INRiM
ISTITUTO NAZIONALE
DI RICERCA METROLOGICA

ACCREDIA
L'ENTE ITALIANO DI ACCREDITAMENTO

A&T AUTOMATION & TESTING

La digitalizzazione dei servizi metrologici e dei certificati di taratura

In collaborazione con INRiM

14 febbraio 2024

Il progetto europeo
“Metrologia per la fabbrica del futuro”

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Primo tecnologo

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Torino, 14 Febbraio 2024

EURAMET's Research Programme

EURAMET's research programme **EMPIR** enables European metrology institutes, industrial & medical organisations, and academia to collaborate on **Joint Research Projects** (**JRPs**).

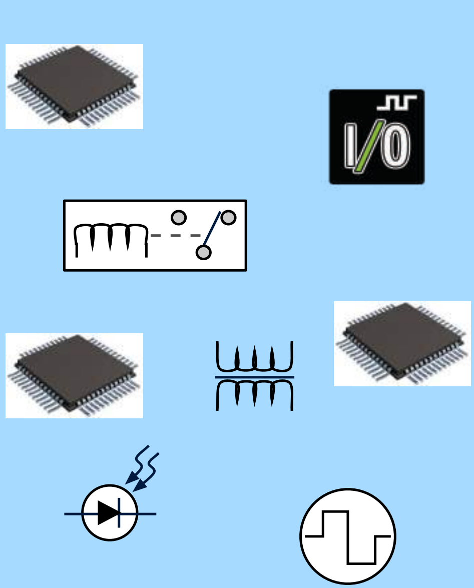
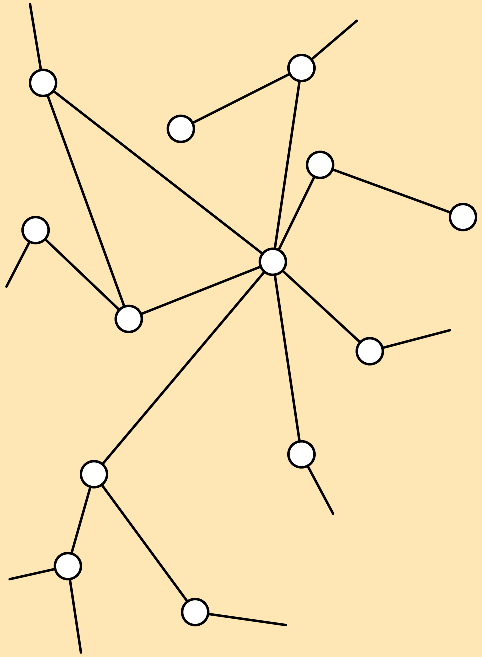
The projects are centred around fields like **Industry**, **Energy**, **Environment**, **Health** and **Capacity Building**. The programme also supports the development of the fundamental **SI system** of measurement units.

EMPIR follows on from the **EMRP** programme, which has now been successfully completed.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

See https://www.euramet.org/ for more details.

Met4FoF - Metrology for the Factory of the Future

Digital sensors and smart traceability	Reliable smart sensor networks	Confidence in smart data analysis methods
		
Dynamic, digital-only output and low-cost MEMS sensors	Synchronisation, co-calibration and sensor fusion	Measurement uncertainty in machine learning and AI

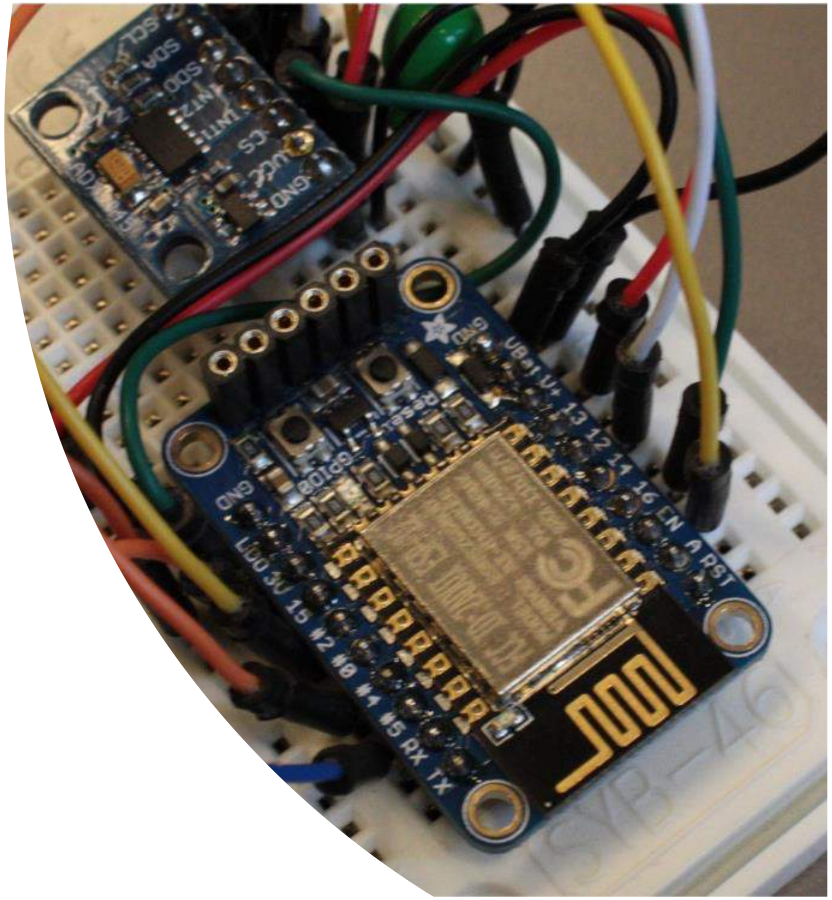
Project objectives

- 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.

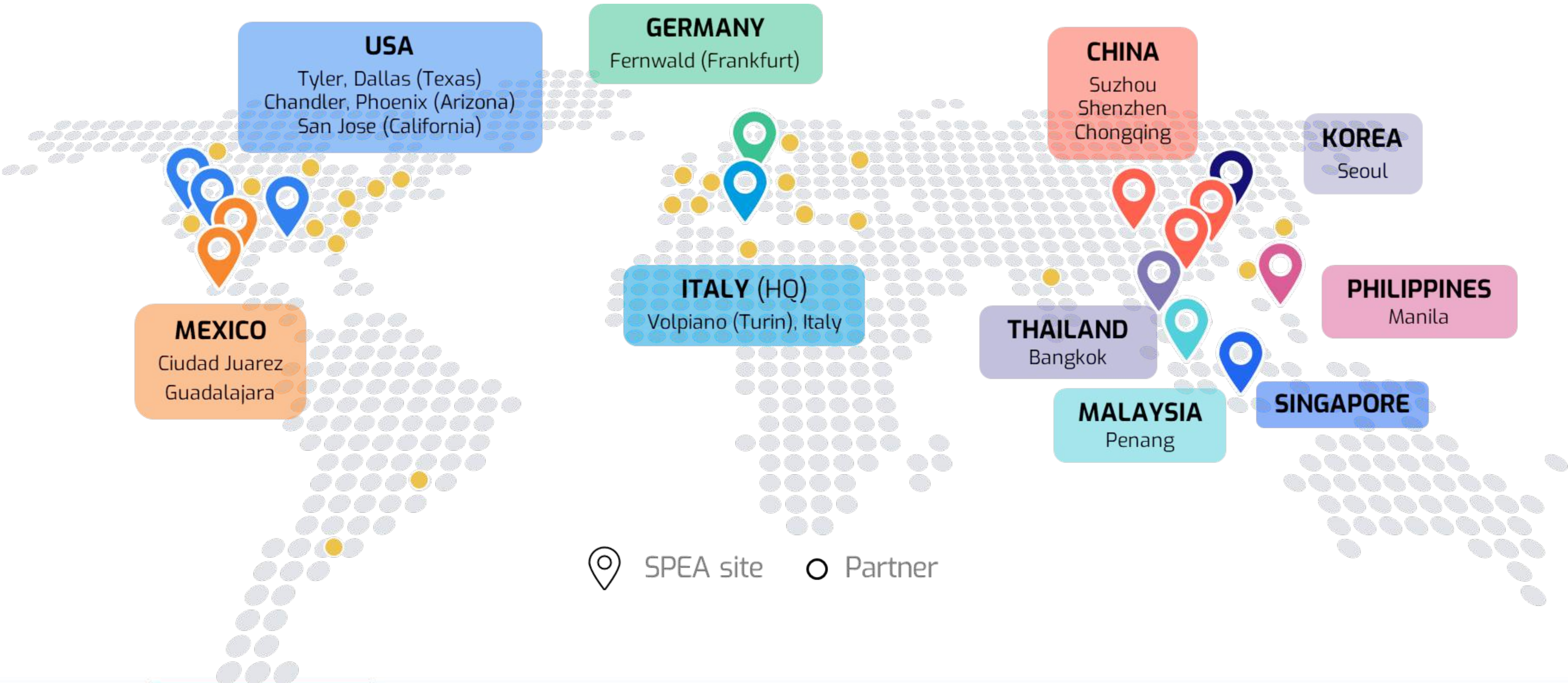
- Implement the methods and frameworks developed in industry-like test environments.



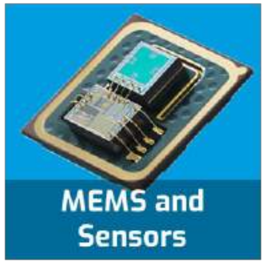
About SPEA

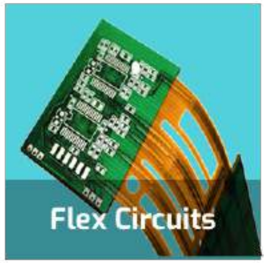

WHO
WE ARE
A global leader
in test equipment
for Semiconductors, MEMS and
Sensors, Electronic Boards,
Batteries and devices.
Since 1976.
SPEA
€210M
2023 Global Revenues
+6% yoy
+20% Average 2020-2023
12,000
Systems installed
worldwide
39
global locations
15
direct operations
serving
1,800+ customers
in
65+ countries

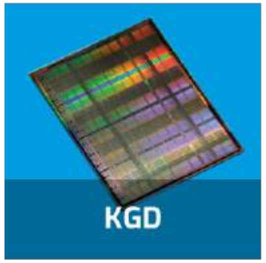
Global presence



Tested Products





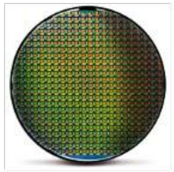


SEMICONDUCTOR
INDUSTRY

ELECTRONICS
INDUSTRY

Electronic testing world

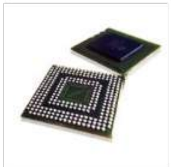
SEMICONDUCTOR INDUSTRIES



silicon wafer

ATE

- Parametric
- Functional



microchip

ATE

- Parametric
- Functional

ELECTRONICS INDUSTRIES

board

ATE

- In-circuit
- Flashing
- Boundary Scan
- Optical test
- Functional test

module

ATE

- Functional test

FINAL USERS

assembled device

FIELD REPAIR

Field return boards

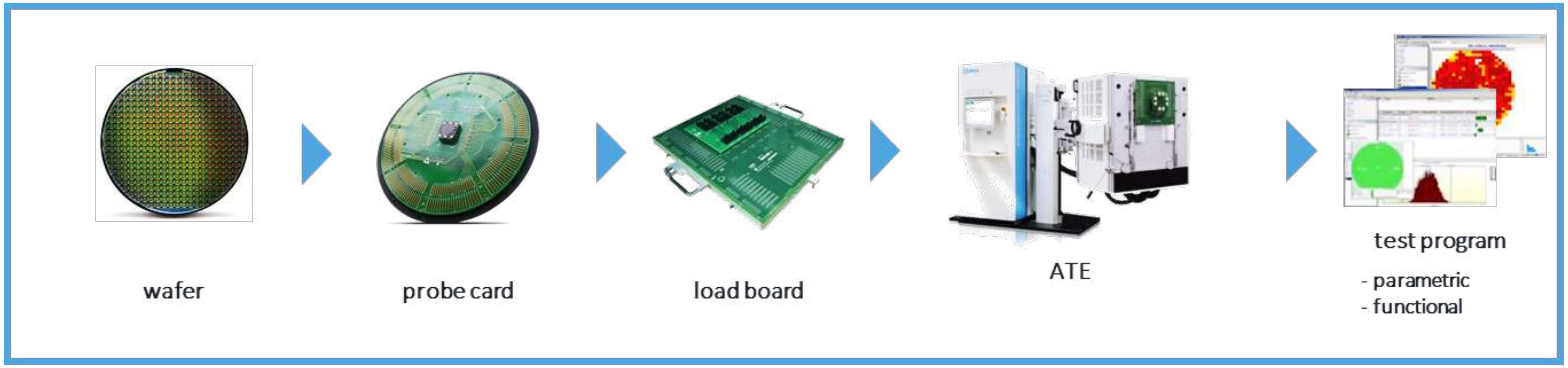
ATE

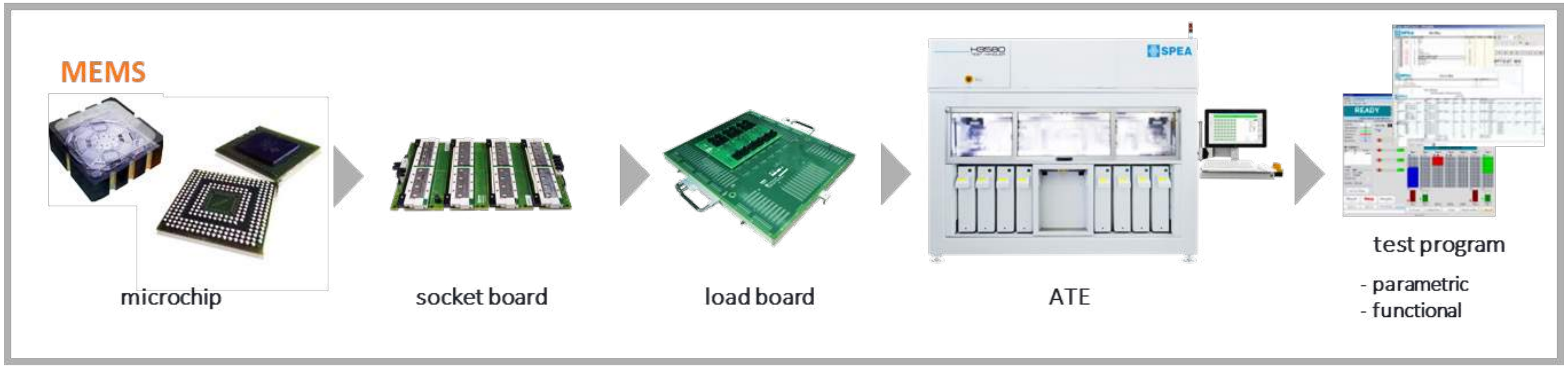
- In-circuit
- Boundary Scan
- Optical test
- Functional test

ATE stands for **AUTOMATIC TEST EQUIPMENT**: industrial machines able to perform all the operations required to verify the correct working of an electronic product

SPEA

Wafer-level and chip-level testing





Product Lines

Semi & MEMS Test

- MEMS test cells
- Mixed Signal, Analog & SoC testers
- Power device testers
- Test handlers

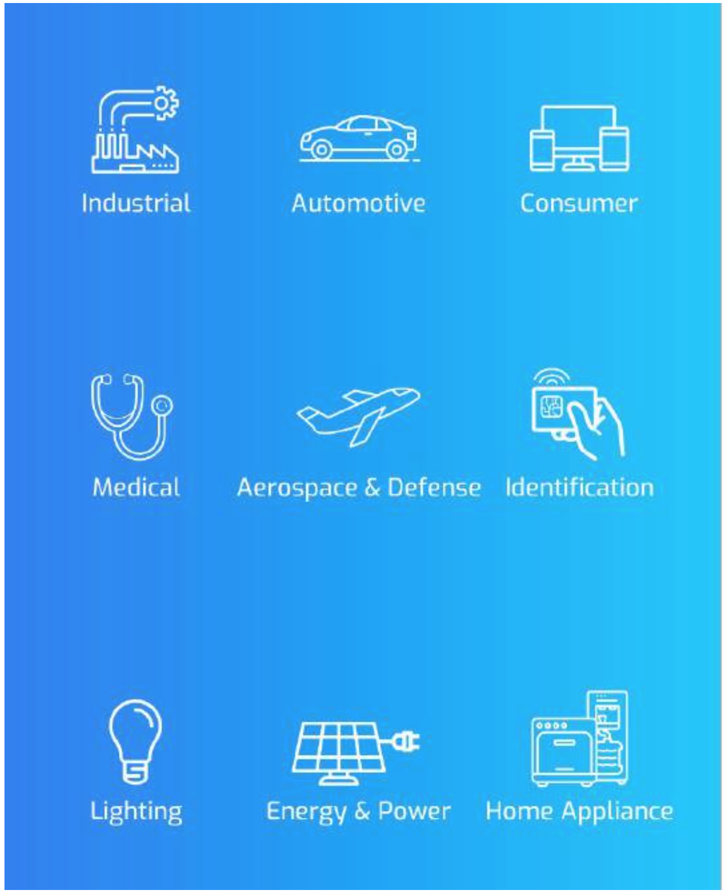
Electronics Test

- ICT testers
- Flying probe testers
- Functional & EOL testers
- Battery testers
- Automatic board handlers
- Custom test equipment

SPEA is the only ATE manufacturer whose product portfolio embraces all the phases of testing.

From semiconductor wafer test to packaged IC and MEMS sensor test, from in-circuit and flying probe test on assembled PCBs to final functional test of assembled devices, performed with dedicated custom equipment.

Industries served











Market Goals

Power & Automotive

Exploit our position of strength in the Power and Automotive Market, taking advantage of the growth trend of this market

Micro controllers

Grow our presence in the microcontroller test market, with dedicated test instrumentation development

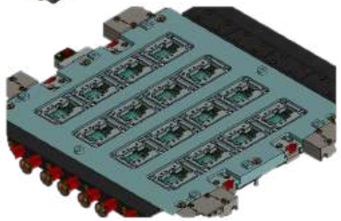
5G & mmWave

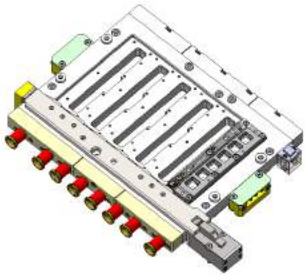
Grow our presence in the RF, 5G & mmWave market segments, with dedicated test instrumentation and low-cost complete test solutions

Computing & Network

Expand our presence in the in the computing and networking market, with dedicated digital test instrumentation

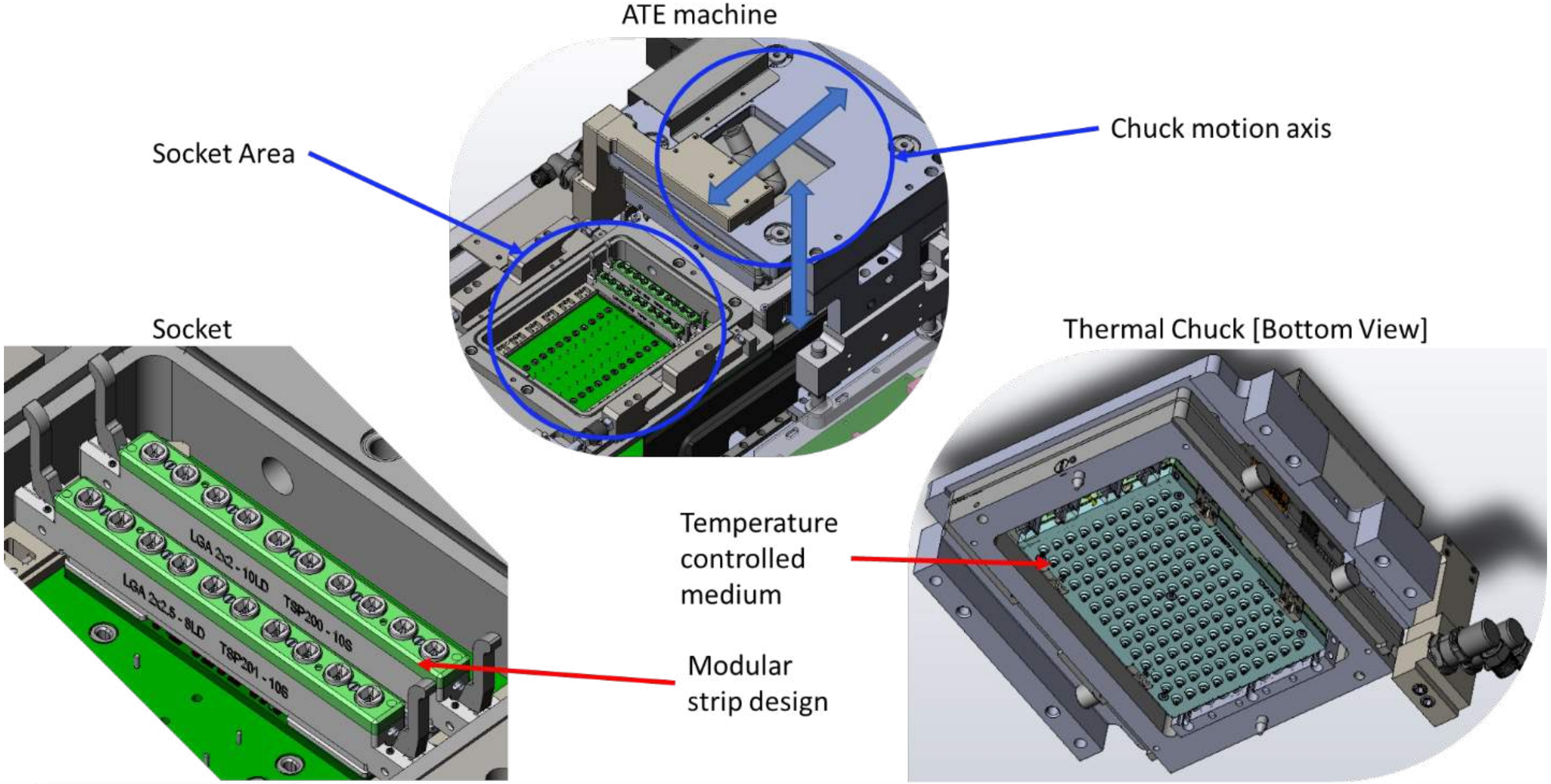
SPEA and MET4FoF



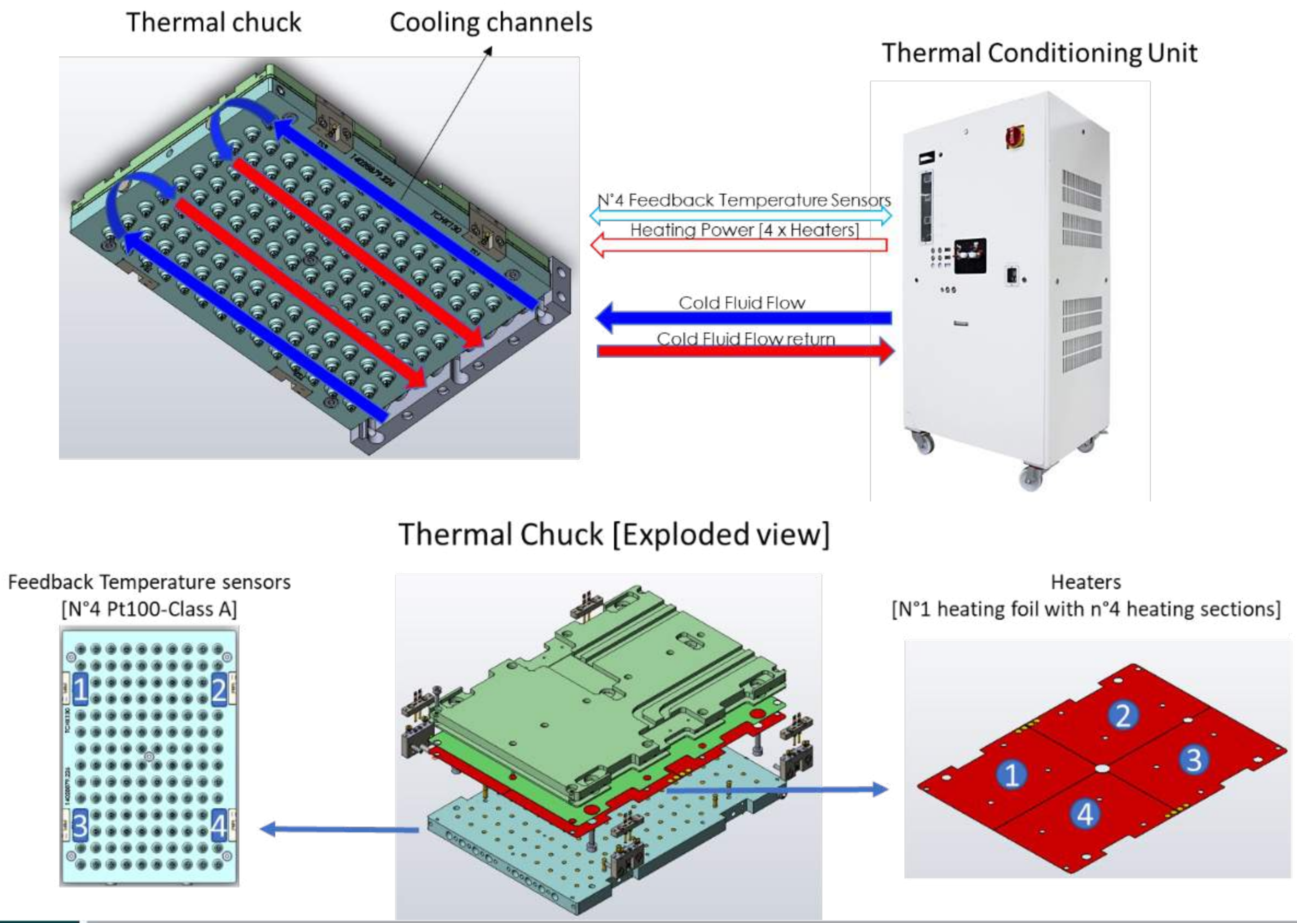


- Provision of in-situ calibration and measurement traceability to a next generation of ATE systems, based on a “reference fixture”
- Demonstration of the effectiveness of the improved ATE system in performing traceable dynamic temperature calibrations of the chucks [the thermal conditioned elements in direct contact with the MEMS]
- Demonstration of the effectiveness of the improved ATE system in performing traceable dynamic temperature calibrations of MEMS sensors

ATE for MEMS temperature testing



Thermal conditioning system

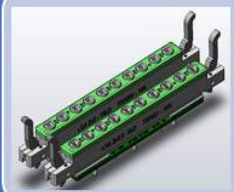


Project objectives of the SPEA testbed

Unit under test (UUT = MEMS)

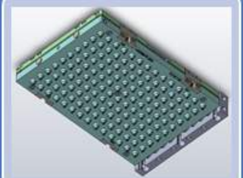
- MEMS sensor to be tested in-situ under proven and traceable temperature conditions.

→ **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.

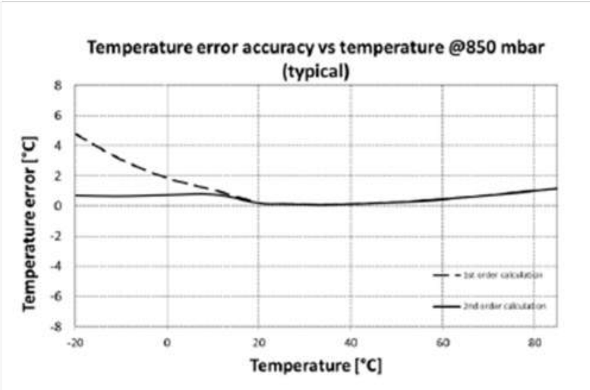
Selected MEMS for demonstration

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		



Process to reach the goal: a traceable calibration framework

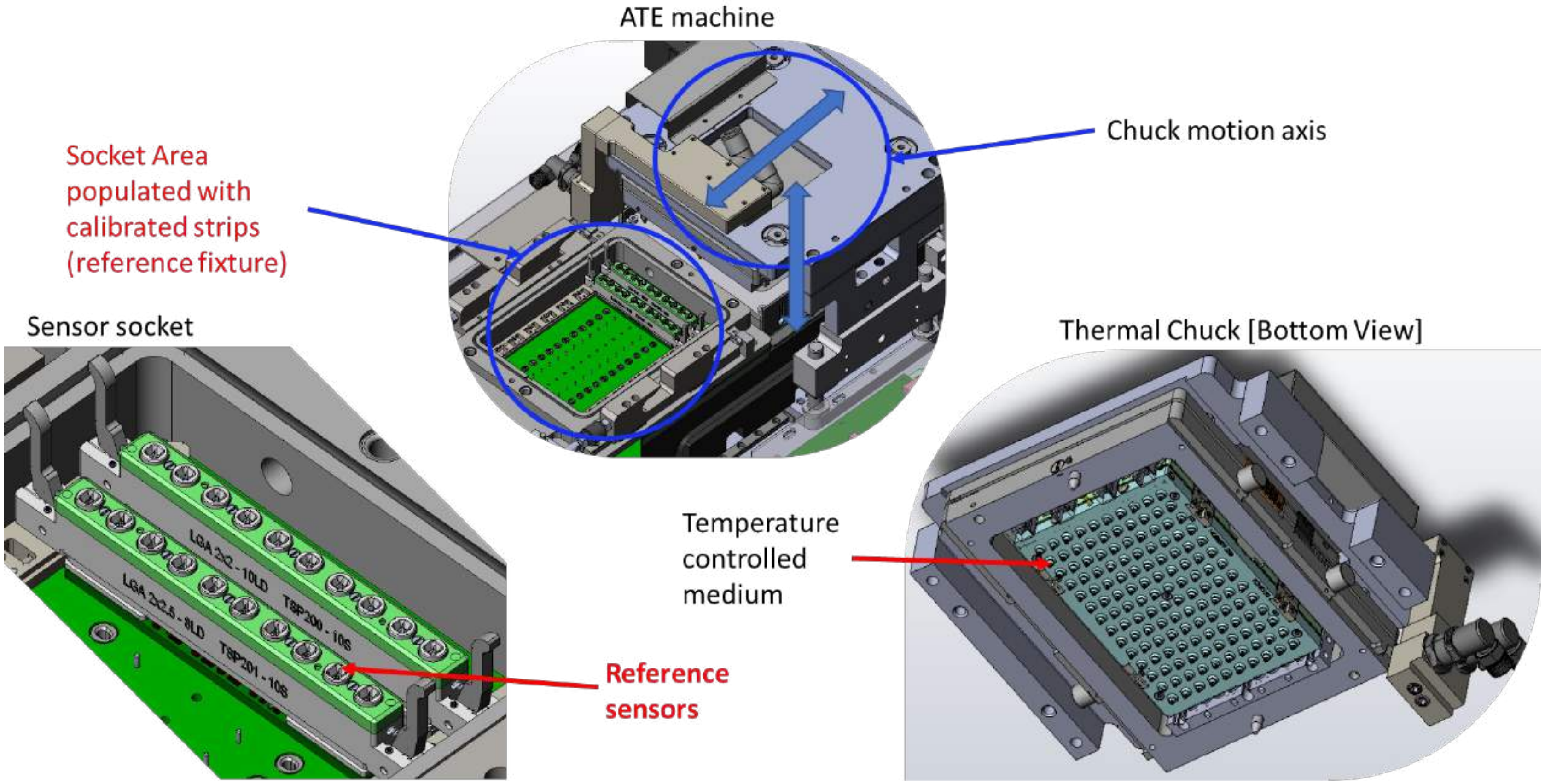
Developing a **reference fixture** to provide traceable temperature and electrical measurements to ATE machines.

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.**

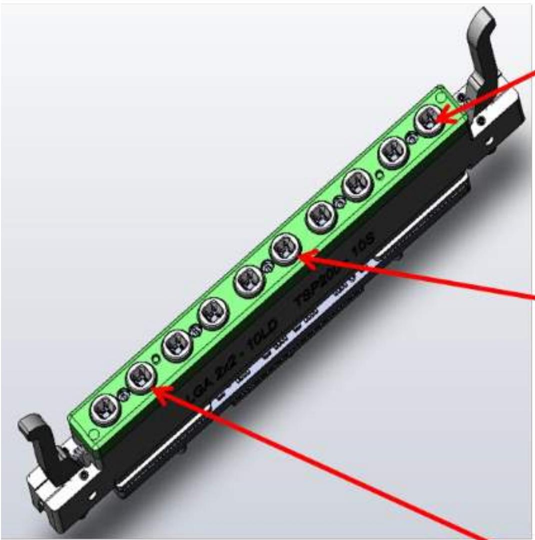
In situ MEMS testing/calibration under traceable temperature conditions.

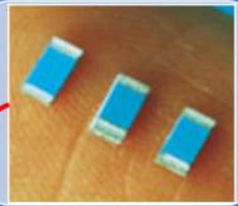
Approach to investigate the ATE thermal stimulus: the reference fixture



Approach to investigate the ATE thermal stimulus

Reference fixture: 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

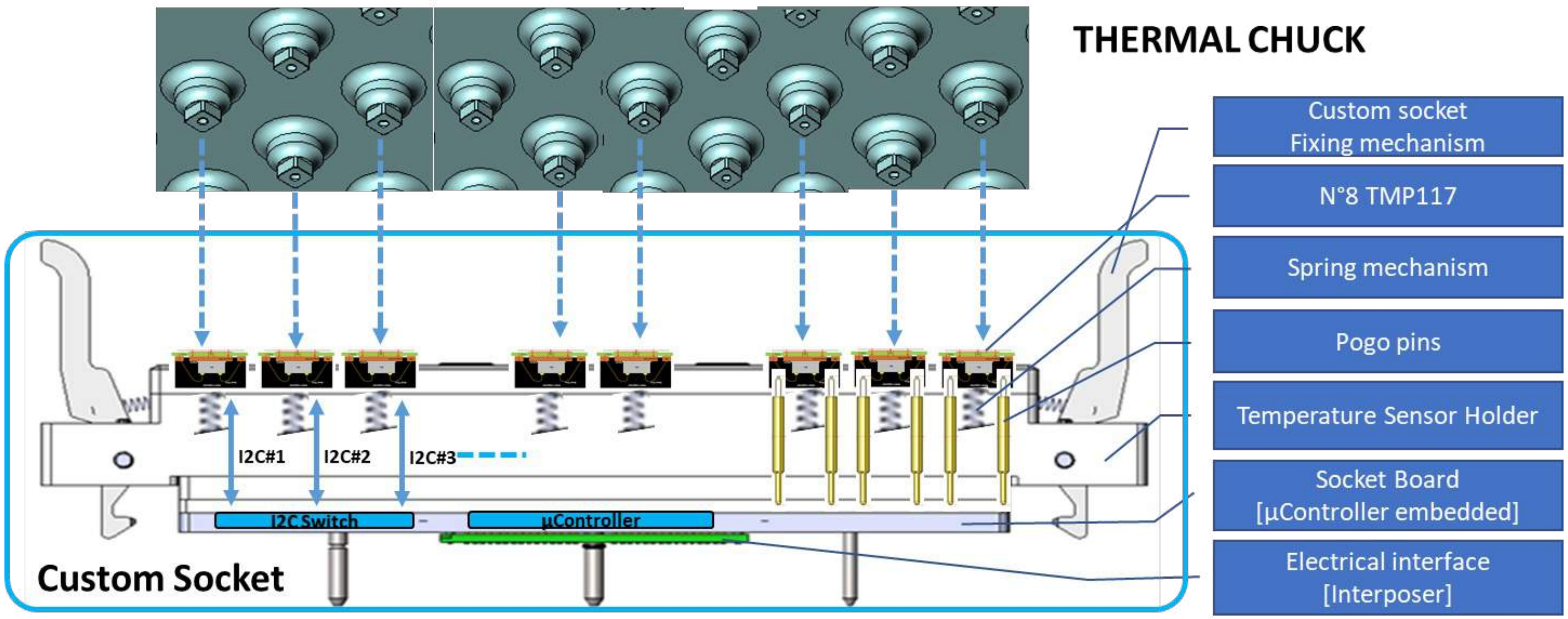
Reference digital temperature sensors: Texas Instrument TMP117

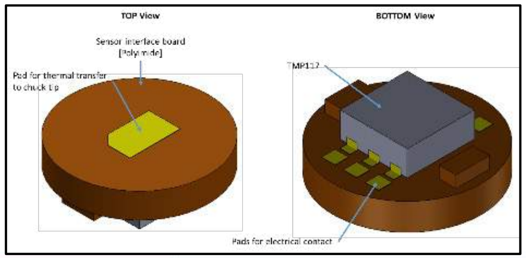
- Temperature range: -55°C ÷ +150°C
- Accuracy: < 0.1°C after calibration
- Resolution: 0.01°C
- Digital I2C bus

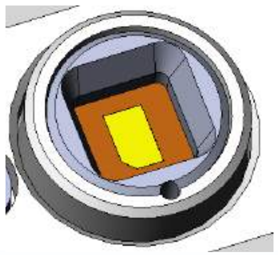
Golden device

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

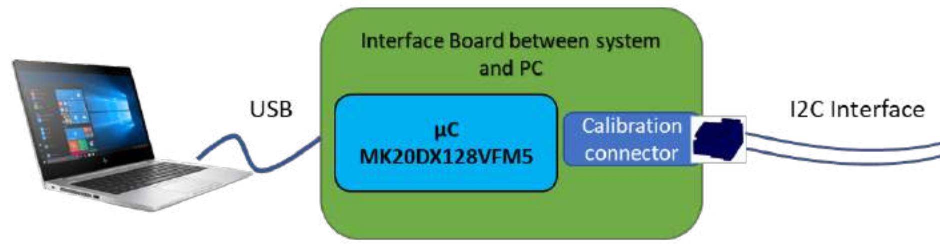
Developing of a reference fixture with digital temperature sensors

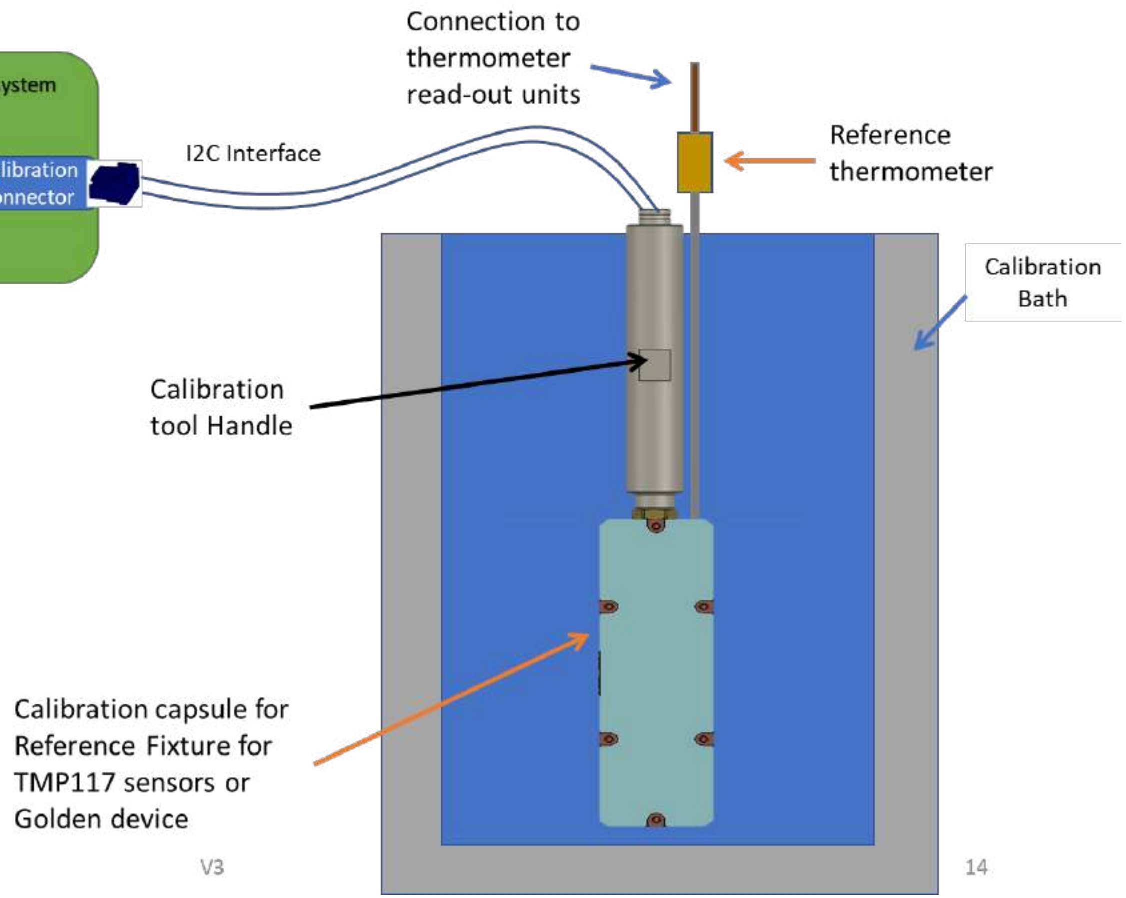






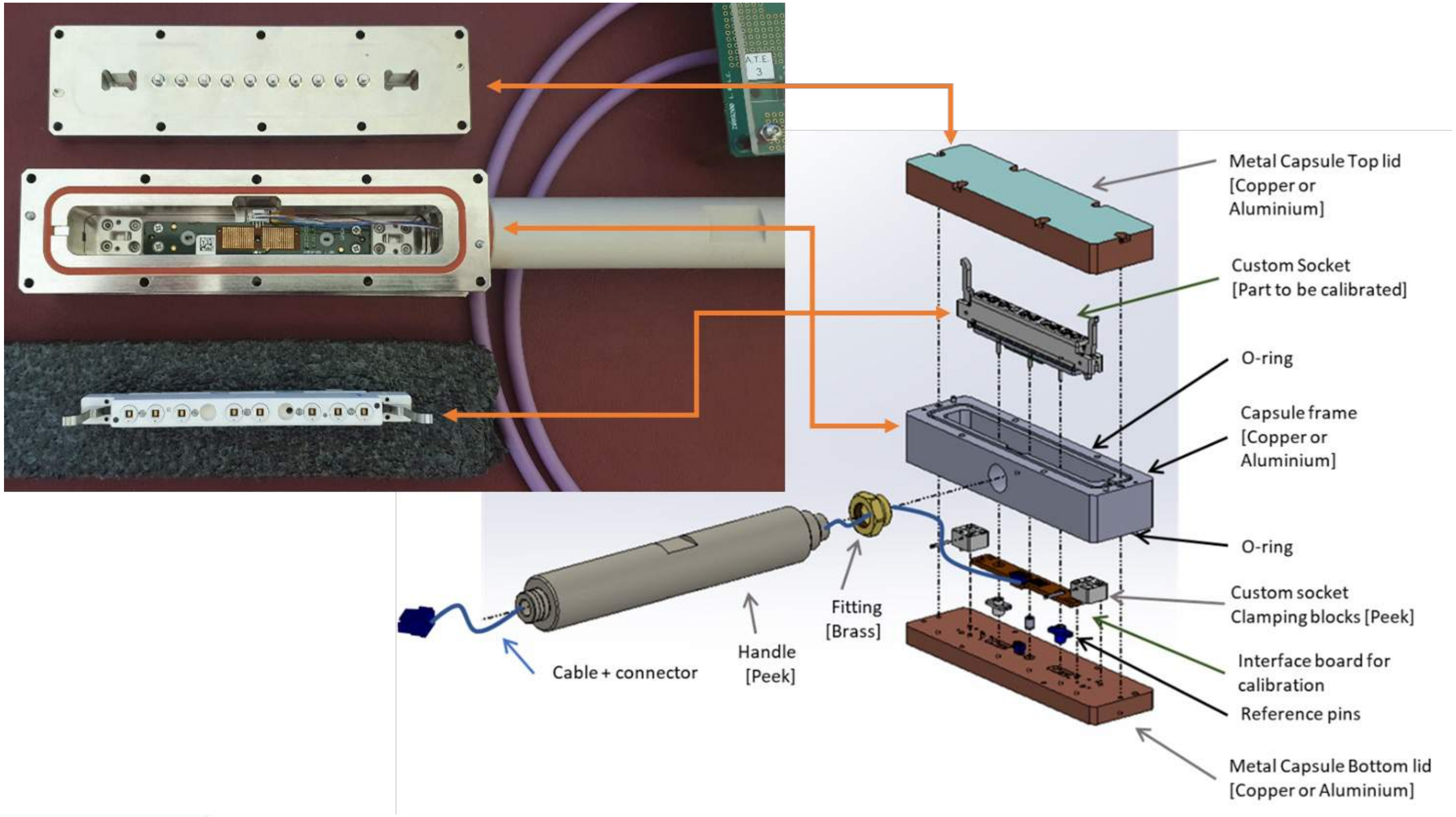
Laboratory calibration of the sensors aboard the reference fixture



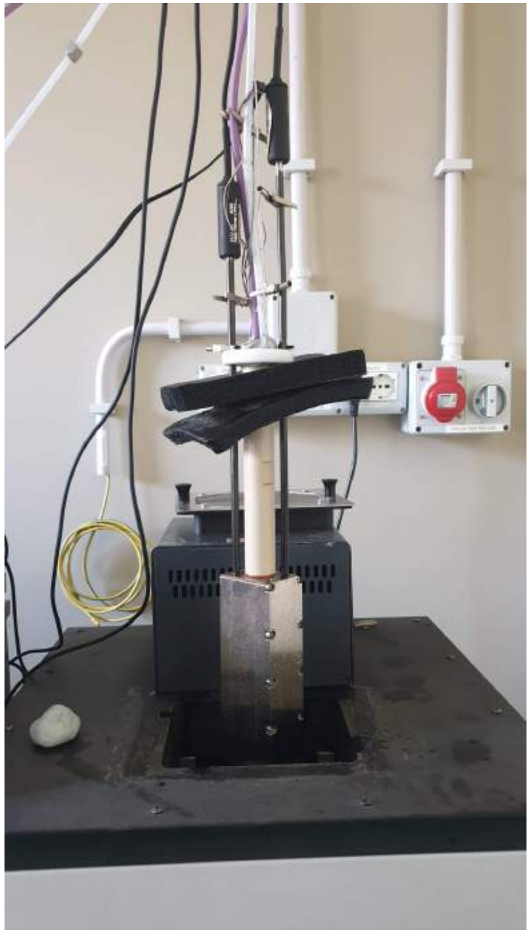


- All the Reference Fixture have to be calibrated by INRIM in a calibration bath;
- The sensor capsule will be able to provide connections for data and power signals. It will be made of proper materials suitable to optimize **reference sensors** temperature calibration over the range -60 °C and +200 °C.

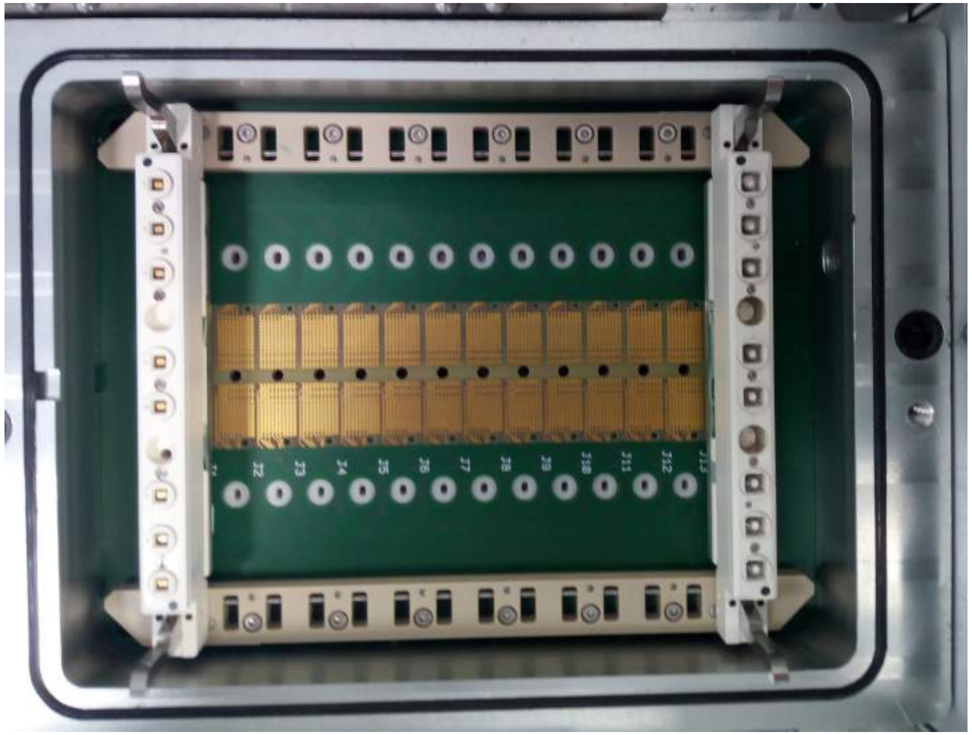
Calibration capsule layout

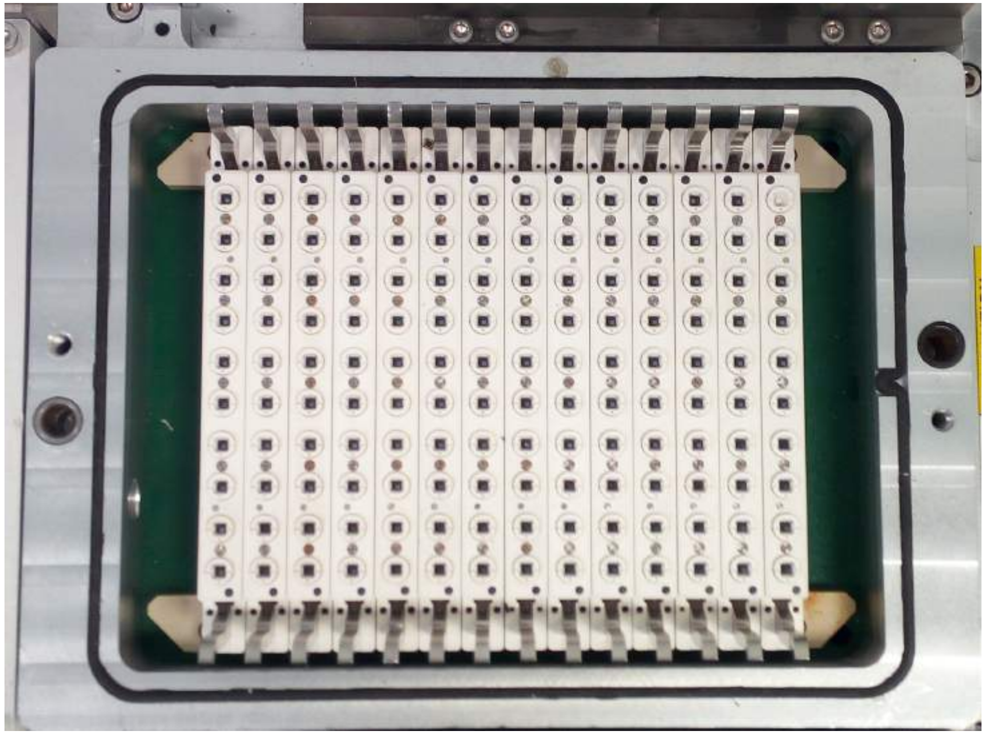


INRIM digital sensors calibration system

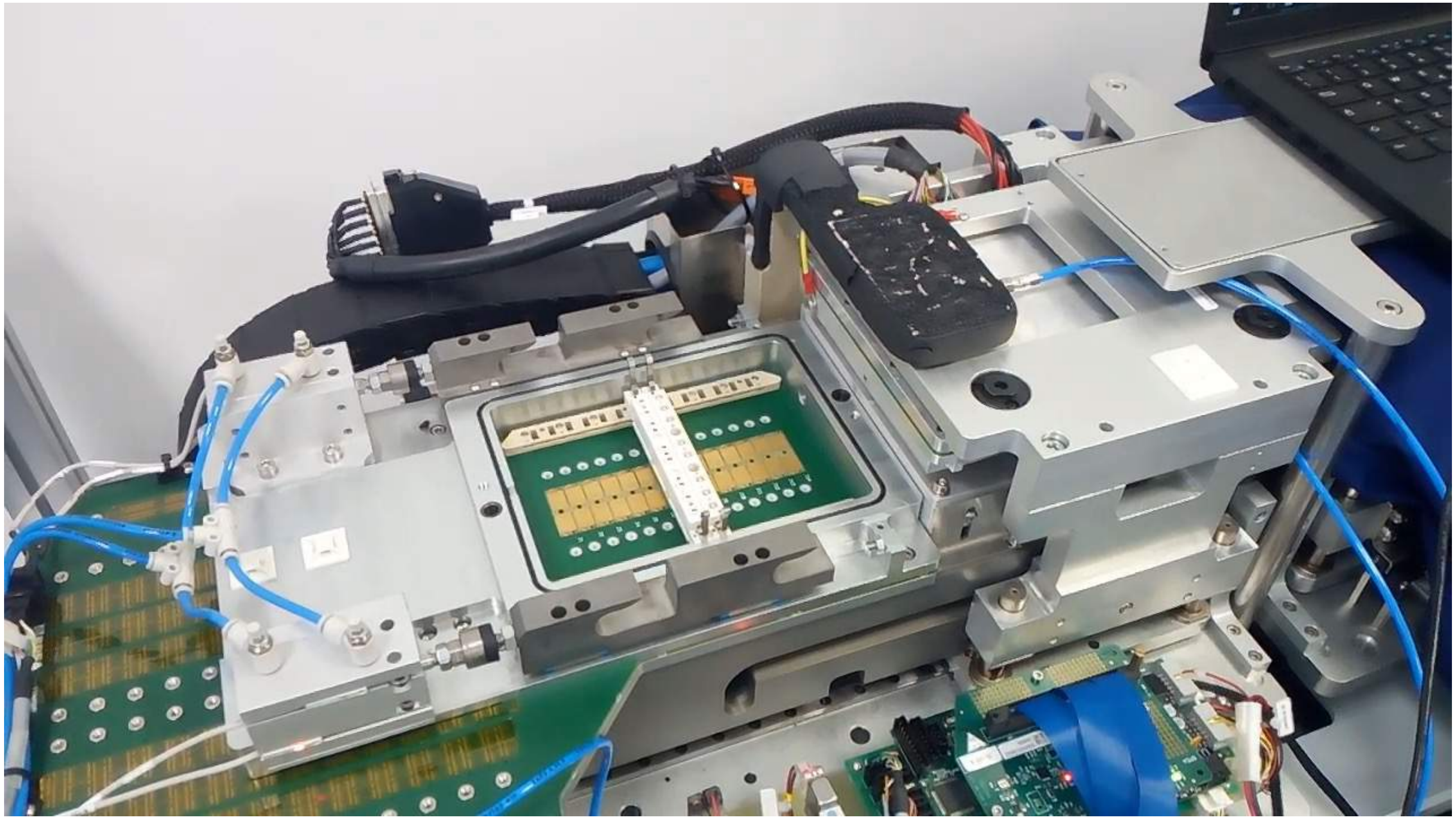


Reference fixture for in situ ATE calibration

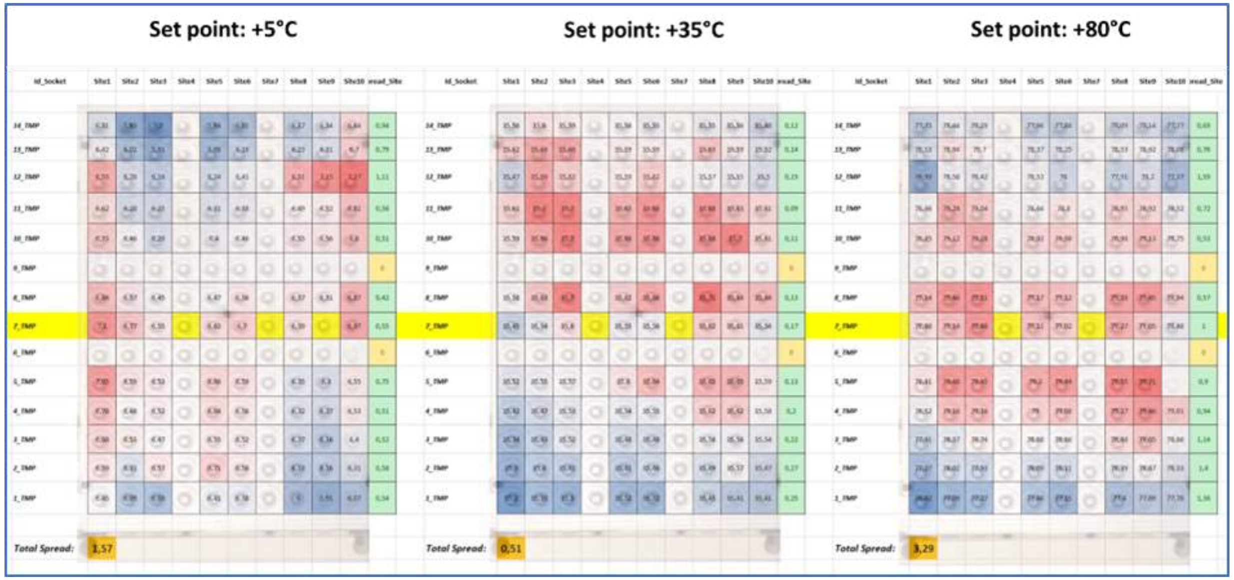




Reference fixture for in situ ATE calibration

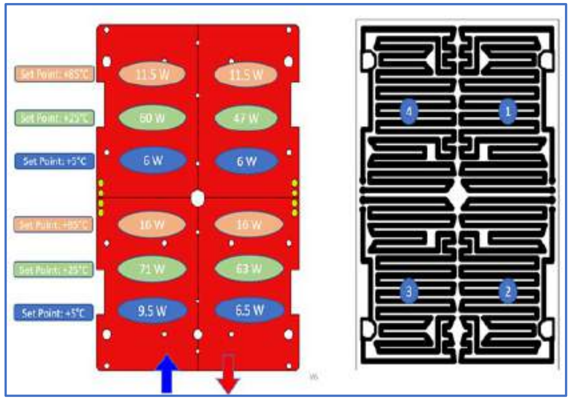


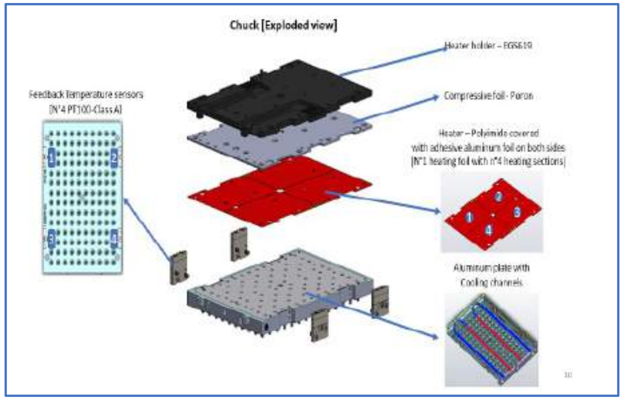
ATE metrological characterization



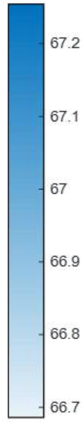
Sensor	TMP117 (Factory Calibrated)		
	°C	**°C**	**°C**
Set point temperature	**5**	**35**	**80**
Max temperature	7.27	35.71	79.71
Min temperature	5.70	35.20	76.42
Temperature homogeneity (max-min)	1.57	0.51	3.29
Mean temperature	6.45	35.56	78.59
Temperature stability	0.02	0.02	0.02
Set-point deviation (mean-set point)	1.45	0.56	-1.41

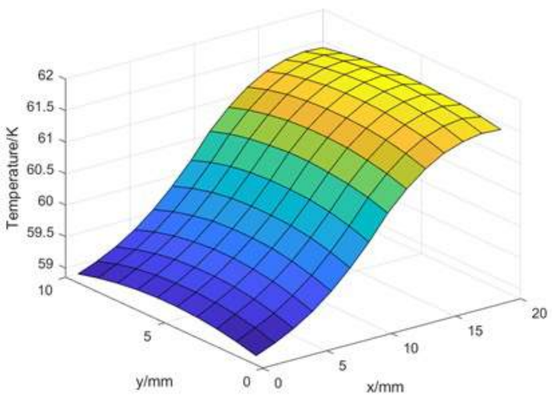
Thermal Modelling of SPEA ATE initial set-up and Optimization Strategy

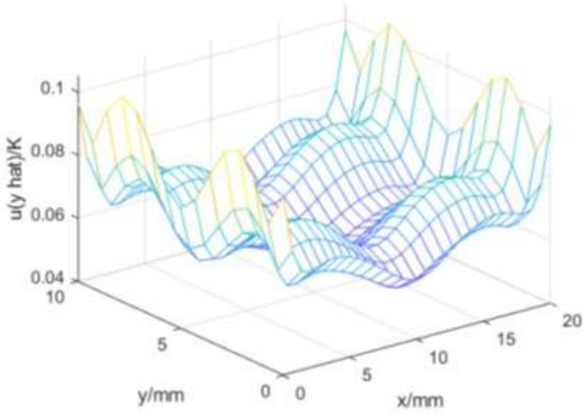


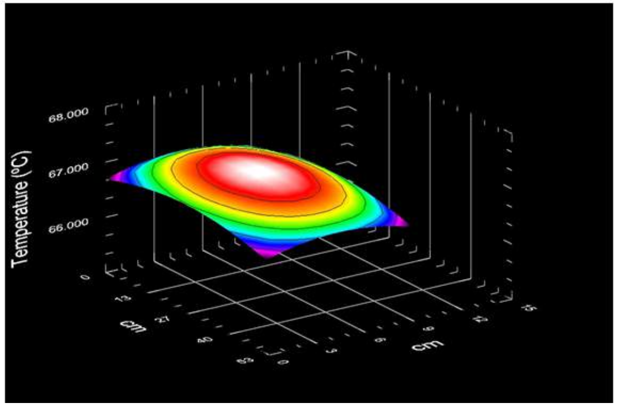


	1	2	3	4	5	6	7	8	9	10
1	66.69	66.77	66.83	66.87	66.89	66.89	66.87	66.83	66.77	66.69
2	66.76	66.87	66.95	66.99	67.02	67.02	66.99	66.95	66.87	66.76
3	66.82	66.94	67.02	67.08	67.1	67.1	67.08	67.02	66.94	66.82
4	66.88	67	67.08	67.14	67.16	67.16	67.14	67.08	67	66.88
5	66.92	67.04	67.13	67.18	67.21	67.21	67.18	67.13	67.04	66.92
6	66.95	67.07	67.16	67.21	67.24	67.24	67.21	67.16	67.07	66.95
7	66.96	67.08	67.17	67.23	67.25	67.25	67.23	67.17	67.08	66.96
8	66.96	67.08	67.17	67.23	67.25	67.25	67.23	67.17	67.08	66.96
9	66.95	67.07	67.16	67.21	67.24	67.24	67.21	67.16	67.07	66.95
10	66.92	67.04	67.13	67.18	67.21	67.21	67.18	67.13	67.04	66.92
11	66.88	67	67.08	67.14	67.16	67.16	67.14	67.08	67	66.88
12	66.82	66.94	67.02	67.08	67.1	67.1	67.08	67.02	66.94	66.82
13	66.76	66.87	66.95	66.99	67.02	67.02	66.99	66.95	66.87	66.76
14	66.69	66.77	66.83	66.87	66.89	66.89	66.87	66.83	66.77	66.69

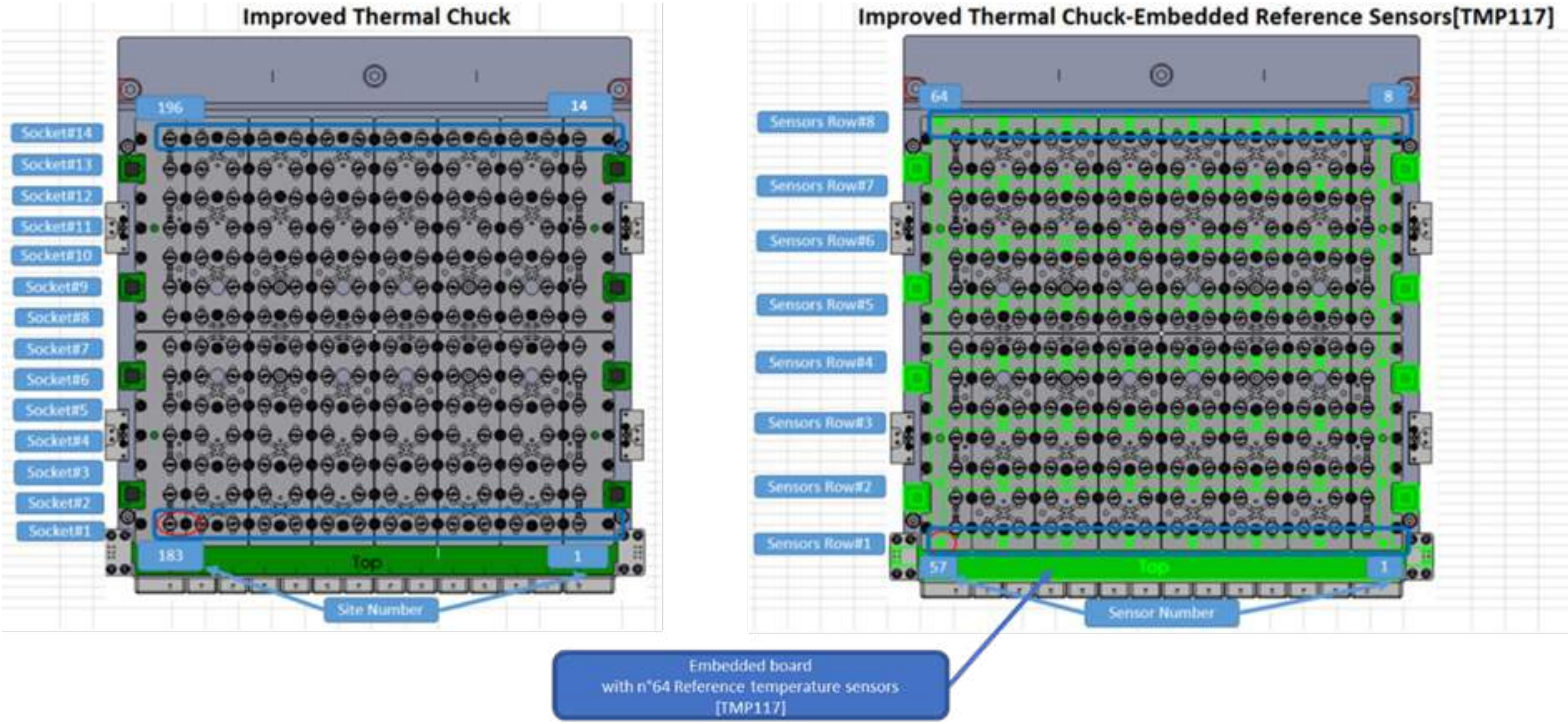








Description of the improved thermal chuck set-up



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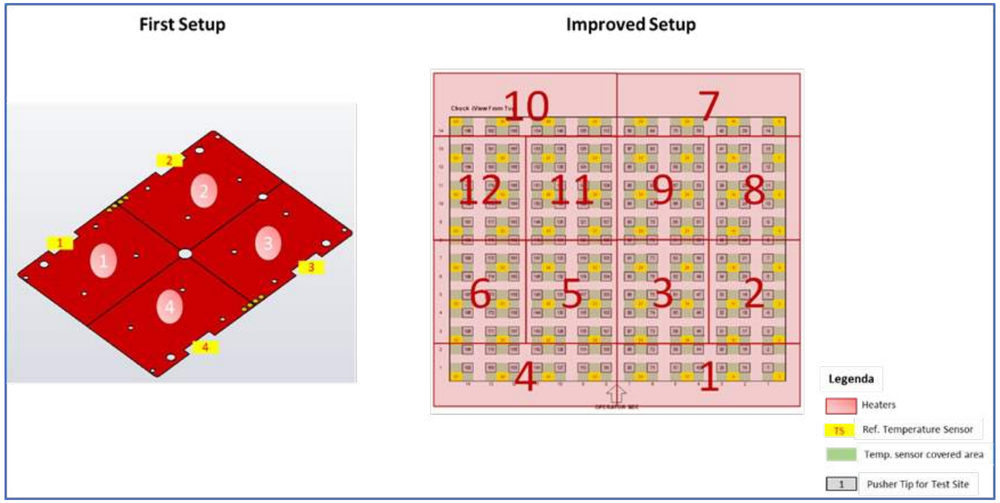
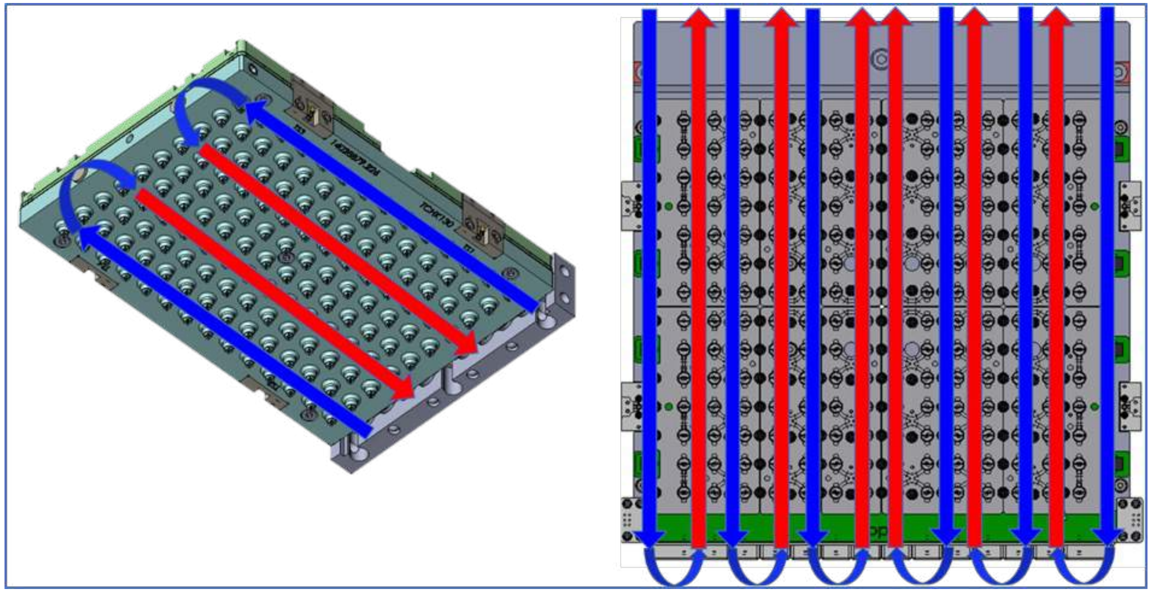




Improved thermal chuck metrological characterization

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

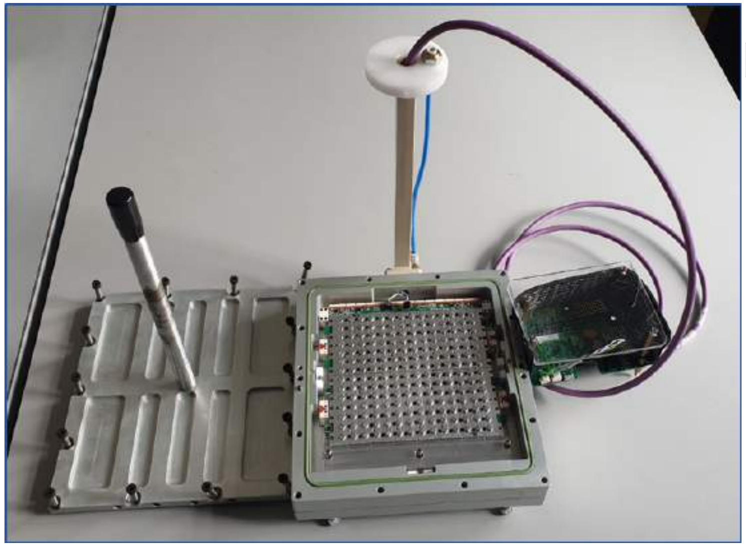
Id_Sensors Row	Site1	Site2	Site3	Site4	Site5	Site6	Site7	Site8
8_TMP	80,02	80,03	80,01	79,93	79,93	80,01	80,05	80,02
7_TMP	79,98	80,14	80,05	79,99	80,02	80,01	80,02	79,98
6_TMP	80,03	80,04	80,04	79,99	80,01	80	79,95	80,05
5_TMP	79,86	79,96	79,97	79,99	79,97	79,98	79,98	80,03
4_TMP	79,89	79,97	79,94	79,98	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

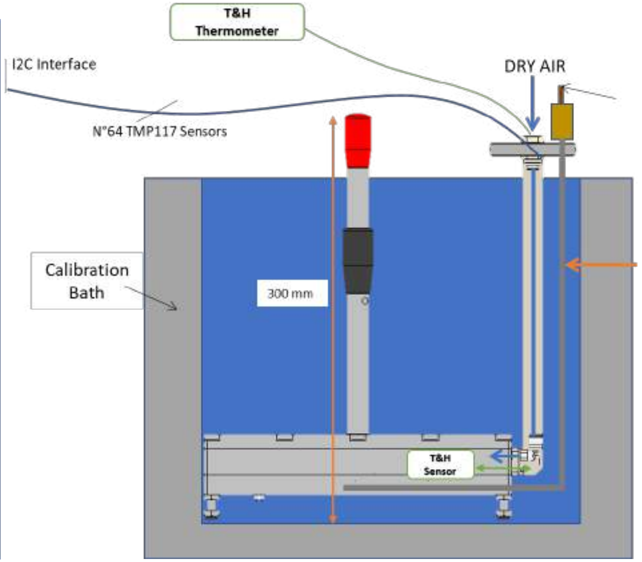
Sensor	TMP117 (Factory Calibrated)		
	°C	°C	°C
Set-point temperature	**5**	**35**	**80**
Max temperature	5.20	35.05	80.17
Min temperature	4.84	34.96	79.64
Temperature homogeneity (max-min)	0.36	0.09	0.53
Mean temperature	4.97	35.00	80.00
Temperature stability	0.02	0.02	0.02
Set-point deviation (mean-setpoint)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

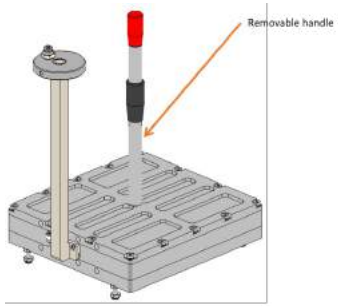
Improved thermal chuck metrological characterization

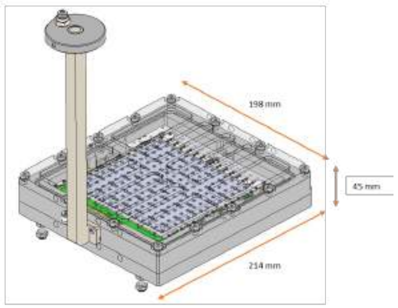
Section	All	All exc 2	12	11	9	8	6	5	3	2	10	7	4	1
°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
Mean	80.00	80.00	80	80.01	80	80	80	80.01	80.01	80	80	80	80	80.01
Max	80.17	80.14	80.14	80.05	80.02	80.05	80.14	80.08	80.08	80.17	80.03	80.05	80.06	80.09
Min	79.64	79.86	79.86	79.97	79.97	79.95	79.89	79.94	79.98	79.64	79.93	79.93	79.94	79.93
*u*_t_homog	0.21	0.08	0.08	0.02	0.02	0.03	0.08	0.04	0.04	0.21	0.04	0.04	0.03	0.05
*u*_t_stability	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
*U*_ac	0.43	0.20	0.19	0.12	0.11	0.12	0.19	0.13	0.13	0.43	0.13	0.13	0.13	0.14

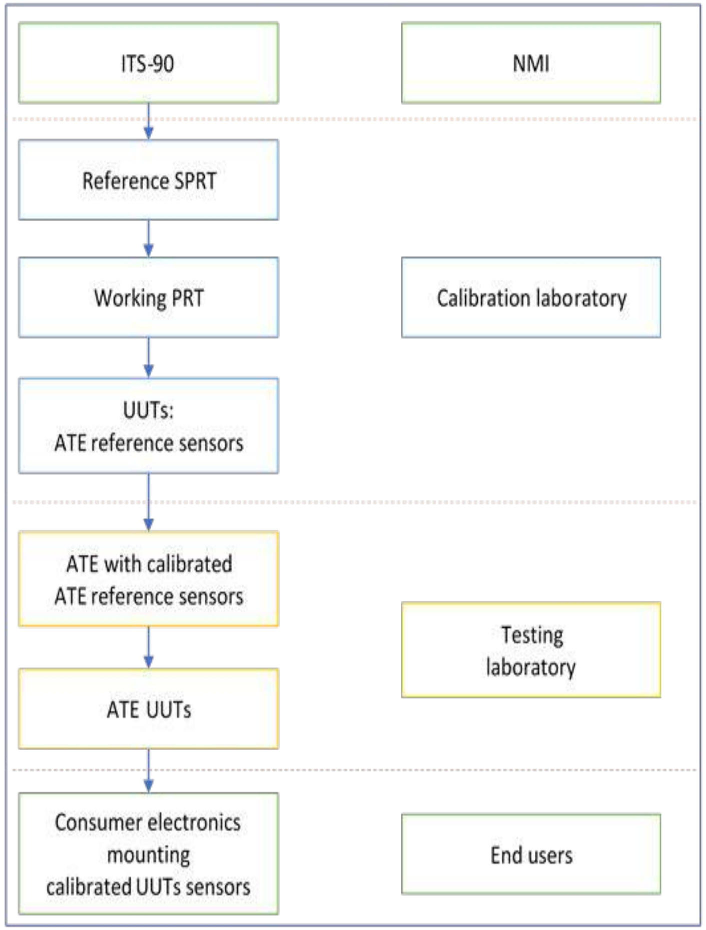
Improved thermal chuck calibration and traceability chain



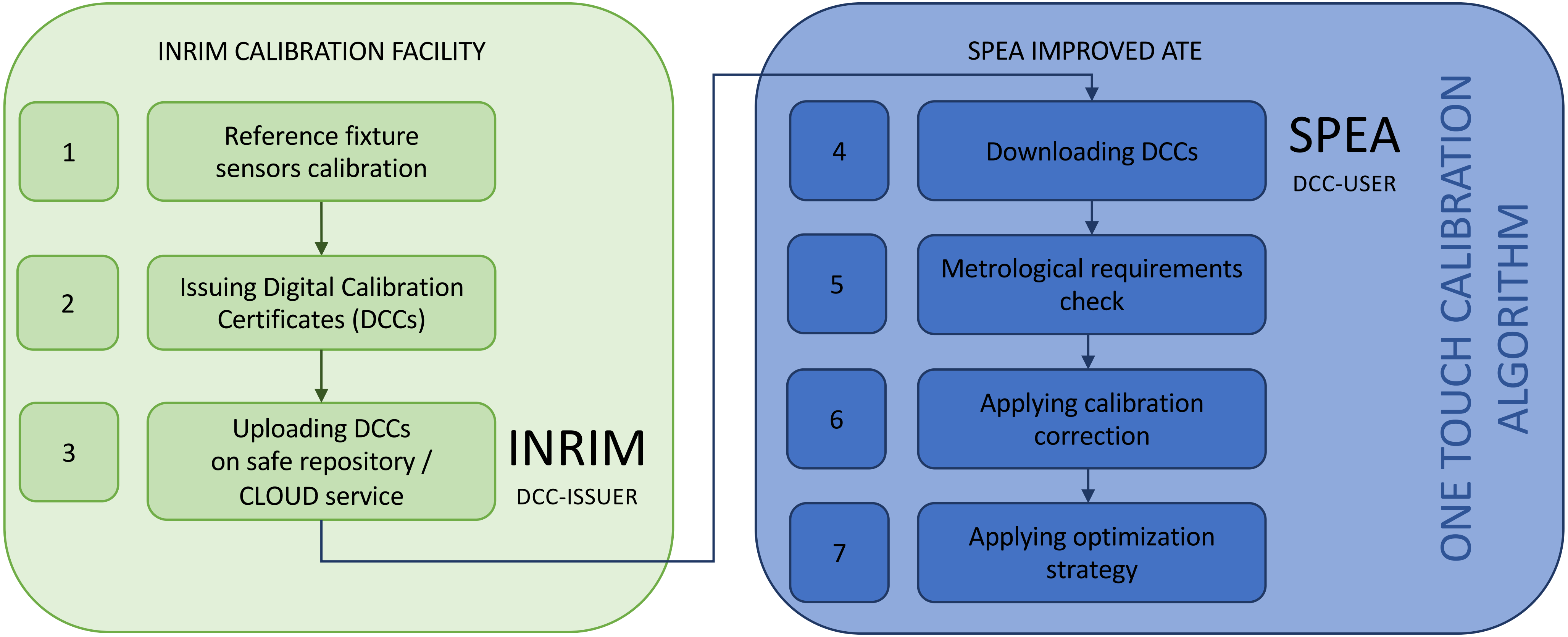








One-touch calibration algorithm for the reference sensors of the SPEA improved ATE systems



Considerazioni sui DCC

INRiM — ISTITUTO NAZIONALE DI RICERCA METROLOGICA

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+39 011 3919.1
+39 011 346384
inrim@inrim.it - www.inrim.it

pag. 1/5

CERTIFICATO DI TARATURA
Certificate of Calibration

N. 21-0264-01 emesso il/*issued on* 2021-09-01

Oggetto *Item/Object*	Sensore di temperatura integrato con uscita digitale/ IC temperature sensor with digital output
Modello/Tipo *Model/Type*	TMP117
Identificazione *Serial number*	RF1-1
Costruttore *Manufacturer*	Texas Instruments
Data ricevimento oggetto *Date of receipt of item*	2021-02-03
Data delle misure *Date of Measurements*	Dal 2021-02-24 al 2021-02-25
Procedura applicata *Applied procedure*	//
Registro di laboratorio *Laboratory record book*	Commessa 21-0264
Committente *Customer*	SPEA SpA
Indirizzo *Address*	Via Torino, 16, 10088 Volpiano TO

Responsabile attività
Responsible for the activities
(Denis Smorgon)

Autorizzato da
Authorized by
Funzione
(Michela Sega)

Il presente certificato attesta la riferibilità delle misure ai Campioni Nazionali (D.M. n. 591/1993) e alle unità di misura realizzate all'INRIM o in altri Istituti Metrologici Primari ai sensi della Legge n. 273/1991.
I risultati qui riportati si riferiscono esclusivamente agli oggetti descritti e alle condizioni di misura specificate.
L'autenticità del presente certificato è attestata dall'apposizione in originale delle firme e del timbro a secco.
La riproduzione del presente certificato è ammessa solo in copia conforme integrale; la riproduzione in copia conforme parziale è ammessa solo su autorizzazione scritta rilasciata dall'INRIM, da riportare con il numero di protocollo sulla riproduzione.

Tabella 2 / *Table 2*. Risultati della taratura / *Calibration Results*

N. ordine	t_{NOM} (°C)	t_{RIF} (°C)	t_{UUT} (°C)	t_{UUT} - t_{RIF} (°C)	U (°C)
1	5	4.58	4.65	0.07	0.07
2	15	14.57	14.64	0.07	0.06
3	25	24.57	24.61	0.04	0.06
4	35	34.56	34.61	0.05	0.06
5	60	59.59	59.63	0.04	0.06
6	80	79.62	79.64	0.02	0.07
7	85	84.62	84.64	0.02	0.07

INRiM — ISTITUTO NAZIONALE DI RICERCA METROLOGICA

CERTIFICATO DI TARATURA
Certificate of Calibration

N. 21-0264-01 emesso il/*issued on* 2021-09-01 - pag. 3/5

Nella tabella 1 è riportato il bilancio di incertezza della parte fissa (u_{fix}) relativa al processo di misura. Esso include i contributi di incertezza dovuti ai termometri di riferimento ed alla sua catena di misura, al mezzo di confronto e alla risoluzione dell'UUT.
Table 1 shows the uncertainty budget of the fixed part (u_{fix}) related to the measurement process. It includes the contributions of uncertainty due to the reference thermometers and its measurement chain, the comparison medium and the UUT resolution.

Tabella 1 / *Table 1*. Stima dei contributi di incertezza fissi del processo di misura / *Evaluation of the fixed uncertainty contributions of the measurement process.*

Code	Contributions	Units	Value	Moltiplicative factor	Pdf	Divisor	St. Dev °C	(St.Dev)^2 °C²
UNCERTAINTIES OF THE REFERENCE CALIBRATION SYSTEM								
1aa	PRT calibration	°C	0.020	1	Normal	2	0.010	1.00E-04
1ab	PRT long-term stability	°C	0.050	1	Rectangular	3.46	0.014	2.08E-04
1ac	PRT fitting	°C	0.025	1	Normal	1	0.025	6.25E-04
1ba	DAQ Calibration or Accuracy	°C	0.010	1	Normal	2	0.005	2.50E-05
1bb	DAQ stability over time	°C	0.010	1	Rectangular	3.46	0.003	8.33E-06
1bc	DAQ resolution	°C	0.001	1	Rectangular	3.46	0.000	8.33E-08
UNCERTAINTIES OF THE UUT								
2ab	UUT resolution	°C	0.001	1	Rectangular	3.46	0.000	8.33E-08
Combined standard uncertainty - u _fix		°C				u_c	**0.03**	

L'incertezza di taratura riportata nella tabella 2 include il contributo u_{fix} composto coi contributi di ripetibilità dell'UUT (u_{UUT_rep}) e della temperatura di riferimento (u_{REF_rep}), e all'omogeneità di temperatura rilevata all'interno del blocco equalizzatore ($u_{homog\_cal\_tool}$). Pertanto l'incertezza di taratura in ogni singolo punto di taratura è calcolato come:
The calibration uncertainty shown in table 2 includes the u_{fix} contribution composed with the UUT repeatability contribution of the UUT (u_{UUT_rep}) and the reference temperature (u_{REF_rep}), and the homogeneity of temperature within the equalizer block ($u_{homog\_cal\_tool}$). Finally, the calibration uncertainty in each single calibration point is calculated as:

$$U = 2 \times \sqrt[2]{u_{fix}^2 + u_{UUT\_rep}^2 + u_{REF\_rep}^2 + u_{homog\_cal\_tool}^2}$$

I risultati della taratura sono riportati nella tabella 2.
The calibration results are shown in table 2.

Tabella 2 / *Table 2*. Risultati della taratura / *Calibration Results*

N. ordine	t_{NOM} (°C)	t_{RIF} (°C)	t_{UUT} (°C)	t_{UUT} - t_{RIF} (°C)	U (°C)
1	5	4.58	4.65	0.07	0.07
2	15	14.57	14.64	0.07	0.06
3	25	24.57	24.61	0.04	0.06
4	35	34.56	34.61	0.05	0.06
5	60	59.59	59.63	0.04	0.06
6	80	79.62	79.64	0.02	0.07
7	85	84.62	84.64	0.02	0.07

Controllato da:
Checked by (Vito Fernicola)

Considerazioni sui DCC

1. *SITE AND MEASUREMENT CONDITIONS*
   INRIM - Laboratorio di igrometria primaria / *Primary hygrometry laboratory.*
   Temperatura dell'aria / *Air temperature:* 25 °C ± 3 °C
   Umidità Relativa / *Relative humidity:* 50 %rh ± 20 °C
2. *RESULTS AND EXPANDED UNCERTAINTIES*

   The calibration results are shown in table 1.

Table 1. Calibration Results

N. ordine	t_{NOM} (°C)	t_{RIF} (°C)	t_{UUT} (°C)	t_{UUT} - t_{RIF} (°C)	U (°C)
1	5	4.58	4.65	0.07	0.07
2	15	14.57	14.64	0.07	0.06
3	25	24.57	24.61	0.04	0.06
4	35	34.56	34.61	0.05	0.06
5	60	59.59	59.63	0.04	0.06
6	80	79.62	79.64	0.02	0.07
7	85	84.62	84.64	0.02	0.07

Legend:

t_{NOM}	=	*; Nominal temperature*
t_{RIF}	=	*Reference temperature*
t_{UUT}	=	*UUT reading*
U	=	*Calibration expanded uncertainty.*

The expanded uncertainty U is expressed as the standard uncertainty multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%. In assessing the uncertainty, the long-term stability of the UUT was not considered.

The UUT reading can be corrected using the correction function described by the following polynomial:

$$y = a_0 + x^1 \cdot a_1 + x^2 \cdot a_2 + x^3 \cdot a_3 + x^4 \cdot a_4 \ldots\ldots + x^n \cdot a_n$$

HUMAN READABLE DCC

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DCC XLM CODE

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

ACCREDIA L'ENTE ITALIANO DI ACCREDITAMENTO