# The need for advanced thermal cooling for Electronic Units

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# Next Generation Spacecraft Increasing Thermal Challenges

- Large emphasized for “flexible” reprogrammable satellites
  - Fully digital satellite with SSPA, Digital transparent processors (DTP)
  - Phased array antennas with large amount dissipative elements
  - Increased on-board processing with more dissipating components

- SSPAs and DTPs have lower efficiency, 30% compared to traditional RF components as well they are operating at a lower temperature.

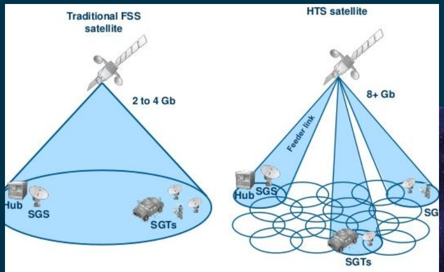
- With the Digitalization of Telecom Payload, the 85° C Zone as decrease and the 65° C has increase in surface area. The heat rejection efficiency has been reduced

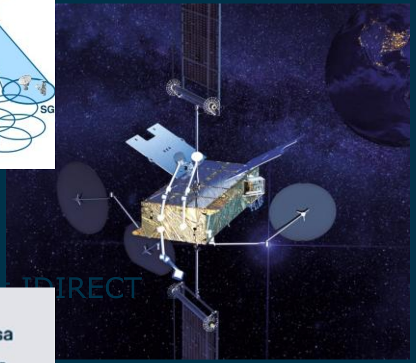
- Technology Vision emphasized on Ultracompact High Performance Satellites and Highly Autonomous systems

- The trend is moving towards higher dissipation but less surface area to radiate

- **Thermal as become more problematic and complex**

- **Thermal will become the bottleneck for future applications hence more attention is required**



Inspire Credit Thales


# *There are system level Heat Rejection Limitations*

- Radiators have large amount of heat pipes to uniformalise the temperature
- Heat Rejection Sizing Rule:  300W/m2 for 85 ºC zone, 200W/m2 for 65 ºC zone
- Qualification TRP at 85 ºC, with operational margin, radiator interface below 50 ºC
- Qualification TRP at 65 ºC, with operational margin, radiator interface below 35 ºC
- Typically for electronic box PCB Qual Temp is 80 ºC to 85 ºC due to soldering qualification and derating temperature on passive component.
- More and more cases where waivers are requested but this will impact reliability


Large Delta T
between Components
and Radiator

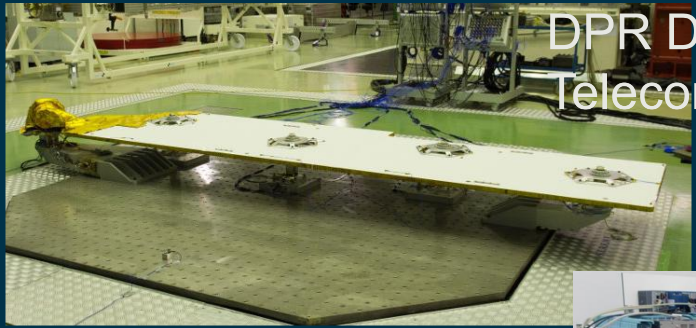
More Power,
More Delta T!!!

AlphaSat OSR radiators cover the maximum available surface on North and South sides to radiate more than 10 kW of dissipation.

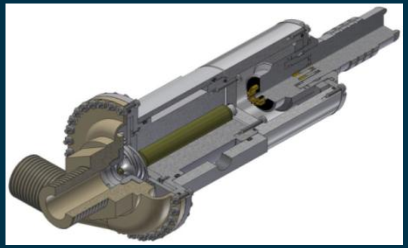
# Thermal System Solutions to Increase Heat Rejection

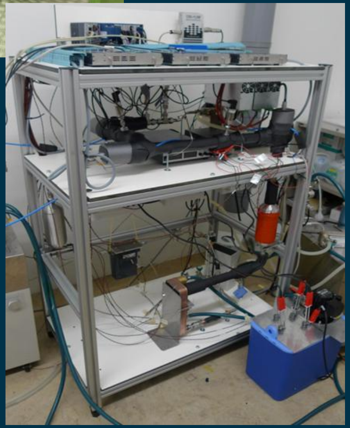
- Space is not getting colder, 4K
- Thermal Optical properties of surfaces are at their limit
- Heat rejection capability to space remain unchanged

- Two options to increase Heat Rejection
  - Increase radiating surface area
    - Limitation on the size of the Radiator due to accommodation
    - Deployable Radiator but with increase complexity
  - Increase Radiator Temperature
    - Using Heat Pump, keeps units below 60° C while the Radiator is at 90° C
    - **Or decrease thermal gradient from Radiator to electronic components allowing the Radiator to operate at higher temperature**



DPR Deployed on Telecom S/C





Heat Pump Compressor Development

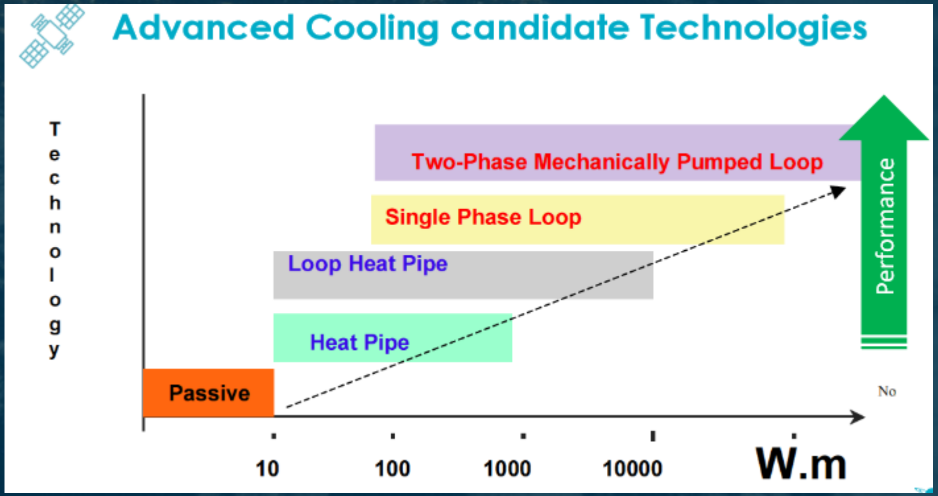
# EOP and Telecom Platform and Payload Developments

- Common and Reduced Interfaces for Mid-Size Satellite Industrialisation (M-IND)
  - Emphasizes industrialization for large-scale production, cost reduction, speed to market, and adaptability to commercial demands like satellite constellations.
  - Synergy with
    - Advanced Data Handling Architecture (ADHA)
    - Advanced Power Architecture

- What is important for thermal to standardize:
  - Standard Form Factor
  - Standardized Electrical, Mechanical and Thermal Interfaces
  - Standardized Component Heat Exchanger/Evaporators for direct Chip Cooling
  - Standardized the location of high dissipating components
  - Standardized Inlet/Outlet Fluid Connection for electronic units  when needed

- Reduce overall cost of advanced Thermal hardware
- Build a catalogue of thermal hardware product
  - Various product for various power dissipation

ADHA 6U and 3U units, and 6U

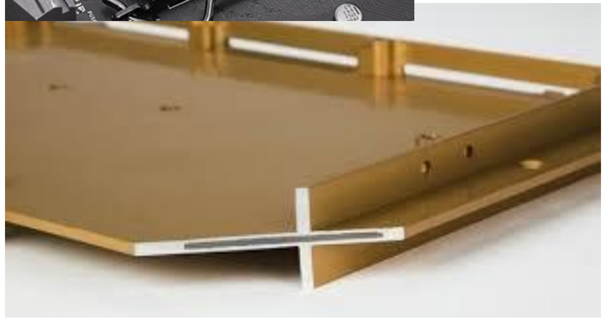



Standard Two-Phase Chip Cooling Example

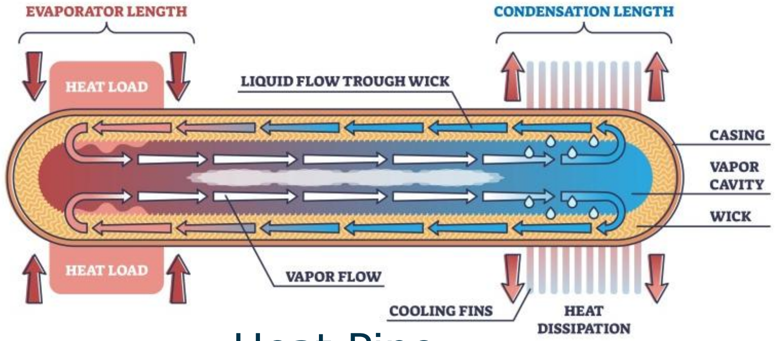
Direct Chip Cooling Example

# Thermal Technology Options for Electronic Box Cooling

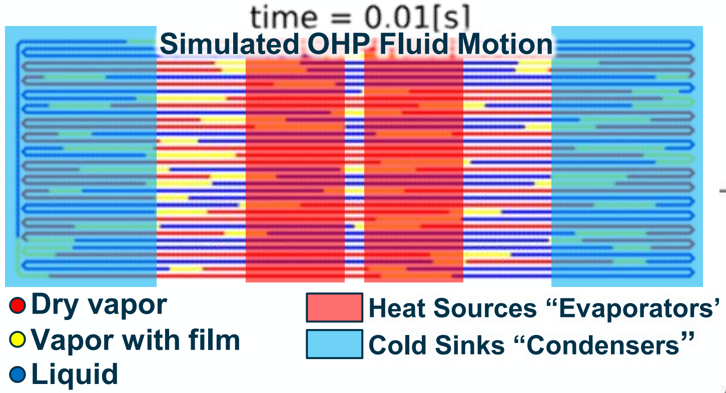
Interface Fillers
RTV, Paste, Liquid Metal



Al or Cu Conduction Only Or Enhanced with Highly Conductive Material as APG
(Credit: Boyd K-Core)

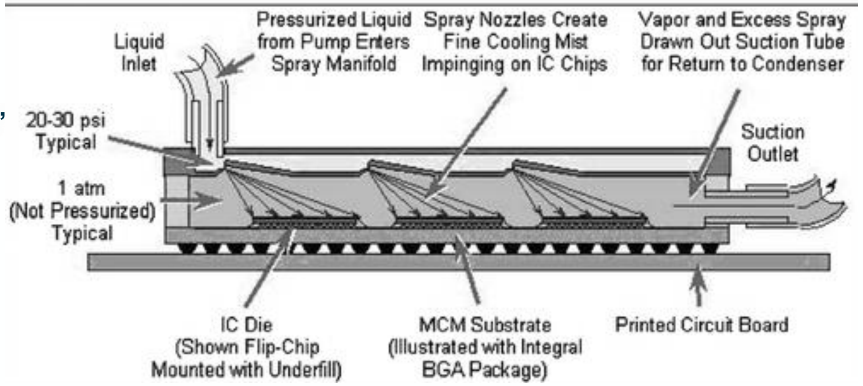



Heat Pipe




Pulsating Heat Pipe
Credit (ThermAvant)


Loop Heat Pipe
Credit (Calyos)

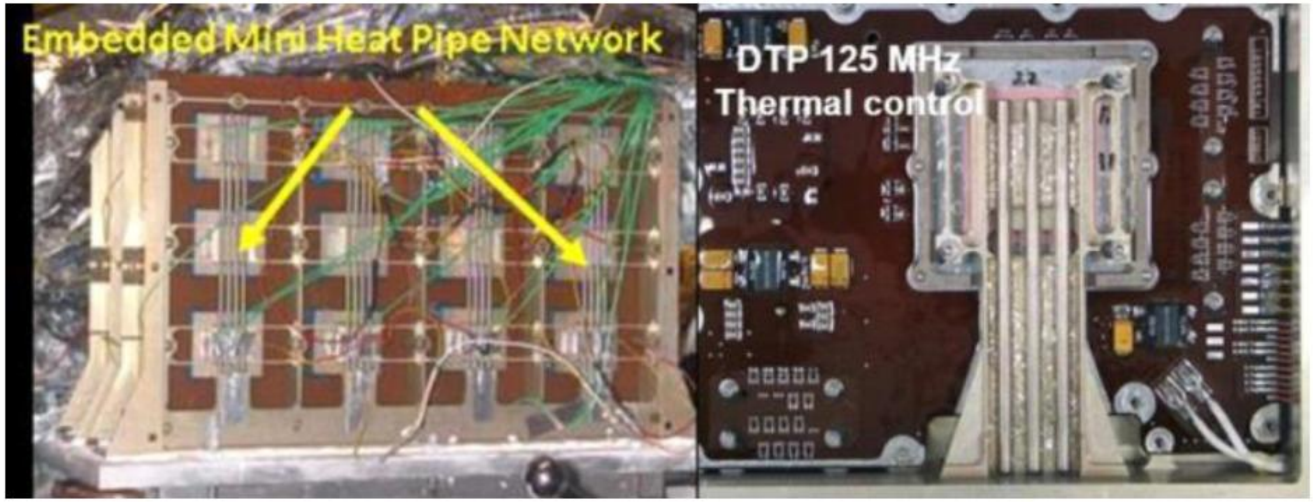



Chip Spray Cooling
Credit (Kandlikar)

# State of the Art for Processor Cooling in Europe

- Conduction method is not sufficient where advanced cooling method is required as Two-Phase Equipment
- Copper Water Heat Pipes have been Qualified by TAS-F for the DTP5G mainly for Ground Testing
    - Assembly manufactured by AAVID BOYD (Thermacore UK) able to transport 55W
    - Issue with Freeze-Thaw where Heat Pipe can burst or delamination of the porous structure can happen over time

ARTES DTP 125 MHz Mini heat Pipe System
(THALES ALENIA SPACE)

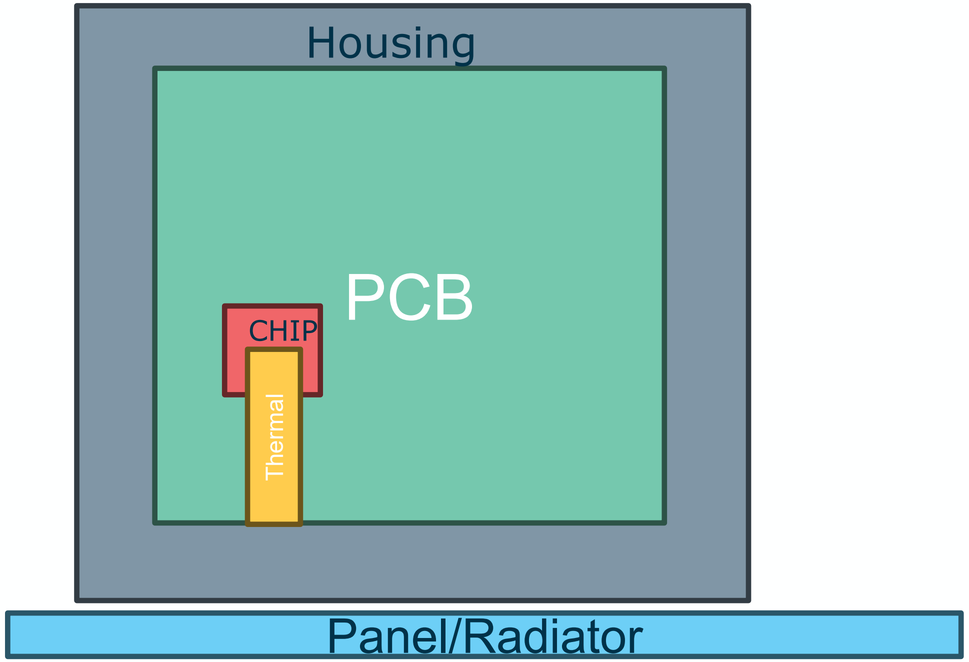



Space Qualified 2010 funded by ESA

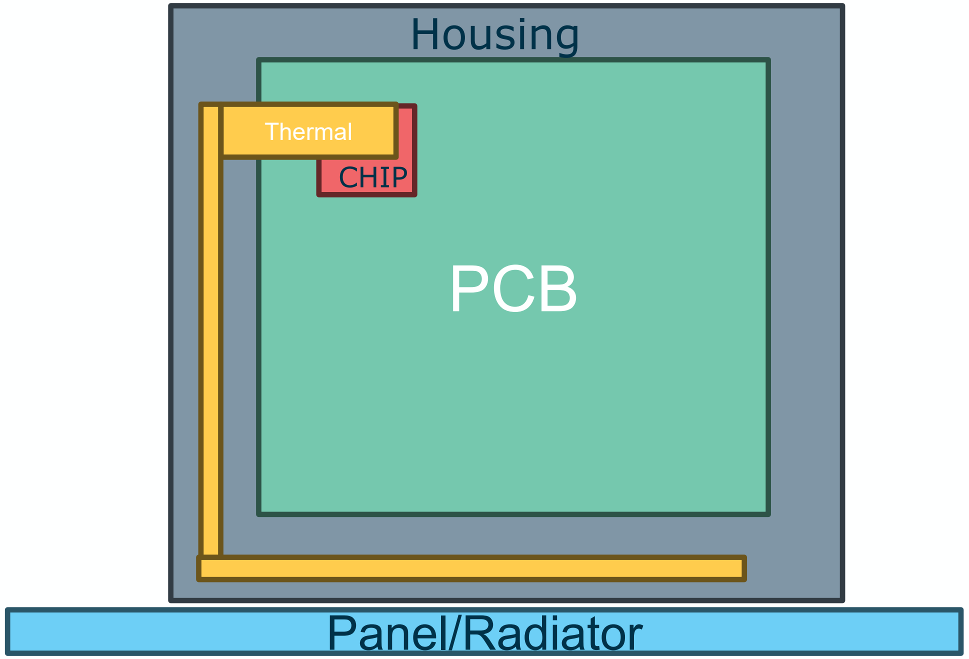
- Fill Ratio of water is extremely important were freeze-thaw can burst the heat pipe or delamination can occur after extended Freeze-Thaw Cycles
- Typically, Survival Constraint above 0° C for Unit is specified to avoid Freezing
- **Despite numerous development on freeze tolerant advanced Thermal products, they are not implemented in flight units**

# Strategy for Technology Implementation in Electronic Box

- To gain confidence in advanced thermal technologies a step-by-step approach is required

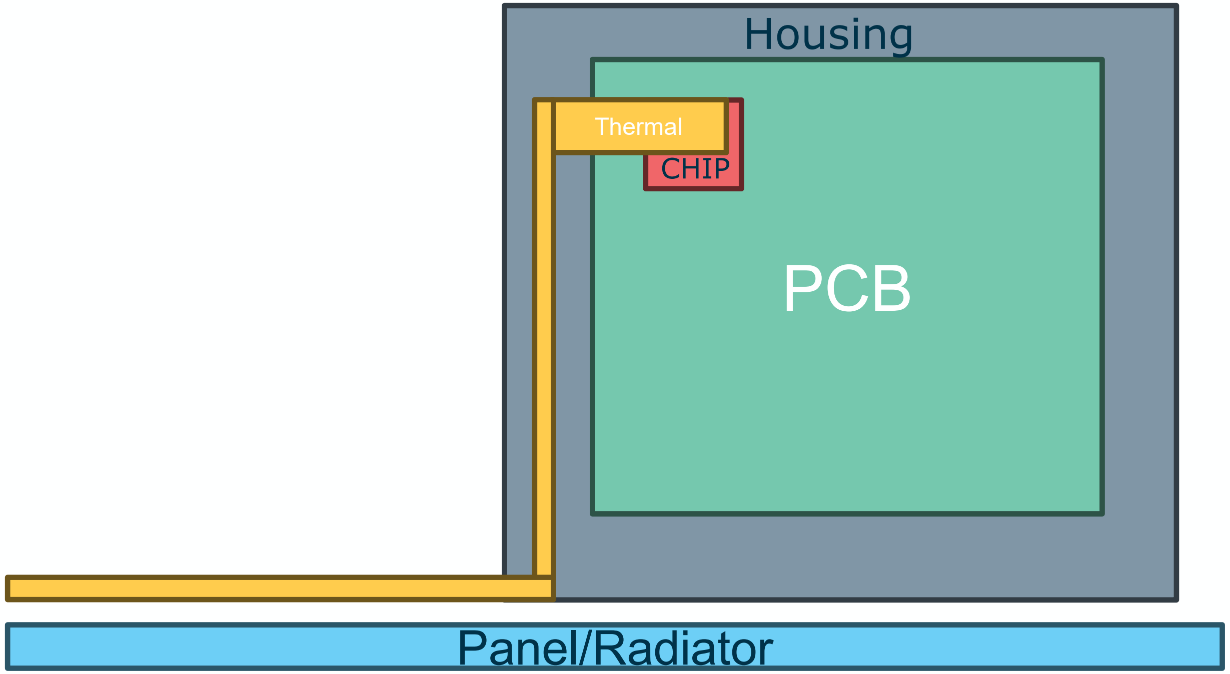



State of the art using copper straps or copper water heat pipes to conduct heat from the chip to the housing. Development on-going on finding new devices that can work against gravity and does not have freezing issues. The length of the device is limited due to the conduction path or the capillary pumping capability is limited due to the height

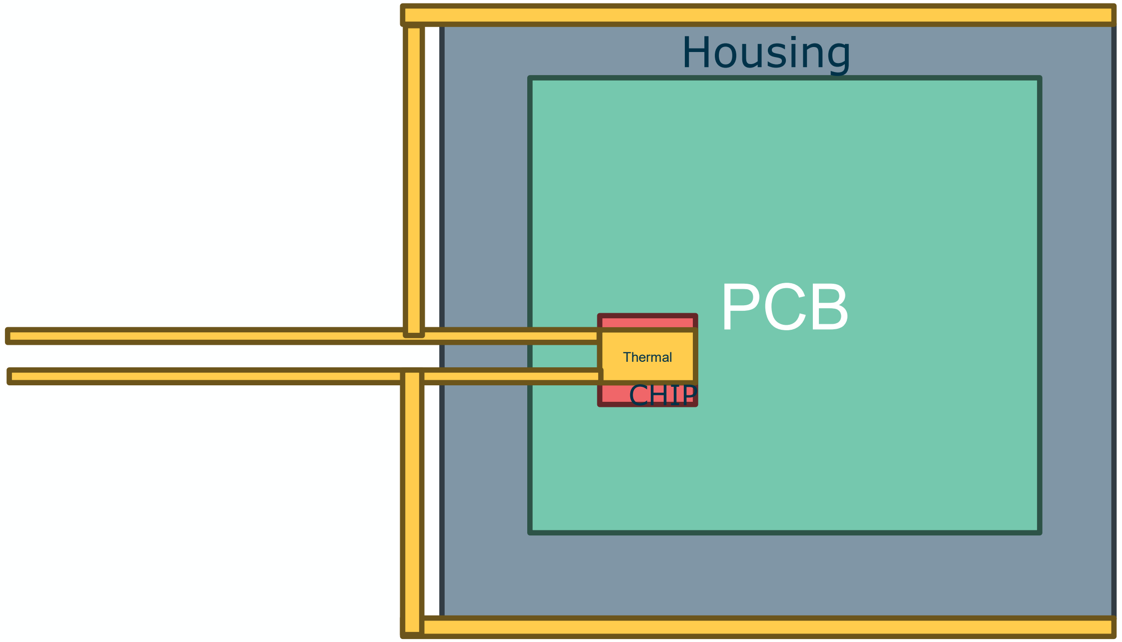



Development on-going to improve the thermal performance of the housing using K-Core or Two-Phase embedded channels to transport heat to the baseplate when the heat source is located far from the mounting surface. This technological step is to reduce the gradients withing an electronic housing

# Strategy for Technology Implementation for Electronic Box




The next technological step would be to "pump" the heat from the electronic component to the radiator panel. This method bypass the housing and can use a large surface area to distribute the heat. The Unit can be mounted to a heat pipe network on the Radiator panel, or the thermal device provides sufficient spreading function where heat pipes on the spacecraft panel may not be required. This could be used on a CFRP Panel construction. The "pump" can be a capillary pump, as a Loop heat pipe

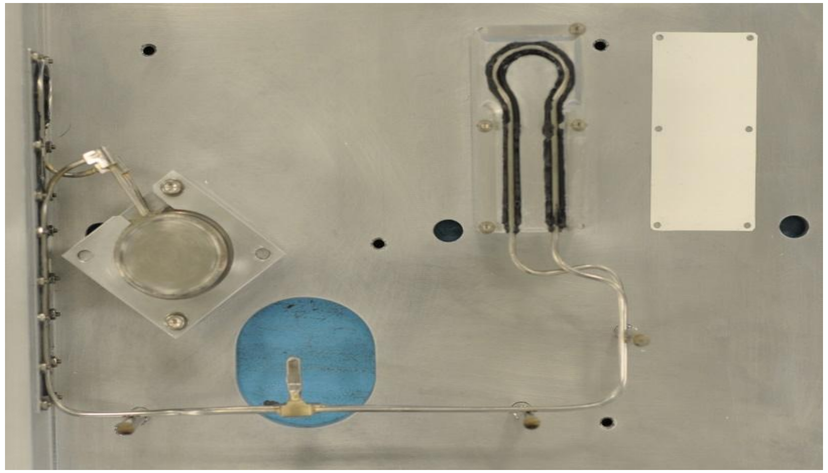



This is the final technological step where a centralize pump system would provide cooling directly to the electronic components. The location of the Unit can be anywhere within a spacecraft since it does not rely to be near the radiator panel. This provides flexibility for the accommodation where harness lines could be reduced as well as to increase performance. In addition, it could help to distribute the C of C since location of each units can be accommodated based on their mass. Furthermore, a centralized system can allow a very dense spacecraft with low volume where deployable radiators could be used to provide the adequate surface area

# Thermal Developments on Direct Chip Cooling

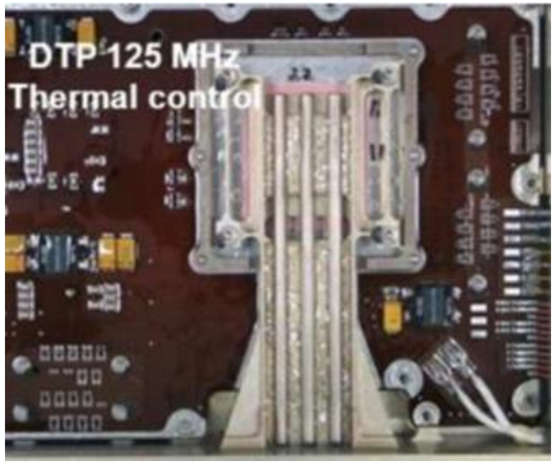
- *Thermal Filler Developments*
  - *Toseda: Thermal Paste*
  - *Thales: Liquid Metal Interface*
- *Heat Pipes*
  - *Boyd Copper Water*
  - *Boyd ALM Ti Ammonia*
- *Loop Heat Pipe*
  - *Airbus/EHP Ammonia*
  - *Arquimea Ammonia*
- *Pulsating Heat Pipes*
  - *KP Labs*
  - *EHP Ammonia*

KP Labs PHP



Airbus/EHP LHP

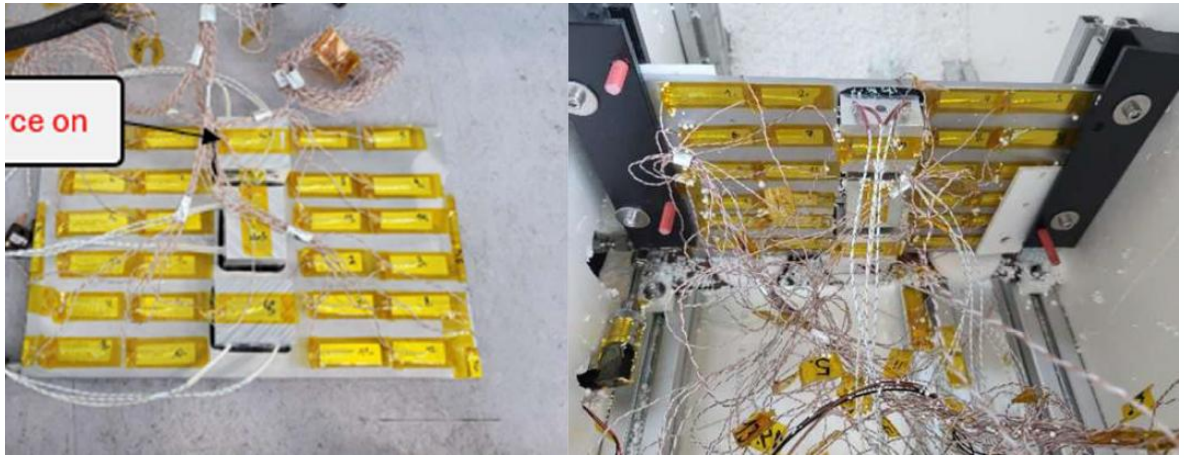
Boyd ALM Ti Ammonia HP



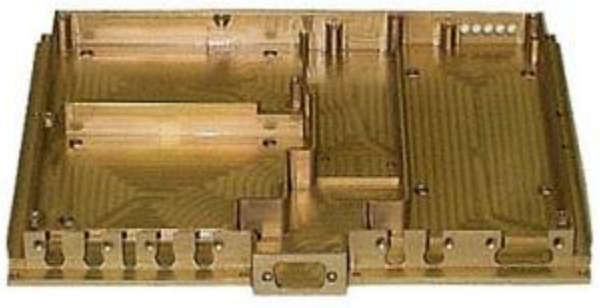

Boyd/Thales Copper Water HP

# Thermal Developments on PCB Frames and Housing

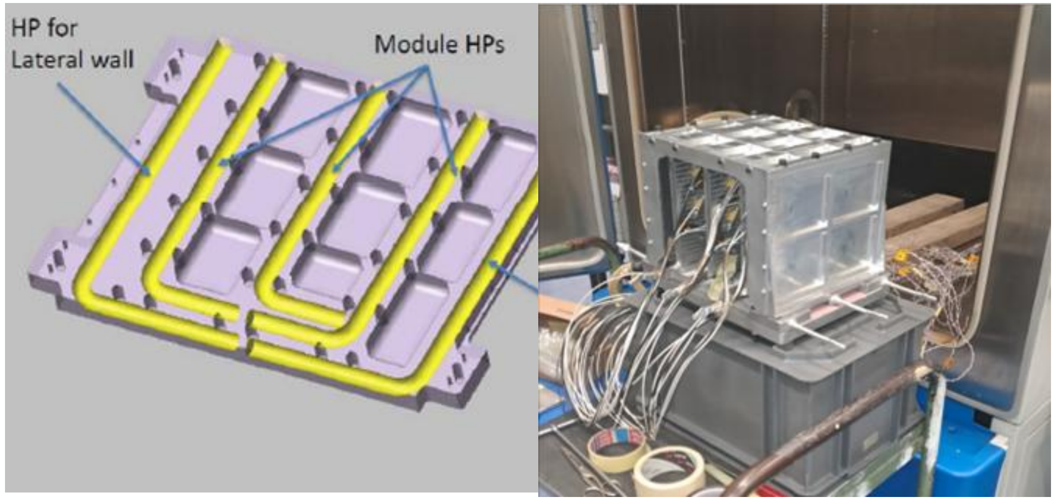
- *Enhance Thermal Conductivity*
  - *Boyd K-Core*
- *Embedded Heat Pipe*
  - *Sogeclair ALM Frame*
  - *POLIMI ALM Module*
- *Vapour Chambers*
  - *EHP ALM Ammonia*



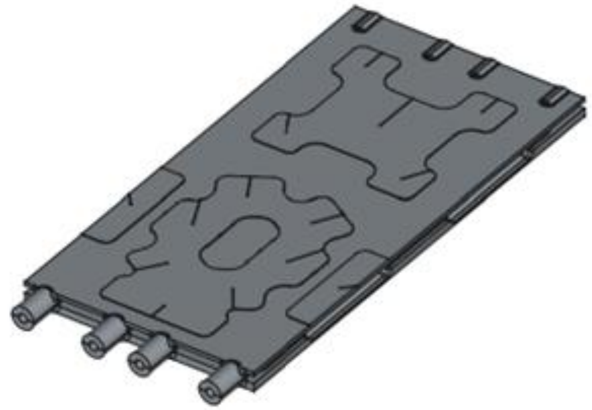
EHP Ammonia Vapour Chamber



BOYD K-Core Frame




POLIMI ALM Module with HP

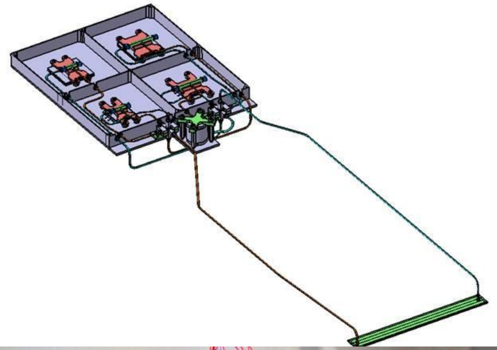


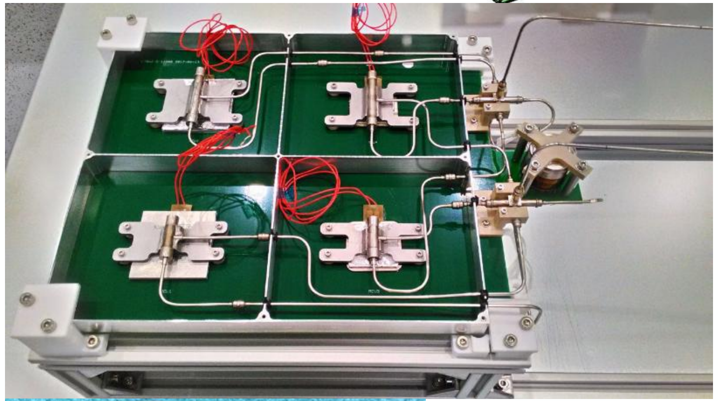
Sogeclair ALM Ammonia
HP Frame

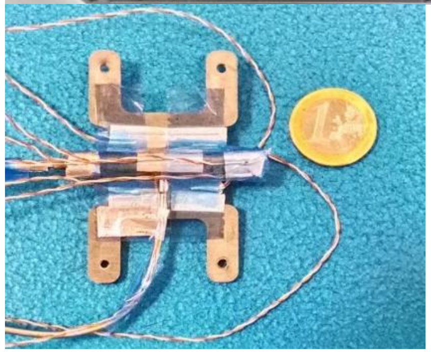
# Direct Chip Cooling with External Heat Transport

- *Loop Heat Pipe Development*
- *Company: Arquimea*
  - Component dissipation can be directly transported onto the spacecraft panel decreasing the overall delta temperature between component and radiator
- Allatherm
  - Flat Loop Heat Pipe

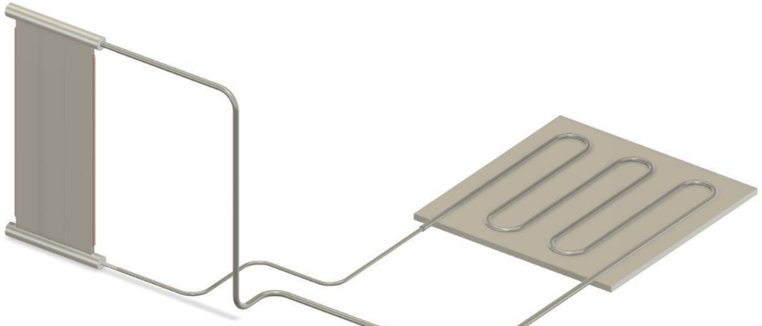
Mini Hybrid CPL EM Design



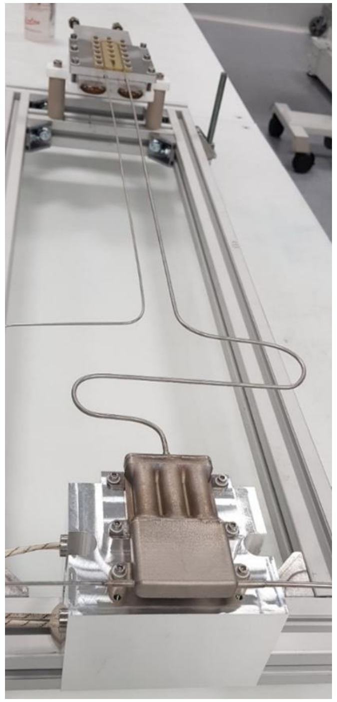




Multi-Chip Cooling credit Arquimea



Allatherm Flat LHP

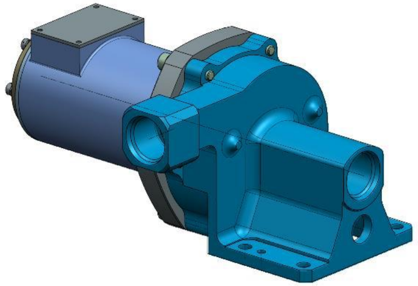


Arquimea ALM LHP

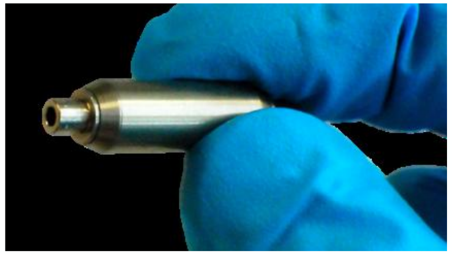
# Mechanical Pumped Cooling Loop Developments

- Mechanical Pumps for platform and electronic cooling
  - AVS: Working fluid Ammonia, flow rate 100 l/h, 1.5 bar pressure rise, temp. -40° C to 85° C
  - COMOTI: Working fluid HFE 7200, flow rate 750 kg/hr, 2.1 bar pressure rise, temp. -20° C to 50° C
  - University of Limerick Micropump with 5-pump manifold at 5 W input power (1 W per pump):
  - Sample operating point: 20 kPa, 70 ml/min
  - DEMCON/NLR/ISISpace Power transported: 40 W, scalable up to 200 W
  - APR TECH Electro Dynamic Pump

PD Pump AVS

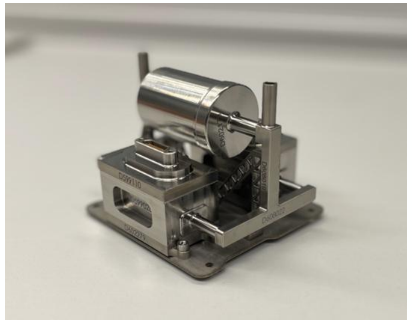


Comoti Centrifugal Pump



Limerick MicroPump

APR Tech EHD

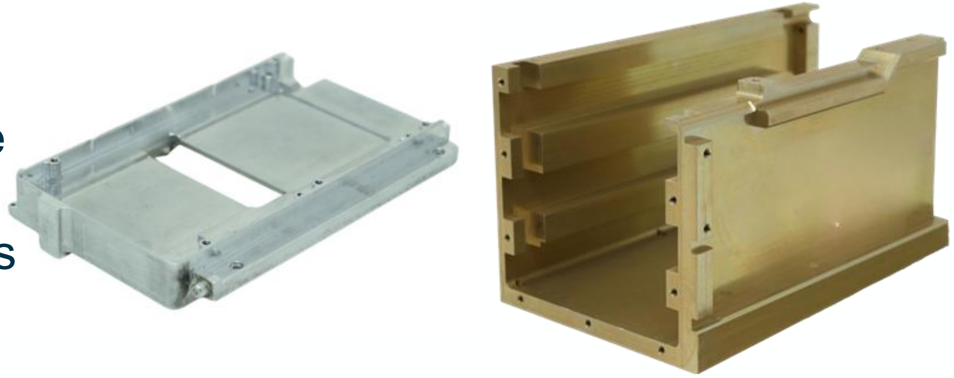


DEMCON MiniPump

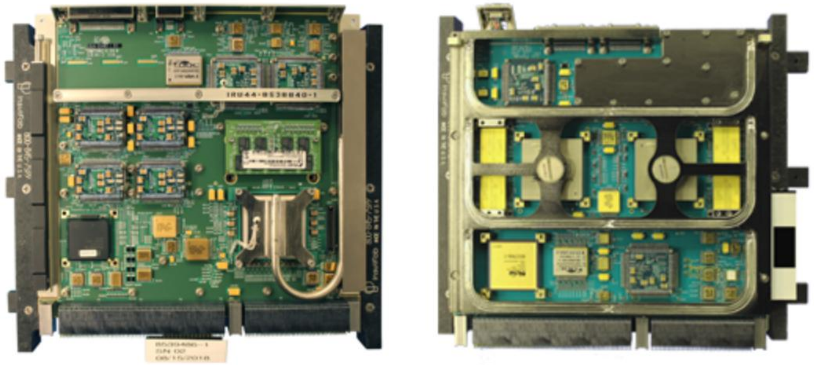
# Conclusion

- Thermal management at system level remains a significant challenge.
- Large temperature differences exist between components and their radiators.
- Numerous thermal design improvements have been made to reduce gradients within electronic boxes.
- Advanced thermal technologies are being introduced, but adoption is progressing slowly.
- The United States, through SpaceVPX, has implemented advanced thermal solutions more rapidly.
- Adoption of standards like **ADHA** is critical to accelerate the integration of advanced thermal technologies.
- ADHA can help reduce costs and enable off-the-shelf thermal solutions for system designers.

- ADHA must address:
  - Form factor constraints
  - Location of high-dissipation components on PCB
  - Standardized thermal interfaces
  - Support for external fluidic connections



ThermAvant 3U SpaceVPX PHP Housing and Heat Frame providing 8X performance



BAE System SpaceVPX using ACT Heat Pipes