Best practices for temperature calibration

Temperature plays a key role in many industrial and commercial processes. Examples include monitoring cooking temperature in food processing, measuring the temperature of molten steel in a mill, verifying the temperature in a cold storage warehouse or refrigeration system, or regulating temperatures in the drying rooms of a paper manufacturer.

A temperature transmitter will use a measuring device to sense the temperature, and then regulate a 4–20 mA feedback loop to a control element that affects the temperature (Fig. 1). The control element might consist of a valve that opens or closes to allow more steam into a heating process or more fuel to a burner. The two most common types of temperature sensing devices are the thermocouple (TC) and resistive temperature detector (RTD).

Fluke provides a broad range of temperature calibration tools to help you quickly and reliably calibrate your temperature instrumentation. A summary of the temperature calibration capabilities of Fluke Process Tools is shown below.
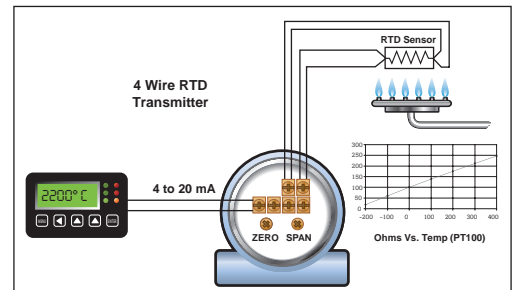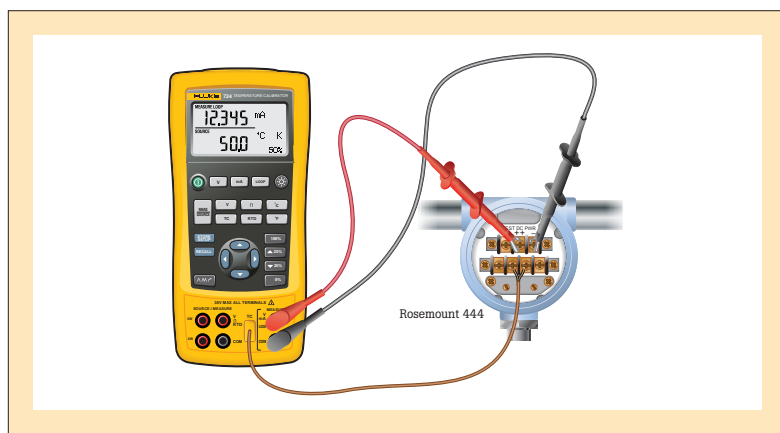
Fluke 724 Temperature Calibrator

Figure 1.

Fluke Temperature Test Tools

Function	Fluke 712	Fluke 712B	Fluke 714	Fluke 714B	Fluke 721	Fluke 724	Fluke 725	Fluke 726	Fluke 753	Fluke 754	9142-P/9143-P/9144-P	9142/9143/9144	9190A-P	9190A	9103	9140	9141	9009	9100S	9102S	6102	7102	7103	7526A
Apply known temperatures to verify T/C and RTD											•	•	•	•	•	•	•	•	•	•	•	•	•	
Provide temperature traceability											•	•	•	•	•	•	•	•	•	•	•	•	•	
Measure temperature from an RTD probe	•	•		•	•	•	•	•	•	•	•		•											•
Measure temperature from a T/C probe			•	•		•	•	•	•	•	•		•											•
Simulate an RTD output	•	•			•	•	•	•	•	•														•
Simulate an RTD into pulsed excitation current		•								•														•
Simulate a T/C output			•	•		•	•	•	•	•														•
Simultaneous output a T/C, measure mA						•	•	•	•	•														•
Simultaneous output an RTD, measure mA		•				•	•	•	•	•														•
Log a temperature measurement							•	•			•		•											
Ramp a temperature signal		•		•		•	•	•	•	•														
Loop power supply						•	•	•	•	•	•		•											•
Multifunction Source and Measure							•	•	•	•														•
Automatically calibrate temperature switches							•	•			•													•
Manually calibrate temperature switches															•	•	•							
Electronic data capture							•	•			•													
Upload documented data to PC							•	•			•													•
Integrated HART communication										•														
Simulate characterized RTD												•												•
Measure characterized RTD											•		•											•
Accredited calibration											•	•	•	•										•
Equilibrate irregularly shaped probes																					•	•	•	
Generate hot and cold temperatures simultaneously																		•						

Typical Temperature Calibration Applications

How to calibrate a Thermocouple input transmitter

Rosemount 444

The Fluke 724 Temperature Calibrator can provide the three things necessary to calibrate a temperature transmitter. You can source a temperature, provide loop power, and measure the resulting output current. The following example shows how to calibrate a Type K TC transmitter that is ranged from 0–150 degrees centigrade, generating an output current range from 4–20 mA.

Basic Calibrator Setup

1. Connect the 724 test leads to the TC transmitter as shown. The output from the thermocouple jacks on the 724 will simulate a temperature input to the transmitter. The red and black test leads will provide loop power to the transmitter and will measure the current resulting from temperature changes into the transmitter.

2. Power on the 724 calibrator. Select the mA button and the LOOP button to select measure milliamps with 24 V loop power applied.

3. Press the Meas/Source button until the lower portion of the 724 display indicates the source mode.

4. Depress the TC button until a TC type of K is displayed.

5. Select the °C button for centigrade.

6. Set the Zero Point for this application into the Calibrator. To do this set the display initially to 0.0 °C. You can use the up and down arrow keys to change the output value. Use the left and right arrows to control which decade value of the display is being changed. When the display reads 0.0, hold down the 0 % key on the 724 and observe that 0 % is displayed in the lower right corner of the screen. This establishes the Zero point for calibration.

7. Set the Span Point in the Calibrator. Set the display to the desired Span value for calibration. In this example the display should read 150 °C. Depress the 100 % key and observe that 100 % is displayed in the lower right corner of the screen. This establishes the Span point for calibration.

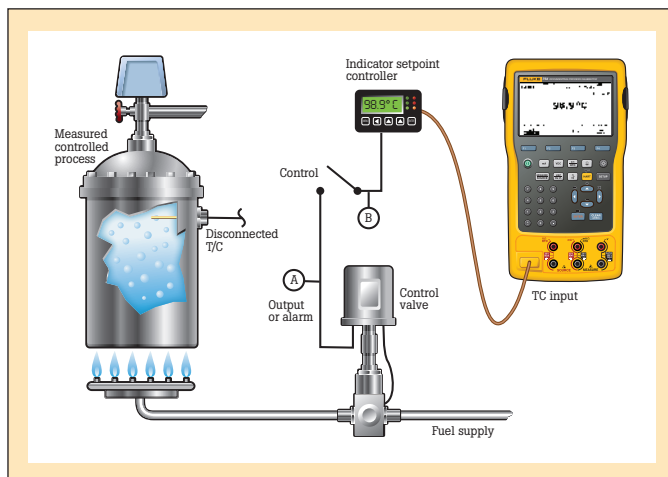### Performing an "As Found" Test

8. Depress the 0 % key; record the applied temperature and the corresponding mA measurement.

9. Depress the 25 %↑ key (2) times; record the applied temperature and the corresponding mA measurement.

10. Depress the 100 % key; record the applied temperature and the corresponding mA measurement.

11. Calculate the errors for each of the (3) points using the following formula: **ERROR = ([(I-4)/16]-[(T/TSPAN])*100** where Error is in % of span, I is your recorded mA measurement, T is the recorded temperature and TSPAN is the temperature input span (100 % – 0 % points). The error calculation table below shows how to apply the formula to actual recorded measurements.

12. If your calculated errors are less than the specified instrument tolerance, the transmitter has passed the As-Found test. If the test has not passed, perform adjustments as necessary.

Adjusting the Transmitter

13. Depress the 0 % key to source the proper temperature for a 4 mA output. Adjust the zero potentiometer until the current reading is 4.00 mA.

14. Depress the 100 % key to source the proper temperature for a 20 mA output. Adjust the Span potentiometer until the current reading is 20.00 mA.

15. Depress the 0 % key again and adjust the zero potentiometer again if necessary, to get a 4.00 mA output.

Perform an "As Left" Test
Repeat steps 8 through 12 to complete the full calibration procedure on your temperature transmitter.

Temperature transmitter error calculation example

| mA Measurement	TC Source	T Span	Formula	Error %
4.02	0 °C	150 °C	([4.02-4)/16]-[0/150])*100	0.1250
11.95	75 °C	150 °C	([11.95-4)/16]-[75/150])*100	–0.3125
20.25	150 °C	150 °C	([20.25-4)/16]-[150/150])*100	1.5625

Sourcing temperature, documented indicator verification

The performance of a temperature indicator can be verified by applying a calibrated signal to the sensor input and noting the results. The performance of the indicator can be documented using the 750 series calibrators by entering the indicator value using the keypad.
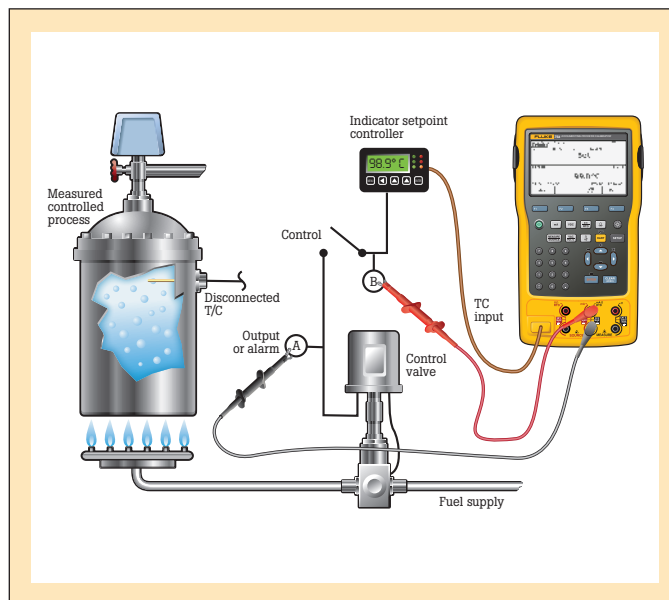
Verifying thermostat or temperature controllers

The performance of a thermostat or temperature controller can be determined by measuring the outputs while applying a temperature signal to the input. In this example, a Fluke 750 series calibrator simultaneously varies the input signal while monitoring contact closure on the output. The calibrator then documents the measured setpoint, reset point and deadband size.
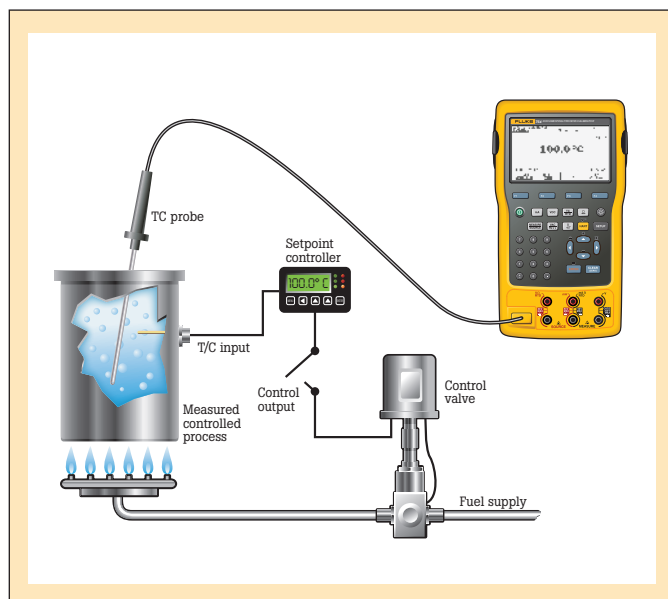

Measuring temperature

Process temperatures can be verified using a temperature calibrator or digital thermometer. In this example, both the controller/indicator and its' input sensor can be verified at the process operating temperature.

Precision RTD Temperature Measurement

Use characteristic RTD probes with the 726 Precision Multifunction Process Calibrator for enhanced temperature measurement accuracy.
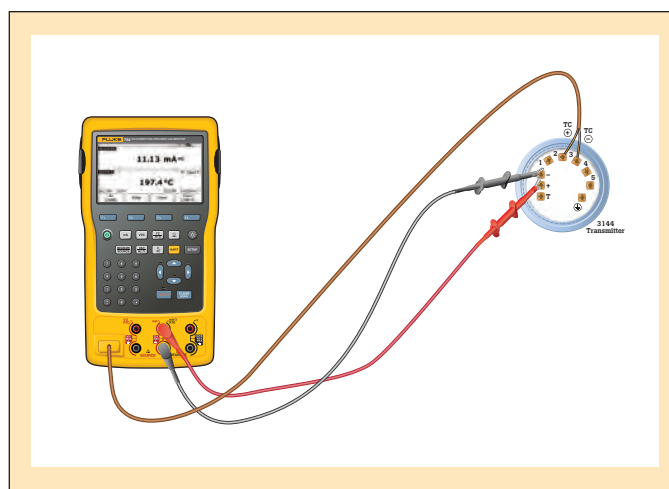
Calibrate a HART temperature transmitter

HART "smart" transmitters require digital adjustment if found to be out of specification. This task requires a precision calibrator and a digital configuration tool. The Fluke 754 shown is connected to a Rosemount 3144 HART tempera-ture transmitter. In this configuration, the 754 applies a T/C simulation signal and measures the mA output and digital PV. If adjustment is necessary, sensor trim, output trim and re-ranging can be performed with the Fluke 754.

Fluke 712B
Temperature Calibrator

- Measure and simulate (13) different RTD types and resistance
- Measure 4 to 20 mA signals while simultaneously sourcing a temperature signal
- Hanging tool designed in and included with every unit.
- Configurable 0 % and 100 % source settings for quick 25 % linearity checks
- Linear ramp and 25 % step auto ramp based on 0% and 100 % settings

Fluke 724
Temperature Calibrator

- Measure and simulate (12) different thermocouple types and millivolts
- Measure and simulate 7 RTD types (see 712)
- Measure or source VDC, Ω
- Measure 24 mA, with or without 24 volt loop supply
- Source TC or RTD while measuring V or mA
- Handles pulsed RTD transmitters with pulses >25 ms

Fluke 714B
Thermocouple Calibrator

- Measure and simulate (17) different thermocouple types and millivolts
- Measure 4 to 20 mA signals while simultaneously sourcing a temperature signal
- Hanging tool designed in and included with every unit.
- Configurable 0 % and 100 % source settings for quick 25 % linearity checks
- Linear ramp and 25 % step auto ramp based on 0 % and 100 % settings

Fluke 725
Multifunction Process Calibrator

All the temperature capabilities of the Fluke 724, plus:
- Measure pressure with Fluke 700Pxx Pressure Modules
- Source or measure frequency to 10 kHz
- Source mA signals

Fluke 721
Precision Pressure Calibrator

- Ideal for gas flow calibration (custody transfer) applications
- Two isolated, stainless steel, pressure sensors with 0.025% accuracy
- Pt100 RTD input for temperature measurement, (probe optional)
- Measures 4 to 20 mA signals
- Internal 24 V loop power supply can power a transmitter under test
- Measure up to 30 V DC, check 24 V loop power supplies
- Extend pressure measurement range with connection to external 700 series pressure modules (29 ranges)
- Large backlit graphic display can display up to three inputs simultaneously
- Store five instrument setups for recall and use

Fluke 726 Precision
Multifunction Process Calibrator

All the capabilities of the Fluke 725 plus:
- 0.01 % accuracy
- Error calculation
- Characterized RTD constants
- Enhanced measurement accuracy
- Measure and source pulse totalization

Fluke 753 and 754 Documenting
Process Calibrators

- Measure and simulate (13) different thermocouple types and millivolts
- Measure and simulate 7 RTD types, per 712 below, plus Cu 10 (47)
- Source or measure volts, ohms, mA, frequency
- Measure pressure with Fluke 750Pxx Pressure Modules
- Electronically capture results of automated procedures
- Communication to PC–USB
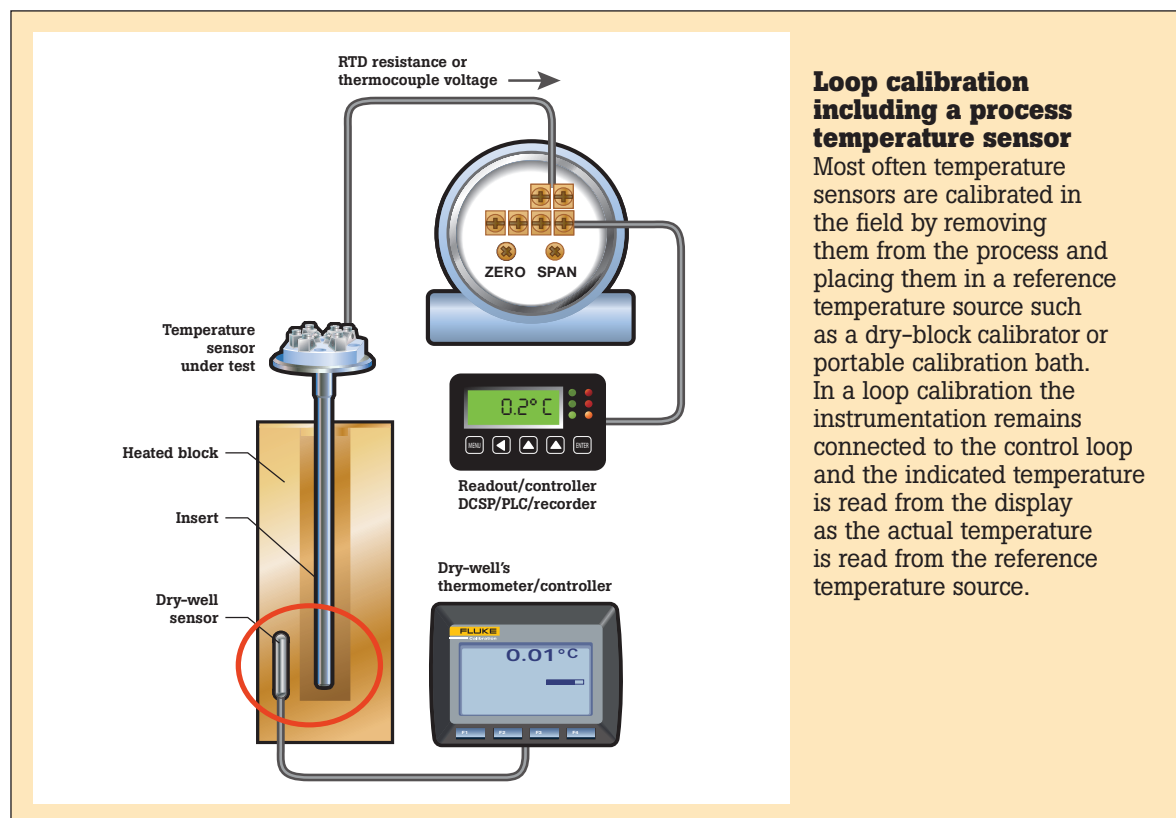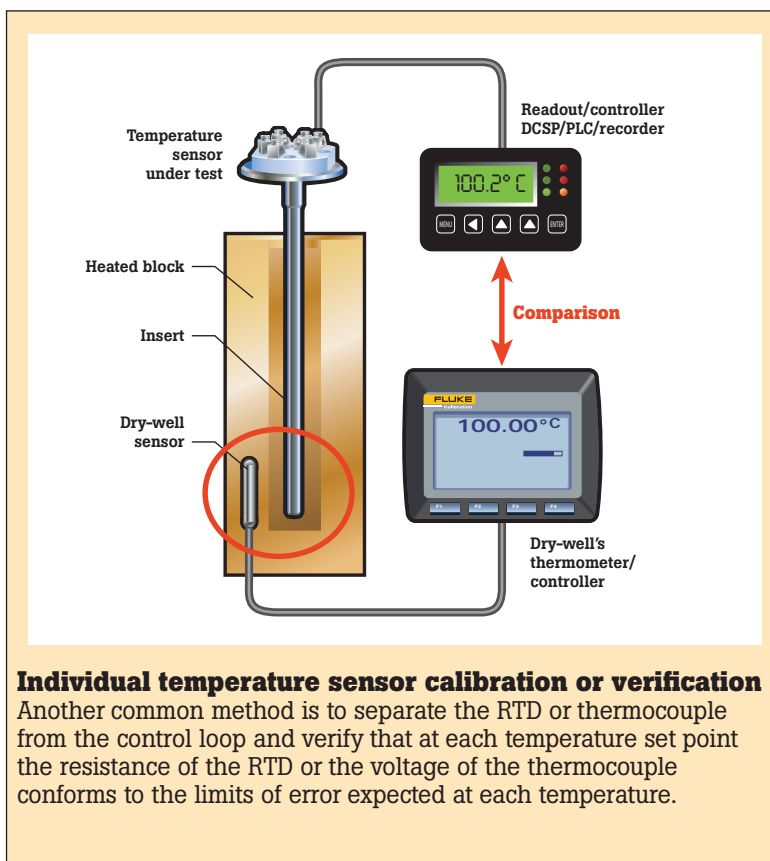- HART communication (754)

Eliminating errors from temperature sensors

In addition to sourcing a voltage or resistance to verify your tempera–ture transmitter or temperature controller you may want to verify your thermocouple or RTD as well. This is especially important for critical instrumentation that could potentially compromise product or process quality if it does not con–form to specifications.

There are a few reasons you may want a traceable calibration that includes the sensor:
- Eliminate up to 75% of the error in a process measurement
- Conform to health, safety, environment, and other government regulations
- Comply with quality standards such as ISO 9000, which require regular calibration of all quality related equipment
- Reduce waste and improve productivity
- Comply with customer contracts requiring traceability to nation–al standards
- Be certain measurements will be reproduced within known limits of error when instruments are replaced

Temperature sensor under test
Heated block
Insert
Dry-well sensor
Readout/controller DCSP/PLC/recorder
100.2°C
Comparison
100.00°C
Dry-well's thermometer/controller

Individual temperature sensor calibration or verification
Another common method is to separate the RTD or thermocouple from the control loop and verify that at each temperature set point the resistance of the RTD or the voltage of the thermocouple conforms to the limits of error expected at each temperature.

RTD resistance or thermocouple voltage
ZERO   SPAN
Temperature sensor under test
Heated block
Insert
Dry-well sensor
0.2°C
Readout/controller DCSP/PLC/recorder
Dry-well's thermometer/controller
0.01°C

Loop calibration including a process temperature sensor
Most often temperature sensors are calibrated in the field by removing them from the process and placing them in a reference temperature source such as a dry-block calibrator or portable calibration bath. In a loop calibration the instrumentation remains connected to the control loop and the indicated temperature is read from the display as the actual temperature is read from the reference temperature source.

Connecting a Fluke 754 to a Fluke Calibration dry-well

Automating and documenting a temperature calibration that includes a Fluke Calibration temperature source is easily accomplished by connecting it to a Fluke 754.

For detailed instructions see the application note "Eliminating sensor errors in loop calibrations": Lit code 2148146.
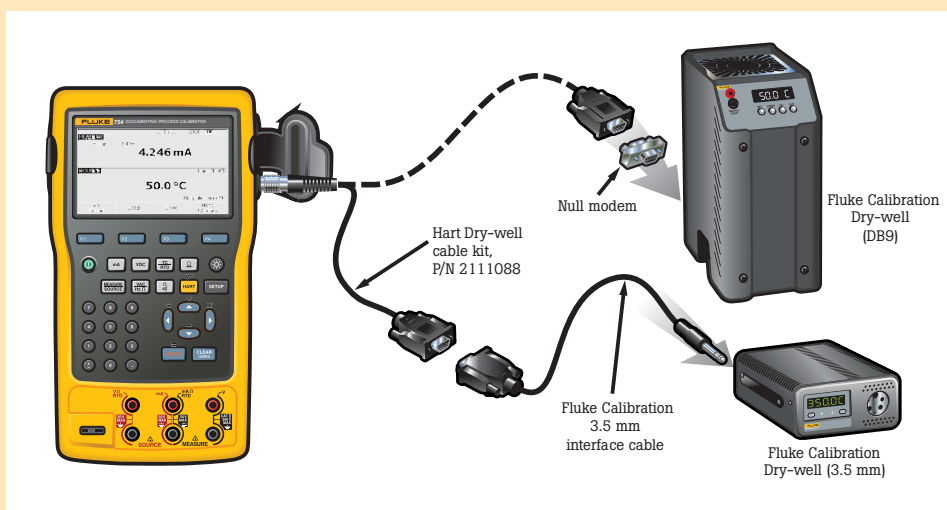
Temperature Source Summary Performance

	Type	Range	Accuracy	Stability	Immersion Depth	Weight	Special functions
9190	Dry-block	−95 °C to 140 °C (−139 °F to 284 °F)	± 0.2 °C Accuracy with External Reference: ± 0.05 °C"	± 0.015 °C full range	160 mm (6.3 in)	16 kg (35 lb)	Process version measures RTDs, Thermocouples, 4–20 mA and will power the loop. Compatible with Fluke 754.
9142	Dry-block	−25 °C to 150 °C (−13 °F to 302 °F)	± 0.2 °C	± 0.01 °C Full Range	150 mm (5.9 in)	8.16 kg (18 lb)	Process version measures RTDs, Thermocouples, 4–20 mA and will power the loop. Performs automated thermal switch test. Compatible with Fluke 754
9143	Dry-block	33 °C to 350 °C (91 °F to 662 °F)	± 0.2 °C	± 0.02 °C at 33 °C ± 0.02 °C at 200 °C ± 0.03 °C at 350 °C"	150 mm (5.9 in)	7.3 kg (16 lb)	Process version measures RTDs, Thermocouples, 4–20 mA and will power the loop. Performs automated thermal switch test. Compatible with Fluke 754
9144	Dry-block	50 °C to 660 °C (122 °F to 1220 °F)	± 0.35 °C at 50 °C ± 0.35 °C at 420 °C ± 0.5 °C at 660 °C	± 0.03 °C at 50 °C ± 0.04 °C at 420 °C ± 0.05 °C at 660 °C	150 mm (5.9 in)	7.7 kg (17 lb)	Process version measures RTDs, Thermocouples, 4–20 mA and will power the loop. Performs automated thermal switch test. Compatible with Fluke 754
9103	Dry-block	−25 °C to 140 °C (−13 °F to 284 °F) at 23 °C ambient	± 0.25 °C	± 0.02 °C at −25 °C ± 0.04 °C at 140 °C	124 mm (4.9 in)	5.7 kg (12 lb)	Thermal switch testing. Compatible with Fluke 754.
9140	Dry-block	35 °C to 350 °C (95 °F to 662 °F)	± 0.5 °C	± 0.03 °C at 50 °C ± 0.05 °C at 350 °C	124 mm (4.9 in)	2.7 kg (6 lb)	Thermal switch testing. Compatible with Fluke 754.
9100S	Dry-block	35 °C to 375 °C (95 °F to 707 °F)	± 0.25 °C at 50 °C ± 0.25 °C at 100 °C ± 0.5 °C at 375 °C	± 0.07 °C at 50 °C ± 0.1 °C at 100 °C ± 0.3 °C at 375 °C	102 mm (4 in)	1 kg (2 lb 3 oz)	Compatible with Fluke 754.
9102S	Dry-block	−10 °C to 122 °C (14 °F to 252 °F) at 23 °C ambient	± 0.25 °C	± 0.05 °C	102 mm (4 in)	1.8 kg (4 lb)	Compatible with Fluke 754.
9009	Dry-block	Hot Block: 50 °C to 350 °C (122 °F to 662 °F) Cold Block: −15 °C to 110 °C (5 °F to 230 °F)	Hot Block: ± 0.6 °C Cold Block: ± 0.2 °C	± 0.05 °C	102 mm (4 in)	4.5 kg (10 lb)	Simultaneous hot and cold block usage. Compatible with Fluke 754
6102	Portable Bath	35 °C to 200 °C (95 °F to 392 °F)	± 0.25 °C	± 0.02 °C at 100 °C (oil 5013) ± 0.03 °C at 200 °C (oil 5013)	140 mm (5.5 in)	4.5 kg (10 lb) with fluid	Compatible with Fluke 754.
7102	Portable Bath	−5 °C to 125 °C (23 °F to 257 °F)	± 0.25 °C	± 0.015 °C at −5 °C (oil 5010)	140 mm (5.5 in)	6.8 kg (15 lb) with fluid	Compatible with Fluke 754.
7103	Portable Bath	−30 °C to 125 °C (−22 °F to 257 °F)	± 0.25 °C	± 0.03 °C at −25 °C (oil 5010) ± 0.05 °C at 125 °C (oil 5010)	140 mm (5.5 in)	9.8 kg (22 lb) with fluid	Compatible with Fluke 754.

Temperature Test Tool Summary Performance: Selected examples

754	753	725	726	724	721	714B	712B	53/54	51/52	Function	Range	Resolution	Accuracy	Notes
							•			RTD PT100–385	Measure –200 to 800C Source –200 to 800C	0.1 °C	0.015 % + 0.18 °C	13 types
•	•									RTD PT100–385	Measure –200 to 800 °C Simulate –200 to 800 °C	0.1 °C	0.02% +0.05 °C	8 RTD types
		•		•						RTD PT100–385	Measure –200 to 800 °C Simulate –200 to 800 °C	0.1 °C 0.1 °C	0.33 °C 0.33 °C	7 RTD types
					•					RTD PT 100–385	Measure –200 to 800 °C Source –200 to 800 °C	0.01 °C 0.01 °C	0.15 °C 0.15 °C	8 RTD types
						•				RTD PT 100–385	Measure –40 °C to 150 °C	0.01 °C	0.015% of rdg	
•	•									Resistance 100 Ω range	Measure 0 to 10,000 Ω Source 0 to 10,000 Ω	0.01 Ω 0.01 Ω	.05 % + 50 mΩ .01 % + 20 mΩ	
		•		•						Resistance 100 Ω range	Measure 15 to 3200 Ω Source 15 to 3200 Ω	0.1 Ω 0.1 Ω	.1 Ω to 1 Ω .1 Ω to 1 Ω	
					•					Resistance 100 Ω range	Measure 0 to 4000 Ω Source 5 to 4000 Ω	0.1 Ω	0.015 %	
								•		Resistance 400 Ω range	Measure 0 to 400 Ω Source 1.0 to 4000 Ω	0.01 Ω	0.015 % + 0.05 Ω	
•	•									Thermocouple Type K	Measure –200 to 1372 °C Simulate –200 to 1372 °C	0.1 °C 0.1 °C	0.3 °C 0.3 °C	13 Types
								•		Thermocouple Type K	Measure –200 to 1372 °C	0.1 °C <1000 °C 0.1 °C >1000 °C	0.05 % rdg + 0.3 °C	JKTERSN
									•	Thermocouple Type K	Measure –200 to 1372 °C	0.1 °C <1000 °C 0.1 °C >1000 °C	0.05 % rdg + 0.3 °C	JKTE
		•	•	•						Thermocouple Type K	Measure –200 to 1370 °C Simulate –200 to 1370 °C	0.1 °C 0.1 °C	0.8 °C 0.3 °C on 726	13 Types
						•				Thermocouple Type K	Measure –200 to 1372 °C Source –200 to 1372 °C	0.1 °C	0.3 °C	17 types
•	•									mV	Measure +–110 mV Source +–110 mV	0.001 mV 0.001 mV	.02 % + .005 % FS .01 % + .005 % FS	
		•								mV	Measure 0 to 100 mV Source 0 to 100 mV	0.01 mV 0.01 mV	.025 % + 2 counts .025 % + 2 counts	
				•						mV	Measure 0 to 100 mV Source 0 to 100 mV	0.01 mV	0.01 % + 1 count	
						•				mV	–10 to 75 mV	0.01 mV	0.015 % + 10 uA	
						•	•			Measure mA	0 to 24 mA	0.001 mA	0.010 % + 2 counts	
				•						Measure mA	0 to 24 mA	0.001 mA	0.010 % + 2 counts	
•	•									Measure mA	0 to 24 mA	0.001 mA	0.010 % + 5 uA	
		•								Measure mA	Measure 0 to 24 mA Source 0 to 24 mA	0.001 mA	0.010 % + 2 counts	
•	•	•		•						Loop Power Supply	24 V dc	n/a	±10 %	

Temperature Terminology

Dry Block Calibrator: A temperature calibrator that uses a precision oven to source precise temperature. This style of calibrator is often used for the verification of temperature sensors.

Excitation current: A constant current applied to an RTD probe to determine actual resistance for temperature measurement. Typical values are 2 mA or less to minimize self-heating of the probe.

IPTS-68: International Practical Temperature Scale of 1968. A temperature standard adopted in 1968 that uses intrinsic standards to define the measurement of temperature.

ITS-90: International Temperature Scale of 1990. A temperature calibration standard adopted in 1990 using intrinsic standards to make it possible to use and compare temperature measurements in a meaningful way, anywhere in the world.

Lead Resistance Compensation: A compensation method used with 3 and 4 wire RTDs and resistance measurement. This method negates the error associated with lead resistance when making an RTD measurement.

Reference Temperature: A reference condition used for comparing measurement results to a standard data set. Examples include 0 °C for thermocouple tables, and the triple point of water for the ITS-90.

R_0 The resistance value of an RTD probe at 0 °C. Example PT100–385, R_0 = 100 Ω.

RTD: Resistance Temperature Device, a temperature measurement sensor that has predictable changes in resistance with a change in temperature. The most common RTD is the platinum PT100–385.

Seebeck Effect: Thermoelectric effect in which the voltage potential increases with temperature (thermocouples) in a junction of dissimilar metals.

Triple point of water: A defining temperature of the ITS-90 occurring at 0.01 °C when water coexists simultaneously in three states: liquid, solid, and vapor.

FLUKE ®

Fluke Calibration 9190A Ultra-Cool Field Metrology Well

- Wide temperature range: −95 °C to 140 °C
- Accuracy using built-in reference thermometer readout: ± 0.05 °C full range
- Basic accuracy: ± 0.2 °C full range
- Reads thermocouples, RTDs, and 4–20 mA (w/24V Loop power)
- Best-in-class stability: ± 0.015 °C full range
- Cools from 23 °C to −95 °C in 90 minutes
- Portable: weighs only 16 kg (35 lbs)
- Built-in front and back handles for easy two-handed carry
- Conforms with EURAMET cg-13 guidance on measurement practices for temperature calibrators

Fluke Calibration 9100S/9102S Handheld Dry-Well Calibrators

- A temperature source that you can take anywhere
- Fast and easy calibrations of temperature sensors
- 9102S weighs only 4 lbs (1.8 kilograms)
- 9102S temperature range: −10 °C to 122 °C (14 °F to 252 °F)
- 9100S weighs only 2 lbs, 3 oz (1 kilogram)
- 9100S temperature range: 35 °C to 375 °C
- 9100S accuracy: ± 0.07 °C at 50 °C; ± 0.1 °C at 100 °C; ± 0.3 °C at 375 °C
- Accuracy: ± 0.25 °C
- Direct interface to the Fluke 754

Fluke Calibration 9142/9143/9144 Field Metrology Wells

- Lightweight, portable, and fast −25 °C to 660 °C
- Built-in two-channel readout for PRT, RTD, thermocouple, 4–20 mA current (P version only)
- True reference thermometry with accuracy to ±0.01 °C
- On-board automation and documentation
- Metrology performance in accuracy, stability, uniformity, and loading
- Direct interface to the Fluke 754

Fluke Calibration 9009 Industrial Dual-Block Dry-Well

- Calibrate temperature sensors fast
- Independently controlled cold and hot blocks
- −15 °C to 110 °C (cold block), 50 °C to 350 °C (hot block)
- Self-contained in a rugged watertight case
- Four removable inserts
- Direct interface to Fluke 754

Fluke Calibration 6102/7102/7103 Micro-Baths

- World's smallest portable calibration baths
- Calibrates sensors of any size or shape
- Stability to ±0.015 °C
- 6102 Temperature range: 35 °C to 200 °C
- 7102 Temperature range: −5 °C to 125 °C
- 7103 Temperature range: −30 °C to 125 °C
- Direct interface to the Fluke 754

Fluke Calibration 9103/9140 Field Dry-Well Calibrators

- Lightweight and very portable
- Accuracy to ± 0.25 °C
- 9103 goes as low as −25 °C.
- Direct interface to Fluke 754
- 9140 is 6 pounds (2.7 kg)
- 9140 reaches max temp in 12 minutes
- RS-232 and Interface-it software included
- Interchangeable inserts
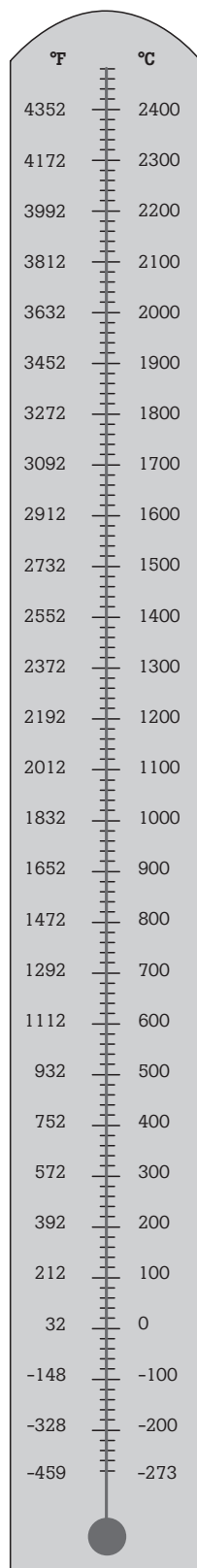- Direct interface to the Fluke 754

Fluke Calibration 7526A Precision process Calibrator

- Sources and measures dc voltage, current, resistance, RTDs and thermocouples
- Precision pressure measurement using Fluke 700 series pressure modules
- Includes 24 V dc transmitter loop power supply
- Measures 4–20 mA loop current
- Includes automated switch-test function
- Accepts ITS-90 coefficients for accurate SPRT measurements
- Compatible with MET/CAL® Calibration Software
- Includes certificate of calibration traceable to national standards (optional A2LA accredited calibration available upon request)

Temperature Conversion

°F	°C
4352	2400
4172	2300
3992	2200
3812	2100
3632	2000
3452	1900
3272	1800
3092	1700
2912	1600
2732	1500
2552	1400
2372	1300
2192	1200
2012	1100
1832	1000
1652	900
1472	800
1292	700
1112	600
932	500
752	400
572	300
392	200
212	100
32	0
−148	−100
−328	−200
−459	−273

Thermocouples

Plug Color	Alloys		Temperature Range	EMF Range
	+	-		
White **B**	Pt–30 % Rh Platinum–30 % Rhodium	Pt–6 % Rh Platinum–6 % Rhodium	600 to 1820 °C, 1112 to 3308 °F	1.792 to 13.820 mV
Red **C**	W–5 % Re Tungsten–5 % Rhenium	W–26 % Re Tungsten–26 % Rhenium	0 to 2316 °C, 32 to 4201 °F	0 to 37.079 mV
Purple **E**	Ni–Cr Nickel-Chromium (Chromel)	Cu–Ni Copper-Nickel (Constantan)	−250 to 1000 °C, −418 to 1832 °F	−9.719 to 76.370 mV
Black **J**	Iron Fe	Cu–Ni Copper-Nickel (Constantan)	−210 to 1200 °C, −346 to 2193 °F	−8.096 to 69.555 mV
Yellow **K**	Ni–Cr Nickel-Chromium (Chromel)	Ni–Al Nickel-Aluminum	−200 to 1372 °C, −328 to 2502 °F	−5.891 to 54.886 mV
Blue **L**	Fe Iron	Cu–Ni Copper-Nickel (Constantan)	−200 to 900 °C, −328 to 1652 °F	−8.166 to 53.147 mV
Orange **N**	Ni–Cr–Si Nickel-Chromium-Silicon (Nicrosil)	Ni–Si–Mg Nickel-Silicon-Magnesium (Nisil)	−200 to 1300 °C, −328 to 2372 °F	−3.990 to 47.514 mV
Green **R**	Pt–13 % Rh Platinum–13 % Rhodium	Pt Platinum	−20 to 1767 °C, −4 to 3213 °F	−0.101 to 21.089 mV
Green **S**	Pt–10 % Rh Platinum–10 % Rhodium	Pt Platinum	−20 to 1767 °C, −4 to 3213 °F	−0.103 to 18.682 mV
Blue **T**	Cu Copper (Constantan)	Cu–Ni Copper-Nickel	−250 to 400 °C, −418 to 752 °F	−6.181 to 20.873 mV
White **U**	Cu Copper	Cu–Ni Copper-Nickel	−200 to 600° C, −328 to 1112 °F	−5.693 to 34.320 mV

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