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Small Satellite Space Environments Effects Test Facility

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Abstract

A versatile space environment test facility has been designed and built to study the effects on small satellites and system components. Testing for potentially environmental-induced modifications of small satellites is critical to avoid possible deleterious or catastrophic failures over the duration of space missions. This is increasingly important as small satellite programs have longer mission lifetimes, expand to more harsh environments (such as polar or geosynchronous orbit), make more diverse and sensitive measurements, minimize shielding to reduce mass, and utilize more compact and sensitive electronics (often including untrusted off-the-shelf components). Our vacuum chamber is particularly well suited for cost-effective, long-duration tests of modifications due to exposure to simulated space environment conditions for CubeSats, system components, and small scale materials samples. The facility simulates critical environmental components including the near earth atmosphere (allographic vacuum (10⁻¹⁰ Torr) to ambient), the FUV/VIS/NIR solar spectrum (120 nm to 2000 nm), electronic plasma fluxes (10⁻³ to 10⁴ e⁻/cm²/s), and temperatures (300 K to 450 K). The UVVIS/IR solar spectrum is simulated using an external class AAA Solar Simulator source, with standard Air Mass Zero (AM0) filters to shape the incident radiation spectrum. This Xe discharge tube has a current of 200 am to 2000 nm range, with up to four Sun light intensities over a CubeSat face. For ultraviolet (10⁻³ to 10⁴ e⁻/cm²/s) is provided by Kr discharge line sources, with a primary emission lines at 122 nm and 137 nm and up to four Sun intensity. This provides an adequate substitution for the solar FUV spectrum, which is dominated by the ultraviolet hydrogen Lyman α emission line at 122 nm. An electron flood gun provides a uniform, stable, low-energy, monochromatic (-20 e⁻/10⁻⁴ e⁻/cm²/s) electron flux of <10⁻³ to >1 g/cm²/cm² over the CubeSat face. A second medium-energy (-20 e⁻/10⁻⁴ e⁻/cm²/s) low-energy electron source uses filament-free photomission. A 50 e⁻/10⁻⁴ e⁻/cm²/cm² high-energy (-30 keV to 2 MeV) electron beam similar to the geosynchronous spectrum; intensities of <5x the geosynchronous spectrum are possible. Electron and photon fluxes are continuously monitored during the sample exposure cycle, using standard Faraday cups and photodiode sensors. All of the electromagnetic and electron radiation sources maintain uniform exposure to within 5% over a CubeSat face. A stable, uniform temperature range from 100 K to 450 K is achieved using a cryogenic reservoir and resistance heaters with standard PID controllers. An automated data acquisition system periodically monitors and records the environmental conditions, sample photographs, UVVIS/IR reflectivity, IR absorptivity/emissivity, and surface voltage over the CubeSat face and x-ray calibration standards in the main chamber during the sample exposure cycle. Samples can be mounted in the main chamber on single-axis rotation high-temperature or cryostat stages; alternately, the modular design allows the source to move separately with a larger chamber with a 5-axis rotation/translation stage that can position five faces of a CubeSat relative to the incident beams.

Space Environment Characteristics

The Space Survivability chamber simulates several critical characteristics of the space environment, including solar electron flux, plasma, temperature and neutral gas environment. Figure 7 shows representative electron spectra for several common environments; the range of the chambers, two electron guns, and SRM source are shown. The solar UV/Vis/NIR spectrum is shown in Figure 9; source includes a standard solar simulator (~200 nm to 2000 nm) and Kr resonance source to mimic the H Lyman-alpha emission at ~121 nm. Samples can be in a face-only irradiated environment, using a neutral or controlled neutral gas environment down to ~10⁻⁸ Torr. Temperature can be maintained for probe temperatures up to ~100 K to ~400 K. This chamber does not yet simulate ions, plasma or atomic oxygen.

Acknowledgements/References

[Dennison, J. R. "Charge-Enhanced Detonation and Environmental Degradation of MOS stealth." STS086 Materials; EE Transactions on Plasma Science, February 2012, vol. 6, no. 1.]

Simulation Chamber for Space Environment Survivability Testing of Small Satellites

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Space Environment Effects

The space environment can modify materials and cause deleterious effects to satellites. Some of these effects are change in reflectivity and emissivity, which lead to changes in thermal, optical, and charging properties. If these aspects remain unchanged, the spacecraft will not operate as designed. The key to predicting and mitigating these deleterious effects is the ability to accurately simulate space environment through long-duration, well-characterized testing in a simulated, versatile laboratory environment.

Radiation Testing

The radiation source mimics high energy (50 e⁻ to 2 MeV) geostationary solar electron flux. A pneumatic actuator controls the attached cryogen of source's shielding materials (Carbon and Tungsten) to expose samples or materials to S3 radiation. A spring returns the shielding material to its safe position which covers the source. This source has an activity rate of 100 mCi and is encapsulated in a stainless steel storage holder. This radiation assembly is compatible with the stand alone vacuum chamber.

Experimental Test Chamber Design

Sample Stage - Sample stage (S) to position samples under probe transverse axis, (T) to position samples under probe longitudinal axis, (O) to position samples under probe-translation stage, (V) to position samples under probe-rotation stage, (F) to position samples under probe-flux uniformity by periodic rotation. Sample stage shown has six 2.5 cm diameter samples (L) plus flux sensors (J J). S3 radiation exposure is attached to 40 cm diameter sample. Uniform temperature over -100 K to 450 K controlled using a cryogenic reservoir and resistance heaters (O). Large thermal mass helps maintain stable thermal.

Legend of Components

- Oxygen
- UV/VIS/NIR Solar Simulator
- FUV Photodiode-UV/VIS/NIR Spectrometer
- EPR Emissivity Probe
- Integrating Sphere
- Photodiode-UV/VIS/NIR Flux Monitor
- Faraday Cup-Flux Monitor
- X-Ray spectrometer
- Optical Grating
- Laser
- Heat Shielding
- 100 mCi Y-121 Cryostat
- Target Chamber
- Data Acquisition System
- Temperature Controller
- Vacuum Controller
- UV/VIS/NIR Solar Simulator Controller
- UV/Vis-NIR Solar Simulator Controller
- Spectrometers and Reflectivity Source

Space Simulation Capabilities

Versatile ultrahigh vacuum test chamber provides controlled temperature and vacuum environment with stable, uniform, long-duration electron and UV/VIS/NIR fluxes at up to 4 times sun equivalent intensities for accelerated testing for a sample area of 6 cm by 6 cm. Particularly well suited for cost-effective tests of multiple small scale materials samples over prolonged exposure.

Electron Flux—Electron flood gun (A) provides S5-10 e⁻/cm²/cm² (~10⁻¹⁴ to 10⁻¹⁰ a cm²/cm²) flux needed to simulate the solar wind at more than the 1005 cumulative electron flux. Mono-energetic energy range is ~0.05 to 100.00001 eV. Gun provides a -98% uniform flux distribution over the full sample area, with "hot-spot" fluxes for continuous exposure over the entire long duration testing. The electron gun was custom designed at USU after work by Seamansathan (2004).

Infrared/Visible/UV/IR Spectra. A commercial Class AAA solar simulator (B) provides NIR VIS AVHRA-E vector electromagnetic radiation (from 200 cm to 1700 nm) at up to 4 times sun equivalent intensity for accelerated testing over an area of 60cmX60cm. Source uses a Xe discharge lamp, a Y121 filter, and a series of Air Mass Zero filters (C) to match the incident radiation to the solar spectrum. Xe bulbs have ~1 month lifetimes for long duration studies.

Ultra Violet/Visible. The Kr resonance lamp (C) provides FUV radiation flux ranging from 10 to 2000 e⁻/cm²/cm² (~121.6 nm) that dominates the solar FUV spectrum. Kr bulbs have ~3 month lifetimes for long duration studies.

Flux Mask-Flux mask (E) located near the chamber's top ports restricts the flux boundaries to the sample stage, limiting equipment exposure and reducing scattering to accommodate uniform exposure. Can be readily modified for different sample geometries.

View Ports. Solar simulator UV/VIS/NIR light passes through a Magnesium Fluoride window (F). Additional viewports allow visual inspection.

Vacuum—Chamber uses standard mechanical and turbomolecular pumps (K) for roughing and an ion pump (P) for continuous operation (base pressure <10⁻⁷ Pa).

Temperature—A temperature range from 100 K to 450 K is maintained at 2 K by a standard PID temperature controller, using a cryogenic reservoir (O) and resistance heaters (P) attached to a large thermal mass sample stage (E).