iVTX Ladder Mechanics

Part 1: Overview of iVTX developments

Part 2: Conductivity measurements of TPG

Part 3: Update on fallback liquid cooling solution for iVTX

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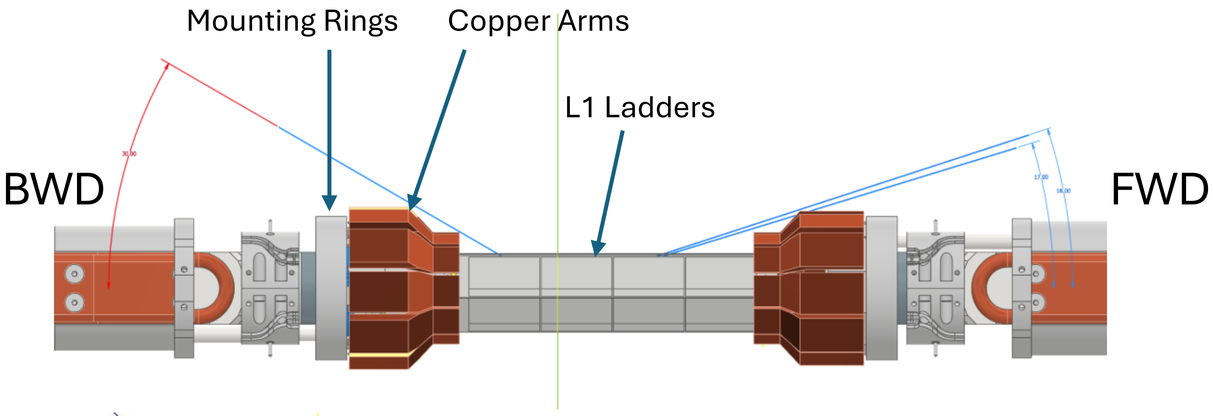
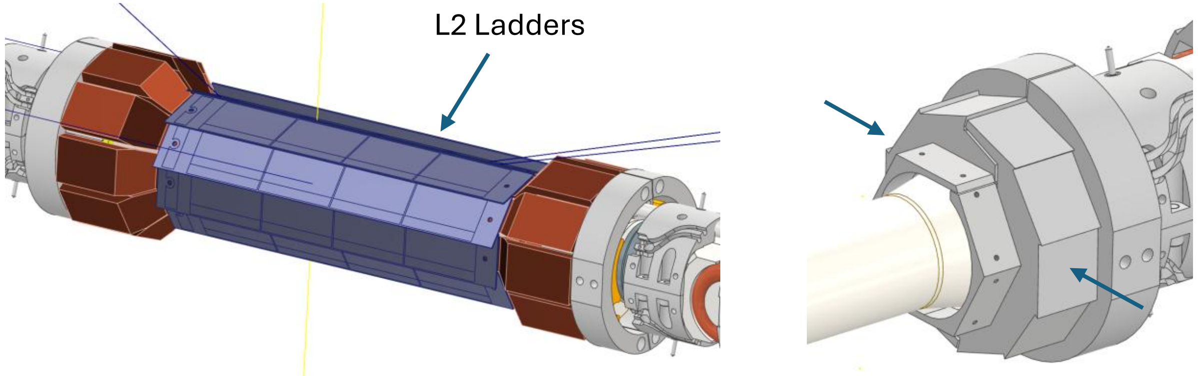
21/04/2026

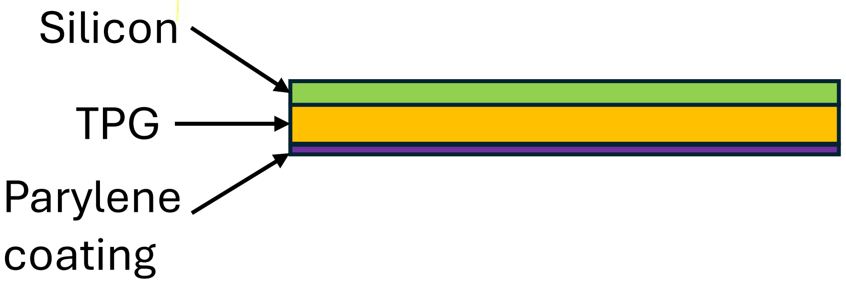
iVTX Design Overview

Overview

- **2 Layer iVTX:**
  - 6 Ladders on Layer 1 at 14mm Radius
  - 10 Ladders on Layer 2 at 22mm Radius
  - The iVTX is split into two half shells that envelop the beampipe from the sides
- **Conduction Cooling:**
  - ~400μm TPG layer glued to underside of ladder, with a thin Parylene Coating
  - Copper “Arm” structures will interface between the ladder and the mounting rings
  - Mounting Rings are paraffin cooled and evacuate the heat through conduction



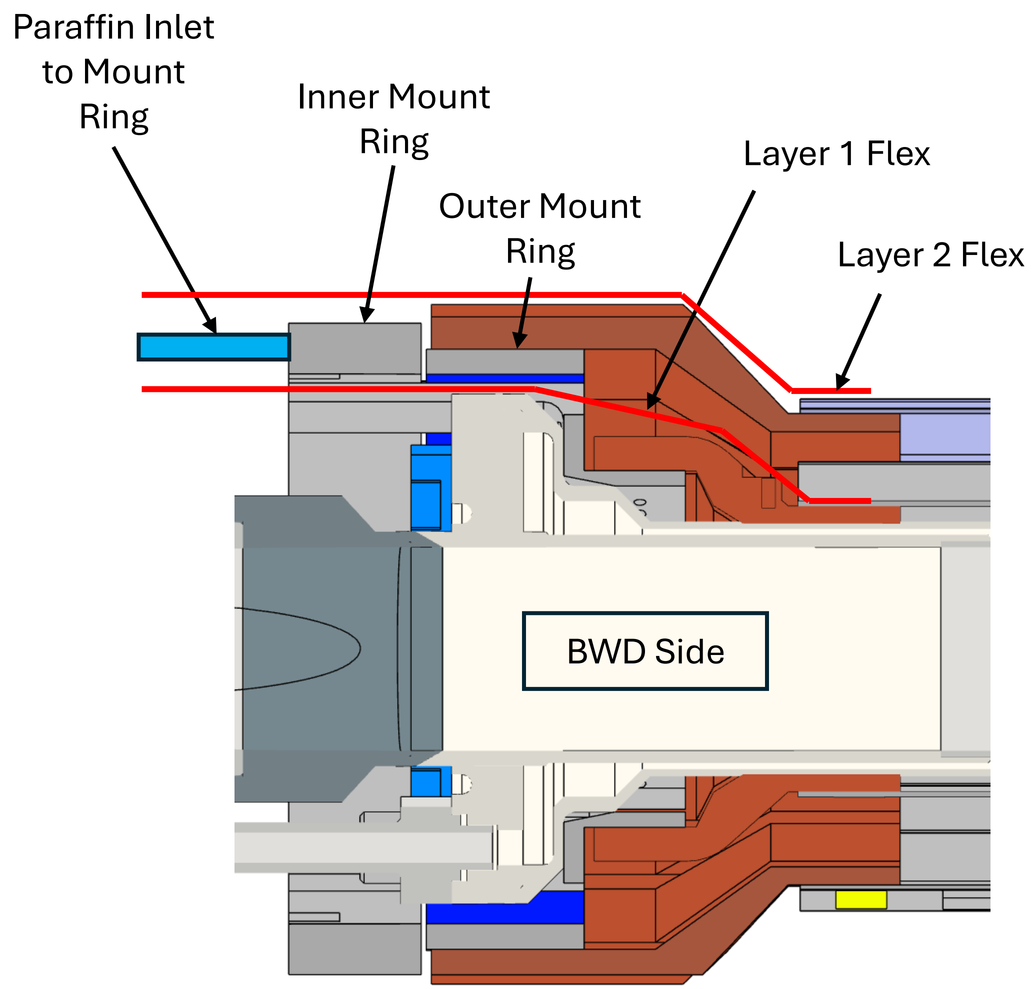




iVTX Design Overview

Services

- **Electrical Services:**
    - Flex cables (~18mm x ~0.5mm) serve the L1 and L2 ladders on BWD Side only
    - Assumption is that the Flex is installed onto the ladder before the ladder is installed onto the iVTX half-shell
    - Therefore, to avoid trying to "feed" the Layer 1 flex cables into slots in the Mount Ring, this mount can be made from two parts (Inner and Outer) on BWD Side only
    - The Inner mount ring contains the main supporting structure and L1 ladder supports
    - After Layer 1 is installed, the outer mount ring is installed onto the inner mount ring, which adds support for L2 ladders

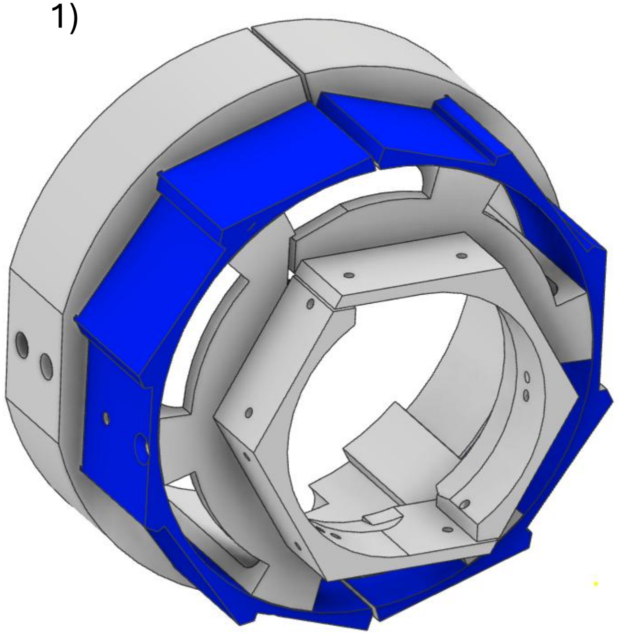


iVTX Design Overview

Services

- **Images to right:**
  - 1) BWD Side inner mount ring (Grey) and the outer component (Blue)
  - 2) With Layer 1 installed and flex cables passing through underneath the blue outer component
  - Note that the models are unfinished and need updating, but the principle remains

1)



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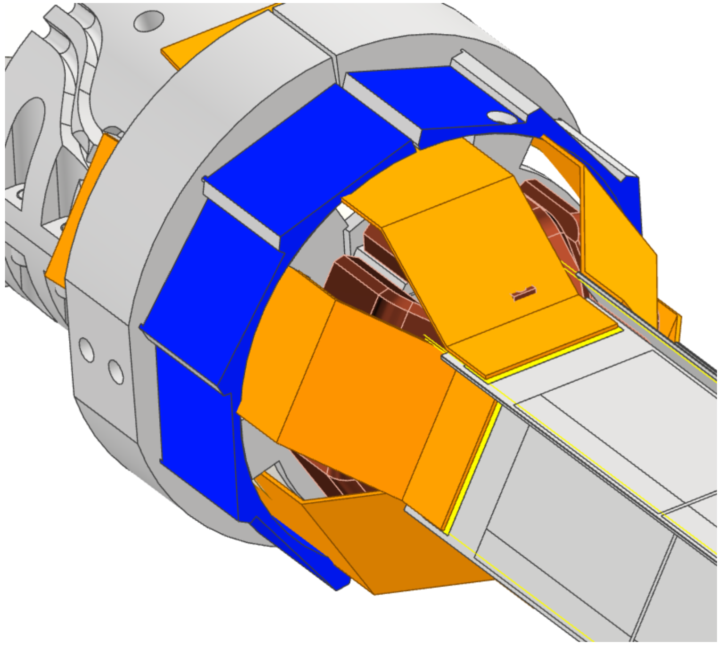
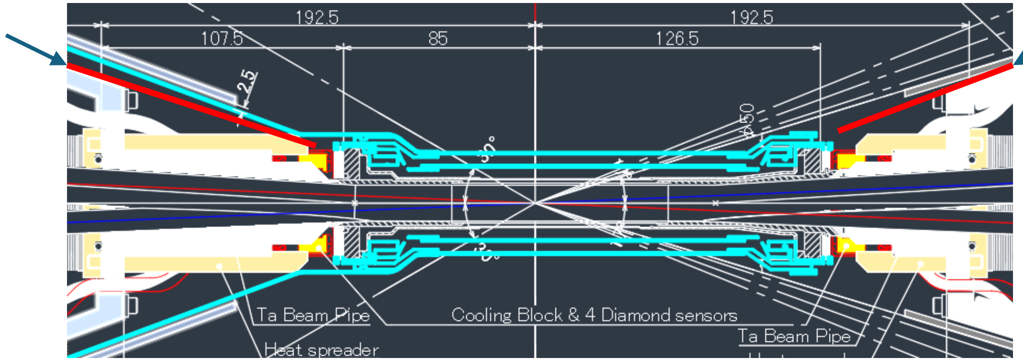


iVTX Design Overview

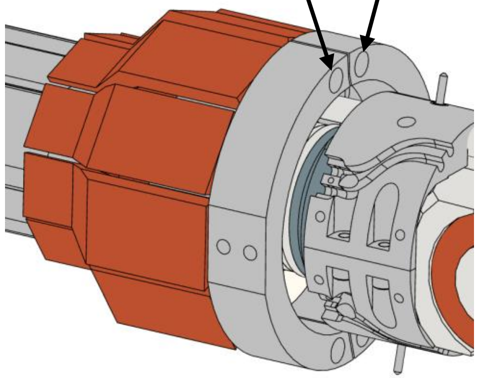
Services

- **Cooling Services:**
    - Cooling services feed into the mounting rings on FWD and BWD sides. Previous concepts looked at thermally coupling the mounting rings to the manifold, or to a cooling block. By serving the rings directly this reduces the number of thermal interfaces
    - Current concept is for paraffin to flow in channels within the mounting ring
    - This could be 3D printed in metal, with post-machining for precision features and surfaces
    - Alternatively, we could thermally interface pipes/capillaries to the mounting ring
    - Work is ongoing to model this in CAD, which will need further optimising through thermal and fluid flow simulation



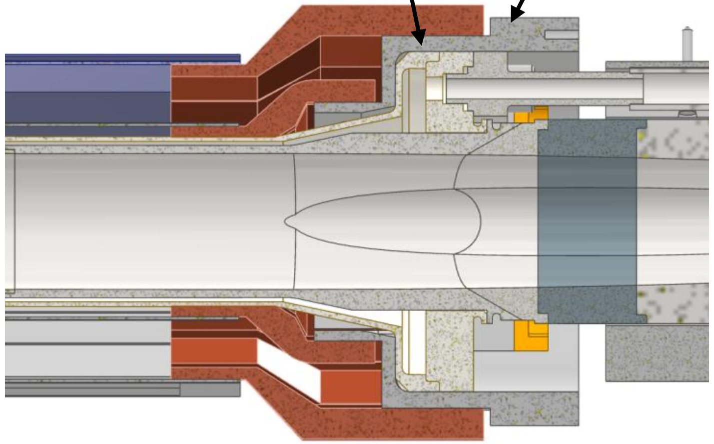
Approximate location of paraffin line entry to iVTX

Paraffin Line Inlets (Ø5mm)



Note thickness may need increasing to accommodate channels

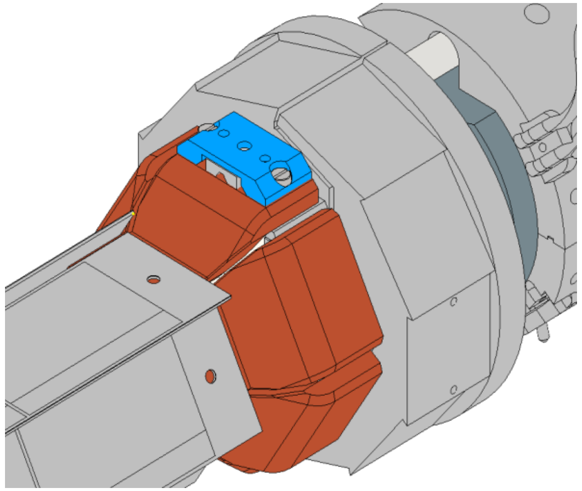
Flow of paraffin through mounting rings



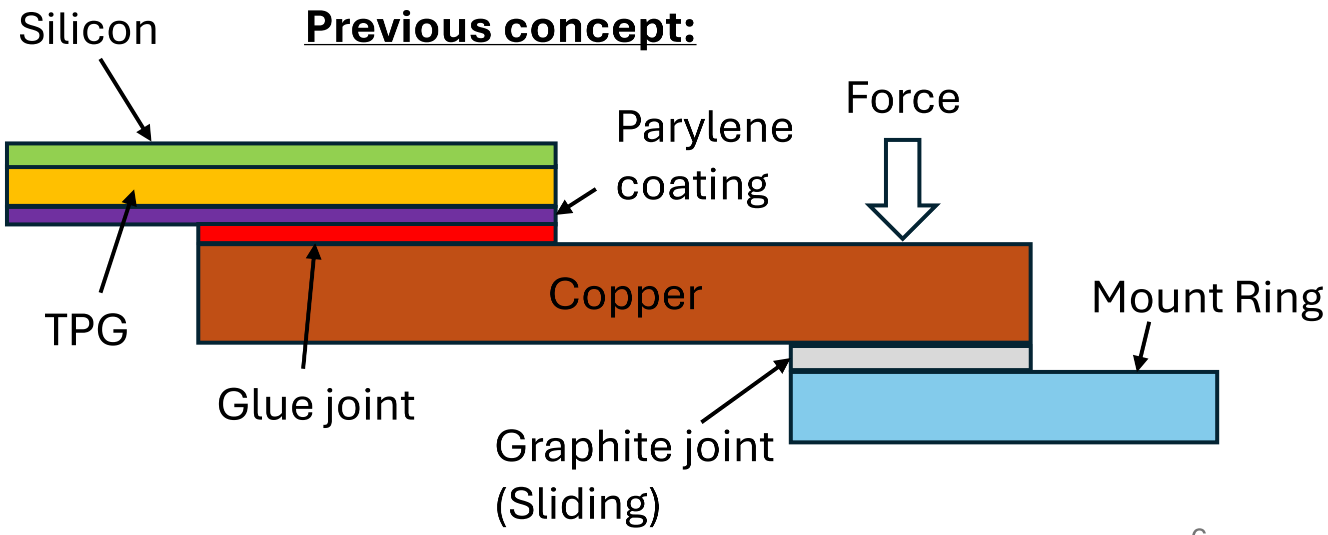
iVTX Design Overview

Sliding Joint

- Theory and experience informs us that we may need a sliding joint on the forward side, to prevent the ladders buckling upon thermal expansion
- Previous designs (shown to right) used a sliding joint between the copper Arms and the Mounting Rings, with a glued connection between ladder and copper
- The proposed sliding thermal interface is graphite
- Group discussions have pointed in favour of moving this joint close to the ladder, which results in a more direct path for the ladder expansion to act, and reduces the added mass to this system
- Challenge of this is to create a robust joint whilst minimising the number of thermal interfaces



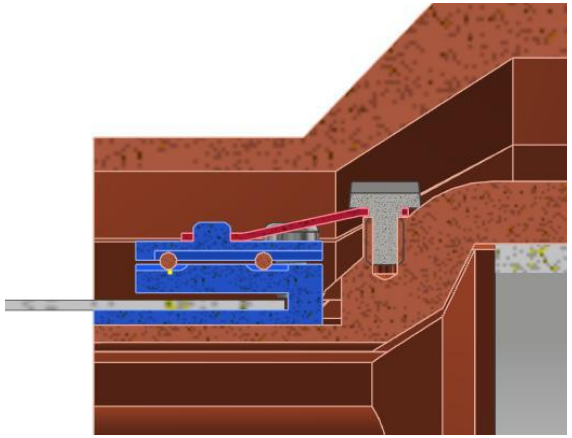
Previous concept:

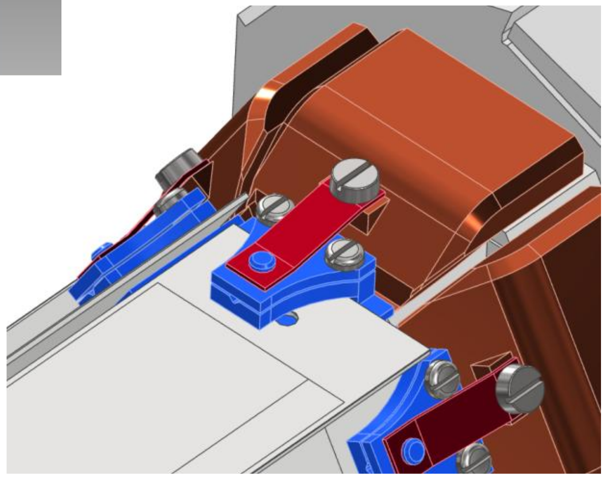


Sliding Joint

- Developments included adding an intermediate copper slide plate, upon which we can push down using a spring to create the strong thermal contact

- However, this still had drawbacks in the complexity of additional components and thermal interfaces



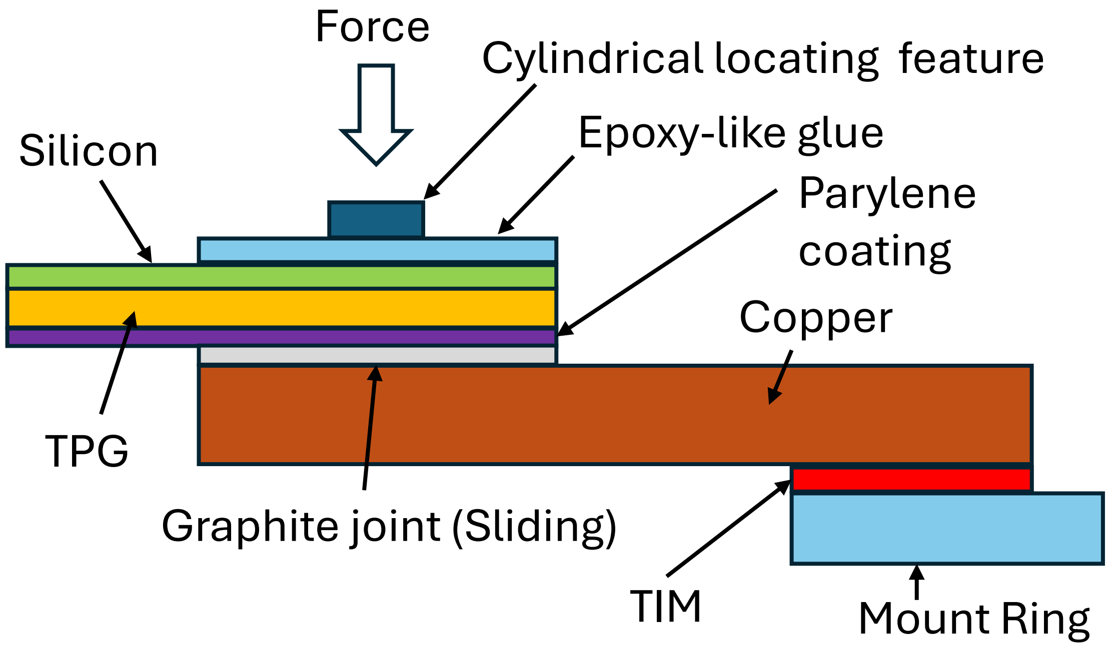


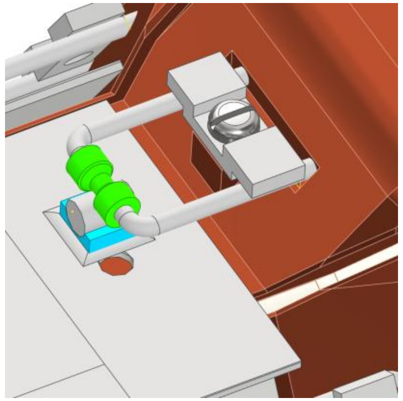
iVTX Design Overview

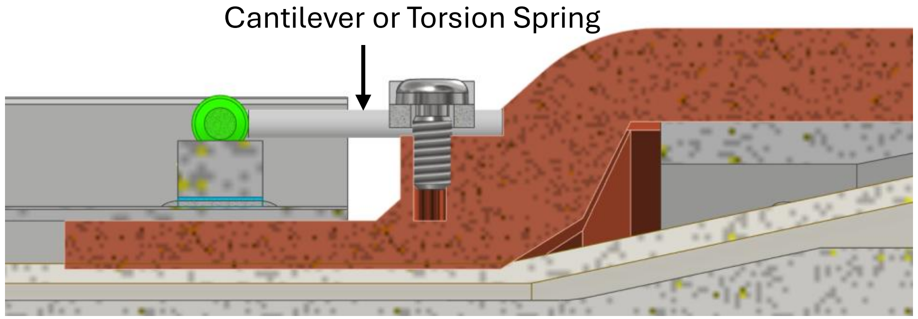
Sliding Joint

- New proposal made on a FWD sliding joint (Shown Right) which provides location (via grooved roller and cylinder) and thermal interface compression using a spring
- Testing required on:
  - TIMs (Thermal Interface materials)
    - Compression force vs Thermal performance
    - Coefficient of friction
    - Effects of repeated sliding
  - TPG/Parylene Coating
    - Durability in response to wear from sliding
    - Thermal performance (Through-plane) when combined with graphite TIM
- Mechanical mock-up
  - Simple mechanical prototype of structures could be developed in a short time scale

Proposal:







Belle II VTX | Queen Mary University of London

Sliding Joint

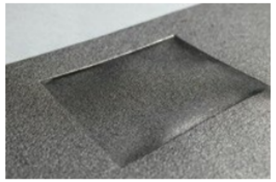
- To the right we see that for our candidate graphite TIM, there is an established relationship between the compression and thermal resistance.
- Therefore, I see it as a problem of optimisation, where we find the minimum compression on the interface which results in good thermal performance; at the same time, the resultant frictional force should be less than the critical buckling load of the ladder (Where sliding occurs before buckling)
- This information can be calculated, but to understand and gain confidence, we need to test using real materials and conditions, as described in the previous slide
- **Though in theory it's calculated that a restrained ladder could buckle under our thermal loading, it's important to test this restraint condition (ladder fixed at both ends) on prototypes, to feel confident in determining that we need a sliding joint (or otherwise)**

Panasonic INDUSTRY

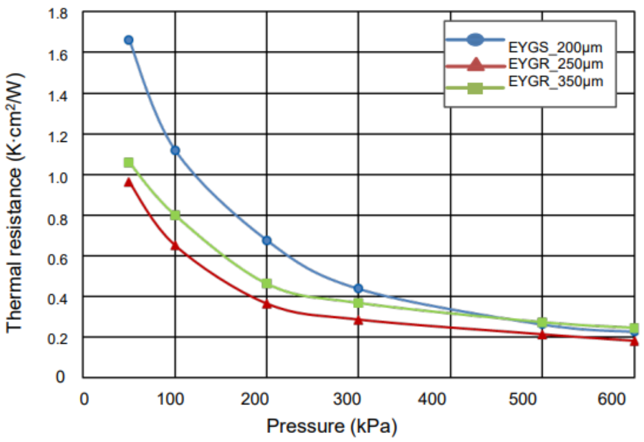
"GraphiteTIM (Compressible Type)"
PGS with low thermal resistance
EYGS, EYGR type

Features

- Thermal resistance : 0.2 K·cm2/W (600 kPa)
  To draw a good thermal resistance from sheet, pressure the GraphiteTIM. A close adherence would make the product fit into the uneven part and enhance the performance.
- Thermal conductivity : X-Y direction 200 to 400 W/m·K, Z direction (28 W/m·K)
- Compressibility : 40% or more (600 kPa)
- High and long term reliability : operating temperature range –55 to 400 °C
- RoHS compliant

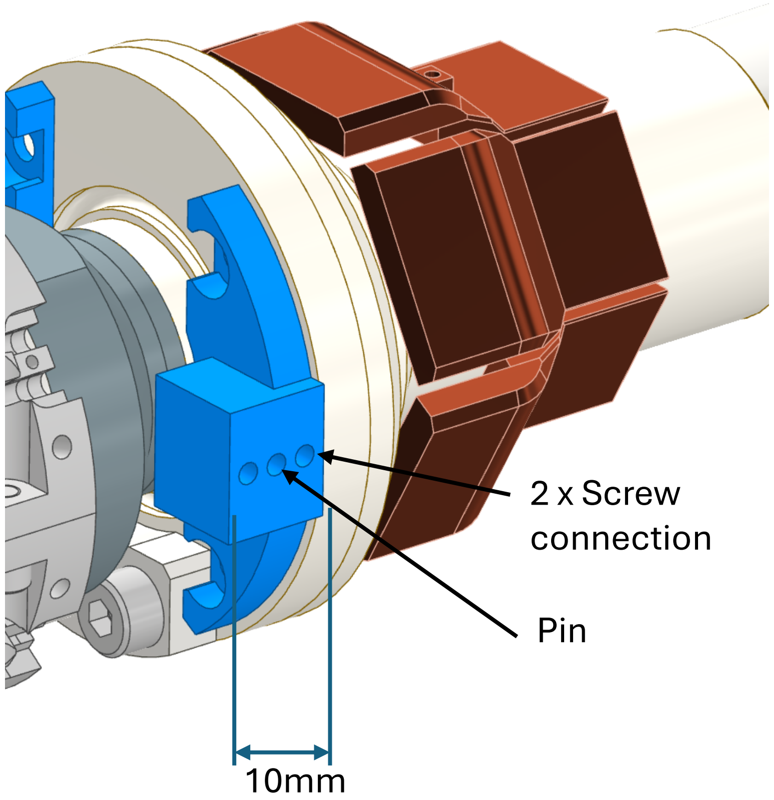


After pressure to GraphiteTIM.



Mount Blocks

- **iVTX Half-shell Mount Blocks**
- The Detector requires mount blocks to locate and install the iVTX half-shells
- The interface width (in Z dimension) is important for accurate location, here 10mm should be sufficient to achieve a good connection
- Each half shell should be fully constrained by this mount block on both forward and backward sides
- The iVTX will be built off-site to the detector. When this assembly is integrated onto the beampipe, we must ensure that the datum surfaces match precisely.
- If they are out of plane, then any bending or forces from misalignment can be transmitted to the ladders and ladder thermal interfaces.
- BWD side can be a pin-hole location, and the FWD side a pin-slot location



iVTX Design Overview

<u>Some next steps</u>

- **CAD modelling:**
    - Modify mounting rings to include paraffin cooling channels, and detail out the interfaces required
    - Bring up-to-date and detail all mechanical support structures to provide a comprehensive solution

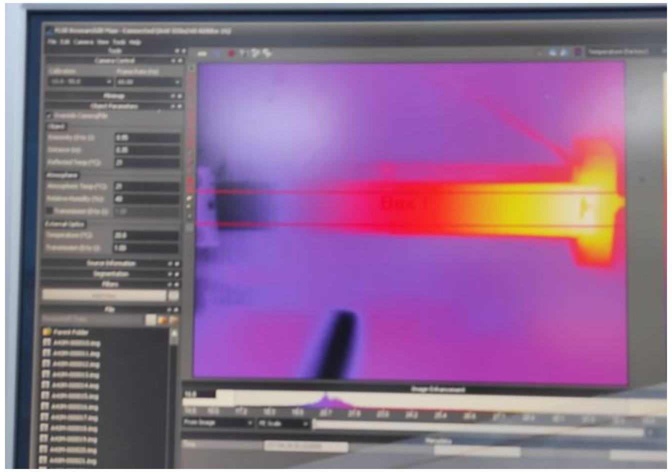
- **Testing/ Prototyping:**
    - Mechanical prototypes of sliding joint and ladder mounting structures
    - TPG conductivity testing (see next slides)
    - TIM Interface material thermal & mechanical tests
    - Collaborate with IJCLab on TPG Ladder thermo-mechanical testing

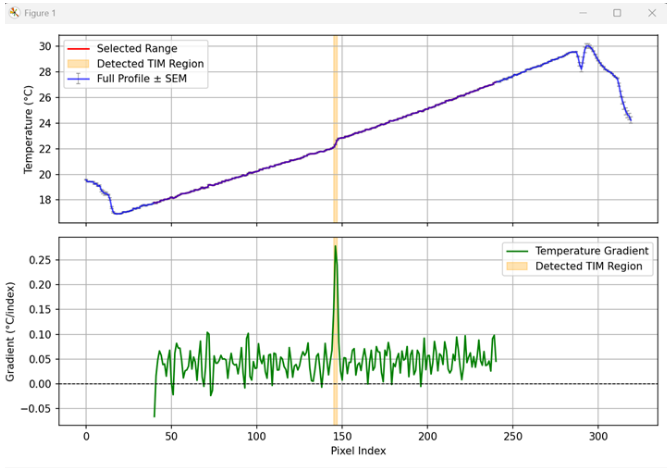
Part 2: Conductivity Measurements of TPG

TIM Tower – Analysis & FEA Modelling

Thermal Conductivity Analysis

- Develop python routine to compute the thermal conductivity using IR image data
- **ΔT across sample = 0.57 °C**
- **Thermal Conductivity = 4.37 W/m-K**

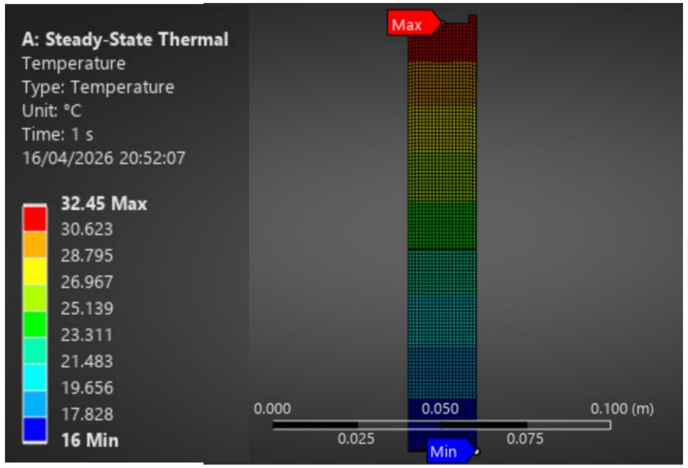


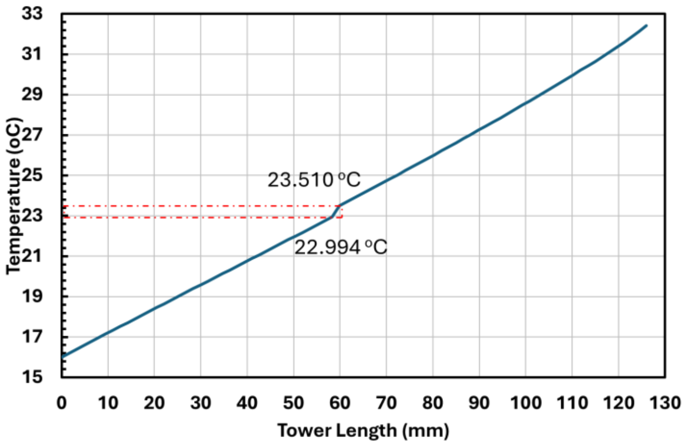


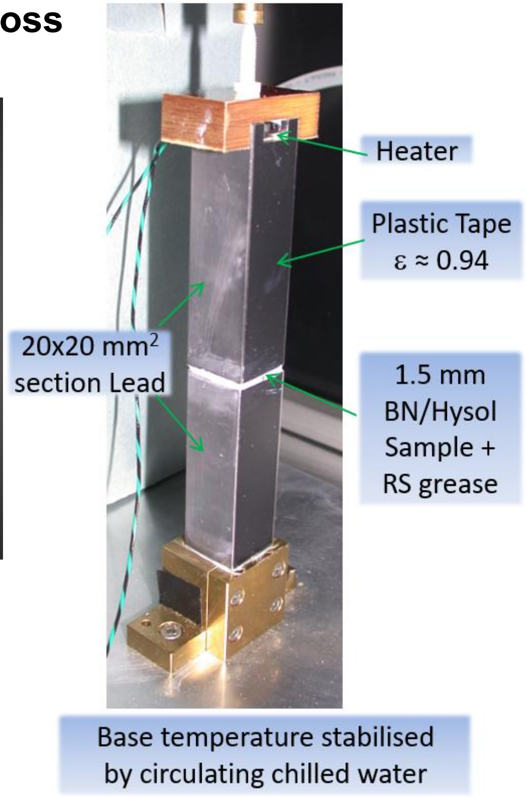
Work by
Ali Awais

FEA Model using Ansys for TIM Tower

- Given the computed value thermal conductivity, input cooling and power.
- The average temperature profile gives **ΔT across sample = 0.516 °C**







* Image courtesy of Graham

In Plane Thermal Conductivity

Work by
Adrian Bevan

Required for TPG Measurements

- Use NTCs
- Readout options: MCP3008 / ADS1115
  - Breadboard system ready for testing (3008)
  - Designs for fabricated boards ready for both methods
  - Need to test with NTCs in situ
- Some concerns over stress relief of cables due to the geometry of the existing setup at QM, that we will work on mitigating.
- If redesigning, would design in a loom to support the readout wires and reduce stress on the thin NTC cable wires going to ground and higher voltage
- Software prepared assuming a Raspberry Pi 5 as the readout solution

$$\frac{1}{T} = A + B \ln R + C(\ln R)^3$$

T = temperature in K
A, B and C are constants
R = R_2 resistance across the NTC

$$R_2 = \frac{V_{R_2} * R_1}{V_{DD} - V_{R_2}}$$

R = R_2 resistance across the NTC
R_1 = resistance across a reference 1k***Ω*** resistor
V(R2) = voltage drop across R_2
V(DD) = voltage drop across R_1

$$\kappa = \frac{QL}{A\Delta T} = \frac{PL}{A\Delta T} = \frac{I_{heater} V_{heater} L}{A\Delta T}$$

Q = Heat (J)
L = distance
P = Power (W)
A = cross sectional sample area
I/V_{heater} = the heater current/voltage

In Plane Thermal Conductivity

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Adrian Bevan

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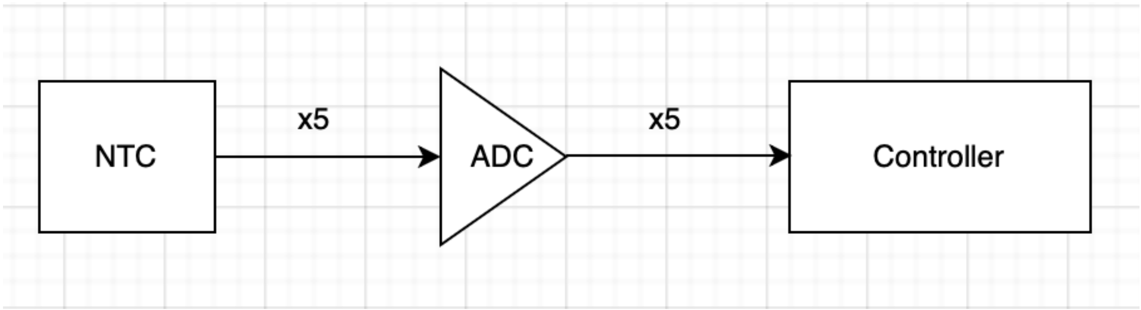
Basic Readout Structure



Need 5 channels, planning to have up to 8 for resilience, just in case…

Code:

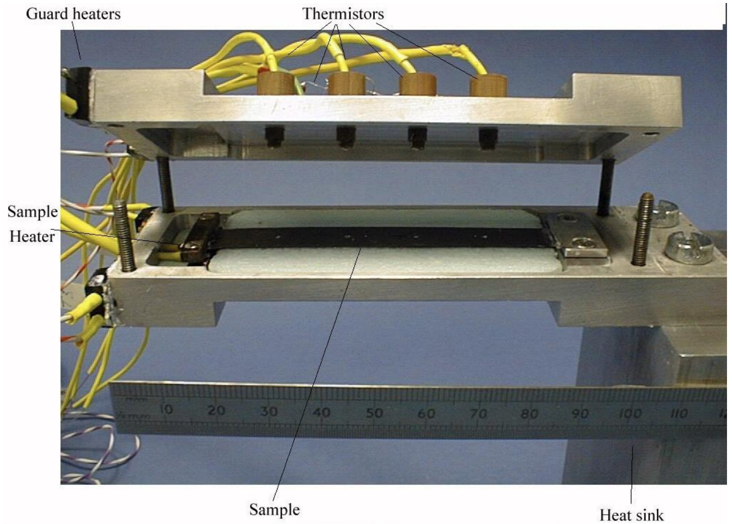
- Python class NTC that encodes all calculations required to convert the measurement of voltage to a value for κ
- Works with a single data point (ΔT, L), or with a set of data points using a fit to the data (ΔT_i, L_i).

In Plane Thermal Conductivity

Work by
Adrian Bevan

Setup:

- Uses 5 NTC's, 4 along a sample, and 1 at the heater



Boards: Breadboard

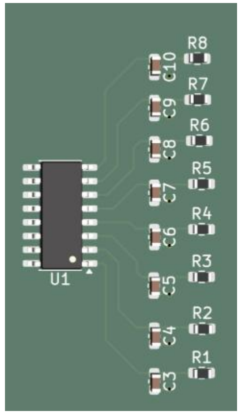
- Working prototype
- Can be a bit noisy – working to reduce this
- Concerns about longer term usage, but good enough to forge ahead in the mean while

PCB designs

Aims:

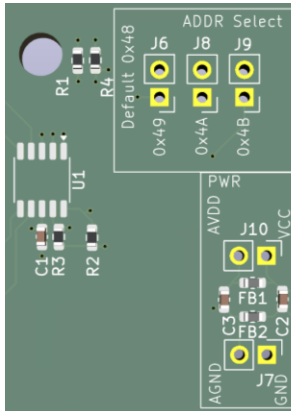
- Provide a robust solution for longer term (reliable) use
- Reduce distance from signal input to ADC input to reduce noise
- Have spares in hand if/when need to scale up for QA
- ... and have a backup approach

12 bit ADC



1 chip, 8 channels

16 bit ADC



2 channels per chip, 5 chips with different addr configs giving 8 channels

Next Steps:

Next 1-2 weeks

- Test breadboard prototype with NTCs
- Work toward a test run using Al foil (expect to get ~236 W/ (m.K)

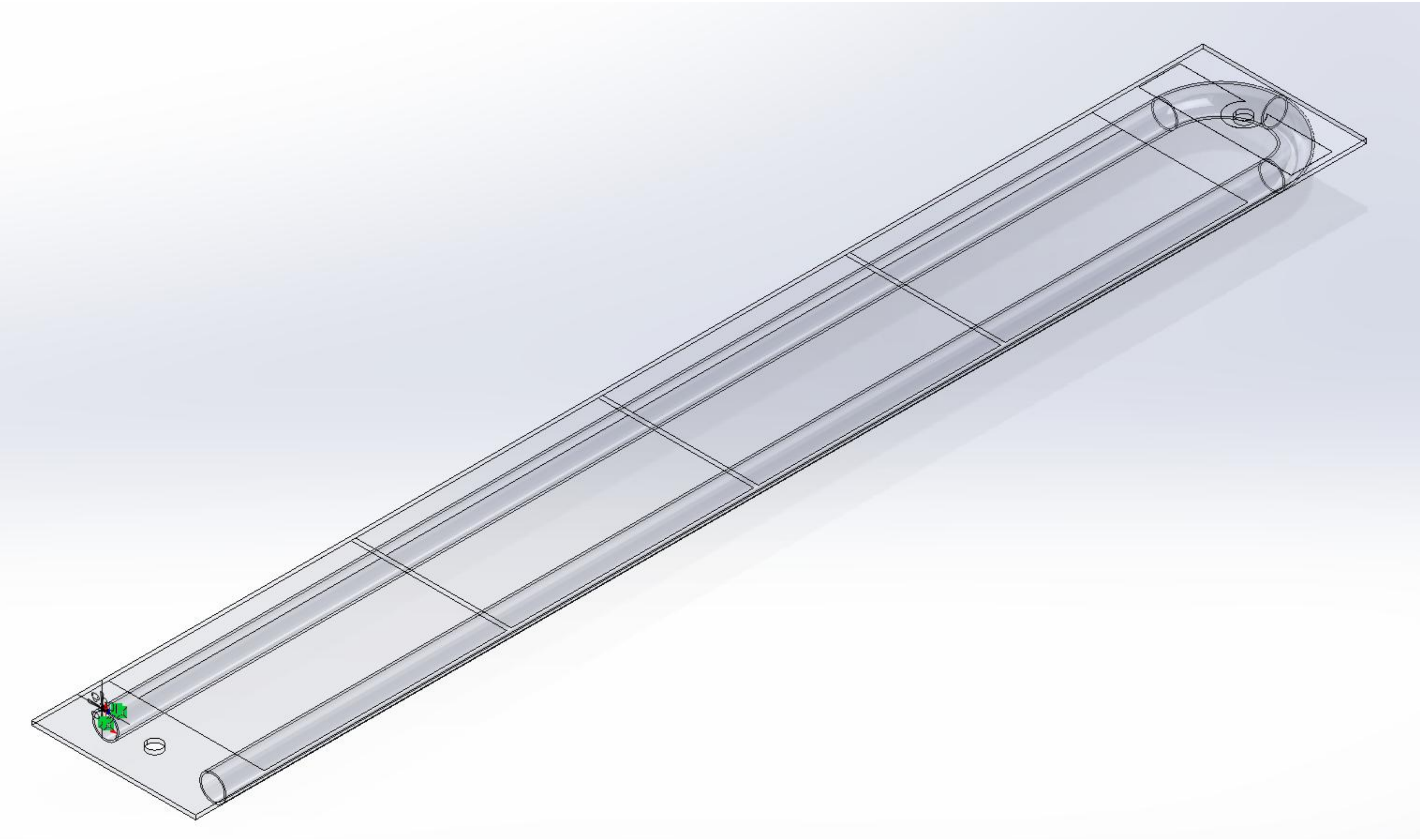
O(1-2 months)

- Modify part footprint to ensure IC package format is in stock for assembly
- Update PCB layout to cater for that & verify mounting holes
- Finalise boards (generate and check BOM/placement files)
- Send for fabrication (approx. 2 week turn around including PCB fab, assembly and delivery)
- Integrate with existing setup & develop tkinter UI to track change with time and analyse the data

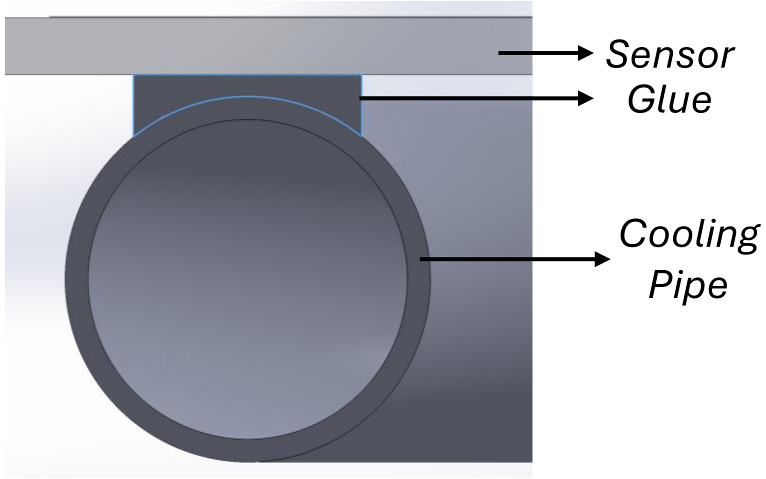
Update on fallback liquid cooling solution for iVTX

Dhyey Joshi

CAD model



Isometric geometry view

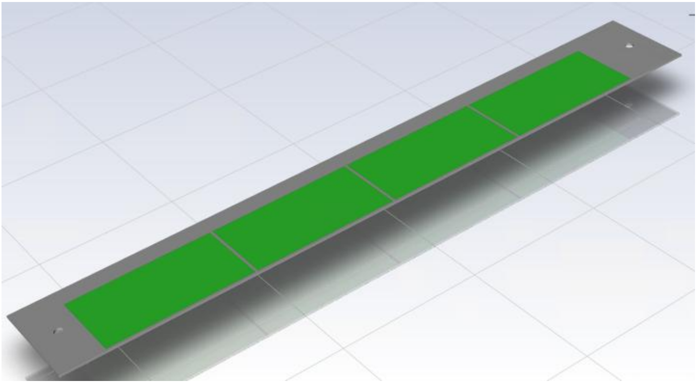


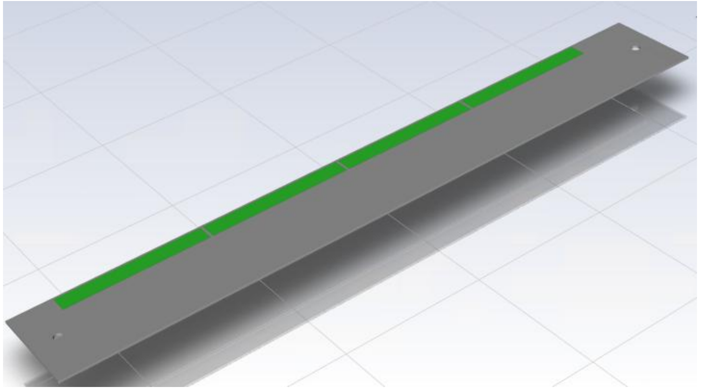
Pipe front view

ANSYS Thermal simulation setup

Coolant: Liquid Water, (n-Decane) Paraffin
Solid:
Sensor layer: Silicon-pure
Pipe: al 6061-t6
Glue: araldite-2011; thermal conductivity = 0.22 W/mk
Boundary conditions:

- **Inlet** – using 0.3g/s mass flow rate, 1.4mm inner radius pipe, temperature 20°C
- **Outlet** – Gauge pressure = 0 Pa





Sensor configuration

Results: Water vs Paraffin

Coolant	Sensor temperature (°C)	Fluid outlet temperature (°C)
Paraffin	44.1	28.8
Water	34.7	24.2

<u>Temperature results using Paraffin (n-Decane) and Water</u>

- Both provide results which don’t meet the <30°C target.
- Paraffin performs significantly worse due to a very low specific heat capacity (2180 J/kgK) compared to water (4180 J/kgK).
- Paraffin has low thermal conductivity than water and a high viscosity, both reducing convection coefficient h.

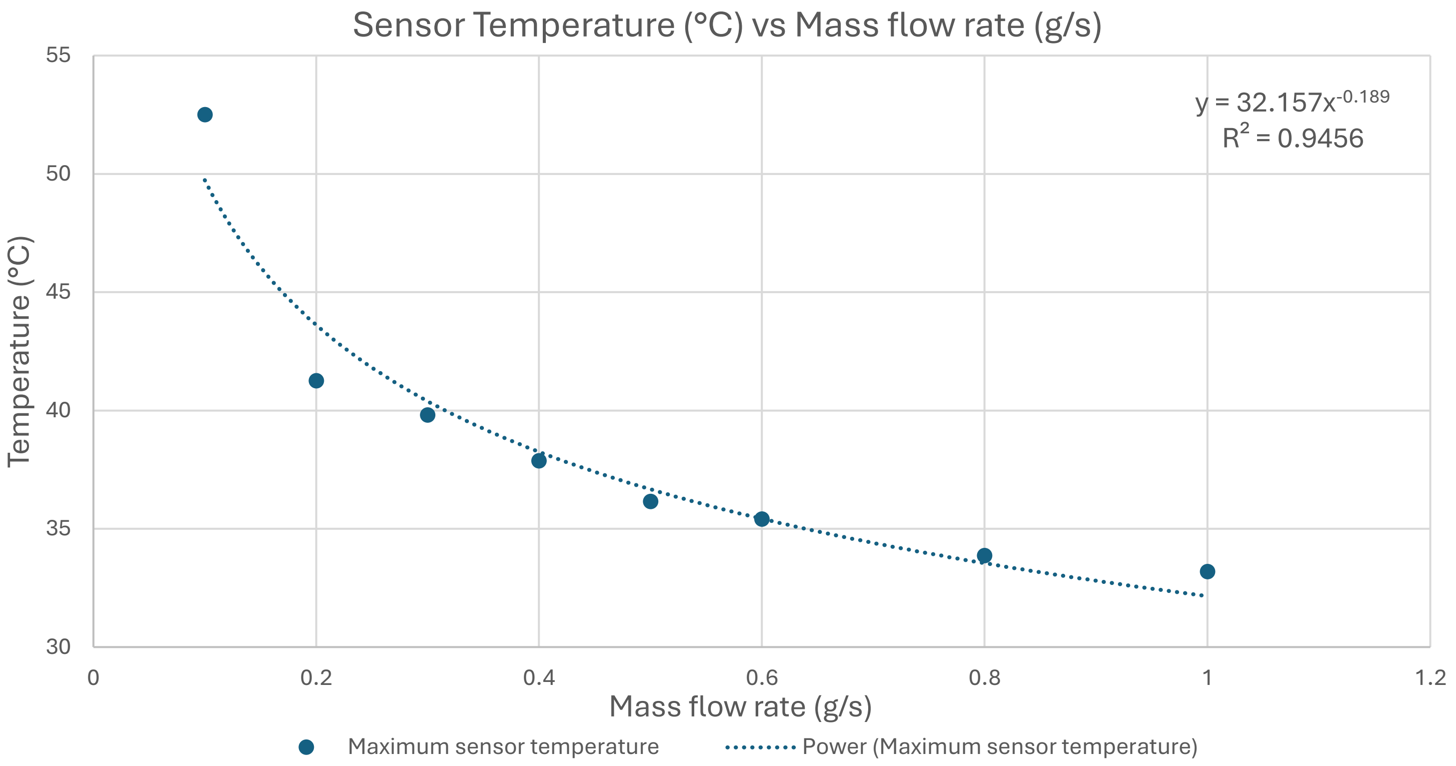
Results: Increasing glue conductivity

Coolant	κ = 0.22 W/mk	κ = 0.44 W/mk	κ = 0.66 W/mk
Paraffin	44.1	39.8	38.5
Water	34.7	31.0	28.85

Temperature results using a low and high conductivity (*κ*) glue

- A roughly 10% reduction in temperature for a 100% increase in conductivity
- Paraffin shows bottleneck for conductivity as glue κ shows small reduction in temperature.
- Reasonable to increase to some degree. Increasing it by a large degree could weaken other properties, such as viscosity and stiffness.

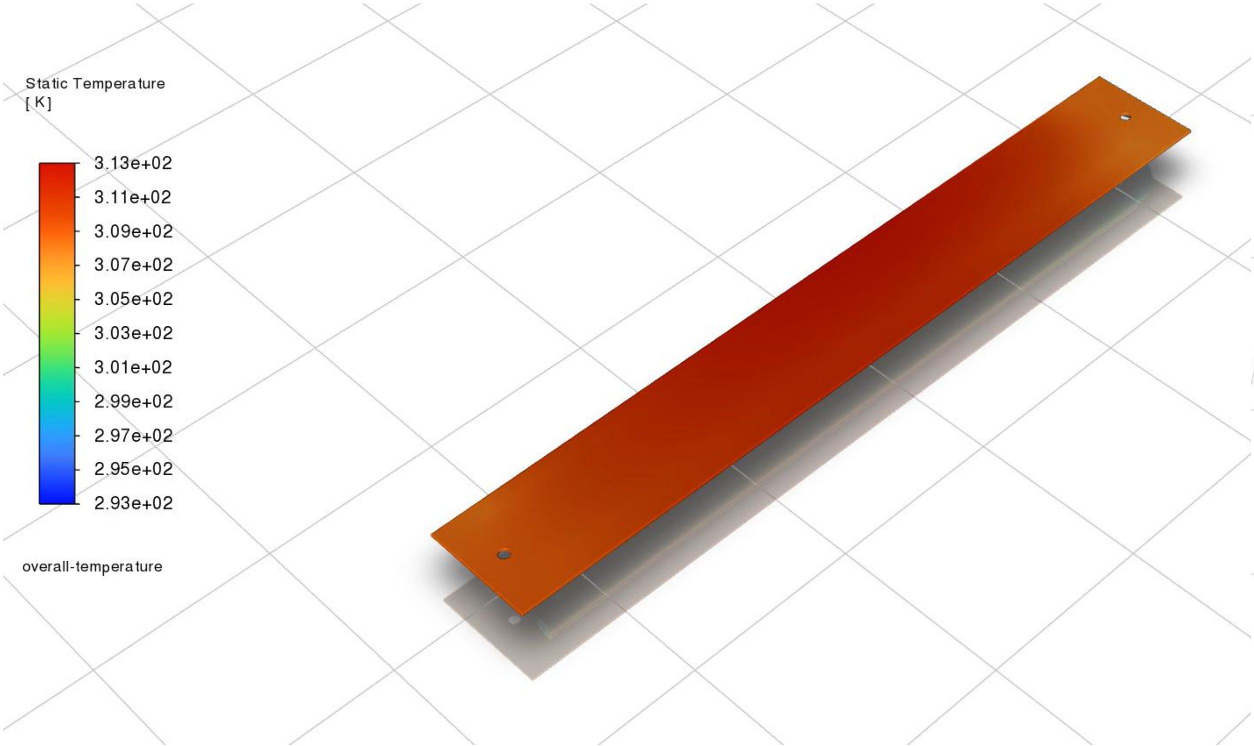
Results: Mass flow rate

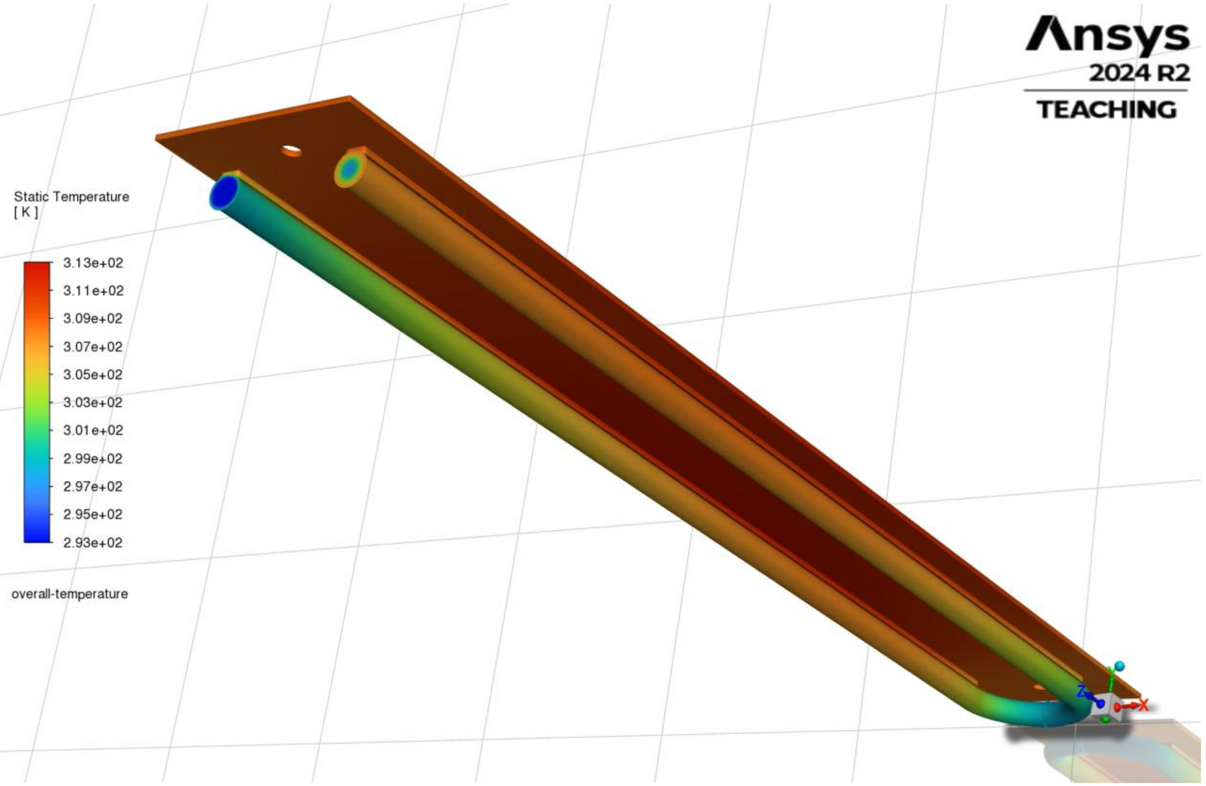


<u>Sensor temperature for varying mass flow rates</u>

- Reference range used was 0.1 – 0.4 g/s.
- Further scope of improvement beyond 0.4g/s before asymptotic behaviour.

Temperature uniformity results





Maximum Temperature animation, 45 second simulation run time

- Using one pipe that curves back leads to worse cooling on one side
- Paraffin is the limiting factor to cooling

Conclusions

Optimizing the setup

- Initial setup with Paraffin does not work.
- Further optimization can be done. Having high flow rate, increase glue conductivity and increase glue contact area
- Current limitations:
  - Ideal glue contact
  - Material properties disregard temperature/environment effect
  - Several other constraints not accounted for (radiation effects)
- Further testing can be done to study non-thermal properties, if this solution is required.