Development of a test bench for measuring emissivity at low temperature for the space sector

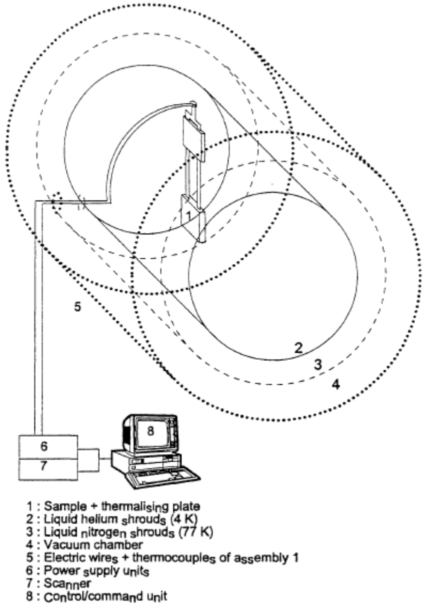
Jean-Pierre MONCHAU[1] , Bruno BRAS[2] , Nuno DIAS[2] , Eliott CARMINATTI-ROUSSET[1] , Léo RAOULT[1]

THEMACS Ingénierie, 2 bis rue Alfred Nobel, 77420 Champs-sur-Marne, France
ESA, European Space Agency, Keplerlaan 1, 2200AG Noordwijk, Netherlands

ADD THE SLIDE TITLE HERE

- Bibliography, study of the state of the art
- Principle of the device
- Design of the measuring device
- Initial measures
- Causes of measurement deviations and remedies

Bibliography, study of the state of the art



MEASUREMENTS OF TOTAL HEMISPHERIC EMISSIVITY AT LOW TEMPERATURES - DESIGNING A CRYOGENIC TEST BENCH

Christophe FABRON, Alain MEURAT

ALCATEL SPACE INDUSTRIES, 100 BD du MIDI, 06150 CANNES LA BOCCA, FRANCE
Email : Christophe.Fabron@space.alcatel.fr, Alain.Meurat@space.alcatel.fr

Calorimetric method:

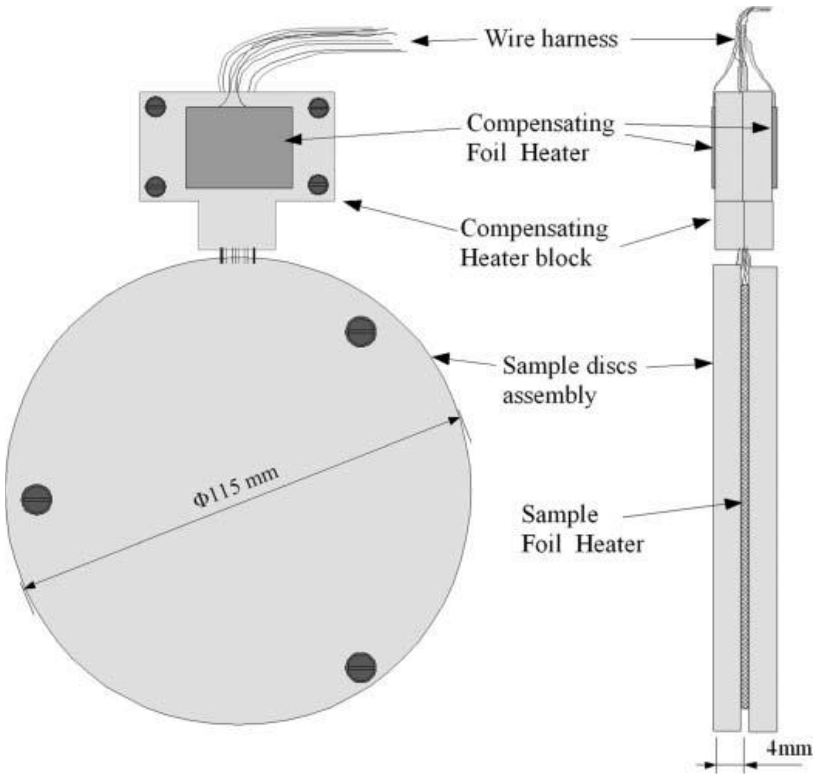
$$P = \sigma.\varepsilon.S \cdot (T_{sample}^4 - T_{chamber}^4) = U.I$$

If $T_{sample} \gg T_{chamber}$

$$P = \sigma.\varepsilon.S \cdot T_{sample}^4 = U.I$$

- A gard is necessary
- The limit is the vacuum chamber temperature (4K for LHe and 77K for the sample)
- Long time for steady state (days)

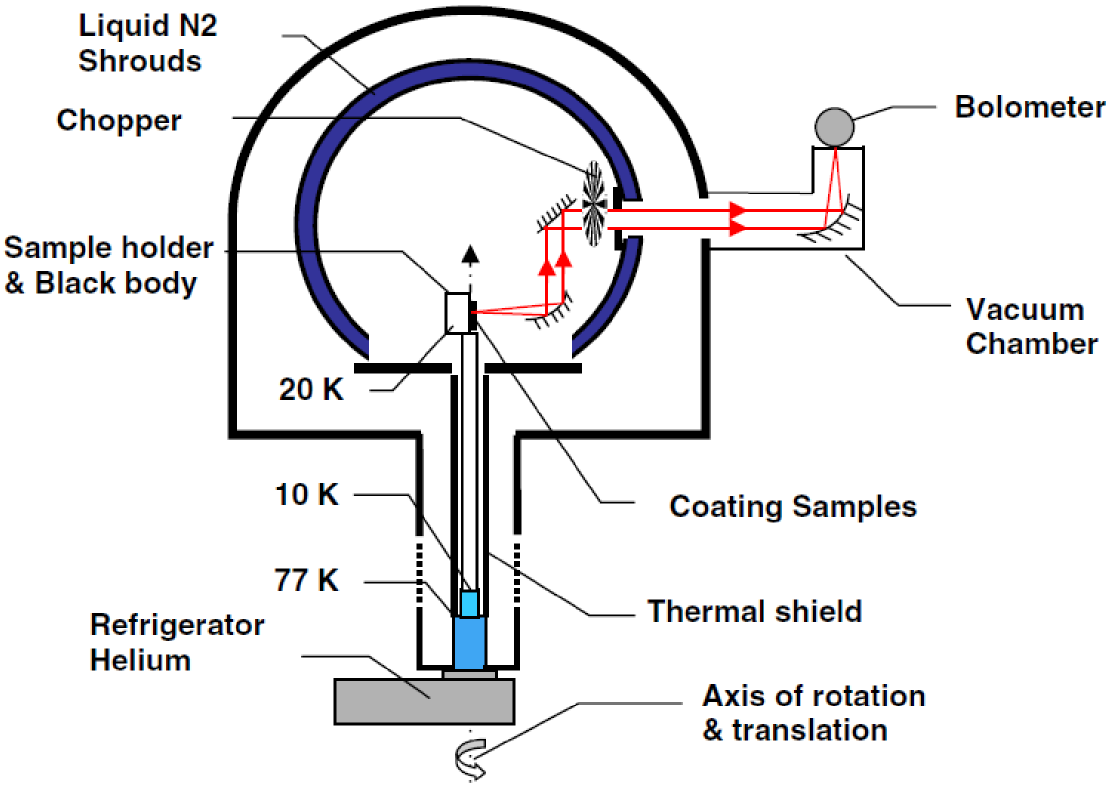
Bibliography, study of the state of the art



Measurement of Total Hemispherical Emittance of Spacecraft Thermal Control Coatings at Low Temperatures

GOVINDA R. YENNI, AMRIT AMBIRAJAN,
NARASINGANALLUR K. SUNDARESAN, and ARUMUGAM RAMASAMY
Thermal Systems Group, Indian Space Research Organisation Satellite Centre, Bangalore, India

Bibliography, study of the state of the art



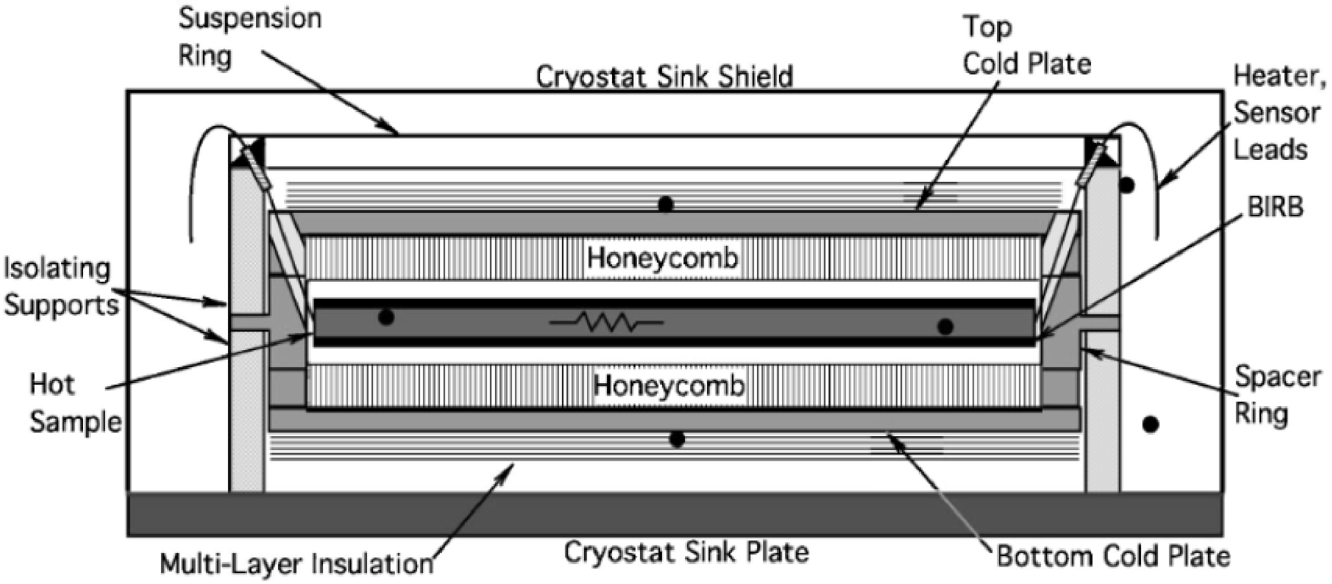
Radiometric method:

- The bolometer must measure the entire spectrum down to very long wavelengths (100 to 500µm).
- Calibration required

Direct measurement of total emissivities at cryogenic temperatures: Application to satellite coatings

P. Herve, N. Rambure, A. Sadou,D. Ramel , L. Francou , P. Delouard, E. Gavila

Bibliography, study of the state of the art



The Total Hemispheric Emissivity Of Painted Aluminum Honeycomb At Cryogenic Temperatures

J. Tuttle[a], E. Canavan[a], M. DiPirro[a], X. Li[a], and P. Knollenberg[b]

[a] NASA Goddard Space Flight Center, Code 552
Greenbelt, Maryland, 20771, USA
[b] Northrop Grumman Aerospace Systems
Redondo Beach, CA 90278, USA

Calorimetric method:

- Need 2 samples
- Constrained sample sizes

- Shorter warm-up time than other calorimetric measurements

$$\dot{Q} = \frac{\sigma A (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

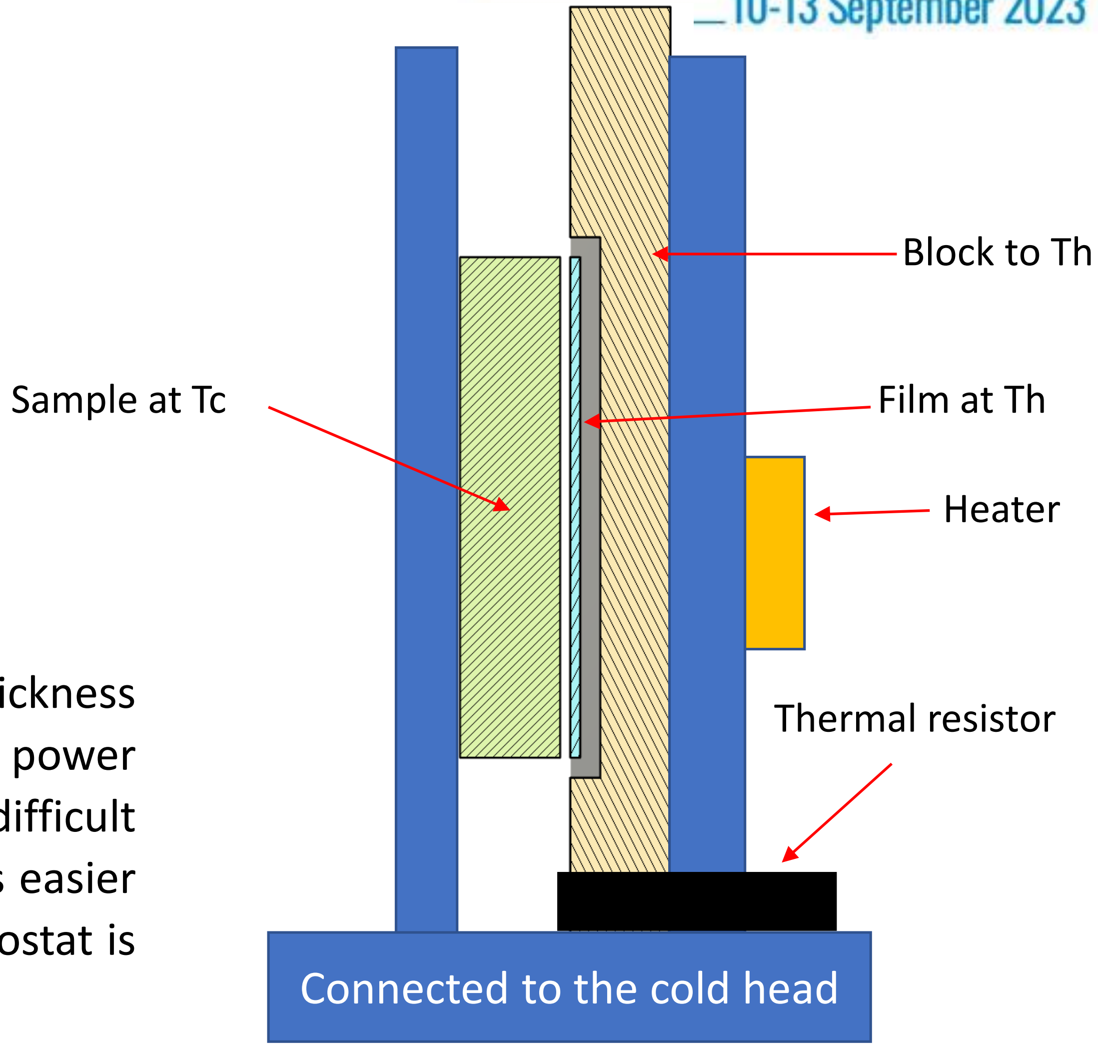
Principle of the device

ESA specifications:

- Measure on samples of different sizes from 25mmx25mm
- No paint on a proof body
- Rapid measurement
- Measures between 20 and 300K

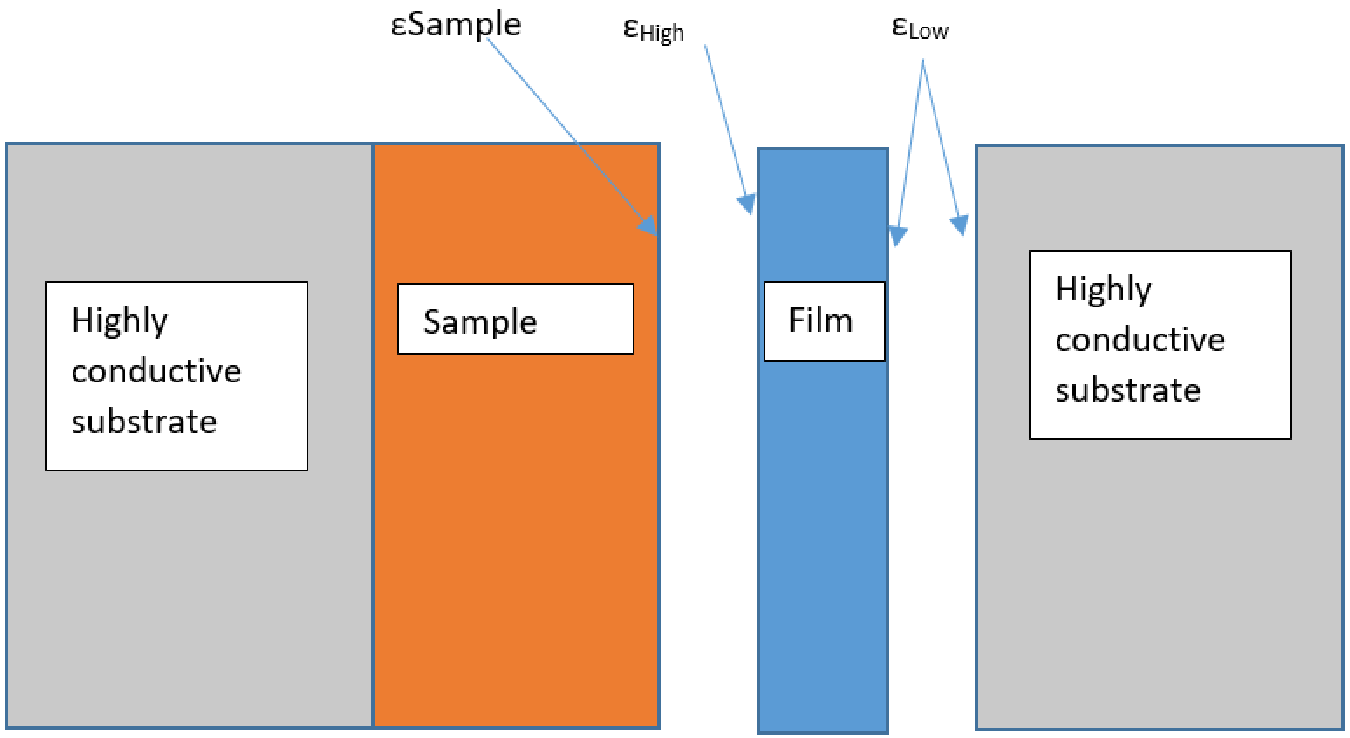
Principle of the device

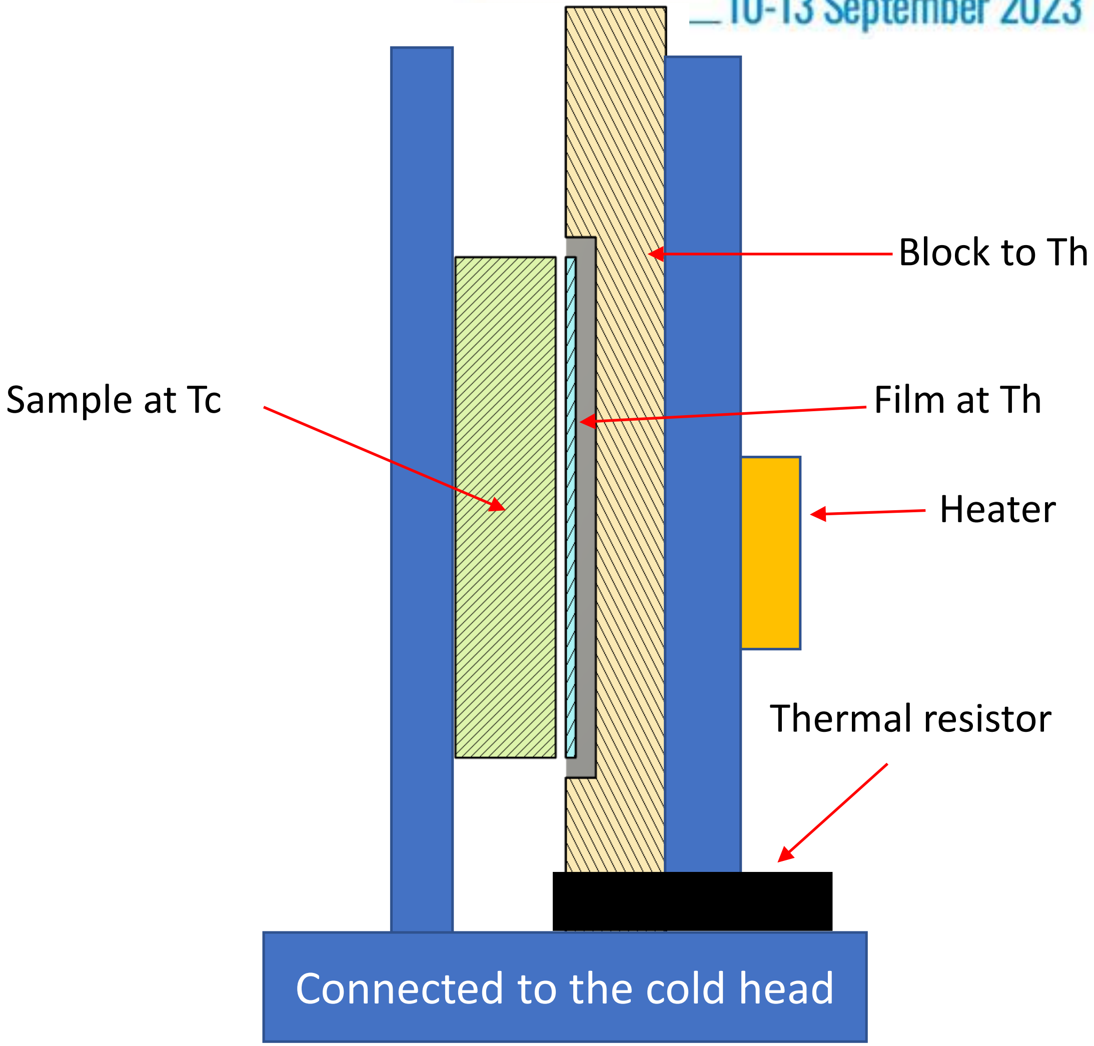
- A heating film of known or measurable emissivity fitted with a temperature gauge
- A block that holds the film in place and acts as a thermal barrier
- The device faces the sample
- different sizes
- The sample is cooled by the cold head and its temperature measured



It is not easy to regulate the temperature of a large sample (thickness greater than 1mm) at very low temperatures and to measure the power required to do so. Indeed, as the heat flows are extremely low, it is difficult to lower the temperature of a large mass (it takes several days). It is easier to set the temperature by connecting it to a thermostat. This thermostat is also connected to a guard block.

Principle of the device





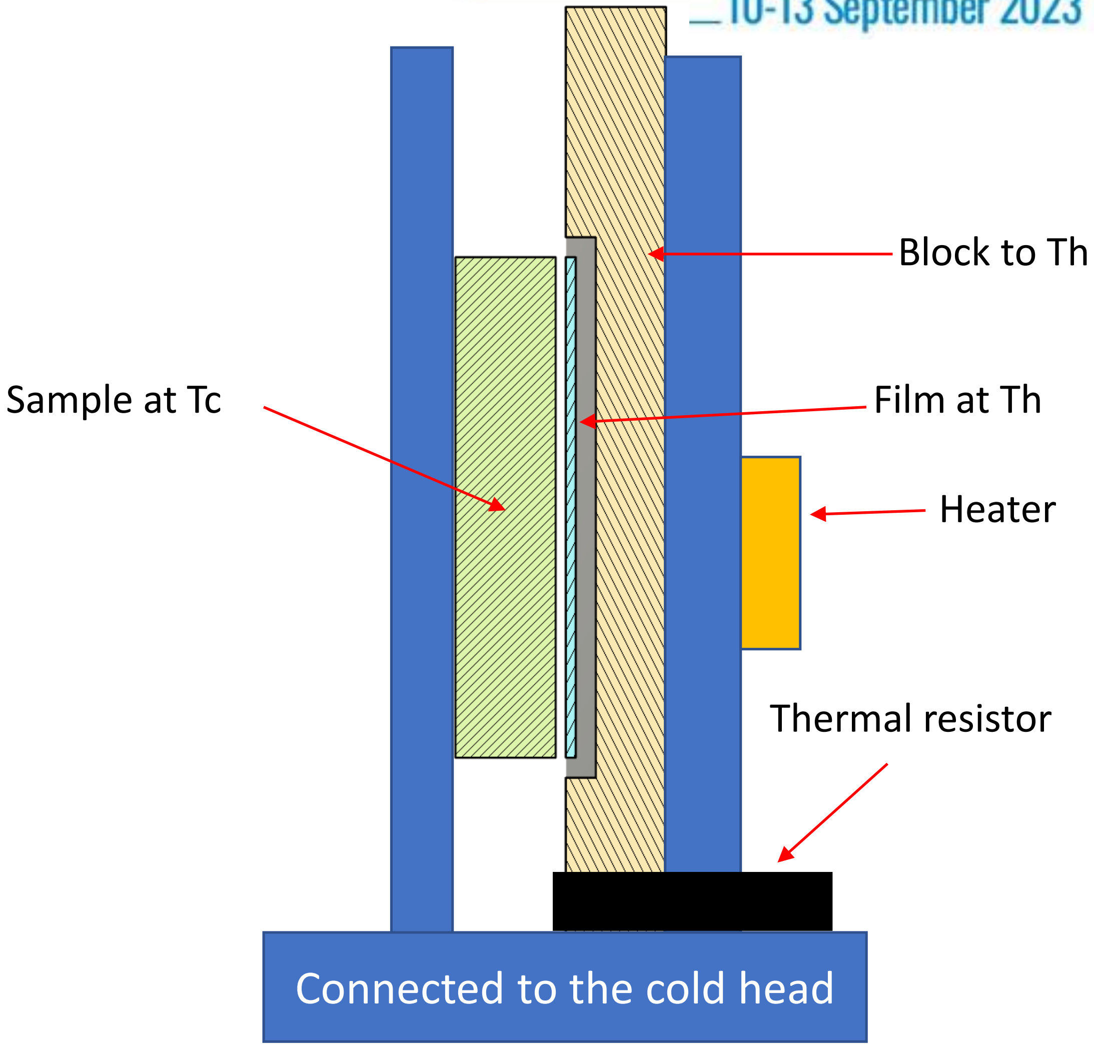
Principle of the device

Assuming a form factor of 1, we obtain the power exchanged at the front end:

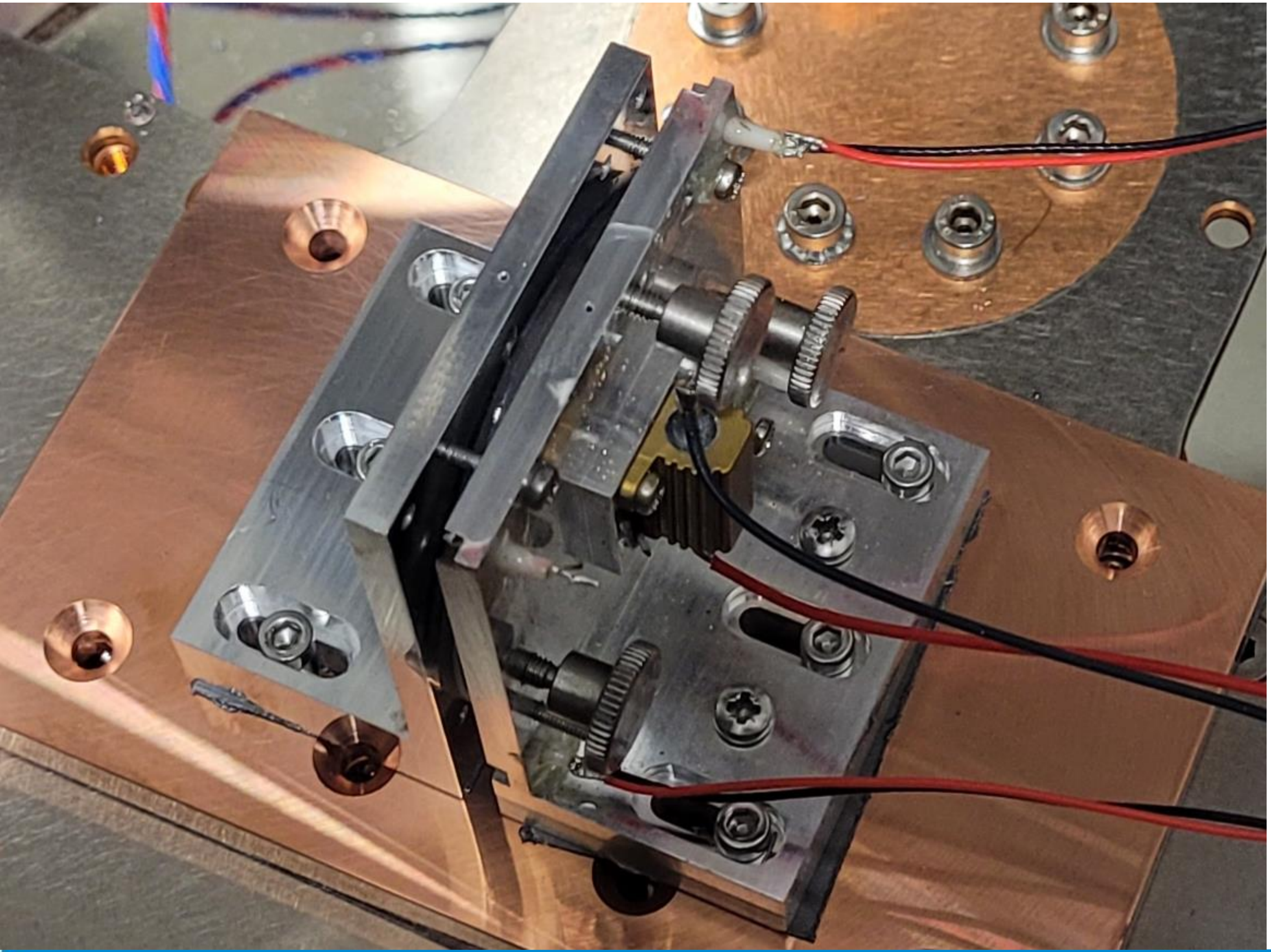
$$P = \sigma.S \cdot \frac{T_h^4 - T_c^4}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

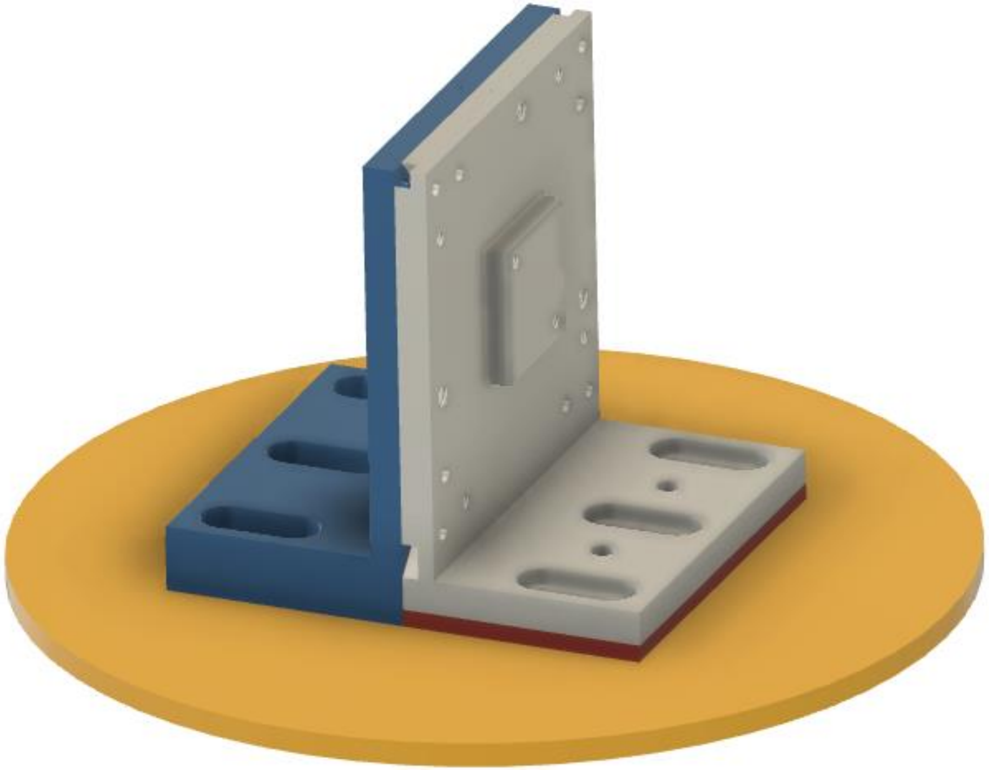
To find out the emissivity of the heating film, a sample is made with the same coating as the heating film, having an emissivity equal to . In this case the expression of the power becomes :

$$P = \sigma.S \cdot \frac{T_h^4 - T_c^4}{\frac{2}{\varepsilon_f} - 1}$$

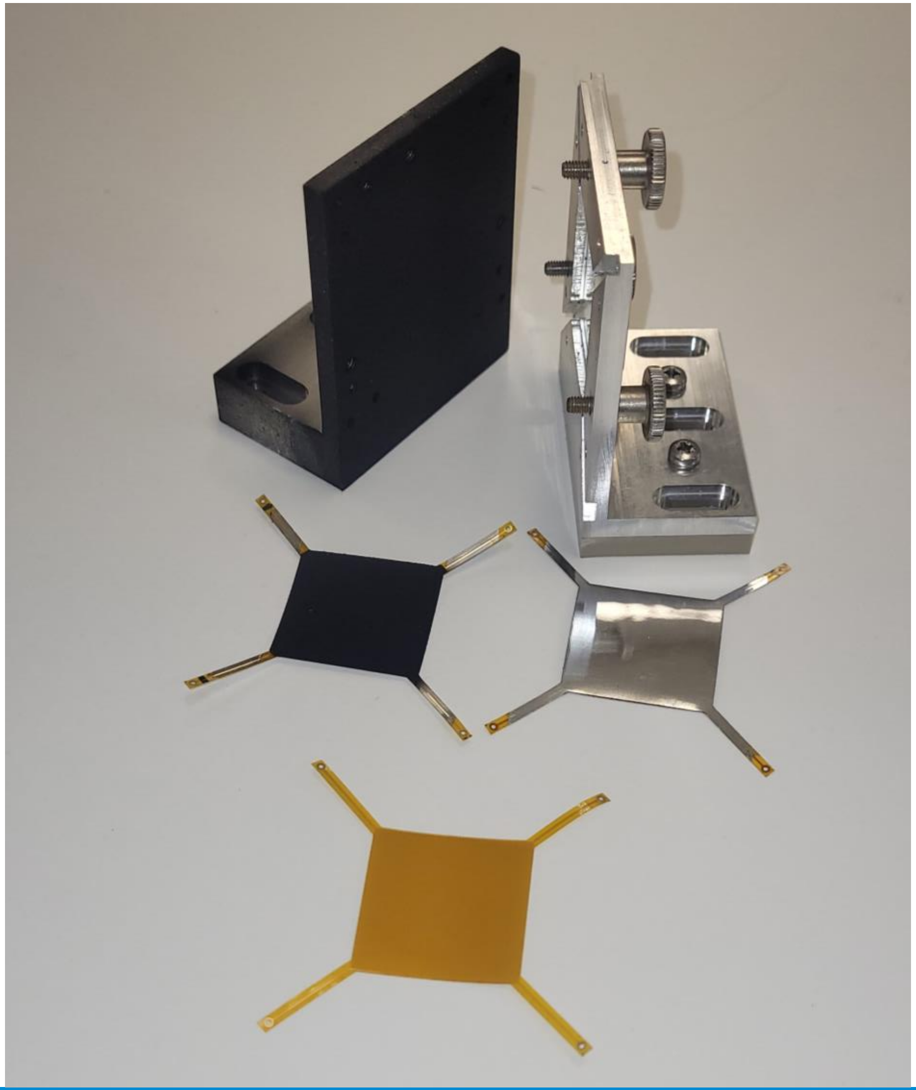


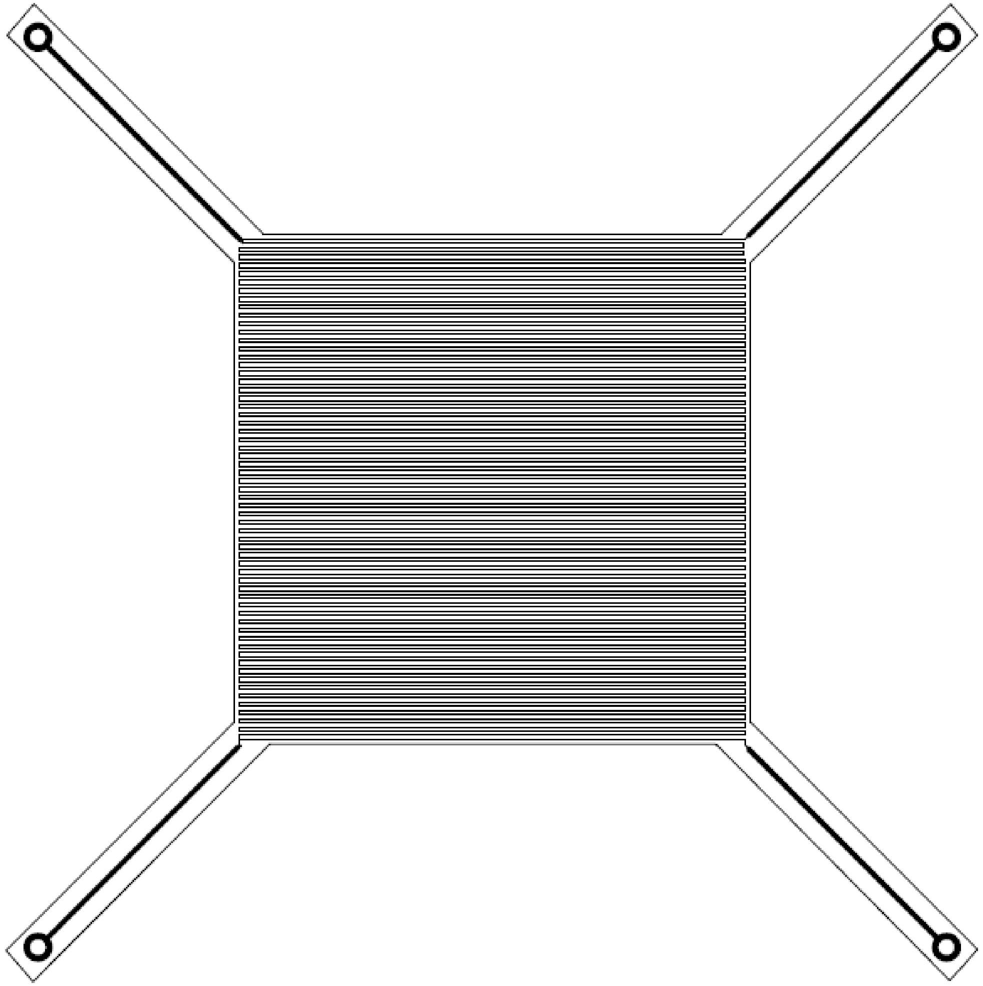
Design of the new device





Design of the new device





Initial measures

To find out the emissivity of the heating film, a sample is made with the same coating as the heating film, having an emissivity equal to . In this case the expression of the power becomes :

$$\text{From: } P = \sigma.S \cdot \frac{T_h^4 - T_c^4}{\frac{2}{\varepsilon_{Nextel}} - 1} \quad \text{->} \quad \varepsilon_{Nextel} = 2 \cdot \left(\sigma.S \cdot \frac{T_h^4 - T_c^4}{P} + 1\right)^{-1}$$

Calculating of emissivity : Assuming a form factor of 1, we obtain the power exchanged at the front end:

$$\text{From : } P = \sigma.S \cdot \frac{T_h^4 - T_c^4}{\frac{1}{\varepsilon_{Sample}} + \frac{1}{\varepsilon_{Nextel}} - 1} \quad \text{->} \quad \varepsilon_{Sample} = \left(\sigma.S \cdot \frac{T_h^4 - T_c^4}{P} - \frac{1}{\varepsilon_{Nextel}} + 1\right)^{-1}$$

Initial measures

Driving the emissivity head prototype and calculate emissivity

1. Regulate the sample and the sensor bulk at the target temperature
2. Start to heat the sensor bulk through the 390 Ohm resistor. the voltage is chosen for a specific difference of temperature (thermal resistor is a 5mm thick PEEK block
3. Start to heat sensor to reach the bulk temperature. The power can be evaluate in the Excel file. After successive approach the two temperature must be the same.
4. Calculate emissivity from power.

Initial measures

NEXTEL Ambient temperature										
Δtsensor-Tsample (K)	ΔTsensor-Tsensor bulk (K)	P Elec (W)	Radiative P (W)	T sensor	T sensor bulk	T sample	NEXTEL emissivity (0.93)	Pelec/Pradiative	surfacic flux (w/m2)	conductive deltaT for 160µm Nextel
11.4	0.8	0.049	0.042	315.8	316.6	304.4	1.133	1.169	78.5934669	0.04836521
11.7	0.3	0.053	0.045	319.7	320.0	308.0	1.143	1.196	85.5966306	0.05267485
12.1	0.0	0.055	0.046	319.0	319.0	306.9	1.138	1.203	88.149201	0.05424566
12.8	-0.7	0.059	0.048	318.6	317.9	305.8	1.132	1.219	94.1988712	0.05796854

The ratio between electrical and radiative power is constant at around 1.2. This ratio corresponds to the strips that were not taken into account when calculating the surface area in the design. If we correct the surface area, we find exactly the right emissivity. (The surplus of strips is 16% in surface area).
The last column represents the temperature drop on the sensor due to the conductivity of the NEXTEL paint.
A similar calculation is made for the 3mm borosilicate mirror (ΔT=7^{E} -3 K).

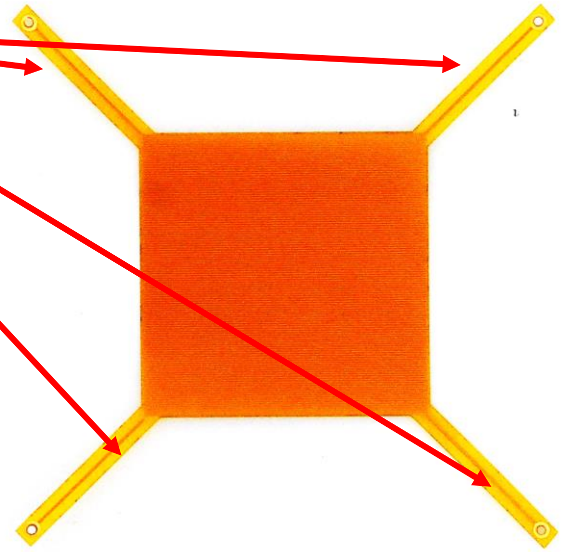
Initial measures

NEXTEL at Cryo temperature							
Δtsensor-Tsample (K)	ΔTsensor-Tsensor bulk (K)	P Elec (W)	Radiative P (W)	T sensor	T sensor bulk	T sample	NEXTEL emissivity (0.93)
16.3	-3.9	0.00092	0.00118	92.8	93.1	80.7	0.72

The difference between the actual value and the measured value (0.72 measured and 0.93 theoretical) can be explained by the poor calibration of the temperature sensors. A difference of 0.02 K is enough to create a heat flow between the guard

Causes of measurement deviations and remedies

To supply the sensor resistor, 4 copper tracks are used (2 to supply the current and 2 to measure the voltage). These tracks are **18µm** thick and **0.25mm** wide.



These tracks have been deliberately made wider so that they do not contribute to heating. However, they do play a major role in heat transfer between the sensor support and the sensor.

Calculation of the power transferred as a function of the temperature difference :

$$P = 4 * \frac{\lambda * S}{L} * \Delta T = A * \Delta T$$

Causes of measurement deviations and remedies

for λ_{copper}=400W/m/K we have :

A_{Copper}=5.3E-4 W/K

For Kapton in 2mm width and 80µm thickness:

λ_{Kapton}=0.25W/m/K : → A_{Total} =5.42^{E} -4 W/K

A_{Kapton}=1.18E-5 W/K

If we compare this with the various radiant powers and measurements observed, we can calculate the temperature difference assumed to explain these differences.

	Thermal radiative power for difference of 12 to 14 K (mW)	ΔT (K) for a maximum of 1% error on power		difference of power between measured and expected (radiative) in W	difference of temperature for this difference (K)
NEXTEL 310K	42.0	0.775		7.1	13.13
Miror 311K	1.6	0.029		-1.4	-2.67
NEXTEL 87K	0.98	0.018		-0.07	-0.12

Causes of measurement deviations and remedies

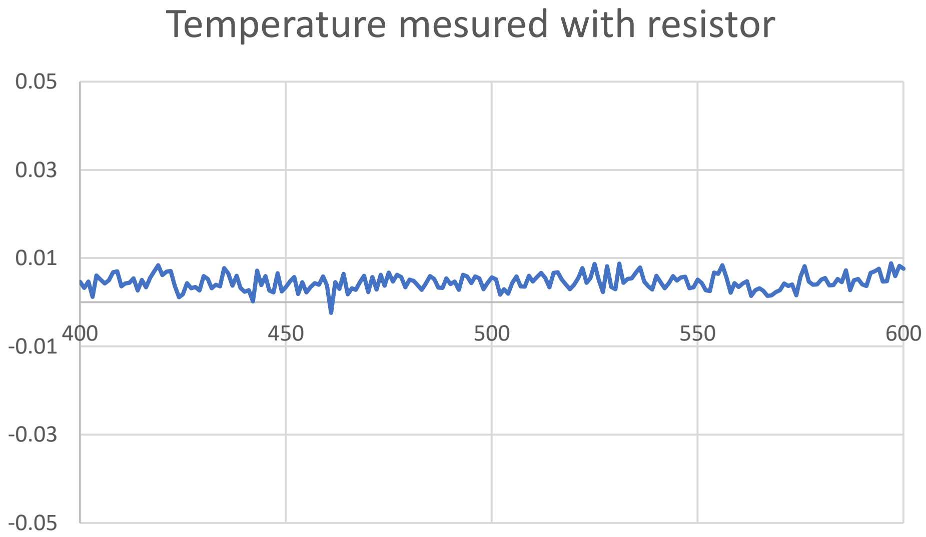
To avoid this, heat transfer must be reduced as much as possible.
- Current-free voltage measurement tracks can be reduced to 0.06mm.
- The width of the supply tracks can be reduced. If we reduce them to 0.06mm, this provides 0.52% power. To avoid this, we can aim for 0.12mm and make the track twice as long.

For a **26mm** long track of **0.06mm** for the measurement and **0.12mm** for the supply, the power input will be 0.48%.
The new transfer coefficient for copper will be $_{Acuivre=1}$.04E-4 W/K

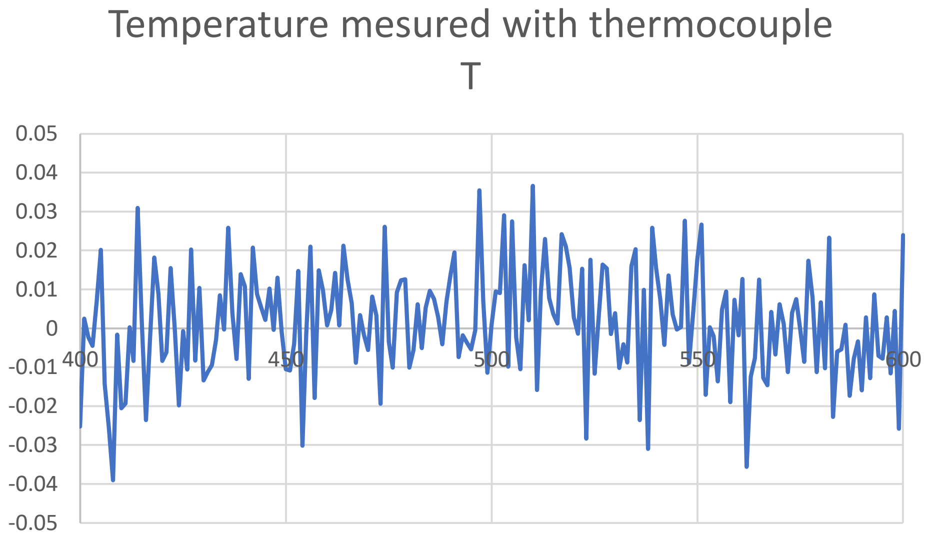
	Thermal radiative power for difference of 12 to 14 K (W)	ΔT (K) for a maximum of 1% error on power		difference of power between measured and expected (radiative) in W	difference of temperature for this difference
NEXTEL 310K	42.0	4.051		7.1	68.66
Miror 311K	1.6	0.153		-1.4	-13.95
NEXTEL 87K	0.98	0.095		-0.07	-0.63 (insteed of -0.12)

Causes of measurement deviations and remedies

- The three measurement sensors need to be calibrated together to be able to measure temperature differences at 0.02K and the absolute temperature at 1K.
- Use an identical resistor to measure the temperature of the guard
- Reduce noise by using a less noisy sensor:



Standard deviation=0.0018



Standard deviation=0.0139

Conclusion

The prototype demonstrated the feasibility of measuring emissivity at low temperatures, but the quality of the measurements needs to be improved.

To improve measurements:

- Better design of feeder tracks (longer, finer)
- Increase the emissive surface by at least a factor of 2 (50mmx50mm is the good size) for low emissivity and low temperatures
- Calibrating measurement sensors with care

Next version soon

Thank you for your attention

Jean-Pierre MONCHAU[1] , Bruno BRAS[2] , Nuno DIAS[2] , Eliott CARMINATTI-ROUSSET[1] , Léo RAOULT[1]

THEMACS Ingénierie, 2 bis rue Alfred Nobel, 77420 Champs-sur-Marne, France
ESA, European Space Agency, Keplerlaan 1, 2200AG Noordwijk, Netherlands

Contact: monchau@themacs.fr

esa

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