II IAA Latin American Symposium on Small Satellites

University of Brasília – Campus Gama

Aerospace Engineering

UNB On-Board Computer Prototype

for CubeSats

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Argentina,
November 2019

Overview

- Research groups of the University of Brasília (UnB) are planning the launch of 3U CubeSat missions as a technology demonstrator [1][2];
- Some studies are already ongoing and all missions will require an Onboard Computer (OBC);

Objectives of the UNB OBC

- Control an optical camera based on CMOS (Complementary Metal-Oxide-Semiconductor) technology;
- Provide control for a Pulsed Plasma Thruster;
- To guarantee a high degree of reliability, even using commercial off-the-shelf (COTS) components;
- To store useful data in a non-volatile memory, for adequate transmission to a ground station;
- To have an anti-locking system;
- Change operation modes according to the energy availability.

Figure 1 – Members of the Alfa Crux project [2].

Components:

- MSP432P4111 (Microcontroller);
- 512KB FRAM M. (Sof. Back-up) ;
- 4GB SD Card M. (Telemetry);
- ACS70331 (Current S.);
- MPU9250 (Inertial Sensor);
- MCP9701T (Temp. Sensor);
- STWD100 (Ext. Watchdog);

Interfaces:

- JTAG (DEBUG);
- 16bit ISA Bus (Communication Bus);

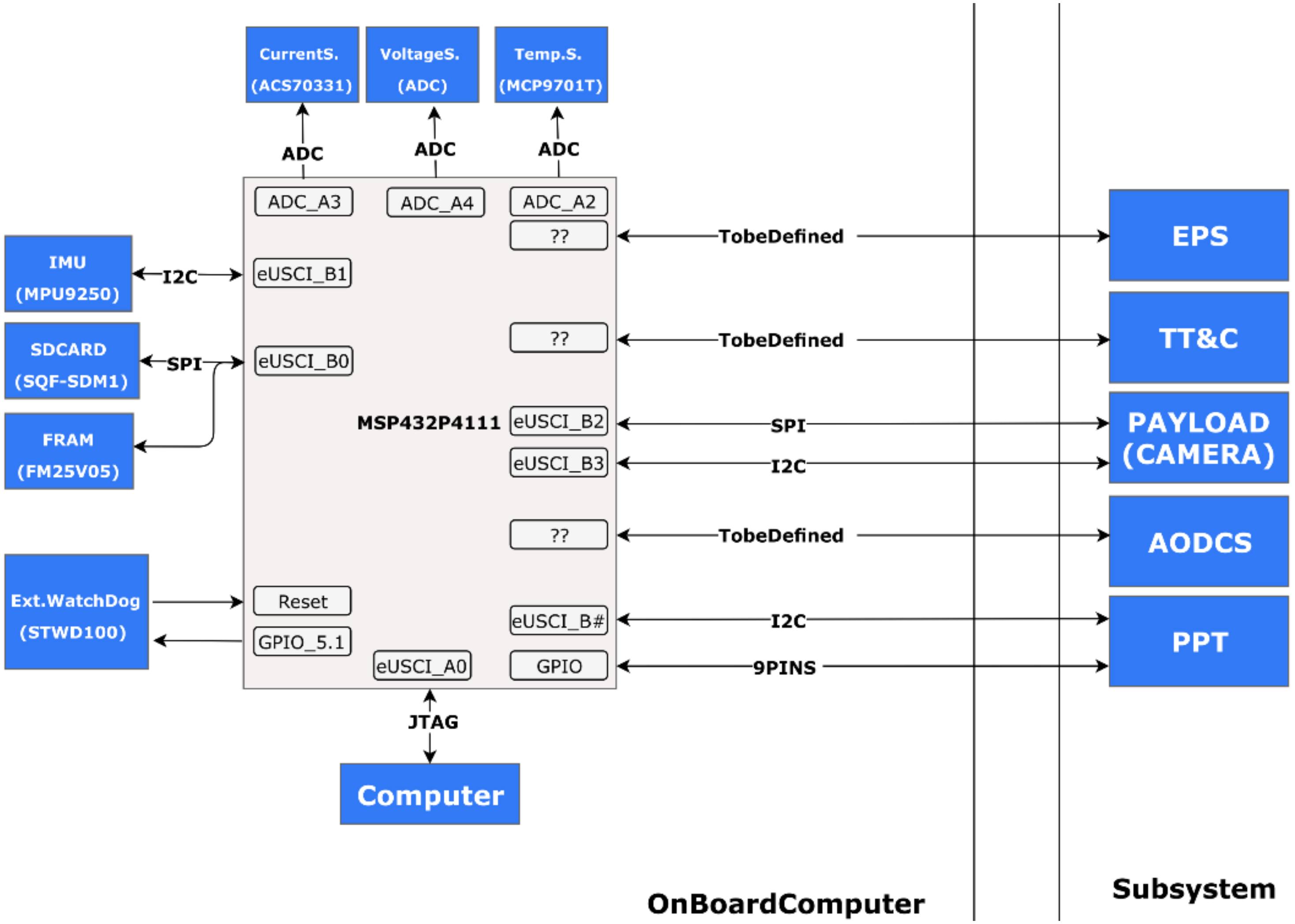


Figure 2 – Block diagram of the OBC, with interfaces.

3. Software Architecture

- The Layered Architecture provide a better software usability and maintenance;
- The Hardware Abstraction Layer (HAL) is performed by the TI-DriverLib [3] and the FreeRTOS was used to meet the requirements of Hard RTOS [4].
- The State Machine has four operation modes;
- one for control (***TaskManager***), one for data collection (***HouseKeeping***), one for data storage (***DataStorage***), one for software locking control (***WatchDogTask***), and 5 to handle CubeSat subsystems functionalities.

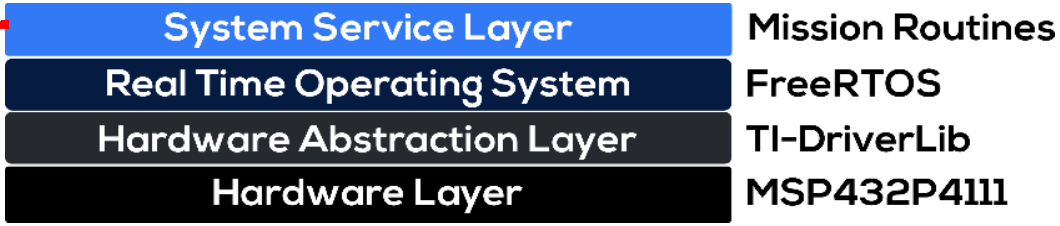


Figure 3 – Layered software architecture.

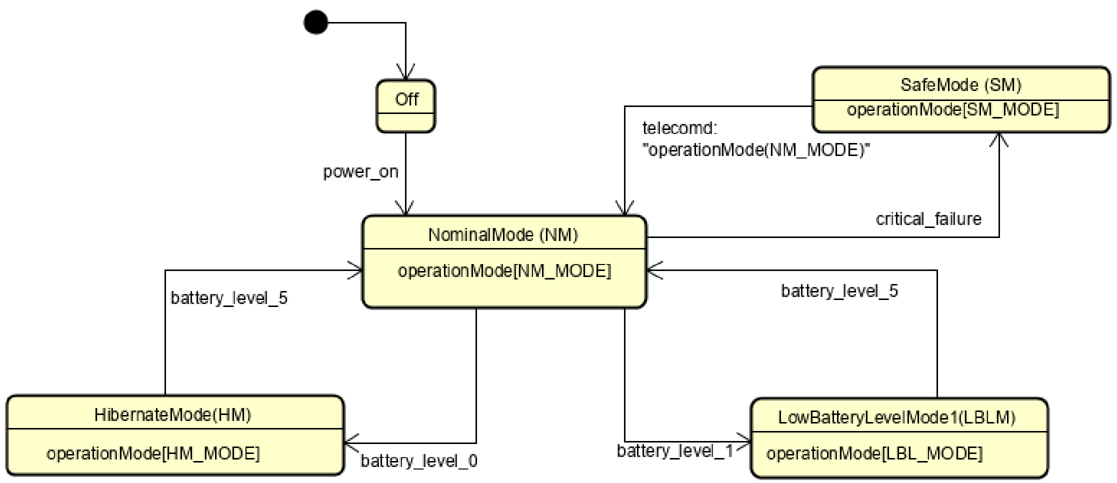


Figure 4 – System Service Layer State Machine Diagram.

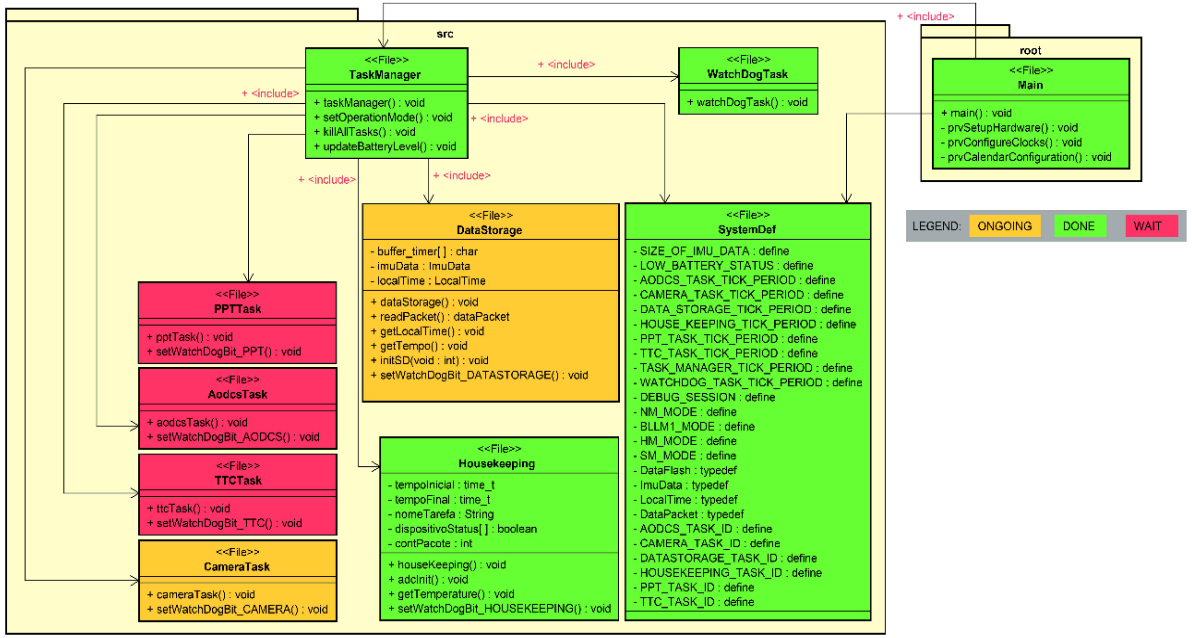


Figure 5 – System File Diagram.

Protoboard Test

- Using a photoresistor to simulate CubeSat EPS;
- Use of commercial off-the-shelf (COTS) components to perform the tests.

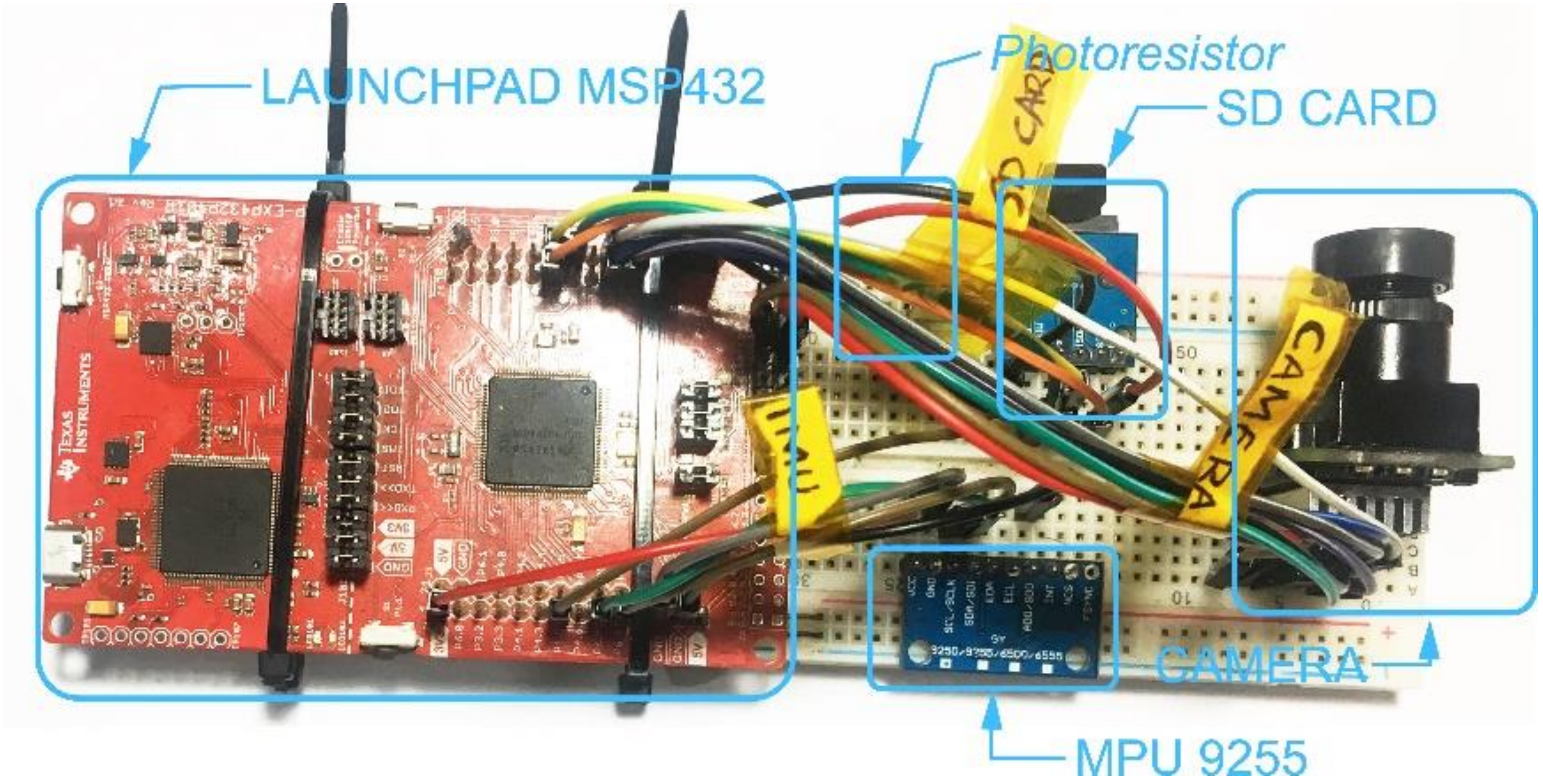


Figure 6– Protoboard with COTS components and LaunchPad.

Data Acquisition and Storage

- Data Acquisition → HouseKeeping Task;
- Data Storage → DataStorage Task;
- Data were stored in ASCII format, for easy viewing;

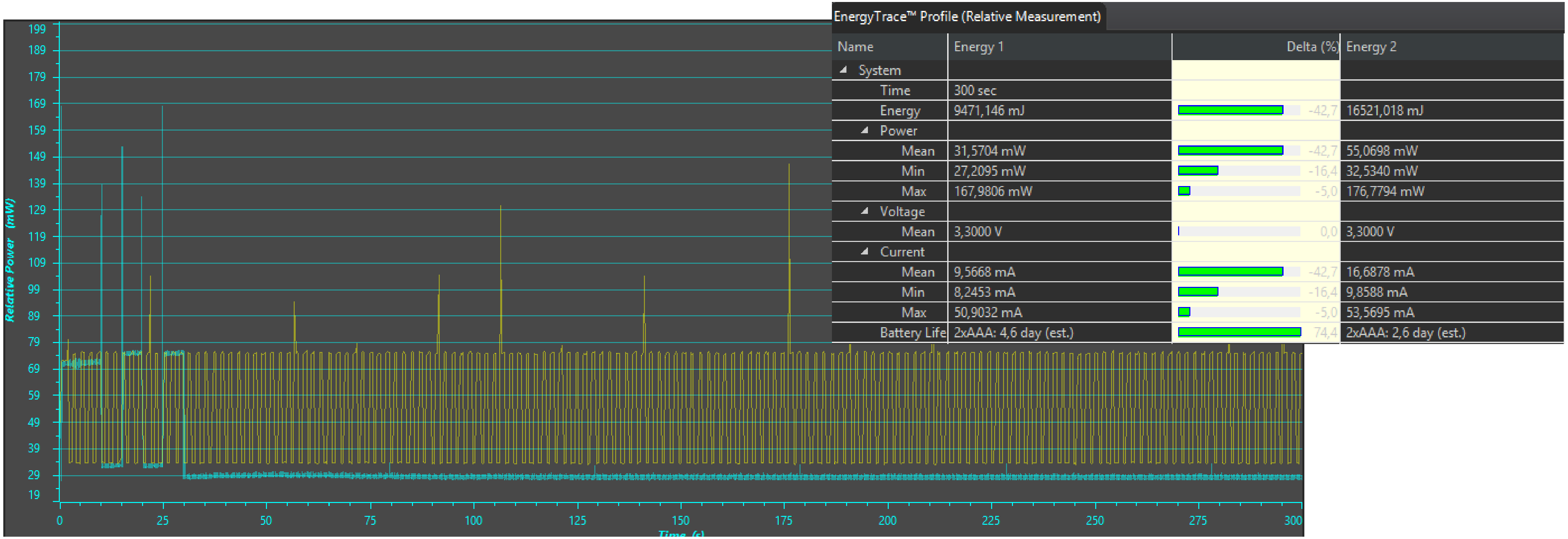
```
4977  L_T: 0 : 0 : 39 |MODE: INIT   |TEMP: 28 |ADC: 5112 1063 0 63 0 63 0 63 |IMU: 2816  -26624 -7424 25600 31744  -3840
4978  L_T: 0 : 0 : 49 |MODE: INIT   |TEMP: 28 |ADC: 5114 1144 0 44 0 44 0 44 |IMU: 2816  -26624 -7680 25600 31744  -3840
4979  L_T: 0 : 0 : 59 |MODE: NM_MOD |TEMP: 28 |ADC: 5113 1054 0 54 0 54 0 54 |IMU: 2816  -17408 -7424 25600 -24576 -3840
4980  L_T: 0 : 1 : 9  |MODE: NM_MOD |TEMP: 28 |ADC: 5111 1359 0 59 0 59 0 59 |IMU: 2816  23552  -7680 25600 -27648 -3840
4981  L_T: 0 : 1 : 19 |MODE: NM_MOD |TEMP: 28 |ADC: 5113 1012 0 12 0 12 0 12 |IMU: 2816  21504  -7424 25600 0 7648 -3840
4982  L_T: 0 : 1 : 29 |MODE: NM_MOD |TEMP: 28 |ADC: 5109 1019 0 19 0 19 0 19 |IMU: 2816  -25600 -7424 25600 -31744 -3840
4983  L_T: 0 : 0 : 0  |MODE: INIT   |TEMP: 28 |ADC: 5107 928  0 8  0 8  0 8  |IMU: 2816  -26624 -7424 25600 -25600 -3840
4984  L_T: 0 : 0 : 19 |MODE: INIT   |TEMP: 28 |ADC: 5114 912  0 2  0 2  0 2  |IMU: 2816  17408  -7680 25856 8192 0 -3840
4985  L_T: 0 : 0 : 29 |MODE: INIT   |TEMP: 28 |ADC: 5112 969  0 9  0 9  0 9  |IMU: 2816  20480  -7680 25600 26624  -3840
4986  L_T: 0 : 0 : 39 |MODE: INIT   |TEMP: 29 |ADC: 5121 1066 0 66 0 66 0 66 |IMU: 2816  -25600 -7424 25600 -29696 -3840
4987  L_T: 0 : 0 : 49 |MODE: INIT   |TEMP: 29 |ADC: 5118 1075 0 75 0 75 0 75 |IMU: 2816  19456  -7424 25600 22528  -3840
4988  L_T: 0 : 0 : 0  |MODE: INIT   |TEMP: 28 |ADC: 5110 914  0 4  0 4  0 4  |IMU: 2816  -28672 -7680 25856 23552  -3840
4989  L_T: 0 : 0 : 19 |MODE: INIT   |TEMP: 28 |ADC: 5114 903  0 3  0 3  0 3  |IMU: 2816  23552  -7680 25600 -20480 -3840
4990  L_T: 0 : 0 : 29 |MODE: INIT   |TEMP: 28 |ADC: 5114 945  0 5  0 5  0 5  |IMU: 2816  7168   -7424 25600 26624  -3840
4991  L_T: 0 : 0 : 39 |MODE: INIT   |TEMP: 28 |ADC: 5116 1077 0 77 0 77 0 77 |IMU: 2816  -22528 -7680 25600 19456  -3840
4992  L_T: 0 : 0 : 49 |MODE: INIT   |TEMP: 28 |ADC: 5117 1065 0 65 0 65 0 65 |IMU: 2816  -21504 -7424 25600 -3072  -3840
4993  L_T: 0 : 0 : 59 |MODE: BLLM1  |TEMP: 29 |ADC: 5117 1085 0 85 0 85 0 85 |IMU: 2816  -13312 -7424 25600 -14336 -3840
4994  L_T: 0 : 1 : 9  |MODE: BLLM1  |TEMP: 28 |ADC: 5120 847  0 7  0 7  0 7  |IMU: 2816  -28672 -7424 25600 -9216  -3840
```

Figure 7 – Telemetry data stored on memory card.

4. Results during the prototyping

Consumption tests were performed using Code Composer Studio's EnergyTrace tool [5];

- **Hibernation Mode x Nominal Mode**
  - Comparing Nominal Mode with Hibernate Mode, there is a savings of over 40%, increasing battery life by two days.



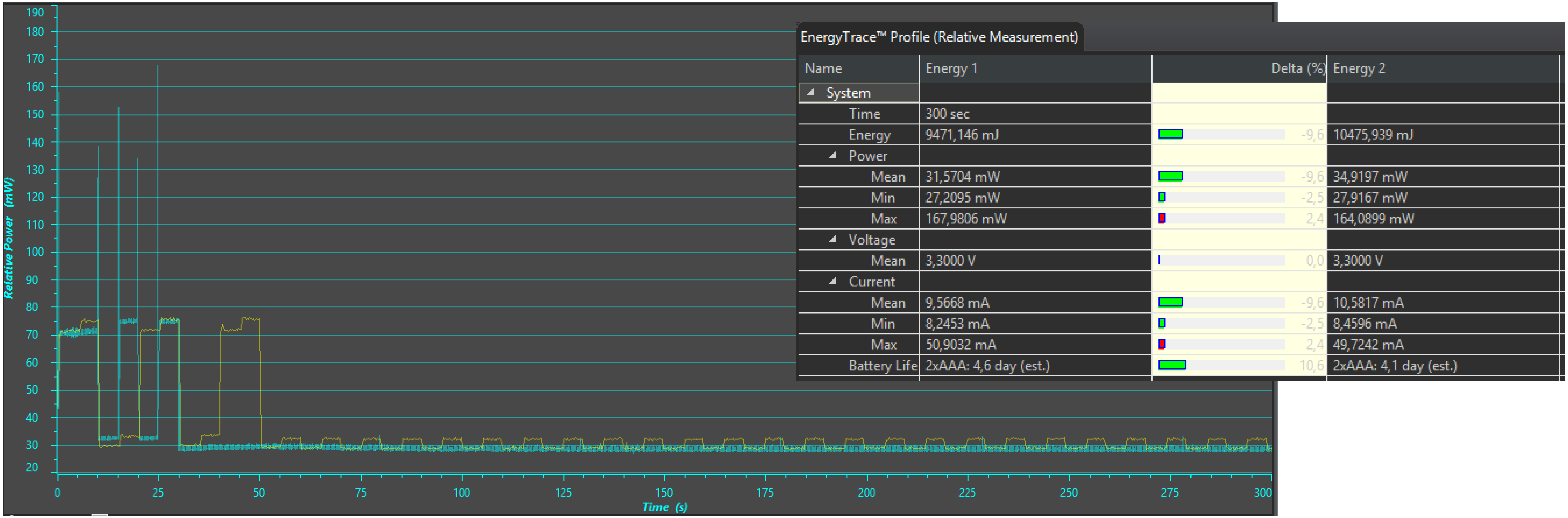
EnergyTrace™ Profile (Relative Measurement)

Name	Energy 1	Delta (%)	Energy 2
System			
Time	300 sec		
Energy	9471,146 mJ	-42,7	16521,018 mJ
Power			
Mean	31,5704 mW	-42,7	55,0698 mW
Min	27,2095 mW	-16,4	32,5340 mW
Max	167,9806 mW	-5,0	176,7794 mW
Voltage			
Mean	3,3000 V	0,0	3,3000 V
Current			
Mean	9,5668 mA	-42,7	16,6878 mA
Min	8,2453 mA	-16,4	9,8588 mA
Max	50,9032 mA	-5,0	53,5695 mA
Battery Life	2xAAA: 4,6 day (est.)	74,4	2xAAA: 2,6 day (est.)

Figure 8 – Comparison between Hibernation Modes (Blue) and Low Battery (Yellow).

Consumption – Hibernation Mode x Low Battery Mode

- Comparing Nominal Mode with Hibernate Mode, there is a savings of more than 9.6%, increasing battery life by 0.5 days.

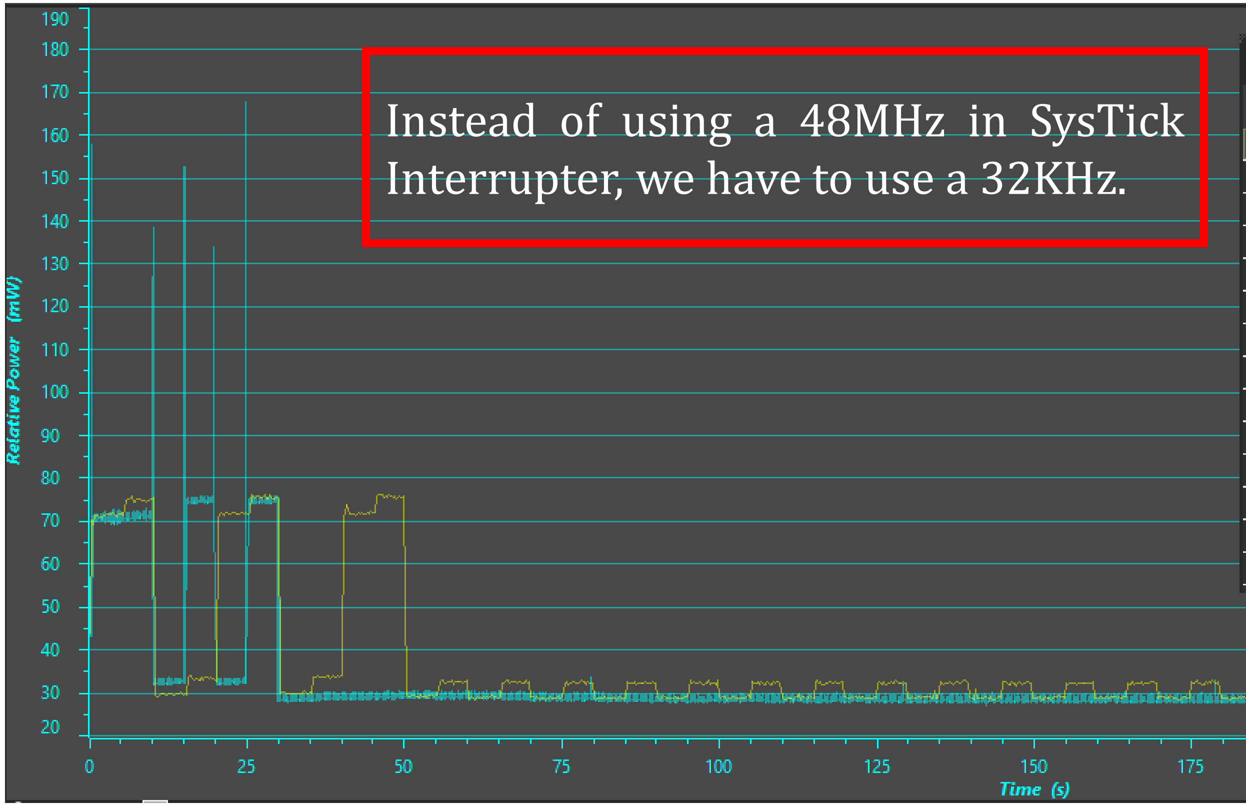


Name	Energy 1	Delta (%)	Energy 2
System			
Time	300 sec		
Energy	9471,146 mJ	-9,6	10475,939 mJ
Power			
Mean	31,5704 mW	-9,6	34,9197 mW
Min	27,2095 mW	-2,5	27,9167 mW
Max	167,9806 mW	2,4	164,0899 mW
Voltage			
Mean	3,3000 V	0,0	3,3000 V
Current			
Mean	9,5668 mA	-9,6	10,5817 mA
Min	8,2453 mA	-2,5	8,4596 mA
Max	50,9032 mA	2,4	49,7242 mA
Battery Life	2xAAA: 4,6 day (est.)	10,6	2xAAA: 4,1 day (est.)

Figure 9 – Comparison between Hibernation Modes (Blue) and Low Battery (Yellow).

Consumption – Hibernation Mode x Low Battery Mode

- Comparing Nominal Mode with Hibernate Mode, there is a savings of more than 9.6%, increasing battery life by 0.5 days.



EnergyTrace™ Profile (Relative Measurement)

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Battery Life	2xAAA: 4,6 day (est.)	10,6	2xAAA: 4,1 day (est.)

Figure 9 – Comparison between Hibernation Modes (Blue) and Low Battery (Yellow).

4. Results during the prototyping

Test aided by Tracealyzer tracing tool [6].

System Initialization:

- Memory allocation for Handlers, Tasks, Queues, etc.
- CPU at 100%;
- Task execution period is 100ms;

Hibernation mode :

- Only ***TaskManager*** are running;
- CPU lest than 10%;
- Task execution period is 500ms;

Nominal mode :

- All the tasks are running;
- No CPU limit;
- Task execution period is 100ms;

Low Battery mode :

- Just ***WatchDog***, ***HouseKeeping***, ***DataStorage*** and ***TaskManager*** are running;
- CPU lest than 10%;
- Task execution period is 100ms;

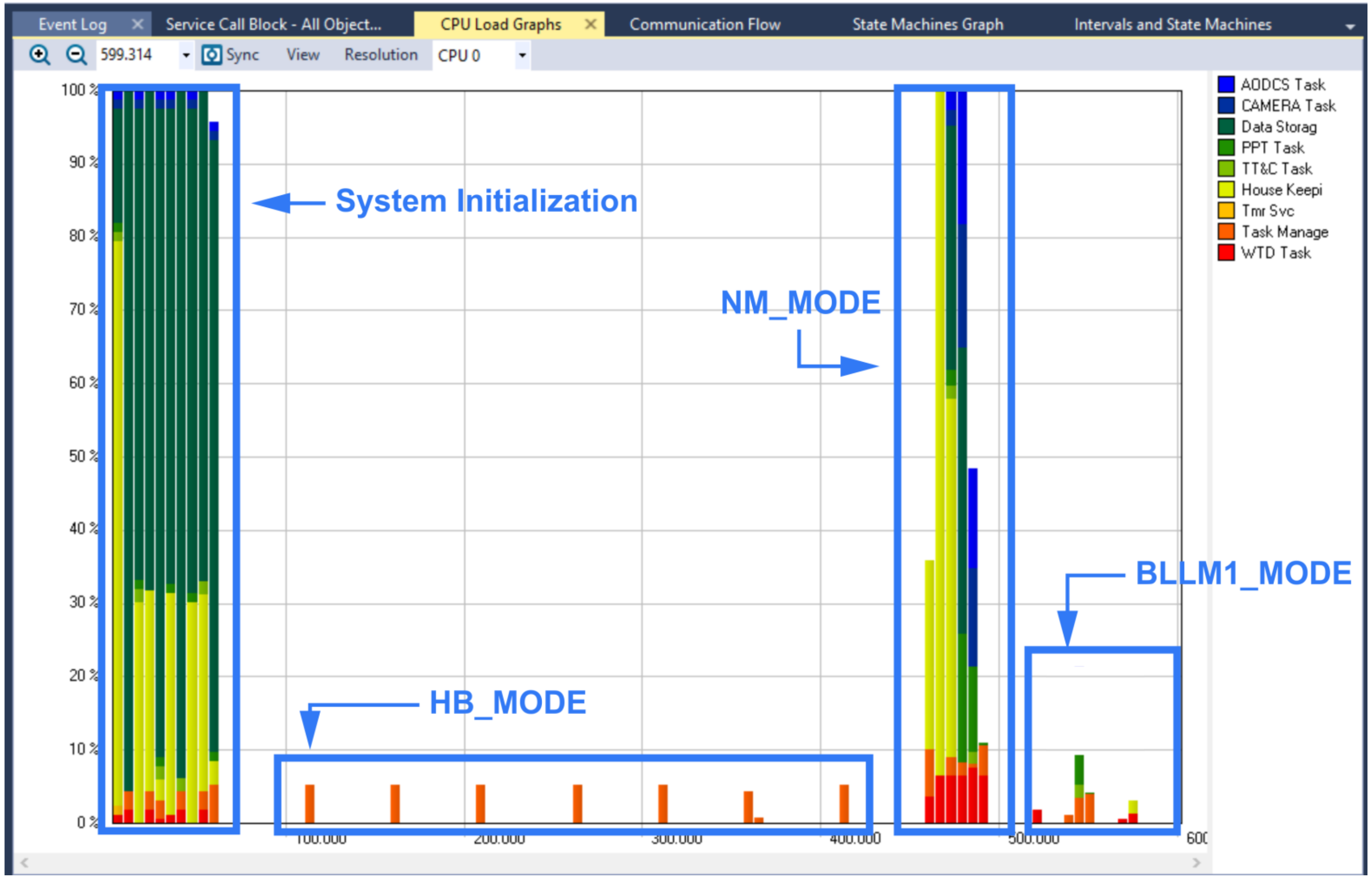
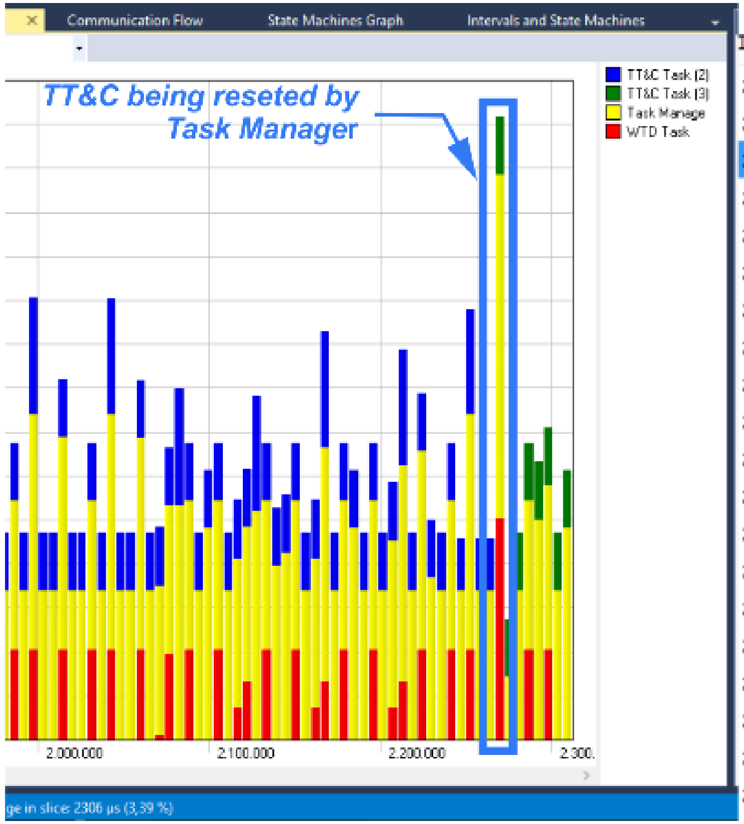


Figure 10 – Tracealyzer snapshoot of the system running.

Anti-Lock System:

- Watchdog at software level;
- This approach prevent Single Event Effect (SEE), but not effects caused by Total Dose Ionization (TID) [7];



Timestamp	Actor	Event Text
2.270.136	WTD Task	free(0x20000A80) released 408 bytes
2.270.173	WTD Task	free(0x20000C18) released 96 bytes
2.270.213	WTD Task	vTaskDelete(TT&C Task (2))
2.270.213	TT&C Task (2)	Context switch on CPU 0 to TT&C Task (2)
2.270.213	WTD Task	Context switch on CPU 0 to WTD Task
2.270.278	WTD Task	xQueueSend(Queue #4)
2.270.306	WTD Task	vTaskDelayUntil(2283)
2.270.349	IDLE	Context switch on CPU 0 to IDLE
2.270.916	IDLE	OS Tick: 2270
2.271.916	IDLE	OS Tick: 2271
2.271.938	IDLE	Actor Ready: Task Manage
2.271.960	Task Manage	Context switch on CPU 0 to Task Manage
2.271.990	Task Manage	xQueueReceive(Queue #4)
2.272.015	Task Manage	malloc(408) returned 0x20000A80
2.272.053	Task Manage	malloc(96) returned 0x20000C18
2.272.131	Task Manage	xTaskCreate(TT&C Task (3))
2.272.144	Task Manage	Actor Ready: TT&C Task (3)
2.272.168	Task Manage	vTaskDelayUntil(2276)
2.272.210	TT&C Task (3)	Context switch on CPU 0 to TT&C Task (3)
2.272.242	TT&C Task (3)	vTaskDelayUntil(2276)

TT&C do not set the bit.

WatchDog deletes the task.

TT&C being reseted by Task Manager

Figure 11 – Tracealyzer snapshoot of the system running.

4. Results during the prototyping

Printed Circuit Board:

- The PCB was designed using the KiCad EDA;
- Two Layers: a signal layer and a ground layer.
- 1206 SMD package;
- To reduce the inductance → Traces with 45° angle corner and as short as possible.
- The feed and ground connections were made using vias, saving space and decreasing the Electromagnetic Interference (EMI).
- It was not possible to have an intact ground plane and some traces were routed on the bottom layer, which may increase the EMI.
- The PCB dimensions are 95.89x90.17mm, which was based on the PC104 specification [8].

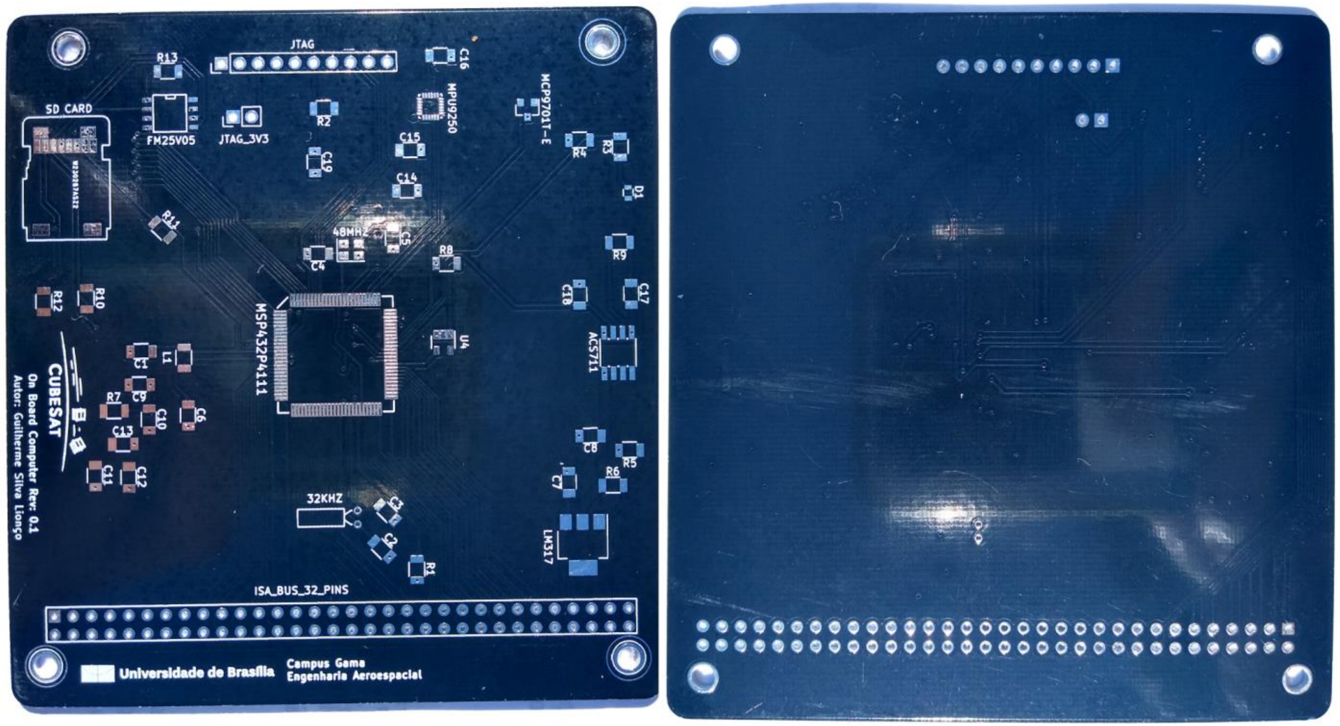


Figure 12 – PCB top and bottom view.

- According to the results, MSP432P4111 is a feasible choice for low power and intermediate performance scenarios. Also, the using of TI-DriverLib as Hardware Abstract Layer helped the Software development, due to its intuitive functions.

- The use of FreeRTOS as a real-time operating system is an adequate choice for low RAM microcontrollers. Also, the using of Tracealyzer helped in the software debug, provide a visualization of the run-time behavior or the system.

- It was also seen that Watchdog at level software worked as a form of redundancy in cases of partial system lockup, avoid all the OBC reset. In addition, preliminary software can now change state according to some input, for example brightness.

6. Future Work

- A point of extreme priority to be resumed is the purchase and welding of the components, as it was not possible to test the PCB. After this step, the software tests may be performed in the OBC hardware, which means that the consumption and performance will be more accurate than in the *TI-Launchpad*.

- The second point is the use of the 32 KHz clock rate as the *SysTick* frequency source during satellite hibernation mode. It has been concluded that using a single clock for both high performances and hibernates mode does not make OBC robust in low battery scenarios.

- The use of multiple watchdog levels is not sufficient to decrease the risk of radiation effects on OBC. The use of COTS components decreases system reliability and other forms of protection should be considered.

References

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Thank you!
Muchas Gracias!