Side-effects of Cooling: Thermals Shocks and Vibrations

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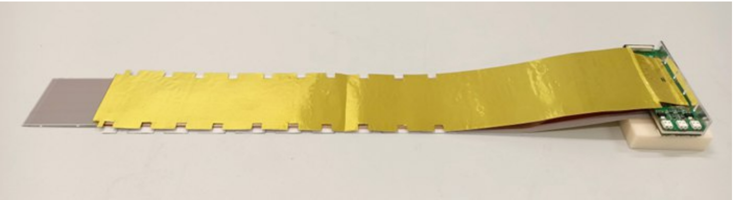
Engineering Design Review CBM-STS Cooling

Introduction

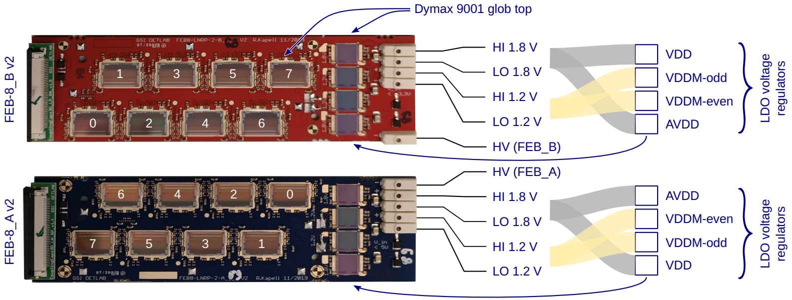
- Detector module: building brick of STS, heat-producing parts:
  - DSDM silicon sensor ($W \approx 150\,\mathrm{V} \times 3\,\mu\mathrm{A} = 0.45\,\mathrm{mW}$ non-irradiated, $W \lesssim 500\,\mathrm{V} \times 3\,\mathrm{mA} = 1.5\,\mathrm{W}$ after $10^{14}\,\mathrm{n_{eq}cm^{-2}}$)
  - front-end electronics, FEE ($\simeq 20\,\mathrm{W}$)
- Thermal management is essential

  sensors: stable low temperature to avoid thermal runaway
  FEE: significant heat dissipation in a limited volume

  - reliable cooling and thermal interfaces are required
  - temperature monitoring during detector operation



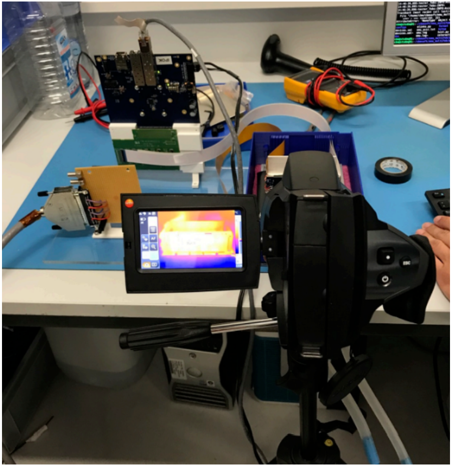
Powering of the STS FEE



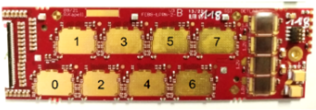
- Two low voltage lines with 1.2 V and 1.8 V are powering ASICs
- Custom low-noise LDOs are used for stabilization of the voltage
- Measurements within the internal diagnostic circuit of the ASIC:
  - V_{DDM} is the voltage on the 1.2 V
  - V_{temp} the internal thermal probe

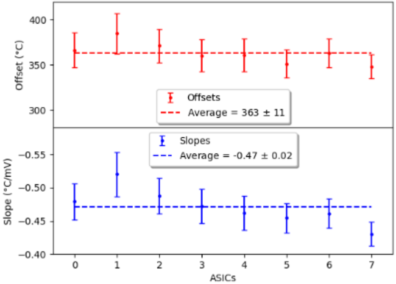
SMX internal thermometer calibration

- Conversion from internal voltage diagnostic circuit to the temperature



L. M. Collazo Sánchez 41st CBM Collaboration Meeting





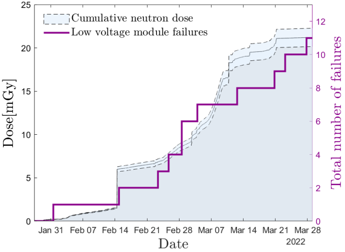
$$a = (363 \pm 11)\,^{\circ}\mathrm{C}$$
$$b = (-0.47 \pm 0.02)\,^{\circ}\mathrm{C/mV}$$

Motivation for the thermal cycling

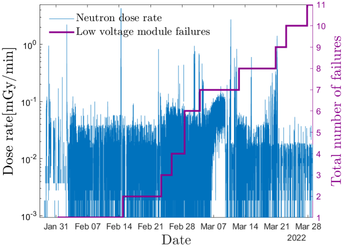
radiation induced power cycles

During the irradiation period, the dose reached 106.1 mSv and 27.7 mSv for neutrons and other particles respectively.

Considering the two scenarios for neutrons we can expect: **49±2 mGy for conversion factor 5**



Accumulated dose form the passive dosimeter adjusted to the active one



Dose rate from active dosimeter

- Average dose before soft error: $4.45^{+1.93}_{-1.25}\,\mathrm{mGy}$
- At highest intensities ($40\,\mathrm{mGy/month}$):
  - 9 SEE per module per month
  - 20 FEBs cycled per hour
  - $\lesssim 200$ cycles per FEB in a lifetime

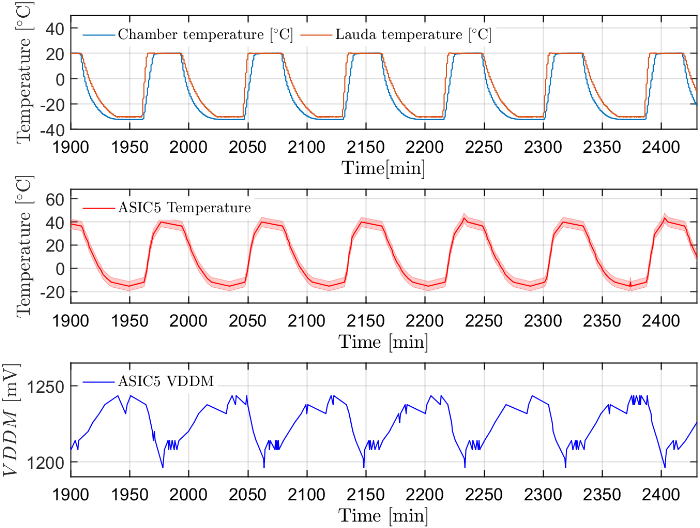
Motivation for the thermal cycling

scenarios and consequences

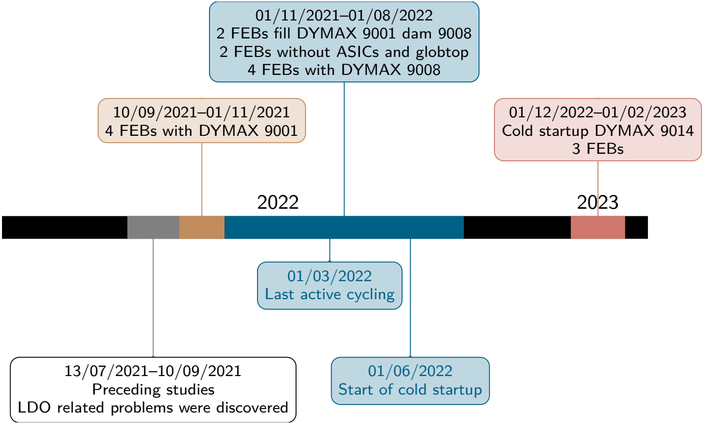
- Study the performance of STS electronics under the thermal stress
  - Different cycling performed:
    - passive cycling
    - active cycling
    - power cycling at low temperature
- Performance degradation
- Failure rate and boundary conditions

Monitored values

during the active thermal cycling

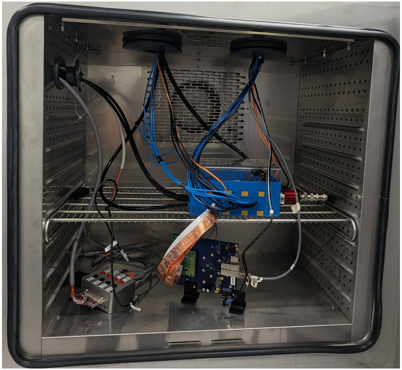


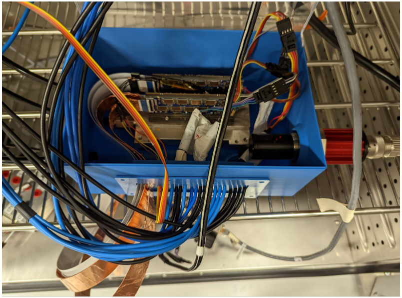
History of thermal stress studies



Overview of the experimental setup

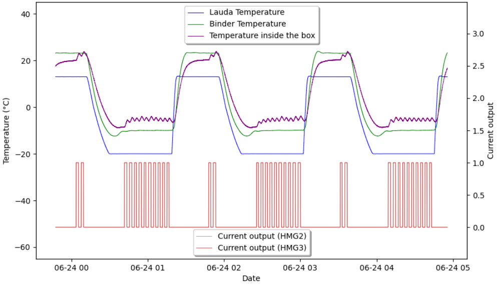
- Climatic Chamber BINDER
- 3D printed box for holding nitrogen
- Cooling plate with copper tubes inside of the box





- Four FEBs v3 (120A, 121A, 117B, and 120B) glued to cooling fins
- The cooling fins are screwed to the cooling plate
- Low Voltage interfaces connected to power supplies (HMP4040)
- GBTxEMU-based read-out chain

Cycling procedure



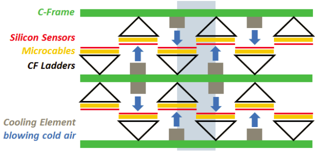
- The difference in temperature between BINDER and LAUDA is always $10\,^{\circ}\mathrm{C}$.
- The purple line represents the temperature inside the box. It is at a similar temperature to BINDER.
- The red and grey lines represent when the power supplies are ON or OFF

Thermal stress studies: Conclusions and Outlook

- LDO voltage regulator is identified as a weak spot
  - most significant power power dissipation om FEB
  - high current density
  - frequent failure at lower temperatures ($\leq -30^\circ\mathrm{C}$)
- Final set of tests performed with 4 FEB-8 v3
  - humidity control with N_2 flow
  - coolant temperature down to $-20^\circ\mathrm{C}$
  - **no power failure after 500 power cycles** (50 temp. cycles $\times$ 10 power-on)
- Data from 500 power cycles with another 4 FEBs is ready

Brief introduction to air cooling

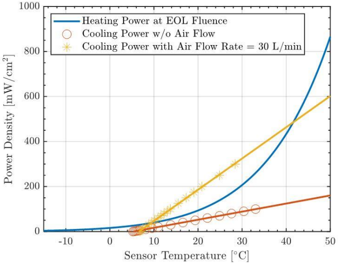
- Only the inner most sensors of all station (x,y, ≤ ± 10 cm), requires active air cooling
- The peripheral sensors of all stations are aimed to be cooled by natural convection
- Cooling power should be sufficient to be away from thermal runaway



Top view of STS station

Perforated tube

Perforated tube based on the theory of impinging jets has been chosen as the cooling element running across the length of sensors



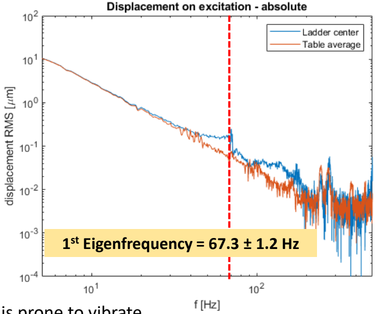
To be at safe margin from thermal runaway, sensors need to be cooled down at flow rate of 30L/min, which could affect the mechanical stability of ladder

More details: K. Agarwal talk, cooling in STS

Eigen frequency measurement of ladder

Study by G. Viehhauser at Uni. Oxford

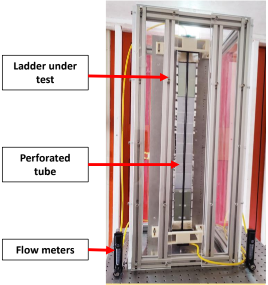
Ladder with dummy modules equipped on a shaker table



- Eigen frequencies are the frequencies at which system is prone to vibrate
- Shaker table at University of Oxford is used to produce the excitement in the ladder using accelerometers
  - Displacement at different eigen frequencies was measured
- 3 capacitive sensors were used to measure the displacement RMS

Next step: Cross check if the eigenfrequency is excited by air flow

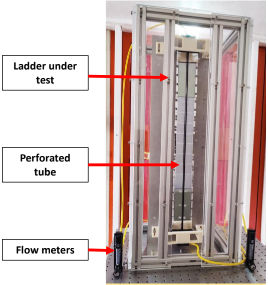
Vibration measurements – setup description



Ladder under air flow

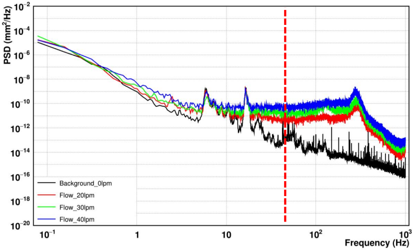
- Testing Procedure
  - A 10 module ladder was mounted on an optical bench to test for the performance under air flow using perforated tube
  - Flow meters at both end of tube were employed to regulate air flow

Vibration measurements – setup description



Ladder under air flow

Setup for measurement

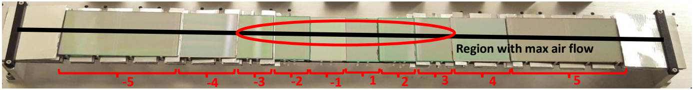


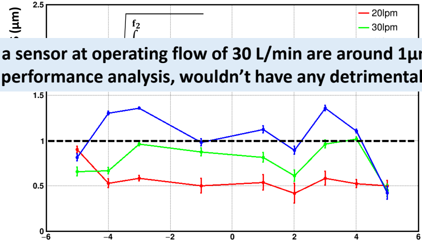
Power Spectral density with changing frequency for different air flow

- Laser doppler vibrometer is used to scan sensor surface
  - Non-contact measurement of surface with wide frequency range
  - Integrated with data acquisition and analysis software
  - Stand-off distance between laser and ladder was ~ 640 mm

PSD spectra shows that eigen frequency of an assembled ladder is not excited because of air flow

Vibration measurements under air flow - results

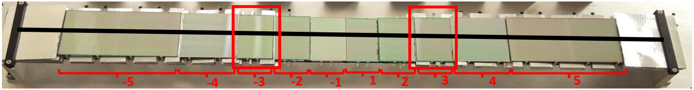


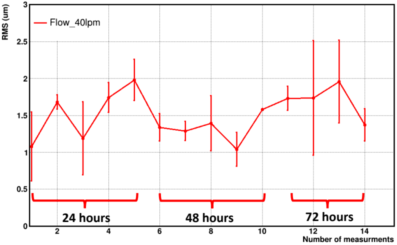


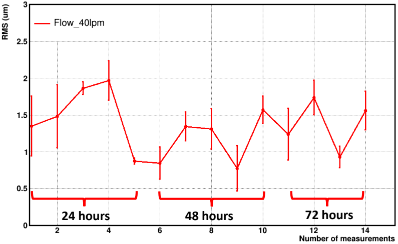
Maximum vibrations on a sensor at operating flow of 30 L/min are around 1µm, which from preliminary track performance analysis, wouldn't have any detrimental effects

- Plot shows the RMS values for over all vibration produced in the sensors along the ladder
- RMS is calculated by subtracting the measurements with flow and the background measurement (without flow)
- Sensors in the middle region vibrates more due to the higher flow in the middle region

Long term measurements for ladder under flow

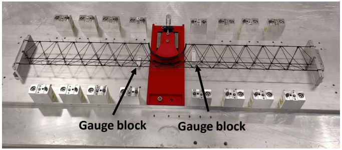


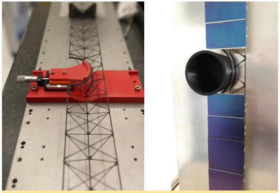




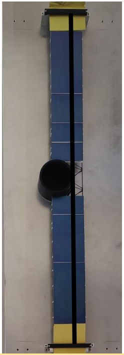
Long term measurement with continuous air flow at 40 L/min for 3 days – RMS is between 1- 2 µm, which ensures reproducible results

Central ladder – Special case

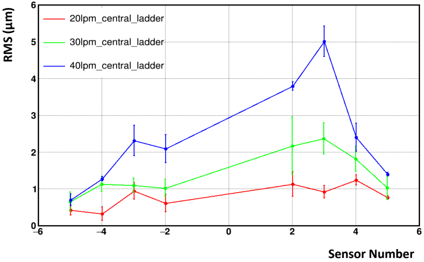




Specialized tool for supporting ladder cut-out during assembly



Ladder with cut-out

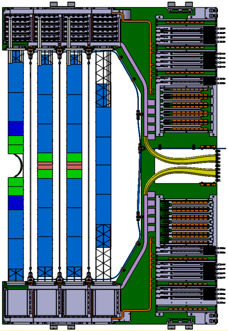


- Thickness of silicon wafers used was 30 % higher than original sensors
- Perforated tube is shifted by 1 cm because of presence of cut out for the beam pipe
- Shift in tube was expected to produce more vibrations

The amplitude of vibration in ladder with cut-out is more because of shift in the perforated tube closer to sensors

Result of air flow on ladder vibration

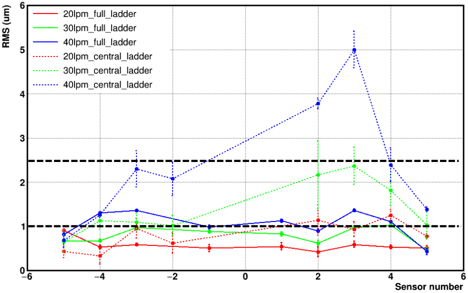
Ladder with and without cut-out



Drawing of ladders with and without cut-out
assembled on C-frame along with perforated tube

Result of air flow on ladder vibration

Ladder with and without cut-out



Ladder with cut-out

Ladder w/o cut-out

Comparison of vibrations in ladders with and without cut-outs

Ladder with cut out shows more vibration then without cut out but amplitude of vibration is still affordable

Vibration studies: Summary and Outlook

- Ladder assembly technique has been exercised to test for the stability and precision mounting of ladders
- The concept of low material budget CF- perforated tubes, which are active source of sensor cooling and could be the source of vibration, has been demonstrated
- Pre- liminary results shows vibration < 1 µm under nominal air flow, in correspondence with track alignment software
- Vibration testing of an assembled ladder at Uni. Oxford shows 67Hz eigenfrequency, which isn't excited by air flow
- Pre-liminary results from central ladders are not very detrimental but need to be optimized

Outlook

- Vibration studies needs to be performed for the whole C-frame to study the impact of neighboring perforated tube effecting vibration amplitude
- Studies to produce more stiffer ladders is ongoing aiming for minimal material budget
- Vibration impact of air flow needs to be cross checked for the central ladder with final ladder variants