CubeSat Demonstrator for Educational Purposes

M. Košút and A. Povalač

Department of Radio Electronics

FEEC, Brno University of TEchnology, Technická 12, Brno, Czech Republic

E-mail: 203263@vut.cz, povalac@vutbr.cz

Abstract—This paper describes the design of a CubeSat with a 1U (10x10x10 cm) size, which will be used in laboratory tasks. It includes six photovoltaic cells, mounted on the top of its mechanical construction. Cells will produce electricity to power all systems and to charge the onboard NiMH batteries to make the CubeSat independent of other sources of energy. The proposed design of an onboard computer combined with a communication system and an electrical power supply system is based on off-the-shelf components. Students will make other subsystems, which will communicate with the built-in onboard computer which will handle incoming data. Modularity, possible future expandability, and easy repair in case of any failure were the key optimization parameters of the design.

Keywords—CubeSat, onboard computer, communication system, electrical power supply

1. INTRODUCTION

The goal of this paper is to describe the design of a 1U sized CubeSat suitable for demonstration purposes in the laboratory. To make CubeSat expendable and easily repairable in the future, the design must meet requirements such as using component packages that are big enough to replace them or making the systems modular and based on off-the-shelf components easily available on the market. On top of the designed subsystems, students will create their custom block, which will be connected to the system bus pin header. This concept is great for education, because students can earn experience from many areas, such as electrical and PCB design, firmware debugging or project management, in the case of working in a group. The onboard computer will save the data from all subsystems interconnected with an RS485 differential communication bus to the onboard EEPROM memory and transmit them via ISM 433 MHz band communication system to the ground station, connected to a PC for later analysis.

2. CUBESAT SYSTEMS

In general, CubeSat consists of several subsystems that are necessary to be fully functional as a unit. The main subsystems used in CubeSats are [1] [2]:

- Onboard computer (OBC) – control of all CubeSat operations and saving measured data through digital communication interfaces such as RS485, CAN, SPI, I2C, etc.
- Communication system (COM) – communication with a ground station; frequency and communication speed are determined by the requirements of the CubeSat mission.
- Electrical power supply (EPS) – the main function is to generate, store and distribute different voltages across the main system bus; used mainly photovoltaic cells are used for power generation due to size constraints, Lithium or Nickel Metal Hydride batteries are used for energy storage.
- Attitude determination and control system (ADCS) – position determination and control of the CubeSat; composed of sensors used to determine location and position change relatively to Earth or stars, position change is completed through magnetorquers which are interacting with Earth's magnetic field or heavy rotating wheels each one in one axis.
- Payload – the main purpose of the CubeSat mission; typically some experiment, science research, earth monitoring, testing new systems developed for large space missions etc.

3. EPS DESIGN

The block diagram of EPS design is shown in Figure 1. Energy from six photovoltaic cells is stored in three Nickel Metal Hydride (Eneloop) batteries connected in series. Batteries are protected against a short circuit with 1.5 A recoverable fuses. Charging and discharging currents are measured with hall-effect current sensor MCA1101-05-3, which has a linear convert characteristic.

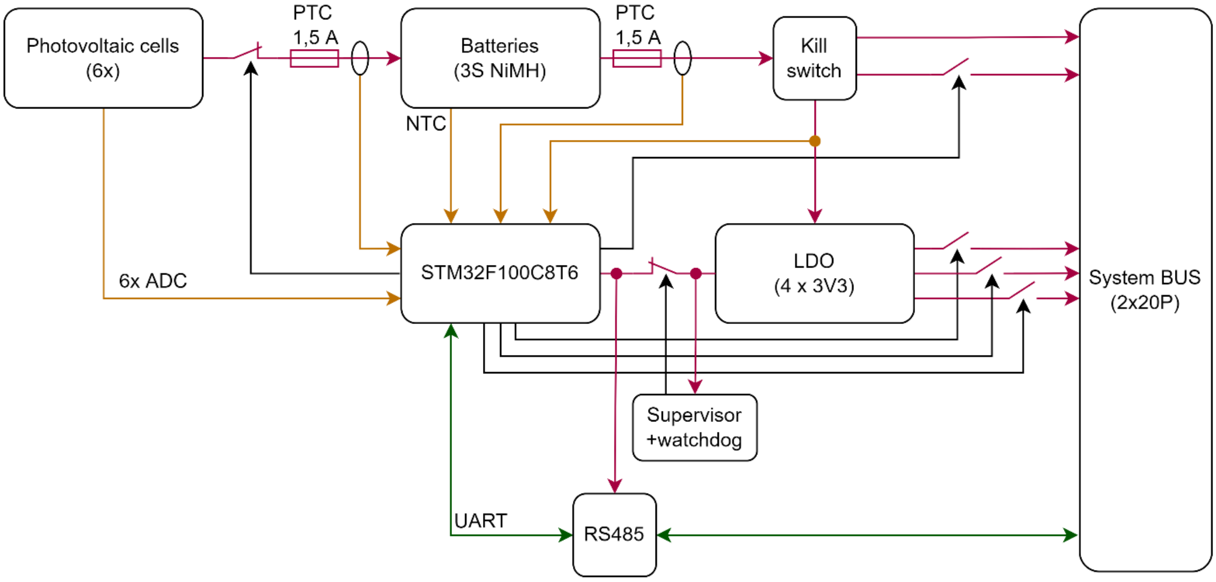

Figure 1: Block diagram of EPS

The main power rail is disconnected through a Kill switch, in case CubeSat is in a deployer, not deployed into a free space yet. It is a simple switch that disconnects all systems from the power using a P-channel MOSFET. Unregulated battery voltage is divided into four 3.3 V power rails regulated with low dropout regulators. Each power rail is proposed for one CubeSat subsystem. The power rail that powers the EPS is connected to a supervisor IC with a watchdog, in case of MCU failure it will be restarted. The main EPS microcontroller is STM32F100C8T6, which monitors all photovoltaic cell voltages, battery voltage, charging and discharging currents and temperature of the battery through 10 channels of the built-in ADC. In case of excess current drain from the battery, the MCU can disconnect any power rail connected to the system bus connector. The system bus is a simple 2x20 pin stack-through header.

The MCU will send all measured values and current states of the EPS to the OBC through the RS485 bus. **Figure 2** shows a 3D model of the designed two-layer PCB.

Figure 2: 3D model of the EPS

4. OBC+COM DESIGN

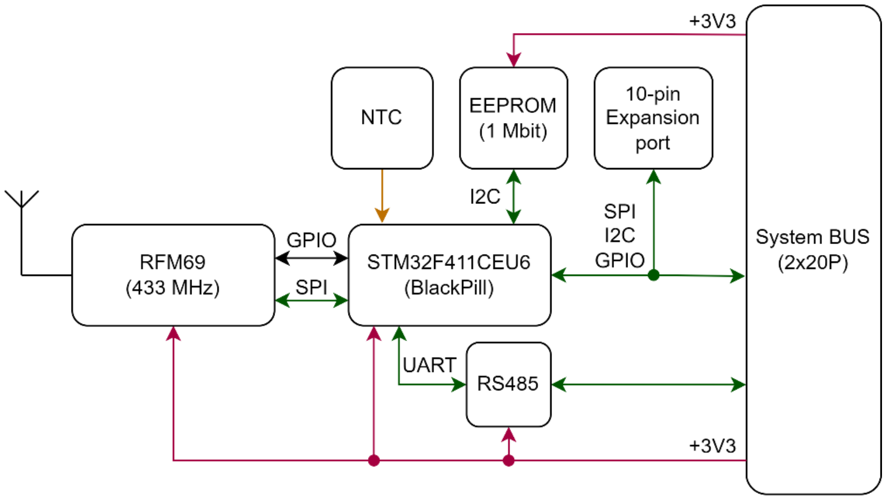

Figure 3: Block diagram of the OBC+COM

The communication system is on the PCB together with the onboard computer. The design is shown in **Figure 3**. The main microcontroller is STM32F411CEU6 soldered on the BlackPill development board, to maintain possible future scalability and repairability. RFM69HW wireless transceiver module is used for communication with a ground station. This transceiver uses the 433 MHz band, FSK modulation with maximum output power up to +20 dBm (100 mW) and communication speed up to 300 kbit/s. It has integrated packet transmission including CRC-16 checksum and AES-128 encryption [3]. The MCU is connected to RFM69 with an SPI bus. The MCU receives data from other subsystems through the RS485 bus, processes them, and saves it into a 1 Mbit EEPROM memory via I2C protocol. After receiving a special command, the MCU will read all saved data and send it wirelessly to the ground station. An NTC thermistor is used for temperature measurement. It is connected to an ADC channel of the MCU. All unused pins and communication interfaces of the BlackPill development board are connected to the system bus, as well as to the expansion port next to the MCU for possible future use. **Figure 4** shows a 3D model of the designed two-layer PCB.

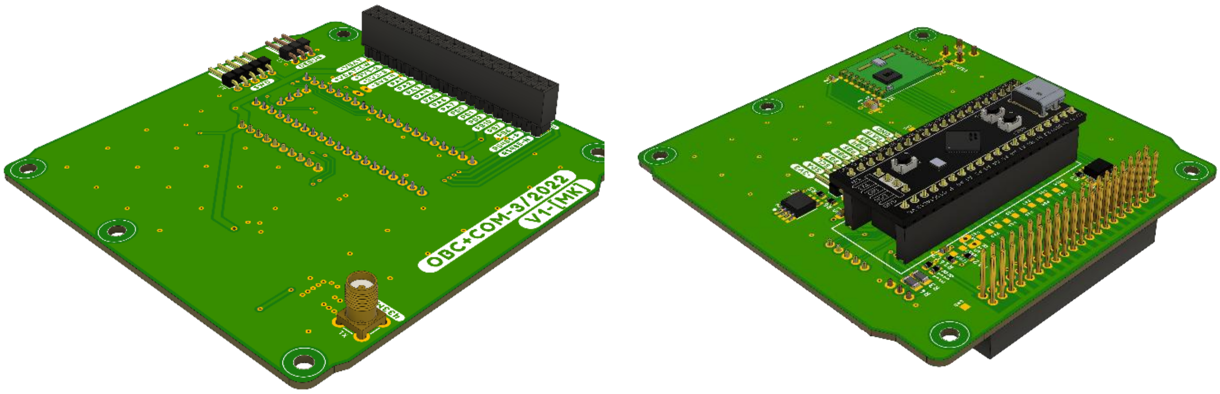

Figure 4: 3D model of OBC+COM

5. MECHANICAL CONSTRUCTION

CubeSats have a defined dimensions, to reduce the overall price of the system because standardized parts and deployers are used. They are usually made from aluminum. For demonstration purposes the goal was to design a 1U size which has defined dimensions to 10x10x10 cm. The mechanical construction is printed on a 3D printer to reduce the overall price and maintain repairability. As a base, a model from the Thingiverse portal was used [4]. Photovoltaic cells will be mounted on all six sides, to produce energy from a light source (halogen/LED light). **Figure 5** shows the final assembly of the demonstration CubeSat with built-in batteries and a basic monopole antenna mounted on the SMA connector, easily replaceable with other types such as dipole on angled SMA outside of the CubeSat. Six photovoltaic cells will be mounted outside of the frame (not shown in the picture).

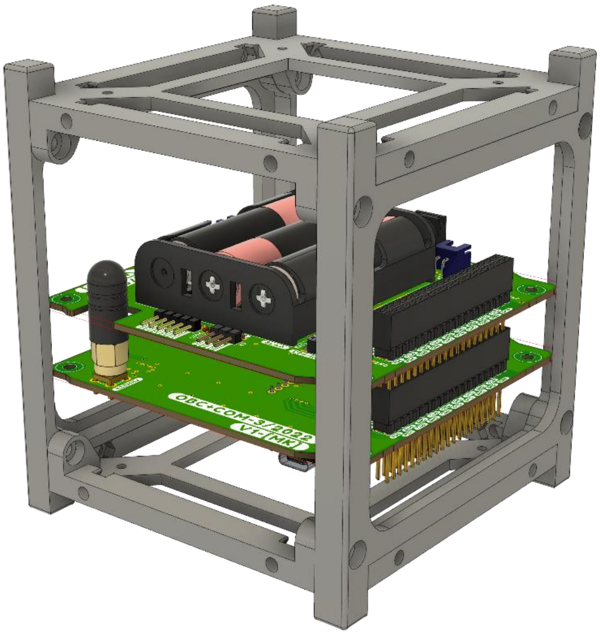

Figure 5: Final assembly of the demostration CubeSat

6. GROUND STATION DESIGN

The design of the ground station is based on the RFM69HW wireless transceiver module with an SPI bus. A 2-layer PCB with Arduino shield dimensions and pin headers is connected to the Nucleo-F030R8 development board. The wireless module has the SMA connector for an antenna. This stack is then connected to a PC to transfer received data or wirelessly transmit commands to the CubeSat.

7. CONCLUSION

This paper deals with the design of the CubeSat. The result is finalized schematic design and printed circuit boards of both the onboard computer combined with the communication system and the electrical power supply system, ready to be manufactured. The electrical power supply system has its own monitoring microcontroller to sense important voltages, currents, and temperature of batteries. In case of any failure, the microcontroller can switch off any power rail based on the excess current drain.

Designed CubeSats OBC+COM and EPS subsystems are the base for students. They will design their custom subsystem PCBs connected to the system bus. The onboard computer will handle incoming data, save, or transmit them wirelessly to the ground station. The design of separate subsystems on additional PCBs with firmware debugging makes this concept a great educational outcome for students.

ACKNOWLEDGMENT

This work was supported by the Internal Grant Agency of Brno University of Technology, project no. FEKT-S-20-6526.

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