ESA recent activities on thermal parts: development and inspection techniques

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Thermal Control Section (TEC-MTT)
4th SPACE PASSIVE COMPONENT DAYS

14/10/2022

Overview

Smart Heaters

TDE activity
2 years nominal duration
Target TRL: 3

Heater Hot Spot Characterisation (Foil2Spot)

TDE activity (small activity)
9 months nominal duration
Target TRL: 3

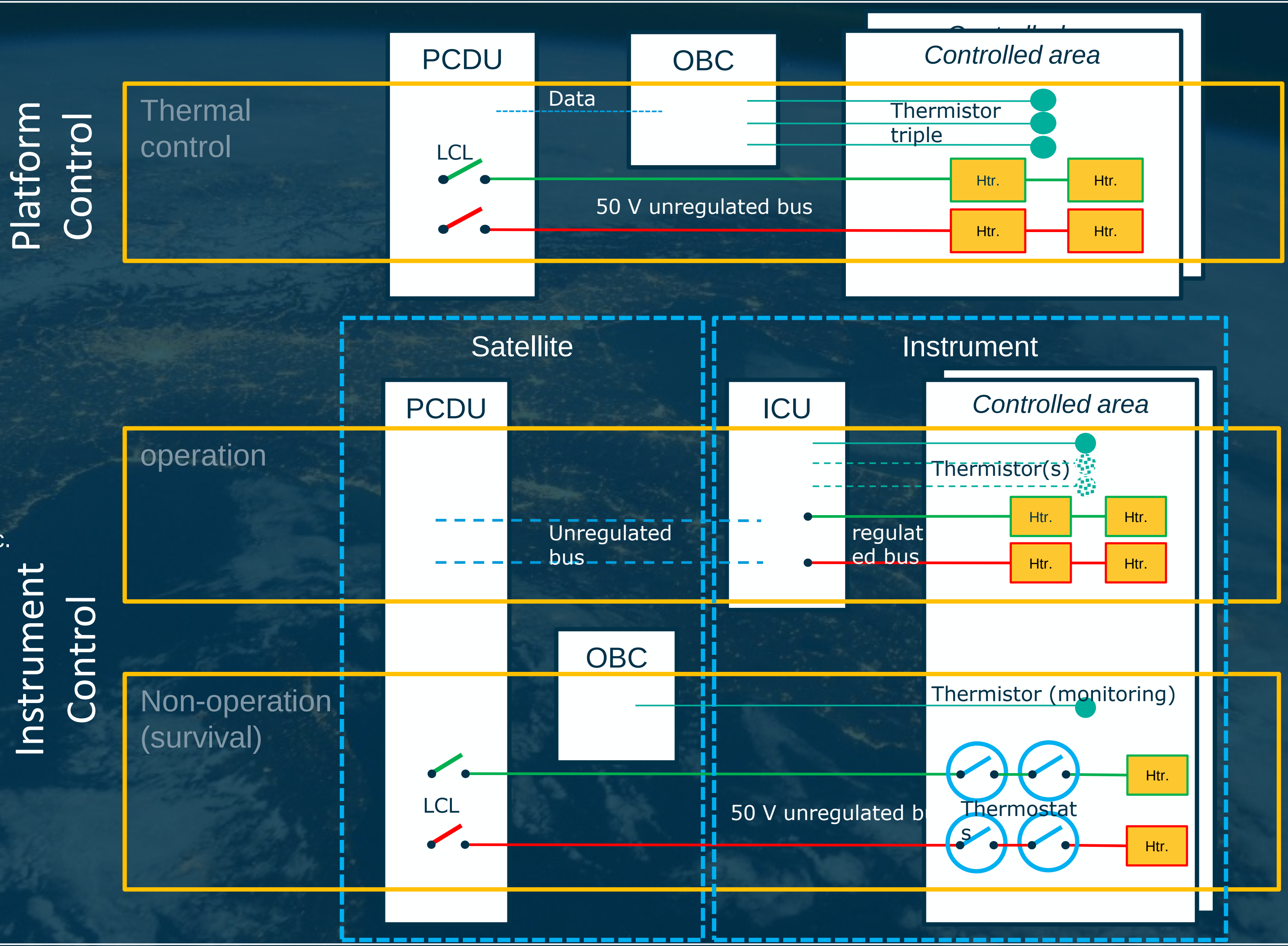
Smart Heaters

Thermal Control Subsystem - examples

Credit: COMEPA Ind.

Credit: Zopas Ind.

Credit: Measurement Spec.

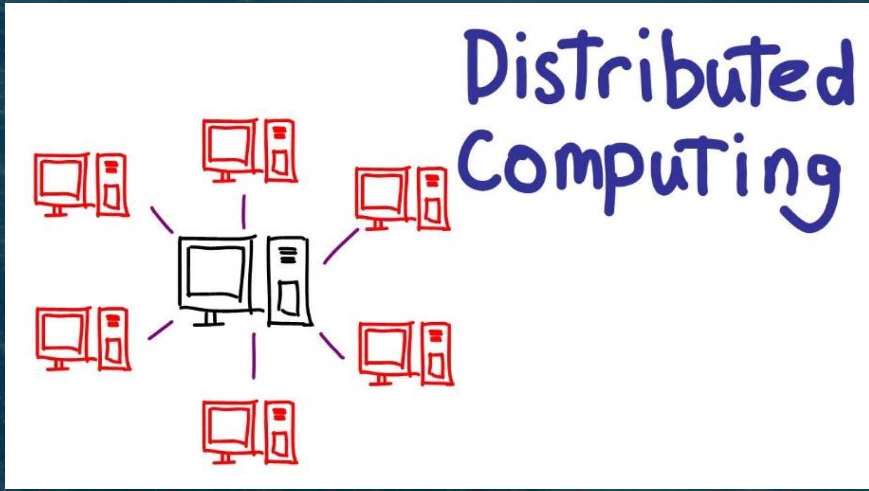


LCL	Latch Current Limiter
PCDU	Power Control and Distribution Unit
OBC	On-board Computer
—	Nominal line
—	Redundant line

Smart Heaters - objectives

Smart Heaters definition:

"A smart heater is a component that achieves the function of re-configurable local temperature control."



Main aspects:

- re-configurability of temperature set-points and heat outputs,
- reduce mass of the thermal control system,
- Similar price segment to standard heaters, thermistors and thermostats.

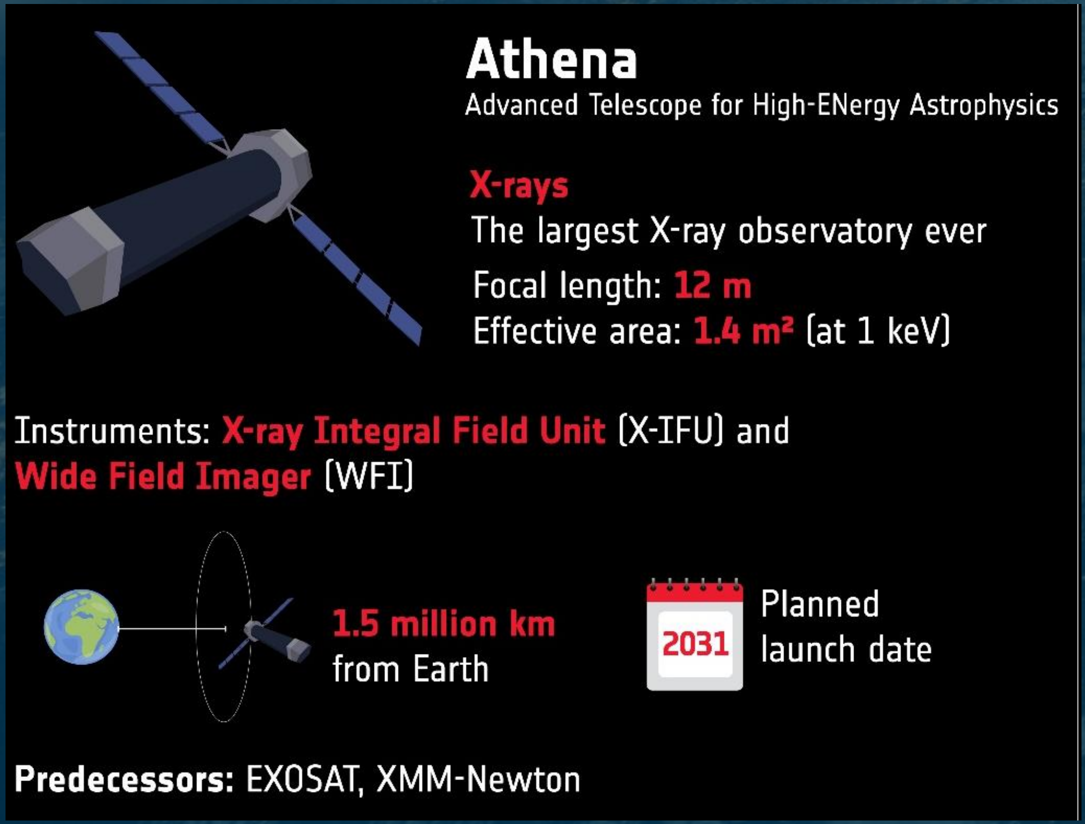
Benefits of smart heaters:

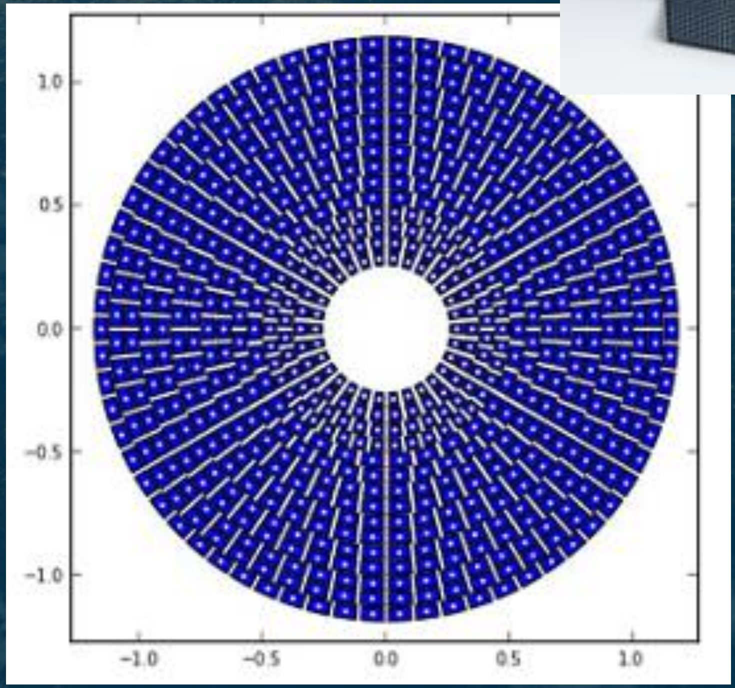
a) distributed components;
b) limited space / real estate on satellite;
c) require a tight thermal control to narrow temperature ranges or gradients; or
d) combination of a) to c).

Potential application & running example

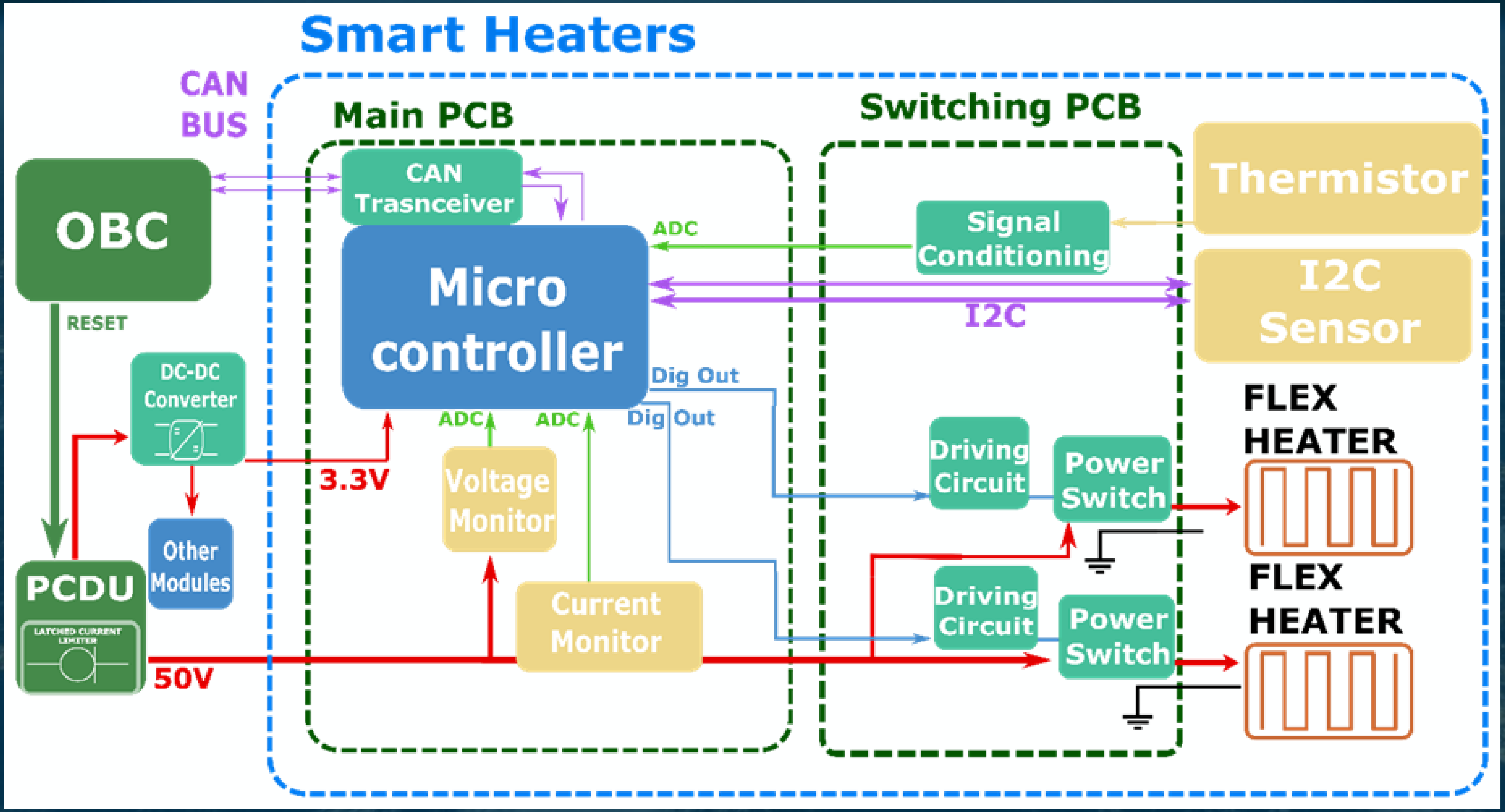
Potential applications

- Scientific missions, constellations, medium and small satellites.
- The Athena mission was used as running example





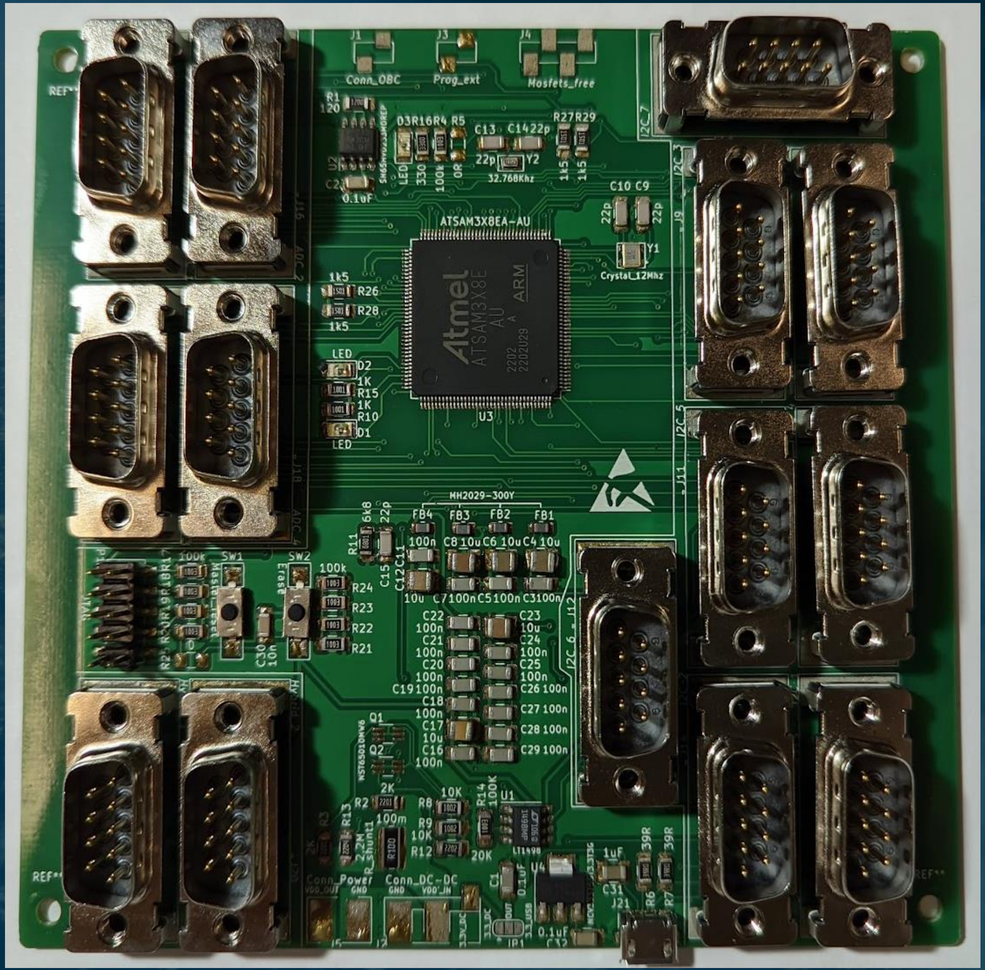
Smart Heaters Architecture



Designed PROTO PCBs – PCB 1

PCB 1 (Main PCB):

- Programming and Communication through Serial Port
- I2C communication using both interfaces -> **I2C sensor temperature reading**
- CAN Bus communication in a duplex dialogue -> **Communication with the OBC**
- ADC measurement readings -> **PT1000 temp reading**
- GPIO activation -> **MOSFET triggering to activate the heaters**
- **DB9 connectors for easy test.** No need of these connectors in the final versions
- Rad-tolerant **microcontroller** for flight version selected but not used in breadboarding activities



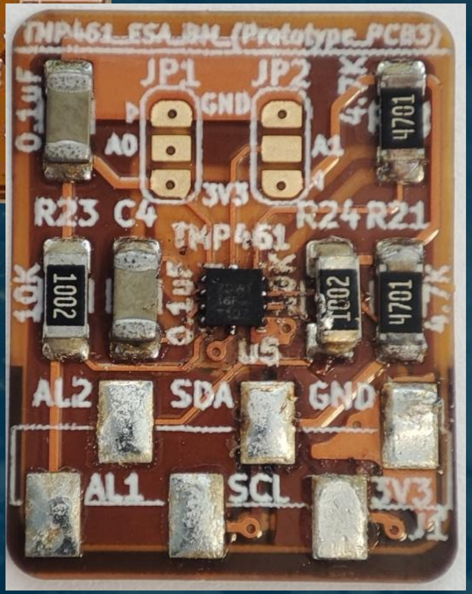
Designed PROTO PCBs – PCB 2 & 3

PCB2 (Switching PCB):

- PT1000 Signal Conditioning -> **PT1000 temp reading**
- I2C communication -> **I2C sensor temp reading**
- MOSFET Driving Circuit-> **MOSFET triggering to activate the heaters**
- One sided component mounting / flex substrate

PCB3 (Sensing PCB):

- I2C communication -> I2C sensor temp reading
- I2C Slave address configuration -> Using multiple I2C sensors
- One sided component mounting / flex substrate



Characterization Tests

Test	Ambient Temperature	Vacuum	Other Conditions	Measurements
Test #1: Step temp control	From -55ºC to +100ºC in steps of 25ºC for 15 min and back to -55ºC	No vac	Heater Set Temp 20ºC higher than ambient at each step	Monitor of temp of Array of 9 T-type thermocouples mounted on heater
Test #2: Output power	25ºC	No vac	Output power variated	Max Achievable temperature at test fixture and set to other 4 intermediate temperatures till ambient
Test #3A: Non-operating Temp 1	-55ºC to 150ºC	No vac	50 Non-Operational thermal cycling	Characterization before and after
Test #3B: Non-operating Temp 2	-150ºC to 150ºC	No vac	10 Non-Operational thermal cycling with increasing lower temp	Characterization before and after
Test #4: Voltage variability	Voltage Bus variation -20% to +5% up to 52V	No vac	Variation of the current adapted	Monitor of the temperature with the test fixture thermocouples
Test #5A: Thermal Vac. Characterization of individual samples	Same as Test#1 in thermal vac	Vacuum < 10E-5 mbar	Heater Set Temperature 20ºC higher than ambient at each step	The number of Temp sensors will be 2 per heater
Test #5B: Thermal Vac. with different loads	Same as Test#1 in thermal vac	Vacuum < 10E-5 mbar	vac chamber temp -50ºC Heater ON regulating every line at 25ºC.	The number of Temp sensors will be 2 per heater
Test #5C: Thermal Vac. with different temperatures	Same as Test#1 in thermal vac	Vacuum < 10E-5 mbar	3 lines at 35ºC 4 lines at 30ºC 4 lines at 25ºC 3 lines at 20ºC	The number of Monitor Temp sensors will be 2 per heater

GROUP	Description	Smart Heaters Samples to test						
		Item 1	Item 2	Item 3 Final Design				
				1	2	3	4	5
STEP 0 Prototype iterations Validation of desing with COTS	Initial prototypes Validation Tests	T	T					
	Design Iterations	T	T					
	Items#2 Validation Limited Temperature Range	T	T					
Procurement	Procurement and manufacturing FINAL DESIGN			T	T	T	T	R
STEP 1	Incoming Inspection Sequence			T	T	T	T	R
STEP 2	Test #1: Step temp control			T	T	T	T	R
STEP 3	Test #2: Output power			T			T	R
STEP 4	Test #3A: Non Operating Temp Cycling with low temp -55ºC			T	O	O	T	R
STEP 5	Test #4: Voltage variability			T	O	O	T	R
STEP 6	Test #5A: Thermal Vac characterization of individual samples			O	O		T	R
STEP 7	Test #5B: Thermal Vac Thermal Vacuum with different loads			O	O		T	R
STEP 8	Test#5C: Thermal Vacuum with different temperatures			O	O		T	R
STEP 9	Test #3B: Non Operating Temp Cycling with lower temp			T				R
STEP 10	Construtional Analysis			T				
STEP 11	Delivery to ESA				D	D	D	O

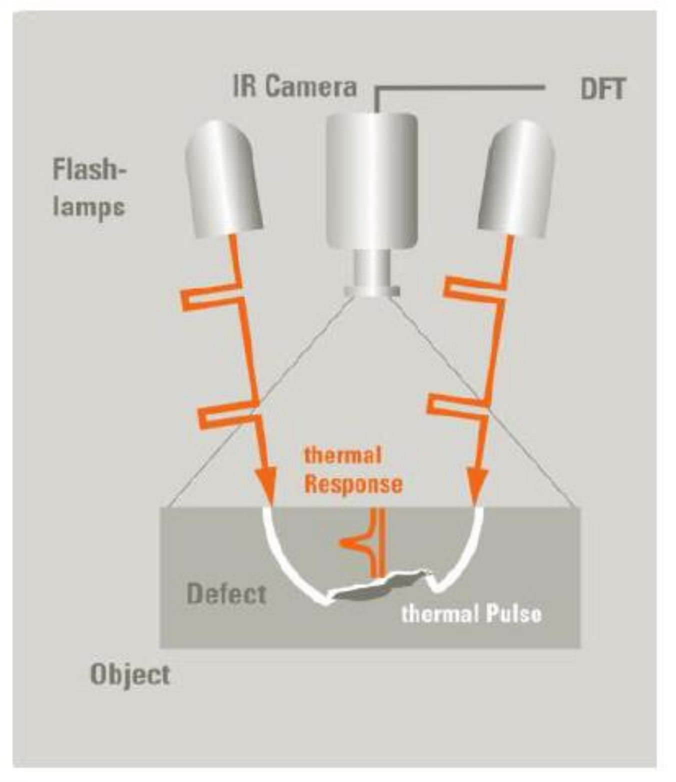
Heater Hot Spot Characterisation

Objectives & Background

- Research, trade-off and select various non-destructive test methods
- Technical assessment of relevant IR camera and measurement set-up parameters (e.g. camera resolution, sensitivity, calibration, distance to test object)
- Conduct tests with heaters of different shape, dimension, adhesives, baking, heating power levels, on different substrates and at different substrate temperature levels.
- **Identify a threshold (figure of merit) for the acceptance or rejection of a heater based on IR camera non-destructive measurements.**

Non-destructive methods and IR cameras

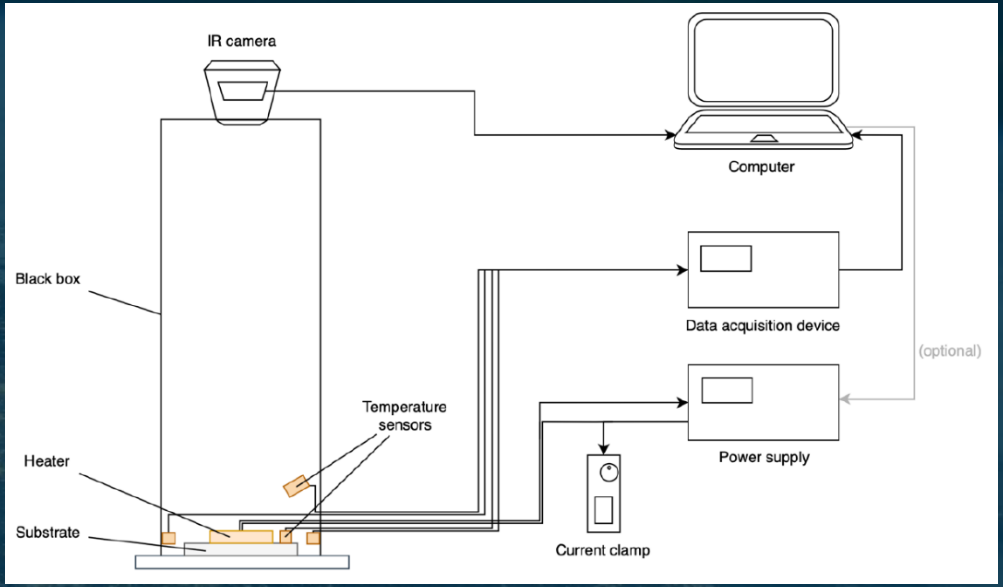
- Multiple non-destructive methods and excitation sources:
  - X-rays
  - Ultrasounds
  - Infrared thermography:
    - Pulsed Thermography (PT)
    - Lock-In or Modulated Thermography (LIT)
    - Pulse Phase Thermography (PPT)
    - Frequency modulated thermal wave imaging (FMTWI)
    - Step-Heating (SH)



- Selected methods for this activity:
  1. Pulsed Thermography, modified with both cooling and heating imaging
  2. Step-Heating targeting the maximum de-rated/rated temperature

Instrumentation and calibration

- **Camera data** are needed in order to design the test setup, influenced by:
  - camera‘s accuracy
  - camera‘s focal length
  - self heating during operations
  - need of initial calibration steps on the camera with known emitting samples



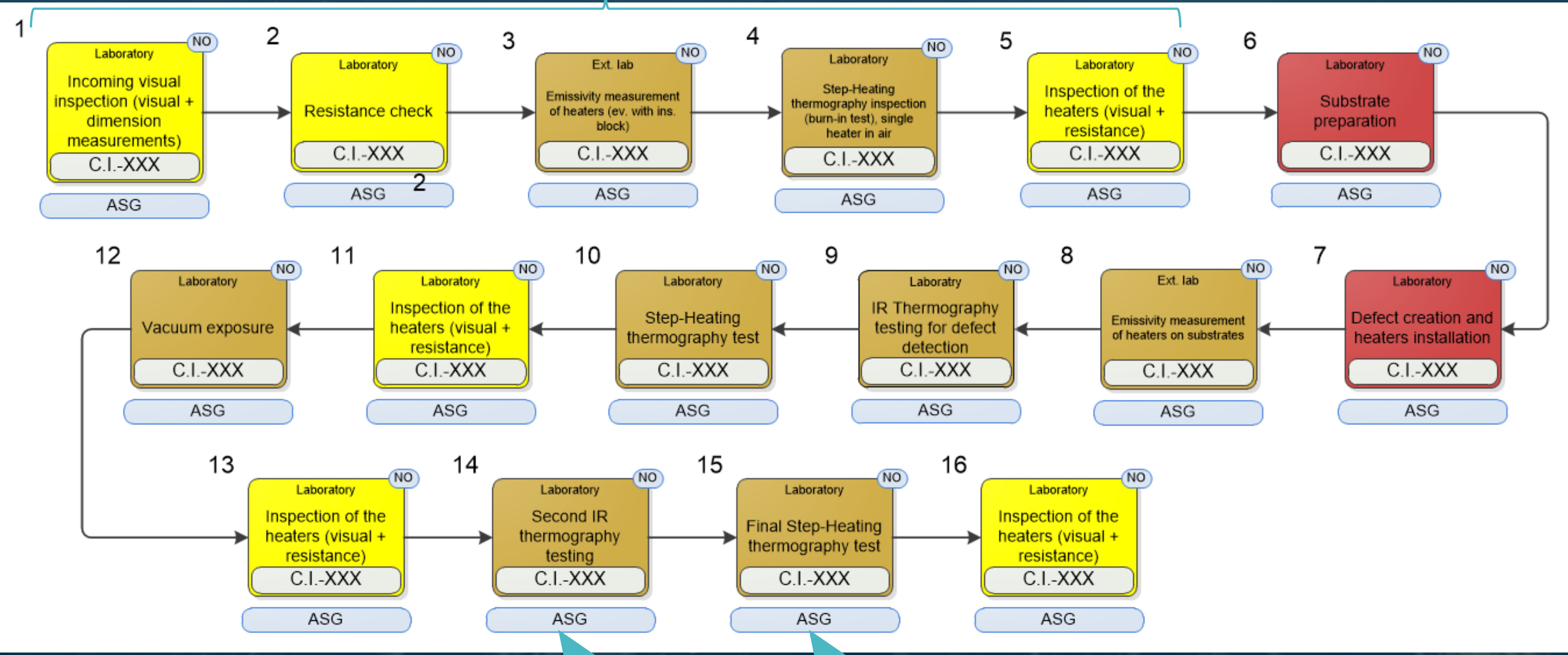
- In addition, **temperature sensors** are needed to validate the measurements obtained by the IR camera

Camera’s focal length

Adapter for cylindrical samples

Test plan

Heater alone



Both heating and cooling imagery

Reaching max rated/de-rated temperature

Test matrix and map of defects

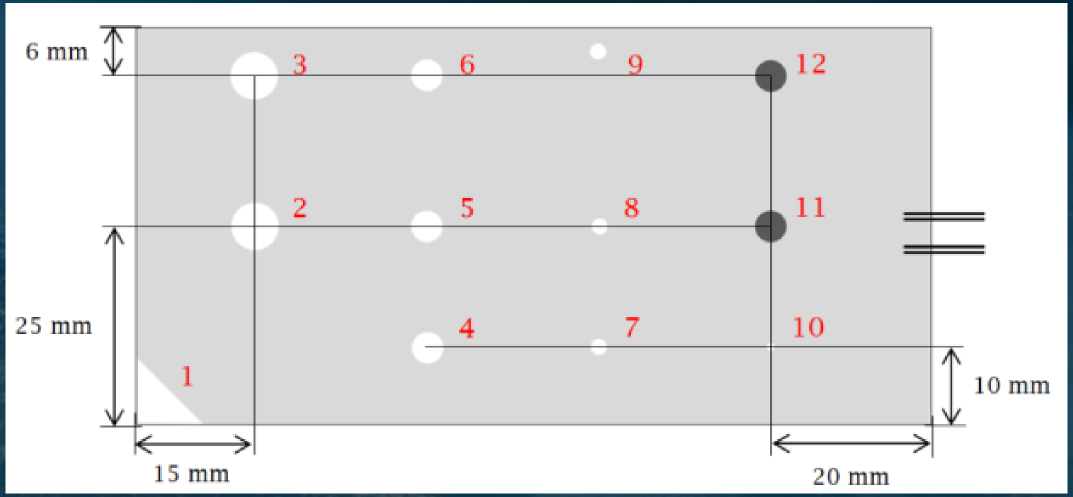
- Total of 30 heaters procured

		Flat Aluminum 9cmx14cm	Flat CFRP 6.5cmx14cm	Cylindrical Aluminum ~33mm Ø*	Cylindrical CFRP 33mm Ø
Single layer	Without Al backing Without PSA	2	2	1	1
	Without Al backing 3M 966 pre-applied	2	2	1	1
	Al backing Without PSA	1	2**	0	0
	Al backing 3M 966 pre-applied	1	2**	0	0
Double layer	Without Al backing Without PSA	2	2	0	0
	Without Al backing 3M 966 pre-applied	2	2	0	0
	Al backing Without PSA	1	2**	0	0
	Al backing 3M 966 pre-applied	1	2**	0	0

* depending on the commercially available sizes

** CFRP samples deemed more problematic from an installation point of view and therefore with one planned sample more than aluminium

Map of defects

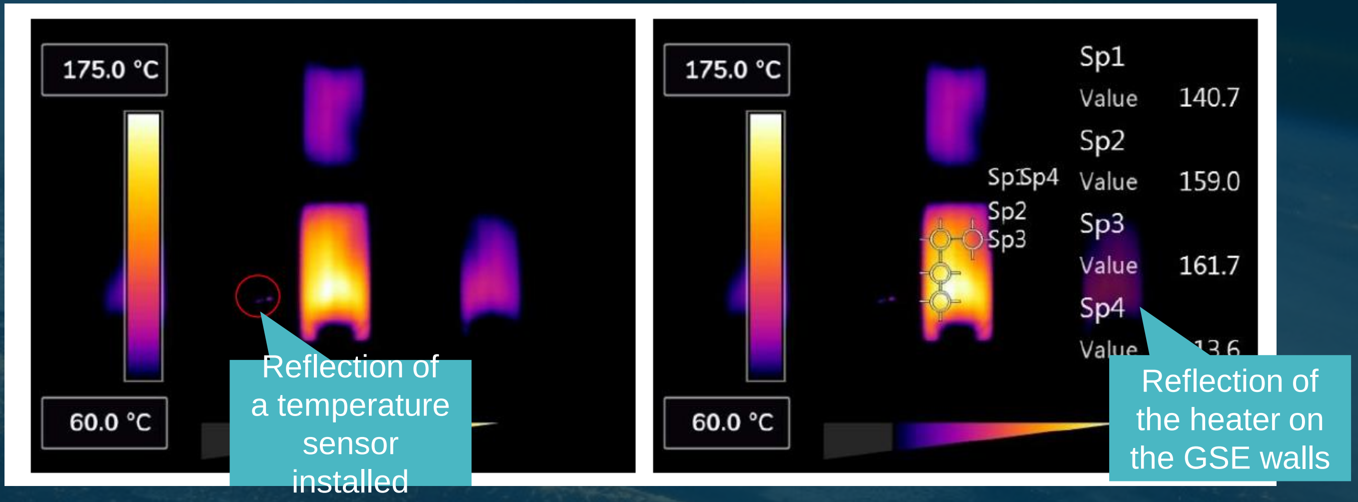


Subset of samples

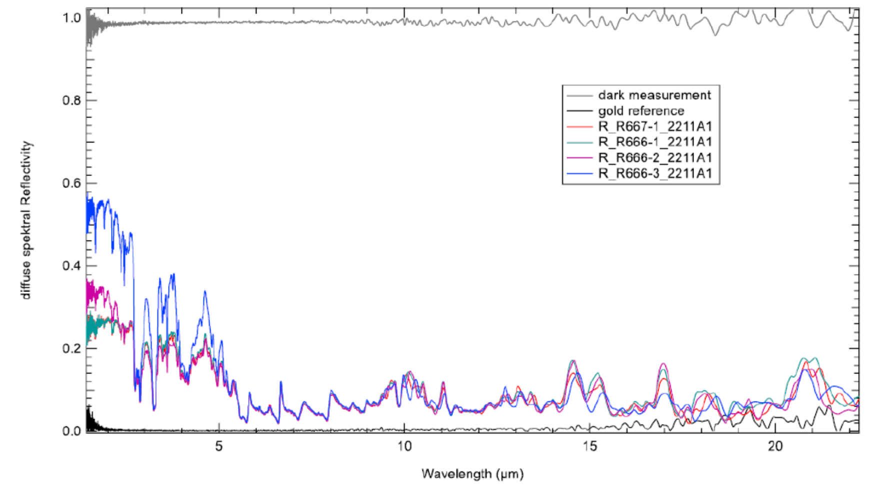
- 24 heaters submitted to tests (20 in a first series, 4 in a second series)

Emissivity calibration & measurement artifacts

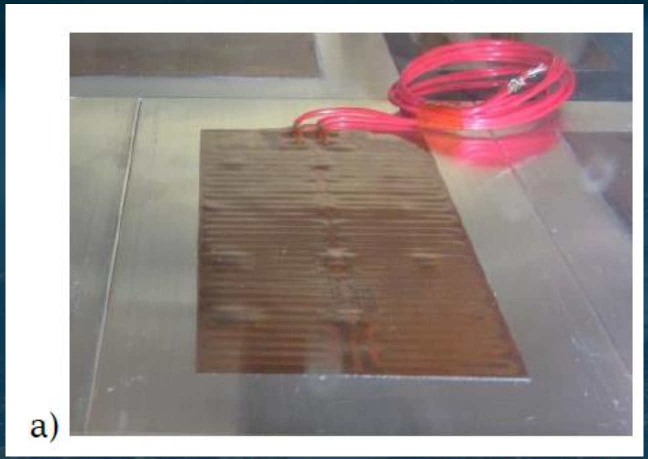
- Emissivity measurements allowed to
  1. Reduce the number of heaters to be tested for emissivity
  2. Avoid re-do the test on heaters as installed (similar values obtained regardless of the backing/substrate)
  3. Obtain values to characterize the measurement environment and its impact on the measurements themselves



Sample identification number	Sample description	Spectral range	IR-emittance (ε)
FOILH2SPOT.1100-P037.01-1.A-01	Without Al backing Without PSA	2.5µm - 22µm	0.925
		7.5µm - 13µm (1)	0.927
		7.5µm - 13µm (2)	0.928
FOILH2SPOT.1100-P037.01-1.A-0lp3	Without Al backing With PSA	2.5µm - 22µm	0.929
		7.5µm - 13µm	0.930
FOILH2SPOT.1100-P037.01-1.A-05	With Al backing Without PSA	2.5µm - 22µm	0.929
		7.5µm - 13µm	0.930
FOILH2SPOT.1100-P037.01-1.A-07	Double-layer Without Al backing Without PSA	2.5µm - 22µm	0.930
		7.5µm - 13µm	0.930

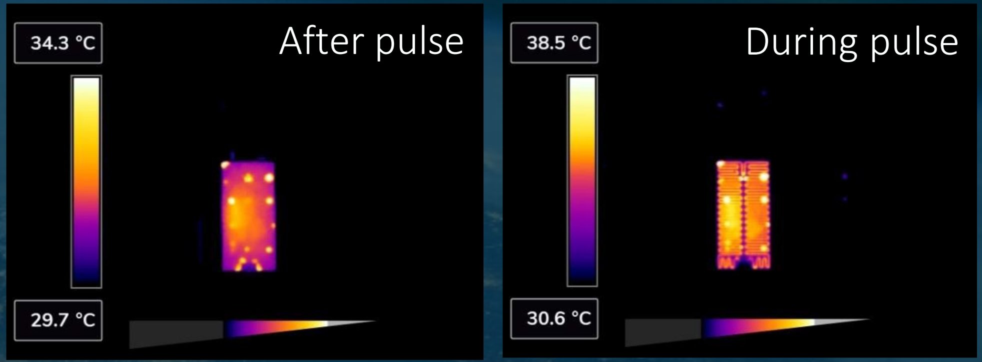


Test results (extract)

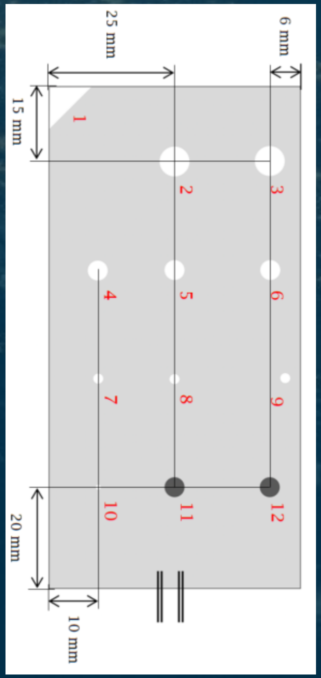


Aluminum plate; heater without Al backing; with PSA; $T_{derated}$ = 145 °C

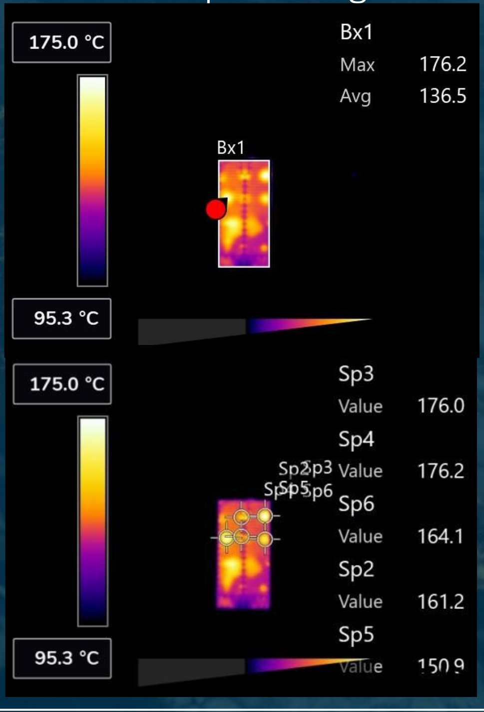
IR thermography



Defects



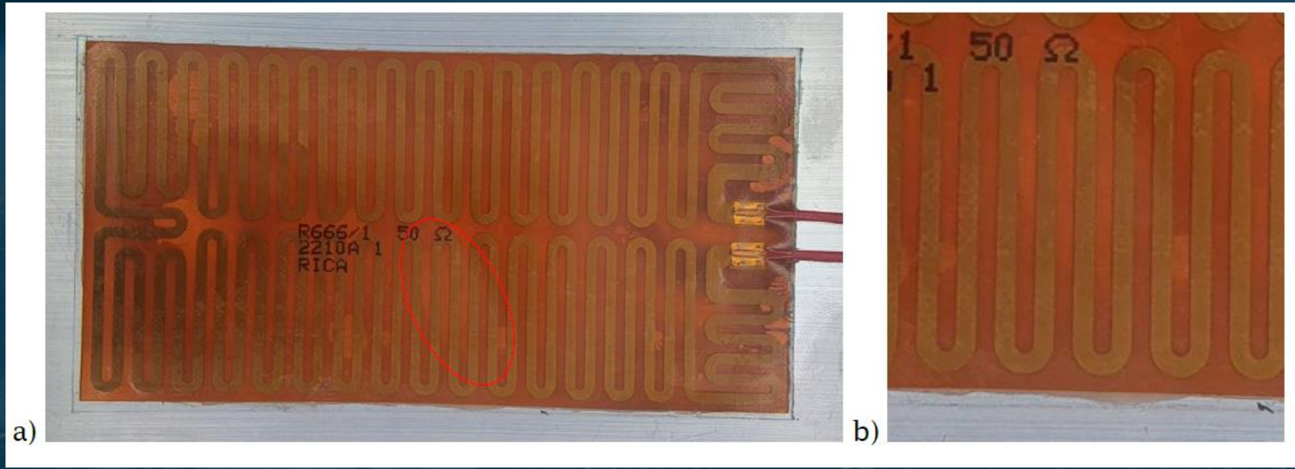
Step Heating



- Two-steps IR inspection selected and used
  1. IR thermography (both heating and cooling assessment) to identify the defects, before and after vacuum exposure
  2. Step-heating to evaluate variation in heaters' behaviour before/after vacuum exposure

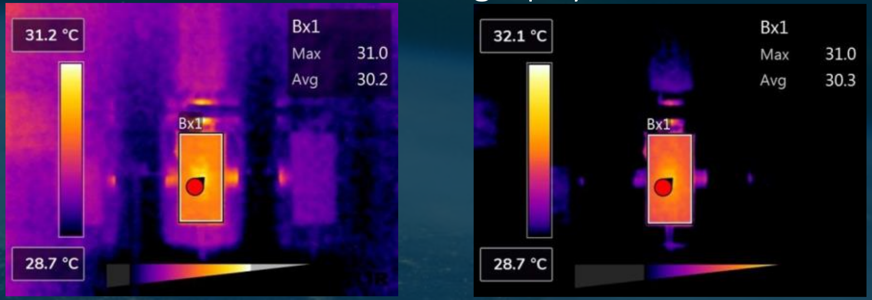
Test results (extract)

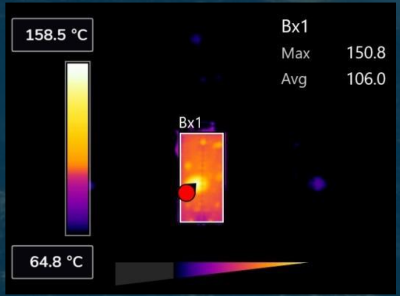
- Undesired defects created



Aluminum plate; heater without Al backing; without PSA; $T_{derated}$ = 120 °C

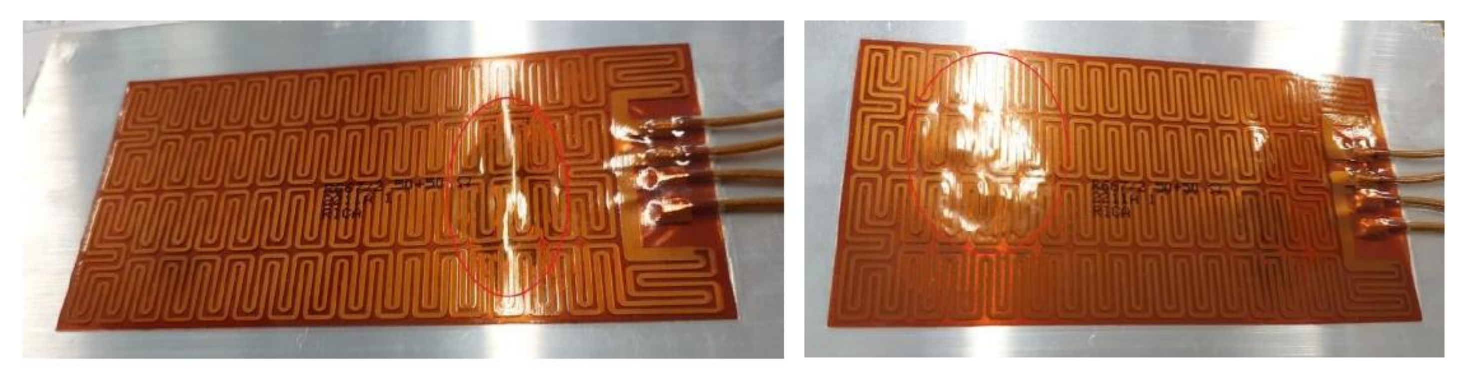
IR thermography



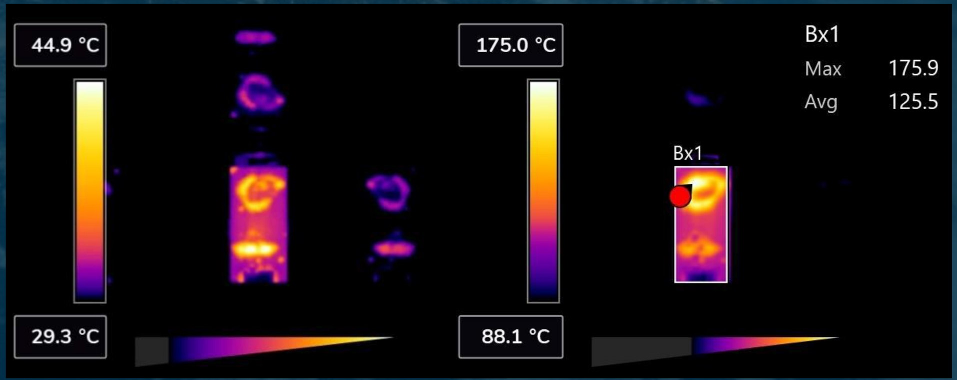


Step Heating

- Delamination/s occurred due to mistaken overheating (above rated temperature)



Aluminum plate; double layer heater without Al backing; with PSA; $T_{derated}$ = 145 °C

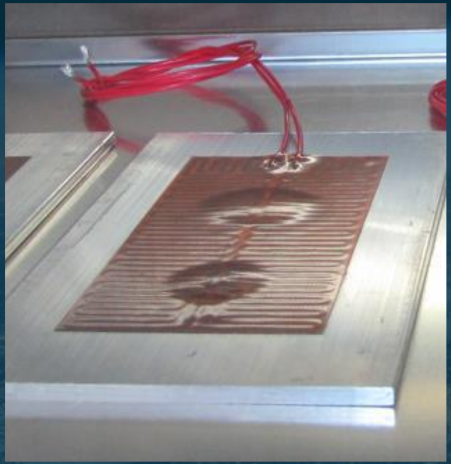


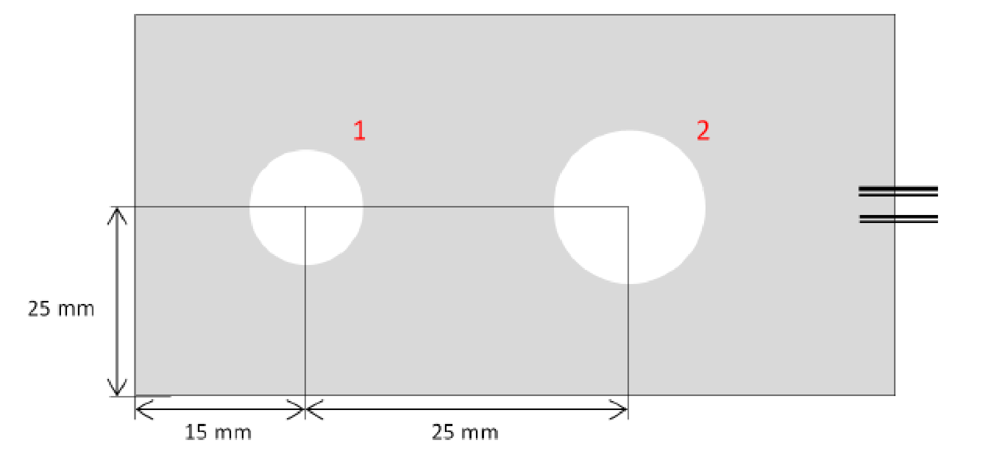
IR thermography

Step Heating

Test results (extract)

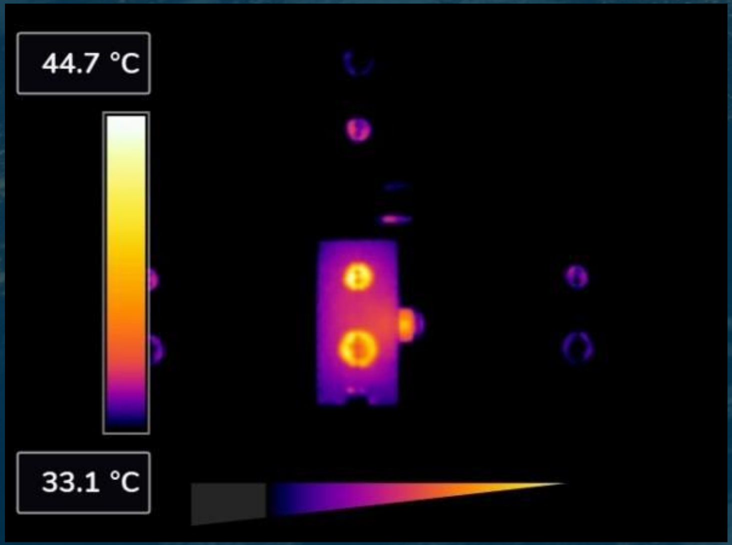
Aluminum plate; heater without Al backing; with PSA; $T_{derated}$ = 145 °C

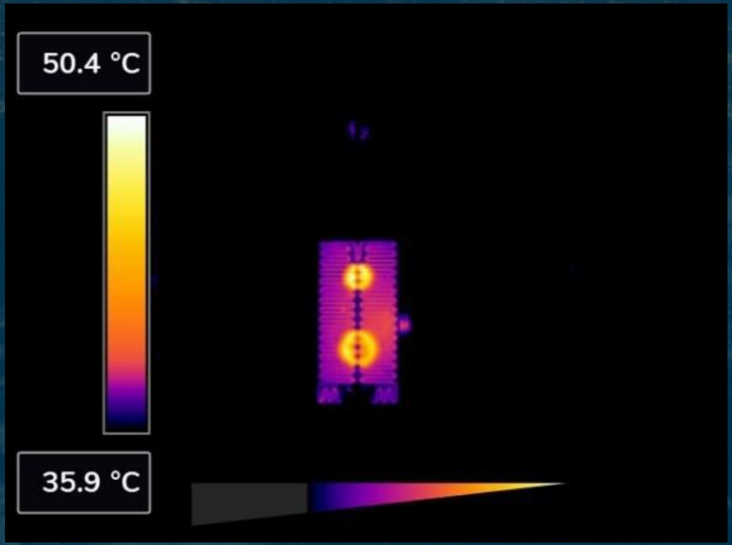


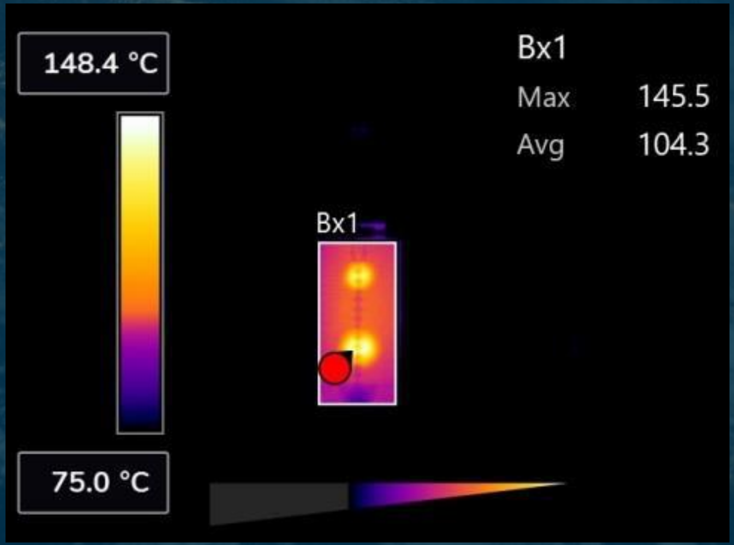


IR thermography

Step Heating







Lessons Learned & Conclusions – Heater Hot Spot Characterisation

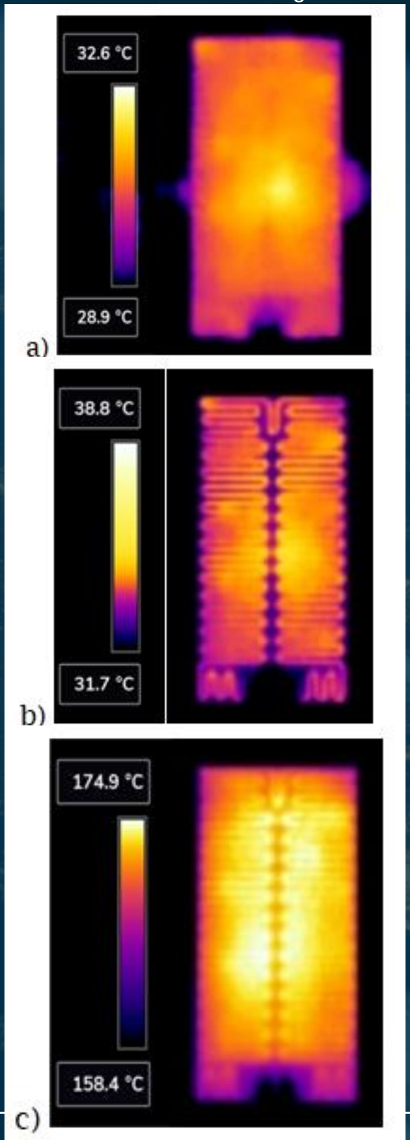
Lessons Learned:

- Heaters with pre-installed PSA had better temperature homogeneity than self installed epoxy.
- No difference for double layer heaters (for the tested versions)
- Heaters with aluminium backing defects are hardly identifiable, hot spot re-distribution capability
- CFRP samples due to their lower thermal conductivity than aluminum, show larger temperature differences between the resistive path and the cold areas

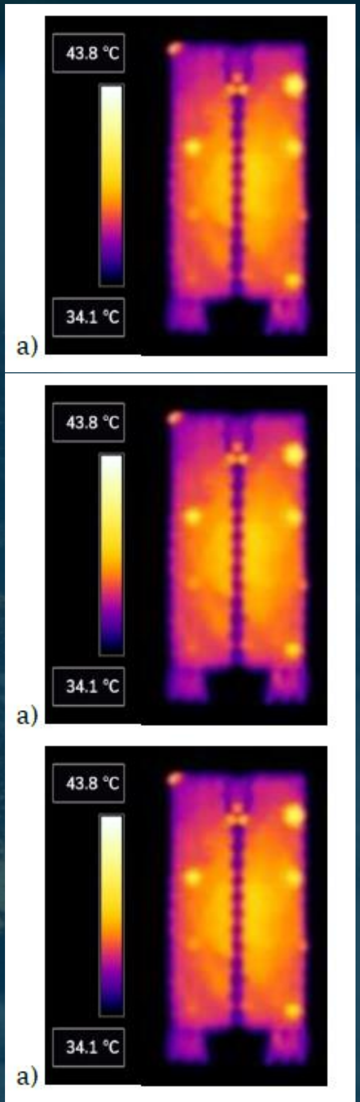
Conclusions:

- Two NDT IR camera based measurement methods successfully tested
- IR Thermography good to identify even small hot spots (4s pulses and 60s pause)
- Not possible to extract a reliable figure of merit from this activity
- Future test campaigns are necessary with
  - Limited number of heaters
  - High number of relevant thermal-vacuum cycles
  - Fixed voltage levels as compared to maximum temperatures

Alu substrate & Aluminium backing



CRFP substrate & No-Aluminium backing



Acknowledgements

Smart Heaters

Team and acknowledgements:

Alter Technologies

- Juan Barbero
- Juan Jose Medina del Barrio
- Ana Morato Cerdan

Universidad Politécnica de Madrid

- Prof. X. Quintana
- Prof. M.A. Geday
- Prof. M. Cano
- J. Pereiro

Heater Hot Spot Characterisation (Foil2Spot)

Team and acknowledgements:

Azimut Technologies

- Luca Celotti
- Morgan Clement