The Development of a Data Acquisition Hardware System for a CubeSat Satellite

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Technical Abstract

This thesis indicates the design and experimentation process for an electronic data acquisition system for a CubeSat satellite. The Spacecraft Design class in the Department of Mechanical and Aerospace Engineering communicated the standards and requirements for the system that were to be adhered to throughout the duration of the Capstone project. The proposed block diagram was translated to a circuit schematic and then to a printed circuit board layout. The design was then tested from both a hardware and software perspective to verify electronic functionality and potential integration with the larger satellite system.

Research Problem

The problem given to me was to create a data acquisition hardware system on a PCB for the CubeSat's mission. This system was required to process a total of eight analog voltage signals: four from four thermocouples placed around the body of the satellite and four from four pressure transducers. Four thermocouple MAX6675 ADC chips were required in processing the thermocouple input and a single MAX11254 ADC chip was required in processing the pressure transducer input. These analog-to-digital converters were required to communicate each of the digitized signals to available pins on the OBC via SPI. The PCB had to follow the PC104 standard and fit within the cubic body of the satellite. None of the electronic components (capacitors, connectors, etc.) on the PCB could considerably exceed 10 millimeters in height. This was simply to ensure that the data acquisition PCB could be stacked on top of the Iridium Transceiver PCB, ultimately reducing space. The PCB was required to be composed of multiple layers of heavy copper to ensure durability against vibrations and harsh movements.

Rationale

As space technology continues to advance, it is natural that more modes of space travel are explored, including hypersonic flight. On a large scale, understanding the conditions of hypersonic flight is necessary in designing large-scale spacecraft that can take on the harsh elements. There are a multitude of relevant measurements that could be taken throughout a mission such as this one, but for the purposes of a small-scale multi-year university project, temperature and pressure were two feasible and relevant ones to gauge and record, as both have the potential to significantly alter the composition and structure of a spacecraft. The goal of this project is to simply make temperature and pressure measurements possible while adhering to the specifications dictated by the Spacecraft Design class, contributing to the ultimate goal of understanding the conditions of hypersonic flight.

Scope and Limitations

The first type of limitation relates to the nature of the overall mission. Since the satellite will burn up upon atmospheric reentry, there is no physical on-board location where temperature and pressure data can be stored. For example, saving all data to a computer's memory would be futile due to the inevitability of the system's disintegration. Therefore, it was chosen that the data be communicated to a ground station in real-time. This requires data to not only be processed by an on-board computer, but transmitted to a satellite and subsequently a ground station while the disintegration is happening. This informs the device selection for the data acquisition system and necessitates an Iridium Transceiver PCB system, which was developed by my other partners, Luke and Connor.

The second type of limitation relates to the structure of the Cubesat itself. The electronics are embedded within the small cubic part of the satellite's body, meaning that there is not ample space to fit the PCBs. To remedy this, bus blocks were included on the data acquisition and Iridium Transceiver boards so that they could be stacked on top of one another and connected to the OBC, ultimately reducing space. This meant that the height of the components on the PCBs could not considerably exceed 10 millimeters. Additionally, to meet size requirements and permit structural soundness, each PCB had to comply with PC104 standard, which indicates the length and the width of each PCB and includes screw-holes in the layout for additional security. From a design perspective, this meant that all components had to fit within the bounds of the PC104 PCB template. For added durability and heat dissipation, the PCBs themselves had to be composed of multiple layers of copper, in addition to the standard copper top/bottom layers which contain routing traces.

The third type of limitation relates to the environment of space travel. Extreme vibrations can be expected during the mission, especially during launch and as the spacecraft reenters the atmosphere. In order for the electronic systems to accommodate this condition, it is advisable that components be staked to the PCB with staking chemicals. The vibrations also mean that thermocouple and pressure transducer connections must also be secure. The connectors chosen were of the screw/terminal variety, so the screws could be locked in place with staking material. The PC104 standard also allowed the PCBs themselves to be screwed together. These were not actually done throughout the project, but they were recommendations examined at the beginning of the semester. Radiation from the Sun or other space bodies could also affect electronic functionality, so the components had to be radiation-tolerant. This meant that all selected capacitors and inductors had to be of the film variety and able to function over a wide range of temperatures.

There was no specific temperature range given by the Spacecraft Design class, but good judgment was used by the experimenters in making tradeoffs and selecting components that accommodate the imposed conditions, such as height, temperature tolerance, and radiation resistance.

Research Approach

In order to implement the design, a KiCad schematic was first devised for the DAQ hardware system. This schematic would include blocks to represent different devices and labeled connections at a high level. This schematic would then be transferred to a PCB diagram also on KiCad. This would include copper top and bottom traces, the several layers of extra copper in the middle, the through-holes for device soldering, and component solder pads. After the first iteration was complete, the PCB was verified using a free online design for manufacturing (DFM) checker. Any design flaws and connection errors were rectified at this point. JLPCB, a PCB fabrication company, was then used to make and order the PCBs. For the first iteration, a single thermocouple connector and thermocouple ADC were soldered onto the board along with a single pressure transducer connector and the quad ADC. Other hardware components, such as connector pins, were also soldered onto the board to permit software testing. Once flaws were identified throughout functionality tests, the KiCad layout was modified and a new board was ordered and verified. The final design consisted of all of the intended parts soldered onto the board.

Research Design

First a high-level block diagram of the system as provided by the Spacecraft Design class to me. It included the blocks representing the core devices along with wire lines indicating the purpose of each connection. A schematic was then created on KiCad, which served as a more in-depth version of the block diagram, as it included elements that permitted system functionality beyond the core devices, such as capacitors and inductors. The schematic is not included in this report, as the initial version was not representative of the final PCB due to a specification misunderstanding. The schematic designs were then translated to the PCB layout, which is illustrated in Figure 3.1. As a general rule for Figure 3.1, devices are labeled with their names, capacitors

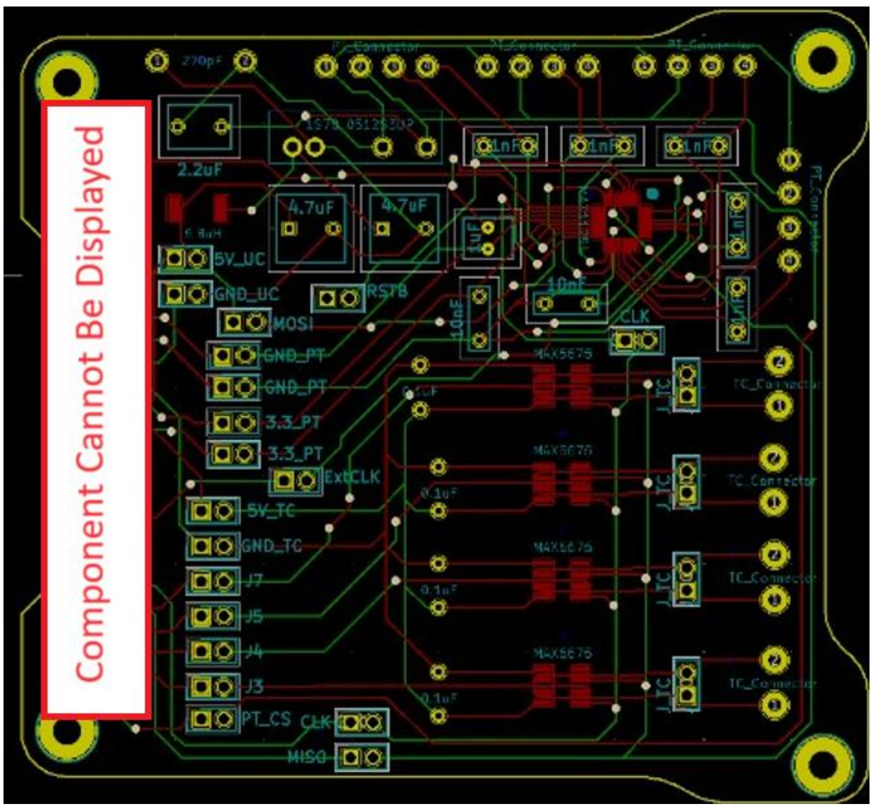

Figure 3.1: Final PCB KiCad Layout

and inductors are labeled with their value, and connectors and jumpers are labeled with their purpose. The label, “5V_TC”, for example, corresponds to the 5-volt supply on the thermocouple ADC. Red traces represent those made on the top copper layer, while green ones represent those made on the bottom copper layer. In addition to a built-in design rules checker (DRC), KiCad permits gerber files to be generated for a project. In this case, they were used for fabrication verification and ordering.

Data Collection and Evaluation Methods

Regarding hardware testing, connection tests were made between components to ensure all traces were routed as expected. The top of the PCB, shown in Figure 3.1, includes a voltage upconverter circuit to properly power the pressure transducers. This could be tested independently from the ADC chips by ensuring that a 5-volt input produced at least a 10-volt output. For the thermocouple and pressure transducer subsystems, my groupmate, Yul, developed software code to test SPI functionality on each ADC. Some of this code came from our embedded engineering class, as there was a topic on SPI communications. We modeled the thermocouple input using a voltage function generator and recorded the values of the resultant SPI data. The ADC chips themselves were connected to a Texas Instruments MSP microcontroller, which was executing Yul's embedded C code. We were able to verify chip functionality if the data values were high when the voltage level was high and low when the voltage level was low. All four thermocouple/ADC pairs were evaluated in this manner. A meaningful temperature conversion was also made to interpret the SPI data. At the end of the project, actual thermocouples were given for testing and functionality was demonstrated using a heat gun with a continuous data output, as blowing the heat gun on the thermocouple would cause the data stream to increase in value. For the pressure transducer, similar methods were employed: analog input was modeled using a function generator and digitized output was measured using Yul's code. The pressure transducer itself could not really be tested, as there were no feasible means to change the pressure surrounding the sensor within the Capstone timeframe. Many roadblocks were experienced while working with the pressure transducer quad chip, so by the end of the project only one out of the four analog inputs were verified by the time of the project's due date. Figure 3.2 illustrates the system at one point in the testing phase.

Due to hardware limitations, two PCB iterations were used at this point during testing, which can be seen in Figure 3.2. The red PCB is the MSP microcontroller that was executing C code. The rightmost device is an Analog Discovery 2 (AD2), which served as both an oscilloscope and function generator in this project.

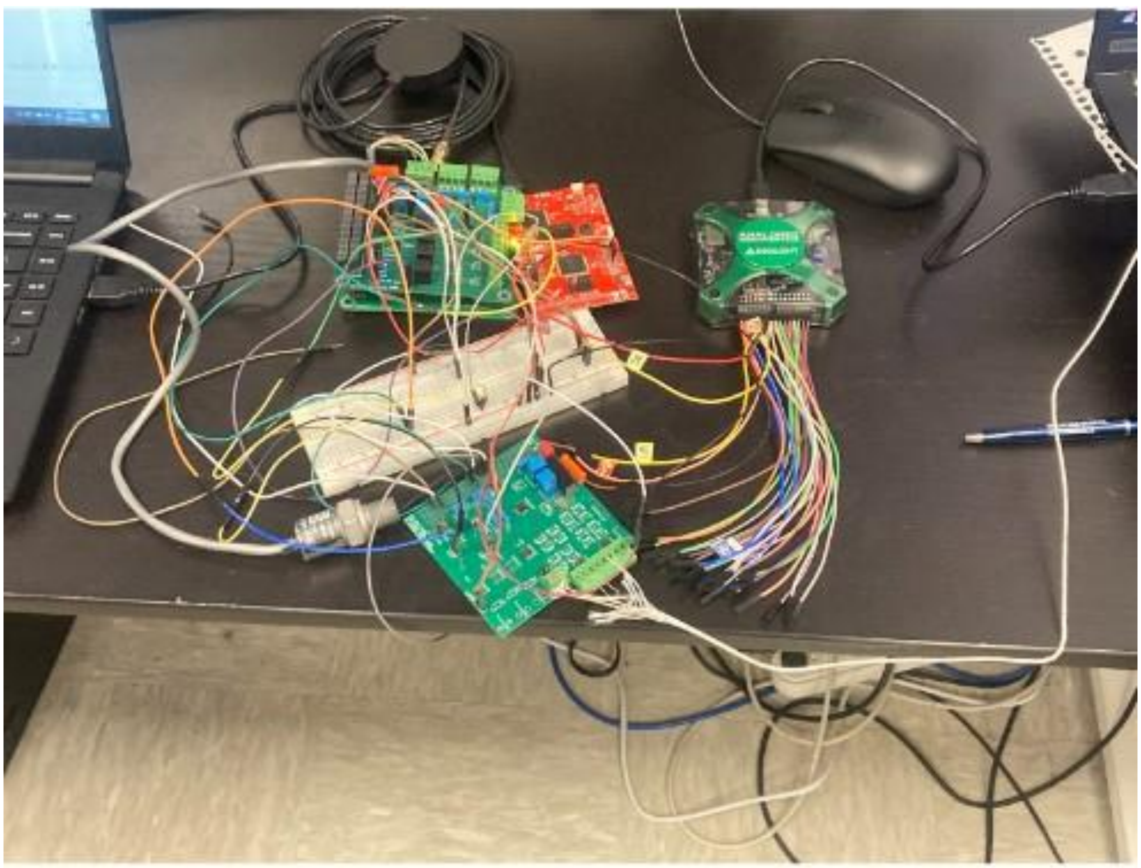

Figure 2.2: ADC Testing System at a Point in Testing Phase