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VZLUSAT-1: Nanosatellite with miniature lobster eye X-ray telescope and qualification of the radiation shielding composite for space application

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A B S T R A C T

In the upcoming generation of small satellites there is a great potential for testing new sensors, processes and technologies for space and also for the creation of large in situ sensor networks. It plays a significant role in the more detailed examination, modelling and evaluation of the orbital environment. Scientific payloads based on the CubeSat technology are also feasible and the miniature X-ray telescope described in this paper may serve as an example. One of these small satellites from CubeSat family is a Czech CubeSat VZLUSAT-1, which is going to be launched during QB50 mission in 2017. This satellite has dimensions of 100 mm × 100 mm × 230 mm. The VZLUSAT-1 has three main payloads. The tested Radiation Hardened Composites Housing (RHCH) has ambitions to be used as a structural and shielding material to protect electronic devices in space or for constructions of future manned and unmanned spacecraft as well as Moon or Martian habitats. The novel miniaturized X-ray telescope with a Lobster Eye (LE) optics represents an example of CubeSat's scientific payload. The telescope has a wide field of view and such systems may be essential in detecting the X-ray sources of various physical origin. VZLUSAT-1 also carries the FIPEX payload which measures the molecular and atomic oxygen density among part of the satellite group in QB50 mission. The VZLUSAT-1 is one of the constellation in the QB50 mission that create a measuring network around the Earth and provide multipoint, in-situ measurements of the atmosphere.

1. Introduction

The main idea of QB50 mission is to demonstrate the possibility of launching CubeSats and scientific utilization. These satellites are designed as a part of a global sensor mesh to perform in-situ measurement in the largely unexplored lower thermosphere [1].

Due to the low orbit of the satellites, their orbital lifetime is limited. With respect to this fact, space agencies are not pursuing a satellite network from industrial satellites for an in situ measurement in the lower thermosphere, because creation of such a network would be very expensive. Measurements in low atmosphere can be nowadays conducted by sounding rockets, however that is a single-point measurement with a duration of only several minutes. One of the options is to use low-cost satellites i.e. CubeSats [2]. These small satellites can realize a network of satellites for in-situ measurements in the lower thermosphere and provide multipoint measurements for a longer time period [3]. Advantageous VZLUSAT-1 is a CubeSat type satellite. The idea of these small satellites is to prove a universal, cheap and lightweight platform mainly for universities and companies which want to test and verify new technologies on orbit or conduct scientific measurements [5] or create sensor networks.

Companies worldwide are manufacturing universal and compatible parts for CubeSats. Creation of a CubeSat can then be only assembling of construction kits. VZLUSAT-1 uses these prefabricated parts - On-board Computer (OBC), Electronic power system (EPS) as the most basic platform to manage power and radio board for communication with ground segment.

2. Scientific goals and motivation

The QB50 mission concept is predestined for swarm experiments. A constellation of satellites with the same experiment on-board will be created. VZLUSAT-1 is a technological satellite with three scientific experiments.

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The first is a small X-ray telescope. X-ray observation of the sky is feasible by various devices, such as sounding rockets, high altitude balloons or X-ray telescopes placed on orbit. Nowadays, the Wolter type optics is commonly used in space experiments. These types of optics represent hollow mirrors, they consist of elliptical and parabolical or hyperbolical surfaces, work on total reflection principle and have approximately 0.5 deg wide field of view. Compared to this, VZLUSAT-1 carries wide-field Lobster Eye type X-ray optics, with parallel flat mirrors in Schmidt arrangement. Because this technology has never been used in orbit, an elementary, bright source of X-ray radiation - the Sun - was chosen for test imaging and technology demonstration (which is the main mission goal). The Lobster Eye optics is expected to focus X-ray images of the Sun in the energy band of 3–60 keV [6]. In the case the mission is successful, another telescope is expected to follow, with a larger optics, higher sensitivity and better angular resolution.

Another part of the VZLUSAT-1 mission is to examine a new material, which is Radiation Hardened Carbon Composite Housing (RHCH). This material is lightweight and due to its volumetric mass density it should be able to block low energy radiation and particles like protons and neutrons. The material slows down neutrons by elastic scattering. A detailed description can be found in chapter 5.3.2. There are several other missions and experiments focused on this problematic [7,8].

The last experiment is the FIPEX. This experiment is focused on the study of residual oxygen in incriminated layer of the atmosphere. Information about this element is interesting for scientific models of the atmosphere. Proportion of oxygen to other elements in the air changes during long-time periods, in the last period it was 10–35%. The amount of oxygen has an influence on the absorbed surface radiation in units of W m^{-2} and can show a connection with global warming [9,10]. It can also have relation to corrosion of spacecraft on orbit [5].

3. Concept of operations

The satellite will be stabilized in attitude tangential to the orbit, with FIPEX instrument on the prow. This placement is important for the best efficiency of the measurement. On the prow, FIPEX sensors have ideal circumstances for gathering oxygen particles. During the flight, position will be corrected by magneto-torquer coils, so this endpoint experiment orientation is guaranteed ±10 deg. Also the whole satellite can be oriented towards the Sun or other X-ray sources for taking pictures. Observation can be started by an automatic trigger, made of UV diodes. When irradiated, it gives a signal to make a picture. The satellite will be exposed to space radiation from far space as well as from the Sun. It will also receive doses from Van Allen belts while orbiting. These total doses are going to be measured by XRB diodes and by a CdTe detector. VZLUSAT-1 will carry RHCH as well. The RHCH is going to be tested for its properties and suitability for shielding radiation and for making construction parts for next space projects like spacecraft or habitats, where the protection of human crew against radiation is needed [11].

The data will be sent twice a day to the ground operational station in Pilsen (Czech Republic) for further processing. Because of limited downlink, basic operations with data will be done on orbit. For example, a picture from the X-ray payload is compressed by binning, from which an on-earth operator can consider whether the real image contains valuable data. During another connection with the satellite, a larger image format can be downloaded on demand.

4. Spacecraft

4.1. Overview

The science mission fits to a small spacecraft, the CubeSat's form factor suits well its requirements. All used payloads and subsystems comprising the satellite were tested in Aerospace Research and Test Establishment, Prague. VZLUSAT-1 includes all necessary submodules for standalone autonomous operations and meets the requirements imposed by the QB50 mission (see Fig. 1).

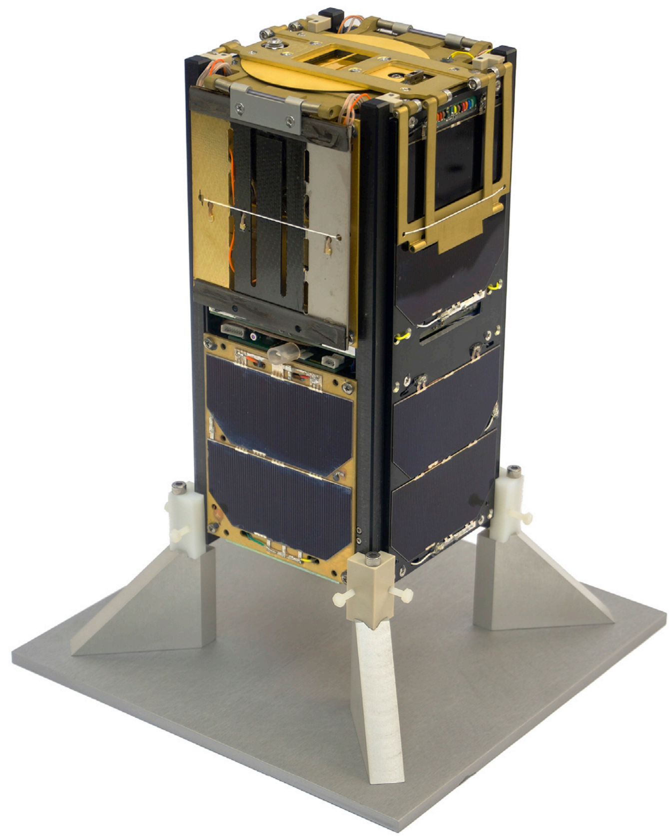

Fig. 1. Folded VZLUSAT-1 satellite placed in a stand.

One of the systems for determining the exact position of VZLUSAT-1 is an array of retroreflectors. A network of ground stations is built around the Earth, capable of detecting satellites equipped with such mirrors. This localization principle was used for example for Chinese navigation satellite Compass-M1 and American-French Jason-2 [12,13]. The system allows to monitor the distance of the satellite with millimetre accuracy. The ground system consists of an ultra-short laser pulses generator and a single-photon detector with an extremely high time resolution and stability. The use of laser pulses provides a better position precision than radio waves. Precise position of the satellite is determined from the time shift and the elevation of a laser beam.

4.2. Structure

CubeSat units can be advantageously connected together as it is the case of VZLUSAT-1. This satellite consists of two units, its launch size is $100 \times 100 \times 230\ mm^3$ and mass is 1.83 kg (see Table 1). VZLUSAT-1 has a deployable system which allows the satellite to expand its size up to three units in orbit. The number of units connected together depends on rules of the mission, financial possibilities of the project and requirements for experiments.

VZLUSAT-1 has three components, which are constructed to be situated at the end of the satellite - the LE optics, the FIPEX and antennas. For this reason, antennas were placed in the middle, on the joint between the two units, although it complicates the assembling. Deployable optics is placed on the top of the satellite, both sides are equipped with a deployable solar panel and a Health monitoring panel. The HM panel is made of a carbon fibre reinforced plastic (CFRP) material with additive manufacturing forming the RHCH. The retroreflector array is placed under the HM panel. A detailed description of the location of the individual parts is in Fig. 2.

This panel carries corner reflectors (retroreflectors) to determine the