OHB System AG
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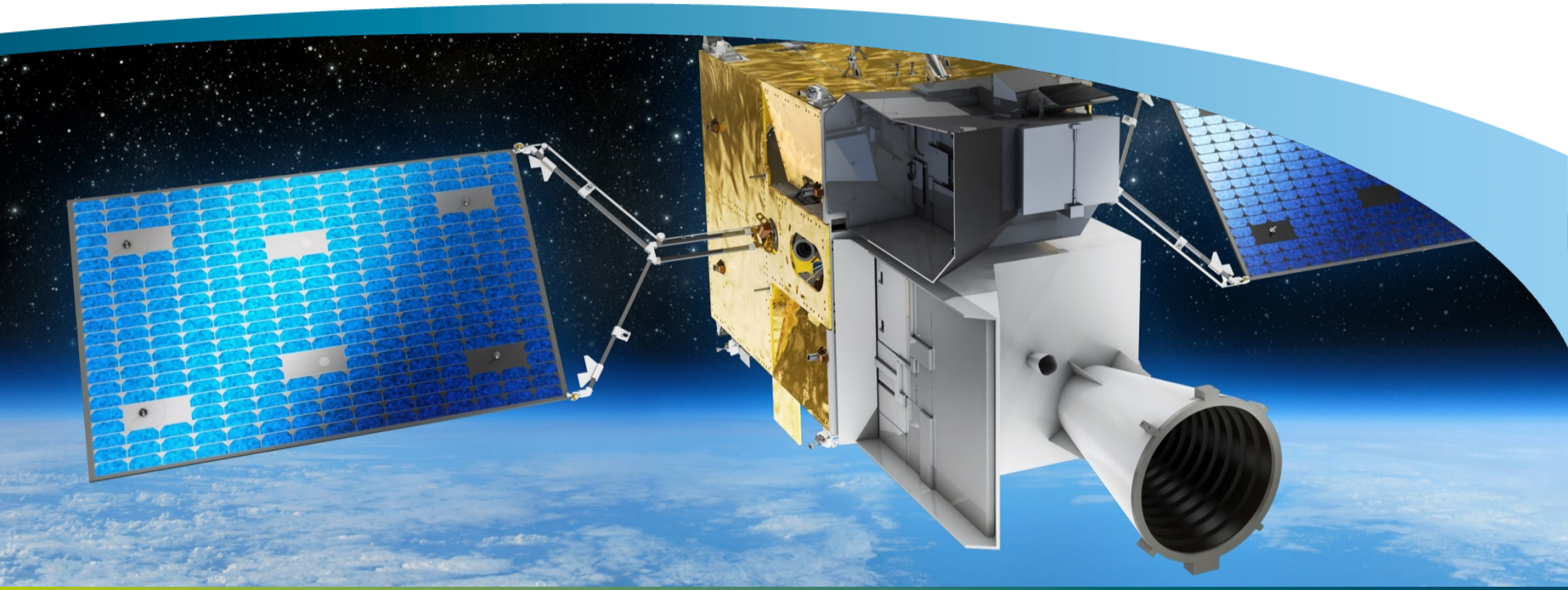
13. 10. 2016, ESTEC Noordwijk



SPACE SYSTEMS

Assessment of the Rules on Heater De-rating

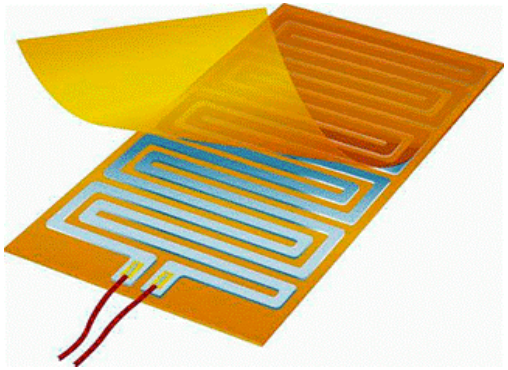
2nd Space Passive Component Days, 12. – 14. 10. 2016

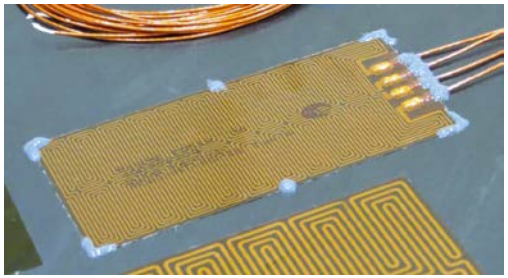
We. Create. Space.

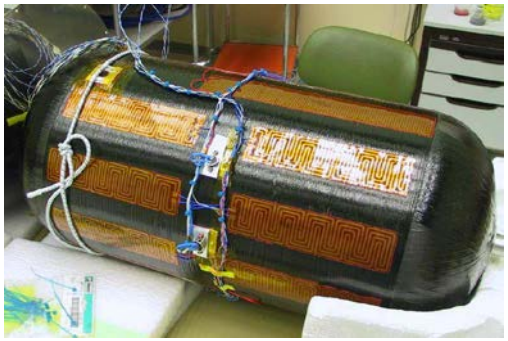
- Introduction
- Background
- De-rating Requirements
- Test Programme (Set-Up and Procedure)
- Test Results and Summary
- Conclusion w.r.t. Rated Power and Derating Requirement

Introduction (Characteristics of foil heater)

- Flexible foil heaters of the type shown here are used in many thermal control tasks
- Build-up: resistance wire networks embedded between two insulation foils (mostly Kapton®) bonded together by an adhesive
- Heater and substrate temperature mostly feedback controlled by sensor or thermostat between -25°C and +10°C
- Heater are generally not used at high substrate temperatures (>50°C)
- Heater are bonded on substrates of different materials, mostly by pressure sensitive adhesive (PSA):
  - Metallic (Al-, Ti-alloys, Invar, stainless steel, ….)
  - Composites (CFRP, polymers, ….)
  - Flat, cylindrical or spherical structures







Background of Study

- Spacecraft designers would like to use heater with high power density in order to reduce heater size (place for heater is limited in particular on radiators).
- De-rating requirement and misunderstanding of specified power density prevent the use of small heater patches.
- De-rating requirement is due to the fact that foil heaters are classified as EEE parts (ECSS-Q-ST-30-11C, 31July 2008, “Derating – EEE components”)
- This classification seems questionable since EEE parts are defined as components located internal to an equipment. ECSS-Q-ST-30-11C states:
  - “Derating is a means of … enhancing the end-of-life performance of equipment” and
  - “The aim is to obtain reliable and high performance equipment without over-sizing of the components”.
- In contrast thermal control heaters are generally located outside of equipment. Critical heaters are configured in addition as internally redundant or are cold redundant.
- These arguments could be used to classify foil heater as a general thermal control hardware item with deletion from the EEE part list

Derating Requirements

- ESCC 4009/002 specifies for foil heater:

  Rated power of 0,54 W/cm^2 at ambient temperature of 25°C and suspended in still air

- This is very often misunderstood as maximum power density for spacecraft application.
- ECSS-Q-ST-30-11C specifies:

  Derating of heater power by 50%

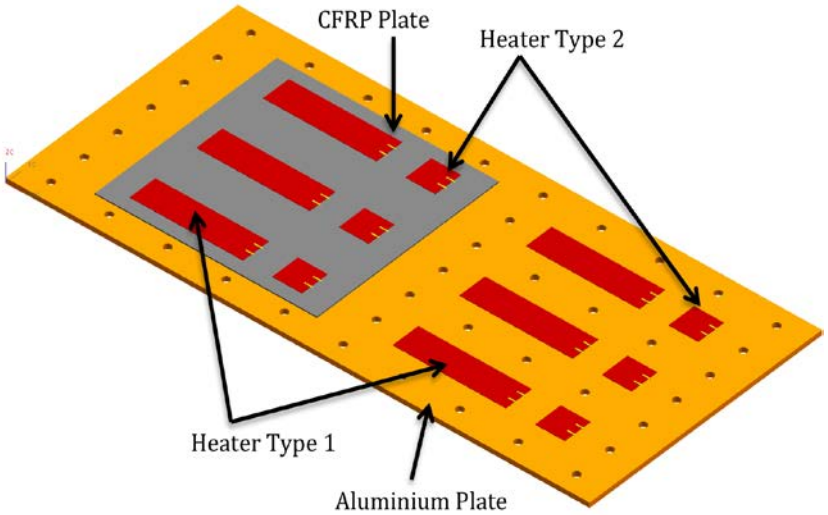
- The interpretation of these requirements are varying for several large S/C projects:
  - SGEO: Max. allowed power density 0,54 W/cm^2, verification of attachment process at 2 x 0,54 = 1,08 W/cm^2 (to meet derating requirement)
  - EXOMARS and MTG: Max. allowed power density 0,27 W/cm^2, verification of attachment process at 2 x 0,27 = 0,54 W/cm^2 (to meet derating requirement)
  - EDRS: Derating requirement has been in some cases waived. Instead heater shall not approach max. qualification temperature of 200°C
- In conclusion:
  - Several projects use 0,54 W/cm^2 as maximum allowed power density or as derated power, although the value is specified for operation suspended in still air.
  - EDRS introduces the maximum operating temperature of heater as a requirement to be met, without any derating requirement.

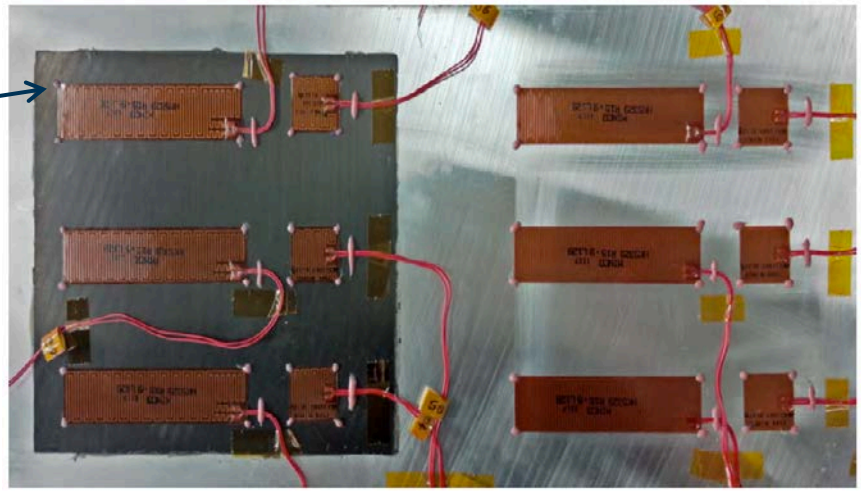
Derating Requirements

- US Standards:
  - EEE-INST-002 “Instructions for EEE Parts Selection, Screening, Qualification and Derating” does not require heater power derating, but specifies to use the heater within the manufacturer’s recommended current, voltage and temperature range.
  - S-311-P-079 contains detailed requirements for heater qualification. For Kapton foil heater with pressure sensitive tape a maximum heat density of 3 Watt/cm^2 is specified for the most useful temperature range up to 50°C. The value decreases linearly to 0 Watt/cm^2 at 100°C.
- In conclusion:
  - US Standards are much more user friendly. They do
    - not require derating for foil heater and
    - specify maximum power density of 3 Watt/cm^2 in the attached state for the most useful temperatures range up to 50°C.

Test Programme

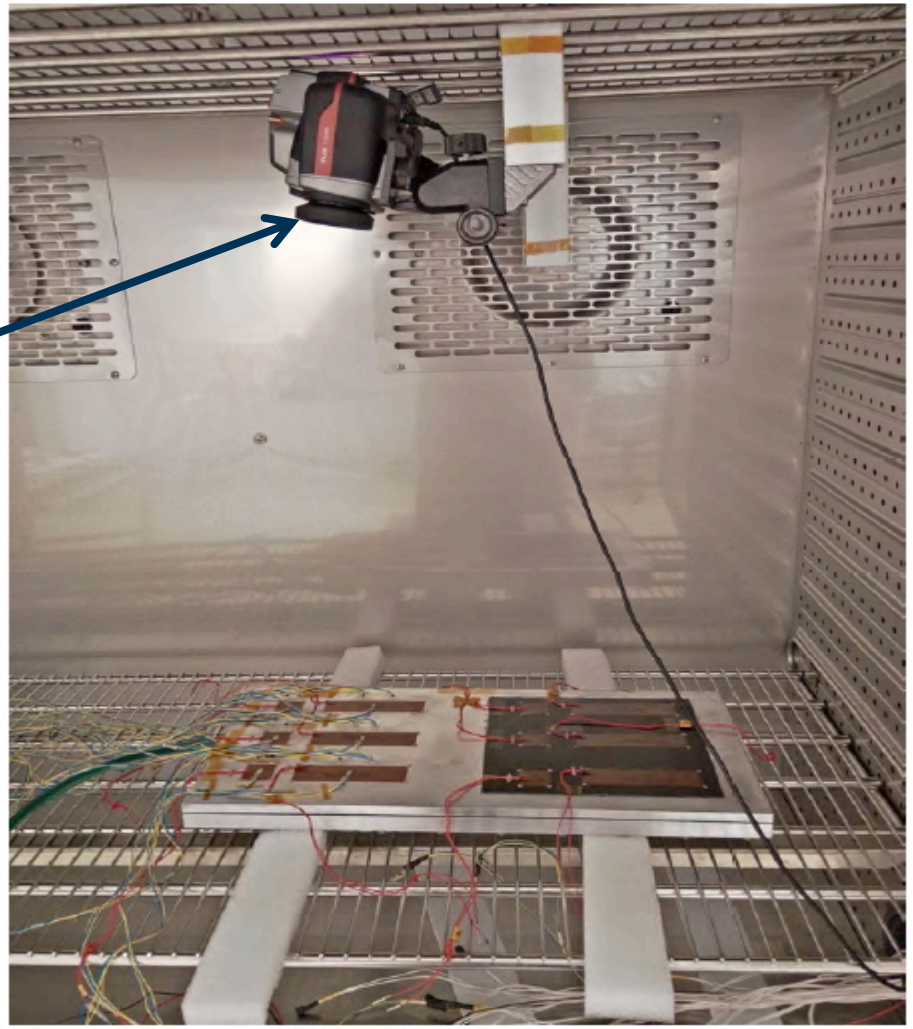
- A test programme was conducted to investigate and understand possible failure mechanisms of this heater type.
- Purpose is to evaluate heater operation limits in order to allow higher power densities without derating.
- Test programme with Kapton® Foil heaters
  - 3M 966 PSA backing
  - Two dimensions: 97 x 25,4 mm (15,9 ∧) and 25,4 x 25,4 mm (7,6 ∧)
- Attached to flat aluminium alloy and flat CFRP surface (including anti-peel adhesive dots)
- Substrates attached to a temperature controlled cold plate
- 2 temperature sensors on substrate close to each heater; 1 sensor on top of each heater





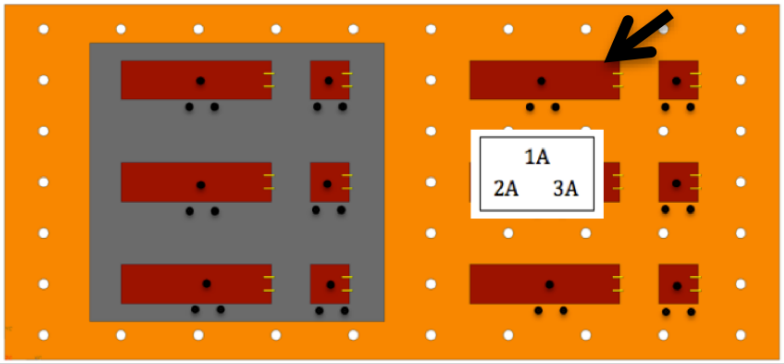
Test Set-Up and Procedure

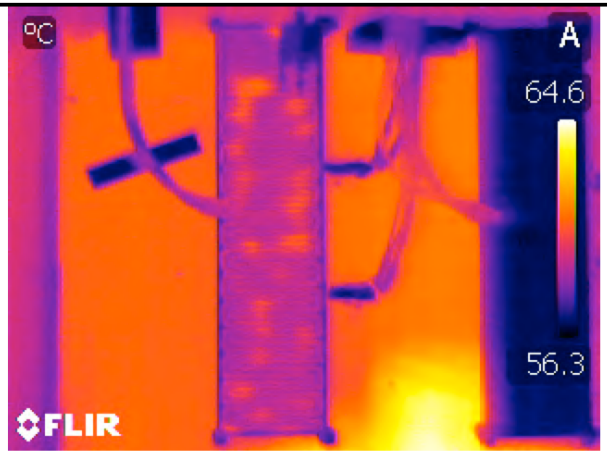
- Testing performed in a climatic chamber under atmospheric pressure
- In addition to temperature measurement by sensors, heater are observed with IR camera
- Heater are operated one after the other by increasing the power stepwise until power supply limit or heater destruction
- Substrates are cooled to obtain as far as possible heater temperatures of 50°C during testing
- >50°C are allowed, when heater are powered up to destruction

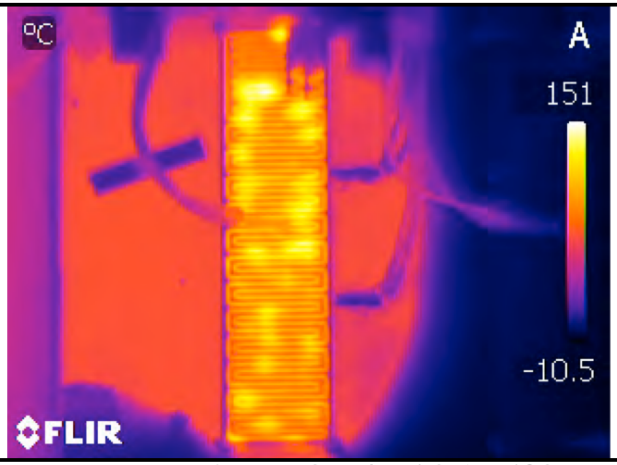


Large heater on aluminium substrate:

Imperfect bonding seen at low heater power, which develop to hot spots at high power. Hot spot temperature 50°C higher than remaining heater foil. Test terminated at 190 Watt due to power supply limitation.



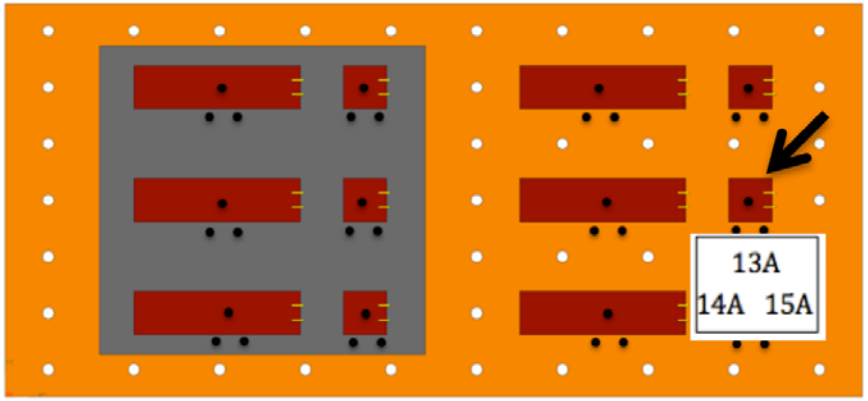


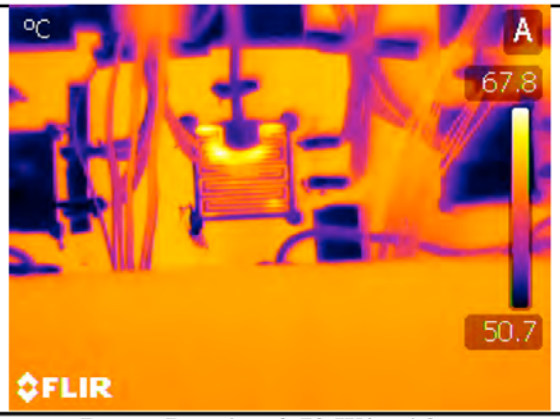


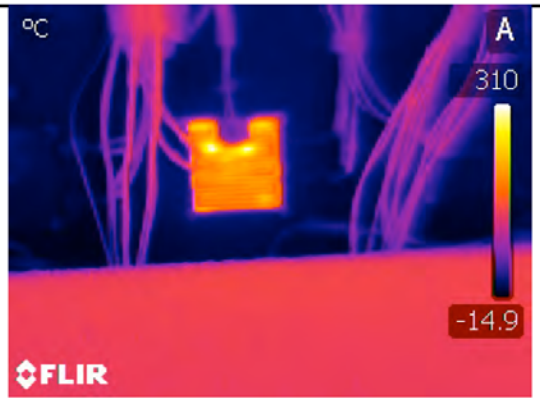
Power Density: 0,26 W/cm^2 *Heater Temperature (1A): 50°C* *Substrate Temperature (2A, 3A): 48°C*	*Power Density: 7,73 W/cm^2 (or 190 Watt)* *Heater Temperature (1A): 68°C* *Substrate Temperature (2A, 3A): -4,0°C*
Temperature Difference Heater – Substrate: 2°C	*Temperature Difference Heater – Substrate: 72°C*

Small heater on aluminium substrate:

Imperfect bonding seen at low heater power, which develop to hot spots at high power. Hot spot temperature 50°C higher than remaining heater foil. Test terminated due to heater destruction at 16,57 W/cm^2.



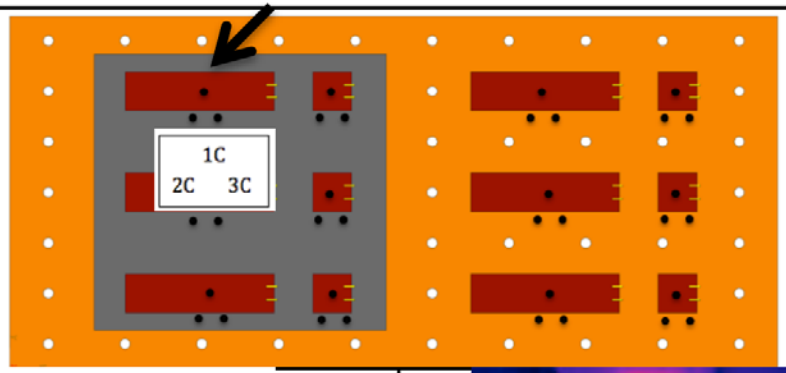


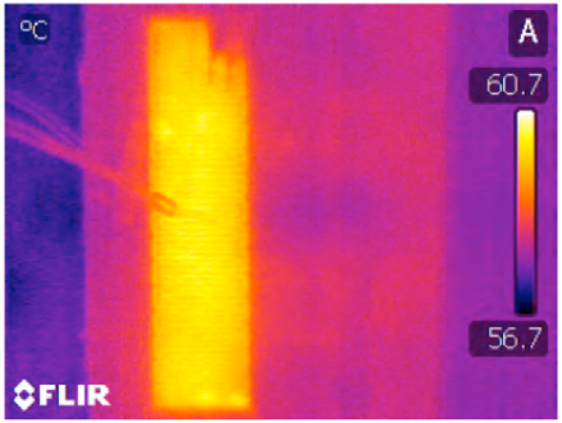


Power Density: 0,73 W/cm^2 *Heater Temperature (13A): 50,4°C* *Substrate Temperature (14A, 15A): 42°C*	*Power Density: 11,75 W/cm^2* *Heater Temperature (13A): 121,5°C* *Substrate Temperature (14A, 15A): -12,5°C*
Temperature Difference Heater – Substrate: 8,5°C	*Temperature Difference Heater – Substrate: 134,0°C*

Large heater on CFRP substrate:

Imperfect bonding at low heater power almost not visible, which develop to marginal hot spots at high power. Test terminated due to heater destruction at 15,18 W/cm^2.

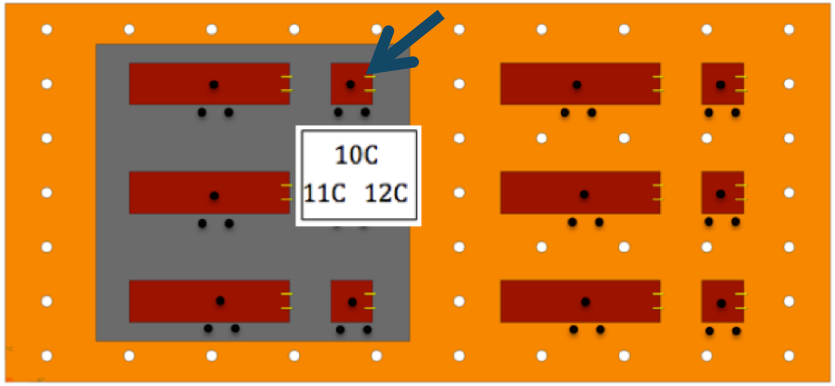


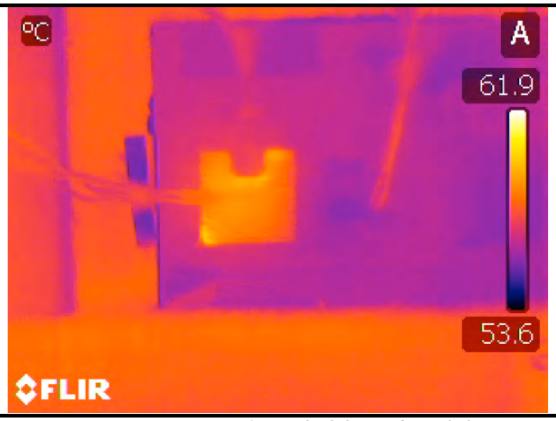


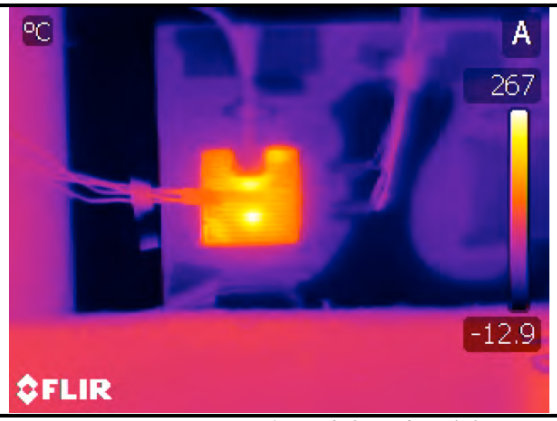
Power Density: 0,06 W/cm^2 *Heater Temperature (1C): 50°C* *Substrate Temperature (2C, 3C): 44,5°C*	*Power Density: 4 W/cm^2* *Heater Temperature (1C): 123°C* *Substrate Temperature (2C, 3C): -11,0°C*
Temperature Difference Heater – Substrate: 5,5°C	*Temperature Difference Heater – Substrate: 134°C*

Small heater on CFRP substrate:

Bonding with good quality except light imperfect spots at lower left and at cable terminations. Hot spots develop there and elsewhere at high power. Test terminated due to heater destruction at 5,22 W/cm^2.







Power Density: 0,08 W/cm^2 *Heater Temperature (10C): 50,1°C* *Substrate Temperature (11C, 12C): 47,7°C*	*Power Density: 4,0 W/cm^2* *Heater Temperature (10C): 105,1°C* *Substrate Temperature (11C, 12C): -10,5°C*
Temperature Difference Heater – Substrate: 2,4°C	*Temperature Difference Heater – Substrate: 115,6°C*

Test Summary

- Heaters are able to operate flawlessly at high power and temperatures. Temperature differences between heater and substrate can reach easily >100°C.
- The quality of heater bonding to the substrate is decisive for maximum allowable heater power density. All heaters, which were operated until destruction, showed an imperfect bonding, but the average heater temperature was well below the specified maximum of 200°C.
- Under vacuum conditions (space environment) small air entrapment could lead to earlier hot spots.
- Not perfect bonding, which may lead to hot spots at higher power, can be detected with an IR camera at already very low power densities. IR-camera monitoring should therefore be introduced for flight heater hardware.

Conclusion w.r.t. Rated Power and Derating Requirement

- Heater failure mechanism is due to a limiting heater temperature and not due to limiting heater power density. Due to the high thermal resistance of the Kapton® and adhesive layers, foil heaters experience high temperature differences to the substrates. Heater temperatures of up to 130°C higher than the substrate temperature have been measured.
- However, only the maximum heater temperature is decisive for safe operation, which depends on the combination of heater size, properties of the substrate and applied power density.

Solution:

- Classification of foil heater as thermal control item (and not as EEE part)
- Careful validation of a reproducible bonding process
- Qualification of the different foil heater types in the attached state under required operating conditions
- Introduction of heater foil in overall mathematical model to predict heater temperature based on tested conductance value to substrate
- De-rating requirement not necessary, if qualification according to ECSS-E-ST-10-03C ”Testing”