IMPROVING SPACE ROBUSTNESS AND RELIABILITY ON NANOSATELLITE ON-BOARD EQUIPMENT

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Small satellites allow the reduction of costs and development time, making it possible to increase access to space and encourage more frequent launches. Gradually it is being used as a resource for teaching space engineering as well as explore for the development of innovative technological and scientific solutions. In addition to universities, research and technology centers have benefited from the opportunities to improve knowledge within their projects or in partnerships. Due to nanosatellites high early mortality rates, it is necessary to constantly improve manufacturing processes in order to provide more resistance and reliability to on-board equipment. In this scenario, this work presents the experience acquired using a nanosatellite payload board for environmental data collection, named EDC for short, where good practices are introduced to the former ones in order to make it more robust to outer space. A partnership was made between the INPE´s space segment engineering located in São José dos Campos and the its Northeast regional unit in Natal, responsible for the EDC development. The EDC project was developed with the objective of expanding a prospective satellite constellation for the Brazilian Environmental Data Collection System (SBCDA) and demonstrating its feasibility on nanosatellites. Improvements to the EDC design were targeted for greater resistance to launch and life-in-orbit efforts, this included quality assurance inspections, electronic board reworks, reinforcement of the coupling between the main and daughter boards, application of resins to encapsulate and to structure components. Thermal and reliability analysis was also carried out and environmental tests performed at INPE´s Integration and Testing Laboratory (LIT) for board qualification. The payload circuitry redesign was kept out this work scope. This proposal is very much in line to the activities developed by INPE's Small Satellites Division (DIPST) for improving space mission success rate and in accordance to INPE's bylaws on fostering science and technology, human resources training and the knowledge dissemination for the benefit of Brazilian society.

1. Introduction

All satellite projects present risks, but for nanosatellites the failure rate is quite expressive, around 35% of unknown causes occur on the first day [2]. Thus, the method to increase the robustness must use several manufacturing techniques and different verification tests, to increase the probability of the flight being successful.

This article discusses a combination of methods to increase the robustness of Printed Circuit Board Assembly (PCBA), with the quality necessary to withstand the rigorous space environment. PCBAs developed for nanosatellites may have characteristics similar to commercial boards and consequently not be considered suitable for the space environment. In order for them to be used, it is necessary to adopt corrective measures to reassess whether they are suitable for being embedded in nanosatellites.

The methodology adopted in this project was applied to the EDC - Environmental Data Collecting equipment, which is a payload developed for nanosatellites to collect data from platforms spread across the Brazilian territory, the PCDs (Data Collection Platform). The data collected on the ground by the Brazilian Environmental Data Collection System (SBCDA) is used for research and climate studies, are also used by other users, who have access to data such as wind speed, solar radiation, rainfall, etc.

Preparing a PCBA for the space environment involves manufacturing issues through to environmental qualification tests. This article will not address design aspects, despite being considered extremely relevant in the space environment.

The work in [1] describes the thermal verification testing of commercial Printed-Circuit Boards for Spaceflight" exemplifies verification methods, which allow early failure detection and also verify final assembly and integration.

In order to carry out the tests, [2] describes how the test sequence was defined and also how it is possible to carry out a thermal screening of components and evaluate possible failures in the process, materials, design and workmanship.

This article presents a method for improving robustness, which was first used in EDC equipment, to qualify boards with characteristics similar to a commercial spaceflight circuit board. It is important to note that the addition of restraints and restraints was necessary for the vibration environment. Additionally, how important it is to investigate the temperatures of components operating in an environment with no convection. Verification is successful when all final components and assemblies complete the test without failure. It should be noted that at this stage the effects of radiation were not evaluated. The EDC equipment has no flight heritage, but qualification-level testing demonstrates that it will be able to withstand the launch and orbit environment.

2. Background

Although nanosatellites have certain particularities, which differentiate them from other classes of satellites, it is important to prove by various methods that the nanosatellite is fit for flight. And fitness for flight is achieved through the adoption of good engineering practices, tests and verifications at different levels of the nanosatellite. Good practices include manufacturing and analysis techniques such as EEE, FMEA, Outgassing, Radiation Resistance, Derating, Reliability in order to manage lifetime related issues.

Therefore, the success and safety of the flight depends a lot on the work of nanosatellite developers [2]. The safety aspect, for example, may involve failure issues, which can also damage the launch vehicle or a main payload or other nanosatellites.

These assumptions must be considered during the different phases of the project, such as conception, detailed design, qualification and acceptance through exhaustive functional tests, environmental tests and during the launch campaign.

The project must define the requirements for the development and qualification of equipment intended for flight, aiming at obtaining equipment, subsystems and systems, capable of functioning without failure in space, which is a hostile environment.

As the rocket also imposes restrictions [3] for launching the nanosatellite, it is also necessary to test and verify the launcher requirements such as: Mass Property Measurement, Vibration Test, Bakeout Procedure and Thermo-Vacuum Test.

Tests and verifications are essential to verify that the requirements are met. If incidents occur, the nature of the problems and the efficiency of corrective actions must also be evaluated. The objective is to increase the chances of success and improve future projects.

3. Quality Assurance

Equipment for nanosatellites tends to use COTS - Commercial off-the-shelf components with flight heritage [4], but from a manufacturing point of view it is important that the assembly and welding processes produce adequate joints, avoiding developing failures, which lead to early mortality. Therefore, it is important to adopt the best manufacturing and quality assurance practices. The IPC J-STD-001F [5] standard presents recommendations on the assembly and soldering of the components, most used by the electronics industry. The major suppliers of equipment for satellites use this standard.

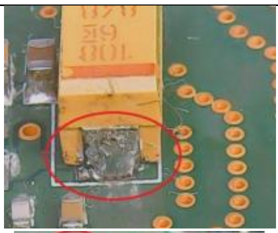
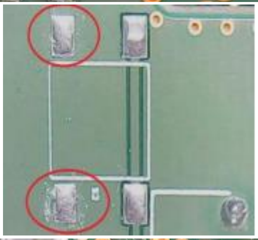
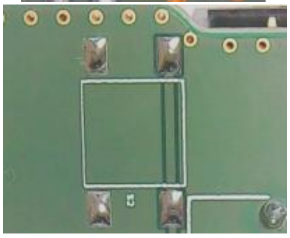
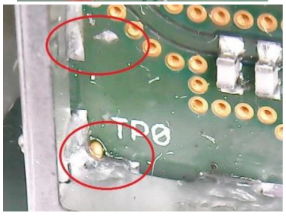
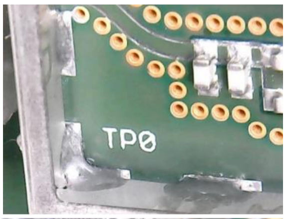
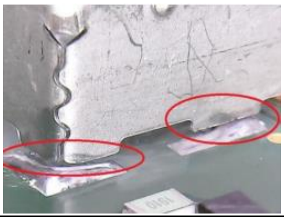
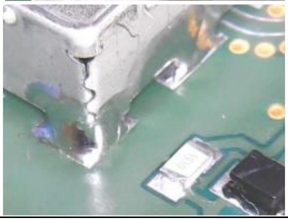
The quality assurance inspection was conducted in order to verify the adherence of the mounting process with the standard requirements IPC J-STD-001F for class 3 [5]. It was identified several non-conformances which includes flux residues, solder excess, disturbed solder, poor wetting, cracks, pinholes, voids, exposed copper, solder balls/splashes, indicating fragility of the final product. These non-conformities pointed out served as guidance for the rework carried out.

3.1. Welding Rework

The batch of EDC units evaluated was manufactured without having to meet the requirements of the IPC standard [5], however the standard was used as a reference for inspections that evaluated the quality of welded joints.

It was decided to rework the joints, with the aim of correcting the problems detected. Table 1 presents some examples of electronic rework performed.

Table 1: Examples of rework performed on the EDC electronic board.

Before rework	After rework	Comments
		Weld with an irregular and inadequate fill. With the rework, the weld was well distributed, without excess, shiny and without major retractions.
		Weld with residue around the pad, grainy and opaque appearance. With the rework, the residues were removed and the weld was shiny and regular.
		Excess solder between Shield and PCBA, fill gaps and solder spatter and other particulates. With the rework the solder was corrected and the PCBA cleaned.
		Contact interface between Shield feet and PCBA pads did not properly form a meniscus between the two parts. With the rework, this union was corrected.

Additionally, the EDC unit was rigorous cleaned with isopropyl alcohol and dried.

3.2. Mechanical Mounting

The electronic components shall withstand vibration during launch and thermal vacuum cycling in space environment. An efficient mounting of the electronic components in a PCBA reduces the mechanical efforts in the connections and improves durability. The mounting can be improved with fixtures made of epoxy resin.

The larger and heavier electronic components, which are more susceptible to damage, were selected to apply epoxy resin fixtures. Figure 1 shows some examples of these fix-tures. The EDC has a mezzanine board (daughter board). In addition to the M2.5 bolt with nut and spacer, normally used to join the daughter board, two blocks made of epoxy resin were installed to increase the points of fixture.

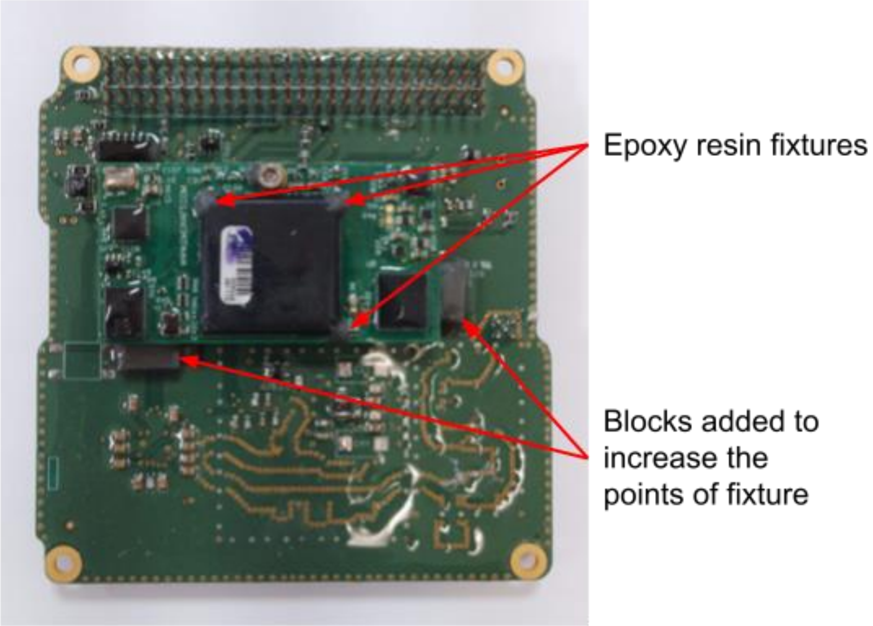


Figure 1: Improvements of electronic component fixture.

3.3. Conformal Coating

Conformal coating, a thin layer of resin applied normally with a painter spray gun, is commonly used in the industry to protect electronic components of harmful agents such as dust and moisture, and to avoid corrosion. Due to the cleanness constraints of the vacuum chamber, it was adopted a qualified resin for use in space.

Figure 2 shows the EDC board before and after applying conformal coating. The conductive parts, such as connectors and shield contacts, shall be protected with masks.

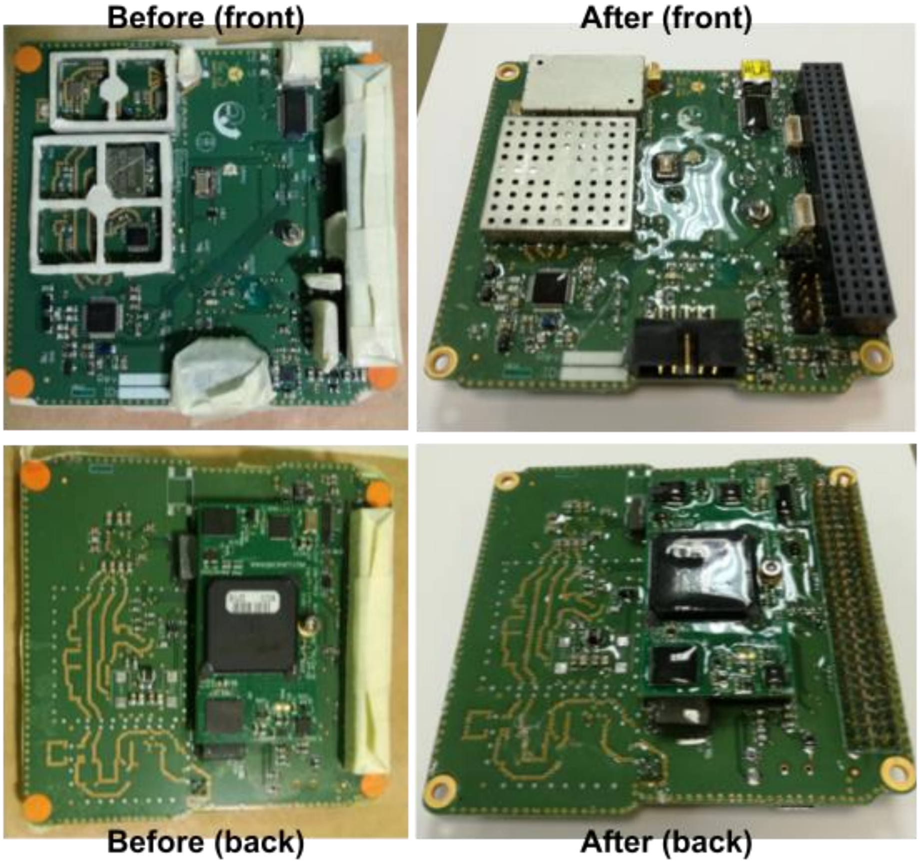


Figure 2: EDC board before and after applying conformal coating.

4. Thermal Characterization

A preliminary thermal investigation was carried out to estimate the operating temperature limits of the EDC Engineering Model PCBA. Such investigation was based on thermographic images obtained in bench tests and mathematical simulations with operating mode thermal load. This partial characterization was necessary since such limits were not specified by the PCBA developer. The results found were used to help defining the temperature limits thermal vacuum tests, preventing the PCBA from being exposed to thermal conditions beyond the limit tolerated by its components.

Figure 3 shows thermographic images of the PCBA, with dissipation in steady state operational mode and laboratory convection thermal conditions.

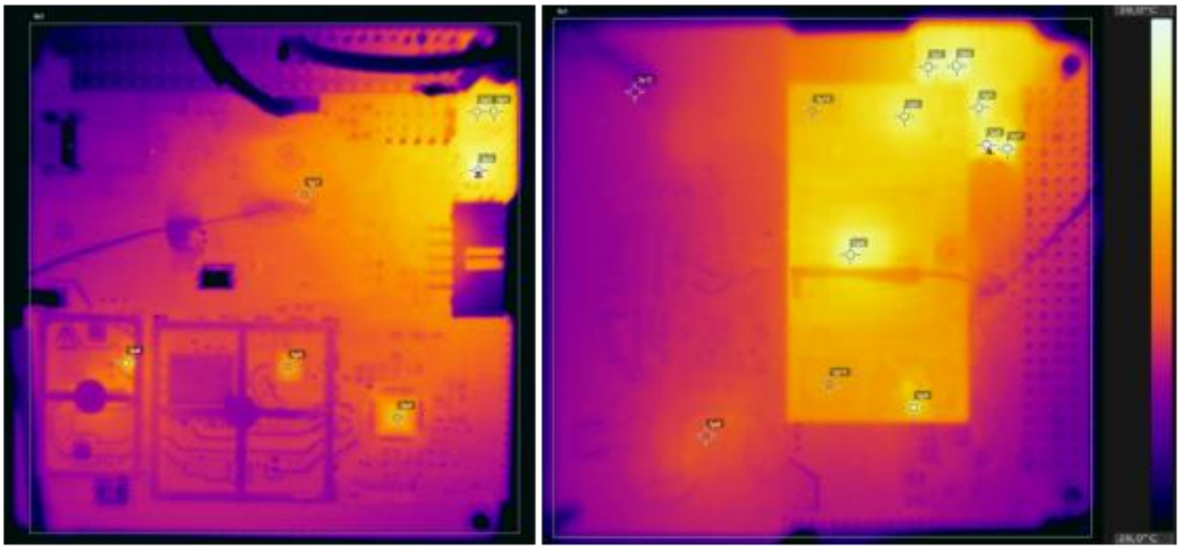


Figure 3: Thermographic image of the PCBA (front and back side).

5. Reliability Analysis

A part count reliability analysis was performed based on MIL-HDBK-217F [6], there are criticisms for being outdated, but it is still widely used [7][8], including INPE, which used the standard in its former projects, and maintains its use as a history and reference for current projects, in order to be able to compare the results between similar projects.

Due to the lack of detailed information at the time of elaboration of this reliability analysis, it was decided to use the method of counting parts, although it is known that this method is used in the initial phase of the project. However, the results obtained add significant information for the analysis of the reliability of the EDC board.

Through this analysis, it was identified that due to the characteristics of the board having relatively few components (378 in total) and being mostly passive components, the equipment failure rate resulted in a low value for a board composed of COTS components, resulting in a high MTTF (Mean Time To Failure), approximately 4 years old. Considering that the standard provides conservative results, we can conclude that despite this fact, the analysis results are satisfactory, as they meet the mission time requirement of 2 years.

6. Environmental Tests

The environmental tests simulate the critical environmental conditions the equipment will be exposed during the mission. During these tests, the equipment is tested from a functional point of view, making it possible to detect failures early and identify problems in final assembly and integration. For the EDC PCBA, vibration and thermal tests were performed.

6.1. Vibration Tests

The EDC board was vibrated as an isolated equipment, not installed to a nanosatellite. The MGSE used to fix the EDC board to the shaker is shown in Figure 4.

Figure 4: EDC Mechanical Vibration Test.

The qualification level established in GSFC-STD-7000B [9] for random vibration was adopted in the vibration test. For each direction was applied an overall of 14,1 GRMS. After the vibration test, functional tests and visual inspection were performed. No damages were detected, indicating that the mechanical mounting procedure was efficient.

6.2. Environmental Thermal Tests

After the vibration test, thermal environmental tests were performed on the EDC PCBA Engineering Model (808681) to prove the unit can minimally withstand the thermal conditions of Space. This unit was tested at the qualification level, considering the temperature limits of critical components, estimated during the pre-test of the characterization of the board. The applied test requirements provide confidence the unit can have a certain level of tolerance in relation to the space thermal environment, based on small satellites typical boundary conditions. These requirements do not include an proper margin to the maximum predicted environmental stress in Space, which depends on each satellite. Considering this equipment as an electronic unit, the test sequence applied was as follows:

1. Thermal cycling “Endurance” test;
2. Functional test;
3. Cold and hot start test;
4. Thermal vacuum test;
5. Bakeout test (although this test is recommended for system level only, it was performed here for convenience, in order to pre-check the contamination rate generated by the unit).

With the objective of optimizing resources and time, tests 2, 3, 4, and 5 were carried out in a combined way in the thermal vacuum chamber. Figure 5 shows a picture of the PCBA inside the climate chamber. The test setup in the thermal vacuum chamber can be seen in Figure 6.

Figure 5: EDC in the Climatic Chamber for the thermal cycling test.

Figure 6: EDC installed inside the thermal vacuum chamber (left). On the right, functional test setup used during the thermal vacuum test.

7. Conclusions

In order to achieve a suitable lifetime in space, satellites need to comply to a minimum list of items on Qualification and Acceptance (Q&A) testing. This work described some procedures that may help ensuring the equipment robusteness in the designs so it may meet the performance expectations required for a specific mission – from assembly and transport to launch and operation.

Manufacturing care prepares the product for the space environment. The fact that the EDC had no flight history motivated it to approach all activities with additional attention.

The screening tests performed before the vibration tests help to discover flaws at the beginning of the hardware development and allow a very assertive analysis about the product to be tested. This approach saves time in the later phases of a project. Infrared thermography of circuit boards is important to identify hot spots on boards. As most vibration test failures are not fully detectable, only thermal cycling can assess the success of the assembly and mission. The association of methods to increase PCBA robustness is considered a good practice, as it improves the ability of this PCBA not to fail under certain conditions.

This method was used in EDC to increase robustness and was designed to meet expected reliability requirements. It has proven to be a successful method to prepare products with commercial plate characteristics and increase their reliability.

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