

Space platform for student cubesat pico-satellite

Marcin Stolarski, Marcin Dobrowolski, Rafał Graczyk, Krzysztof Kurek

Institute of Radioelectronics
Warsaw University of Technology
Nowowiejska 15/19, 00-665 Warsaw, POLAND

ABSTRACT

Paper presents a satellite platform developed in Institute of Radioelectronics, Warsaw University of Technology, for present and future student pico-satellite missions. The platform consists of all systems necessary to proper operation of payload equipment that could be placed on the satellite: mechanical structure, power supply unit, communications and control system.

Keywords: satellite, cubesat, pico-satellite, satellite platform

1. INTRODUCTION

Cubesat is a small cubic satellite with dimensions 10x10x10 cm and weight below 1 kg, according to standard defined by California Polytechnic State University and Stanford University [1]. Due to relatively simplicity and small cost, building of such satellite is an ideal solution for education space projects, giving for students possibility to practical realization of all satellite subsystems. Such projects are realized by many European Universities i.e. at Warsaw University of Technology that builds PW-Sat satellite. The main goals of PW-Sat mission are testing the de-orbit technology demonstrator using unfolded structure, and data gathering by distributed ground network DGSS (Distributed Ground Station System). Payload of PW-Sat satellite will consist of three parts:

- LEONIDAS - unfolded sail mounted on the skeleton made of the shape-memory material, allowing to test the de-orbit technology demonstrator using deployable structure.
- GADGET - APRS repeater on satellite, working in 437 MHz frequency band, allowing to test the data gathering by distributed ground network. After redefinition of system architecture concept this subsystem has been incorporated to communications and command subsystem of the space platform.
- OBC – developed on-board computer for the initial concept of PW-Sat as an additional payload, allowing to test its behaviour in space. The computer is foreseen to use as an additional OBC system (OBDH-Node) for ESEO satellite.

Simple satellite platform has been developed considering its simplicity and functionality allowing to proper operation of payload planned to use in PW-Sat mission. Platform allows to power supply of other systems of satellite, communications with ground stations, using APRS transmission to send telemetry and low rate data from satellite payload. Next chapters describe architecture of the platform, and its individual system.

2. PLATFORM ARCHTECTURE

Developed space platform for cubesat satellite consists of four subsystems (Fig. 1), necessary for proper operation of satellite payload, defined by aims of mission:

1. Mechanical structure consisting of six aluminum parts for convenient integration of other satellite systems.
2. Power Supply Unit - PSU that consists of solar panels, battery, DC/DC converters and protection circuits.
3. Communications & Control Subsystem – C&CS that consists of digital control logic for performing satellite actions and radio circuits for communication with ground stations using low bit rate transmission.

4. Access Port – AP that provides connector for EGSE (Electrical Ground Support Equipment), for external ground control over satellite system. Additionally AP holds battery for supply of satellite systems when the satellite will be in shadow of the Earth.

System diagram of all system interactions is presented in Fig. 1. Green and violet lines are power lines and blue ones are data lines. There is no stabilization system foreseen in the current version of the platform. All subsystems are mounted in stack, and electrical connections between them are realized using 40 pin bus, stack-through type. Such modular construction of the satellite platform assures an easy and convenient integration of all satellite subsystems and allows to simple replacement and adding of new ones. The mechanical configuration of the platform is presented in Fig. 2. The platform allows to accommodate a payload that could have weight up to 300 g and volume up to 60% of volume of cubesat satellite.

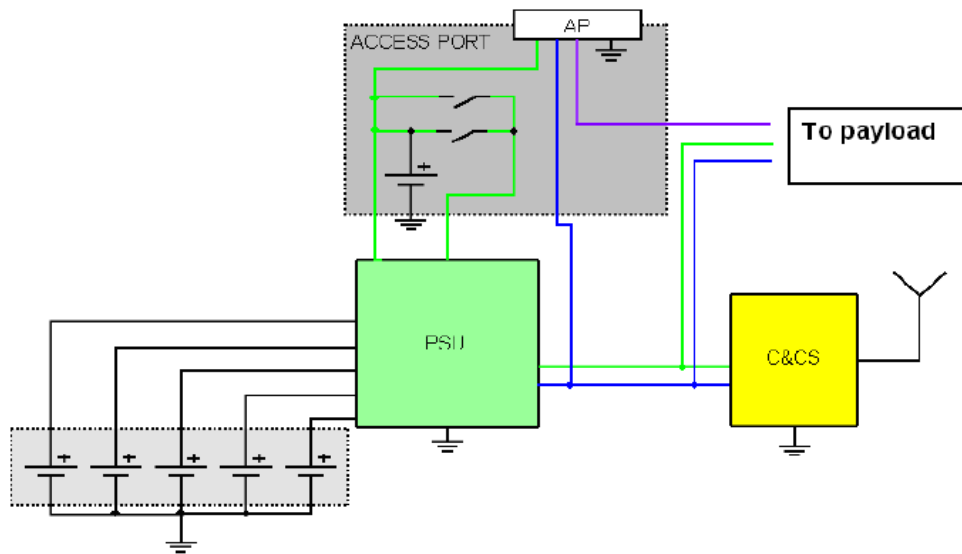


Fig. 1 Block structure of the satellite platform

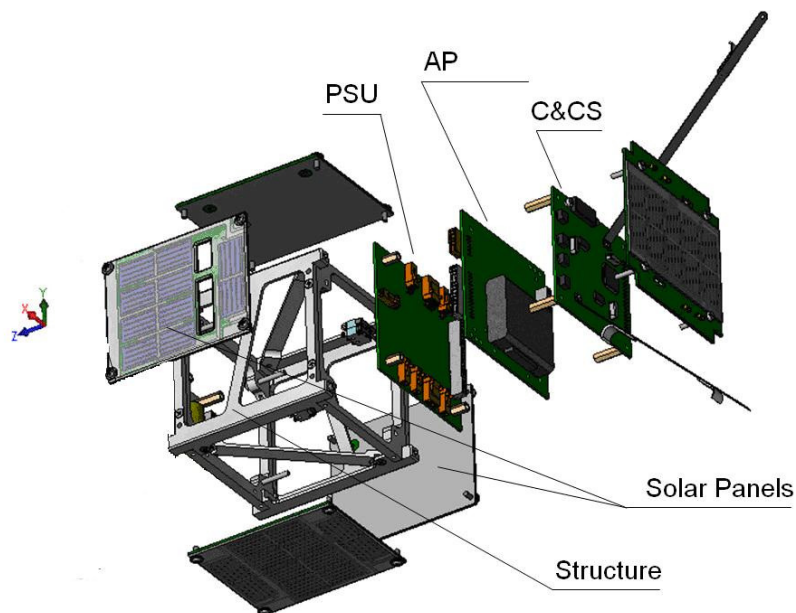


Fig. 2 Mechanical configuration of the satellite platform

3. MECHANICAL STRUCTURE OF SATELLITE

The mechanical structure is designed to fulfill cubesat standards [1] and launcher requirements. The system level functional requirements for the satellite structure are as follow: to provide housing for the payload, to provide mechanical interfaces for the subsystems, to withstand the mechanical stresses the spacecraft is exposed to during launch phase and to provide a radiation shielding for inner parts.

Taking into consideration the fact that mass of the complete satellite must be below 1 kg, structure will have to be made as light as possible, and Stanford University proposed to use either aluminum 7075-T6 or 6061-T6 for the frame.

The developed structure of the satellite is divided in two parts:

- primary structure that carries major loads, and is made from four machined aluminum 7075-T651 frames fixed together by eight M3 flat head machine steel screws (Fig. 3). To protect satellite rails from cold welding during the contact with P-POD in vacuum all aluminum parts are hard anodized.
- secondary structure containing the satellite walls is made using FR4 glass-epoxy laminate boards. Side walls are covered with solar cells and resin therefore forming solar panels (Fig. 4). Additionally digital thermometers are mounted on the walls, to gather valuable telemetry data.

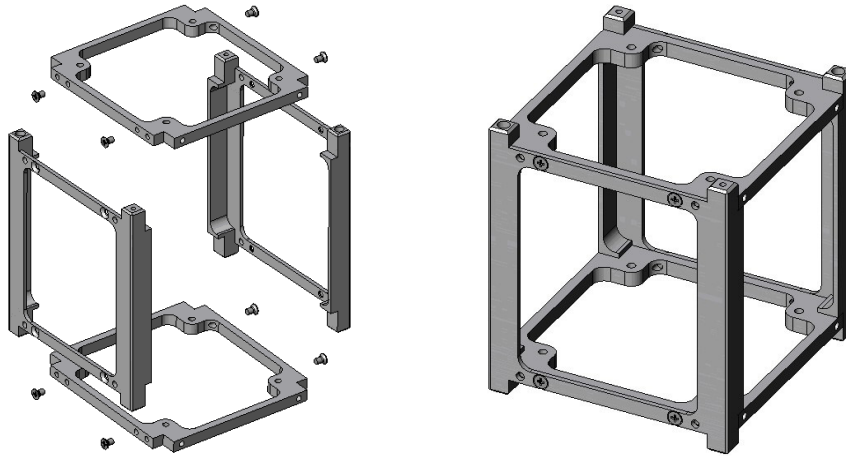


Fig. 3 CAD model of primary structure of the satellite: in parts and assembled

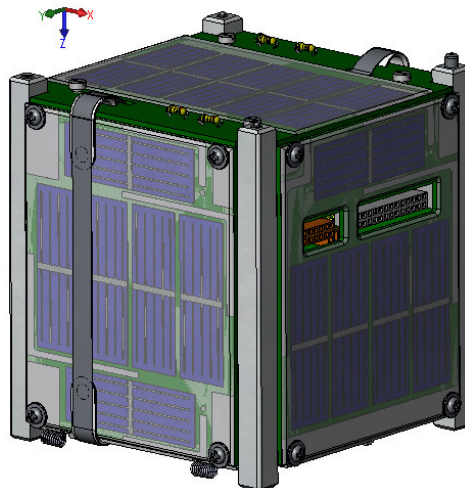


Fig. 4 CAD model of the satellite with walls with solar panels as secondary structure

4. COMMUNICATION AND CONTROL SUBSYSTEM – C&CS

Communications and Control Subsystem of the developed satellite platform realizes two tasks:

- communications with ground stations, realizing two communications channels – transmission of CW beacon signal using Morse code, and transmission and reception of APRS frames [2] using AFSK modulation, to receive telecommands and send telemetry and payload data.
- control and steering of all satellite systems - execution of received telecommands and preparing telemetry data.

Block diagram of C&CS is presented in Fig. 5, the system consists of two RF modules: beacon transmitter and APRS transceiver, and microprocessor controller. Both RF modules are almost identical, consisting of CC1000 transceiver and power amplifiers in transmission part (medium power amplifier AH117 and high power amplifier M68710H). Power of transmitted signal is 20 dBm for CW beacon transmission and 30 dBm for APRS transmission using AFSK modulation. Communications with the ground stations is realized using two separate frequencies in 437 MHz band, and beacon signal is transmitted continuously, while APRS data packets are transmitted in burst mode (each 30-60 seconds, depending on available power supply budget), with bit rate of 1200 b/s. APRS transceiver can also be switched to repeater mode of operation, allowing a realization of communications via satellite for radio amateurs. Both RF modules are connected to separate antennas, and switches are used to allow the use the same antenna for transmission and reception of radio signal. It was assumed that also the beacon transmitter can operate in receiving mode, allowing to receive telecommands in emergency cases. Generation of CW and AFSK modulated signals, as well as preparation of APRS frames for transmission and their decoding for reception, are realized by software of the microprocessor controller. Because CC1000 module is specialized only for FSK modulation, so for transmission of AFSK signal the controller generates signal with frequency 1200 or 2200 Hz, depending on data bit value that is sent to CC1000 FSK modulator. Similarly for the signal reception frequency of FSK demodulated signal is measured to obtain the received data.

System can be remotely configured, and it is possible to change modes of transmitter, type of modulation, operating frequency, RF power. Communications realized by APRS transceiver is compatible with radio amateur standard AX25 [3], APRS [2], GENSO network [4], [5] and DGSS system [6], [7], so global coverage of communications with satellite can be assured, using existing radio amateur ground stations.

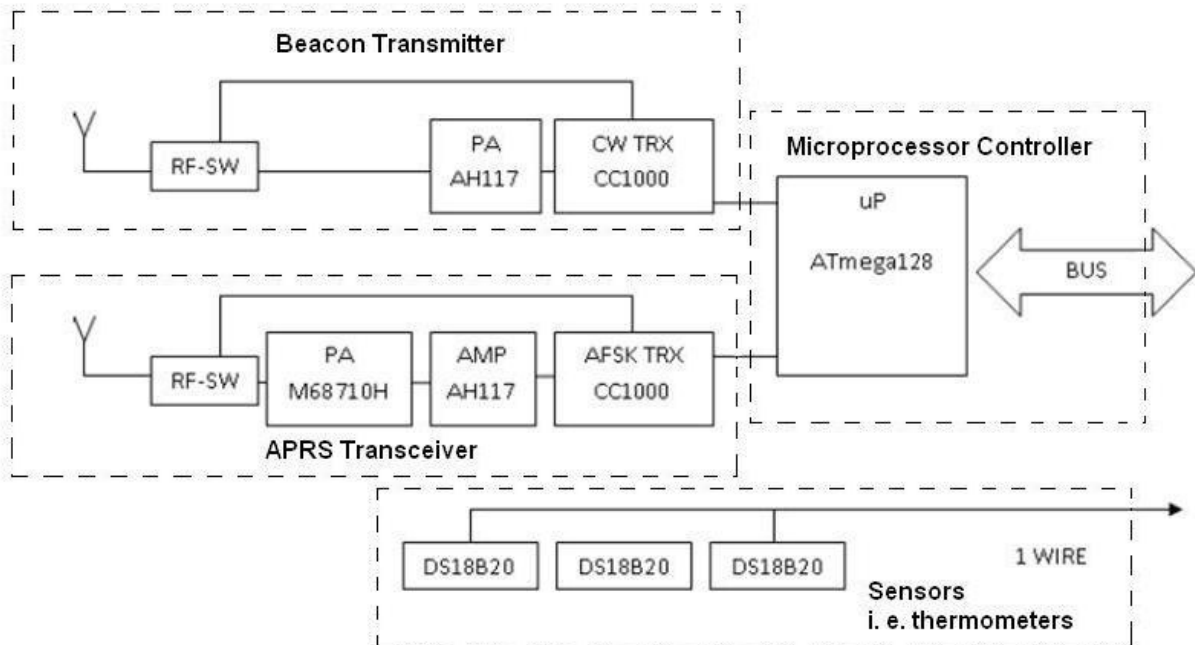


Fig. 5 Block structure of C&CS

Signal transmitted by the beacon transmitter can be used to determine parameters of satellite orbit, what will be necessary for PW-Sat LEONIDAS experiment, to measure a braking effect caused by the unfolded sail. Changes of Kepler elements of the satellite orbit will be calculated using measurements of Doppler frequency shift of the received beacon signal.

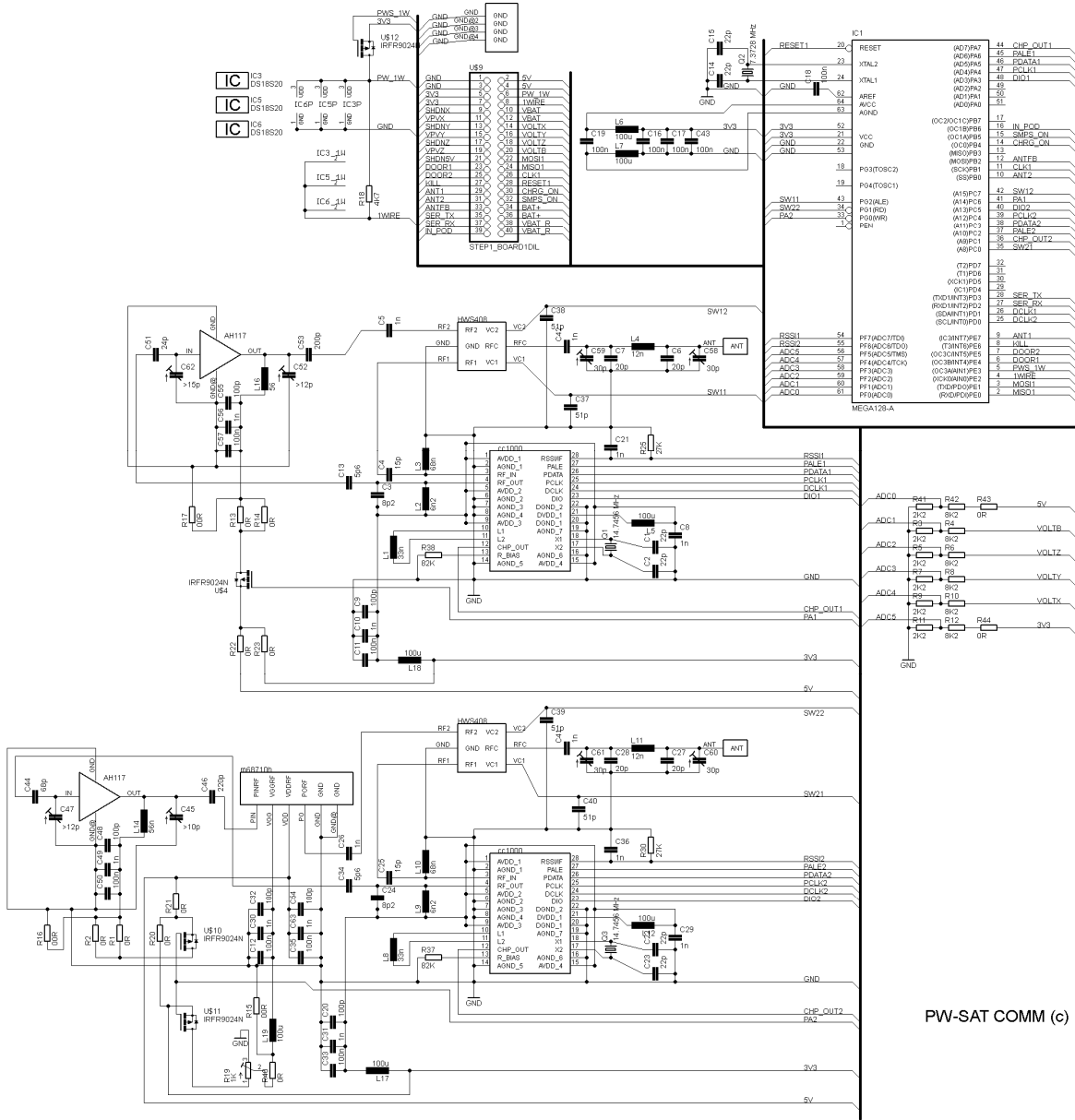


Fig. 6 C&S electrical schematic

Microprocessor controller also realizes following functions:

- coding and decoding of AX25 and APRS packets (Terminal Node Controller - TNC),
- decoding and realization of telecommands sent by the ground control station: i.e. opening antennas, opening payload equipment, changing operation mode of satellite subsystems

PW-SAT COMM (c) by M.Stolarski

- collection of telemetry data and preparation of packets to be send to the ground station, by measuring temperatures in different points in the satellite using Dallas DS18B20 digital chip thermometers connected to 1 Wire bus, and measuring supply voltages and currents of different satellite subsystems using built in A/D converter.
- data storage of collected data in EEPROM memory, for situation when the satellite is not in a coverage area of the ground station
- watchdog protection

System is supplied from two voltage lines: 3.3 V for digital devices and CC1000 transceivers, and 5 V for power RF amplifiers. Two voltages to power supply of C&CS are used to minimize power consumption and to increase efficiency of RF power amplifiers. During the functional tests the power consumption of the system has been in range of 250 mW for RX mode only of both RF modules, 500 mW for CW beacon transmission and RX mode for APRS transceiver, and 4 W for transmission mode of both RF modules. Measured output RF power of transmitted signals was equal 18 dBm for the CW beacon transmitter, and 31 dBm for the APRS transmitter.

Electrical schematic of C&CS is presented in Fig. 6, and assembled printed circuit board (PCB) of the system in Fig. 7. The system is mounted using FR4 laminate with dimensions 80x80 mm, and it is placed at top of the satellite (under solar panel board). The RF modules of the system are directly connected to separate antennas. Two orthogonally mounted $\frac{1}{4}$ wave monopoles are used, to separate their radiation patterns and minimize coupling between both RF modules.

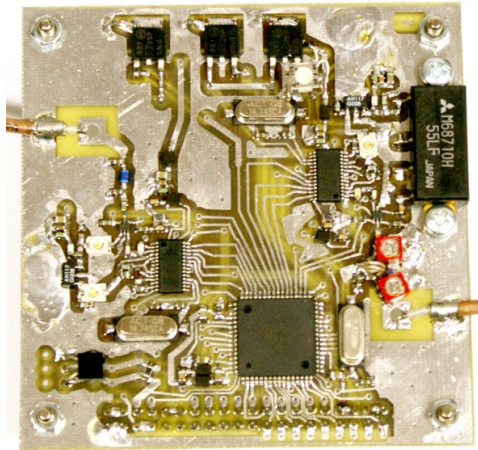


Fig. 7 Assembled C&CS

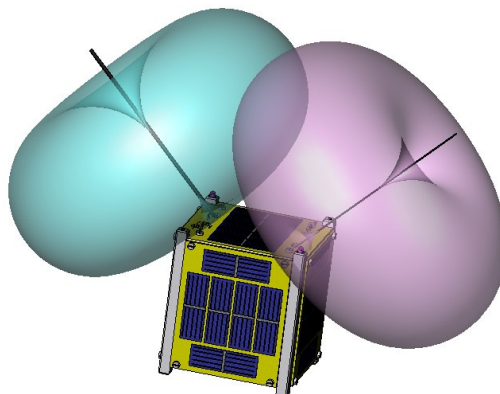


Fig. 8 Prediction of radiation patterns of antennas used in C&CS

Tab. 1 PW-SAT radio link budget calculation

Name	CW			AFSK					
	downlink			downlink			Uplink		
Distance [km]	600	2000	3000	600	2000	3000	600	2000	3000
TX power [dBw]	20	20	20	30	30	30	47	47	47
TX antenna gain [dB]	0	0	0	0	0	0	15	15	15
FSL [dB]	-140	-151	-154	-140	-151	-154	-140	-151	-154
RX antenna gain [dB]	15	15	15	15	15	15	0	0	0
RX sensitivity (BER<1E-3)	-121	-121	-121	-121	-121	-121	-110	-110	-110
Budget [dB] (must be >0)	16	5	2	26	15	12	32	21	18

Calculation of power budget of radio link between the satellite with C&CS and the ground station is presented in Tab. 1, for following assumptions:

- beacon transmitter: frequency – 437.205 MHz, output TX power – 20dBm, antenna gain – 0 dB
- APRS transceiver: frequency 437.425 MHz, output TX power – 30 dBm, RX sensitivity – -110 dBm, antenna gain – 0 dB, bit rate – 1200 b/s
- ground station: output TX power – 47 dBm, RX sensitivity – -121 dBm, antenna gain – 15 dB
- distance between satellite and the ground station in a range 600 – 3000 km

5. POWER SUPPLY UNIT - PSU

PSU supplies the satellite with conditioned power from two sources: solar panels mounted on satellite walls and a battery providing power for satellite during flight through the Earth shadow. One of main goals in designing of PSU was to achieve the subsystem stability by making it as simple as possible with minimal use of any additional control logic. Therefore PSU is fully autonomous and independent from rest of the satellite subsystems. Block structure of PSU is presented in Fig. 9, it can be divided into five basic functional blocks that are spread on several printed circuit boards:

- solar panels mounted on five walls of the satellite
- first stage DC/DC converters (#1, #2, #3) for converting input voltage from solar panels (varying according to the panel irradiation angle) to stable battery voltage (4.1V for safe battery charging)
- lithium-ion battery Saft MP144350
- second stage DC/DC converters (#4, #5) for converting the battery voltage to 5V voltage to supply RF power amplifiers in C&CS, and 3.3V voltage to supply rest of the satellite systems
- watchdog circuit for reliable, few seconds long, system reset by power down in case of C&CS malfunction

Both output voltages are protected against latch-up cases. All converters are heavily de-rated, mainly due to heat dissipation issues. Converters and their circuits transferring power from solar panels are calculated to work with both low and high efficiency solar panels.

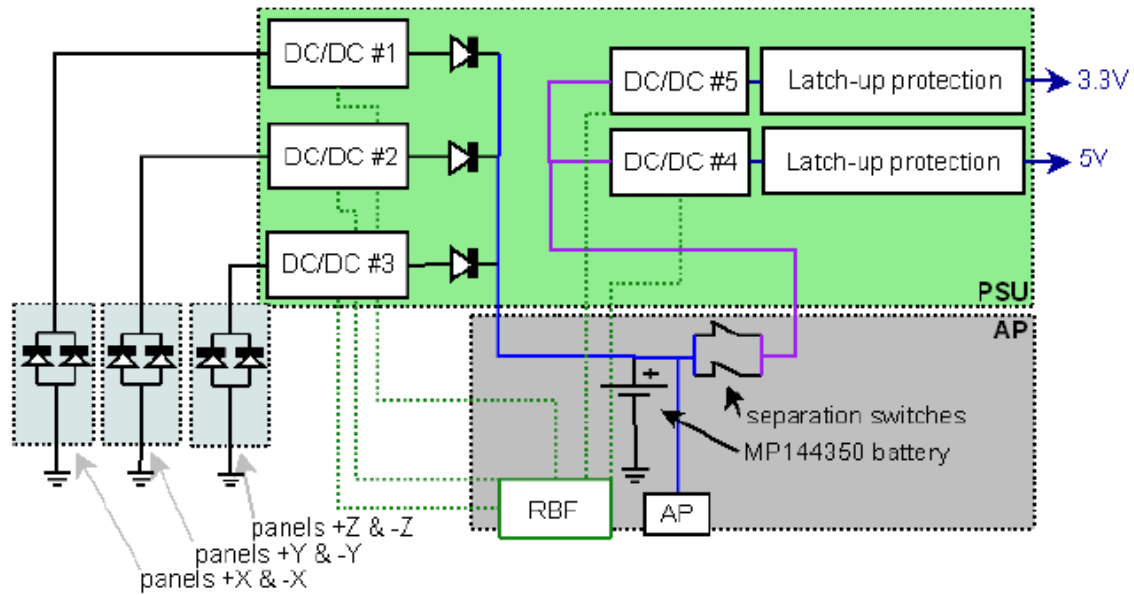


Fig. 9 Block structure of PSU

Theoretical maximum power that can be generated by panels placed on one satellite wall is about 2.3W (assuming solar irradiation of $135\text{mW}/\text{cm}^2$, 64 cm^2 solar cells area and 27% energy conversion efficiency). In reality power output from panels is expected not to be larger than 2 W as there is no optimal power matching between panels and the DC/DC converter. Nevertheless, PSU has to provide enough power for satellite subsystems in every mode of the satellite operation. The estimated power consumption in each of the modes is listed in Tab. 2. *Minimum* operation mode is for keeping satellite bus up and gathering measured data. It is suitable for the battery charging. *RX* operation mode is when the radio reception circuits are on and the satellite is ready to receive commands from the ground control station. *TX_{beacon}* operation mode is when the satellite beacon transmitter is on, and therefore the satellite is sending basic telemetry data like housekeeping information, temperature readouts. This mode is very convenient for keeping track of the moving satellite. *TX_{full}* operation mode is for sending complete telemetry packets by APRS transceiver, with all gathered data and using maximum available transmitter power.

Tab. 2 Estimation of power consumption of communications system

<i>Operation mode</i>	Consumed power
<i>Minimum</i>	260mW
<i>RX</i>	323mW
<i>TX_{beacon}</i>	530mW
<i>TX_{full}</i>	~4000mW

Main source of energy for PSU are solar panels that use triple-junction gallium arsenide solar cells CTJA manufactured by Italian supplier, CESI [8]. Used solar cells have high energy conversion efficiency of 26.5 to 27.5% and are fully qualified for space. For these cells open circuit voltage is 2.5V and short-circuit current is $17.2\text{ mA}/\text{cm}^2$, measured for solar constant AM0 and the cell temperature of 25 degree Celsius [8]. Solar panels, which are solar cells, electrically connected in right way and glued to glass-epoxy laminate serve as satellite walls (and secondary structure). Five out of

six satellite walls are covered with solar cells. Each two opposite panels are connected to the same first stage converter through blocking diodes.

Secondary power supply source is MP144350 battery. Its nominal capacity is 2600 mAh and it can operate in wide temperature range. Discharge can take place in temperatures between -50 to $+60$ degree Celsius and charge can take place in temperatures between -20 and $+60$ degree Celsius. Such operational temperature range makes this battery suitable for Low Earth Orbit (LEO) satellite missions. The battery is integrated with miniature printed circuit board that contains a charge controller circuits. The charge controller cuts the battery off when its voltage drops to 2.5V to prevent overdischarge. Similarly, when the battery voltage is above 4.4V, the battery is cut off to prevent overcharge and leading destruction of it. Additionally, the charge controller allows the battery to be loaded with a maximum current of 3 A [9].

Electrical schematic of C&CS is presented in Fig. 10, and assembled printed circuit board (PCB) of the system in Fig. 11. First stage converters transfer power from solar panels to the battery circuit (to be exact: they charge the battery and/or supply second stage converters). Converters are built using MAX1797 controller that operates for input voltage from 1 to 5V. All three controllers are set to provide voltage on the battery of 4.1-4.2V for optimal charging and leaving some margin to the battery overcharge threshold. Every converter is connected to the battery via low voltage Shottky diode setting current flow to the battery only. MAX1797 allows users to achieve conversion efficiency of 80-85% for current below 100mA and 90-95% for current above 100 mA [10]. Each converter circuit has a current limiter, preventing converters to draw maximum possible current from panels making their voltage drop to near zero value and rendering them virtually useless. With the current limiter, there is power matching between the solar panel and the converter, and energy can be transferred to the battery.

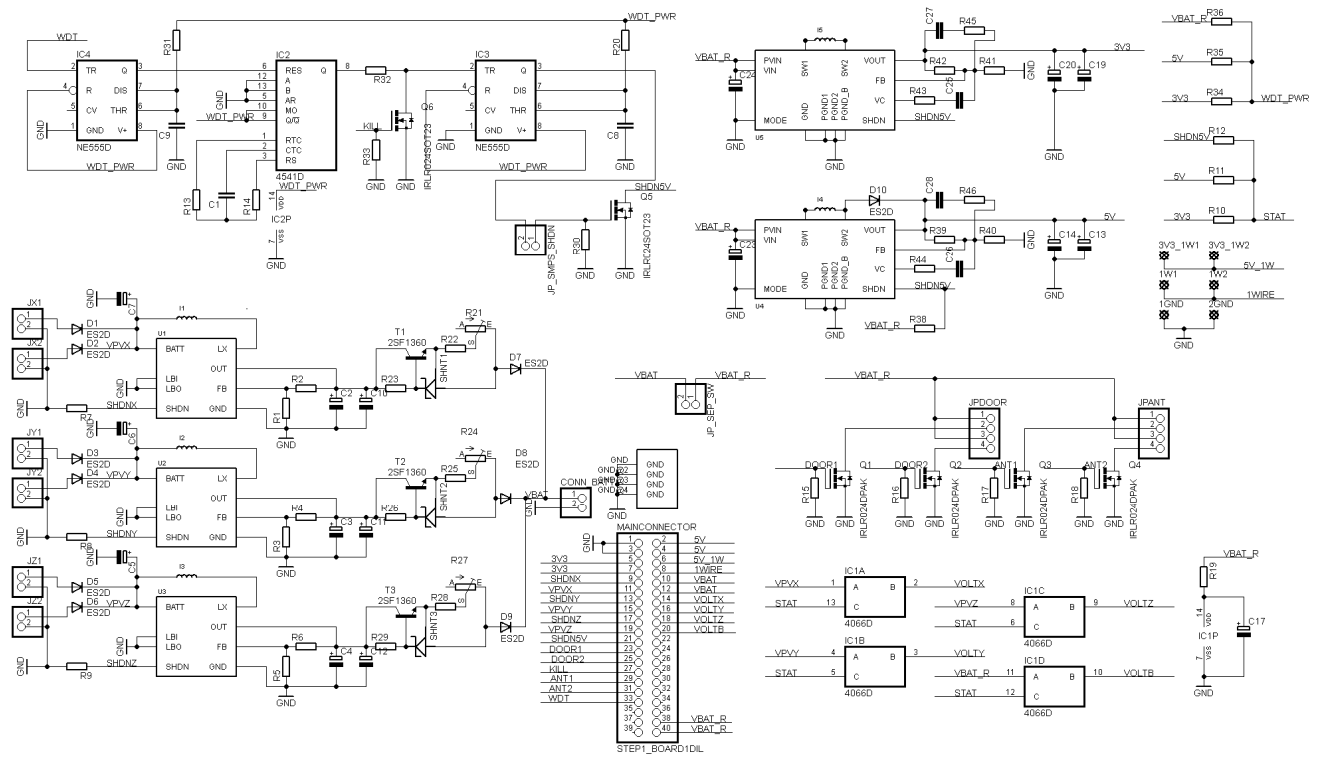


Fig. 10 Electrical schematic of PSU (main board)

Second stage converters have inputs connected to the battery circuit, and provide power supply for C&CS and payload. Those converters are based around LTC3443 controller. Reason to change the controller from the one used in first stage is simple – completely different requirements for second stage converters. First important change is that those

converters will be loaded with much higher currents, therefore they have to easily handle them and dissipate any heat losses. Second change is the mode of operation. In first stage, input voltage was always lower than output voltage, then step-up operation was enough for controllers to work properly at any conditions. In second stage, 3.3V converter has input voltage between 2.5 V (battery deeply discharged) and 4.2V (battery charging) which means, the controller has to be buck-boost type to work properly in whole range of input voltages. Although 5V converter will not work in both modes, it will have to handle up to 800 mA of output current so good thermal connection to Printed Circuit Board (PCB) of LTC3443 placed in DF12 package is of value [11]. Especially, as electronics will work in vacuum so excessive heat will be only conducted and radiated. Derating of power electronics, according to aerospace practices should be around 50-70 % which makes LTC3443 convenient choice for both 3.3V and 5V channels in terms of modes of operation and its physical properties. Additionally, LTC3443 has a “True Shutdown” function that completely disconnects its input from output and is necessary to implement Remove Before Flight (RBF) functionality. When RBF is activated, the satellite remains unpowered and inactive during it’s installation in P-POD container at final integration with launch racket [1].

PSU has several additional circuits. Watchdog, for instance, has important effect on whole satellite bus reliability. Its role is to switch off power on both 3.3V and 5V lines, for several seconds (5 i.e. but this time can be easily changed, depends on few resistors and capacitors value) if C&CS didn’t issue a “reset” command for described watchdog in past 2 seconds. Such command is just a falling edge on one of lines in main electrical connector. Whole watchdog is built using two classic 555 timers (as unstable switchers, for pulse forming) and a CD4541 13-bit binary counter with carry.

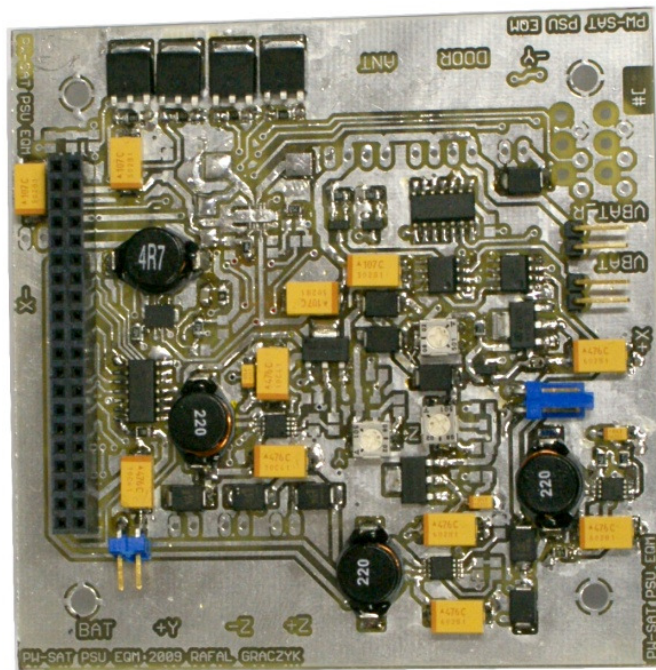


Fig. 11 Assembled main board of PSU

PSU board holds also four transistors that act as switches for wire melting resistors. Resistors melt Dyneema wire for antennas and payload equipment deployment. Transistors are driven by the microprocessor controller of C&CS.

PSU printed circuit board for main board is manufactured using FR-4 laminate (homogenous, low outgassing in vacuum) covered with 17 um copper foil. Subsystem assembly is done according to ESA standards, covered by Q-ST-70C norm [12]. All components used in design have extended or military grade operational temperature range therefore resulting temperature operating range is quite wide, 45 to +85 degree Celsius. All components heavier than 5g have to

be glued to PCB using ScotchWeld 2213 glue [13]. Similarly, all components that are expected to dissipate heat are covered with thermal glue STYCAST2850 [14] to increase their thermal contact with surrounding PCB. Finally, as a last process whole board is covered with silicone conformal coating to mitigate negative environmental conditions during storage (like dirt, humidity) and to decrease outgassing levels, especially from plastic integrated circuits packages (which is a requirement imposed by launch operator).

6. CONCLUSIONS

Paper presents a satellite platform developed in Institute of Radioelectronics, Warsaw University of Technology, for present and future educational missions with cubesat pico-satellite. The platform consists of all systems necessary to proper operation of the satellite and payload equipment placed on it, in space in low earth orbit. The platform is as simple as possible to realize functional requirements placed by possible payload in such missions. Developed platform can be used with payload with weight up to 300 g, volume up to 600 cm³, and power consumption up to 0.5 W. Detailed description of mechanical structure of the satellite, communications and control subsystem, and power supply unit has been presented. The platform is used in PW-Sat satellite educational project, realized at Warsaw University of Technology with support of European Space Agency. The satellite is foreseen to be launched by VEGA racket during its first start of at beginning of 2010.

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