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Assuring Measurement Traceability to ATE Systems: One-touch calibration of MEMS temperature sensors

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IPQ

SPEA

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Digital Calibration Confidence Data quality metrology for the factory of the future

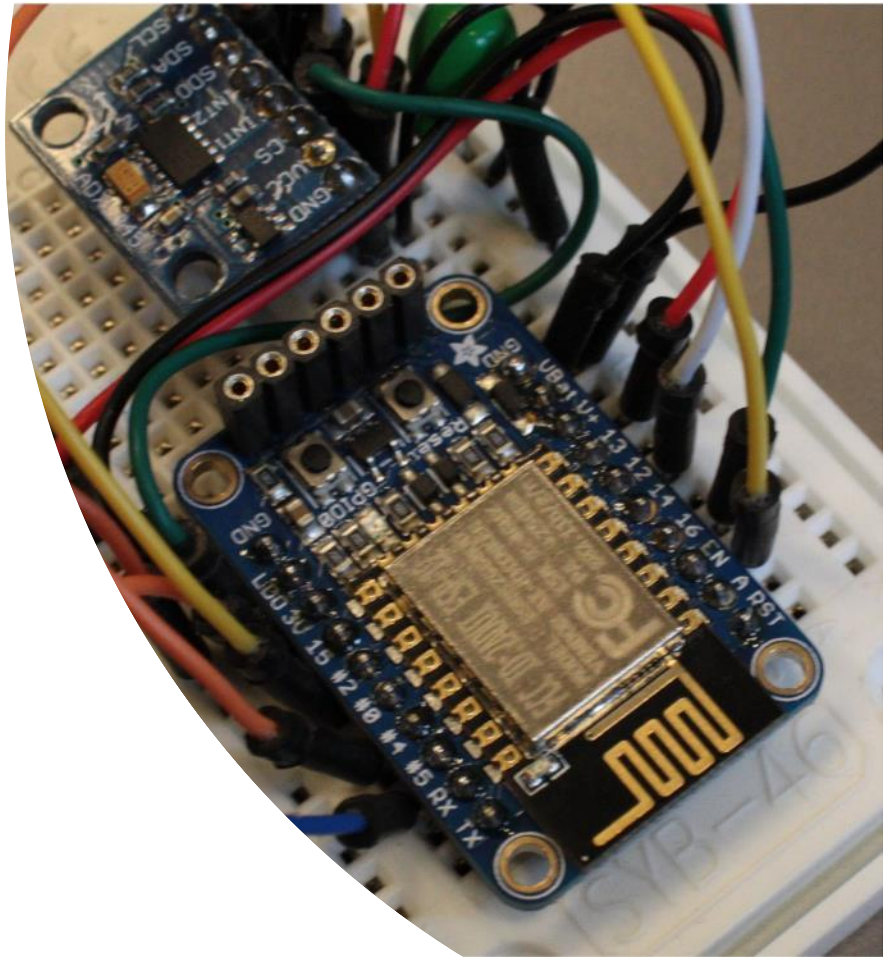
Synopsis

Assuring Measurement Traceability to ATE Systems: One-touch calibration of MEMS temperature sensors

- Metrology for the Factory of the Future – Met4FoF
- Background to Automatic Test Equipment (ATE)
- Testbed for MEMS testing and calibration
- Design of a temperature reference fixture
- *In situ* calibration/validation of ATE/MEMS
- Improved design of reference fixture
- Validation of the improved design
- One touch Calibration

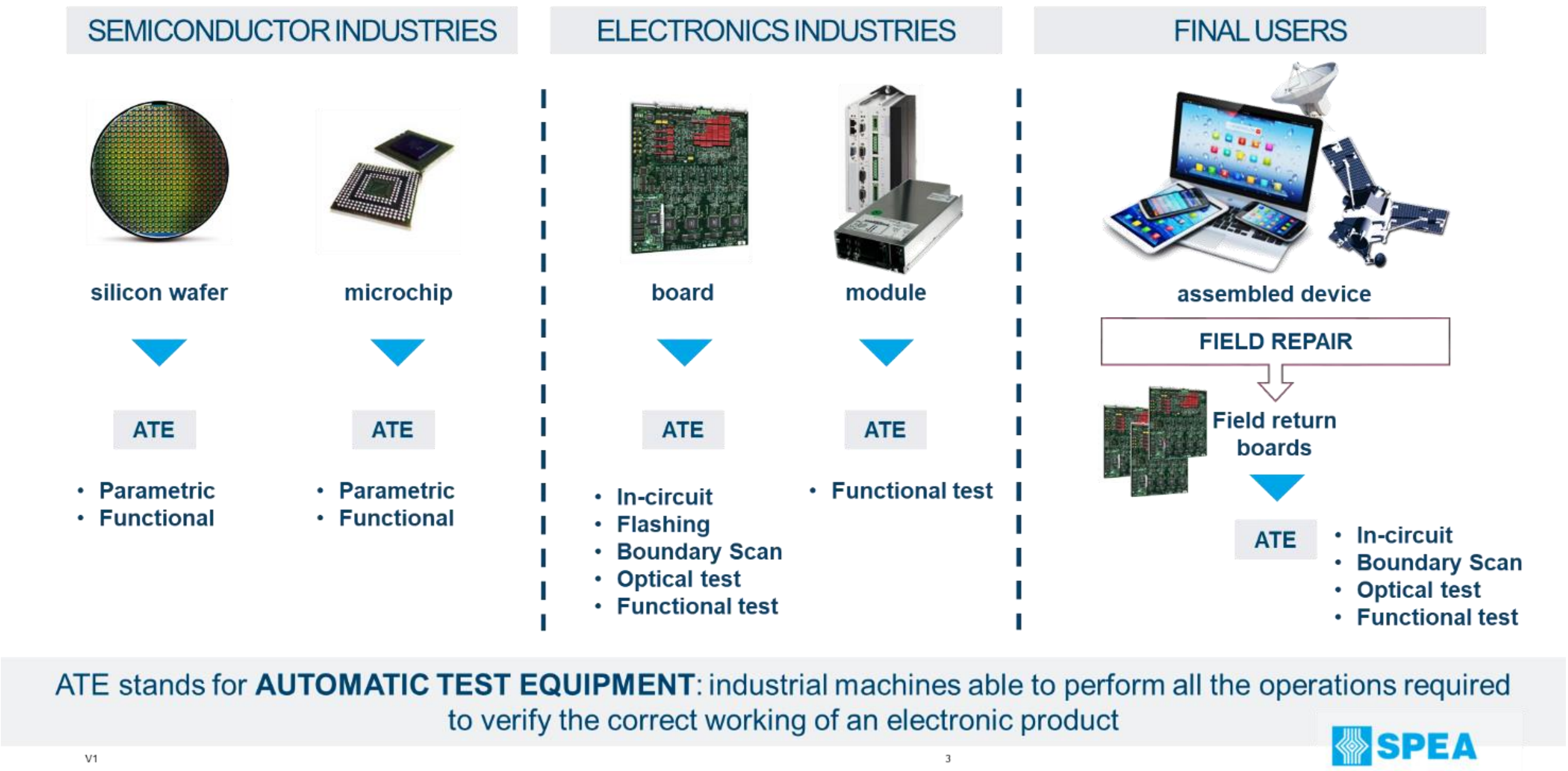
Project objectives

- Develop calibration framework for sensors with digital pre-processed output and internal signal processing.
- Develop a reference system for in-situ calibration of MEMS measuring ambient conditions.
- Develop metrological infrastructure for real-time data aggregation and machine learning in industrial sensor networks.
- Implement the methods and frameworks developed in industry-like test environments.

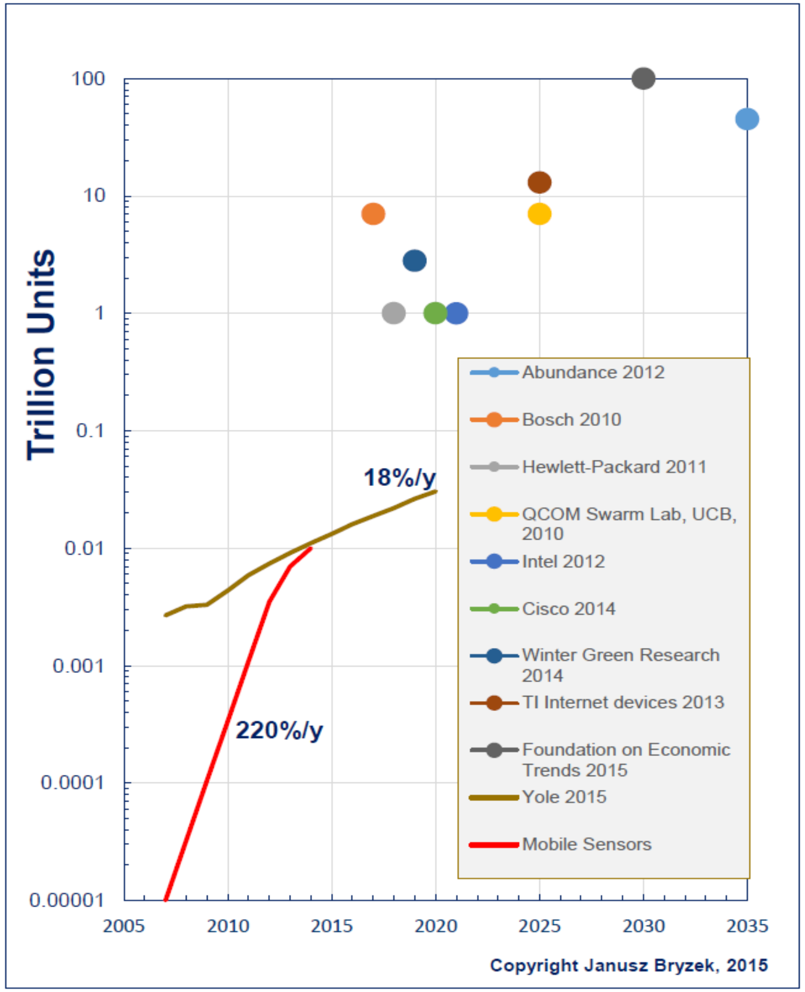


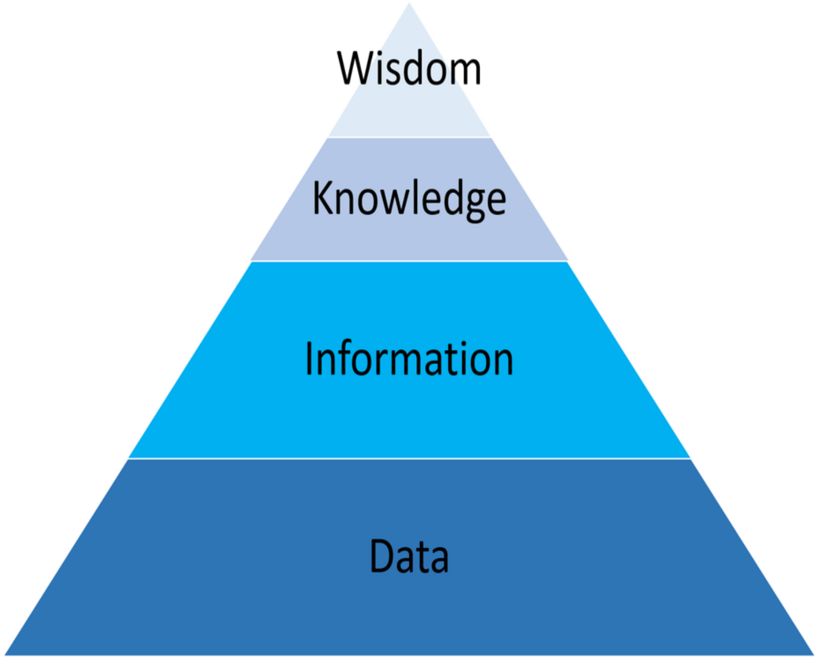
Picture taken by PTB

Electronic testing world



Trillion sensors scenario

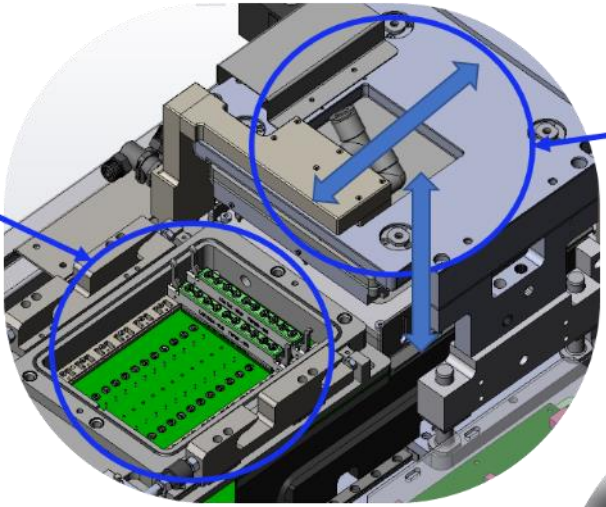




- Exponentially growth of measurement data.
- Unique opportunity to provide metrological traceability.

ATE for MEMS temperature testing

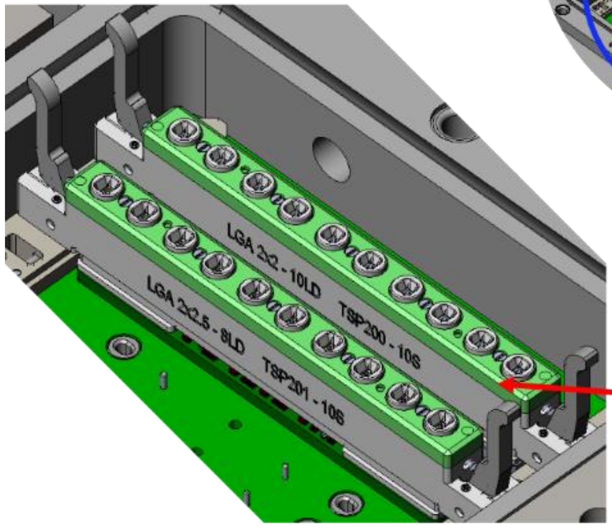
ATE machine



Socket Area

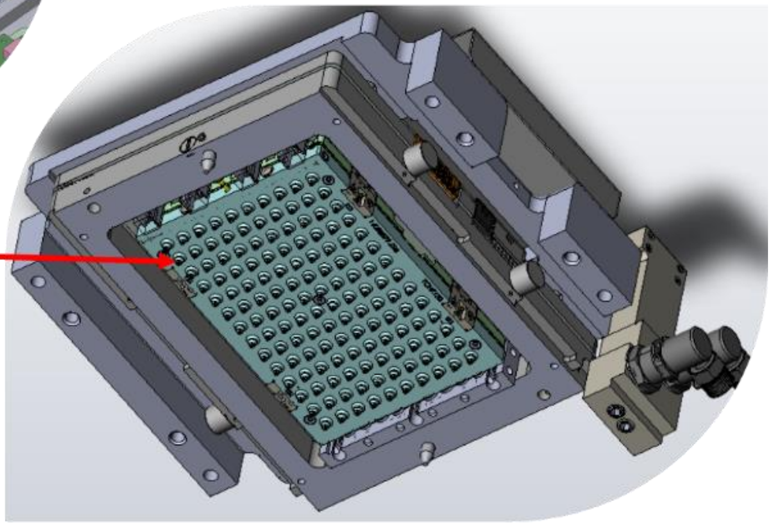
Chuck motion axis

Socket



Modular strip design

Thermal Chuck [Bottom View]

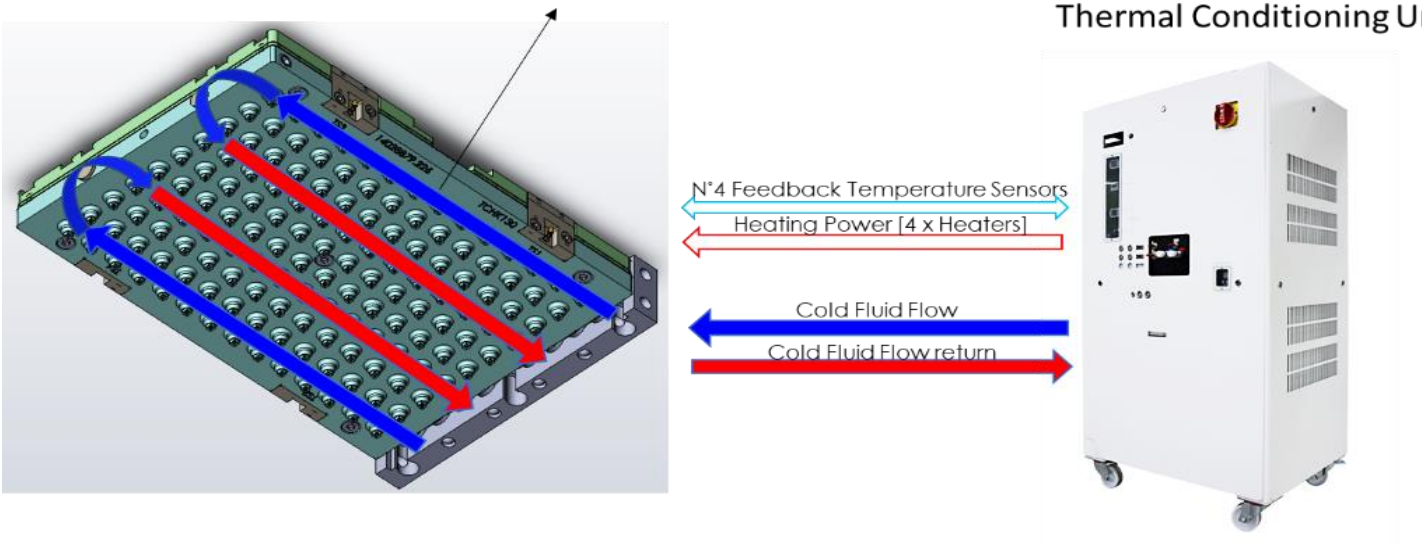


Temperature controlled medium

Thermal conditioning system

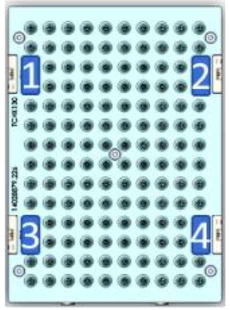
Thermal chuck Cooling channels

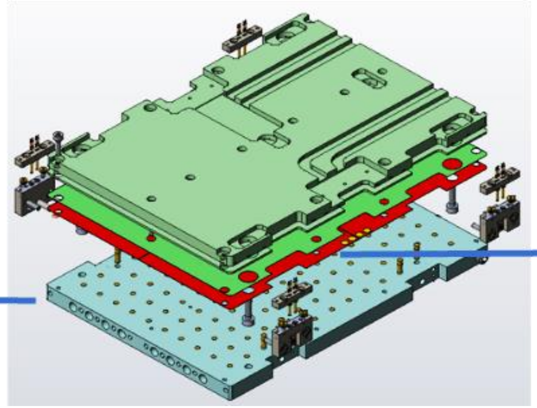
Thermal Conditioning Unit



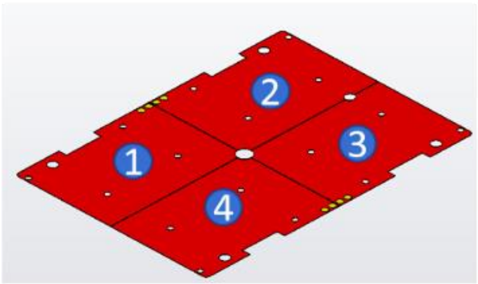
Thermal Chuck [Exploded view]

Feedback Temperature sensors
[N°4 Pt100-Class A]

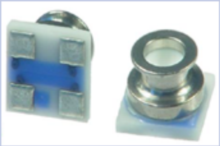




Heaters
[N°1 heating foil with n°4 heating sections]



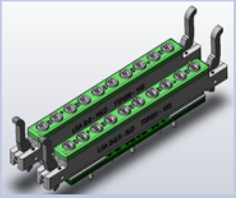
Objectives of the SPEA testbed



Unit under test (UUT = MEMS)

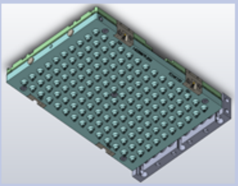
- MEMS sensor to be tested in-situ under proven and traceable temperature conditions.

→ **GOAL**



Sensors socket

- Part used to keep in place the UTTs during the test and provide power and data connection.

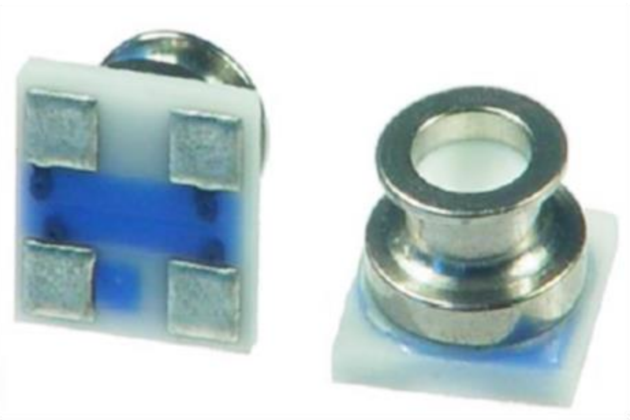


Thermal chuck

- High thermal conductivity and diffusivity medium to provide homogeneous temperature to UUTs under transient conditions.
- Each UUT has a custom-designed thermal chuck.

Layers to be investigated to reach the goal.

Selected MEMS for demonstration

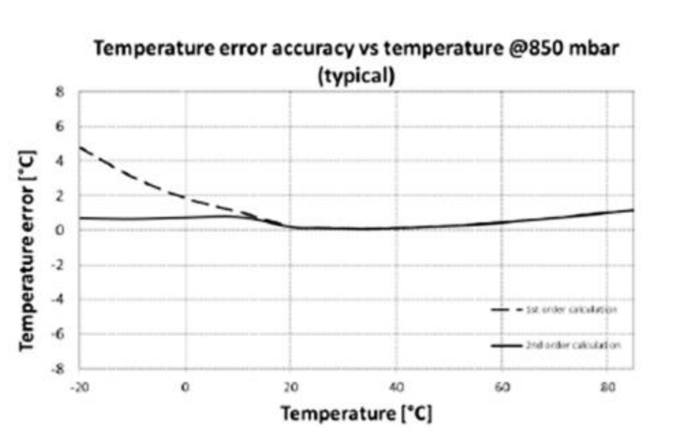


Features:

- Type: Pressure and Temperature sensor;
- Operating range: 300 to 1200 mbar, -20 to +85 °C
- Interface: I2C
- Temperature accuracy: ±2°C (**Factory calibration**)
- Dimensions: 3.3 x 3.3 x 2.75mm
- Integrated 24 bit ΔΣ ADC

TEMPERATURE OUTPUT CHARACTERISTICS (V_{DD} = 3 V, T = 25°C UNLESS OTHERWISE NOTED)

Parameter	Conditions		Min.	Typ.	Max	Unit
Relative Accuracy	-20…85°C, 300…1100 mbar		-2		+2	°C
Maximum error with supply voltage	V_{DD} = 1.5 V…3.6 V			±0.3		°C
Resolution RMS	OSR	8192		0.002		°C
		4096		0.003		
		2048		0.004		
		1024		0.006		
		512		0.009		
		256		0.012		



Traceable calibration framework and timeline

Developing a **reference fixture** to provide traceable temperature and electrical measurements to ATE machines.

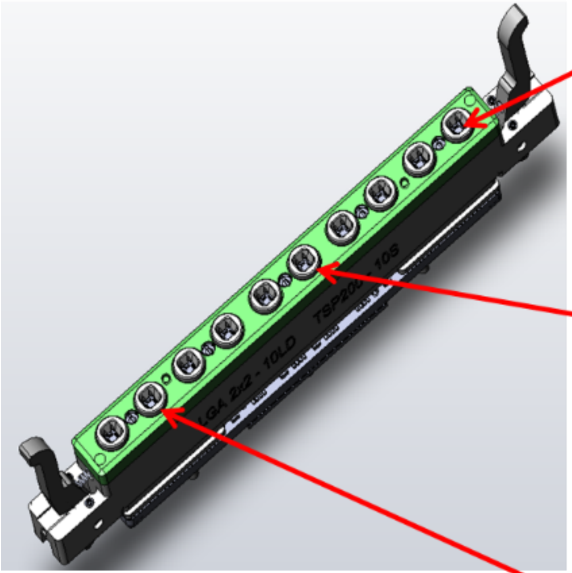
Implementing **good metrology practice** in a novel ATE machine able to calibrate *in situ* electronic circuitry and reference temperature sensors.

- Optimizing the temperature control system.
- Validation of the generated thermal conditions to estimate **MEMS calibration uncertainty.**

In situ MEMS testing/calibration under traceable temperature conditions.

ATE *in situ* calibration/validation

<u>Reference fixture:</u> Instrumented sensor socket equipped with a network of **calibrated reference sensors.**



Reference PT100 Class A (thin film or SMD)

- Temperature range: -50°C ÷ +250°C
- Accuracy: better than 0.1°C after calibration
- Nominal resistance: 100 Ω at 0 °C
- Long term stability: < 0.04 % at 1000 h at 130 °C

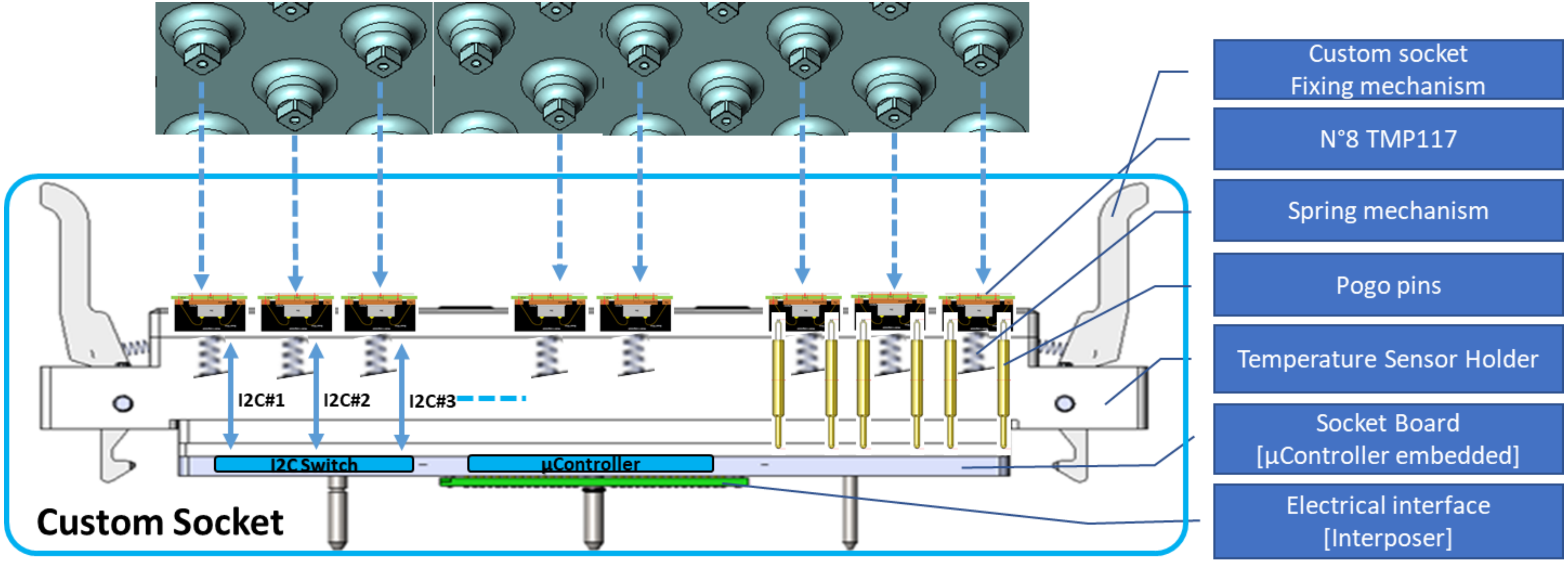
Reference digital temperature sensors: Texas Instrument TMP117

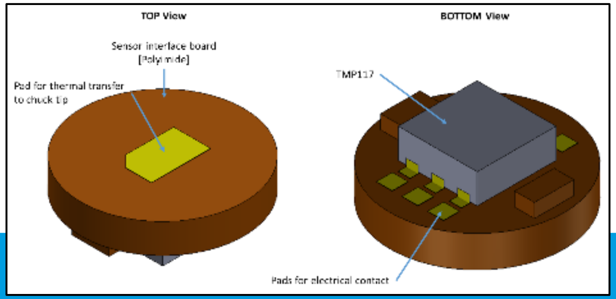
- Temperature range: -55°C ÷ +150°C
- Accuracy: < 0.1°C after calibration
- Resolution: 0.01°C
- Digital I2C bus

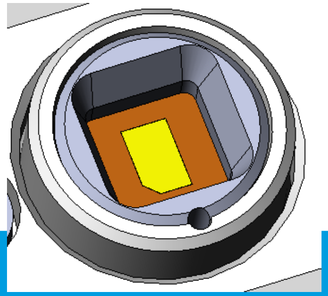
Golden device

- Laboratory calibrated MEMS of the same kind of those under tests

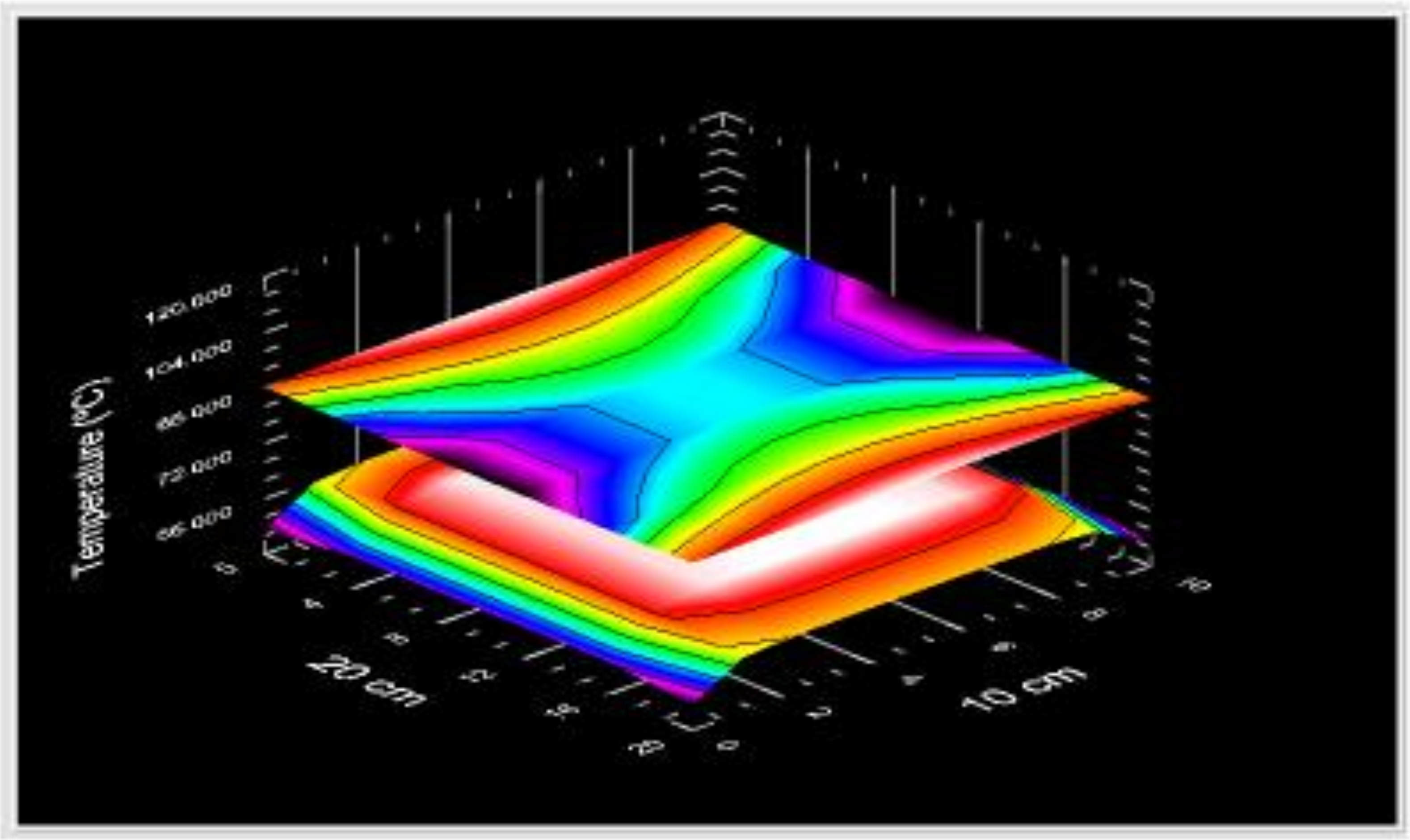
Reference fixture with digital temperature sensors





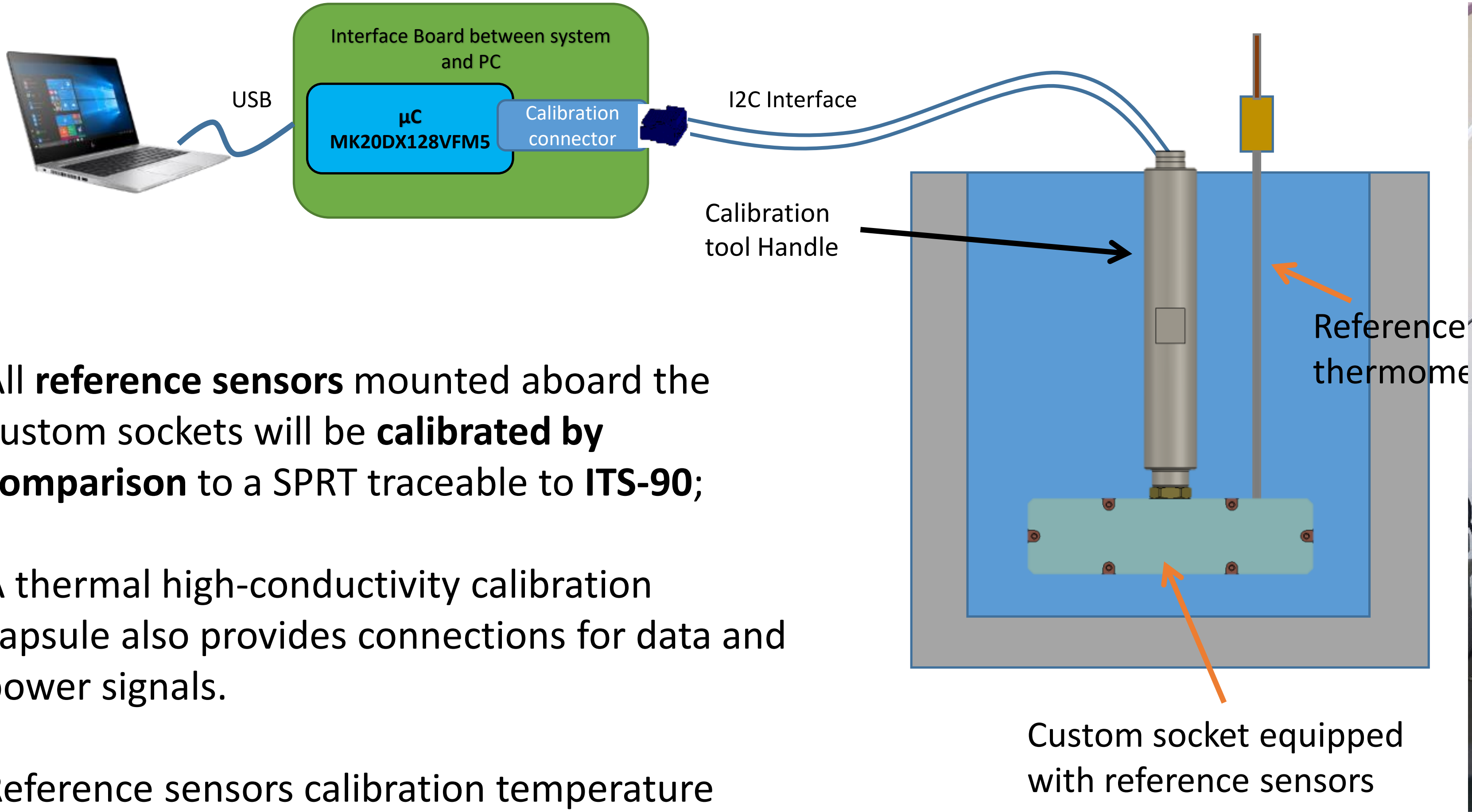


Numerical simulation of heat transfer processes



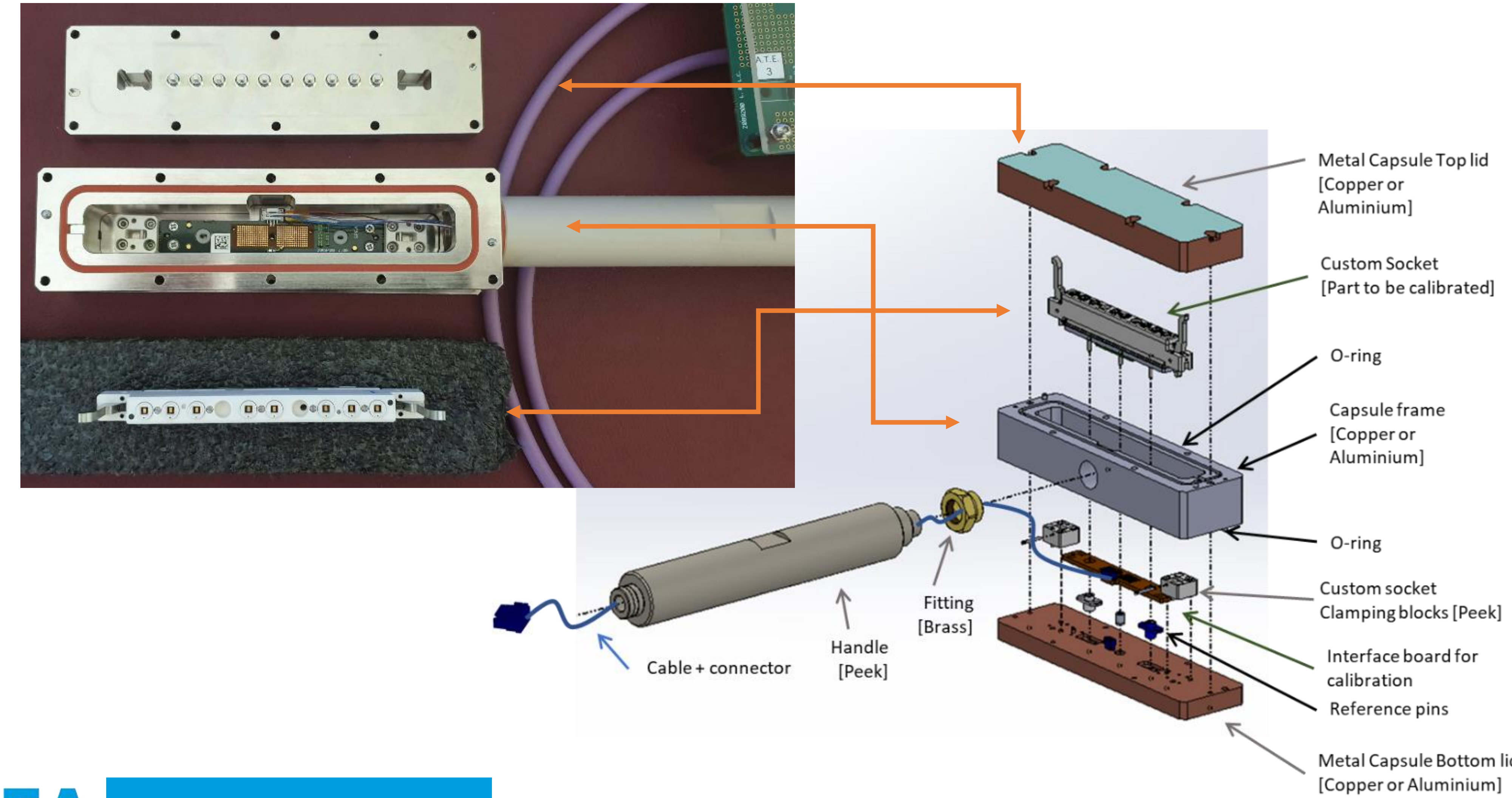
- Heat transfer simulation
- Optimum number of sensors
- Preliminary results at 85 °C
- No cooling fluid
- 4-zone heater

Laboratory calibration of the reference sensors



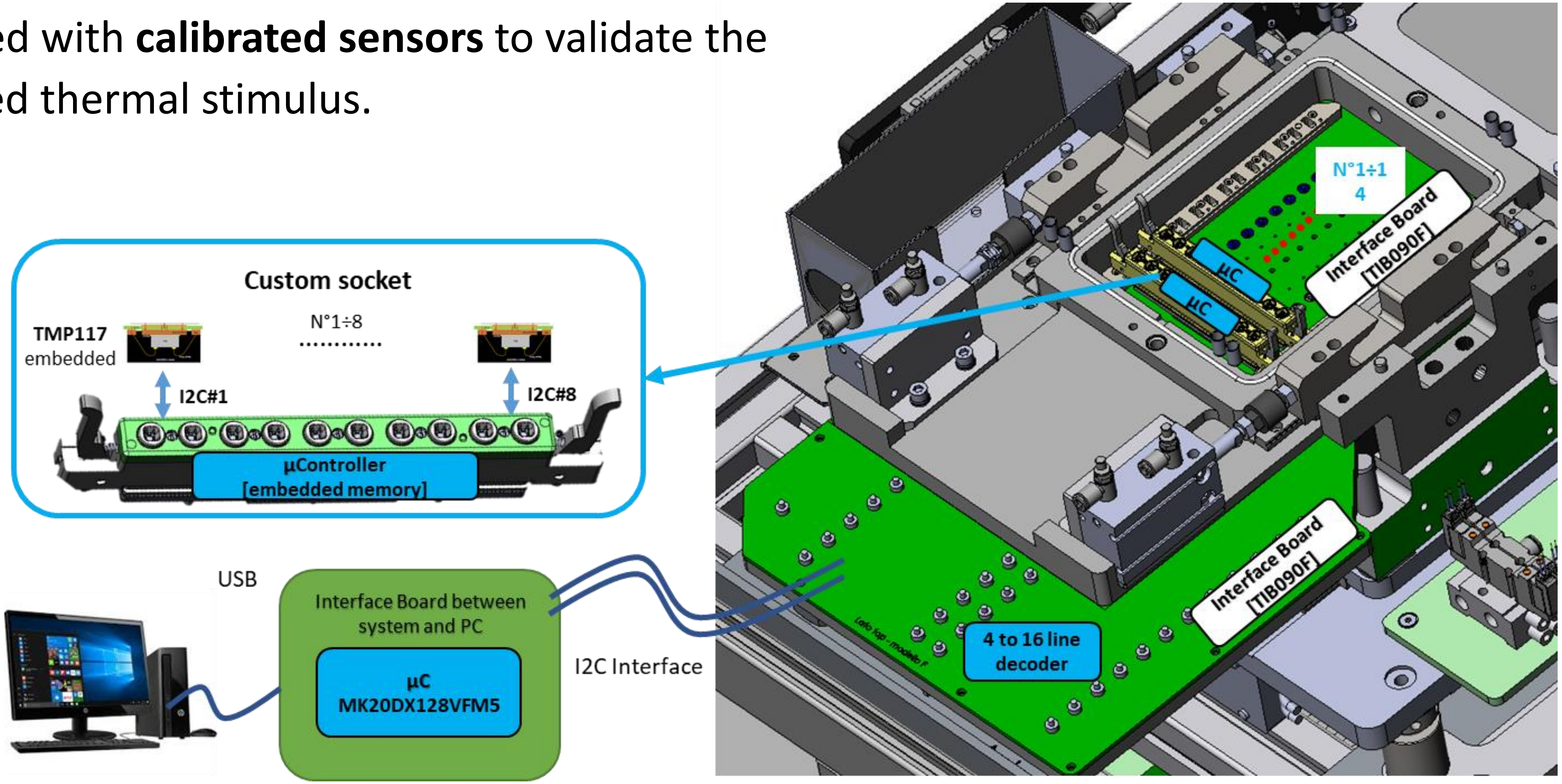
- All **reference sensors** mounted aboard the custom sockets will be **calibrated by comparison** to a SPRT traceable to **ITS-90**;
- A thermal high-conductivity calibration capsule also provides connections for data and power signals.
- Reference sensors calibration temperature between -60 °C and +200 °C.

Layout of the calibration capsule



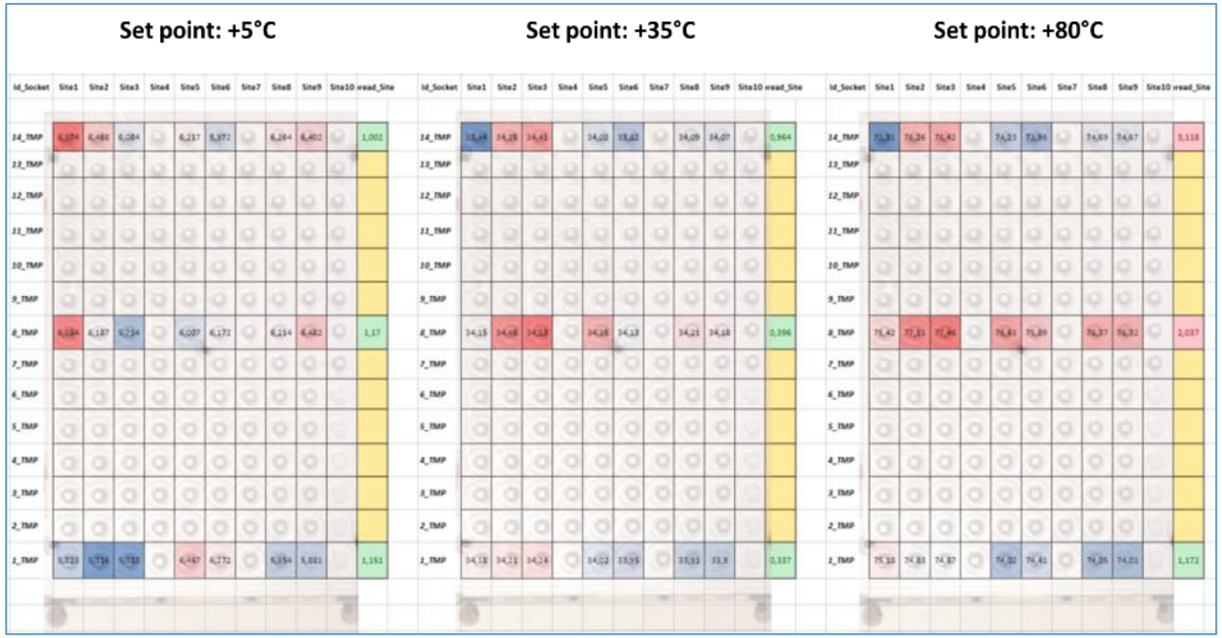
Reference fixture for *in situ* ATE calibration

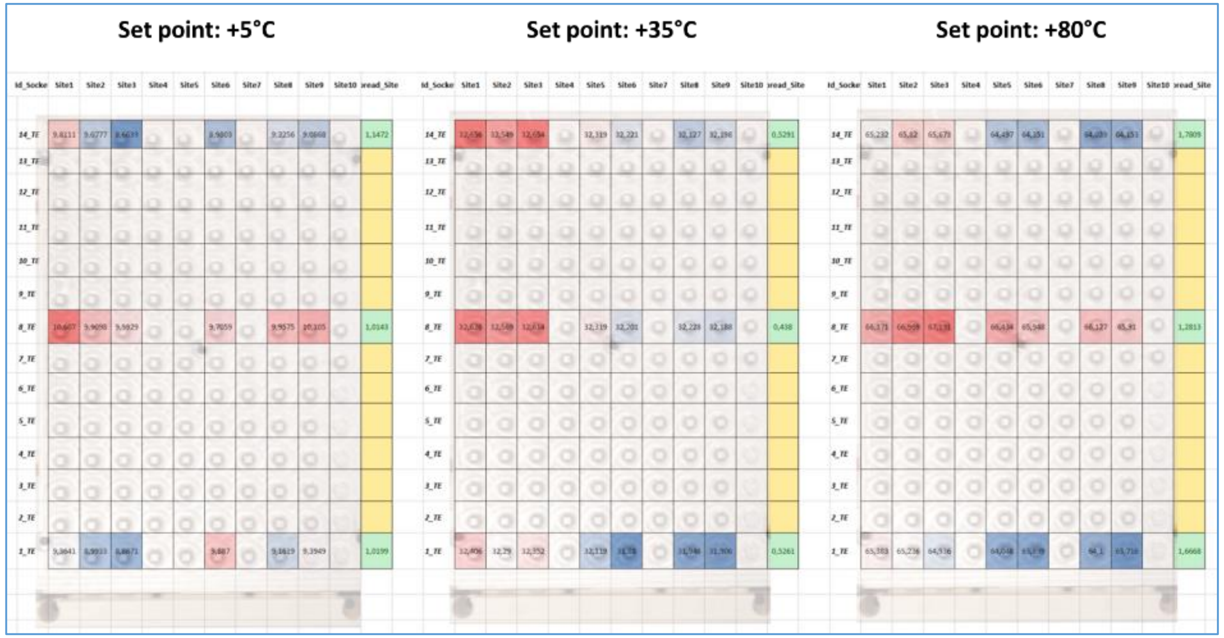
The **reference fixture** consists of an array of sensor sockets populated with **calibrated sensors** to validate the generated thermal stimulus.



SPEA ATE set-up experimental investigation

- The thermal chuck assembled with 3.8-N springs is investigated at 5 °C, 35 °C and 80 °C - reference fixture
- 3 calibrated strips equipped with both TMP117 digital and TE MS5837 MEMS sensors





SPEA ATE set-up experimental investigation

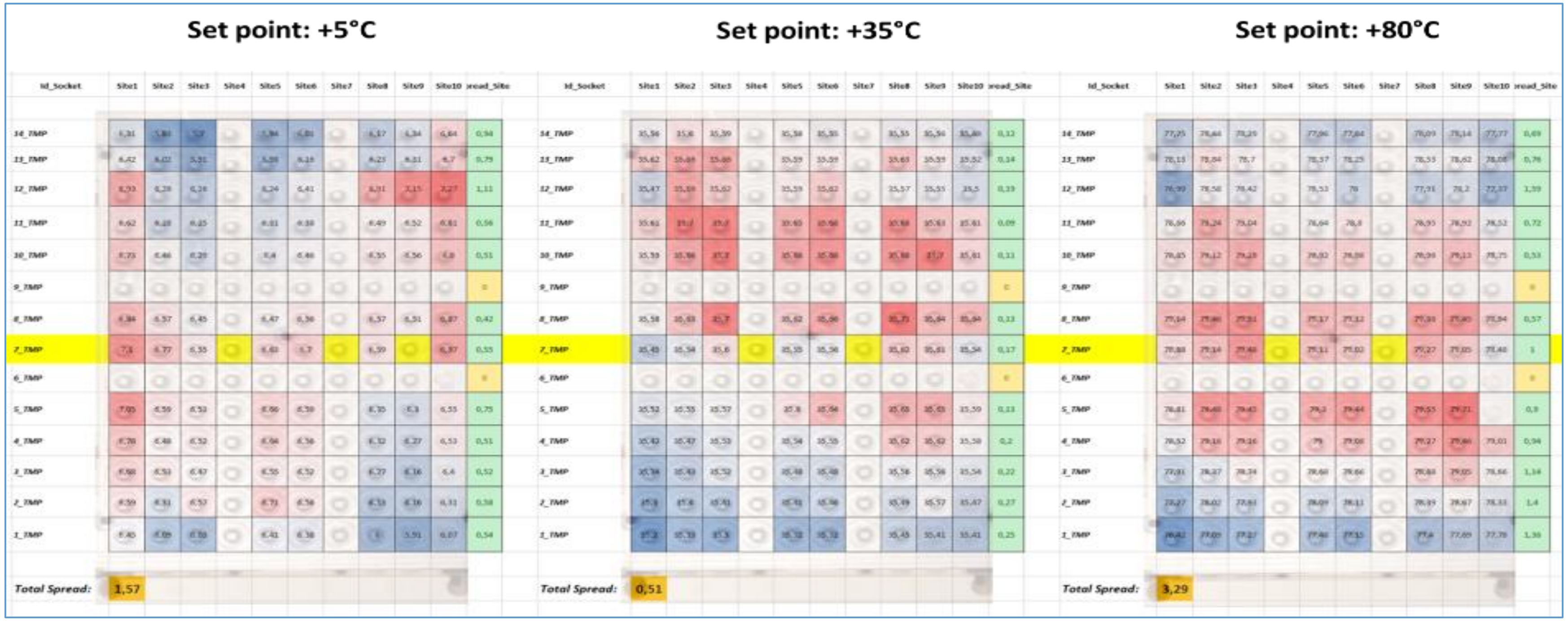
- The thermal chuck assembled with 3.8-N springs is investigated at 5 °C, 35 °C and 80 °C - reference fixture
- 3 calibrated strips equipped with both TMP117 digital and TE MS5837 MEMS sensors

Sensor	TMP117 (Calibrated)			MEMS (Calibrated)		
	°C	°C	°C	°C	°C	°C
Set point temperature	5	35	80	5	35	80
Max temperature	6.97	34.53	77.46	10.61	32.66	67.19
Min temperature	5.32	33.44	73.31	8.66	31.88	63.72
Temperature homogeneity (max-min)	1.66	1.08	4.15	1.94	0.78	3.47
Mean temperature	6.14	34.12	75.24	9.47	32.30	65.24
Temperature stability	0.02	0.02	0.02	0.02	0.02	0.02
Set-point deviation (mean-set point)	1.14	-0.88	-4.76	4.47	-2.70	-14.76

- Not acceptable. This is due to the ineffective mechanical coupling between the specific sensor and the thermal chuck, which resulted in a too high thermal resistance

SPEA ATE set-up experimental investigation

- Optimized testing configuration: 13 not-calibrated and 1 calibrated sensor sockets equipped with TMP117 digital sensors to ensure
  - uniform mechanical and thermal load
  - uniform heat dissipation over the thermal chuck



SPEA ATE set-up experimental investigation

- Optimized testing configuration: 13 not-calibrated and 1 calibrated sensor sockets equipped with TMP117 digital sensors to ensure
  - uniform mechanical and thermal load
  - uniform heat dissipation over the thermal chuck

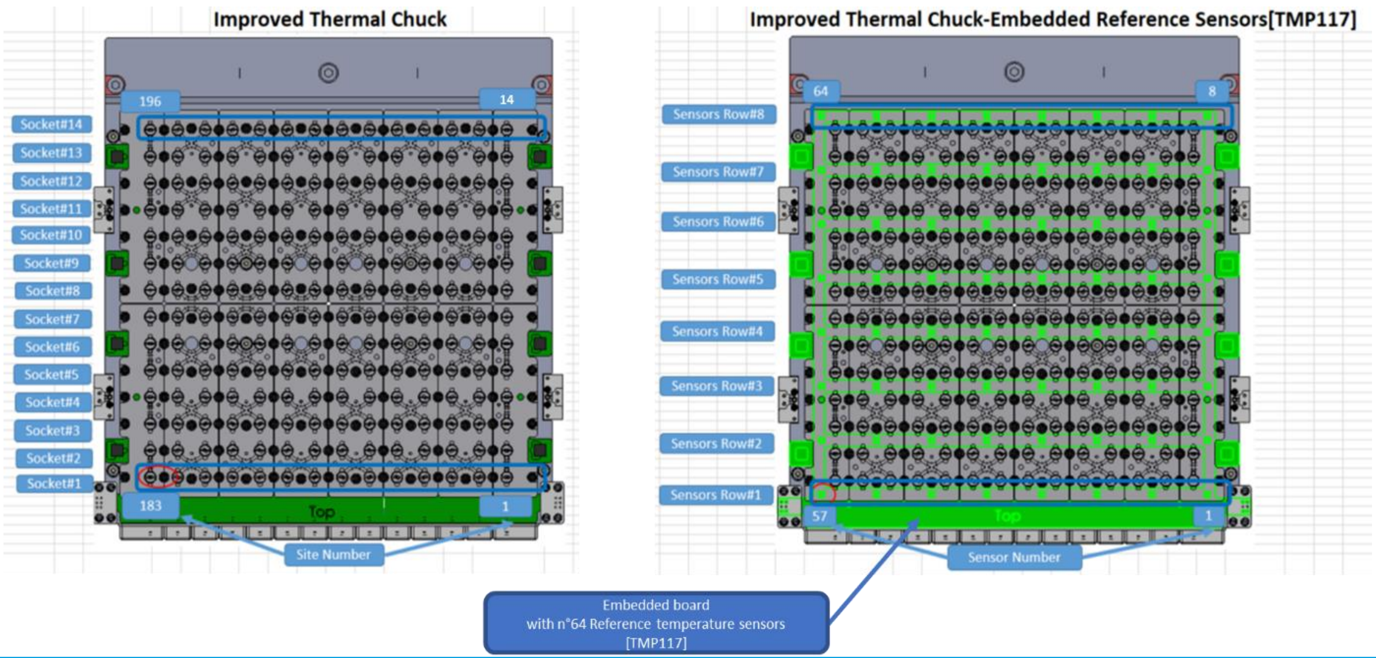
Sensor	TMP117 (Not Calibrated)		
	°C	°C	°C
Set point temperature	5	35	80
Max temperature	7.27	35.71	79.71
Min temperature	5.70	35.20	76.42
Temperature homogeneity (max-min)	1.57	0.51	3.29
Mean temperature	6.45	35.56	78.59
Temperature stability	0.02	0.02	0.02
Set-point deviation (mean-set point)	1.45	0.56	-1.41

  - Data acquired by uncalibrated TMP117 sensors are reliable (manufacturer accuracy of ± 0.2 °C verified during the TMP117 calibration to meet the stated specifications) → data summarized are consistent, although performed with uncalibrated sensors
  - A significant improvement appears at 35 °C and 80 °C both in terms of the temperature homogeneity and the difference from the set point temperature

SPEA ATE improved set-up

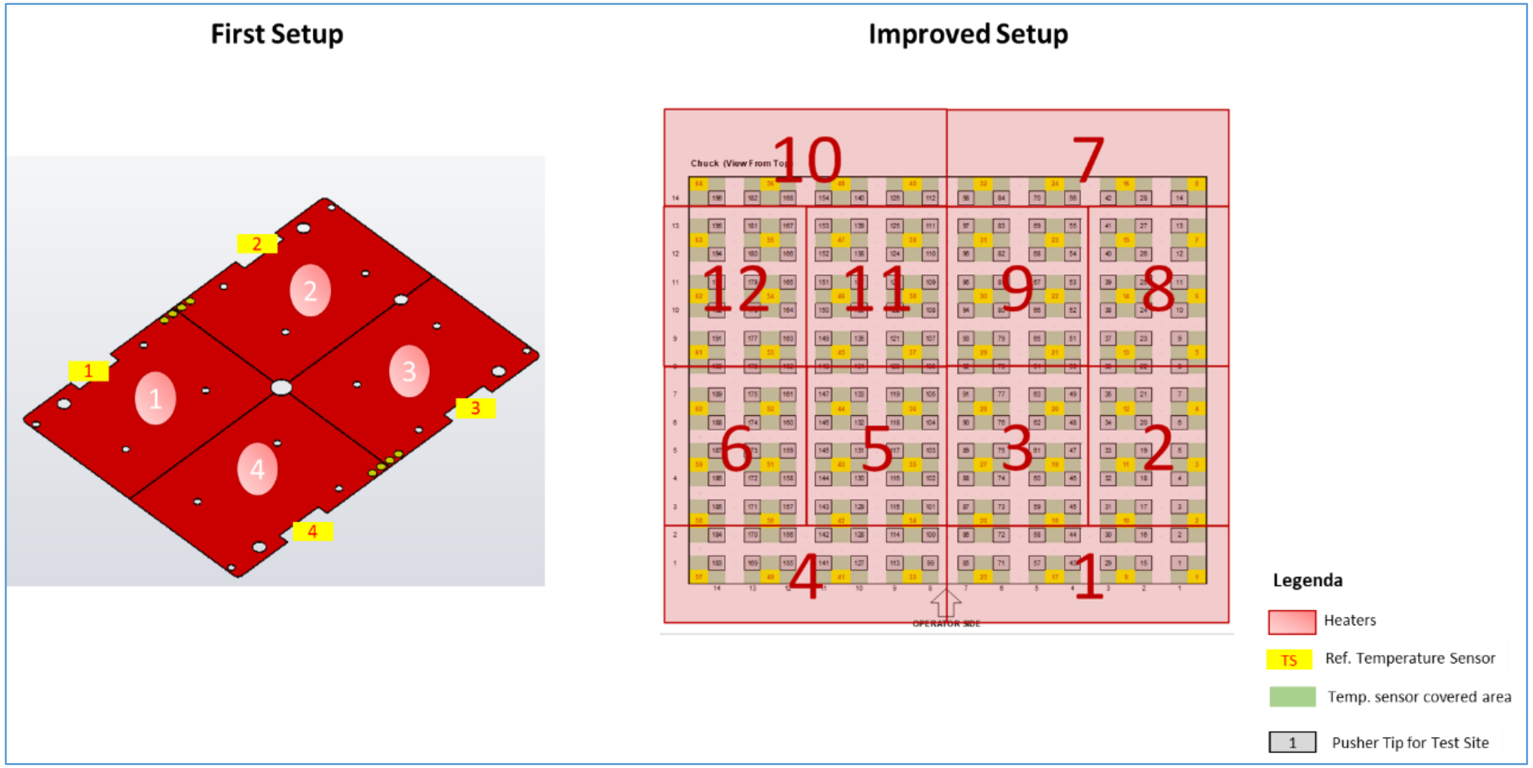
metrology for the factory of the future

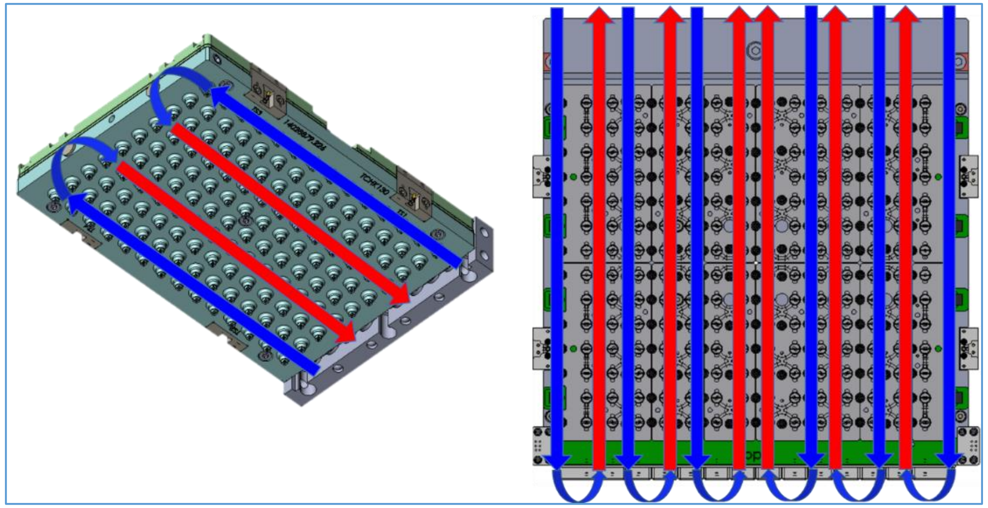
- Due to successful industrial development in the MEMS testing market it was decided to develop a revised thermal chuck and exploit it for testing a novel MEMS sensor family:
  - 14 sockets, each socket hosting 14 sensors → 196 sensors at time
  - 64 TMP117 permanently embedded as reference sensors for temperature measurement and control → additional sensors network layer with respect to the initial set-up(‘reference fixture’ always aboard
  - This reference fixture is placed between the heaters layer and the nipples which contact the UUTs for heat transfer of the thermal stimuli



SPEA ATE improved set-up

- the new set-up entails 12 temperature-controlled sections → temperature homogeneity improved
- Each independently-controlled temperature section is made of PID controller, a heater and a group of TMP117 sensors acting as the feedback sensor. The mean value of the TMP117 sensor group of the same section corresponds to the feedback temperature value for the PID controller





SPEA ATE improved set-up

- The experimental data from the novel thermal chuck set-up highlight a significantly improved performance with respect to the initial set-up.

Id_Sensors Row	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8
8_TMP	4,95	4,91	5,02	5,05	5,06	4,98	4,88	4,92
7_TMP	5,01	4,98	5,03	5,09	5,07	4,98	4,92	5,02
6_TMP	5,03	5,01	5,04	5,05	5,09	5	4,99	5,09
5_TMP	5,06	5	4,98	5,03	5,02	5,02	4,97	5,14
4_TMP	5	4,97	4,92	4,96	4,97	4,94	4,94	5,2
3_TMP	4,93	4,9	4,88	4,91	4,91	4,84	4,88	4,97
2_TMP	4,88	4,9	4,9	4,91	4,91	4,85	4,88	5,02
1_TMP	5,01	4,92	4,91	4,96	4,93	4,92	4,91	5

Id_Sensors Row	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8
8_TMP	35,02	34,97	35,01	34,99	34,98	34,98	34,97	35,03
7_TMP	35,01	35,02	35,02	35,02	35,02	34,99	34,98	35,02
6_TMP	35,01	34,99	35,03	35	35,02	34,98	34,96	35,05
5_TMP	34,98	34,99	34,98	35,02	34,99	35	34,97	35,05
4_TMP	35,01	35,01	34,96	35	35,01	35	34,98	34,97
3_TMP	34,98	35,01	35	35,02	35	34,97	35,01	35,05
2_TMP	34,98	35,03	35	34,99	35,01	34,99	35	35,01
1_TMP	35,02	35,02	34,96	35,01	35	34,98	35,02	34,99

Id_Sensors Row	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8
8_TMP	80,02	80,03	80,01	79,93	79,93	80,01	80,05	80,02
7_TMP	79,98	80,14	80,05	79,99	80,02	80,01	80,02	79,98
6_TMP	80,03	80,04	80,04	79,99	80,01	80	79,95	80,05
5_TMP	79,86	79,96	79,97	79,99	79,97	79,98	79,98	80,03
4_TMP	79,89	79,97	79,94	79,98	79,99	79,99	79,98	79,64
3_TMP	79,95	80,02	80	80,03	79,98	79,99	80,06	80,17
2_TMP	80,05	80,14	80,08	80,01	80,02	80,08	80,16	79,99
1_TMP	80,06	80,05	79,95	79,94	79,93	79,95	80,09	80,05

SPEA ATE improved set-up

- The experimental data from the novel thermal chuck set-up highlight a significantly improved performance with respect to the initial set-up

Sensor	TMP117 (Factory Calibrated)		
	°C	°C	°C
Set-point temperature	5	35	80
Max temperature	5.20	35.05	80.17
Min temperature	4.84	34.96	79.64
Temperature homogeneity (max-min)	0.36	0.09	0.53
Mean temperature	4.97	35.00	80.00
Temperature stability	0.02	0.02	0.02
Set-point deviation (mean-setpoint)	**-0.03**	**0.00**	**0.00**

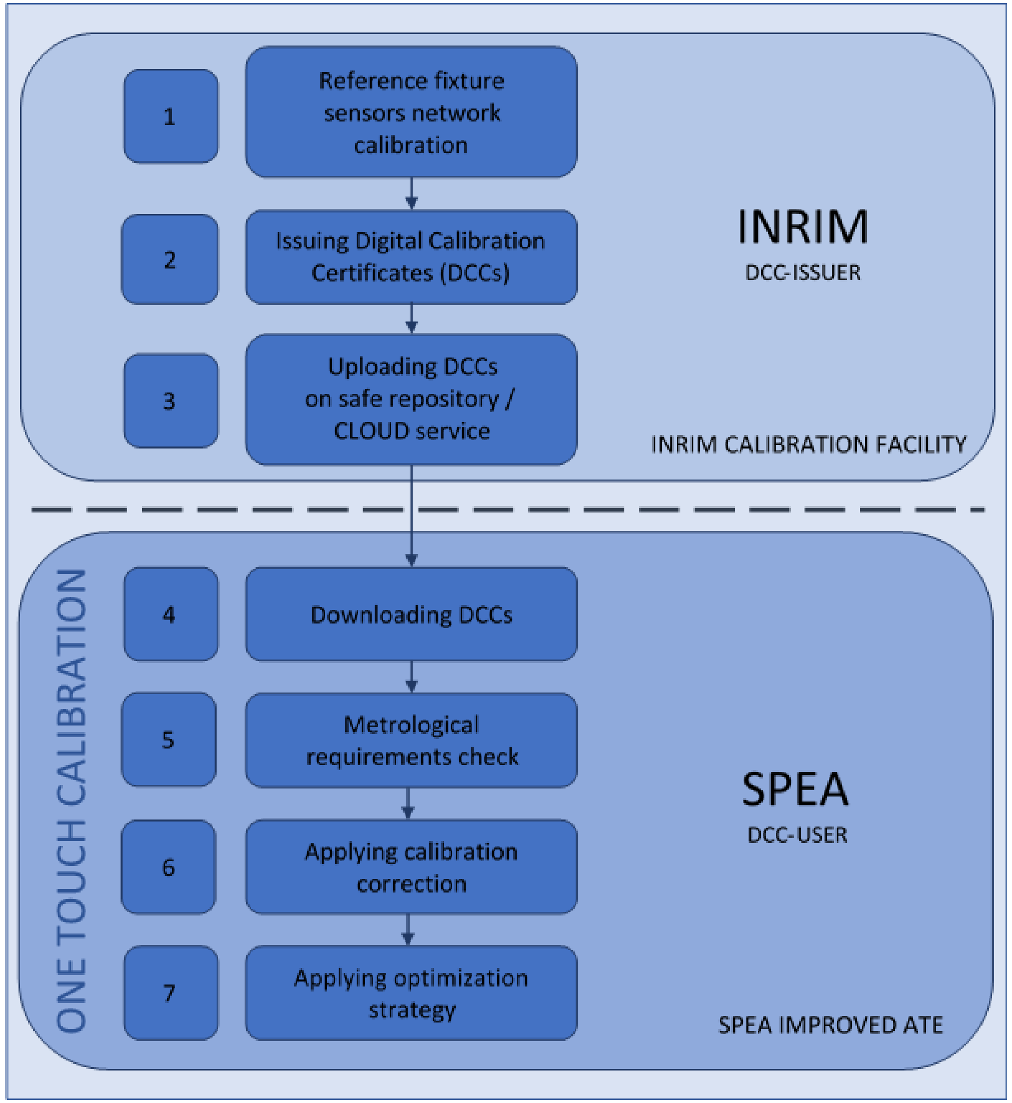
- Significant improvement in the thermal homogeneity over the whole thermal chuck at all explored temperatures is achieved
- With this configuration even the difference of the mean value of the temperature over the chuck surface with respect to the set point temperature is almost reduced to zero over the whole range

Towards One-Touch Calibration

- The possibility to issue a calibration certificate in digital format enabled the SPEA improved ATE system of self-calibrate autonomously its own TMP117 reference fixture sensors
- New improved design allowed the implementation of the "one-touch calibration"
- In order to apply this self-calibrating feature named in the project "one touch calibration" some conditions have to be respected by both sides of the M2M framework.
- This means that the DCC format in its native XML code have to be known obviously by the certificate-issuer (INRIM) and by the certificate-user (ATE system owner e.g. SPEA)
- So a special code have to be installed in the ATE system in order to read the digital calibration results and apply them in shape of corrections to each single sensor

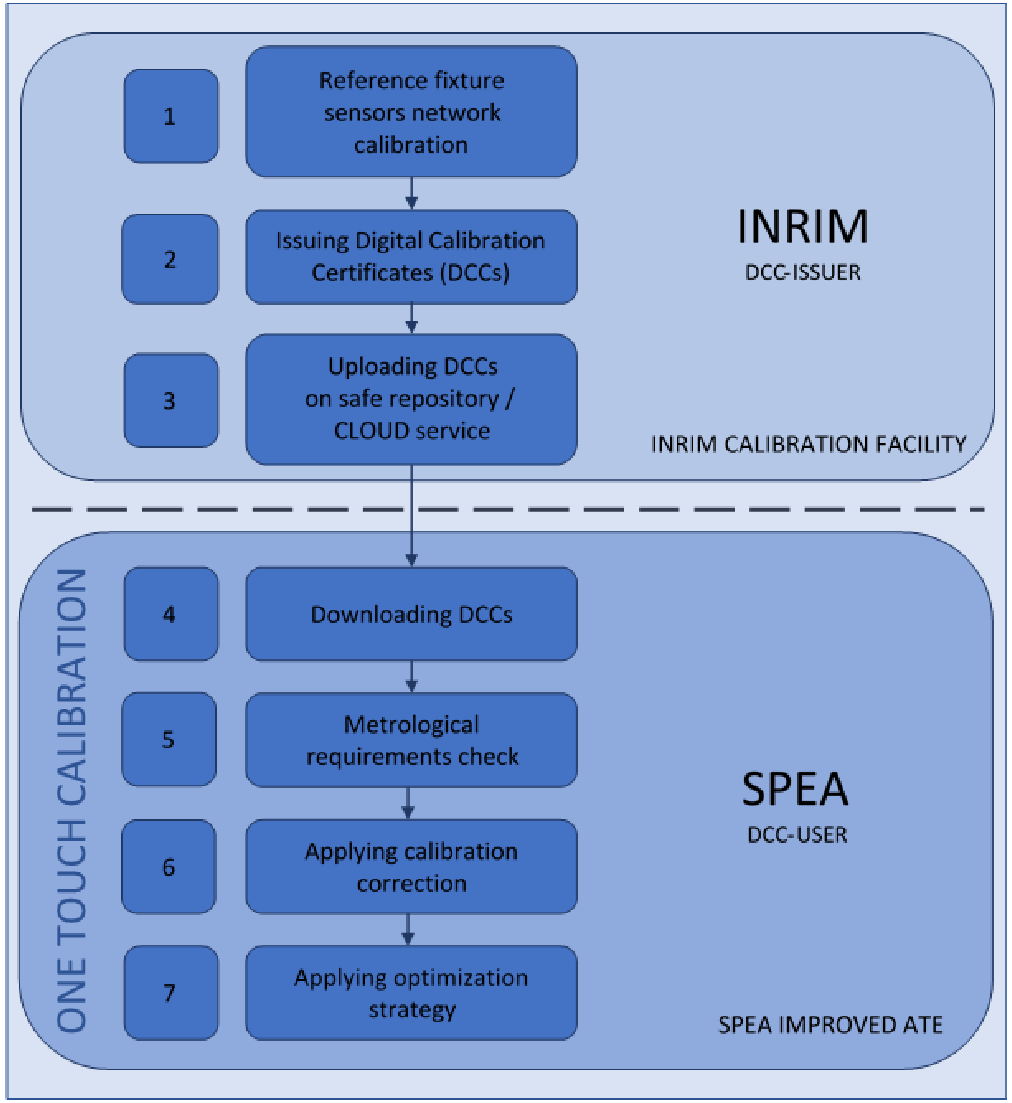
Towards One-Touch Calibration

- calibration provider acting as DCC-issuer perform the calibration of the reference fixture sensors (Step 1)
- The DCC-Issuer, INRIM in this example, prepares the DCCs (Step 2) according the standardized XML code and
- makes them available on a remote repository or on a cloud service (Step 3) accessible to the DCC-User, SPEA in this example
- Previously the DCC-Issuer and the DCC-User agreed the format and the position where the information are reported on the XML code



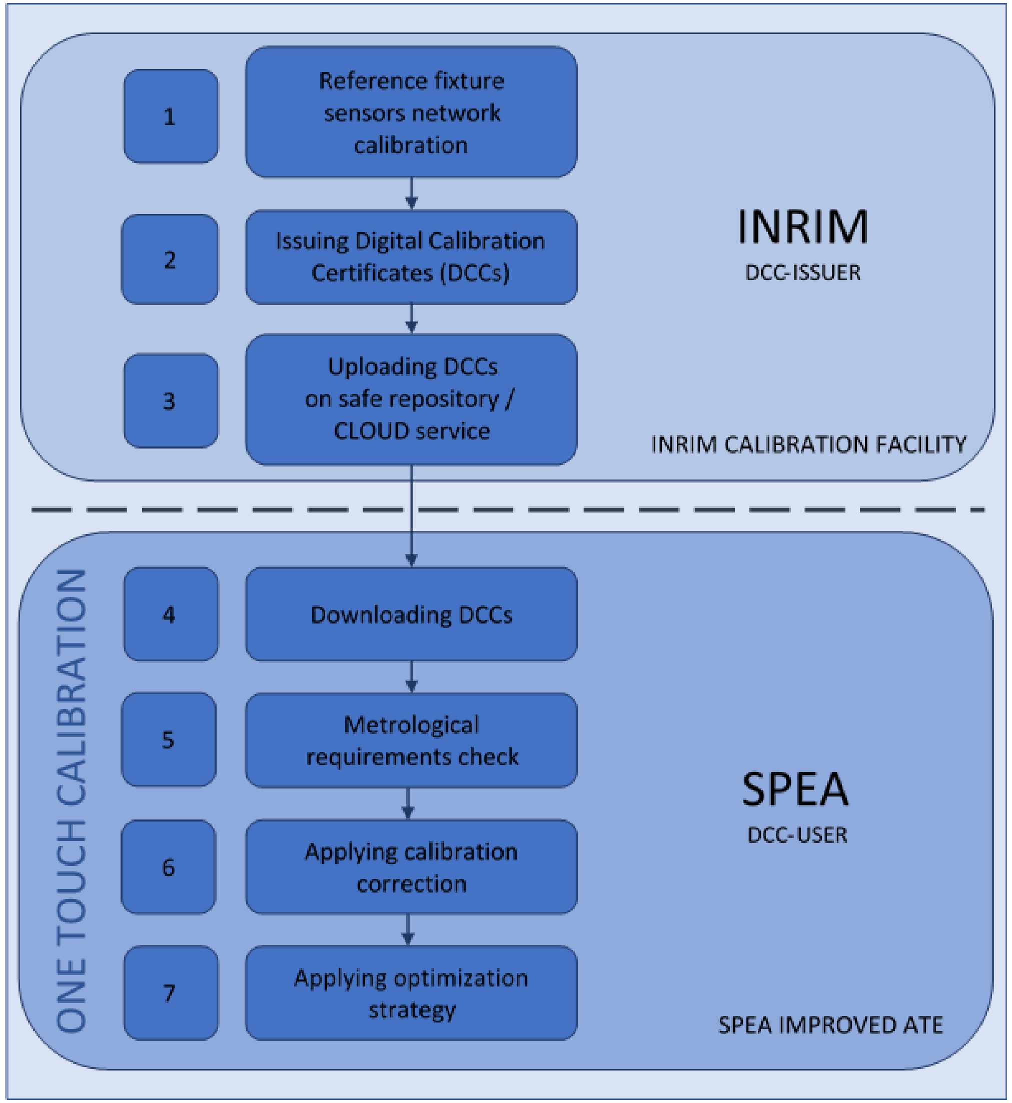
Towards One-Touch Calibration

- The DCCs (one for each single calibrated sensor) are downloaded locally to the DCC-User location (Step 4)
- The metrological information are parsed to check if they meet the metrological requirements (Step 5). For example the calibration uncertainty can be verified to be lower than a certain limit value, but many other checks can be implemented by the DCC-User depending by the scope of ATE system. In the field of temperature sensors, a usual check is the verification of the long-term drift from a previous calibration for example



Towards One-Touch Calibration

- With a "passed" DCC, the calibration corrections can be applied to each sensor (Step 6), so that, from that time every measurement carried out by the reference fixture sensors can be considered reliable and traceable
- In case of "partial-passed" DCC and according to the improved thermal chuck design some optimization strategy (Step 7) can be applied in order to exclude measurements carried out only in a limited number of sections of the thermal chuck or with a worse but known and reliable metrological performance
- The ATE system starts to test UUTs as usual, but after 1TC the UUTs will be tested under controlled and traceable temperature conditions



Next goals

- Validation at customers' sites
- Updating exploitation plans
- Investigating research opportunities enabled by Met4FoF results
- Issuing internal and external seminaries for disseminating Project results

Thank you for your attention !