Educational PocketQube Satellite Demonstrator

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***Abstract*—This paper presents the design of a 2P (50×50×50mm) PocketQube satellite which will be used in STEM laboratory classes. The proposed system was designed with emphasis on modularity, ease of replacement using commercial off-the-shelf components, and easy understanding of the subsystems one can find in a satellite of this type. It also encourages students to come up with their own ideas and modules. The satellite itself is made out of four main modules: On-Board Computer, Communication module, Electric Power System module, and Payload module. These four modules are encapsulated in a structure made entirely out of PCBs and together form the basis of the satellite.**

***Index Terms*—On-board Computer (OBC), Electrical Power System (EPS), Communication system (COM), PocketQube, PCB, STM32, LoRa**

I. Introduction

The PocketQube is a type of microsatellite with a base unit of 1P (50×50×50mm), and its structure is standardized by Alba Orbital, Delft University of Technology, and GAUSS Srl [1]. The aim of this paper is to describe the design of a 2P-sized PocketQube satellite for STEM educational purposes in a laboratory setup. In the classes, students will be encouraged to contribute by designing their own modules compatible with the proposed system bus pin header and satellite architecture. Through this approach, students will gain invaluable practical experience in firmware, electrical and printed circuit board (PCB) design, problem troubleshooting, functional analysis, and system engineering.

The satellite's architecture is designed according to the PocketQube standard [1] and its structure is purely made out of PCBs. To ensure easy satellite modularity, the design incorporates easily replaceable components through standard commercial off-the-shelf (COTS) parts and is partially influenced by the design of already existing 1U (100×100×100mm) CubeSat microsatellite [2] in the student's laboratory to ensure some level of compatibility between those two systems.

II. PocketQube Systems

Just like CubeSats [3], PocketQubes are composed of several subsystems that, when integrated into one unit, ensure satellite operations. Among the most commonly used subsystems in PocketQube satellites are:

- On-board Computer (OBC) – Satellite's central processing unit. The OBC takes care of mission and telemetry data handling and utilizing available interfaces (I^2C, SPI), executes commands, and operates the mission autonomously.
- Electrical Power System (EPS) – This system acquires electrical energy through photovoltaic cells and then stores it in an on-board battery/ies. It also regulates and provides that energy to other subsystems and the rest of the satellite through the system bus, ensuring the operational capacity of the entire satellite.
- Communication System (COM) – This subsystem ensures communication between space and Earth, utilizing advanced transmission technologies and an antenna for receiving commands and sending satellite data back to Earth. The parameters of the COM, such as bandwidth, frequency, or transmission speed, are typically determined by mission requirements.
- Payload – This is the main mission objective. It typically involves some scientific experiment, technological demonstrator, Earth observation, etc.
- Attitude Determination and Control System (ADCS) – This subsystem is in charge of positioning the satellite based on its relative position to the stars or the Earth which is obtained from various input sensors all across the satellite. The positioning itself is achieved using e.g. reaction wheels (one wheel per axis) or magnetorquers locked to the Earth's magnetic field. This system is not considered to be implemented in this work.

A. OBC Design

The On-Board Computer (OBC) is implemented using a separate module, as depicted in Figure 1. It is driven by the STM32F44RET microcontroller with an external 8MHz clock, which is directly soldered onto the PCB module.

The module further includes a connector for the SWD interface for firmware uploading and debugging purposes, external EEPROM memory for data logging connected via the I^2C interface, a debug UART interface, and a system bus.

The system bus is a connector linking the OBC to the rest of the satellite and is standardized across all modules. Through the system bus, the OBC is capable of acquiring

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data from the EPS or processing and transmitting data through the COM module. All other unused pins on the MCU are left unconnected. A general description of satellite software operations can be seen in Figure 2.

The OBC module mainly utilizes the SPI and I^2C interfaces (as depicted in Figure 3), with an extra I^2C_CSP interface, which is isolated from the first I^2C interface and is destined to be used in the future, specifically designated for communication over the CubeSat Space Protocol (CSP) [4].

For the proper functioning of the satellite, the OBC module also serves as the control unit for the EPS, monitoring the available battery capacity to determine whether to continue operations according to current settings or to suspend the satellite's activities and put itself into a sleep mode.

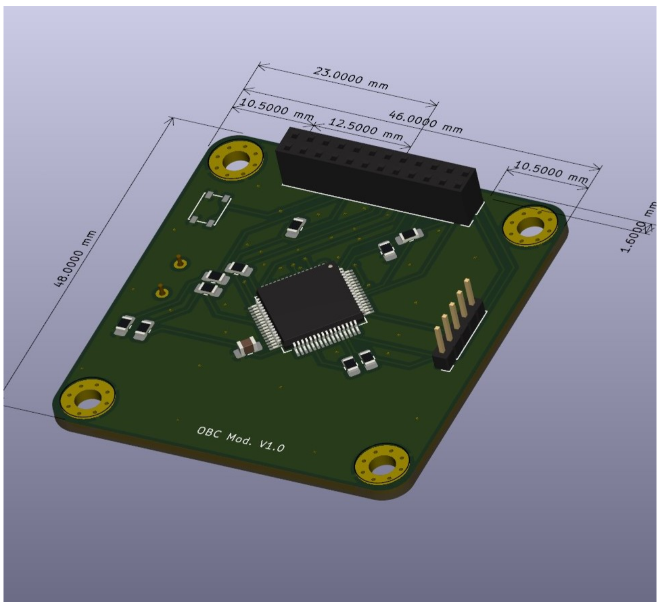

Fig. 1. 3D model of OBC.

B. COM Design

As the heart of the communication (COM) module was used the RFM98W RF Transceiver from HopeRF which has communication speed up to 300kbit/s, integrated CRC check, maximum output power of +20 dBm (100mW), and supports a wide range of modulations (FSK, GFSK, LoRa, OOK) [5]. This module operates at a selectable frequency in the range from 410 to 525MHz and uses the LoRa modulation which is employed for transmitting telemetry data from the satellite and receiving commands from the ground station. The transceiver module is directly soldered onto the PCB along with an SMA connector for an antenna connection. One of the main reasons why the transceiver is not integrated with the OBC into a single board is to ensure that the resulting system remains as modular as possible, allowing students in the future to experiment with different configurations and communication types. The entire COM module is connected via a system bus to the rest of the satellite utilizing the SPI interface for communication between the OBC and the RFM98W. Apart from the SPI interface, the reset and interrupt pins are also connected, so the OBC can effectively control the module and receive an interrupt when incoming communication for processing is received.

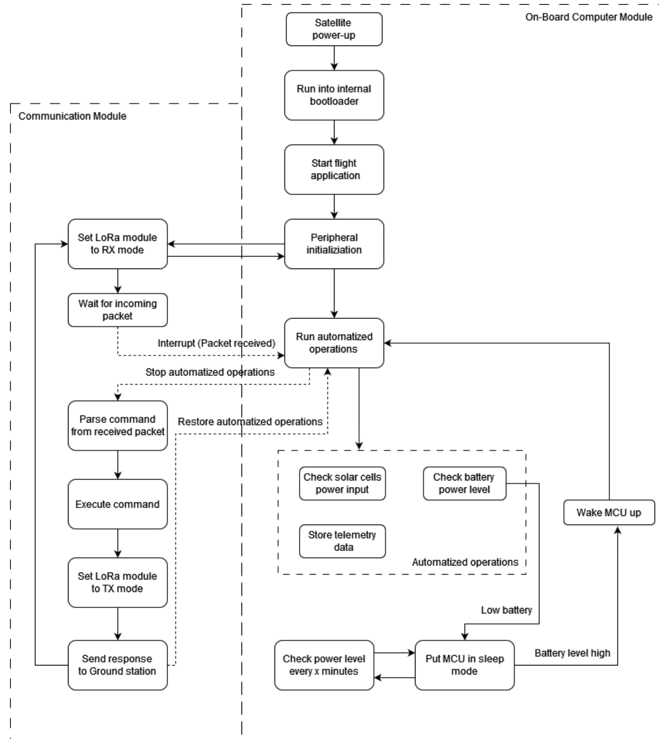

Fig. 2. Block diagram of the satellite's software.

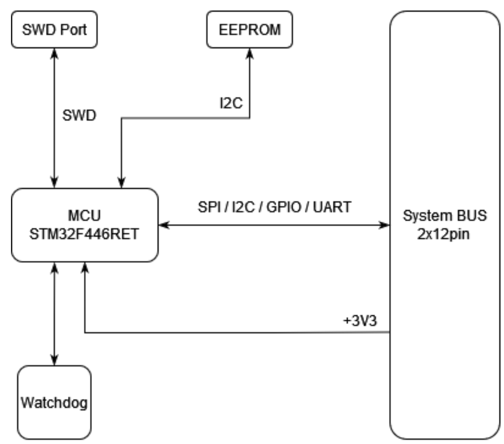

Fig. 3. Block diagram of the OBC.

C. EPS Design

The energy from 20 solar cells (45×15×2.1mm) of maximum peak power 123mW per cell and cell efficiency of 25% typically [6] is stored in one Li-Ion 18650 battery with a capacity of 3350mAh. These solar cells are connected in 10p2s configuration with Schottky diodes on each parallel set for short circuit protection and soldered directly onto the satellite's construction PCBs (see chapter III) and their input is monitored from OBC via ADC lines connected to ADC

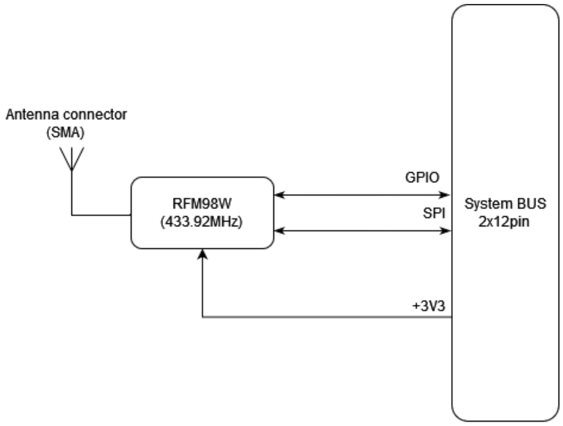

Fig. 4. Block diagram of the COM.

expander. This is to ensure that the energy keeps flowing into the system even if not all of the solar cells are illuminated. The battery itself is protected against a short circuit with 1.5A recoverable fuses and the input and output current is measured by two INA219 modules on its ends. These two modules are connected via the I^2C interface to the OBC which then regulates the power consumption itself. To turn the satellite on, a kill switch is connected to the main power rail with a P-channel MOSFET that disconnects the power rail if the switch is in the off position. The EPS main power rail provides only 3.3V of voltage power since the satellite has no needs (and space) for anything else. The block diagram of the EPS can be seen in Figure 5.

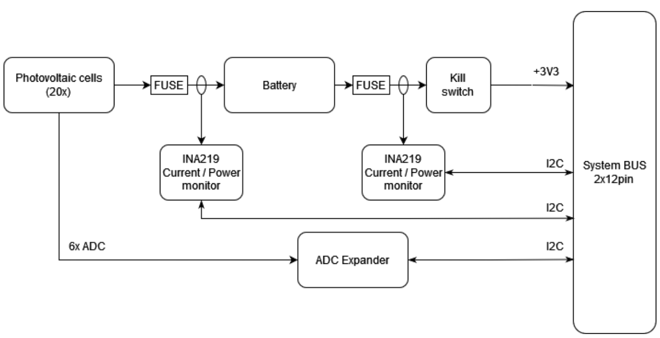

Fig. 5. Block diagram of the EPS.

III. Satellite Construction

The proposed PocketQube consists of two parts – an external 2P-sized structure (114×50×50mm without the backplate) and a so-called "sliding backplate" (58×128×1.6mm) which forms one of the sides and serves for securing the satellite into the deployer (as can be seen in Figure 6). The entire structure is implemented using six PCBs with a thickness of 1.6mm, which are assembled by soldering and screws. Solar cells that are directly connected to the EPS are also soldered on these PCBs. Thanks to this solution, more volume and weight budgets are available in the final c onstruction f or the internal modules. In the PocketQube standard, we are limited

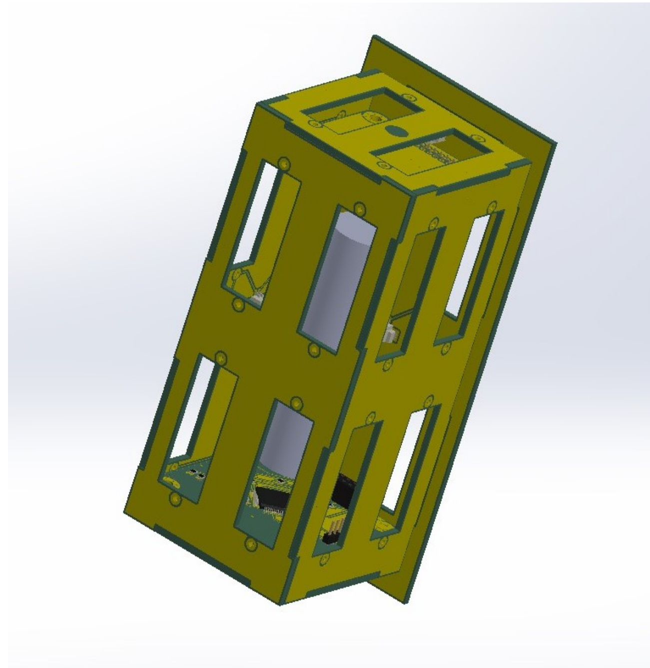

Fig. 6. 3D model of the structure with example layout of inside components.

to a maximum mass of 250g/1P, however, this fact was not taken into account, as it is only an educational model.

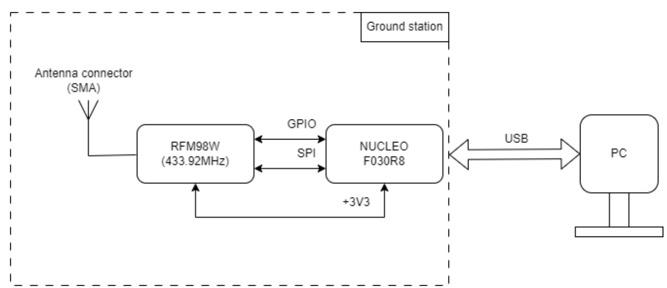

Fig. 7. Block diagram of the Ground station and PC assembly.

IV. Ground Station Design

The Ground station was designed similarly to the communication module for the satellite – utilizing a COTS RFM98W module operating at 433.92MHz frequency and an SMA connector for an antenna. The module is designed as a shield with Arduino Uno V3 connector spacing which is then connected to the STMicroelectronics Nucleo-F030R8 development board (as can be seen in Figure 7). This configuration is then connected via an USB connector to a computer, thus enabling communication with the satellite for data reception and command transmission. The ground station communicates with the satellite via a wireless, LoRa-modulated connection. The processes of data reception and command transmission are managed in an application executed on the computer to which the ground station is connected.

V. Conclusion

In this paper, we described the design of a 2P PocketQube for educational purposes with emphasis on modularity, ease of understanding, replaceability, and hands-on learning experience. The outcomes were finalized schematics, diagrams, PCB designs, and structural designs ready to be manufactured. In this configuration, the OBC is the sole computing unit that controls the COM and EPS modules although that can be changed in the future, thanks to the integrated support of the CubeSat Space Protocol.

The designed satellite is completely modifiable and serves as the basis for future student projects, laboratory tasks, or entirely new modules which makes it an ideal educational tool.

Acknowledgment

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References

[1] The PocketQube Standard [online]. [cit. 2024-03-10]. Available at: http://www.albaorbital.com/pocketqube-standard

[2] KOŠÚT, Martin. Návrh a realizace výukového CubeSatu. Brno, 2022. Dostupné také z: https://www.vut.cz/studenti/zav-prace/detail/141541. Diplomová práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav radioelektroniky.

[3] CAPPELLETTI, Chantal, Simone BATTISTINI a Benjamin K. MALPHRUS. CubeSat handbook: from mission design to operations. San Diego, CA, United States: Academic Press is an imprint of Elsevier, [2021]. ISBN 978-0-12-817884-3.

[4] libcsp. The Cubesat Space Protocol (Source code) [online]. [cit. 2024-05-04]. Available at: https://github.com/libcsp/libcsp/

[5] HopeRF: RFM98W RF Transceiver Module (Datatsheet) [online]. [cit. 2024-03-10]. Available at: https://www.hoperf.com/modules/lora/RFM98W.html

[6] SM141K04LV ANYSOLAR High Efficiency SolarMD (Datasheet) [online]. [cit. 2024-03-10]. Available at: https://ixapps.ixys.com/DataSheet/SM141K04LV.pdf