Ultra-High Vacuum Test Platform for Mini-CubeSat Subsystems Technology Readiness Level 5 Qualification

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This material is based upon work supported by the NASA NVSGC Under Grant No. 80NSSC25M7094

Abstract

The successful transition of minicubesat subsystems to Technology Readiness Level 5 (TRL 5) requires rigorous testing in a relevant environment, necessitating an ultra-high vacuum environment of approximately 10^{-9} torr. This stringent vacuum requirement is primarily mandated to perform a critical bake-out and validation process aimed at mitigating outgassing. Outgassing is the release of volatile organic compounds from spacecraft materials, which in the vacuum of Low Earth Orbit (LEO) can condense on and critically degrade the performance of sensitive surfaces, particularly optical components and thermal radiators. The high-vacuum test ensures component thermal control operates solely via conduction and radiation, verifying overall system integrity under flight-like conditions. This report focuses specifically on the rigorous preparation and qualification protocols executed to achieve the necessary vacuum conditions, a critical precursor to full system integration (TRL 6).

Objectives

- Validate subsystem functionality in 10^{-8}-10^{-9} Torr vacuum.
- Asses thermal performance in vacuum during operational cycling.
- Measure outgassing using RGA monitoring.
- Identify any degradation in electrical, mechanical, or structural behavior.
- Establish readiness for TRL6 environmental qualification.

UHV SYSTEM COMPONENTS

Vacuum Chamber

- Pressure range: 10^{-6}-10^{-9} Torr
- Turbo-molecular + scroll backing pump
- Ion pump for extended stability
- Bake-out capability: 150-200°C

Instrumentation

- Residual Gas Analyzer (RGA) for molecular species monitoring
- Thermocouples and/or *IR thermal scan*
- Electrical feedthroughs for in-vacuum operation
- Optical access windows

Subsystem Mounting

- Conductive aluminum baseplate
- Low-outgassing cable harness
- Temperature-controlled mounting interface

Test Procedure

Phase 1 – Pre-test Preparation

- Subsystem cleaning and contamination control
- Chamber bake-out
- Electrical continuity and functional baseline tests

Phase 2 – Pump-Down

- Stepwise pressure reduction
- Stabilization at UHV
- RGA baseline scan for contaminants

Phase 3– Operational Testing

- Power-on testing inside UHV
- Functional verification (communication, sensors, interfaces)
- Thermal cycling: -40°C to +60°C (per subsystem requirement)
- Long-duration run: 24-72 hours

Phase 4 – Post-Exposure Verification

- Physical inspection
- Comparison of pre/post electrical and thermal performance
- Outgassing analysis summary

Validation for TRL5

The subsystem successfully reached TRL5, meeting all evaluation criteria:

- Demonstrateds operation in a relevant vacuum environment
- Verified stability under thermal transitions
- Characterized materials and outgassing
- Confirmed compatibility with space-relevant contamination control requirements

This position the subsystem for TRL6 environmental qualification, including:

- Vibro-acoustic testing
- Thermal-vacuum cycling (TVAC)
- EMI/EMC testing
- Integrated CubeSat stack testing

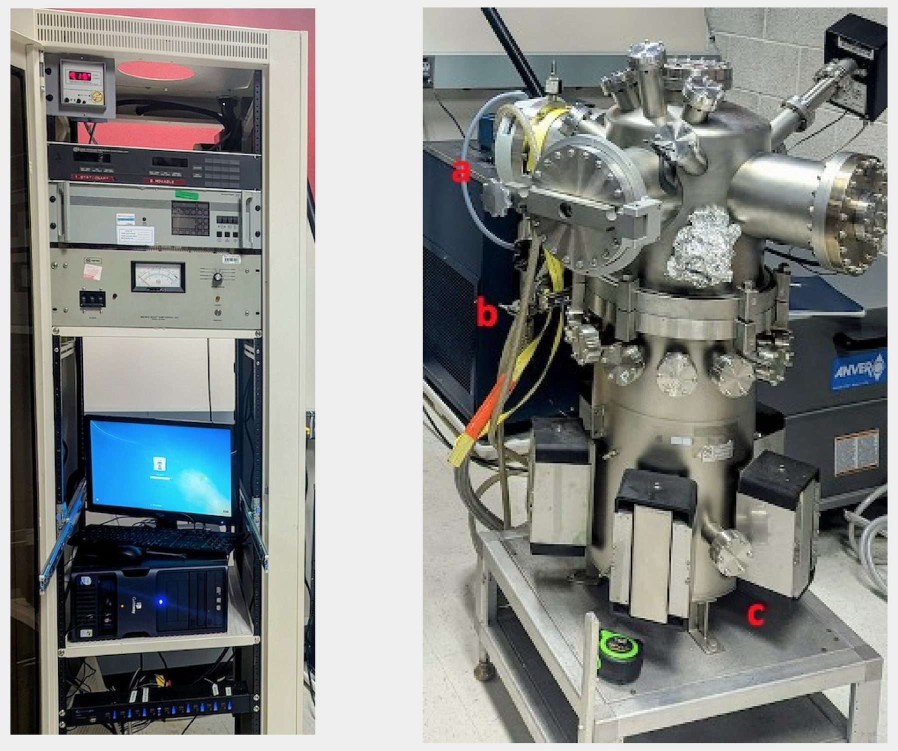

Figure 1. UH-Vacuum system for CubeSat TRL5 qualification. a) Turbo pump, b) Roughing valve and c) Ion pumps.

Conclusion

UHV Test Platform will validate:

- The subsystem's readiness for further environmental qualification.
- Performance remained stable under vacuum and thermal stress.
- Material outgassing and contamination behavior met spacecraft requirements.
- Qualify CubeSat subsystem is now a candidate for mission integration and TRL advancement.

References

- Messenger, G. C., & Ash, M. S. The Effects of Radiation on Electronic Systems. (A fundamental reference for the physics of radiation damage and SEE.)
- Barth, J. L., et al. Spacecraft Microelectronics Single-Event Effects (SEE) Environments and Effects. (Focuses on the mechanism of SEU/SEL and architectural solutions like TMR.)
- NASA SP-R-0022A (or equivalent): Vacuum Outgassing Data for Spacecraft Materials. (This provides the data on material outgassing used to set TVAC requirements.)
- AIAA S-110-2005 (or current): Space Systems—Criteria for Evaluating Satellite-Design and Test Practices.