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The experience of designing and developing the on-board electronics of a Cubesat in Brazil

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In this paper, the design and the development process of the on-board electronics for a Brazilian nano-satellite is described. The Floripa-Sat mission is under development by undergraduate students from UFSC and IFSC, organized in five main teams: On-board computer; Energy; Communications; Attitude control; and Payload. Since May 2013, undergraduate students have been working in the Printed Circuit Board (PCB) design for the satellite's subsystems, under the direct supervision of graduate students. Although the process of sourcing, purchasing and assembling the components for an embedded system is well known and established, depending on the region where it takes place it may encounter particular issues regarding available suppliers, logistics and taxation. This paper discusses several challenges and solutions, resulting from the group's experience in the process of Floripa-Sat's PCB design and manufacture in Brazil, exposing some differences when working with local and international service providers.

Introduction

The Floripa-Sat project started in July 2012 with the release of the internal report entitled "Floripa-Sat: Project Presentation Document"[1]. This document was used to motivate and to guide undergraduate students in the development of a complete Cubesat mission. At the beginning of the project, the students had to search the CubeSat literature, in order to understand the development process. For almost 18 months, all aspects of Cubesat missions have been studied and investigated. Since May 2013, undergraduate students from UFSC and IFSC have been working in the Printed Circuit Board (PCB) design for the satellite's subsystems, under the

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direct supervision of graduate students. The students are organized in five main teams: On-board computer; Energy[2]; Communications[3]; Attitude control; and Payload.
The teams have experienced issues regarding the development of this type of project in Brazil. For instance, when compared to developed, and even with other under development countries, the Brazilian legislation makes the project costs and duration increase considerably. In addition, some technical decisions have to be revised as a result of suppliers availability, costs and deadlines.
In the remaining of this paper, all these aspects are further discussed. The designed boards are introduced, and the next steps are presented.

The Beginner's Challenges

Almost all the team members are new to the field of PCB design for space applications. As a result, since its beginning the project had as a secondary goal to acquire knowledge. The fact that the team is composed by students from different levels, each one with its own schedule, it results in extra challenges for the project management. However, the team members natural curiosity and the project's challenges and innovative nature overcome all the difficulties.
As a starting point, the team decided to explore their established knowledge used in the development of non-aerospace PCBs.
As the satellite dimensions were already known, one of the first decisions was to define the PCB's sizes. As for the PCB characteristics, the decision was for a regular FR4 dual layer board. The 0805 size passive components were chosen, as although small, they are big enough to allow hand soldering. The exception was some components in the communication section where 0602 was needed in order to strictly comply with recommendations from the manufacturer datasheet. Also a special attention regarding the components temperature interval tolerance was necessary, due to the high temperature variation during both, the satellite's transport, and the operation phases in space (facing the Sun or in the shadow).
The welding process was performed manually but, in order to obtain higher quality, the process was outsourced to the PCB manufacturer (internal development was done until the gerber generation phase).
The PCB's solar panels connections were designed to be fully disconnected from the battery during the transport stage. This was an important rule learned in the development phase.
Another special attention in the design process, is related to the connectors. The initial option, making a direct connection between PCBs with

male/female pairs was abandoned and replaced by flat cables. Using this alternative, the connections became more tolerant to vibrations and, at the same time, there is more freedom to choose which signals are interconnected between PCBs. This was an important decision, as in the early stage of the development process, it was defined that all PCBs would have a 16 bits microcontroller and all microcontroller I/Os needed to be available in the PCB's connector. With the flat cable policy, it became possible the selection of which signal the firmware would use on its development phase.

Floripa-Sat System Design

Floripa-Sat is divided in three main PCBs. The main reason to split the electronics in three boards is to enable each group to work independently on each subsystem without depending on the other, as shown in Fig. 1. Therefore tests can be performed in each of the systems without interfering with the other teams delivery dates. The subsystems division was made as follows: the first board manages the CubeSat energy and power supply, in the Energy Unit. The second comprises of the On-Board Computer, named Processing Unit, responsible for all the data handling and housekeeping. The last one is the board with the communication system, designated as Communication Unit.

Each one of the three boards has a Texas Instruments MSP430 microcontroller[4] as its core.

Several project decisions were made in order to improve the development time. It is important to note that the actual version of the PCBs are not the final revision nor the engineering model, they were made to test and develop the software, communication and integration of the CubeSat as whole.

Fig. 1 depicts an overview of the Floripa-Sat system design and intercommunication between the three boards and the payload.

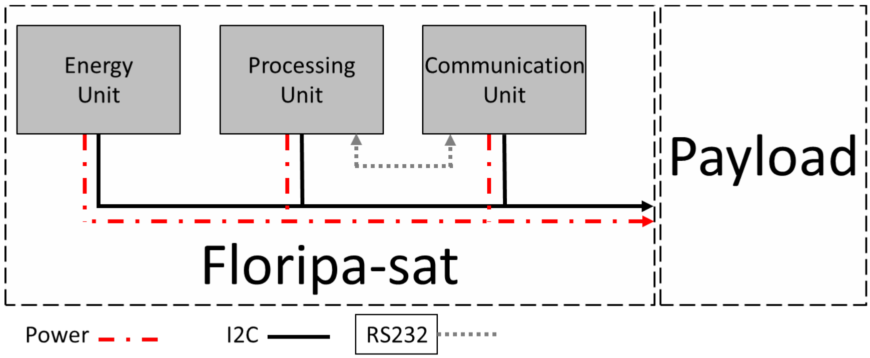

Fig. 1. Floripa-sat Diagram.

When developing the PCB a whole series of decisions for each system needed to be taken into account. The first decision made was choosing the MSP430 microcontroller. This Family was chosen due to its ultra-low power, high robustness and with the documentation needed freely available. In addition it is also very active in the microcontroller market, and the development tool is free.

Within the family, the MSP430F249 was chosen. This microcontroller was selected as it presents the following features [4]:

- Consumption Active Mode: 270 uA at 1MHz 2.2V. The msp430F24x / 10 family. It's a family item with many features and at the same time with ultra-low power;
- 8-CHANNEL 12-Bit Analog-to-Digital (A/D) Converter. Necessary for the power system requirement of at least 6 channels to read the power produced by each panel in order to monitor energy generation;
- 2 UART for communication between systems, with two I2C channels;
- And finally for its temperature tolerance. The satellite has to withstand -40 to 40 degrees on the way into space and into orbit[2]. This microcontroller has a temperature range of -40°C to 105°C. There is also an enhanced performance version of MSP430F249 with the same aboce features, and improving the temperature resistance of -55°C to 125°C, the MSP430F249-EP.

The Energy Unit[2] and the Communication Unit[3] are detailed in separate documentations. For the Processing Unit we include the details shown in Fig. 2..

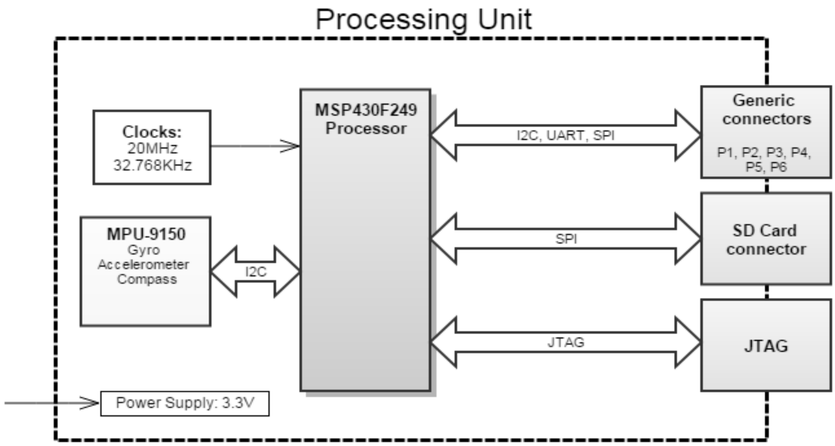

Fig. 2. Processing Unit block diagram.

The main goal of this board is to support the Floripa-Sat's OBDH (On-Board Data Handling) subsystem which is responsible for collecting, analyzing and storing data from housekeeping and payload. The data must be handled in real time, reducing as much as possible the response time of the OBDH system. Therefore, this board was designed focusing on the establishment of communication between the subsystems and the improvement of the data processing time.
The board is composed by a MSP430, acting as the system's core microprocessor and connected to two clocks (20MHz and 32.768KHz), by six generic connectors (10-pins each), that will be used to communicate with other subsystems, and by a JTAG interface, used to debug the program.
Moreover, since the OBDH intends to use an RTOS (Realtime Operating System), an SD Card reader was added to the board to make sure the system has enough memory to store logs, housekeeping, payload and the RTOS data. Finally, the board has an inertial measurement unit, the MPU9150 from Invensense, that has 9 degrees of freedom and includes three gyros, three accelerometers and three compasses (one of each type per axis) making it possible to perform a variety of measurements, which can be usedin the validation of the attitude control of the satellite. The collected measurements will be important for possible improvements in future nanosatellites missions.

Developed PCBs

In this section, the designed PCBs for the Floripa-Sat mission are described. The Processing Unit is shown in Fig. 2.
According to the FR-4 dual layer option, the Top layer and the Bottom layer, are shown in Fig. 3 and Fig. 4, respectively.
Following the Cubesat standard, the PCB shape is a 90mm x 90mm square. With this policy, it would be simpler tp organize the PCBs within the cube in a “sandwich way”.
From Fig.3 and Fig.4, it is possible to observe that the amount of components is very low. In general, each PCB has: a microprocessor, some microprocessor I/O ports adapted for the unit function, and the rest of the I/O ports routed to header connectors to connect to other PCBs, or for future improvements. In this way, PCB interconnections are easier to make, and also to be changed in case of new requirements.
Another concern is the soldering, and the 64 pins microprocessor is the component more critical, dserving more attention. In any case, as the final PCBs will be subject to strong vibration and extreme temperature variations, all solder need to be done and verified with accuracy.

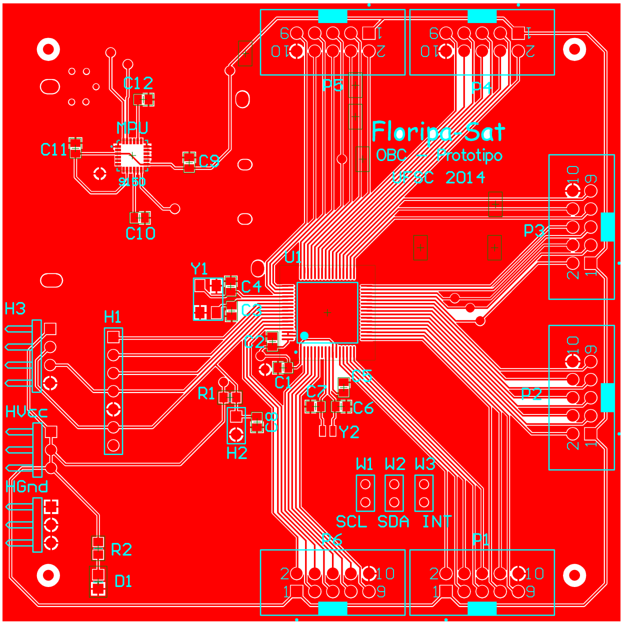

Fig. 3. Processing Unit PCB - Top.

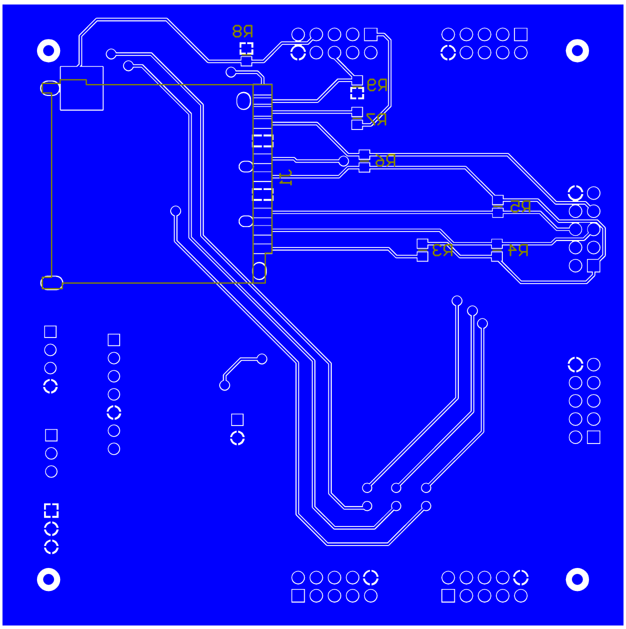

Fig. 4. Processing Unit PCB - Bottom.

Components sourcing and logistics

The main difficulty faced when developing a hardware based project in Brazil is the bureaucratic importation process. The lack of local production of specialized integrated circuits (eg. microcontrollers, analog to digital converters, etc) makes the importation mandatory. Due to the extended bureaucracy, more players are required along the process, increasing the final cost and delivery times.

There are basically two routes for imported items: formal importation, in which the items are taxed according to their specific tax value, based on the item type, that also takes into account the purpose and entity responsible for the purchase; or a standalone importation, where the tax is independent of the item type and flow through a simpler process, as long as the total amount of the goods plus shipping costs are under US$ 3,000.00, but the tax is based on the maximum applicable value (60%). In both cases, there is also an additional tax of 17% (ICMS), calculated in cascade after the importation tax.

When items flow through formal importation an authorized third-party customs agent is required to oversee the process, having an additional cost around US$ 1,000.00. The chosen method for the Floripa-Sat was to import components by private courriers (ie. FEDEX, DHL, UPS) in the standalone importation. This is the preferred method for most research and development projects in Brazil. Formal importation is mostly used only by business with high volume orders.

Another relevant factor is the time of delivery. Goods purchased by regular post shipping from North America and Europe arrive in Brazilian territory between 1-3 weeks, while others from Asia between 2-4 weeks. After that they go through customs clearance, taking usually from 4 to 12 weeks. The in-country delivery occurs usually after 1 to 2 weeks. The mean time for receiving a purchase that flows through regular importation process is around 12 weeks. This is valid for regular items with no special customs clearance requirement and weight below 3 Kg. This 12 week delay is not solely regarding the purchases placed for the Floripa-Sat project, and somehow exceptional. It's similar with previous purchases, distributed placed along the year.

This delay of about 2,5 months poses several difficulties in the schedule of projects that depends on imported goods. Whenever possible local suppliers are chosen, but it's mostly possible for common passive components.

Private courriers have an special flow through customs clearance that makes it significantly faster. The tribute cost is charged by the courrier itself (which

later forwards to the authorities) and the good is immediately cleared for regional shipping. This usually occurs between one to two days. Purchases from North America and Europe usually arrive between 5 to 10 days, and 10-15 days from Asia. The additional service cost of courriers (around US$ 30.00) and the tribute at the maximum value usually is the only option to meet the project schedule.
For illustration purposes, a purchase of US$ 89.69 in value from an USA supplier had the additional cost of US$ 108.51 in shipping and taxes. It is common that research and development teams in Brazil work with an estimate of 2.5 times the value of the regular item price, representing a major barrier to innovation in the region.

Conclusions and Future Work

In this paper, we presented the design and development process of the on-board electronics for a Brazilian Cube-Sat.
As a result, the group's knowledge was greatly enhanced. This will speedup future PCB designs, when considering space applications standards, achieving a higher maturity level in all its development stages.

Acknowledgment

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