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Progress Report: FlatSat Platform for GOLDS-UFSC and Future Missions

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Abstract

CubeSats are small satellites, known as "nanosatellites," that are used for Earth observation, scientific research, and remote sensing applications. Despite their growing popularity, CubeSat missions usually suffer from a significantly high failure rate. To address the issues encountered in CubeSats, a more rigorous verification and validation (V&V) process of the system can be adopted, using a FlatSat. A FlatSat is an electrical model of the satellite with the subsystems mounted side by side on a workbench. This approach is gaining popularity in small satellite applications due to its ability to integrate and test systems at a level that would otherwise be complex and error-prone. An example of a FlatSat platform is the one developed at SpaceLab/UFSC for testing the FloripaSat family of satellite platforms. This FlatSat was designed to be highly configurable, capable of testing and monitoring CubeSat subsystems, reading operation data, and injecting faults into communication buses. However, the FlatSat platform itself has not yet been fully tested, and no full satellite mission has been developed using it. This paper presents the initial exploration of the platform, starting with basic electrical testing and progressing to reading real data from a CubeSat subsystem. The tests are divided into three parts: (i) first, electrical and power tests are performed to validate the physical structure of the FlatSat board; (ii) then, the MicroZed is attached for initial design validation and on board sensor tests; (iii) finally, satellite's subsystems are connected to conduct temperature and current reading tests, as well as interface with a subsystem simulation application running on MicroZed. To carry out these tests, embedded Linux and the MicroZed's programmable logic are used, providing a highly

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reconfigurable and versatile platform for testing and data acquisition. This configuration allows for future expansion of FlatSat functionality, including more complex applications than those initially envisioned. The first part of the tests aims to create a validated and secure environment for implementing the MicroZed and satellite modules, as well as conducting their tests. These tests are designed to simulate CubeSat operational conditions, and the results aim to validate the basic use of FlatSat, paving the way for future applications.

1 Introduction

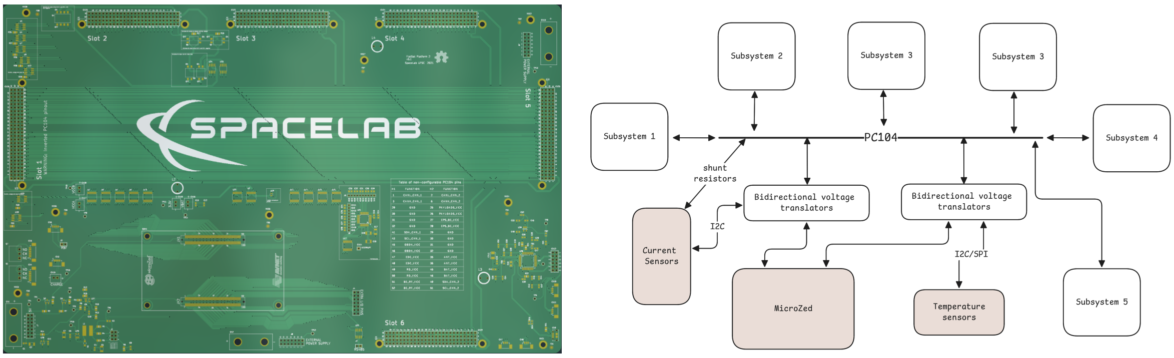
The space industry's small satellite development has grown explosively over the years, in particular CubeSats, which are nanosatellites, with lower cost and complexity, played a important role in it [1]. Because of these characteristics, CubeSats have shown great importance in the area of technology demonstration and in-orbit validation [1]. In addition, these satellites are widely used in student-driver missions, contributing to student training while fostering technological and scientific development [2].

Even tought these satellites can be developed relatively fast and inexpensively, numerous issues can arise both during development and throughout their mission. For instance, launch-related mechanical failures, software bugs, and radiation-induced faults are just a few of the potential complications. To mitigate these, a extensive Verification and Validation (V&V) campaign can be used [3], which employs various methods to validate the system against likely and unlikely scenarios, observing its behavior in a way to indentify vulnerabilities.

One valid option for the V&V campaign is the usage of a FlatSat, which is a eletrical model of the satellite, where the satellite's subsystems are assembled and connected side by side over a workbench [4]. Such platforms, according to [4], have grown in popularity among small satellite applications. FlatSats provide a broad view of the system operability, easing the V&V process from both the hardware and software perpective, they allow the early detection of some of the problems mentioned previously, as seen in [5, **?**]. For instance, software bugs and system-level integration testing can be quite complex and error prone without proper testing instrumentation, especially if the team lacks experience, as it happened in FloripaSat-1 [6] V&V campaign.

During Latin American CubeSat Workshop (LACW) 2022, a FlatSat was proposed at [7] with the aim of aiding the development of satellites at the SpaceLab laboratory at the Federal University of Santa Catarina. The project support up to six subsystems, including service modules and payloads, interfacing with a MicroZed [8] and build-in circuits for sensing, monitoring and controlling the system. The aim of the MicroZed is to make it possible to simulate the inputs and outputs of satellite modules in order to observe the response of a dispositive under test. Figure 1 describes how the project is architectured.

In order to utilize the FlatSat implementation proposed by [7] to its full potential, with similar funcionality to an Electrical Ground Support Equipment (EGSE), there is a need to validate the platform itself. This first step aims to create a validated and secure enviroment to actually conduct tests and is composed of the basic eletrical validation of the Printed Circuit Board (PCB), which includes checking for design and fabrication flaws, checking the power circuitry operation and evaluate the built-in



(a) FlatSat2 Platform

(b) Architecture diagram

Figure 1: FlatSat Architecture

sensors of the board.

Following the platform validation, the plan is to attach a satellite subsystem to collect real operation data, specifically ambient temperature and current measurements. Naturally, a subsystem will need to communicate with other subsystems, which will be simulated by the MicroZed. The MicroZed will also collect data from the onboard sensors and store it to further processing and analysis. Additionally, subsystem data obtained from the simulated communication the MicroZed will also be presented.

As said previously the platform has yet to be tested and, currently, there is no application developed for it, thus conducting this initial exploration is necessary to validate the basic funtionality of the proposed FlatSat. This study paves the way for more complex applications, including EGSE-like operation, futhermore, it also allows the platform usage for testing GOLDS-UFSC and future missions, enhancing their V&V campaigns.

The remaining of this work is organized as follows. In section 2, the methodology used to validate and collect data of the FlatSat is described. The process of testing, validating and collectiong operational data of the platform are desbribed in detail in section 3. Additionally, obtained results are also discussed in section 3. Further discussions and directions are shown in section 4. Finally, in section 5, conclusions are presented.

2 Methodology

Taking in account the aforementioned objectives, a test flowchart becomes necessary, mainly to ensure result validity for each test and to provide an overall test suite organization. In addition, it also helps to avoid possible unrelated sources of error interfering with the results. The flowchart can be seen at Figure 2. The tests follow the SpaceLab's methodology for initial subsystem testing, which can be seen at [0, 0], additionaly they also follow the European Cooperation for Space Standardization (ECSS) testing standard [0] when applicable.

2.1 Electrical validation

The electrical validation process of the PCB is essential for identifying manufacturing and

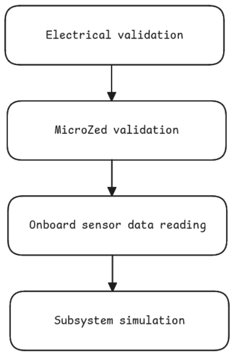


Figure 2: Tests flowchart

assembly errors, such as short circuits, open circuits, poor soldering and missing components. It also helps uncover design flaws that could lead to permanent damage to connected modules or cause malfunctions. Initially, considering the need to guarantee this safety, continuity and connection inspection tests were carried out in order to validate the design and manufacture of the board [0]. To do this, all the connections on the board were tested using a multimeter, along with the design schematic (in order to check that the connection is consistent with what was planned). After this first stage, it was possible to carry out power and signal tests along the board, i.e. to ensure that the power supply and the signal applied to the FlatSat are able to reach all the expected points [0]. To carry out this experiment, stimuli was applied via the power supply bench and then the voltages at the expected points were measured using a multimeter and an oscilloscope.

2.2 MicroZed validation

As mentioned earlier, the FlatSat has a MicroZed embedded in its design, this addition extends quite a lot the functionality of the platform. However, the System on Module (SOM) has to be tested before the integration with the board, as to eliminate any possibility of hardware failures unrelated to the FlatSat. Testing it also involves booting the SOM with a embedded linux operating system as well as the Zynq's Programmable Logic (PL) design. Those were used for all operations of the MicroZed, such as simulating subsystems or collection sensor data.

Choosing Linux as its operating system was done mainly for future use, as Linux provides a highly customizable system with a very large ecosystem of libraries, device drivers and packages. By using it, development time is reduced, especially as application complexity grows towards a EGSE-like functionality.

Next, the MicroZed was integrated into the platform, and its operation reevaluated to identify any errors introduced by the FlatSat design. Once any present errors are addressed, the test suite can progress to collecting data from the onboard sensors. This next step intends to only verify the basic functionality of the sensors and its communication with the MicroZed, since a more thorough test is done later in a real operation setting, with satellite subsystems integrated to the FlatSat.

2.3 Functional tests with real subsystems

Following the test suite, the GOLDS-UFSC mission's Electrical Power System (EPS), named as EPS 2.0, was connected to the FlatSat as a representative subsystem. Being part of the FloripaSat-2 platform, proposed in [0], this subsystem has been thoroughly tested in the previous FlatSat version and during integration tests with the Engineering Qualification

Model (EQM) of GOLDS-UFSC satellite.

As a well known module, the usage of it as a testing reference facilitates the validation of the FlatSat, since its usual behavior is already documentated.

After the EPS validation step, it was possible to test the sensors in a real setting. In this sense, the Environmental Data Collector (EDC), proposed in [0], was used as a payload. As is the case with EPS, EDC has been thorougly tested and has a well known behavior, since it is the main payload for the GOLDS-UFSC mission [0] and was also tested with the EQM.

The test aims to collect readings from the built-in sensors and verify its accuracy and feasibility. In it, there was two measurements being collected concurrently, one being ambient temperature readings by the TMP112 [0] sensor and the other one being EDC current consumption readings using the INA219 [0]. Measurements of the EDC current were also made using a Keithley DMM6500 digital multimeter [0] to serve as a reference.

Lastly, the test suite's final test aims to collect real operation data from the EPS, by simulating the FloripaSat-2 platform OnBoard Data Handling (OBDH) module [0] through the MicroZed. During simulation, the SOM gathered the available telemetry data obtained by mimicking OBDH commands in the EPS's Inter Integrated Communication (I2C) interface.

The OBDH simulation was running simultaneously with the measurements from the previous test, so that the EPS telemetry data could be compared with the platform's built-in sensors data. Perfoming both tests concurrently served to assess MicroZed's ability to handle multiple applications running simultaneously, which will be used extensibly in future works.

Furthermore, having access to the satellite communication busses allow the FlatSat's usage for communication and fault injection analysis as done in [0], as well as to do a performance characterization of the bus like the one made in [5]. Therefore, the proposed test also serves to evaluate the feasibility of conducting these intricate tests and analysis.

3 Implementation & Results

In order to test a system, in this case the FlatSat platform, it is imperative to build a sequence of operations that are consistent with the system and the related objective. For this article, the test flow described at Figure 2 was followed.

3.1 Electrical Tests

With a view to electrical validation and the safety of the other devices, the first step was to ensure that there were no short circuits within the power systems and then to investigate the signal connections on the board. To carry out both steps, an inspection was carried out using a multimeter and the original schematic of the board. As a result, it was possible to find several short circuits in the voltage translators, as well as one between one of the input voltages and ground. These problems were caused during the soldering stage of the FlatSat components, making it necessary to remove excess solder flux and replace some of the voltage translators.

After ensuring that Flatsat was electrically coherent with what had been developed, it was necessary to check the routing on the board, so that it would be possible to understand and analyze how it worked. An inconsistency was found in relation to the board's purpose: the pinouts related to the communication protocols were not consistent with those found on Zynq's available peripheral controllers for the Processing System (PS), making it impossible to use the board for these protocols via PS. In order to continue testing the rest of the board, access via PL was used.

Finally, with regard to the system's power system, there was two problems in the circuit, one relating to the Power_Enable power input, making it necessary to use an external source to supply 3.3V directly. While the other one was a misdirection of the Zynq's IO banks enable pin, which is an output signal generated by the SOM, however, the FlatSat circuitry considered this signal to be an input, therefore, to avoid any issues, this part of the power circuitry was not populated.

3.2 MicroZed Setup

After making sure that the platform's power circuitry and the SOM itself work as intended the next step is to create a custom embedded linux image and hardware design. For that, it was used Xilinx's Petalinux and Vivado Design Suite tools. Using Vivado, a simple hardware design was made, which basically routes the relevant peripherals, like the I2C controllers, to the sensors and subsystems interfaces.

For the Progamming System (PS) side of Zynq, a custom embedded linux was made, which includes essential libraries, device drivers for the FlatSat sensors, custom services and user applications. The image includes a sensor reading service, which provide a simple interface to enable specific sensor readings, manage log files, etc. Futhermore, it also have a application for OBDH simulation that communicates with EPS, requesting its telemetry periodically.

With the SOM configured and working individually, it was attached to the FlatSat aiming to test the software applications, also serving as a preliminary test for the onboard sensors. To assess the INA219 functionality and the sensor reading service, resistors and one light emitting diode (LED) were connected to the power busses of the platform, which were powered by a digital power analyzer. Additional resistors were added in 30 second intervals, as to change the current drawn by the LED and test the responsiveness of the current sensor.

The results came in as expected, the service was able to read data from the onboard sensors, which includes temperature measurements from the TMP112 and current, bus voltage, shunt voltage and power measurements from the INA219. At this stage, it was discovered an issue regarding current readings, which had a greater inacurracy as the drawn current gets smaller, particulary when the current is less than 10 milliamperes (mA). This happens mainly due to the device driver resolution, which only provides measurements that are integer multiples of milliamperes, therefore changes on current of less then 1 mA will most likely be unnotice. More discussions about measurement adequacy are made at subsection 3.3.

3.3 Functional Tests

As per the test suite, a test setup was made to allow the execution of functional tests with real subsystems, these will involve mainly the EDC and EPS subsystems, both having well documented behaviors, which aids the valida-

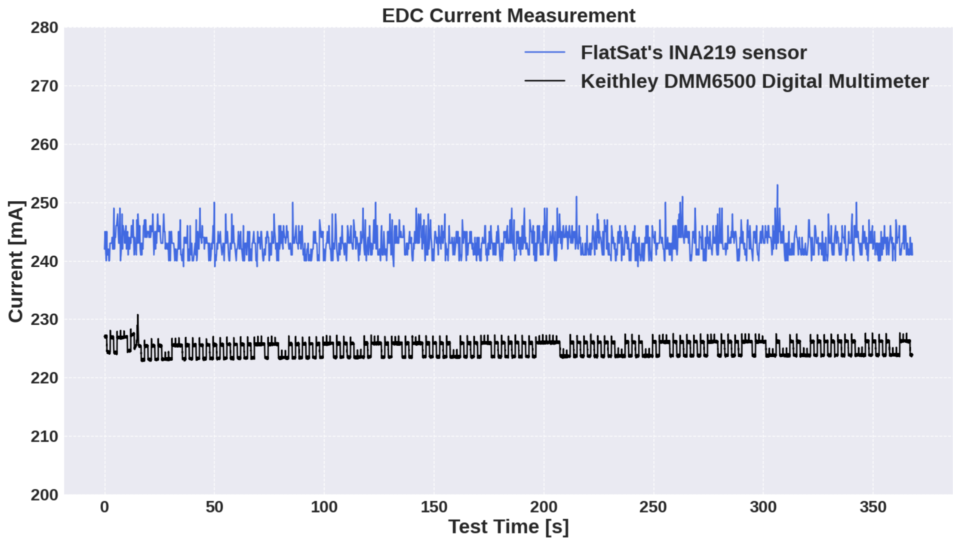


Figure 3: EDC current test readings.

tion process of the FlatSat. A diagram describing the setup can be seen at Figure 4, for simplicity the diagram does not include the power connections besides the 5V payload bus, which is produced by EPS.

Both EPS and EDC were powered by a lithium-ion battery, being the same as the one used in the GOLDS-UFSC mission satellite. As for the MicroZed and the onboard sensors, they were powered by a digital power analyzer connected to FlatSat's power circuitry, which had to be adapted due to the problems described at subsection 3.1.

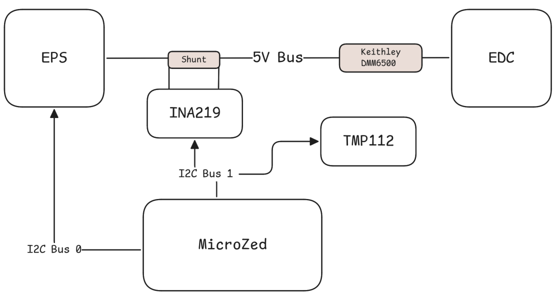
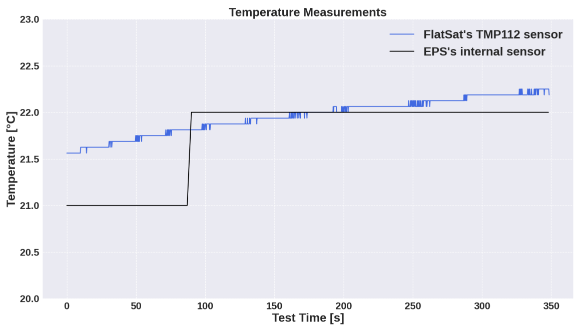


Figure 4: Test setup diagram.

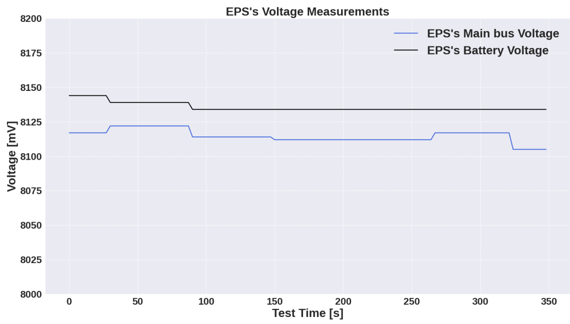
As stated in section 2 this setup is used for two tests to run simultaneously, where the first one is composed of current measurements to monitor EDC power consumption, taken in 250 millisecond intervals by both the INA219 and DMM6500, and the second consists of reading EPS telemetry and TMP112 data every three seconds.

The EDC consumption results can be seen at Figure 3. The comsumption itself is in line with EDC's datasheet [0] and the one observed during tests of GOLDS-UFSC mission. By looking at the chart it becomes clear that the INA219 readings, represented by the blue curve, have quite a bit of deviation from DMM6500's reference readings, with the largest sample to sample deviation being of, approximately, 27 mA, the lowest 13 mA and the average 18 mA, which represent 10.81%, 5.37% and 7.51% of relative error, respectively.

This difference can be explained by driver details and overall precision difference between the devices. As discussed previously, the



(a) Temperature readings.



(b) EPS voltage readings.

Figure 5: Subsystem simulation readings.

INA219 driver used, which is the linux kernel device driver for INA2xx devices [0], can only provide integer multiples of milliamperes, moreover, it also sets a default calibration configuration on the sensor, those two factors can explain the deviation seen at Figure 3.

To mitigate this, a custom device driver can be made to provide a runtime calibration configuration and microampere reading resolution. However, that would be quite time consuming and would require a specific analysis to determine whether it is justified. After all, if a highly precise reading is imperative to the test, using the DMM6500 or a similiar device directly would be a prefered approuch.

Concurrently to the EDC consumption test, the MicroZed had a running application that simulates OBDH data requests to EPS and was collecting ambient temperature readings. The application simulates OBDH data requests using it's own firmware drivers and tasks [0] developed to communicate with EPS, minor modifications had to be done at the low level interfaces due to OBDH running FreeRTOS as an operating system, as opposed to the MicroZed running embedded linux. The data requests were composed of battery voltage, main bus voltage and temperature, all acessible in the EPS parameter table [0] through its I2C interface.

A graphic containing both the ambient temperature from TMP112 and EPS microcontroller temperature measurements can be seen at Figure 5a. The purpose of the comparison is to quantify the difference of temperature experienced by EPS and the actual ambient temperature. This difference is relevant not only to understand the heat produced by the board, but also to verify the behavior of the subsystem, since it takes in to account the current temperature to enable specific modules. By looking at the Figure 5a, it becomes clear that the exposed temperature paremeter is a integer value, nevertheless, it still allows for a rough estimate of its behavior, which, in this case, resembles very much the ambient temperature readings from TMP112.

As for the voltage paremeters from Figure 5b, both measurements are obtained directly from EPS and represent the FlatSat's capability to track the system's parameters and facilitate behavioral analysis of all available data, which can be used to perform more sophisticated tests, as described in subsection 2.3. The readings itself are not that interesting, since the test time was about 6 minutes and, for a good understanding of the battery behavior over time, much more time would be needed, moreover, charge measurements would be better for that type of test as opposed to voltage ones. An interesting result taken from the Figure 5b is to observe the power loss due to the EPS circuitry, which manifests in the voltage drop between battery voltage and main bus voltage.

4 Discussions and Directions

This article developed a test suite in order to do a follow up of the work presented at LACW 2022 [7], in particular, it aims to perform the initial validation of the proposed FlatSat.

As the test suite was carried out, the validation importance became apparent, specially the electrical validation, which, if had not been done, would result in several functional issues and could cause permanent damage to the platform components. In addition, the schematic reassessment was also critical to the tests, since it unveiled routing issues that would hinder MicroZed's ability to communicate with the subsystems.

For the validation's software side, the decision to start with embedded linux has facilited considerably the application and service development, it also eased testing them. Furthermore, the flexibily that a linux based operating system brings has allowed the applications and services to be integrated in a much simpler way, which will be crucial to the platform as new tests and services get added.

Moreover, effort on developing these new features are already being made. Examples of them are: adding a internal database to MicroZed, as well as a cloud based one, to organize test data, extending the simulation application to replicate more subsystems, adding support to other sensors, MicroZed remote access through Secure Shell (SSH), among other software applications. Extending hardware capabilities of the platform through daughter boards is also planned, with a major example being a board to interface other connector types with the PC104.

5 Conclusion

This article presented the beginning of the V&V process of the FlatSat platform proposed by [7]. In addition, applications and services were developed to utilize the platform's builitin features.

A overall design revision was made, including a schematic review, in which both problems and improvement points were found. For instance, the MicroZed routing and FlatSat's power circuitry will have to be corrected in the next version of the platform.

Moreover, an effort to test and validate the platform's onboard capabilites, specially the MicroZed and sensor integration, was carried. It covered both the hardware and software side, starting with electrical tests of the platform, passing to basic software applications embedded in the SOM, to, finally, collecting real operation data from both onboard sensors and real CubeSat subsystems.

From obtained results, it was possible to see that the addition of onboard sensors and the MicroZed provides much more data retriving capabilities to the platform, which eliminate the need to rely on the subsystem's sensors to monitor the whole system's behavior. Even thought the sensors accuracy have some caveats, like in the INA219 case, it, nevertheless, can be useful for estimates and overall monitoring. In addition, MicroZed's presence provide a wide range of possibilities, including test automation and subsystem simulations, which will be explored in order to enhance V&V campaigns for future missions.

Finally, lessons learned and future directions were discussed. As addressed throughout this work, the FlatSat has a great potential for aiding V&V campaigns, however, there still much effort to be done to realize that potential, for that, possible additional features to be developed were presented. Furthermore, the project of the platform is open source and can be found at: `https://github.com/spacelab-ufsc/flatsat-platform2`.

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