Cost Effective Thermal Vacuum Testing System

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Overview

In the field of small satellites, thermal vacuum testing is an essential phase of development. Many material properties of common electronic devices are radically different inside of a vacuum environment with large temperature swings. As there is rarely room for “redundant” parts on a small satellite, every non-flight heritage board must be modified and verified to work in these conditions. Currently, this is done using very expensive thermocouple controllers, vacuum pumps, and thermal conditioning units. Research was conducted to create a more budget friendly solution. A new, more economical thermal vacuum testing system has been designed to address these issues. It employs a cylindrical copper thermal conditioning shroud that fits around a small satellite up to 3U in size and uses predominantly Arduino based control for main operation. Cooling is accomplished by circulating liquid nitrogen through copper tubing wrapped around the outside of the shroud, while heating is accomplished via four heating elements on the inside of the shroud and a rope heater wrapped on the outside. Thermal measurements are taken via T-Type thermocouple probes that interface with an Arduino-based interface board. These measurements are then transferred to a host computer for long-term data logging. As all vacuum pumps and gauges were also chosen to be as cost effective as possible, the overall system cost is well below equivalent commercial solutions, making this a potentially disruptive advancement in the small satellite industry.

Design Requirements for the System

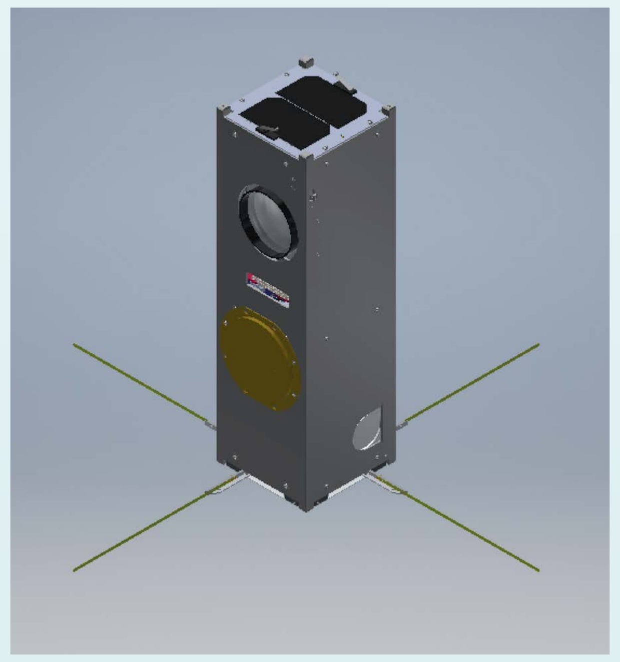

Figure 1

The SSRL currently works on two missions: SPOC and MOCI. The latter is commissioned by the U.S. Air Force and has very specific guidelines for how the satellite must be built and validated. The requirements for thermal/vacuum testing are the following:

1. Parts must reach min/max of simulated results
2. Parts must experience a minimum temperature swing of 60ºC
3. The maximum rate of temperature change shall not exceed 5 degrees per minute
4. Vacuum testing must occur at 10^{-6} torr or lower

Figure 2 shows a time graph of how thermal/vacuum testing should occur. During the nitrogen phase of testing, three thermal cycles are conducted. In the vacuum phase of testing, two cycles are conducted.

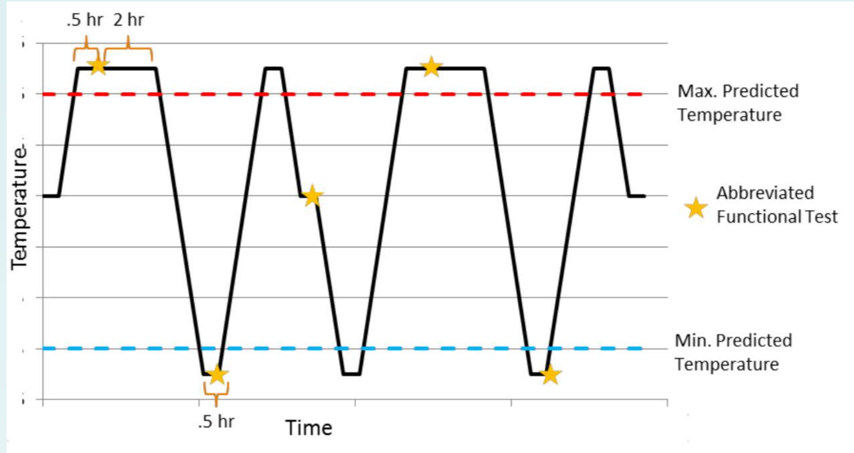

Figure 2 (UNP Users Guide)

Designing the Chamber

For the base chamber of the system, the SSRL utilized an older vacuum chamber donated by the UGA Physics department. This chamber was previously used to produce specific atomic lattices for physics experiments and was operated at vacuum levels of ~10^{-10} torr with the help of an ion pump. For the SSRL’s purposes, a simple roughing-turbo pump system will be used for generating vacuum.The chamber is also relatively large for cubesat testing, so had it not been donated, a much more modest chamber would have been used.

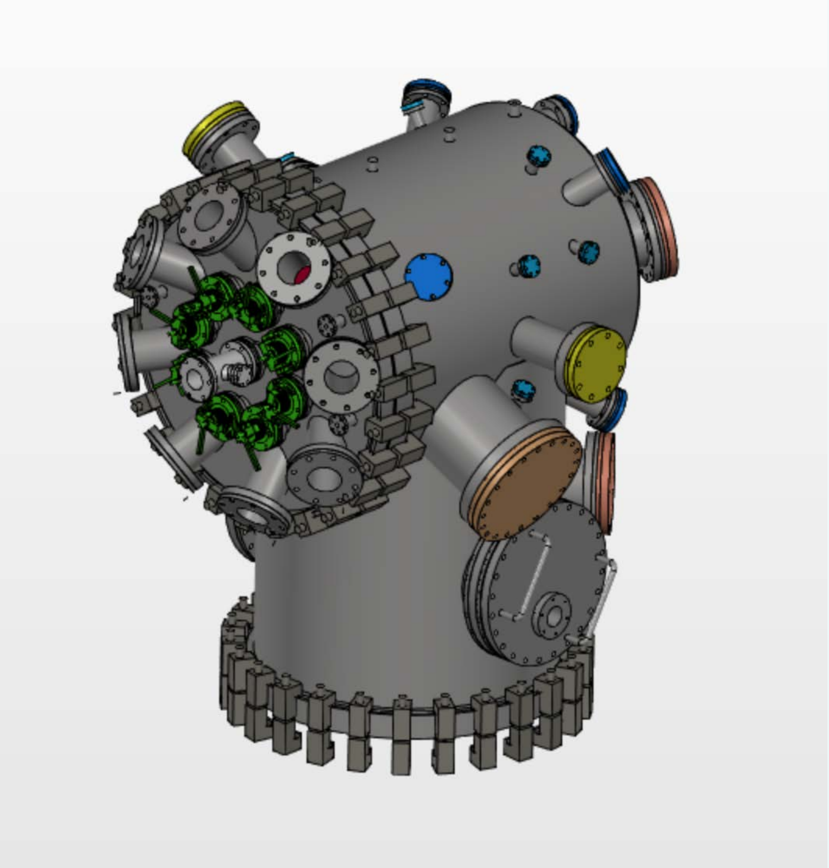

Figure 3

To create an adequate environment for thermal/vacuum testing to occur, the SSRL designed a shroud to surround the satellite or satellite components inside the vacuum chamber. The shroud was designed to fit on a 10” CF flange mount, and is attached to the bottom part of the vacuum chamber. The walls of the shroud are made out of a thin copper sheet to maximize thermal transfer from the heating and cooling elements to ensure an even temperature throughout the shroud. To facilitate cooling, copper tubing was wrapped around the outside of the shroud. This would serve as a “cold trap,” by pouring liquid nitrogen in one end and venting the excess gas out the other. This should easily hit -30ºC.

Figure 4

To heat the shroud, four 4500W heating elements are positioned to heat the four sides of the satellite. These were purchased from a hardware store and would normally be used inside a water heater. To control the thermal output of the heating elements, two AC switches are used (one switch controls two heating elements). An arduino is connected to both and sends a employs a PWM scheme with a configurable duty cycle to expose to the heating elements to the desired effective power level.

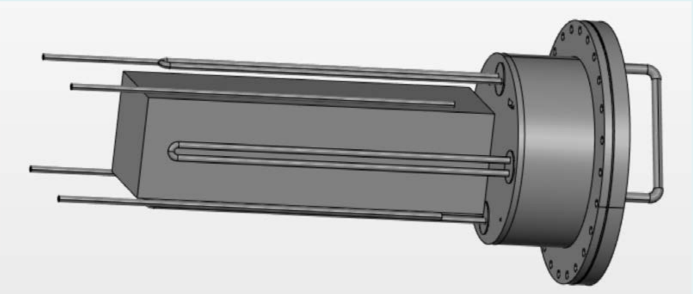

Figure 5

Figure 6

To determine the temperature at various points within the system, another arduino equipped with two T-type thermocouple controllers. Each as four ports, giving the system a total of eight thermocouples to use. T-type thermocouples were chosen as they have a very linear voltage to temperature relationship below 0ºC and up to ~100ºC making them perfect for this application.

Assembly of the system

Figure 7 shows the fully assembled thermal/vacuum chamber. The total system cost was below $5000, with the major expenses being the turbopump and the thermal shroud (mostly due to initial design oversights that had to be corrected). Once fully integrated, the chamber had to be leak tested and sealed by pressurizing the chamber with nitrogen gas and systematically testing all attachment points.

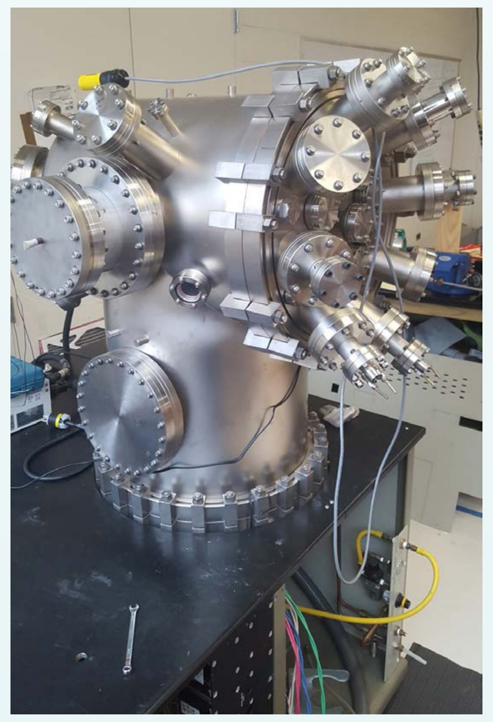

Figure 7

Future work

Currently the chamber is awaiting a few parts to properly seal it prior to pump down. Once they arrive, full testing and validation of the design can commence. The SSRL will be partnering with Dr. Ullrich of the Physics Department, to determine the exact physical properties of the chamber with various test masses.

Figure 8
(www.carvilleplastics.com)

Testing of the SPOC and MOCI components will take place over the summer as engineering and flight models arrive. In order to facilitate the testing of smaller parts, a special mount for each will be designed and 3D printed out of heat resistant plastic material such as PEEK. The mounts will then slide onto the rails already present within the shroud.

As the results of the thermal testing are received and tabulated, they will be used as updated inputs with the SSRL’s thermal simulations. This will likely drive new insights into the thermal design of both missions (especially for MOCI) and will in turn drive the SSRL to test different regions of the satellite.

At the conclusion of each mission, the SSRL will publish the results of all the thermal testing and “real world” data received during orbit to advance the field of small satellite thermal mitigation and design.

For more information about CubeSats, the Small Satellite Research Laboratory (SSRL), our missions, visit www.smallsat.uga.edu.