The budget TVAC-test chamber

The Orbit NTNU organization has developed a low-cost vacuum heater as part of efforts to simplify environmental testing of components. The team members are students at the Norwegian University of Science and Technology.

Orbit consists of 65 students across 9 technical groups, in addition of a marketing group and the board. Together we cover everything from mechanical design and electronics, to software engineering, as well as management. This way, we appeal to almost every field of study.

Håkon Kindem

TEAM LEAD - SYSTEMS ENGINEERING

I have been the Systems Engineering TL at Orbit NTNU since 2018. During this time I've been responsible for the design and development of two cubesat missions, with a focus towards concept exploration, system architecture and test & verification.

Johannes Ihle

TEAM MEMBER- SYSTEMS ENGINEERING

As a member of Systems Engineering since early 2021, the majority of my work has been related to testing. Primarily I have been involved in the practical execution of these tests, but I have also participated in the development of some of our testing equipment.

Sivert Høilund Sivertsen

TEAM MEMBER- SYSTEMS ENGINEERING

I have been part of Systems Engineering since 2020 . My work has mostly consisted of designing equipment used for testing our satellite components. This has resulted in me primarly working towards testing and verification of different subsystems.

Isak Andrade Sæternes

TEAM MEMBER - ELECTRICAL ENGENEERING

Been a part of Orbit's Electrical Engineerings team since the beginning of 2020. I have mainly worked with PCB design and cable management in addition to developing test equipment.

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Introduction

Environmental testing is a time-consuming and often costly activity for university CubeSat projects. In particular, thermal vacuum (TVAC) facilities are in high demand with low availability. Universities typically have access to high-grade vacuum chambers capable of reaching pressures lower than 0.1 to 0.01 pascal, which is sufficient for eliminating most of the air conductivity**.** Vacuum chambers can be combined with heating elements and temperature sensors in order to test the thermal balance of single PCB CubeSat components and outgassing of materials. These tests will not be up to ECSS standards but will be sufficient to provide important clues into the thermal characteristics of CubeSat components.

Additionally, this strategy can be augmented by using thermal chambers to verify thermal characteristics at temperatures lower than room temperature. In this case, air conductivity will provide an environment that is colder than the equivalent space environment. This combination of vacuum chambers and thermal chambers may allow CubeSat projects to gain continuous on-demand insights into the thermal characteristics of the systems during the development of subsystems. This testing strategy is not able to cover rapid changes in environmental temperatures as the heating elements are thermally insulated and cool slowly in a vacuum environment.

Design

Heating Elements

The main criteria of the heating elements were that they should be able to reach at least 125°C and radiate with 75 W per 10 cm^2. Additionally, the structure should be able to mount PC-104 form factor PCBs and reach and maintain uniform temperature ±2°C across a mounted PCB.

The heating elements consist of a shaped Kanthal *heating* wire fitted between two metal plates, with Kapton tape as insulation between the metal plate and the heating wires. The plates are sized to 14 cm by 14 cm in order to create a narrow view angle to non-heated areas for the mounted PCB under test. The metal plates are placed between the heating wires and the PCB being tested, as this averages out the heat flow from the heating wires. This design choice increases the latency in the heating system but ensures that the heating is more uniform. Each panel can deliver 150 W in parallel, while in series, it falls to 75 W. Thermal simulations have shown this to be more than sufficient for the required temperature ranges. Four 3 mm metal bolts and eight nuts are holding the metal plates and wires together. These are also used for mounting PCBs. Spacers are used to adjust the distance between the test PCB and heating elements.

Temperature Logging System

This system is designed to monitor both the test article and the heating elements. The logger must have at least 4 sensors but should support at least 10 sensors. This is achieved by placing a microcontroller in the vacuum chamber, which controls a set of temperature sensors. Arduino nano was chosen for this purpose as it is of relatively small size with low outgassing, provides ease of use through the Arduino IDE and is compatible with a host of code libraries. The Arduino nano inside the chamber is connected to a laptop outside the chamber through an Arduino UNO, which provides a stable and consistent interface. This is done by UART, requiring 2 dedicated pins in addition to power and ground.

Vacuum grade temperature sensors must be used in this system. The sensors should have few cables and be easy to place and remove from the test article and heating elements. Thermocouples and temperature sensor chips have been considered and tested. After testing a thermocouple system, we converted to the DS18B20 digital temperature sensor, a one-wire sensor with 3 pins (GND; DATA; VDD). The sensor can be connected in parallel on a common data line, significantly reducing the number of cables and data select pins. This results in minimal wiring, which has been proven useful for our tests. Looking at the measurements of the sensors, they have an uncertainty of 0.5°C, which satisfies our requirements for TVAC-measurements.

Implementation

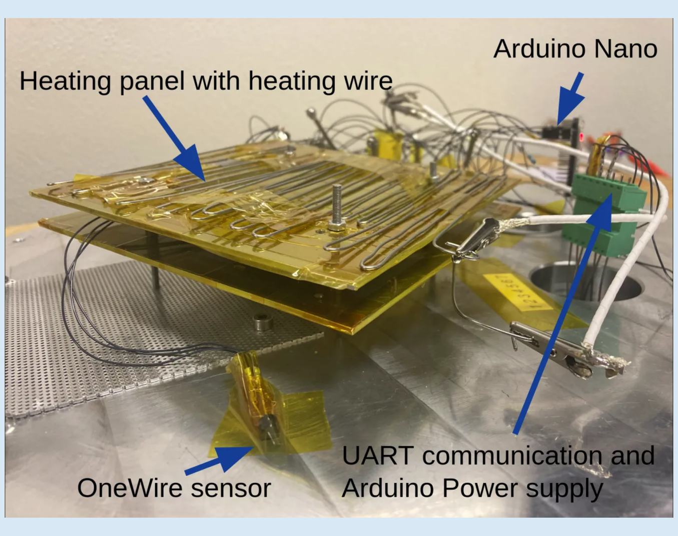


Figure 1: Test setup

The overall structure of the system is as shown in **Figure 1**. The inside of the vacuum chamber consists of the heating panels and Arduino Nano, the latter connected through the bus to OneWire sensors. Both the Arduino nano and the heating panels are connected to supply and UART interfaces through connectors built into the chamber. In the panels' case, these cables lead to a variable power supply situated beneath the vacuum chamber, capable of delivering a voltage range of 0V to 30V and up to 150W. The Arduino nano within the chamber is connected to an Arduino UNO located outside the chamber. This second Arduino is further connected to a stationary computer beneath the chamber. This computer supplies power to the entire system apart from the heating panels. It also displays temperature data in real-time, as well as logging the data and offering plotting capabilities.

Usage and test results

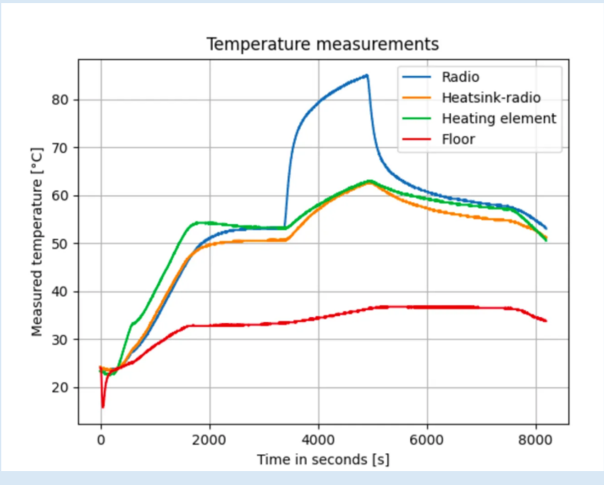


Figure 2: Test data

Testing starts by assembling the heating panels to be as close as possible to the test subject being heated. This is done to minimize the view angle between the heating elements and lower the watts needed to heat the test article. This is primarily achieved by using spacers of varying length between the two panels. The test subject is generally fastened using Kapton tape, or, in the case of our PCBs, they fit naturally with the heating panel spacers, as they are designed to be the same dimensions as the PC-104 form factor.

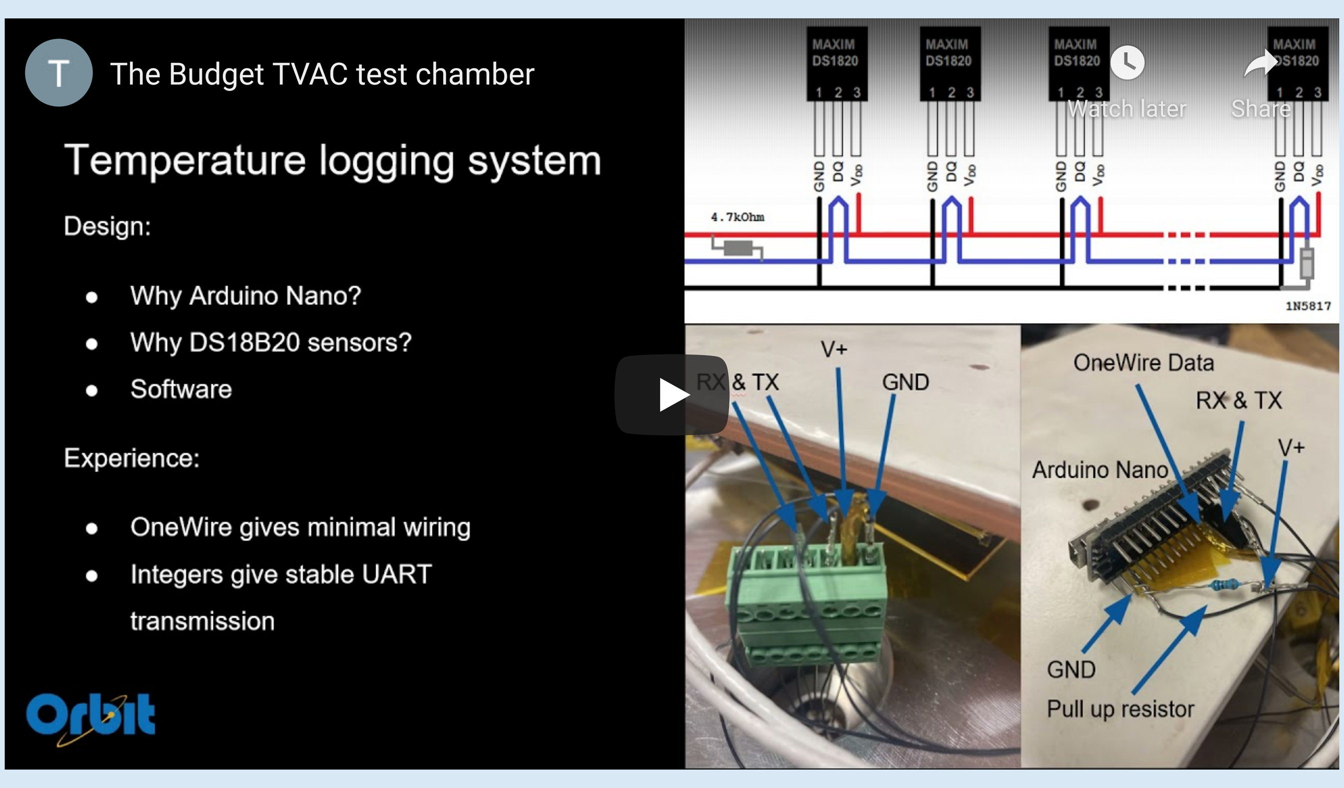
After placing the FTTR and its sensors where desired, cabling is set up and tested. After sufficiently low pressures have been reached, the environment is stabilized at the desired temperature. This is done by oscillating the voltage supplied between high and low values, continuously narrowing the span between them based on the system's response.

Our results have been useful, as illustrated in **Figure 2**. We've been able to stabilize our system at a range of different temperatures, from outgassing tests at 125°C to functionality tests at 50°C and 30°C. We've also managed to keep our system's inherent outgassing beneath the capabilities of our vacuum chamber, as we've been able to reach pressures as low as 10^{-9} Bar. Access to vacuum thermal balance testing has allowed the team to verify heat sink designs rapidly and has driven several design revisions by significantly decreasing the time it takes to plan and complete a test, from weeks down to days. The ability to rapidly schedule and complete tests have increased confidence in the design and given vital clues into operational constraints on high-watt systems such as the radio and magnetorquers.

Future work

The response time of the heating panels is a major area for improvement. Stabilizing the desired temperature takes a great deal of time and attention with the current setup. With a quicker response time, it would be possible to implement a heating process regulation system. The demonstrated test rig does not have proper connectors and robust wiring, which is vital for ease of use.

Video



Orbit NTNU

We are a non-profit student organization, who are aiming to design and build Norway's first operational student satellite. We are stationed at the Norwegian University of Science and Technology in Trondheim.

Our current and first project is the SelfieSat. It started out as a simple satellite project; we wanted to make an operational satellite that is able to communicate while it is orbiting earth. However, we wanted to make things a bit more interesting. While SelfieSat is in orbit it will be able to display a selfie of any person on earth, which will be uploaded from our ground station at NTNU. A deployable arm with a camera attached will photograph the screen with the earth in its background. Finally this picture will be sent back to the selfie-taking individual!