

THE KUMU A‘O CUBESAT STRUCTURAL AND THERMAL SUBSYSTEM

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ABSTRACT

The Kumu A‘o cube satellite will need to survive two extreme environments one in which is during launch and the other during its mission life. Prior to launch, the engineering model of the satellite is required to pass a launch loads test simulating the actual loads during launch. In addition, the satellite’s endurance in space temperatures will be tested in a thermal-vac chamber prior to launch. Before these tests are performed, the satellite will need to be designed to handle these two extreme environments. This will be done using FEA software that calculates the effects of random vibration and temperature cycling on the satellite’s PCBs. An initial guess as to the external temperatures expected in orbit is predicted along with the frequency and magnitude of the most violent vibrations during launch. Finally some PCB population recommendations are made according to established ESA (European Space Agency) standards.

INTRODUCTION

Kumu A‘o, a cube satellite developed by the University of Hawai‘i at Mānoa College of Engineering, is scheduled for launch within the next two years. The orbit of Kumu A‘o will be at distance of 600km, circular, retrograde and sun-synchronous with an angle of inclination of 98 degrees. The satellite’s main purpose is to demonstrate the flight worthiness of a cube satellite bus standard developed by UHM CoE. The first main objective of the Structural and Thermal subsystem is to ensure that the satellite will endure the launch loads of launching to orbit. It is during launch that it is the largest loads in the shortest period of time will be acting on the satellite during the satellites entire mission life time. While in orbit, the satellite must survive the temperature cycling experienced. The structural and thermal team will ensure that the satellite’s temperatures will remain within a temperature range that the electronics can tolerate for the entire mission life. Lastly, to ensure that a reliable link is maintained between the satellite and ground-station, an effective yet simple form of attitude control system will need to be implemented on the satellite.

This final report will give an overview of the progress made in the temperature monitoring and vibration analysis areas of the Structural and Thermal Subsystem for the Kumu A‘o satellite. The temperature modeling and attitude control system design are left as later work to accomplish.

TEMPERATURE MONITORING

Over the past three months changes have been made from the original design of the shareboard. Enough changes were made such that the design of the shareboard will be overviewed again here.

The temperature monitoring circuit samples a total of eight thermistors. Six of these thermistors are located on the exterior of the satellite where they will measure the temperature of the body-mounted solar panels. The other two thermistors will be located inside the satellite with one on the battery and the other on the transmitter.

The shareboard is a printed circuit board that holds circuits from the structural, telecom, and CDH subsystems hence its name. These circuits consist of the temperature monitoring circuit, the data/morse multiplexing circuit and transceiver, and the nichrome wire burn circuit for antenna deployment.

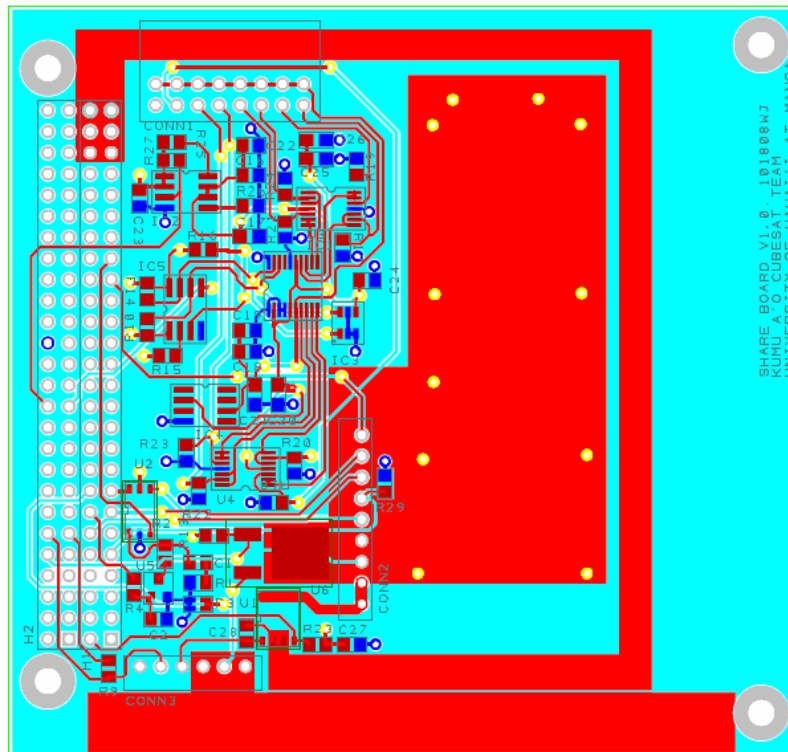


Figure 1. Draft layout of the shareboard PCB

Layer Changes

Previously, to save on cost and complexity, the shareboard was designed with only two layers. Both of these layers contained a mixture of signals and power traces. When the structural and telecom circuits were added to the PCB layout, it was obvious that more layers were needed in order to ensure low resistance pathways for high current traces.

All the signals and power traces were routed on a 4 layer board manually in PCB artist according to the schematic shown below. The middle two layers deliver the 0V and +3.3V traces from the dedicated EPS rails on the PC104 bus to all the ICs on the shareboard. The outer layers are primarily the signal layers for the non-power circuit connections. Since the transceiver draws up to 1.5A of current, an exceptionally large trace is routed to the transceiver connector from the dedicated Vbatt rails on the PC104 bus. In addition, the ground return for the radio is shared with the ground return of the nichrome wire burn circuit. To sink heat from the nichrome burn MOSFET, it is attached to the HIGH_CURR_0V copper pour on the top layer. In addition

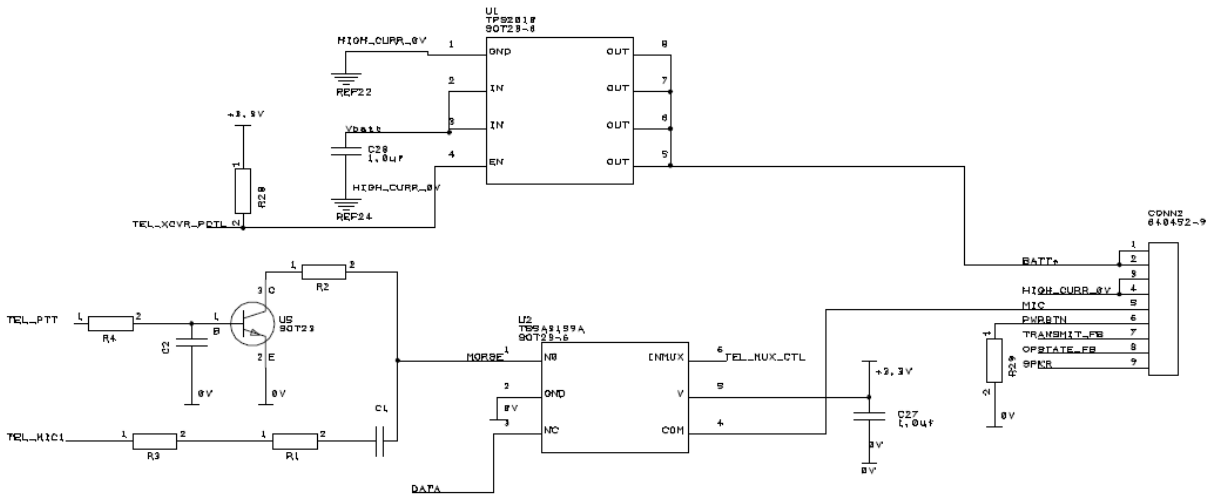


Figure 3. The telecom circuit consists of three main portions aside from the transceiver: the data/Morse multiplexer, PTT circuit, and high current power switching IC.

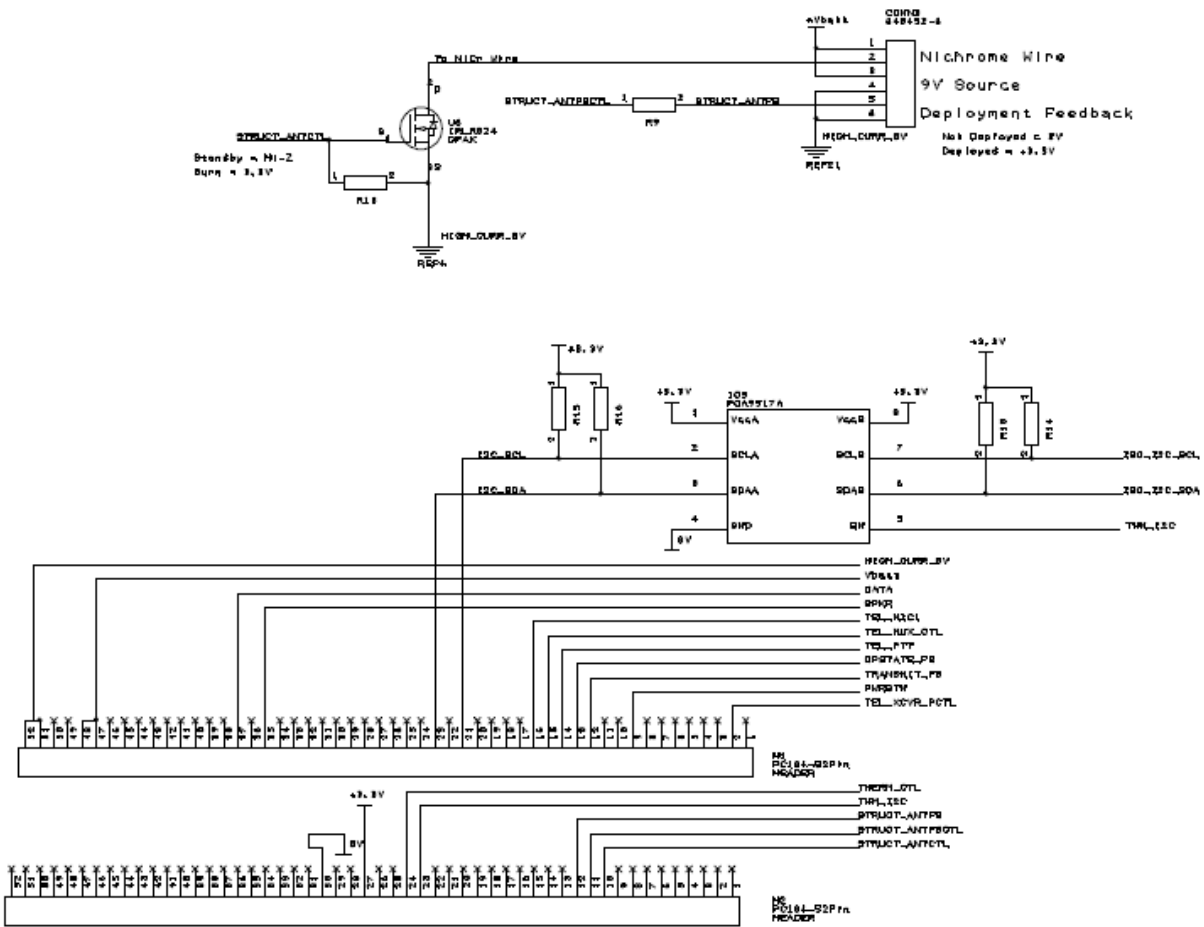


Figure 4. The structure circuit in the upper portion of this figure consists of MOSFET and a feedback switch and the bus interface consists mainly of the 12C isolator other than the PC104 headers.

TEMPERATURE MODELING

The temperature modeling for the satellite is very critical since the satellite is expected to experience a wide temperature range. It is important that this temperature range is within the operating range of the ICs and even more important that the battery's temperature to not fall outside of its range. Otherwise, the battery's capacity will degrade and will no longer receive a charge. The temperature distribution within the satellite is no easy task, and to derive an accurate temperate profile, a finite element modeling program should be used. Although there are many such programs capable of doing this, the program chosen is called CFDesign.

Aside from calculating the steady state temperature of critical components within the satellite, temperature evaluations will be made on specific points over time to determine the time response of the temperature sensitive components within the satellite. By knowing this, the maximum time the satellite can be in the sun or in the dark, based on the operating temperatures of the battery and some of the ICs, can be determined and compared to the operating temperatures of the critical components within the satellite. If it is determined that the components will get too cold or hot, then the heat will need to be distributed so that components remain in their operating temperature range.

Data acquired by CalPoly SLO's CP3 temperature sensors indicate that at an orbit with an apogee of 787.5km and perigee of 659.5km the temperature fluctuations were at most +/- 30degC. Since our orbit is circular and at an altitude less than the smallest dimension of the CP3 orbit, it is predicted that our temperature swing will be less than +/-30degC. If this is so, the internal temperature of the satellite will never be lower than -30degC or greater than 30degC therefore thermal insulation or heaters would not be required.

VIBRATION ANALYSIS

The harshest dynamic environments experienced by the satellite will be during launch. Due to the harsh dynamic loads due to vibration experienced during launch, it is most probable that things will fail before the satellite's mission begins! As instructed by the project manager of the LEONIDAS project, the satellite should withstand an axial acceleration of up to 12.5Gs. The maximum lateral acceleration due to the spin of the booster was also calculated to be at most 6Gs. These are the maximum accelerations that any of the SPARK 1 payloads is expected to experience. The axial accelerations are due to forces being transmitted from the launch vehicle to the satellite due to vibrations between stages and shock during stage separations. These maximum accelerations are not expected to occur at all times, but randomly and during the most violet frequencies of the launch. It is important to know at which frequencies these potentially damaging vibrations will occur so that the interface between the satellite's structure and the circuit board stack can be tuned so that the natural frequencies within the stack does not overlap these frequencies.

For launch vehicles with an established heritage, a plot called a Power Spectral Density plot or PSD plot can be obtained from the vehicle's users' guide to identify the most energetic vibrations for the launch. However, since the SPARK 1 payload fairing for the launch vehicle is still under development, these frequencies are not yet known. Instead, we were instructed to use frequencies from the PSD plots that were published in the DNEPR safety compliance requirements document for the DNEPR launch back in 2006 and apply the 12.5Gs to be the maximum axial accelerations at those frequencies.

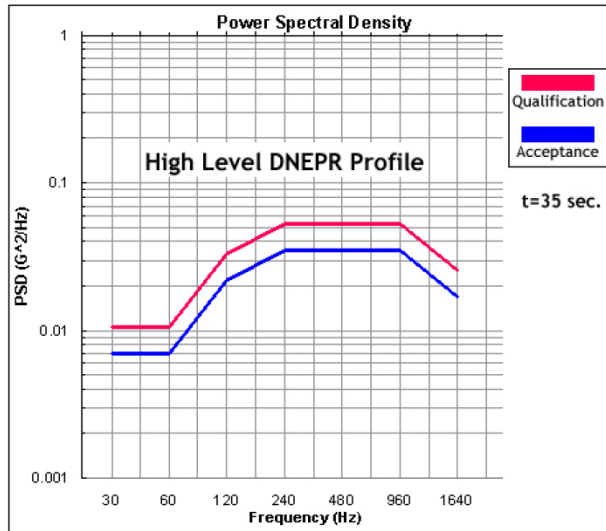


Figure 4. High-intensity random vibration PSD plot for DNEPR launch vehicle.

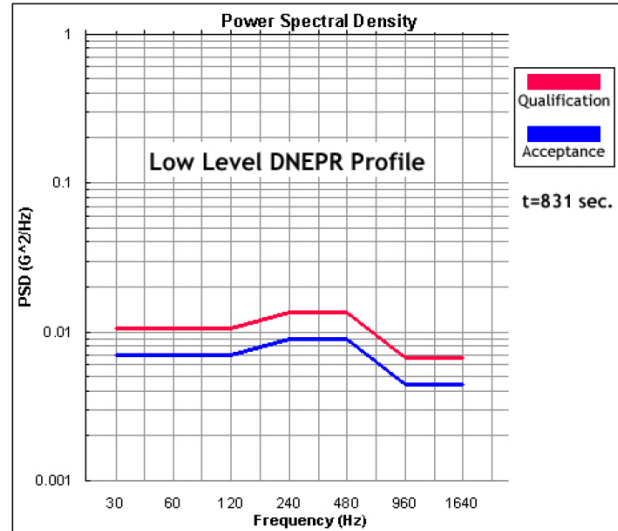


Figure 5. Low intensity random vibration PSD plot for DNEPR launch vehicle.

Since the vibration response through the launch vehicle’s structure is random as opposed to periodic, a PSD chart will plot the mean square acceleration at a given frequency. The frequencies in which the vibrations are most intense are indicated by the highest points of a PSD plot. Therefore, the frequencies in which we can expect the most violent vibrations to occur and are between 240Hz and 960Hz and the maximum acceleration expected at these frequencies are expected to be no more than 12.5Gs. Since the payload faring for the SPARK 1 is still in development, the PSD data for our specific launch vehicle is not available. Instead, it was recommended that the team uses the DENPR PSD profiles as a minimum requirement to meet for now.

SOLDERING PREPARATION AND STANDARDS

Since the satellite will be under relatively large accelerations for very short periods of times, it is critical that there be a standard in place for soldering of PCB components onto the PCBs. Although there are many soldering standards already established by well known organizations such as NASA and the ESA, the team does not have all the resources to adhere to all of these standards. Therefore, only ones deemed important to follow by the team will be chosen as standards for our team. It is important to note that the reasoning behind choosing to follow standards is to ensure that that the solder joints mechanical characteristics of the joints are sufficient to survive the vibrations of launch. It is especially important for the team to develop a soldering ethic that prevents cold solder joints as they are brittle and can fail under vibration.

One of the critical parameters in preventing cold solder joints is a high enough solder tip temperature. It is very important that all solder within a joint “flows”. This means that the lead/tin alloy must melt and all the flux within the joint must be in its liquid state. In addition to a minimum temperature, it is also important to not have the tip as too high of a temperature. Otherwise excess heating of the component pins can damage the component. In addition, there is a maximum time of contact that is governed by the time required to flow the joint. ESA is currently in the process of renumbering and reissuing their standards. Two of three batches of

standards have already been released with the third and final batch scheduled to be released by the end of February. Unfortunately, the standards for manual soldering are part of the third batch so a reference cannot be made here. So an older set of standards will be referenced.

ESA's space product assurance standards for manual soldering of high reliability electrical connections states that for normal soldering of electronic components, **a soldering-bit temperature of 280 °C is recommended**. It also states that at **no instance shall the solder-bit temperature exceed 330 °C**. One exception allows the soldering-bit to be at temperatures up to 360 degC for joints heat sinked or for large PCB ground planes.

In addition to the soldering temperature, it is also important to clean and demoisturize the PCBs prior to soldering. According to the same standards as above, **PCBs should be baked in an oven at 90 °C to 120 °C, depending on the laminate materials, for a minimum of 4 hours, or by a vacuum bake at a lower temperature.**

CONCLUSION

This paper revisits the design of the shareboard and outlines the modifications from the design presented in the last final report. A brief discussion of the temperature profile modeling for the satellite was made along with identifying the most violent vibration frequency and acceleration magnitudes for the launch. Then finally a more detailed discussion was made for soldering standards that are being proposed to the team to ensure the prevention of cold-soldered joints that can be a sort for entire satellite failure during launch. The bulk of this report was spent on predicting the launch loads that the satellite will be under and the temperature range while in orbit based on CalPoly data. Since the launch loads include violent vibrations resulting in accelerations up to 12.5Gs, a brief look was made into identifying proper soldering-tip temperatures according to the ESA to prevent cold-soldered joints that can fail during launch.

ACKNOWLEDGEMENTS

Although this report only contains work completed over a single semester since the submission of the previous final report for this subsystem, it should be mentioned that the Hawai'i Space Grant Consortium has provided the conduct to formalizing the design process of the thermal and mechanical subsystem of the Kumu A'o cube satellite. Without their aid, the progress of this subsystem would most likely be less direct. Much appreciation goes to Dr. Shiroma and the Hawai'i Space Flight Laboratory for providing us the facilities to meet and work as a team. I would like to also thank all of the Kumu A'o cube satellite team for their aloha spirit and teamwork. Specifically, I would like to thank Mr. Jeremy Chan and Mr. Zachery Lee-Ho for their guidance with designing the share board.

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