Temperature metrology

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Fluke Precision Measurement

Temperature metrology

- Properties of thermometers
- Sensor types
- Why calibrate
- Calibration techniques

Properties of a thermometer

- It must be reproducible
  This means that whatever the measured property of the device, that property should have the same value (or very nearly so) whenever the temperature is the same

- It must be insensitive to things other than temperature
  This means that whatever the measured property of the device, that property should not depend on factors such as the humidity or pressure, or on the materials of which it is made, or on special properties of the thing being measured such as its colour or size

- It should be convenient to use
  Factors such as size, cost, speed of response, ruggedness, immunity to electrical interference, etc, will be important to varying degrees in different applications

- It must be calibrated
  This means that we must know how to convert the measured property (length, resistance, etc) to temperature

Properties of a thermometer

- Platinum resistance thermometer or a thermistor - the property measured is the electrical resistance of a piece of 'sensing' material
- Thermocouple - the property measured is the voltage generated along the wires making up the thermocouple

Why calibrate ?

- Provides confidence that the instrument has been, and is, operating to the manufacturers specification
- Ensures compliance with quality systems and industry regulations
- Provides traceability to your measurements
- In case of higher accuracy sensors calibration is actually characterisation

Sensor types

SPRT's	±0.00035°C [at Ga]
Secondary standard PRT's	±0.005°C
Thermistors	±0.01°C
PRT's	±0.1°C
Thermocouples	±1.5°C

Calibration methods

- Absolute Method
  - The Unit Under Test is subjected to a physically defined standard such as a repeatable phenomenon of nature

- Comparison Method
  - The Unit Under Test is compared against another measuring device of known and superior accuracy

Calibration equipment

- Factor of 5000 difference between most and least accurate sensors
- No one set up will be suitable for all sensors
- Uncertainty required determines calibration system

Calibration uncertainty

Total Calibration Uncertainty (RSS) = $\sqrt{A^2 + B^2 + C^2 + D^2}$

A = Reference probe accuracy*

B = Reference probe readout accuracy

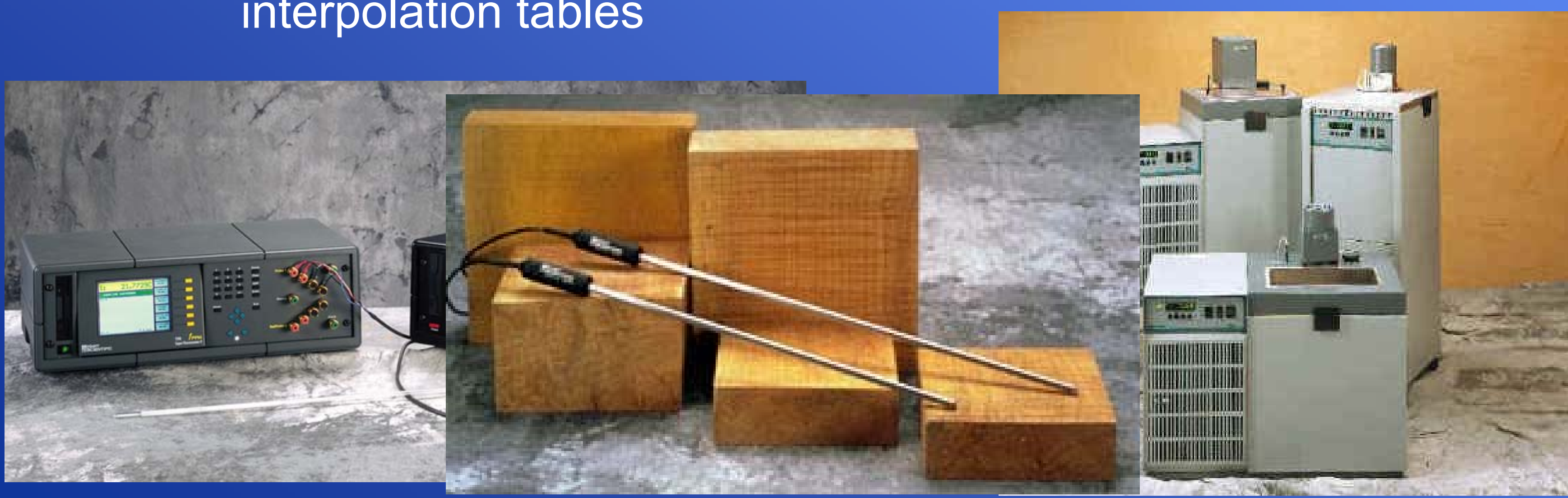
C = Temperature source stability

D = Temperature source uniformity

**calibration accuracy and short term drift*

Calibration system

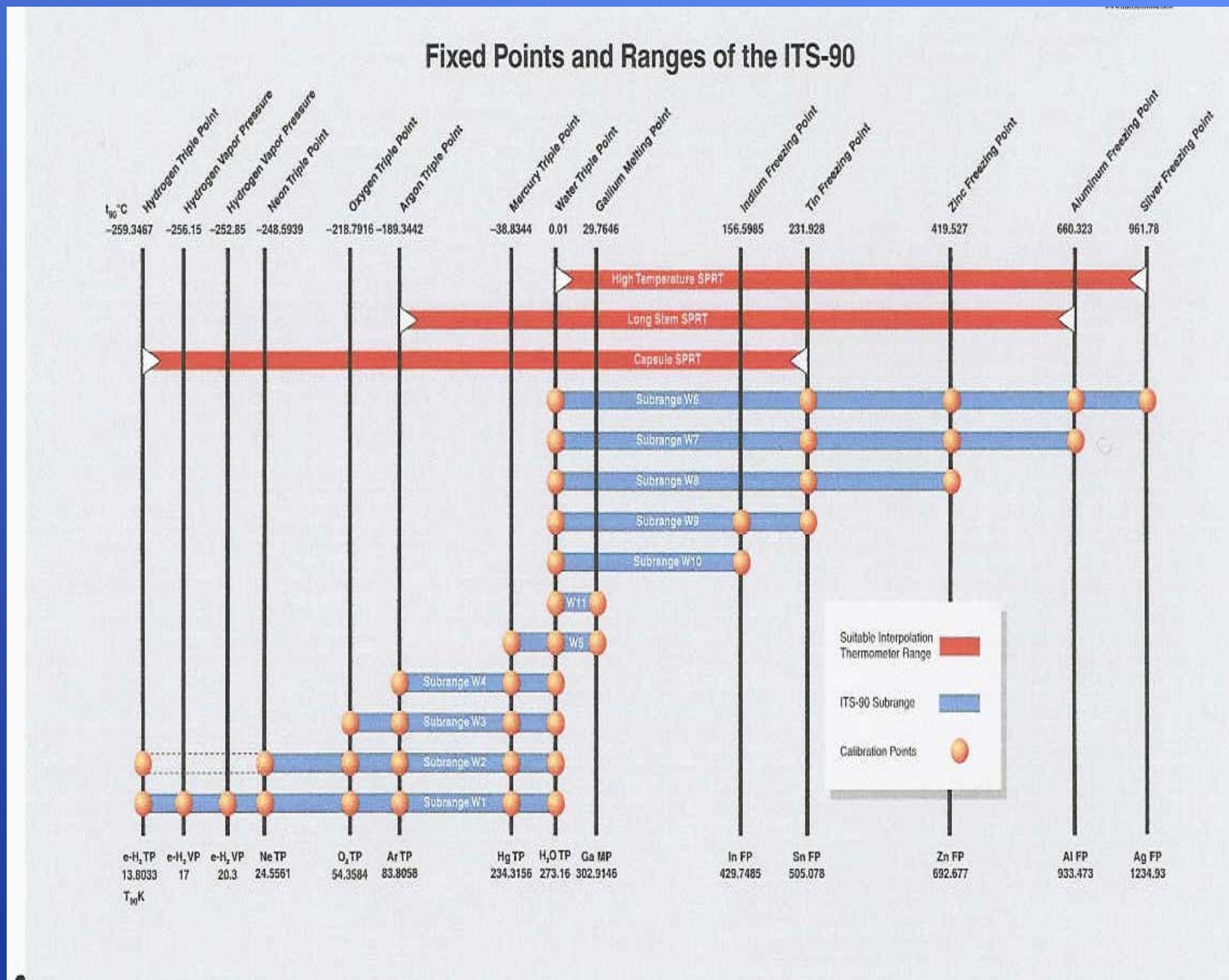
- High stability isothermal heat source
- Reference SPRT’s or PRT’s
- Readout for measurement of SPRT’s and UUT’s
- Software for generation of calibration coefficients and interpolation tables



SPRT Calibration

- SPRT is defined by ITS-90
- Absolute method of calibration
- Calibrated using
  - *ITS-90 defined fixed points*
  - *resistance ratio measurements made with bridge*
- Calibration is actually characterisation
  - *resistance readings fitted to a mathematical expression*
  - *we use Mathcad ITS-90 reduction software*
  - *also produces interpolation tables*

ITS-90 ranges



SPRT Calibration

Equipment Type		Specifications	Suggested Equipment
Bridge	Accuracy	±0.1 ppm	MIL 6010T
Standard Resistors	Values	1,10, and 100 Ω	DC: Tinsley 5685 series
	Accuracy	±2.0 ppm	
Fixed Point Cells	Cells	Ag, Al, Zn, Sn, In, Ga, TPW, Hg	Hart scientific 59XX series
	Accuracy	±0.00005 to 0.005 °C	
Reference SPRT	Range	-200 to 0.0 °C	Hart Scientific 5683
	Accuracy	±0.0002 °C	
Fixed Point Furnaces	Range	30 to 962 °C	Hart Scientific 7312, 7012, 7008, 7060
	Stability:	±0.1 to 0.5 °C	
Liquid Nitrogen Apparatus	Range	≈ -196 °C	Hart Scientific 7028
	Stability:	±0.0002 °C	
Annealing Furnace	Range	235 to 1000 °C	Hart Scientific 9117
	Stability:	±0.5 °C	

SPRT Calibration - coefficients

Deviation function for the subrange 83.8058 K to 273.16 K (–189.3442°C to 0.01°C):

$$\Delta W_4(T_{90}) = a_4 \cdot (W(T_{90}) - 1) + b_4 \cdot (WT_{90}) - 1) \cdot \ln(W(T_{90})) \quad (4)$$

Where: $\Delta W(T_{90})$ = calculated deviation value at temperature T (from equation (2))
$W(T_{90})$ = calculated resistance ratio at temperature T (from equation (1))
a_4, b_4 = resulting calibration coefficients

Reference function for the range 273.15 K to 1234.93 K (0.00°C to 961.78°C):

$$W_r(T_{90}) = \sum_{i=0}^{9} C_i \left(\frac{(T_{90} - 754.15}{481} \right)^i \quad (5)$$

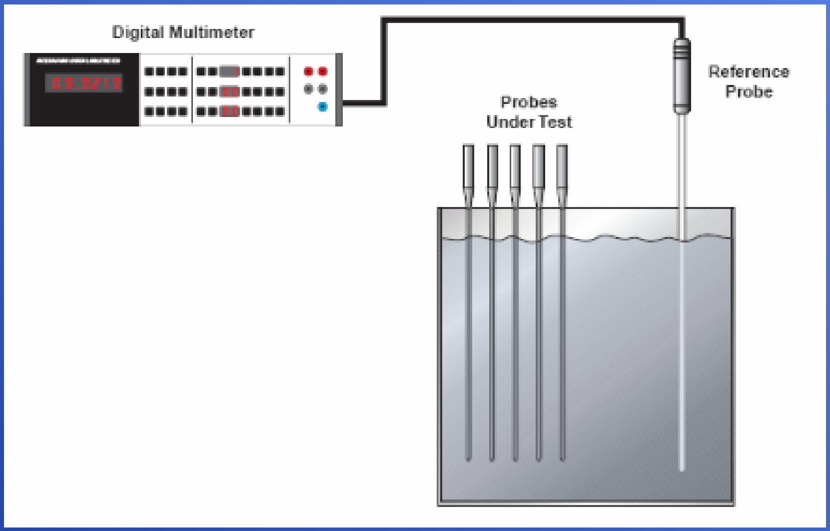
Where: $W_r(T_{90})$ = reference function value at temperature T
C_i = reference function coefficients from definition

Deviation function for the subrange 273.15 K to 692.677 K (0.00°C to 419.527°C):

$$\Delta W_8(T_{90}) = a_8 \cdot (W(T_{90}) - 1) + b_8 \cdot (WT_{90}) - 1)^2 \quad (6)$$

Where: $\Delta W(T_{90})$ = calculated deviation value at temperature T (from equation (2))
$W(T_{90})$ = calculated resistance ratio at temperature T (from equation (1))
a_8, b_8 = resulting calibration coefficients

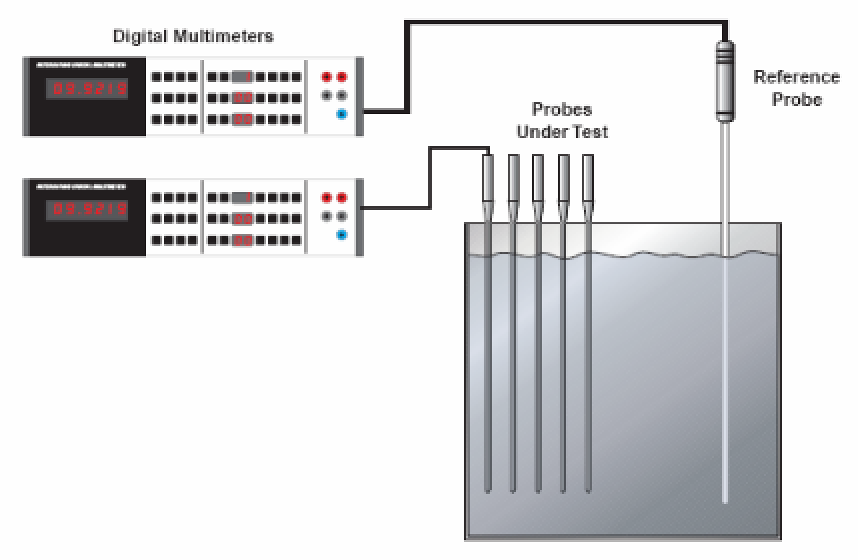
PRT calibration



- Probes as close together as is practical
- Preferably in radial pattern – reference at centre
- Sensing elements on same horizontal plane
- Wait for equilibrium

Disadvantages

- Time consuming
- DMM's do not allow input of unique cal coefficients
- Need to use look up tables or software
- Does not provide real time temperature data
- Unstable heat source will introduce errors due to delay in temperature calculations
- Two DMM's quicker but still have conversion delays



PRT calibration

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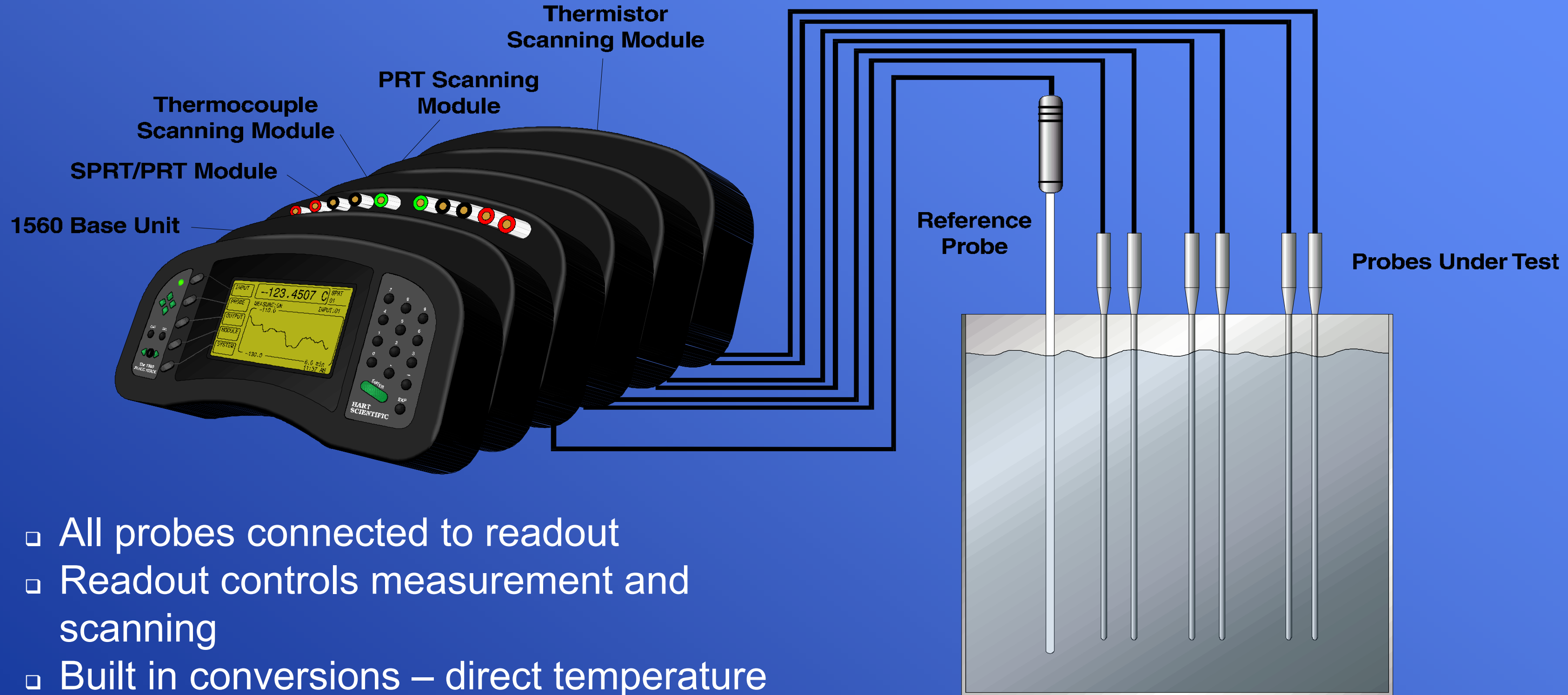
A better method



- All probes connected to readout
- Readout controls measurement and scanning
- Built in conversions – direct temperature reading
- Can be software controlled

PRT characterisation

High accuracy

use ITS-90 fit

Medium accuracy

Callendar van Dusen (CVD) – simpler mathematics

Basis of temperature scales of 1927, 1948 and 1968

Limitations on precision of fit

History, simplicity and suitability make it preferred fit for medium accuracy

Low accuracy

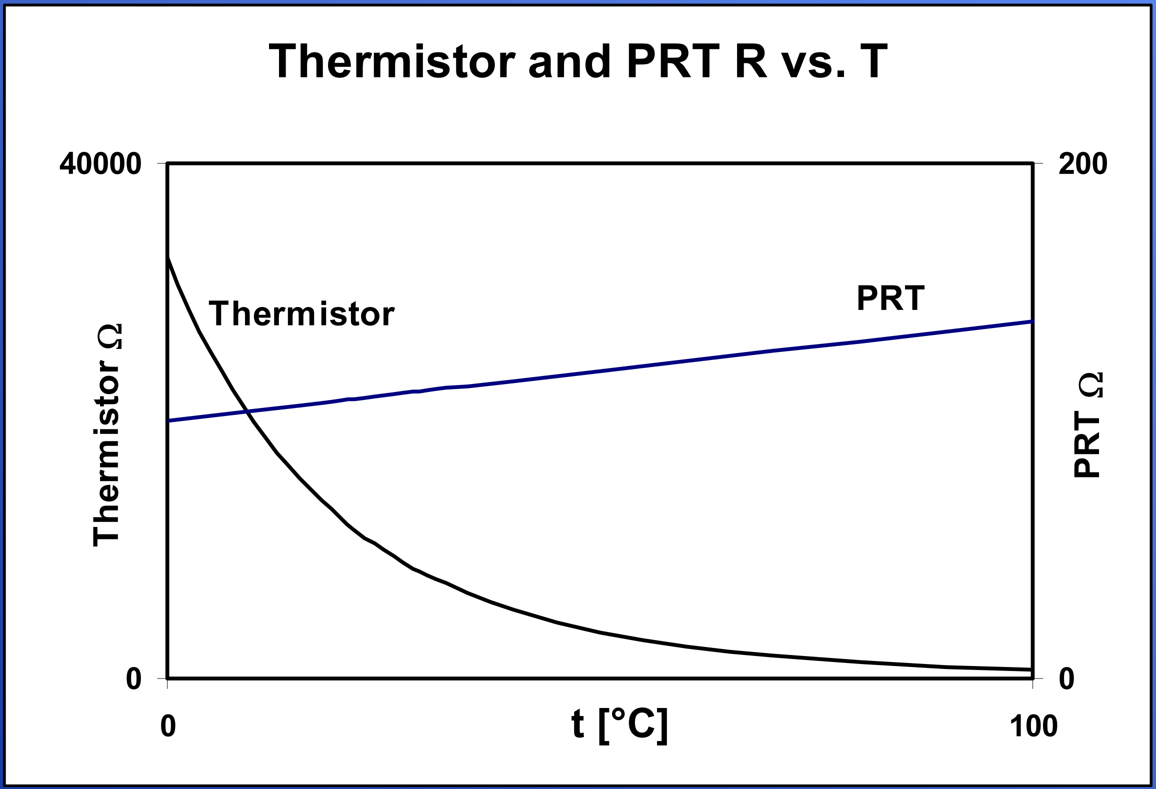
Not characterisation but tolerance testing

Does it conform to DIN curve

Class A ±0.15 + (0.002.t)^{o}C

Class B ±0.30 + (0.003.t)^{o}C

Thermistor characteristics



- All accuracy levels
- Semiconductor sensor
- Narrow temperature range (-50 to 200 °C)
- Exponential with high sensitivity
- Negative TCR
- Stable over time and temperature

Thermistor calibration

- Comparison calibration as for PRT’s
- Use Metrology Well or bath depending on accuracy
- Characterisation for medium to high accuracy
  - *Third order polynomial – exponential curve*
  - *Steinhart-Hart equation*
- Tolerance testing at low accuracy

Thermocouple calibration

- Comparison calibration
- Use industrial dry well, Metrology Well or bath depending on accuracy
- Bare wire or probe configuration will also determine heat source
- Use a reference PRT (SPRT for Pt-Au T/C's)
- Readout
  - *Unless using a reference thermocouple two readouts will be required – or use 1529/1560*
  - *Generally tolerance testing to conform to thermocouple type*

Automated calibration

All techniques described have one major disadvantage

Calibration software

- Automated or semi-automated calibration
- Calculate calibration coefficients
- Generate interpolation tables
- Print calibration certificate

Questions

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