BSUSat-1 – Research/Educational Lab – One Year in Orbit

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***Abstract*— Scientific and educational nanosatellite of CubeSat 2U format launched by Belarusian State University October, 29 2018 is under use as Research/Educational lab for students, researchers and global amateur radio community.**

Keywords*— *nanosatellite, CubeSat 2U format, Research / Educational lab, Payload, Camera, Radiation Spectrometer, IR detector,

I. Introduction

The training of qualified specialists in the aerospace industry is impossible without a modern experimental base that takes into account the latest trends in the development of hardware and software for conducting space experiments or developing skills in controlling small spacecraft.

A very good alternative to creating an affordable laboratory base for training specialists in the aerospace industry can be ultra-small spacecraft, which have been actively developed over the past decade thanks to the huge achievements in the field of microelectronics, computer science, mass production and the availability of elements. space systems. In developing this class of spacecraft, commercial components are used on which new technologies in the space sector can develop more efficiently and cheaply.

The advantage of such an ultra-small spaceship is the opportunity for the student to participate in all stages of the project - from design to processing flight data over the entire life of the satellite.

The most attractive in terms of quality, price, development time is the standard of pico- and nano-satellites "CubeSat". The emergence of the CubeSat standard is associated with the need to solve one of the most important problems of training specialists in the space industry - the problems of conducting practical exercises. On the one hand, practical work on the creation and operation of real, even the simplest, satellites could significantly increase the level of training of future specialists. On the other hand, such work requires considerable time and simply does not fit into the curriculum, and the necessary financial resources for this are too large even for the budgets of the largest training centers. Therefore, the initial premises of the concept of creating CubeSat satellites proposed by Professor Stanford University (USA) R. Twiggs in 1999 were as follows [1]:

• develop a satellite in a short period (1-2 years);

• the cost of creating a satellite should be low: up to hundreds of thousands of US dollars;

• actively attract students, graduate students and young specialists at all stages of the design, development and use of the satellite.

The CubeSat standard imposes restrictions on the size and weight of the satellite: its body should be an aluminum cube with a volume of 10 x 10 x 10 cm3, the total mass of which should not exceed 1 kg. The developer chooses the characteristics of all other systems and devices at his discretion. Since the device for their integration with the P-POD (Poly Picosatellite Orbital Deployer) launch vehicle can simultaneously display up to three satellites, also called 1U (single unit), the standard provides the possibility of creating double (10 x 10 x 20 cm3 and weighing 2 kg - 2U) and triple (10 x 10 x 30 cm 5.3 kg - 3U) satellites. At present, T-POD and X-POD devices are also used to integrate CubeSat with the LV.

So, at the end of 2015, Belarusian State University begins a project to develop a university satellite with the goal of:

• Mastering complex technologies for the development, creation and operation of spacecraft.

• Perform research experiments using payload equipment.

• Providing the educational process for training specialists for the aerospace industry.

II. THE CONCEPT OF DEVELOPING A SCIENTIFIC AND EDUCATIONAL SATELLITE

The most attractive in terms of quality, price, development time is the standard of pico- and nano-satellites "CubeSat", the concept of which (R. Twiggs in 1999) was:

- short terms (1-2 years);
- cost up to hundreds of thousands of US dollars;
- actively attract students, graduate students and young professionals at all stages.
- this is a flying research and development laboratory designed to: development of integrated technologies for the development and operation of spacecraft; scientific experiments using payloads; providing the educational process for training specialists in the aerospace industry.

III. CONSTRUCTION

The block diagram in and flight model of BSUSat-1 are represented on Fig. 1, 2. Satellite design 2U CubeSat, i.e. 2 cubes include:

- 1 cube, includes a set of utility systems, telemetry, radio line, including digital D-star radio signal translators, is developed on the basis of modules supplied by the Technical University of Berlin;
- 2 cube - stabilization system, scientific and technological load including: passive-active stabilization system on ferrites, solar sensors and magnetometers; navigation receiver (NTLab) for experiments in determining the location and passage of signals in the upper atmosphere; radiation sensors (Polimaster) for studying the background radiation and cosmic rays' memory elements (Integral) for conducting experiments on the radiation resistance of microelectronic elements.

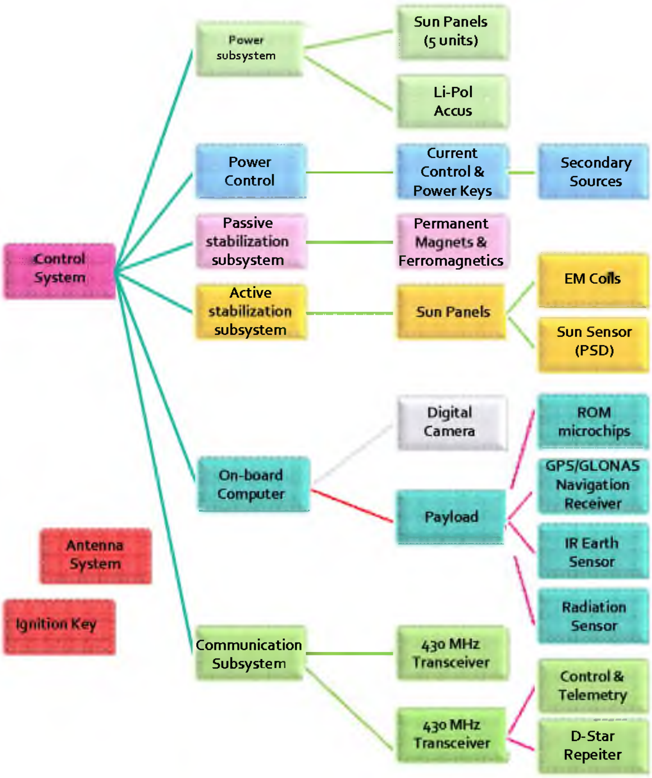

Fig. 1 Block diagram of the BSU nanosatellite

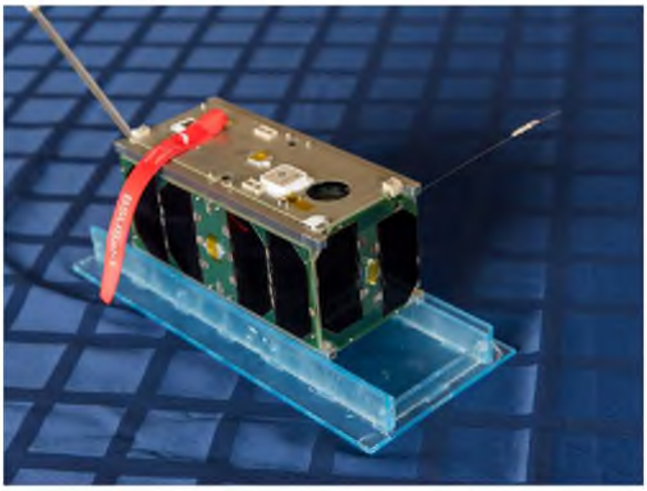

Fig. 2 Flight model of BSUSat-1

A. 2U Nanosatellite Frame

Structurally, such nanosatellites are anodized aluminum frames. The four faces are the guides along which the satellite slides at the moment of separation from the transport and launch container mounted on the launcher body.

The frame rests on two rigid bulkheads of square section, to the two opposite sides of which are attached the long sides of the satellite. End bulkheads with a square section of 100x100 mm act as a frame that prevents the satellite chassis from "twisting", and at the same time serve as the basis for placing both radio antenna elements (upper bulkhead) and the start switch (lower bulkhead). This design solution provides an easy access to the internal components of the satellite during debugging and ease of assembly - the heaviest components (battery compartment, optical elements, block of electronic cards connected by hard connectors) are initially attached to internal and external bulkheads of the frame in a single unit, around which the side panels are assembled. Fragile solar panels are attached to the satellite's rigid structure at the last stage.

To develop a framework using the T-Flex automatic design system, a parametric model was developed that allows you to quickly prepare software for CNC machines.

B. Power supply system

The composition of this system includes: primary source of energy (solar panels); secondary source of electricity (batteries); converting devices (secondary voltage stabilizers for electronic boards); chargers and control automation unit.

The power supply system in automatic mode provides: joint operation of a multi-sectional solar battery based on three-stage photoelectric converters and rechargeable batteries (batteries) for a common load; performs the functions of voltage stabilization; controls battery charge and discharge, controls temperatures, voltages and currents at all stages of energy conversion; supports the internal satellite interface bus for issuing all the necessary telemetry to the onboard satellite control system.

C. On-board computer

As the main processor, a 32-bit processor with the ARM ST 32F427 architecture from STMicroelectronics is used (the core is Cortex-M4, ALU with floating point support, flash memory is 2 MiB, the maximum frequency). on-board computer) 168 MHz, operating temperature range - from 40 to 105 ° C).

One of the advantages of using STMicroelectronics microcontrollers is a wide range of development tools. Software for STM32 includes proprietary software manufactured by STMicroelectronics, Open Source, and commercial software.

D. Soft and hardware architecture of the radio channel

The AX.25 protocol is widely used in amateur radio communications and is therefore used to transmit data from the satellite. The main disadvantage of this protocol is the lack of error correction function. Therefore, to ensure communication between the ground control centers and the satellite, the more reliable Mobitex protocol is used, which is implemented in hardware based on the modem used. At the same time, the AX.25 protocol provides a better ratio of the transmission time of useful information to the time of a communication session, since it occupies a larger part of the packet compared to overhead information.

To ensure reliable data transfer, redundancy added during channel coding is used. Algorithms and error handling methods used: checksum (CRC), direct error correction (FEC), automatic repeat request (ARQ).

To prevent the possibility of unauthorized control of the satellite, a message verification system has been developed based on the use of message authentication codes with a hash key. Thus, authentication and data integrity are ensured simultaneously.

The satellite has 2 VHF transceivers with the following characteristics: output power 300 mW; sensitivity -115 dBm; various types of modulation; Doppler shift correction; algorithms for monitoring and correcting errors during telemetry transmission (RAW, Mobitex format); baud rate 9600 bps; D-star repeater (digital data and voice)

IV. Payload

A. Navigation Module

In the process of researching the market of specialized modules, we settled on the MNP-M6 navigation receiver manufactured by the Izhevsk Radio Plant (Russian Federation), which has already been successfully tested in space conditions.

In addition, the GLONASS / GPS GNSS navigation module “G2 - Glonasha” (hereinafter - the G2 module) developed by NTLab was installed for testing.

The composition of the product includes microcircuits: single-band receiver of GLONASS / GPS signals; microcontroller (correlator-processor); non-volatile program memory; reference frequency of the generator.

The principle of operation of the module is based on the parallel reception and processing through 24 measuring channels of the GNSS GLONASS navigation satellite signals (ST code in the L1 band) and GPS (C / A code at the L1 frequency).

B. Stabilization and Orientation Control Subsystem: Sensors and Actuators

The subsystem of stabilization and orientation of the nanosatellite is intended for: pay off the initial angular velocity obtained after separation from the transport and launch container and the launch vehicle; for the orientation of the nanosatellite in the orbital coordinate system; provide triaxial orientation of the payload (lens, antenna) with a given accuracy; determination of the orientation relative to the Sun and the Earth in normal / standby mode; determination of the geographical position in orbit.

The combined stabilization and orientation system includes: 5 channels of PWM generators for magnetic stabilization coils, 5 sun direction sensors, panel temperature sensor, IR sensor of the Earth, MEMS - sensors (gyroscope, accelerometer, magnetometer), permanent magnets and hysteresis elements.

The accuracy of the orientation and stabilization control system is at least 50. To control the orientation, nine magnetic coils are used located on mutually perpendicular sides of the satellite.

C. Photoelectronic devices and software interfaces

Among the huge variety of software interfaces for connecting video capture tools, OpenMAX IL and MMAL were chosen.

OpenMAX IL is a free cross-platform development programming interface that provides a set of tools to accelerate video streaming and work with various multimedia systems designed for use regardless of the operating system or hardware platform.

In OpenMAX IL, components are separate function blocks. Components can be sources, codecs, filters, mixers, etc. Depending on the implementation, the components can be part of hardware, software, or a combination of both. The interface abstracts the hardware and software architecture of the system. OpenMAX IL allows the user to download, manage, plug and download individual components. V4L2 is a software interface for capturing audio and video for Linux operating systems. Video4Linux integrates tightly with the Linux kernel.

MMAL (Multi-Media Abstraction Layer) is a software interface that is used to provide low-level access to the components of the VideoCore graphics accelerator, which is used in the Broadcom ARM processor family. VideoCore can be found, for example, on the Raspberry Pi debug board.

The MMAL API is based on the concept of components, ports, and buffer headers. Clients create MMAL components that provide ports for each individual elementary data stream that they support (such as audio / video). Components provide input ports for receiving data from a client and provide output ports for returning data to a client.

The disadvantage of the MMAL API is the almost complete absence of public documentation, which greatly complicates the creation of applications using this software interface.

D. Infrared detector

For calibrated temperature measurements towards the Earth, and as an additional element to control the orientation of the device, an infrared sensor - MLX90614 MELEXIS with a temperature range of 40 ... + 125 and a measurement accuracy of +/- 0.1C is installed (Fig.3).

E. *Ionizing radiation sensor and radiation tests of selected elements and assemblies*

To study ionizing radiation, the PM1403 spectrometric detector based on a CsI scintillation element (Tl from Polimaster LLC (Minsk) was included in the target equipment) (Fig.3).

The PM1403 detector is intended for: measuring the ambient equivalent dose rate of x-ray and gamma radiation (photon radiation); search for photon radiation sources; registration and accumulation of scintillation spectra of gamma radiation.

To calibrate the detector, spectra of sources were taken with it, for which the photopeak energies (^{60}Co, ^{137}Cs, ^{22}Na) are known. After the calibration, the PM1403 detector was mounted on a nanosatellite (Fig. 3) to record and accumulate the spectra of the gamma component of space radiation in order to more thoroughly study the radiation conditions in orbit.

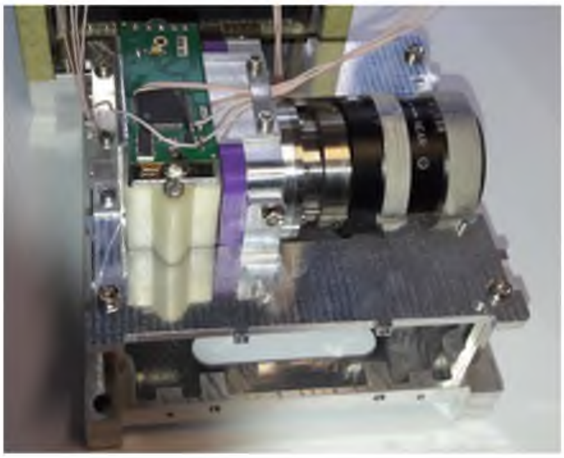

Fig. 3 PM1403 spectrometric detector mounted behind the camera and infrared sensor MLX90614 MELEXIS

V. STRUTURAL, SERVICE PLATFORM AND PAYLOAD TESTS

Some samples of engineering (a) and flight (b) models with payload are shown in Figure 4.

Test bench and the position of the control vibration sensors (1, 2, 4, 9, 10) are shown in Figure 5. The numbering corresponds to the numbers of the measuring channels of the vibration-diagnostic stand. Measuring axis of vibration sensors (1, 4). coincides with the axis of vibration (X axis), one of them is used for feedback of the vibration stand. The control sensor 9 is mounted on the internal battery compartment of the satellite. The control sensor 10 is mounted on the camera. The control sensor 2 is mounted on the upper guide of the satellite construct.

Impulse impact was tested on the bench shown in Figure 6.

Frequency response measurements is shown in Table 1. All satellite modules passed thermal vacuum tests (Fig. 7) and also performance checks and calibration (Fig 8, 9).

The test results showed that the mass-size model and the engineering model of the university nanosatellite comply with the test requirements.

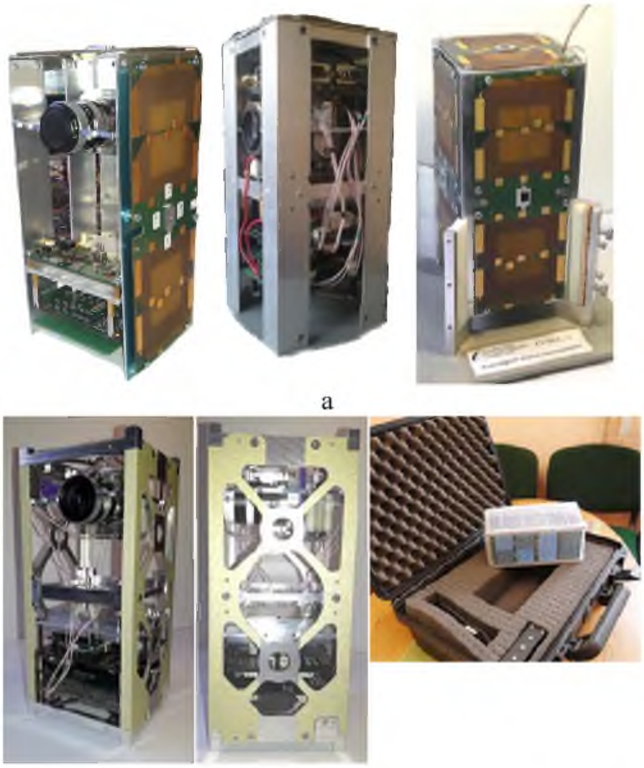

Fig. 4 Engineering (a) and flight (b) models

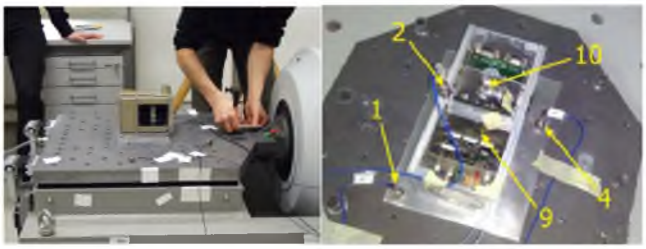

Fig. 5 Test bench and the position of the control vibration sensors

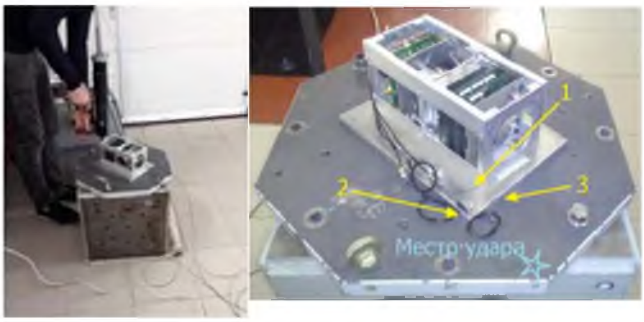

Fig. 6 Ground Control Complex

Fig. 7 Tests in a vacuum chamber

Fig. 8 Sun sensor and electromagnetic orientation/stabilization system tests

Fig. 9 Batteries testing and balancing

VI. Ground Control Complex

To perform the tasks of the operational and technical guidance on the receiving and processing of telemetric and scientific information, control the nanosatellite, training specialists in simulation mode at different time scales, develop and test hardware and software for flight control and on-board equipment and scientific instruments of the ground-based spacecraft control complex (GCC) (Fig. 10).

Fig. 10 X-axis Broadband Random Vibration bench and placement of sensors along the axes X, Y, Z

The spacecraft remote maintenance complex is based on 140/435 MHz antenna systems; transmitting and transmitting Kenwood TM-D710A and ICOM ID-1 radios operating at the Center for Aerospace Education, BSU amateur radio station, modem matching devices; control computers with software.

To control the spacecraft, conduct experiments to test equipment and effectively training specialists, it includes the following subsystems: control of the spacecraft; space planning and implementation; ballistic navigation support; receiving, processing and storage of payload data; technical support; telemetric control.

To involve radio amateurs community and partner universities for telemetry and payload information receiving and processing distributed network based on the WEB portal was developed (11).

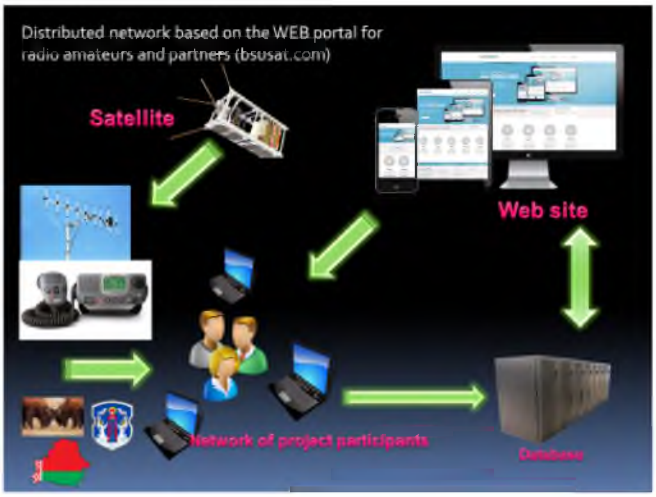

Fig. 11 Distributed network based on the WEB portal for radio amateurs and partners (bsusat.com)

The project team for the period 2015 - 2018 was involved 10 university staff and more then 10 students (Fig. 12).

Fig. 12 Project team

VII. Results

University nanosatellite BSUSat-1 was launched 29 October. The BSUSat-1 operating program was divided into stages: minimum, average and maximum.

Minimum: At the first stage, reliable two-way communication was established for the stable receipt of telemetry. The first telemetry package was received and decoded by BSU ground station after four hours after launch (Fig.13). We made sure that the satellite life support systems are working properly. With the help of the International Amateur Radio Organization, the telemetry of our device has already received and entered into the database more than 200 receiving stations around the world. More than 60,000 telemetry packages have already been received. Senior students of specialties "Aerospace radio-electronic and information systems and technologies" and "Radio Physics" process the received telemetry data. More than 10 term papers, dissertations have been completed. Results are reported at conferences of various levels.

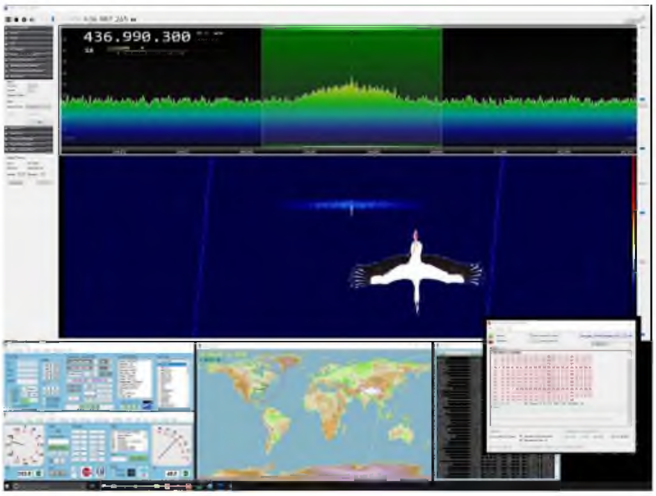

Fig. 13 The first received telemetry package

Average: Successively tested the operating modes of various systems and the target load. An orientation system has been developed to stabilize the device in space.

Maximum: Work in normal mode with a target load (camera, spectrometer, IR detector, etc.). First images have been received (Fig. 14). Experiments with the working modules of the service platform and the target load continue.

Fig. 14 Received image from camera

The complex "Nanosatellite BSU - ground-based control system" is used to master complex technologies for the development, creation and operation of spacecraft. The target equipment of the BSU nanosatellite allows us to conduct scientific experiments and provides an educational process for training specialists for the aerospace industry. During the operation of BSUSat-1, students of the specialties "Aerospace Radio-Electronic and Information Systems and Technologies" and "Radiophysics" completed 11 term papers and dissertations based on telemetry data (more than 60,000 packets were received in total). Within the framework of the International Amateur Radio Organization, BSUSat-1 telemetry is received and entered into the database by more than 200 receiving stations around the world. All information received by BSU from the nanosatellite is freely available on the Internet at bsusat.com.

VIII. CONCLUSION

BSUSat-1 is a flying educational and scientific laboratory, consisting of service systems (power supply, control, reception and transmission of data, navigation, orientation and stabilization of the device) and payload (digital camera, radiation spectrometer, infrared sensor installed for testing in outer space navigation receiver manufactured by the Belarusian company and radiation-resistant memory elements of OJSC Integral.

Along with the satellite, a full-featured ground-based complex for monitoring, receiving and processing data was developed, which made it possible to work out the indicated technological modes during the operation of the BSUSat-1 BSU satellite.

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