Communication and Data Handling System for BRICsat Satellite

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Abstract—**The paper describes proposed satellite mission BRICsat for which all electronics parts has been designed. The modes of operation as well as data formats for telemetry and archive data are described. The results from the evaluation measurements are included in the paper.**

Keywords—Experimental satellite; communication system; data handling system; data coding

I. Introduction

During recent years, a great expansion of various small satellite missions can be observed. Their intended orbits vary from very low Earth orbits (LEO) with height of 320 km, through 350km orbit (in case of satellites deployed from International Space station ISS), to higher LEO and medium Earth (MEO) orbits. Three experiments with a satellite deployment from the ISS were proposed by Bob Bruninga [1]: Psat-A [2], Psat-B and BRICsat. First two missions are double-size cubesats and the third is designed as sub-cubesat sized, in order to be deployed from the Psat-B. The main experiment is intended to show possible extension of the satellite life by increasing its specific weight. Such a change can double satellite life from approx. 5 months up to one year. The size of the satellite is restricted to cube with 76mm side length in order to be accommodated by launcher-satellite Psat-B. The satellite will be spin stabilized with passive magnet.

II. Satellite subsystems

The payload consists of power subsystem, experimental band monitor, command receiver and transmitter with on board computer. Whole electronic is situated on two double-sided boards with identical sizes 63x63mm. Power subsystem consists of 6 solar cells, so that each is placed on one side of the cube. Each cell is connected to one of five rechargeable NiMh batteries with 1800mAh capacity through isolating diode, while the top and bottom cells charge the same battery cell. This design ensures satellite operation even in the case if some solar panel or battery cell fails to open, or to the short state.

The receiver is designed as double conversion super-heterodyne with input in 28MHz band and audio output of demodulated signal with 2.5kHz bandwidth. Typical received signal is multiple BPSK31 transmissions, which are spread in 2.5kHz band around 28.120MHz. Receiver consists of antenna matching circuit, input filter, preamplifier and band filter, followed by the mixer. The signal chain continues with quartz band pass filter, variable gain amplifier and second mixer for conversion to audio band. Receiver includes automatic gain control with 60dB dynamic range, detection of BPSK31 modulation in the received channel and a command channel output as can be seen in Fig.1. The TX board also includes four channel A/D converter for battery cells voltage and receiver board temperature monitoring. For telemetry data storage purposes is used 8kB EEPROM memory. Both chips are connected via I^2C bus with the controller. The whole receiver is supplied via 5V low drop stabilizer, however full functionality of the device is tested down to 3.5V. Realized flight prototype can be seen in Fig.2.

The core of the transmitter is an ISM IC from Analog devices (ADF7012), followed by power MOSFET transistor from Mitsubishi to achieve 27dBm power level. Finally, the signal is filtered by a band pass. The transmitter output signal is always FM modulated with audio signal from the output of

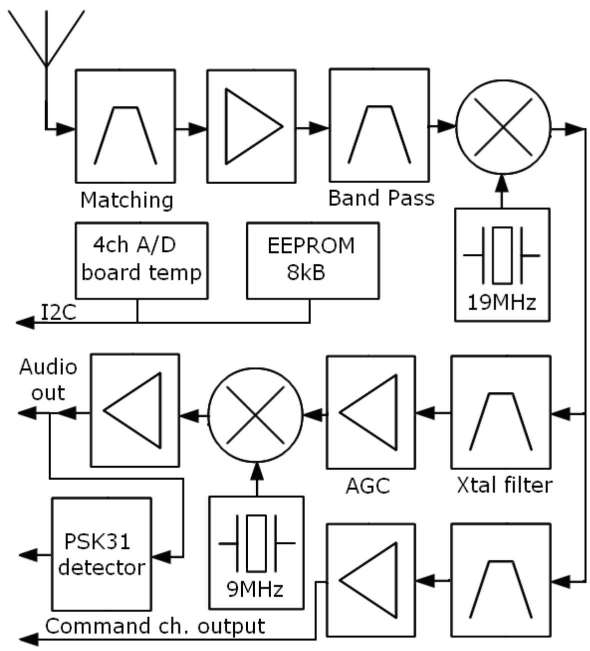

Figure 1. Receiver board block diagram.

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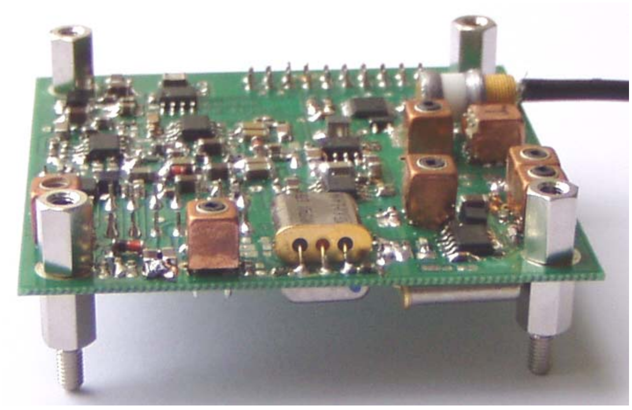

Figure 2. Receiver board flight prototype.

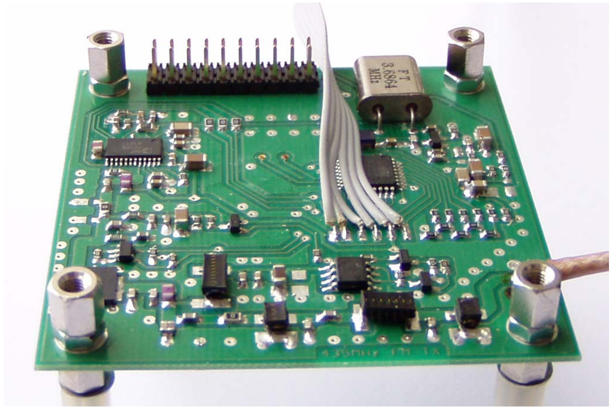

Figure 4. Transmitter board flight prototype.

the receiver. In order to identify the downlink signal and to transmit telemetry data, a beacon is added into the audio modulation signal using an audio sub-carrier 375Hz. The beacon signal is constructed from sampled waveforms for the symbols 0 and 1 to ensure smooth zero crossings in BPSK modulation. A block diagram of the TX board can be seen in Fig.3. The transmitter controller ATmega8 from Atmel provides the transmitter IC configuration, control the PA power supply switch and monitor actual temperature of the PA. If the maximum allowed temperature is reached, the controller immediately shut the PA down to preserve it from overheating. Realized flight prototype can be seen in Fig.4.

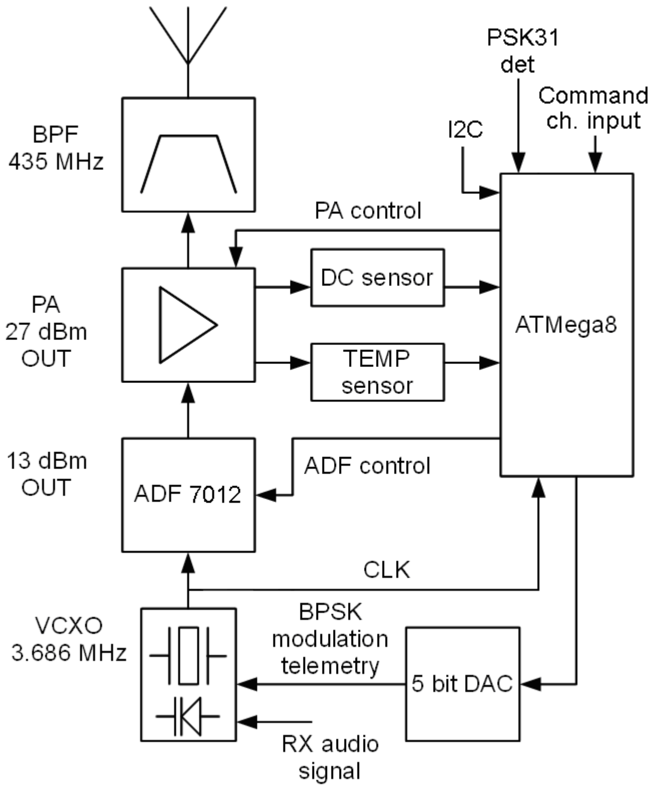

Figure 3. Transmitter board block diagram.

III. Data Handling System

The same controller in the transmitter also takes care of entire data handling onboard the satellite. First task is to set up the beacon data frame from the values measured at the A/D converter inputs and temperature sensors. The beacon data are transmitted in following order (each symbol is described in Table.1):

aaaaa beacon b ccc dd ee fff ggg hhh iii jjj kkk ±ll ±mm

Each symbol (except mode of operation) is a numeral value. Count of symbols in the message is fixed in order to keep length of the telemetry frame constant. The mode of operation is represented by letters A, B or C. All transmitted telemetry data are also stored to external EEPROM memory via I^2C bus. The controller also decodes a command channel from the receiver output, which is used for commanding the satellite from the ground station. Therefore we are able to remotely change the satellite configuration by setting three main parameters: the highest mode of operation, threshold voltage for mode switching and maximum allowed PA temperature.

We can also force the telemetry data, which are stored in the EEPROM memory, to be transmitted on a beacon sub-carrier. The memory has enough capacity to keep complete data set from the whole orbit of the spacecraft. We have also implemented higher modulation rates (BPSK64 and BPSK125) to ensure whole data set transmission during a single satellite pass over the ground command station. In addition, a simple compression method was developed to further increase the data throughput. Then the data stream consists of uncompressed (full) frame followed by a certain number of compressed frames.

Full frames are transmitted in a numeral system with base 32. All 32 values are represented by symbols "a" for 0 to "z" for 25 and "A" for 26 to "F" for 31. Such representation allows to encode numeral values in range 0 to 1023, with use of two symbols only. Temperature values are moved up by adding 100 to avoid the necessity of sign transmission. The described coding results in about 50% transmission time reduction - partly due to the symbol count reduction and partly due to use of alphabetic symbols, which are represented by shorter binary symbol in BPSK Varicode coding. After the full frame, a compressed frame is transmitted. The compressed frames are obtained as a difference between last and previous value of each telemetry channel plus 14. If the result lies in 0 to 31 range, the value is transmitted as one symbol, otherwise the value is sent as its full representation preceded by space. Such compression is very effective and easy for implementation in the satellite controller as well as in a decoding ground station. Practical tests have shown, that almost all channels (except AGC and BPSK signal sensing) are quite static and thus in majority are coded in one symbol. As an example, three datasets can be seen below, with the interpretation in the Fig.5.

gy ag ba os lh hx fi cm ev dF dD

frozzyvsqnofinxvvusppofustttrqpooffszzyvsqoo

Here, the first line represents coded full frame of all eleven telemetry channels including frame number, next line represents the four following frames coded as differences. All differences fitted here into single symbol representations, the coding is efficient.

if aa dd kB fE cq ao bf cn dE dD

fooE id et cyn eaoofo bt mw jm fC dBFxppfo aF nr kh gx eqzunnfrn oe kA hjCvqpo

Second dataset is shoving problems in the differences, where lot of them is represented in fact with full values.

is ad bb ts pw lz hA dE fx dF eh

nlrnnooooonrroooononomnllooopomnlnolvttrqopj

Third dataset shows that when great changes in the data values faded away, coding is again efficient. Fig.5 shows only five channels of battery cells voltages decoded, which dropped rapidly and then were recharged.

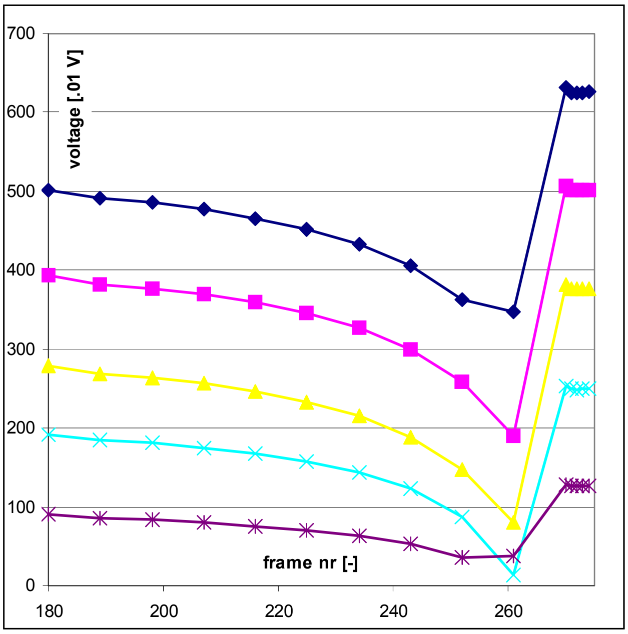

Figure 5. Telemetry channels for battery cells.

TABLE I. TELEMETRY BEACON CHANNELS DESCRIPTION

symbol	*width*	*description*	*unit*
aaaaa	5	Call sign assigned by IARU	-
b	1	Mode of operation	-
ccc	3	Frame number	-
dd	2	PSK sensing	-
ee	2	RX AGC	-
fff	3	Battery voltage across all 5 cells	10mV
ggg	3	Battery voltage across 4 lower cells	10mV
hhh	3	Battery voltage across 3 lower cells	10mV
iii	3	Battery voltage across 2 lower cells	10mV
jjj	3	Battery voltage across 1 lowest cell	10mV
kkk	3	Transmitter current consumption	mA
±ll	3	Receiver temperature	°C
±mm	3	Power amplifier temperature	°C

IV. SATELLITE MODES OF OPERATION

The satellite can work in four modes of operation. Receiver and controller are always on, while transmitter state varies.

Mode A means that the transmitter is always on and the beacon transmits telemetry in 20s intervals.

In mode B, the transmitter is switched on only if BPSK31 signal is detected in the received audio signal. Switching is based on 20s timing. If the transmitter is on, the beacon transmits telemetry. If there is no activity in the receiving band, the transmitter is switched on in 120s intervals in order to transmit each 120s one telemetry frame.

In mode C, the transmitter is switched on to transmit one telemetry frame each 180s in order to save batteries.

Mode D is the most power saving mode. The transmitter is switched on each 180s to transmit only the call sign. No telemetry is transmitted in mode D.

Switching between different modes is available both via the uplink commands from the ground station, or by setting the threshold voltages and temperatures. This ensures positive energy budget of operation, which results in increased battery life and stable satellite operation.

V. PRACTICAL TESTS

The project is currently in phase of electronics and power subsystem integration to the flight body. The electronics and onboard firmware has been fully tested and it has successfully passed the thermal tests as can be seen in Fig.6. The test was performed at three temperatures: -10°C, 25°C and 55°C. Receiver and transmitter boards start proper operation from supply voltage 3.5V. Power consumption of the receiver board is very stable both with voltage and with temperature variation. In the case of transmitter board, the variation with supply voltage results from the direct connection of the power amplifier to the battery without any regulation. This causes according variation of the output RF power. The considered

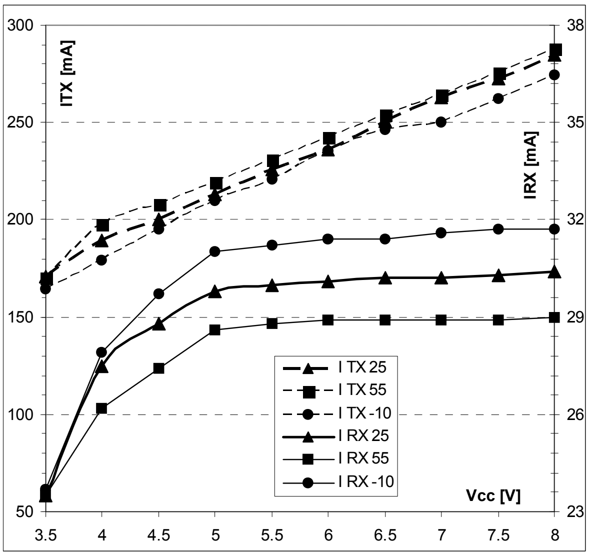

Figure 6. Current consumption of receiver and transmitter (dashed lines) boards vs. supply voltage and temperature variation.

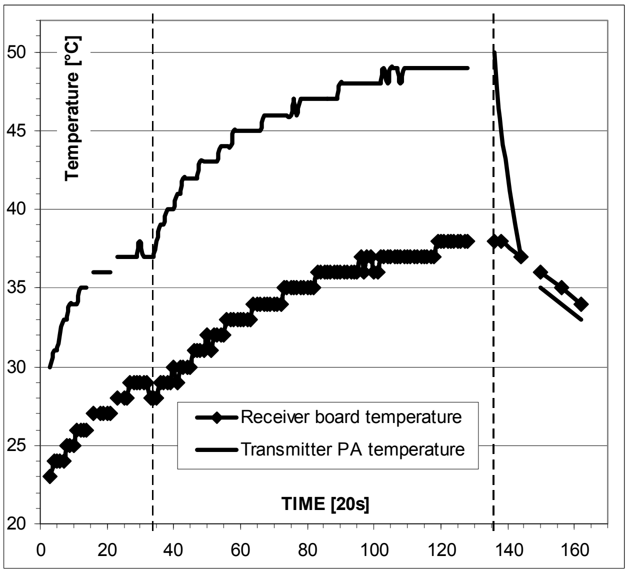

Figure 7. Thermal vacuum test.

operating temperature range of the satellite electronics is between 0 and 30°C. Fig.7 shows the measured data from the vacuum thermal test. The graph is divided by two vertical lines into three regions. From the left, the first line shows the state of the device at atmospheric pressure. The transmitter is switched in mode A and PA temperature is settled at 37°C. Then, after the vacuum pump was switched on, the temperature of the device started to rise in the second region. After leveling at 49°C, which is satisfactory result, the satellite was commanded to mode B, where the transmitter operates every 120s for 20s long period (in order to transmit one telemetry frame). This resulted in rapid temperature drop of both receiver and transmitter boards and test was ended. The duration of the test was one hour. Test has shown that cooling of the power amplifier is well designed and prepared for space environment.

VI. CONCLUSIONS

Both receiver and transmitter boards were designed for the BRICsat mission. Data format was described for standard telemetry beacon as well as the compressed format for downloading the telemetry data stored in memory during one orbit. Practical tests in thermal chamber and in vacuum chamber have shown that the device is well prepared for space environment operation. The decoding software for telemetry data handling, which has been developed in Matlab, is fully available for experiments.

REFERENCES

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