attached to the satellite body centre and its axis are oriented paralelly to: (i) local Nadir-Zenit direction, (ii) direction normal to the orbital plane and (iii) direction perpendicular to (i) and (ii) what means that it approximately match to direction of the velocity vector of the satellite. Reference frames used for the purpose of analysis in a frame of this project has been presented at Fig. 3.

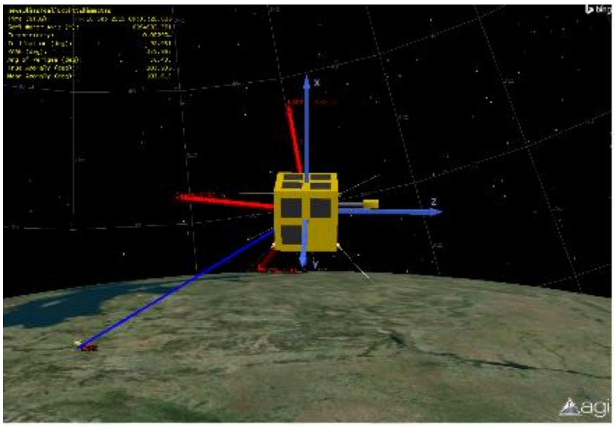

Fig. 3. Reference frames definition for the satellite localized on the orbit. GCRF - red, body frame - blue.

2.3. Ground station

Ground station facility for BRITE-PL is located at NCAC premises in Warsaw. Besides its main function (communication with BRITE satellites) station is capable to establish communication with most amateur satellites using VHF/UHF and S bands (downlink)[7]. With small adaptations it can be also possible to receive signals on higher bands up to 6GHz. What is more, the station may be used for receiving data from NOAA satellites, communication with ISS or weather balloons.

In BRITE project station holds the function of communication (uplink and downlink) and data storage centre. Communication antennas are mounted on two-axis rotator controlled automatically to track the satellite while it passes over. It is equipped with 0,1 degree precision positioning to meet the requirements of tracking satellite with S-band antenna having its 3dB beam width of 2 degree. Rotator is controlled by a tracking software which have its satellite data updated daily.

Uplink channel utilizes amateur frequency on UHF band. The reason is that coordination and formal permissions to operate on such band are much easier to obtain. Typical P_{TX} output power is 300W. However, due to severe radar interferences over Europe it is periodically required to use higher P_{TX}. Ground station is equipped with four cross-yagi antennas used for uplink communication. RHCP polarization is used to mitigate signal fading due to polarization mismatch with moving satellite. Transmitted signal is GMSK modulated with 9 kbps throughput. The uplink telecommand signal is present through the whole time of communication session and its frequency is Doppler corrected according to data from tracking software. Downlink channel, located in S band (2,2GHz) is beyond the scope of the paper.

The communication heart of the ground station is Terminal Node Controller (TNC) which is routing signals from and to satellite. TNC is an actual interface between radio hardware and digital data. TNC is connected to control computer through Ethernet network. Control computer is running operational software which is responsible for issuing telecommands, receiving telemetry and payload observational data. Payload data is parsed and stored in external database for further use.

2.4. Radio link budget calculation

Radio link budget is an accounting of all gains and losses in the transmission system. Due to the fact, that process and methodology of radio link budget calculation has been already widely described in available literature e.g.[6] authors will present only its approach to the issue, and shows results of theoretical simulation with data gathered by telemetry system of Heweliusz satellite.

The general equation of the radio link budget, utilizing UHF band, is as follow:

$$P_{RX} = P_{TX} + G_{TX} - L_I - L_{FSPL} + G_{RX} \tag{1}$$

Where:

P_{RX} – Power of received signal
P_{TX} – Power of transmitted signal
G_{TX} – Transmitting antennae gain
L_I – Transmitting line attenuation
L_{FSPL} – Free Space Path Lose
G_{RX} – Receiving antennae gain

To calculate free space path loos (L_{FSPL}) it was essential to determine distance between satellite and ground station – it was done based on time stamp and location data provided by the satellite.

$$L_{FSPL} = 10\log\left(\frac{4\pi d f_0}{c}\right)^2 \tag{2}$$

Where:

d – distance between satellite and ground station

f_0 – carrier frequency

c – speed of light

All values of the parameters are presented in Tab 3.

Tab. 3 Parameters and their values for the link budget analysis

Component	*Unit*	*Value*
P_{TX}	dB	24,7
G_{TX}	dBi	16
L_I	dB	3
L_{FSPL}	dB	variable
G_{RX}	dBi	0
d	km	748 - 3130
f_0	MHz	437,365
c	m/s	299792458

From a various set of results the most interesting cases are chosen, and presented:

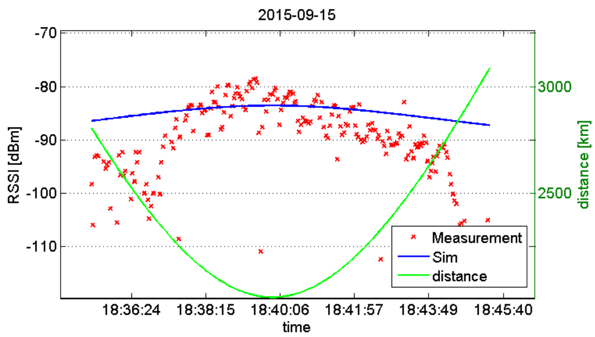

Fig. 4. Data for satellite pass with max. elevation 9,7°

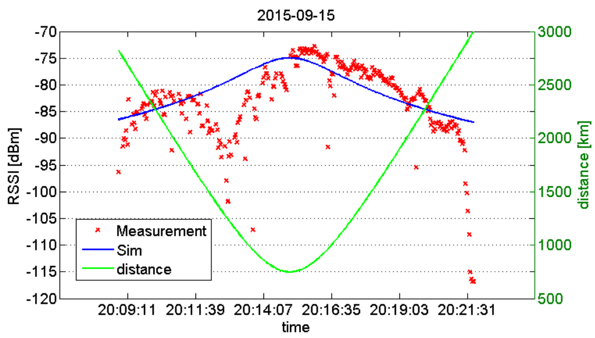

Fig. 5. Data for satellite pass with max. elevation 54,3°

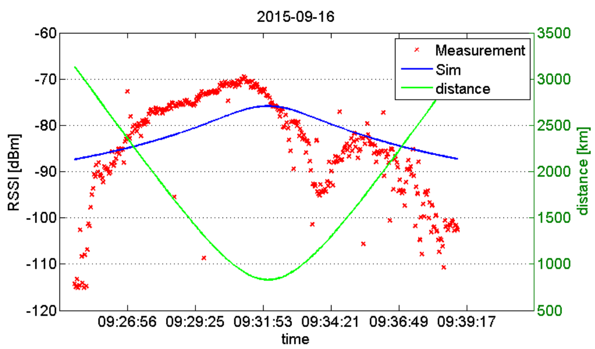

Fig. 6. Data for satellite pass with max. elevation 47,6°

Figures presents RSSI measurement points (red), distance (green) and simulated RSSI (blue) in time domain to avoid any misunderstanding of presented plots interpretation.

3. Summary

In the paper authors presented an analysis of the measured RSSI in comparison with theoretical calculations based on UHF radio uplink budget. The least significant parameters, like e.g. an atmospheric loses, ware omitted due to their marginal influence (in UHF band) on the final values.

What is worth to notice is the difference between Fig. 5 and 6, caused by an inbound satellite direction. Morning communication sessions are North – South passes, while evening are South – North.

Noticeable at both figures (Fig. 5 and 6) measured RSSI distortion is caused by a terrain obstacle - strongly influencing first Fresnel zone and causing transmitted signal level degradation.

REFERENCE

[1] Weiss, W. W.; Rucinski, S. M.; Moffat, A. F. J.; Schwarzenberg-Czerny, A.; Koudelka, O. F.; Grant, C. C.; Zee, R. E.; Kuschnig, R.; Mochnacki, St.; Matthews, J. M.; Orleanski, P.; Pamyatnykh, A.; Pigulski, A.; Alves, J.; Guedel, M.; Handler, G.; Wade, G. A.; Zwintz, K. 2014. BRITE-Constellation: Nanosatellites for Precision Photometry of Bright Stars. *Publications of the Astronomical Society of the Pacific*, Volume 126, issue 940, pp 573-585, 253–266.

[2] Schwarzenberg-Czerny, A. 2014. „BRITE constellation: the nanosatellites for asteroseismology". Contributions of the Astron. Observatory Skalnaté Pleso, vol. 43, no. 3, p. 499-499.

[3] D. Baade, Th. Rivinius, A. Pigulski, A.C. Carciofi, Ch. Martayan, A.F.J.Moffat, G.A.Wade, W.W.Weiss, J. Grunhut, G. Handler, R.Kuschnig, A. Mehner, H. Pablo, A. Popowicz, S. Rucinski, and G. Whittaker, 2016, Short-term variability and mass loss in Be stars. I. BRITE satellite photometry of eta and mu Centauri, *Astronomy and Astrophysics* (in press).

[4] A. Pigulski, H. Cugier, A. Popowicz, R. Kuschnig, A. F. J. Moffat, S. M. Rucinski, A. Schwarzenberg-Czerny, W. W. Weiss, G. Handler, O. Koudelka, J. M. Matthews, St. Mochnacki, P. Orleański, H. Pablo, T. Ramiaramanantsoa, G. A. Wade, G. Whittaker, E. Zocłońska, and K. Zwintz, 2016, Massive pulsating stars observed by BRITE-Constellation. I. The triple system β Centauri (Agena), *Astronomy and Astrophysics* (in press).

[5] Piotr Orleanski, Rafal Graczyk, Miroslaw Rataj, Aleksander Schwarzenberg-Czerny, Tomasz Zawistowski, Robert E. Zee, 2010, BRITE-PL: the first Polish scientific satellite, *Proc. SPIE* 7745, 77450A.

[6] ITU, 2002, Handbook on Satellite Communications - 3rd Edition

[7] Marcin Stolarski, Grzegorz Woźniak, Radio communications systems for small satellites based on Polish experience, Microwave Radar and Wireless Communications (MIKON), 2012 19th International Conference on, p 413 – 417