Thermal Vacuum and Control of Spacecraft Variable Emissivity Devices, Fall 2020

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BACKGROUND

- Micro-modular satellites currently operating in low-Earth orbit (LEO) experience time-dependent heat fluxes
  - –Produce unwanted thermal stress variations on satellite surfaces and payloads
  - –Requires a thermal management sub-system designed to mitigate thermal fluxes
  - –Operating in the vacuum of space augments mechanical and thermal loads
- A controllable, alternative Variable Emissivity Device (VED) provides a potential solution
  - –Thermal flux is controlled by alternating the opaque and transparent states of alternative VED's
  - –Alternative VED's include Smart Window technology and an electrophoretic display (EPD)

OBJECTIVES

- Design, manufacture, and test a thermal vacuum chamber capable of simulating LEO environmental conditions
  - –Generate and maintain vacuum within medium-to-transitional regime
  - –Voltage passage for VED control and thermal applications
- Design and test a control system capable of detecting and inducing temperature variations
  - –Induce and detect the three modes of heat transfer
  - –Compatibility with thermal conductivity test designs
  - –Achieve and maintain steady-state temperatures

PROJECT MILESTONES

- Designed and Manufactured a Vacuum Chamber
  - ◦Successfully generated vacuum at $1700 Pa$
  - ◦Verified vacuum pump ultimate pressure of $0.67\ Pa$
- Designed Pressure Transducer Circuit
  - ◦DAQ capabilities for evacuation and venting processes
- Thermal Control System Design
  - ◦Derived electrical energy output to thermal energy input
  - ◦Modeled a closed-loop PID control system
- Integrated Electrophoretic Display (EPD) with Thermal Vacuum Chamber
  - ◦Verified EPD control and compatibility with thermal vacuum system
  - ◦Performed vacuum testing on EPD

DESIGN CRITERIA

Thermal Vacuum Chamber Design

1. Material: 304 - Stainless Steel
   - ◦Inner Diameter,$D_{inner} = 5.5\,in$, Height, $H_{chamber} = 7.0\,in$, Wall Thickness, $t_{wall} = 0.25\,in$
2. Vacuum pressure range: $0.1\,Pa < P_{gauge} < 2000\,Pa$
3. Operating Volume greater than 1000 m^3 Contain
4. Contain 1 View-port for VED Sample Observations
5. Operate and Maintain Temperature Between $-35^oC < T_{op} < 35^oC$
6. Thermal conduction and radiation generation, detection, and control capabilities.

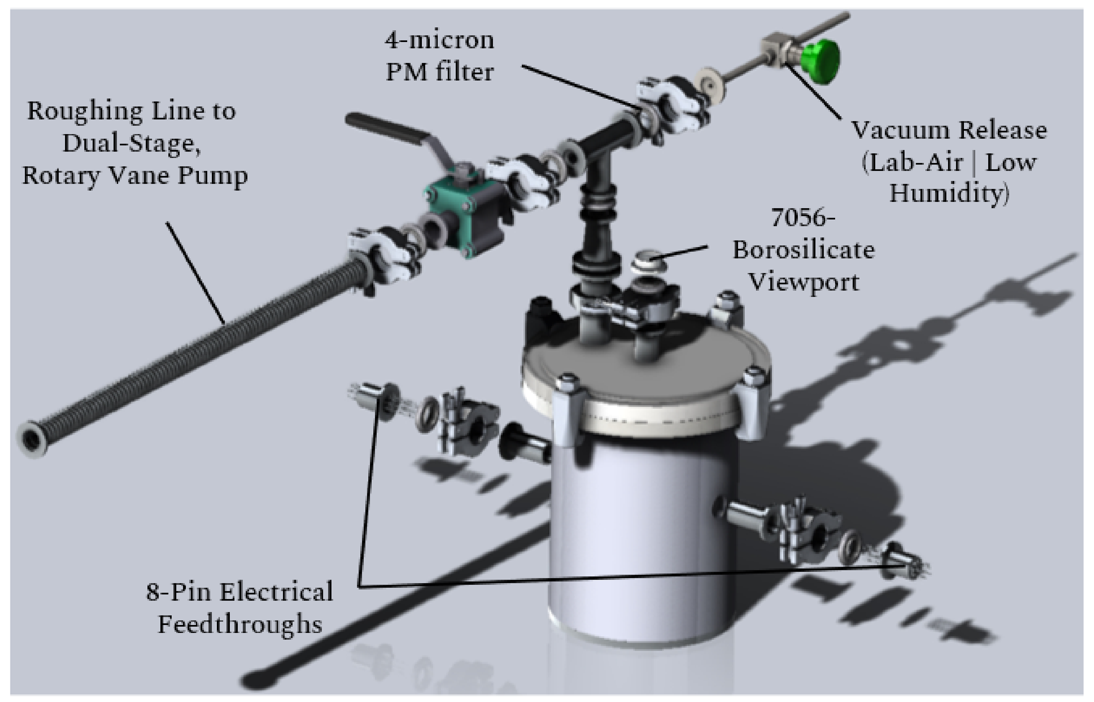

Figure 1: Finalized SolidWorks Design of Thermal Vacuum System.

MODELING AND RESULTS

Heat Transfer Analysis

Table 1: Thermal Conductivity and Emissivity of Alternative VED's, and LEO Operations.

VED Type	Equation	Description
Electrophoretic Display (EPD)	$k_{EPD} = \dfrac{q_1 L k_{Cu} k_{Al}}{A(T_1 - T_5)k_{Cu}k_{Al} - q_1 L(k_{Al} + k_{Cu})}$	• Thermal conductivity • Vacuum Conditions
Smart Window Technology	$k_{SW} = \lambda_{SW}\left(\dfrac{\Delta T}{q_{TC}} - R_{Al}\right)^{-1}$	• Thermal conductivity • TC-Control Lab – Heat Source
Satellite Surface VED (*General Formula*)	$\varepsilon_{VED} = \dfrac{\left(\dfrac{Q_{int}}{A_{s,VED}} + q_{solar}\right)}{\left(\sigma T_{VED}^4 - I_{EIR}F_{EIR} - \dfrac{I_{solar}\rho_{alb}F_{alb}}{N_{VED}}\right)}$	• 500 km Altitude Conditions • Approximates low-Earth orbit (LEO) • Requires emissivity ε_{VED} and solar absorptance α_{VED} ratio

Smart Window Behavior and Thermal Conductivity Testing

Table 2: Averaged Thermal Conductivity Values of Smart Window.

Smart Window	Thermal Conductivity, $k_{sw}\left[\frac{W}{m\cdot K}\right]$
Opaque State	0.445
Transparent State	0.607

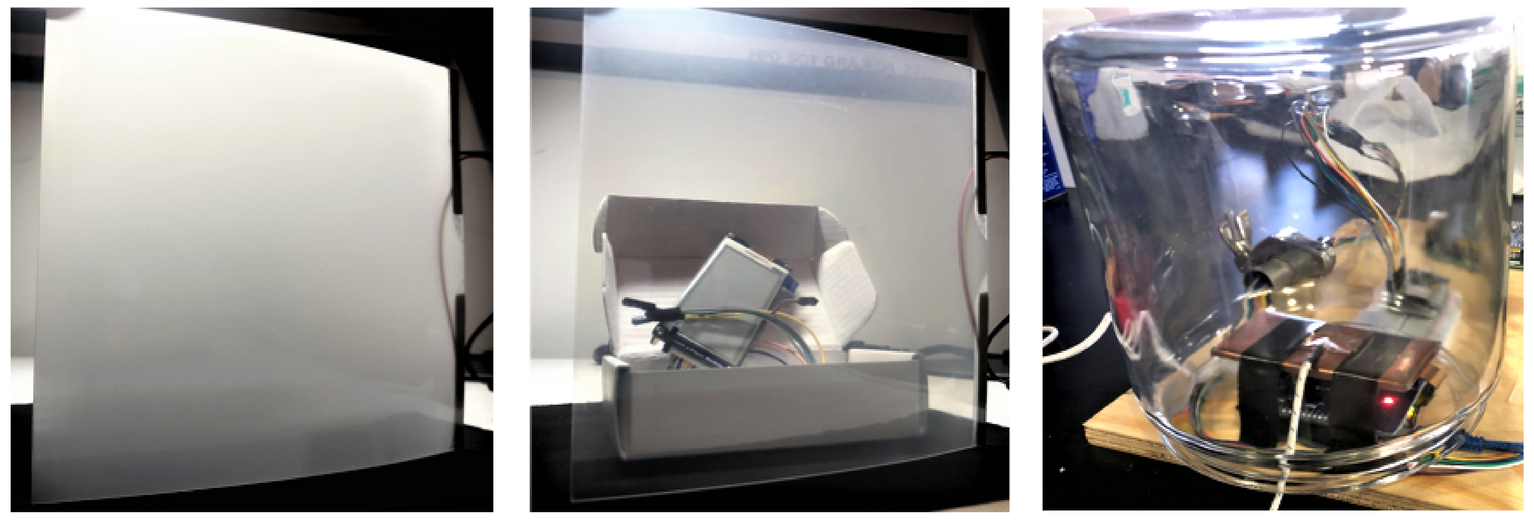

Figure 2: Alternation Between Opaque (*left*) and Transparent (*middle*) States; Thermal Conductivity Testing (*right*).

EPD Behavior, Control, and Vacuum Chamber Integration

Table 3: EPD Absorbance in Proportion to Wavelength.

EPD	Absorbance, $[OD_{EPD}]$
Light State	0.99
Dark State	1.26

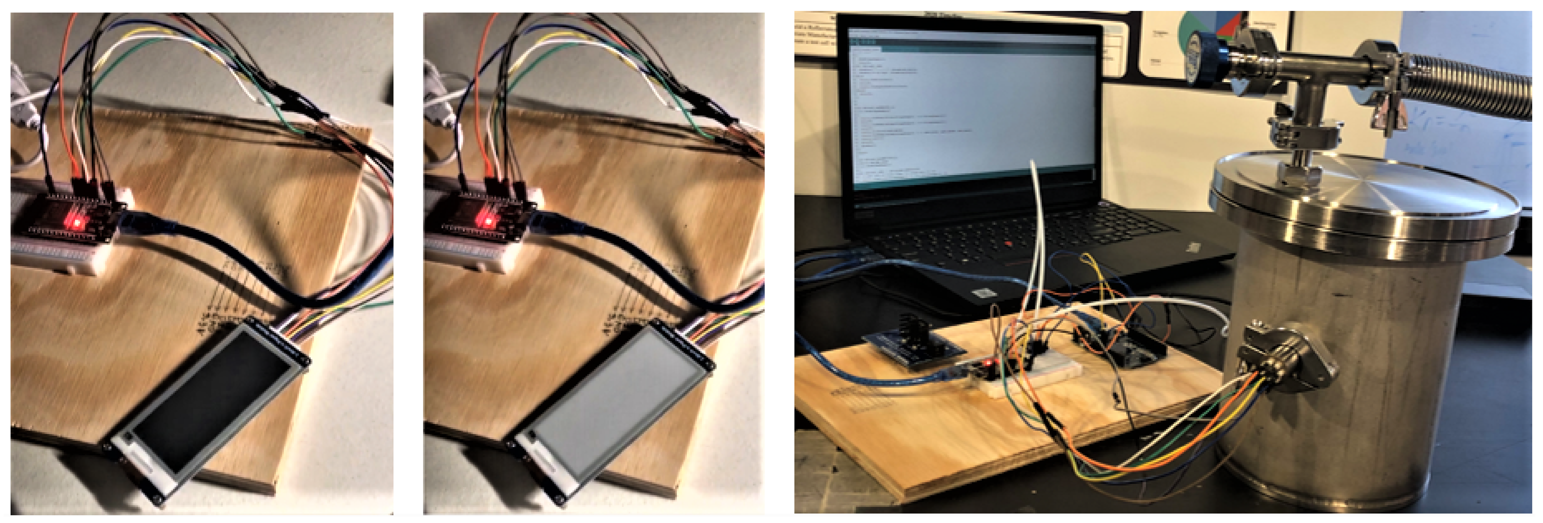

Figure 3: Alternating Between Dark (*left*) and Light (*middle*) States; Vacuum Testing and EPD Integration (*right*).

DESIGN FINALIZATION

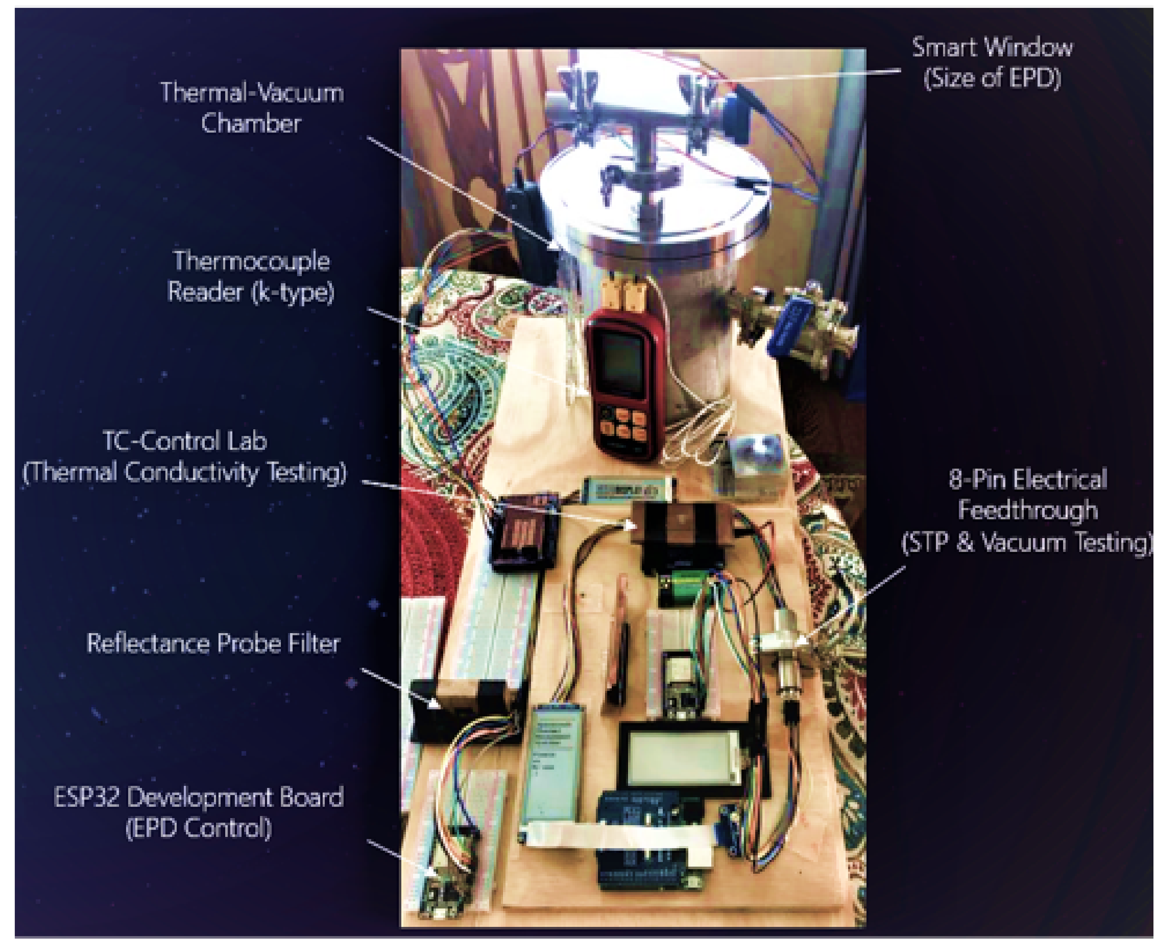

Figure 4: Finalized Design of Thermal Vacuum Chamber and Control Systems.

- Control board is capable of controlling the alternation between the lighter and darker states of the EPD, as well as the opaque and transparent states of the Smart Window
- Vacuum pressures and thermal mechanisms are employed into the vacuum chamber through a hermetically sealed, 8-pin electrical feed-through
- Reflectivity, absorptivity, and emissivity testing of the alternative VED's with reflectance probe and sample holder

FUTURE WORK

1. **Action Item [a]:** Obtain a View-port and Integrate a Solar Emittance Device (SED) to Simulate the Solar Flux of the Sun $(1366\frac{W}{m^2})$
2. **Action Item** [b]: Obtain Cryopump to Generate $0.1Pa$ Vacuum Pressure

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TEAM STRUCTURE