ProtoSat & MEMSat:
Princeton University's First ThinSats

**Figure 8.** ProtoSat going through thermal cycling in a toaster oven and lab freezer for enriching student data.

Additionally, the "host" TSL Payload Board (TSLPB) provides a suite of its own interesting results. Performance results showed minimal change in spring clip preload/contact resistance, indicating that the Voltera PCBs were not as susceptible to the same degree of non-vacuum conditions as the ProtoSat board. All circuits survived the thermal cycling, but the PCBs showed a slight degradation in performance according to §2.2.5.

**Figure 2.** Voltera V-One printing conductive ink on a PCB.

**Figure 4.** Voltera PCB for MEMSat, demonstrating the true limits of low-launch loads and different colocated MEMS systems, as part of Princeton's undergrad Nanosat Lab.

Due to COVID-19, MEMSat was designed, tested, and assembled by Kyle in his own bedroom! The PCB was significantly more complex than the ProtoSat board, and this design proved to be reliably student-manufactured on the same Voltera PCB printer used for ProtoSat (see left).

**Figure 5.** Data Dashboard, and the Voltera PCB printer!

**Figure 6.** ThinSat program accessible to more students, just the right size!

**Figure 7.** The ThinSat program has a significant impact on the availability of space research and development opportunities for students.

**Figure 9.** ProtoSat on a vibration testing stand.

Easier, faster, safer, and even more student-friendly than CNC milling! Non-standard FR1 PCBs... ordered. 3D-printed ThinSat Engineering Model, their Space Systems, as part of their Engineering Program.

**Figure 3.** CNC-milled PCB for ThinSat programs (still tuning the achievable temp limits), but promising initial results and TVAC/radiation susceptibility? Hazard, for more student-safe milling/drilling. Interesting questions about outgassing mitigations by students.

**Figure H, I.** Comparing readouts of both IMUs to expected tri-axial magnetic units (IMUs):

- Sparkfun MPU-9250 and BNO055
- BNO055
- BNO055

**Figure D.** Broken trace.

- Prior to PCB fabrication, the circuit was tested on a breadboard (Figure G, H, I).
- Ensured solder joints and hardware were under the 1mm clearance on the back side of the board (Figure G).
- And soldered the components on using NASA-recommended solder and copper wires.

**Figure A.** Placement of components and soldering hardware ordered. 3D-printed ThinSat Engineering Model, their Space Systems, as part of their Engineering Program.

**Figure E.** Melted trace due to soldering.

- This particular circuit design deemed too complex for reliable Voltera printing, especially after the breadboard testing.

**Figure H.** Breadboard setup.

**Figure I.** Calculated placement of both IMU boards such that the IMU chips were as close to the center of gravity as possible.

- Designed a circuit that integrated three different popular MEMS inertial measurement units (IMUs):
  - Sparkfun MPU-9250
  - BNO055
  - BNO055

- Filtred "basic mode", especially convenient and accurate absolute orientation, but we learned that this filtering of ALL sensor data, to yield armed capable of reading out 1RPM acceptably above their noise. It should be noted that the smoother performance of the BNO055 may be partially attributed to onboard processing by an its integral ARM Cortex-M0 based processor.

- Compared readouts of both IMUs to expected tri-axial magnetic units (IMUs):
  - Sparkfun MPU-9250
  - BNO055
  - BNO055

**Figure 6.** ThinSat program accessible to more students, just the right size!