Enhancing CubeSat and small satellite reliability through improved thermal management

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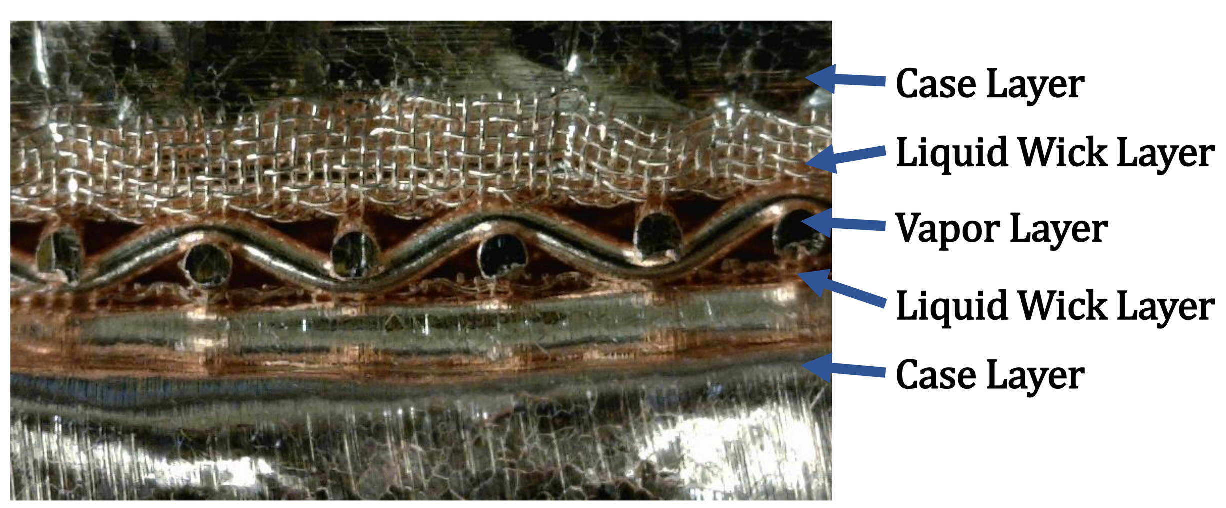
Overview

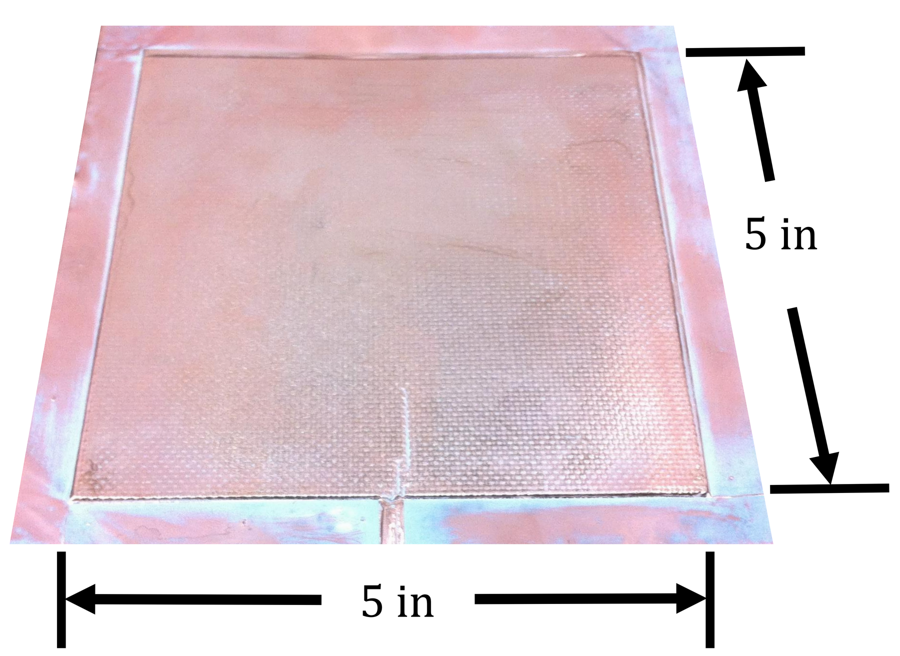
One major challenge in CubeSat system design is heat dissipation and thermal management. To meet the high power density demands of CubeSat systems, a flat, lightweight and conformable heat strap was developed called FlexCool. Thermal analysis of a CubeSat system was performed to show the effect of a high conductance thermal strap. Additionally, a reliability study was used to demonstrate the increase in lifetime of on-board electronics.

FlexCool Heat Strap

- All copper construction
- Bonded layers and case
  - >135 psi internal gauge pressure

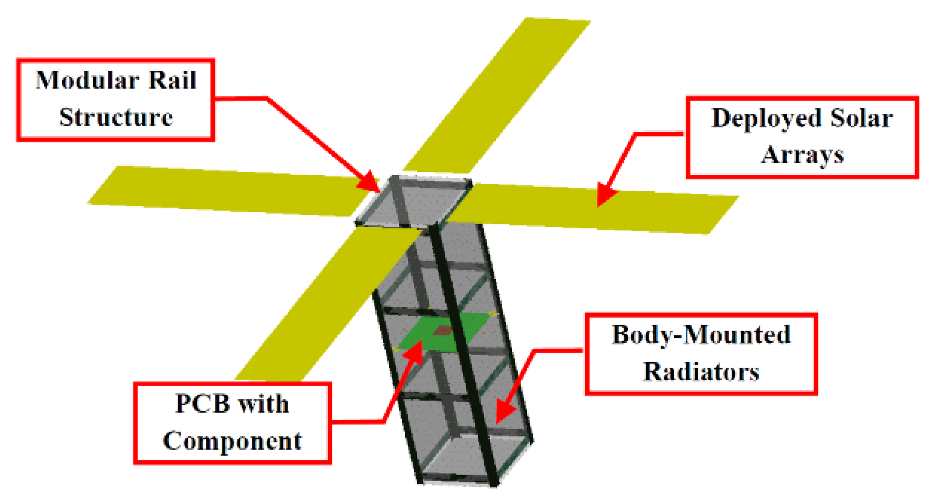


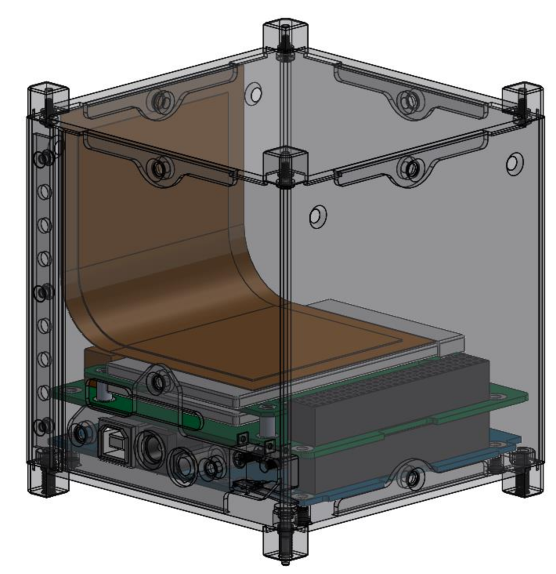
- <1 mm total thickness
- Lightweight and conformable



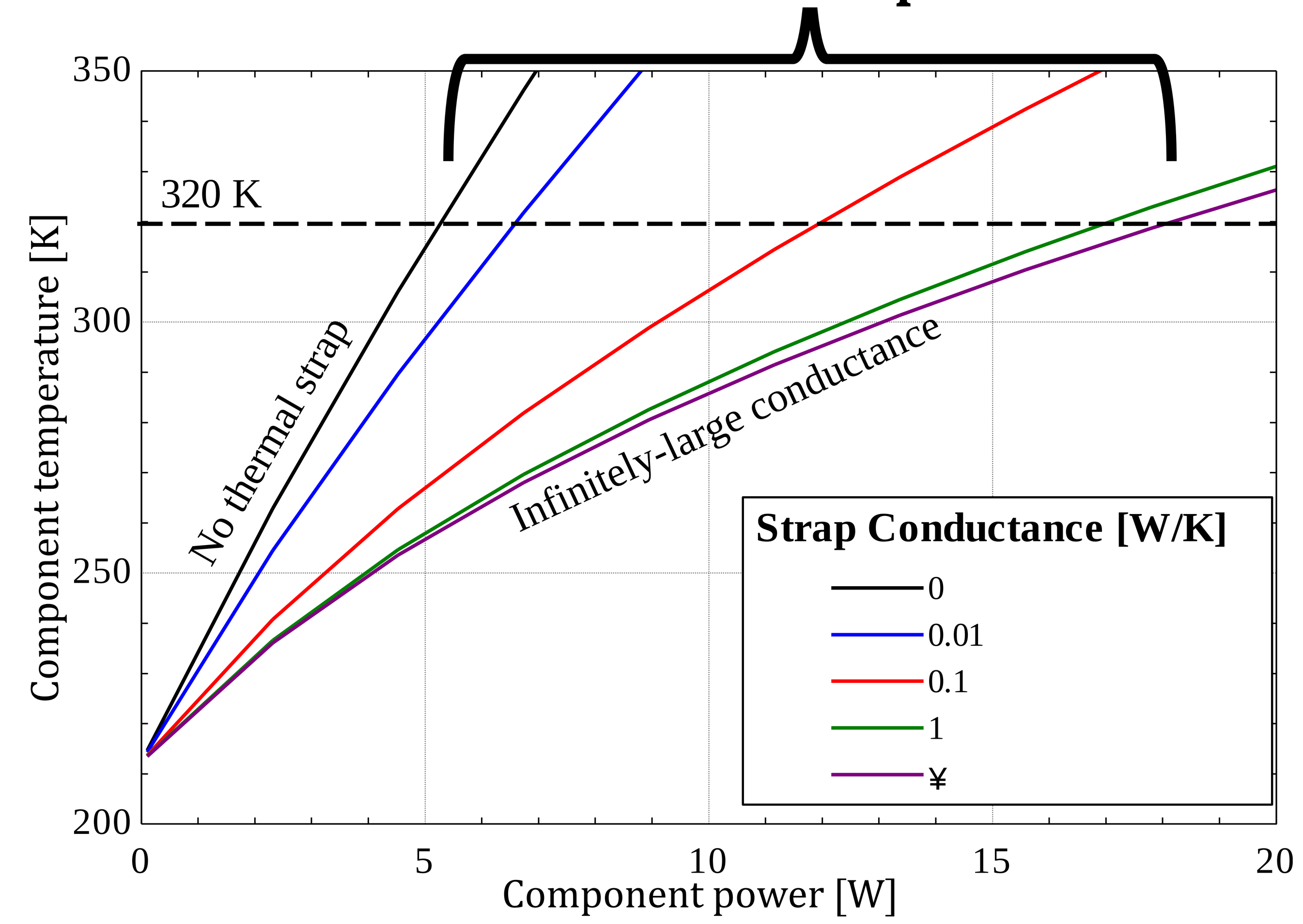
Orbital Analysis

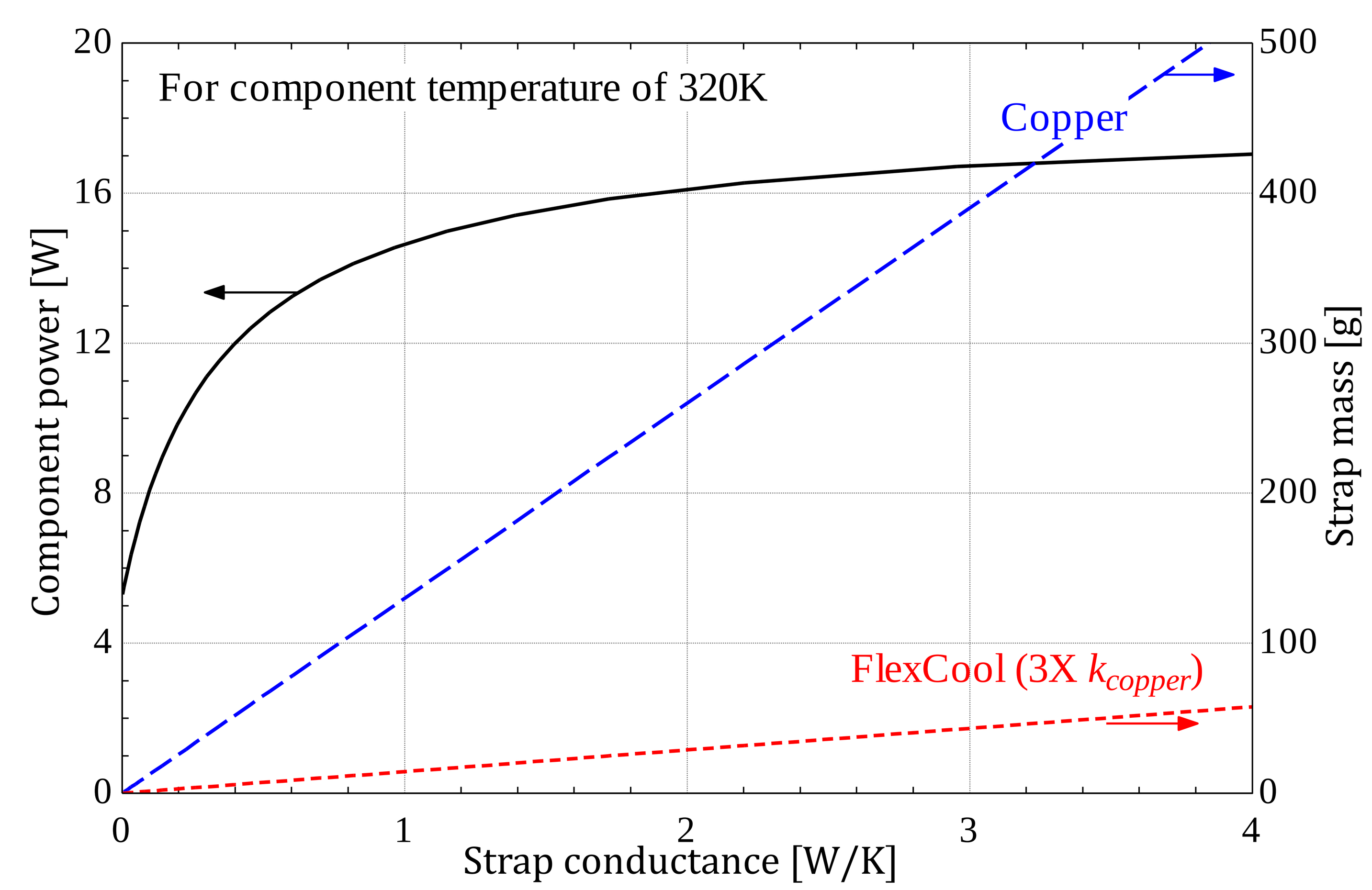
- Thermal Desktop analysis
- 1U and 3U CubeSat systems
- Orbital-averaged temperatures



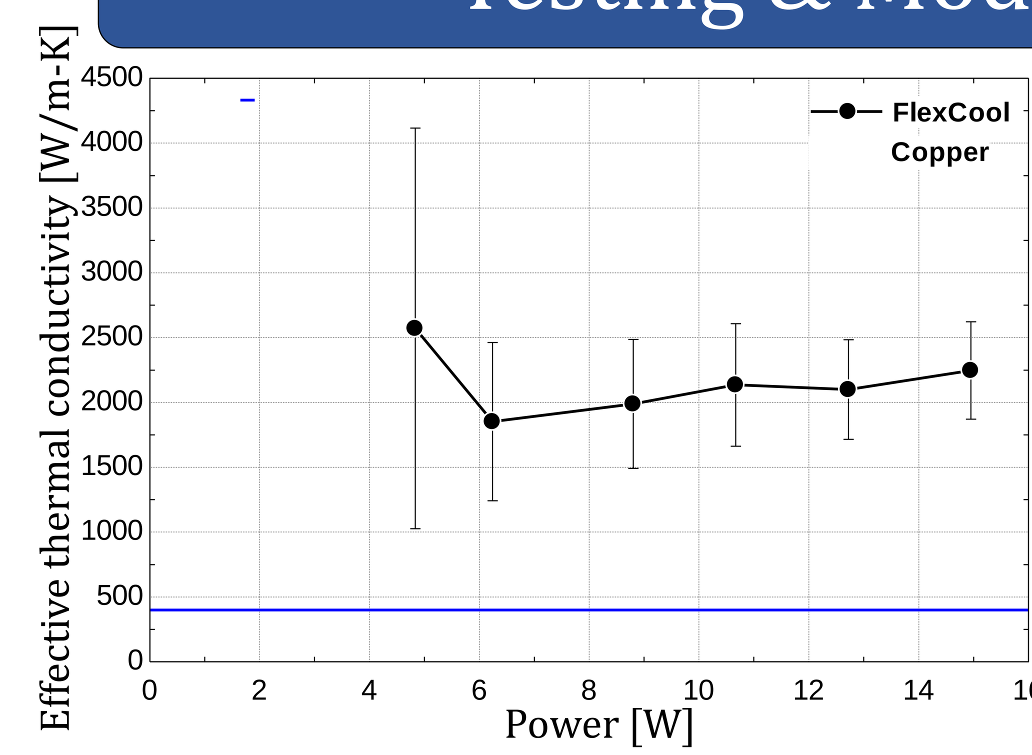


Thermal strap effects





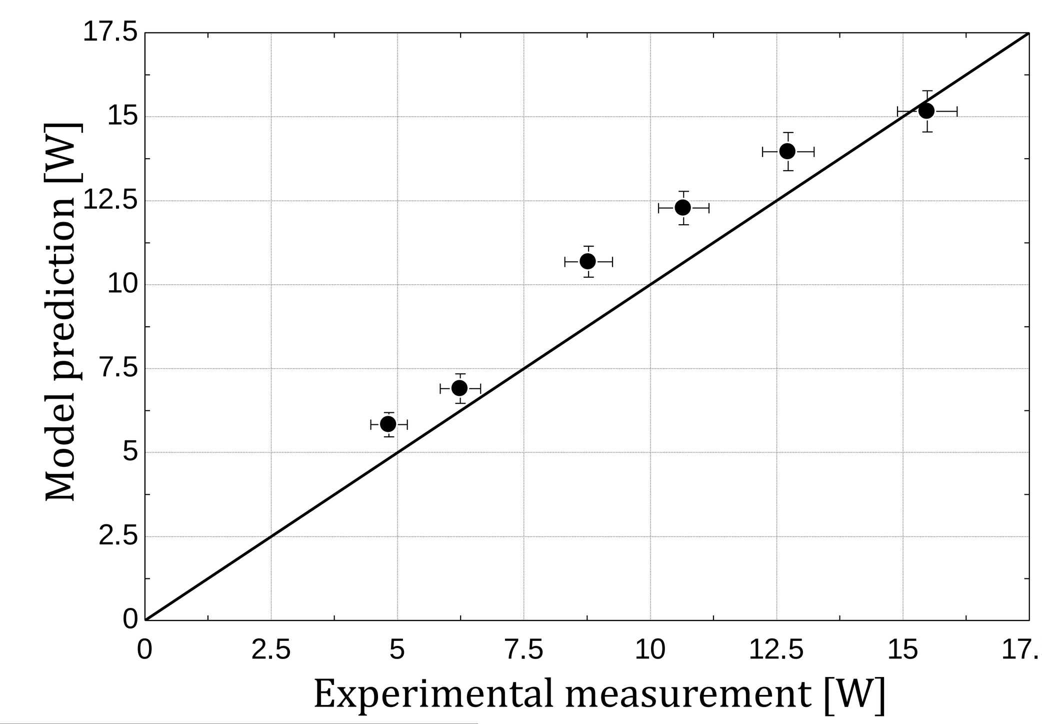
Testing & Modeling

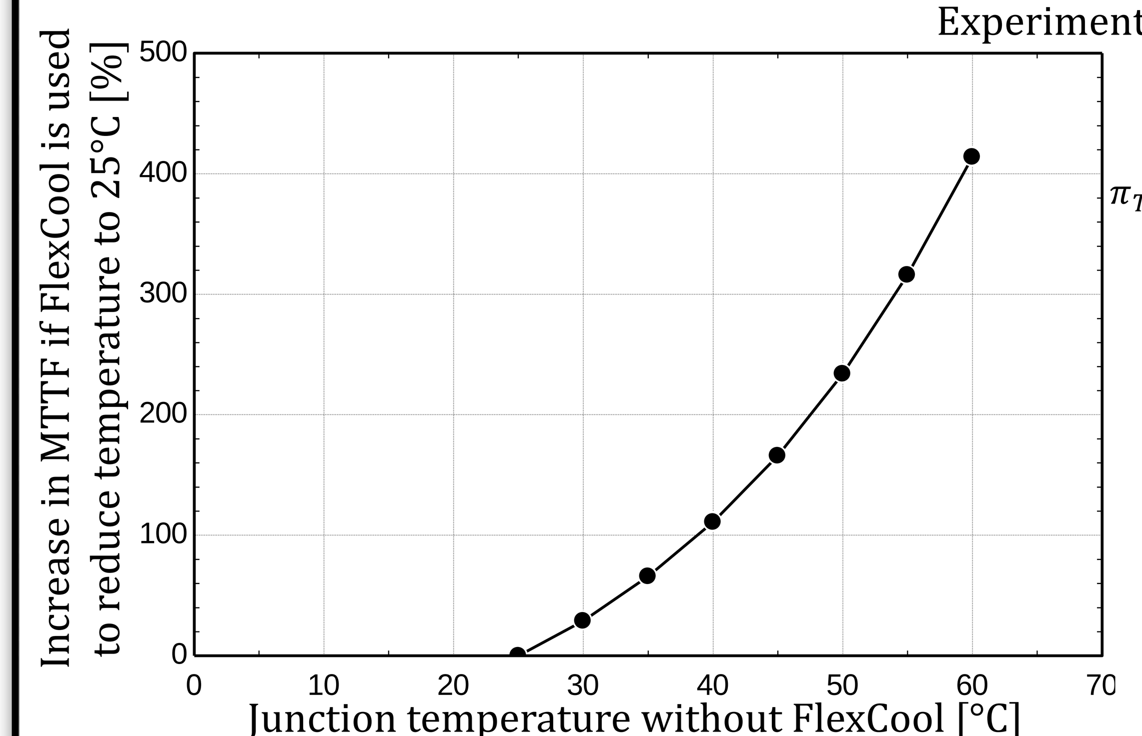


- Working fluid: Acetone
- One-dimensional measurements
- Single, uniform heat source
- 2.83 in effective length

Capillary Limit [1]

$$(\Delta P_c)_{max} \geq \int_0^{L_{eff}} \frac{\partial P_l}{\partial x} + \int_0^{L_{eff}} \frac{\partial P_v}{\partial x}$$





Temperature effect [2]

$$\pi_T = 0.1 \exp\left[\frac{-Ea}{8.617e^{-5}}\left(\frac{1}{T_j} - \frac{1}{298}\right)\right]$$

Failure rate [2]

$$\lambda_p = \lambda_b \pi_T$$

Mean time to failure [3]

$$MTTF = {}^{1}/_{\lambda_p}$$

[1] Peterson, G. P., "An Introduction to Heat Pipes: Modeling, Testing, and Applications"
[2] MIL-HDBK-217F
[3] Ellerman, P., 2012 "Calculating Reliability using FIT & MTTF: Arrhenius HTOL Model" Microsemi

Conclusions

The FlexCool heat strap developed at Roccor demonstrated an effective thermal conductivity up to 2,149 W/m-K (5x higher than copper) with a total thickness of 0.86 mm. Use of a FlexCool strap in a CubeSat system can greatly decrease the average orbital temperature, resulting in an exponential increase in MTTF of the on-board electronics.