Performance Comparison of Two-Phase Heat Spreaders for Space Modular Electronics

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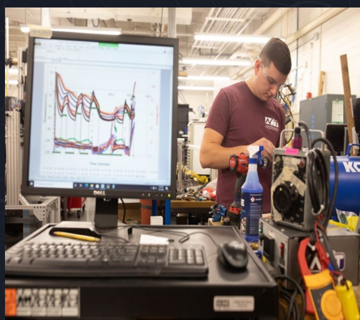


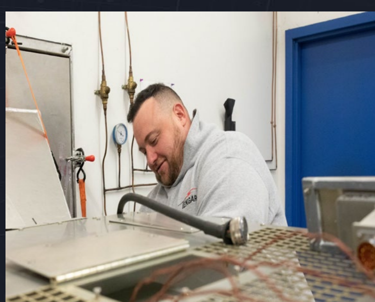



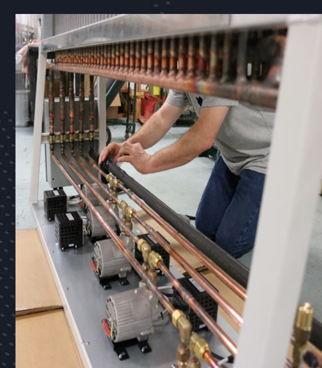

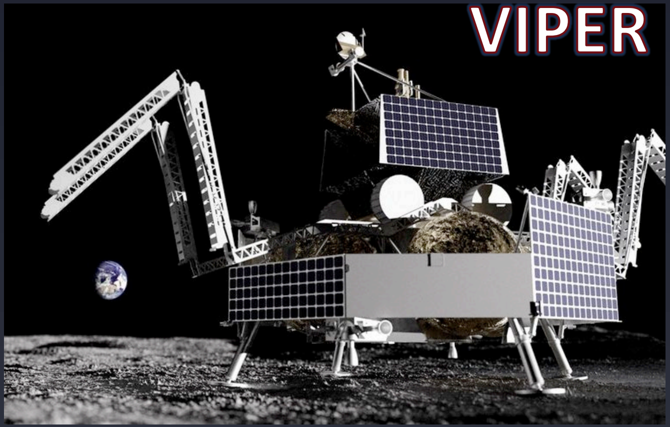

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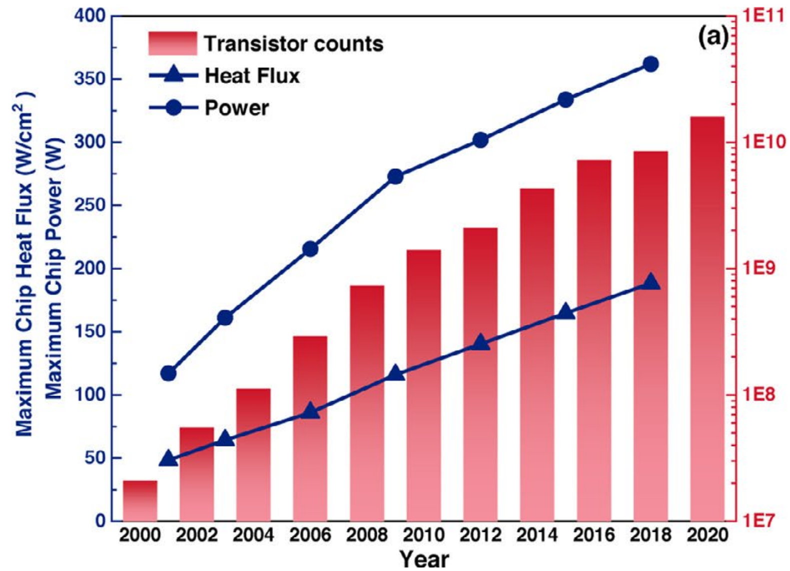
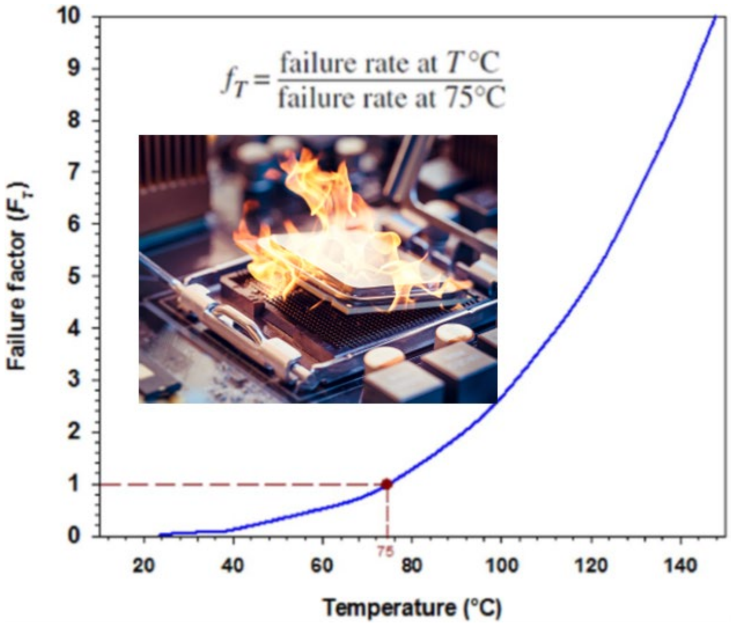
Thermal Management of Electronics

- Evolving semiconductor technology is pushing power capacity and thereby waste heat flux of the electronics cards
- This stray heat must be dissipated effectively for safe and reliable operation

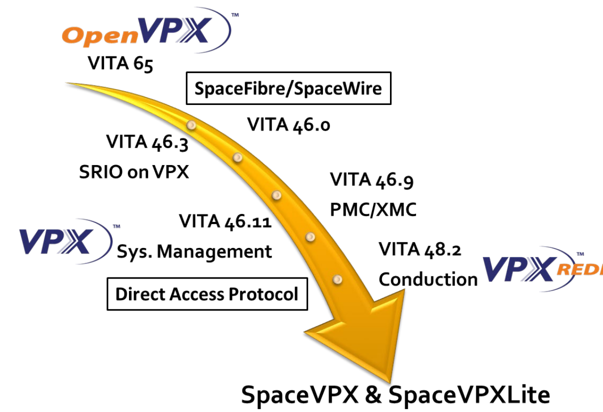


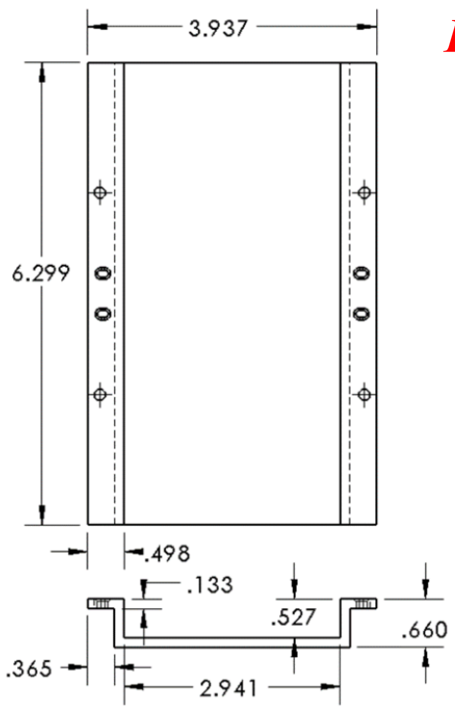


- Failure rate expedites if maximum temperature on card surpasses 75 ° C
- High performance heat handling technologies are needed

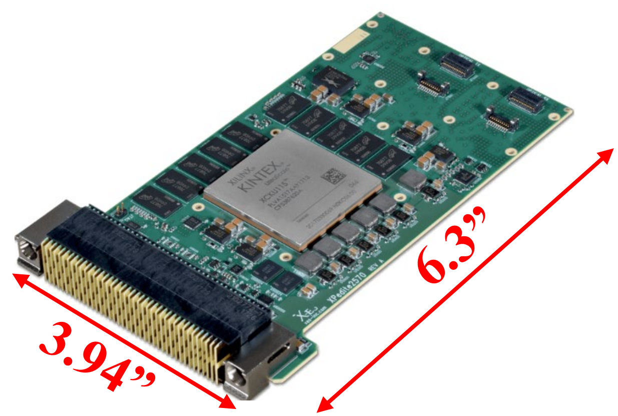
Modular Electronics Specifications

- There is a strong interest in modularizing electronics for easy cross-platform applications and reducing costs
- VPX guidelines are widely followed for modular form factors
- VITA 48.2 forms the basis for electronics mechanical architectures





Example: 3U card based on VPX

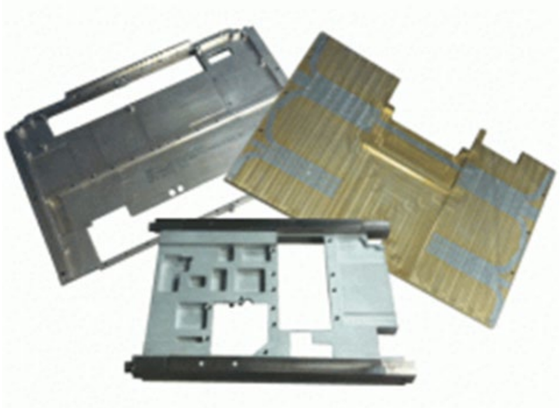


Refs: NGSIS Space VPX™ and Space VPX Lite tutorial (VITA 78 & 78.1 Working groups)
Access: https://www.vita.com/Tutorials

Entities using Space VPX standard

Heat Spreaders for Modular Electronics

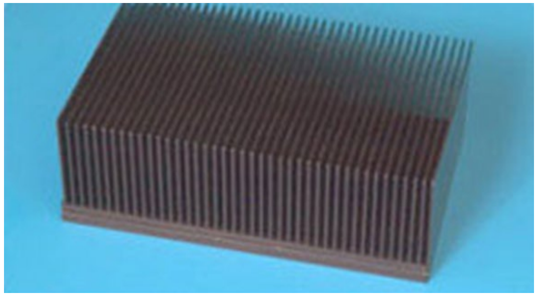
- Commercial heat-spreading solutions for electronics involve aluminum conduction cards
- High-performance heat spreaders based on two-phase are being adopted
- ACT has developed several two-phase solutions for various applications including electronics cooling
  - **Embedded heat pipe heat spreaders-EHP (HiK™ plate)**
  - Vapor chambers
  - **Pulsating heat pipe-PHP (R&D)**



Material	Density	Spreading	Thermal Conductivity W/m K	Max. Heat Flux, W/cm^2	Minimum Thickness	Max. Height, cm	Direct Die Attach
Aluminum	1	2-D	200	Depends on Geometry	Structural Considerations	N.A.	N
Spot Heat Pipe	~1.3	1-D	10,000 to 100,000	75 (500)	3 mm (< 1.8 mm flattened)	~ 25 cm (10 in.)	N
HiK™ Plate	0.98-1.2	1.5-D	600-1,200	75	1.83 mm (0.072 in.)	~ 50 cm (20 in.)	Y
Vapor Chamber	~2.8	2-D	5,000 to 100,000	750 (1 cm^2)	3.0 mm (0.120 in.)	15 cm (6 in.)	Y
Encapsulated Conduction	0.9-1.0	2-D	~ 550	Depends on Geometry	1.5 mm (0.060 in.)	N.A.	N

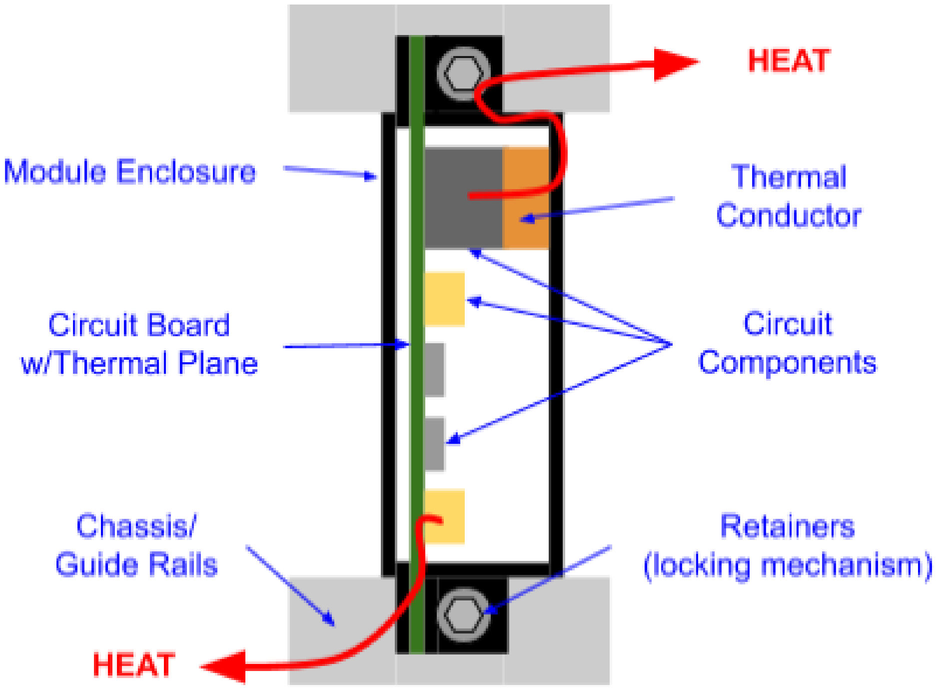
Technology comparison for conduction cooling vs two-phase cooling

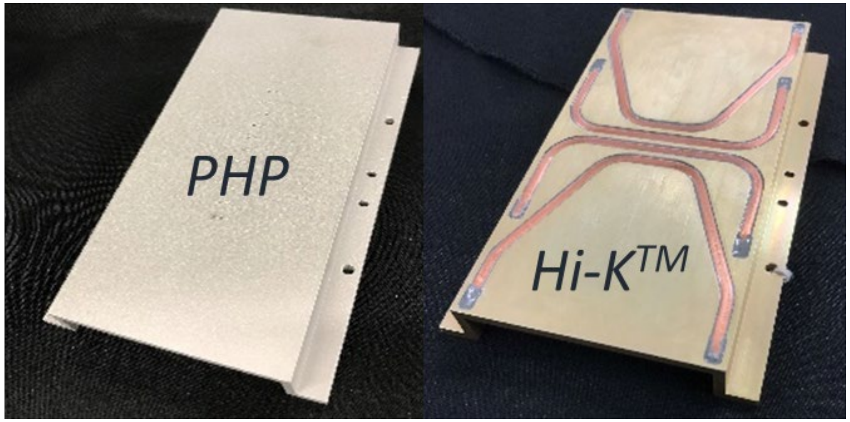
https://www.1-act.com/when-to-use-heat-pipes-hik-plates-vapor-chambers-and-conduction-cooling/



Heat Spreaders for Modular Electronics

- Under the existing NASA SBIR Phase II program (80NSSC22CA205), ACT is developing and maturing the pulsating heat pipe-based heat spreaders.
- A performance comparison between PHP and Hi-K^{TM} plate specifically for 3U modular electronic cooling applications will be discussed in this presentation

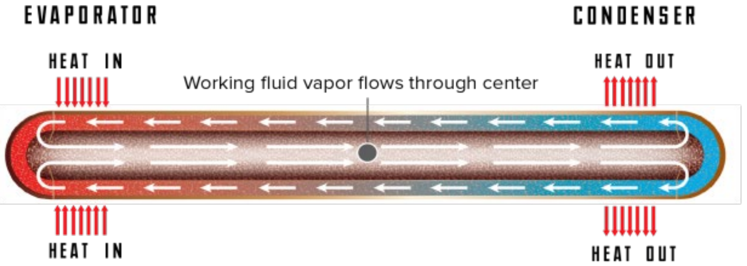


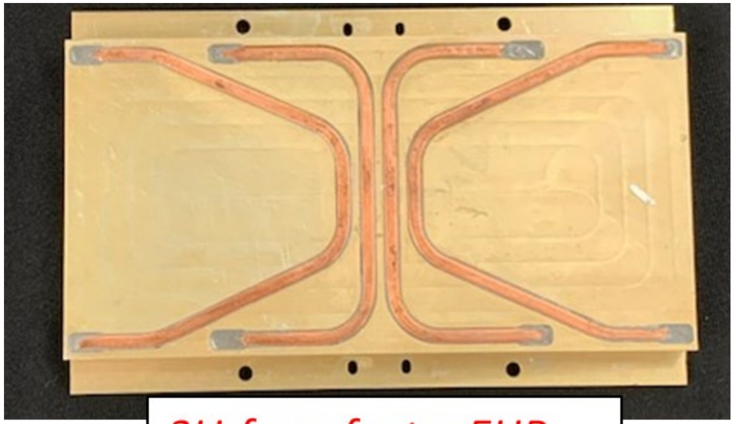


Embedded Heat Pipe (EHP): HiK™ plate

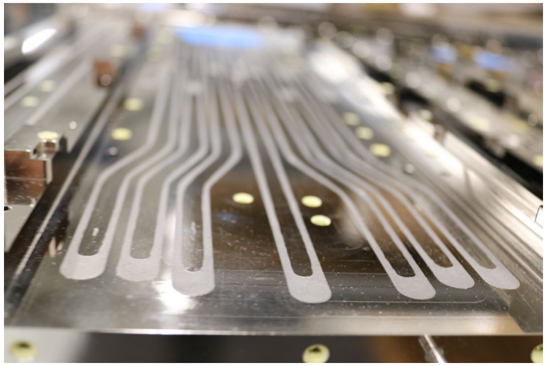
Heat pipes are embedded into the base plate

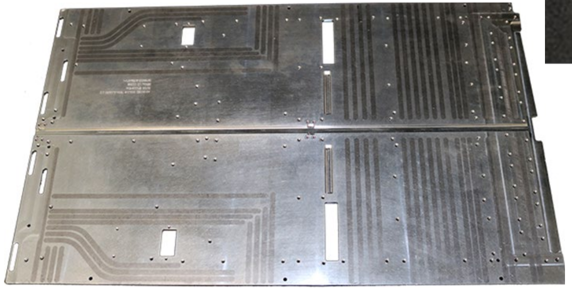
- Heat added in the evaporator vaporizes the working fluid which is then transported to the other end
- The vapor condenses in the condenser rejecting heat to the heat sink
- ACT manufactures EHPs for various applications
- Typical thermal conductivity: 3-6X conduction plates





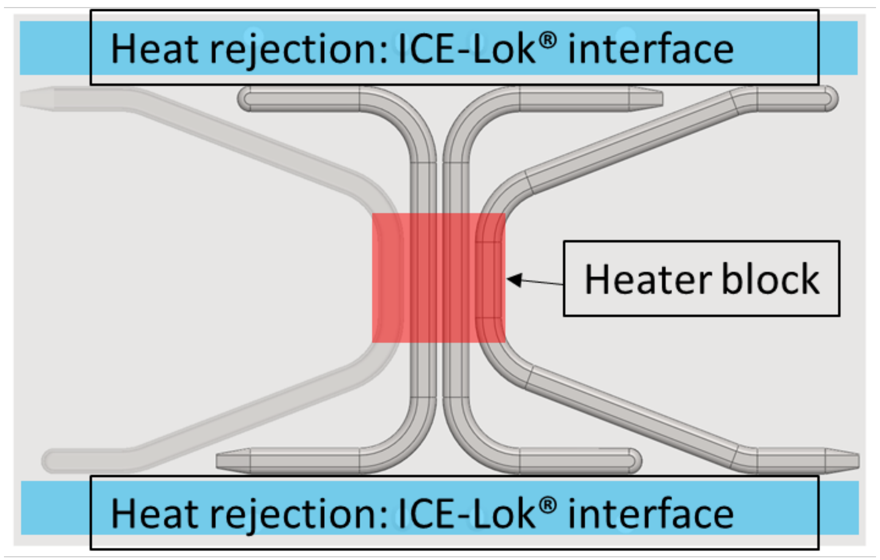
3U-form factor EHP

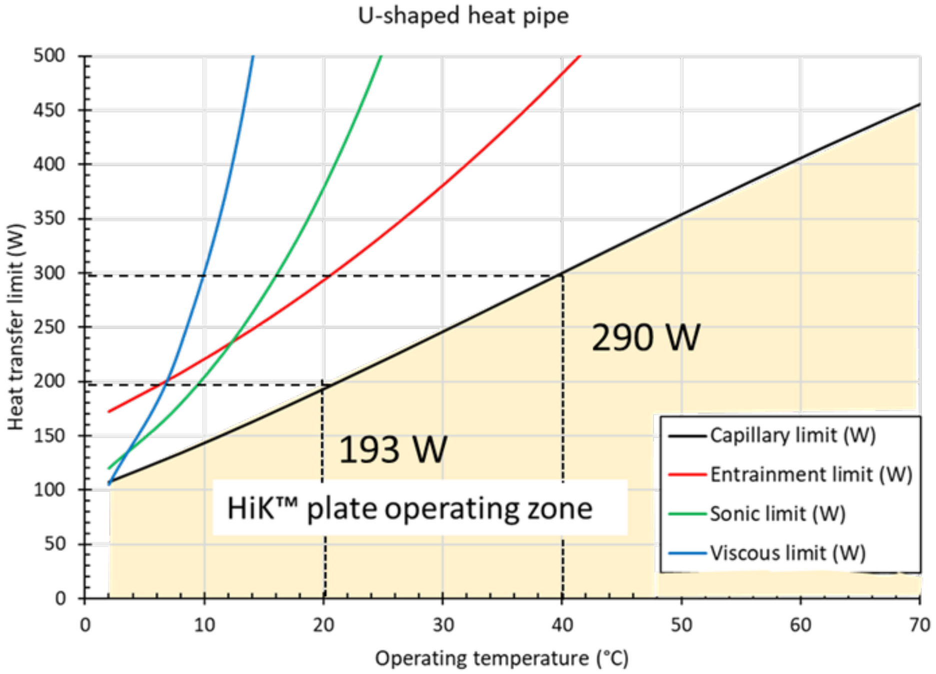




Design of EHP Heat Spreader

- A 3U-form factor EHP was fabricated according to ACT's design & manufacturing approach
- U-shaped 4 Cu-H_2O heat pipes were selected based on the chosen heating & cooling configuration
- Heat input at the center and cooling at the stepped plane

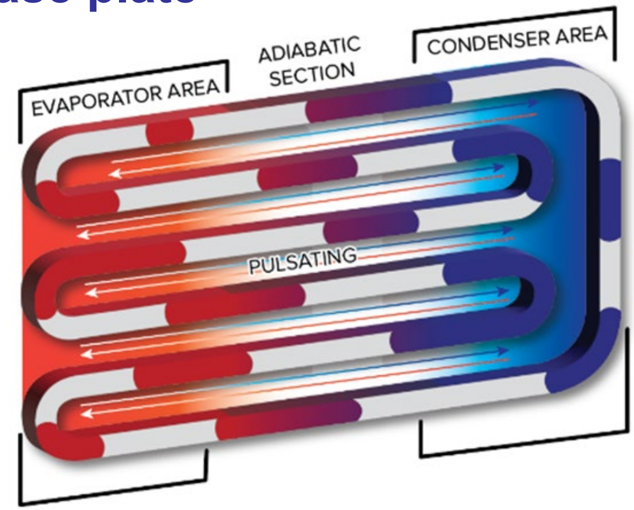


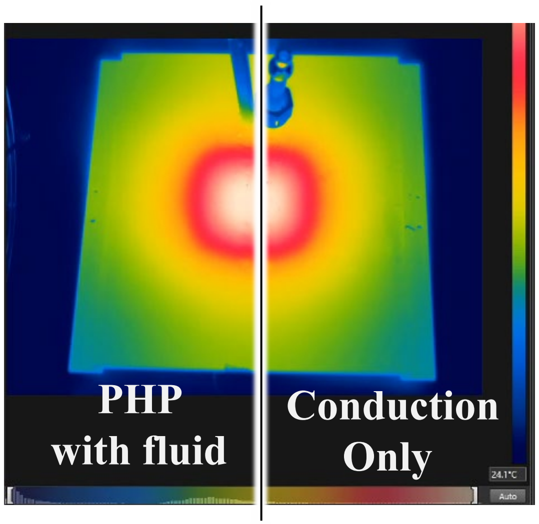


Pulsating Heat Pipe (PHP)

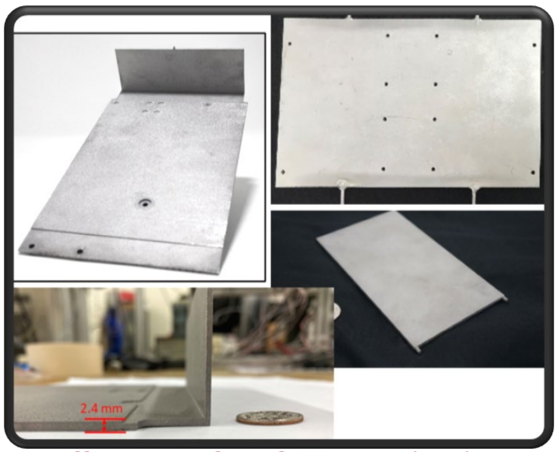
Working fluid path is inside the base plate

- Heat transfer is by pulsation of working fluid
- In evaporator, vapor pressure expands by partially vaporizing working fluid
- In condenser, the bubble shrinks or collapses rejecting the heat
- Simultaneous action results in fluid pulsation

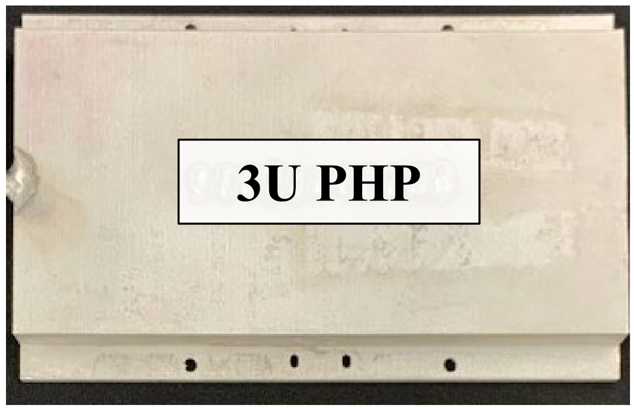




A side-by-side characterization of heat spreading through the PHP against plate conduction

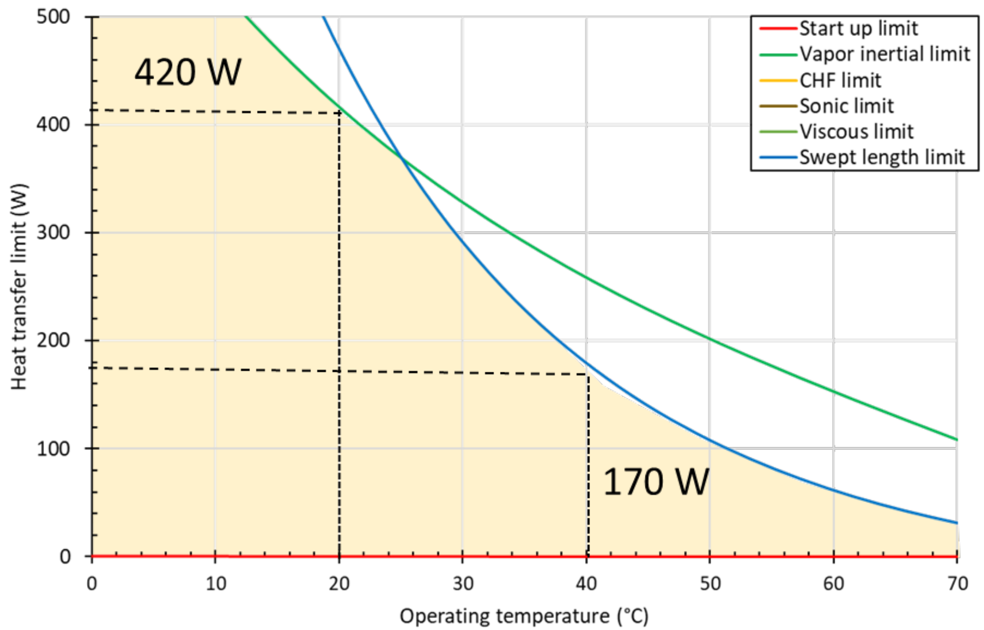


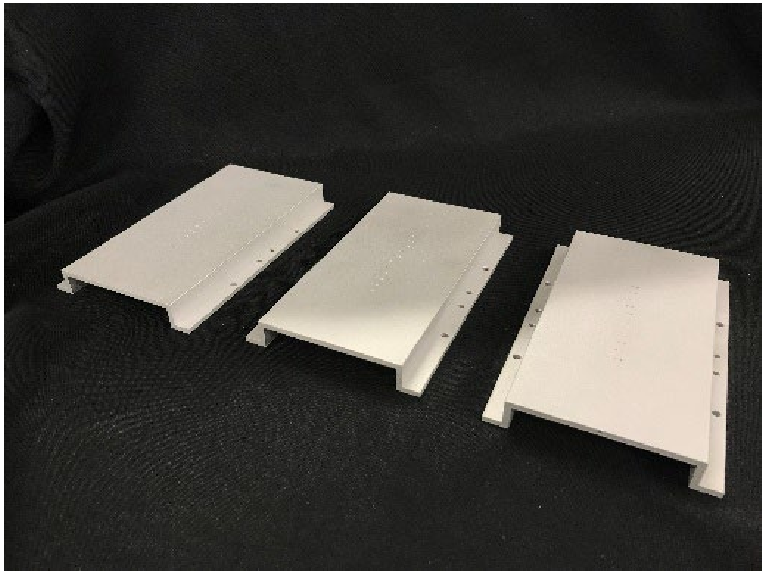
Different PHP form factors tried and tested at ACT for different applications



Design PHP Heat Spreader

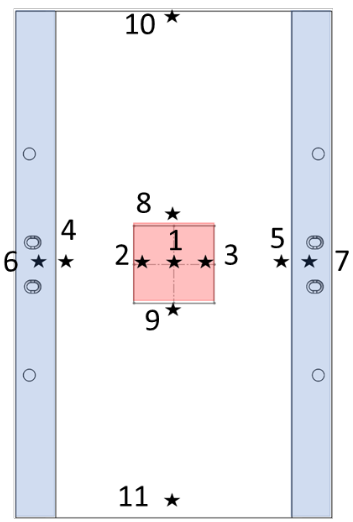
- Fabricated by additive manufacturing with aluminum
- PHP design consisted of fluid channels of size 1.5 mm (0.06")
- Propylene was chosen as working fluid
  - High Merit number in desired operating temperature range (-20C – 75° C)
  - > 200W heat removal within desired operating temperature range
  - The heat transfer limits model is used as a qualitative assessment tool
- PHP channels extend to stepped edges

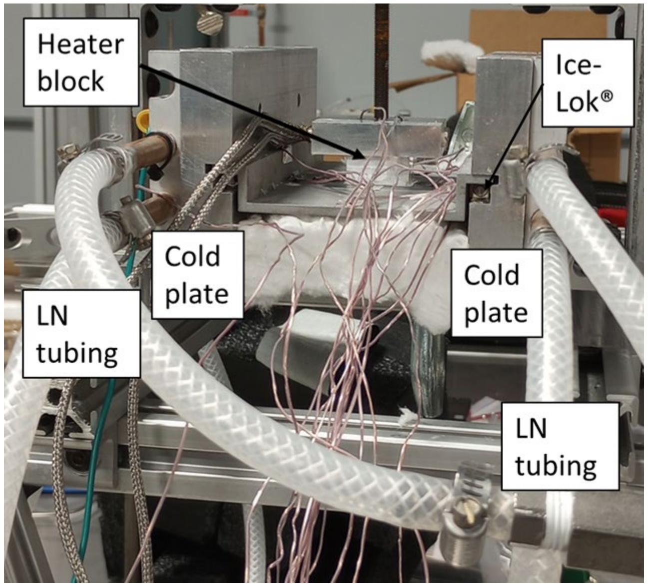


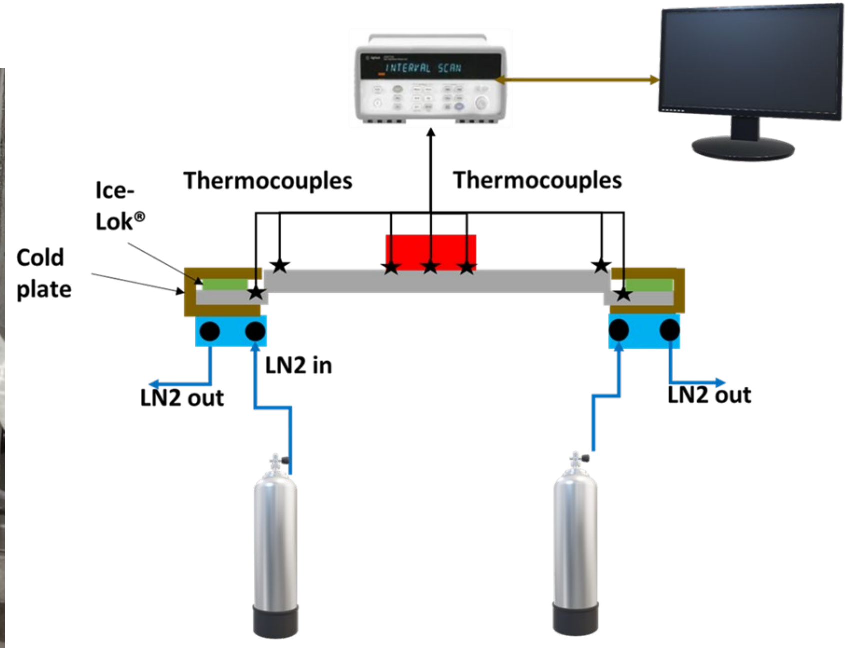


Performance Testing Methodology

- Quasi-steady state testing method adopted for heat spreader performance testing

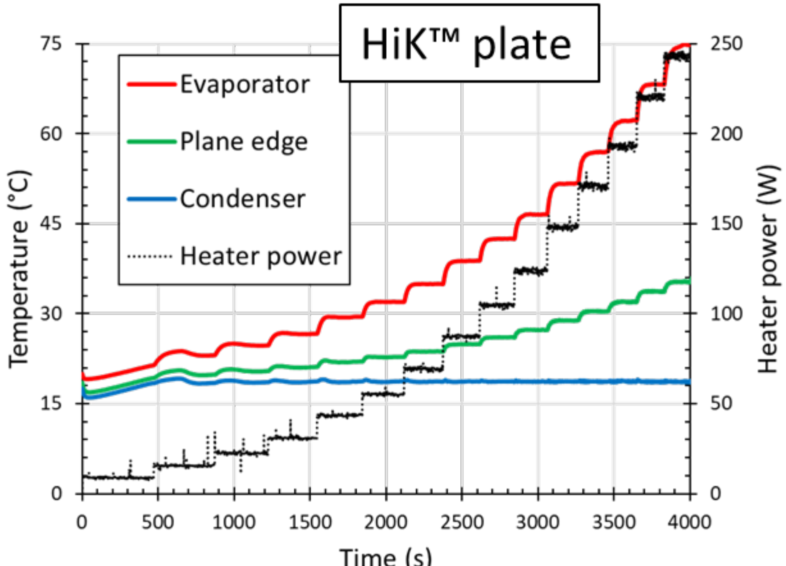


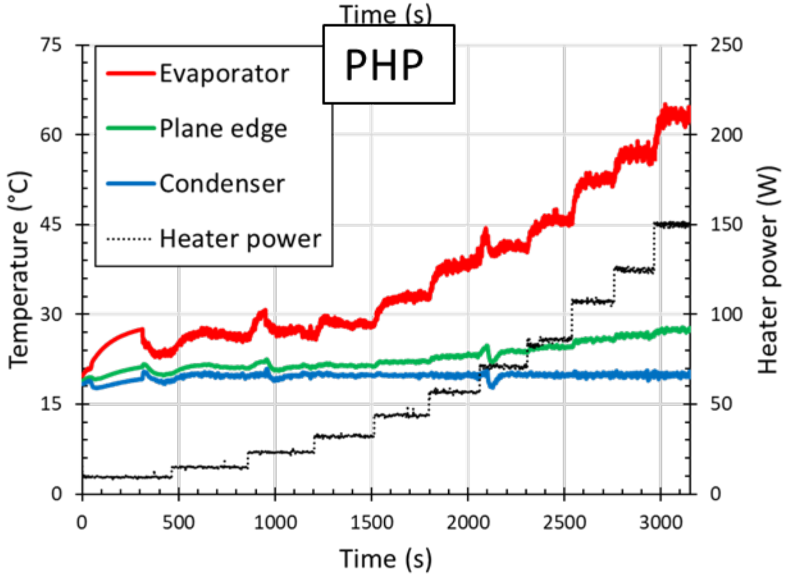


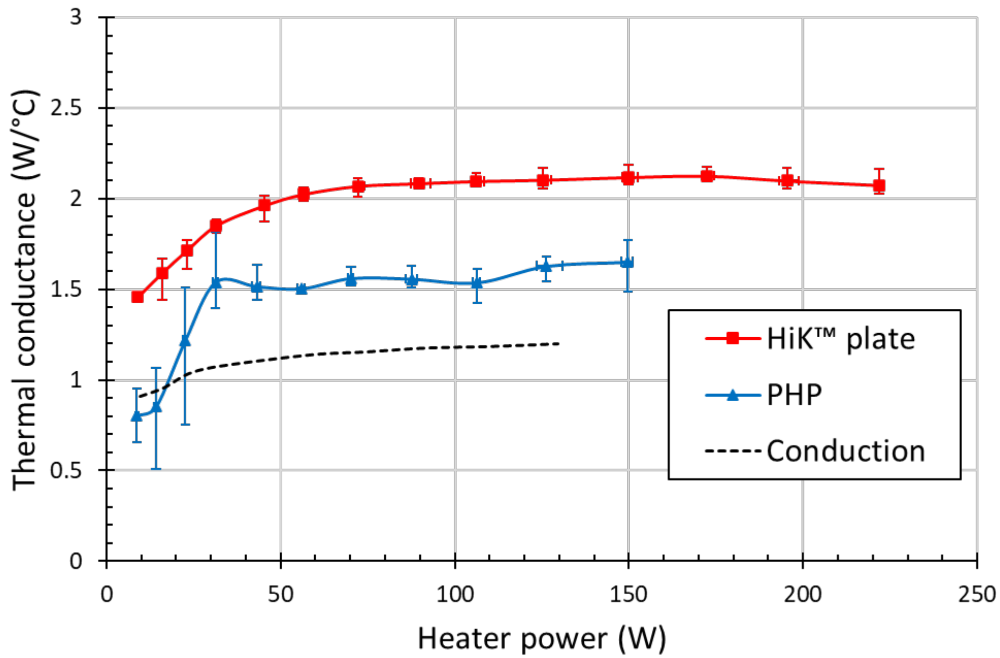


- Semi-automatic
- Test shut-down condition:
  - Maximum temperature on the heat spreader: 75 ° C
  - Dry-out occurs in the heat spreader
- Condenser (TC4, TC6) maintained at constant temperature and referenced as operating temperature

Performance Comparison of: EHP & PHP

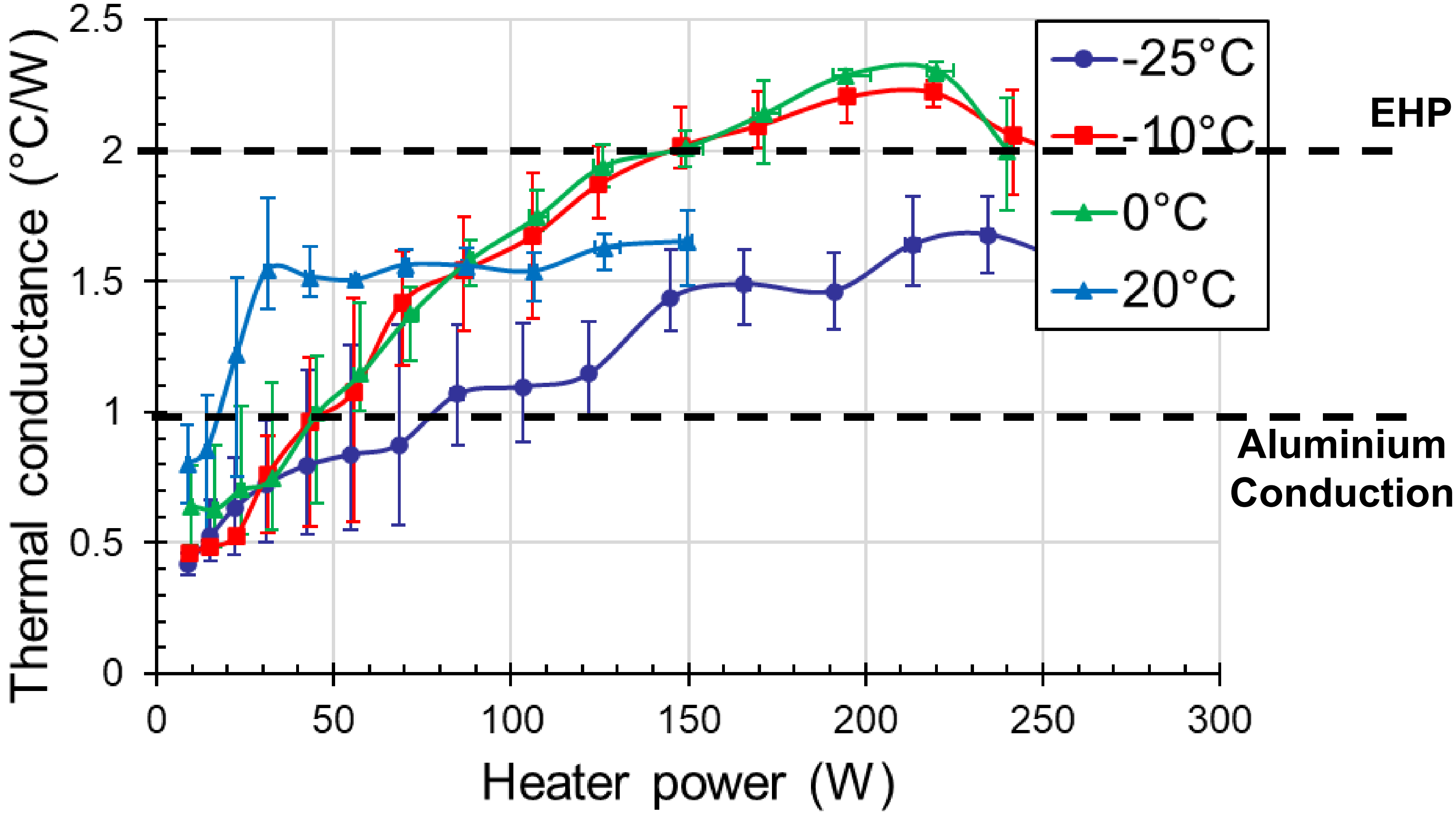






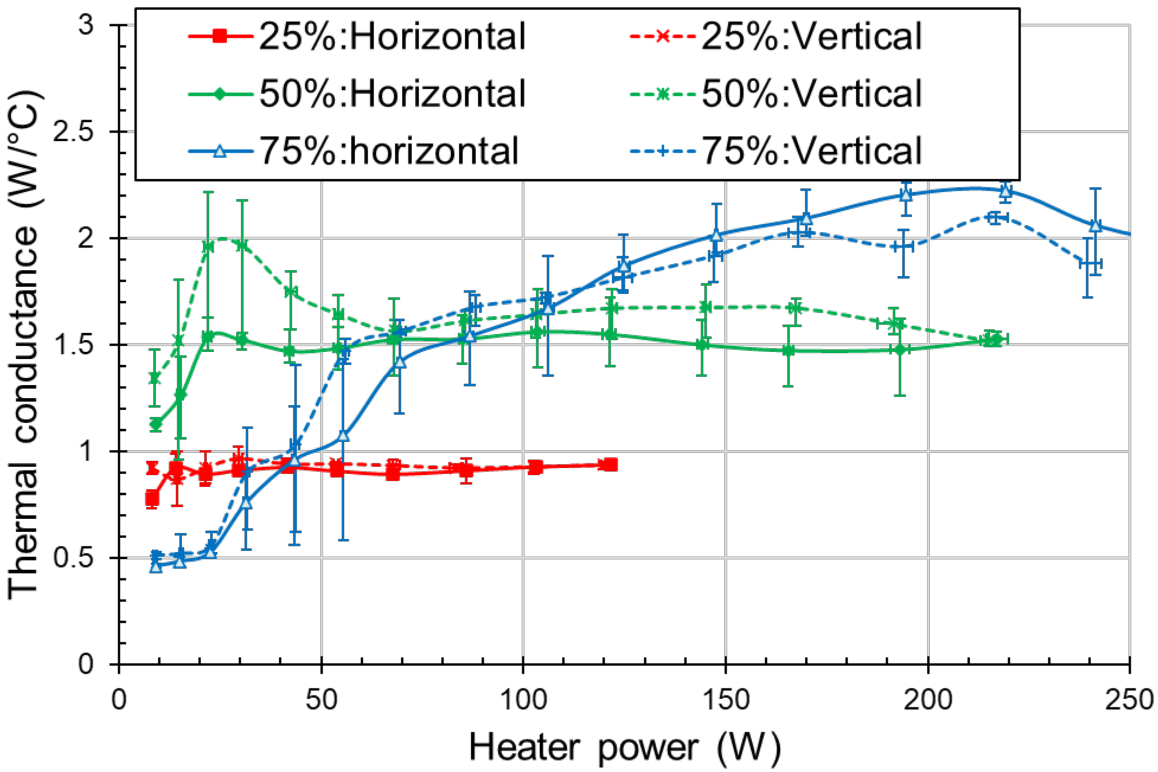
- Performance comparison shown for operating temperature of 20 ° C
- HiK™ plate has up to 2X improvement in thermal performance over baseline
- PHP has up to 1.5X improvement in thermal performance over baseline

PHP Parametric Study: Condenser Temp



- Optimum temperature range for PHP is between -10 ° C and 0 ° C
- As the condenser temp increased to 20 ° C, PHP operated near dry-out region
- At lower condenser temp, PHP showed start-up issues

Filling Ratio and Orientations



- Fluid fill ratio influences PHP performance
- Low fill ratio (25%) yielded poor performance
- Higher fill ratio (75%) has delayed start-up
- 50% fill ratio operated well at lower powers
- Optimal fill ratio: between 50 to 75%
- Gravity had less influence on PHP performance

Conclusions & Future Direction

Summary

- EHP had better performance at 20 °C operating temperature
  - Conductance improvement over conduction plate was 2X
  - PHP performance improvement over conduction plate was 1.5X
- PHP performance was ideal at operating temperature -10 to 0 °C
  - PHP performance was about 2X conduction plate at power > 150 W
  - Fluid fill ratio influences start-up and dry-out behavior
  - Performance of PHP was less influenced by gravity

Future Direction

- Comprehensive investigation to determine the optimum operating zone for PHP and EHP heat spreaders by testing heat spreaders at various operating conditions of interest.
- Investigate PHP performance with other working fluids
- Develop Modular Electronics Units (MEUs) with two-phase heat spreaders and test them in a space-simulated environment.
- ACT will design and develop an integrated channel enclosure chassis for improved chassis-level thermal conductance.

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  - Justin Boyer
  - Philip Texter
  - Tim Wagner (welding)

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- Pulsating heat pipe and embedded heat pipe heat spreaders for modular electronics cooling, Case Studies in Thermal Engineering, vol 49, 103256, 2023 https://www.sciencedirect.com/science/article/pii/S2214157X23005622?via%3Dihub

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