FLUKE®
Calibration

Temperature calibration equipment:
A technician's guide

Application Note

Have you ever been brought a new thermometer to calibrate, and asked yourself, "What am I going to need to calibrate this?" This guide is intended to help you work out the kind of equipment you need for your particular calibration situation. Of course, there are many considerations—including accuracy, temperature range, automation requirements and budget. This guide covers the main points, but you'll probably want to speak with an experienced Fluke application specialist before you make a final decision; as always, we stand ready to help keep you up and running.

Getting started

Most often, thermometer type determines the kind of equipment needed. Some of the most common items that need to be calibrated are listed in Table 1. The equipment types shown in the Needed equipment column should not be considered definitive. For example, the same equipment used to calibrate an RTD or an SPRT could also be used to calibrate a PRT, but this is a good guide to what you would most likely use. In addition, choice of equipment may depend on where the calibration is performed. For example, you might use a calibration bath and temperature standard to calibrate an RTD in a laboratory, but a portable calibrator would be more appropriate for on-site calibrations. More about the equipment needed will be explained below.

Calibration method

No matter what your temperature calibration application, you're going to need a temperature source to heat or cool your thermometers to a known temperature. During the calibration, the thermometers are placed into a heat transfer medium in the temperature source. The heat transfer medium might be a stirred fluid, a metal block, or a fixed point cell. The heat transfer medium maintains a constant and uniform temperature environment that allows the reading of the thermometer under test to be compared to a more accurate known temperature.

The known temperature value is going to come from one of two places:

- **Naturally occurring phenomena**, such as the triple point of water (0.010 °C)
- A **temperature measurement**, made by a temperature standard

These two different methods of getting the more accurate known temperature lead to two distinct methods of calibration: comparison calibration and fixed point calibration.

Comparison calibration is the most common type.

Table 1. Common thermometers that need to be calibrated

Workload	Where calibrating?	Needed equipment
Dial thermometer	On-site	A portable temperature calibrator
Liquid in glass	Laboratory	Calibration bath, fluid level adapter, magnifier, carousel, and temperature standard
RTD	On-site	A portable temperature calibrator and (optional) temperature standard
	Laboratory	Calibration bath and temperature standard
PRT	On-site	A portable temperature calibrator and (optional) temperature standard
	Laboratory	Calibration bath and temperature standard
Thermocouple	On-site	A portable temperature calibrator and (optional) temperature standard
	Laboratory	Calibration furnace and temperature standard
Thermistor	Laboratory	Calibration bath and temperature standard
SPRT	Laboratory	Fixed point cells, maintenance furnaces/baths, a standard resistor, and a resistance bridge
Infrared thermometer	On-site	Radiometrically calibrated infrared calibrator
	Laboratory	Radiometrically calibrated infrared calibrator, or an infrared calibrator (plate) and a reference radiometer, or an infrared blackbody (cavity)

Comparison calibration

For contact thermometer comparison calibrations, you will need:

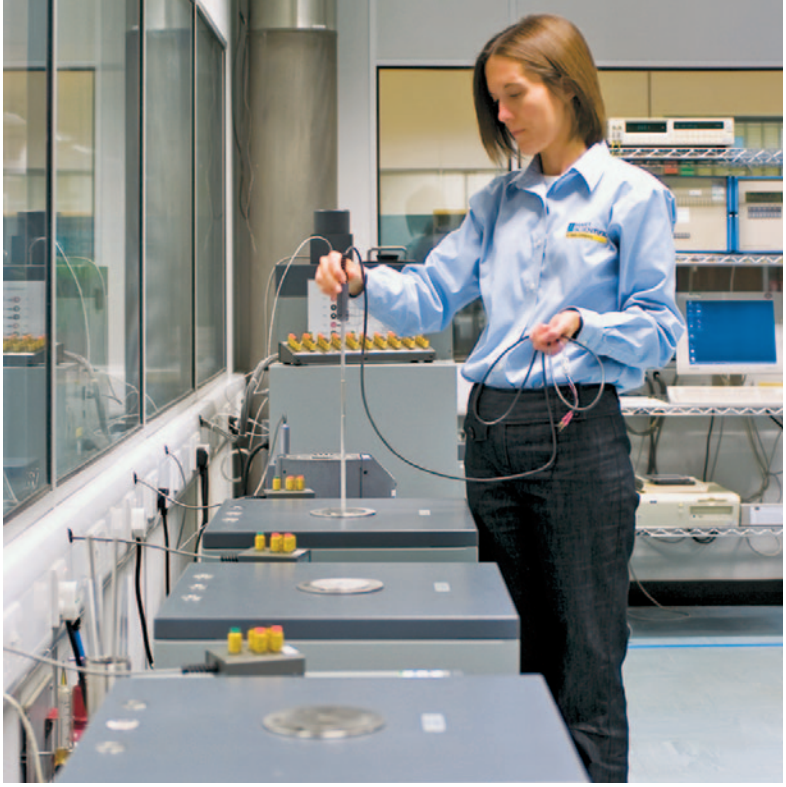
- A temperature source to heat or cool the thermometer(s) under test
- A temperature standard to provide the accurate known temperature that is compared with the thermometer under test
- (Optional) Measuring devices to read the temperature standard and/or thermometer(s) under test

As the name implies, during a comparison calibration, a thermometer under test is compared to a more accurately calibrated temperature standard, while both are maintained at the same constant temperature in the temperature source. Typically the standard is four times more accurate than the thermometer under test. Any thermometer can be calibrated by comparison, and comparison calibrations can take place either in a laboratory or on-site.

For non-contact thermometer comparisons you will need:

- A radiance source to generate the known radiance observed by the infrared thermometer
- A radiometric temperature standard to provide the accurate known temperature that is compared with the thermometer under test

The radiance source can be either a painted surface or a blackbody cavity. Good blackbody cavities have a well known emissivity value (i.e. 0.95 ±0.001). The key performance indicator of a radiance source is its spectral emissivity. The spectral emissivity depends on wavelength, the geometry of the surface, the finish of the surface, and the types of plate material and paint used. The emissivity of a painted surface is different for each wavelength; therefore, its radiance is only known if it is measured over the same wavelengths used by the infrared thermometers being calibrated. For example, measurements of surface by a radiometer over the band of wavelengths from



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8 to 14 microns will be good for calibrating thermometers of the same bandwidth (8 to 14 microns).

Surfaces used to calibrate infrared thermometers should be calibrated radiometrically over the correct bandwidth, or else a radiometric temperature standard (radiometer) with the correct bandwidth needs to be compared with the thermometers under test during calibration. For example, the Fluke, Hart Scientific 4181 Precision Infrared Calibrator is calibrated radiometrically from 8 to 14 microns and does not require a separate radiometric temperature standard over that bandwidth. Alternatively, the Hart 9132 Infrared Calibrator is not radiometrically calibrated and does require a separate radiometer for infrared traceability.

Fixed point calibration

For the most accurate thermometers under test, the only sufficiently accurate temperature standard is a primary standard. Fixed point cells are the primary standards used in temperature calibration. In a primary standards laboratory, SPRTs are placed in fixed point cells and given ITS-90 calibrations. The ITS-90 is the international temperature scale used by the International System of Units (SI) to define Kelvin and Celsius temperature values for the world.

Fixed point cells rely on the intrinsic properties of nature to provide a very precisely known temperature. Extremely pure substances (i.e. tin, zinc or water) under the right conditions of temperature and pressure become very precise and reliable temperature standards. Thermometers are calibrated by placing them inside the cell so that the thermometer and the fixed point cell are resting at the same temperature. This means a fixed point cell is both a temperature source and a temperature standard. Fixed point cells are the most accurate type of temperature calibration equipment but they are also the most difficult to use and are found mainly in primary standards laboratories.

For fixed point calibrations, you will need:

- A fixed point cell (temperature source)
- A device to maintain the temperature surrounding the cell (i.e. bath or furnace)
- A resistance bridge to measure the SPRT being calibrated

Choosing a temperature source

When choosing a temperature source, you often need to choose the best compromise between accuracy and some other technical requirement. Table 2 compares various types of temperature sources against some common technical requirements.

Choosing a calibrated thermometer (temperature standard)

For comparison calibrations, you need to choose a calibrated thermometer for your temperature standard. There are several types to choose from. Your choice depends on your temperature range and the required accuracy of your measurements. Table 3 provides a guide for finding the right type of thermometer for your application. Other conditions that should be considered are degree of ruggedness, and needed probe dimensions such as length and diameter. A general rule for resistance thermometers such as PRTs, SPRTs, and HTSPRTs is that the more rugged the instrument, the less accurate it becomes.






Table 2. Temperature sources						
Technical needs	**Fixed points**	**Baths**	**Metrology wells**	**Field metrology wells**	**Micro-baths**	**Dry-wells**
Accuracy ±0.001 °C to ±0.01 °C	●					
Accuracy ±0.01 °C to ±0.1 °C		●	●			
Accuracy ±0.1 °C to ±1.0 °C				●	●	●
Calibrate on-site			●	●	●	●
Eliminate fluids	●		●	●		●
Get to temperature fast			●	●	●	●
Calibrate multiple sizes and shapes		●			●	
Automate calibration	●	●	●	●	●	●
Use fewer tools				●		
Learn in less than 15 minutes						●
Use easily		●	●	●	●	●

Caption to go here

Table 3. Thermometer types					
Technical needs	**Thermistor**	**PRT**	**SPRT**	**HTSPRT**	**Thermocouple**
Range					
0 °C to 100 °C	●	●	●		
–200 °C to 660 °C		●	●		
0 °C to 961 °C				●	●
0 °C to 1450 °C					●
Accuracy					
±0.001 to ±0.01	●		●	●	
±0.01 to ±0.10		●			
±0.1 to ±2.5					●

Once you have chosen the type of thermometer probe you will use as the temperature standard, you need to choose a device to measure it. This device could be a specialized thermometer readout, or it could be a general purpose instrument like a digital multimeter. Thermometer readouts deliver the best results because their ranges, current settings and firmware are designed for temperature measurement. Selection criteria for thermometer readouts include the type of thermometer and level of accuracy required and other factors like need for battery power, number of inputs, and whether data can be recorded for future retrieval. See Table 4.

Don't forget that if you are calibrating temperature sensors like RTDs and thermocouples, you will need thermometer readouts for them too. A multichannel thermometer readout can be used to measure your temperature standard and your thermometers under test at the same time.

Table 4. Thermometer readouts from Fluke, Hart Scientific

Technical needs	1523	1524	1502A	1504	1529	1560	1595	Calibrators with measurement capability	914X	917X
Measure RTDs	●	●	●		●	●	●		●	●
Measure PRTs	●	●	●		●	●	●		●	●
Measure SPRTs						●	●			
Measure HTSPRTS						●	●			
Measure thermistors	●	●		●	●	●	●			
Measure Thermocouples	●	●			●	●			●	
Measure transmitters									●	
Measure thermal switches									●	●
Calibrate on-site	●	●	●	●	●	●			●	●
Battery powered	●	●			●					
Use fewer tools									●	●
Single channel	●		●							●
Multi channel		●			●	●	●		●	
Record data	●	●			●		●		●	
Automated data logging		●			●		●			
Graphing	●	●				●	●			
Fixed point calibration							●			

Use two probes and the 1524 to read, log, graph, and calibrate twice as much.

The 914X-P can act as the indicator for transmitters, thermocouples and RTDs and even a reference PRT to improve accuracy.

Table 5. ITS-90 fixed point calibration equipment	
Temperature	**Needed equipment**
–196 °C	Boiling Point of Liquid Nitrogen with 7196–4 Vacuum Flask Dewar
–38.8344 °C	5900 Triple Point of Mercury (TpHg) Cell and 7341 Mercury Maintenance Bath
0.010 °C	5901–D–Q Triple Point of Water (TPH20) Cell and 7312 TPW Maintenance Bath
29.7646 °C	5943 Melting Point of Gallium (MPGa) Cell and 9230 Gallium Maintenance Apparatus
156.5985 °C	5904 Freezing Point of Indium (FPIn) Cell and 9114 Freeze Point Furnace
231.928 °C	5905 Freezing Point of Tin (FPSn) Cell and 9114 Freeze Point Furnace
419.527 °C	5906 Freezing Point of Zinc (FPZn) Cell and 9114 Freeze Point Furnace
660.323 °C	5907 Freezing Point of Aluminum (FPAl) Cell and 9114 Freeze Point Furnace
961.78 °C	5908 Freezing Point of Silver (FPAg) Cell and 9115A Freeze Point Furnace
–196 °C to 961 °C	5581 Primary Standard Automated Resistance Bridge
	5313–002 10 Channel Scanner for Automated Resistance Bridge (optional)
	5313–004 Software for Automated Resistance Bridge
–196 °C to 660 °C	5430–10 10–Ohm Resistance Standard and 7108 Resistor Maintenance Bath
0 °C to 961 °C	5430–1 1–Ohm Resistance Standard and 7108 Resistor Maintenance Bath

As mentioned earlier, fixed point calibration is a little different from comparison calibration and requires different equipment. Table 5 shows the kind of equipment used in a primary standards laboratory that performs fixed point calibrations on SPRTs.

There is at least one fixed point cell that is used in almost all temperature calibration laboratories around the world. The triple point of water cell is the backbone of the temperature calibration laboratory, even if comparisons are the only type of calibration performed. The triple point of water is not just required for calibrating SPRTs, it's also required for maintaining their accuracy after calibration. So if you own an SPRT, you should also own a triple point of water cell. Even secondary reference PRTs used as calibration temperature standards are also checked regularly at the triple point of water to ensure their continued reliability. Mini triple point of water cells are available to make this more convenient and economical.

A few examples

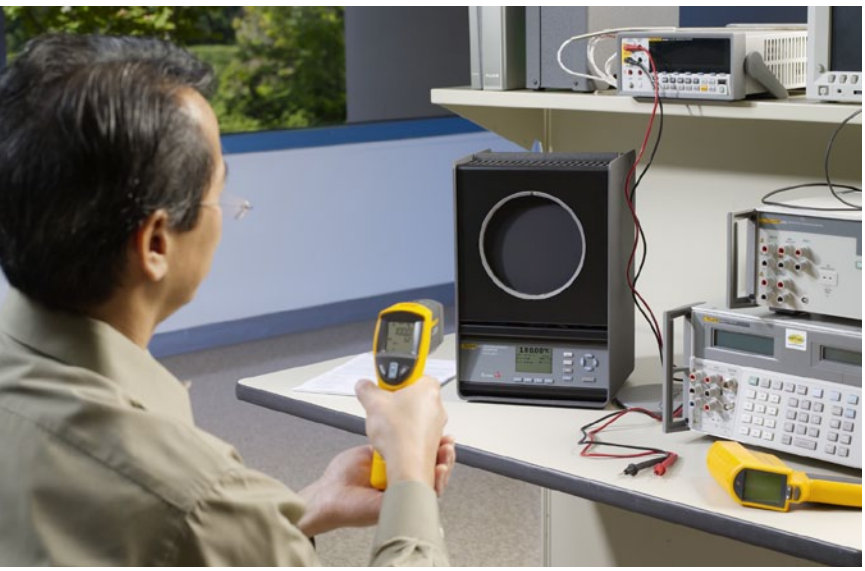
To reinforce this discussion, a few examples arranged in a good, better, and best format are summarized in table 6. A good solution for performing calibrations on–site is a dry–well. If you are new to on–site temperature calibration, a handheld dry–well like the 9100S or 9102S is a good place to start. You can learn to use these in less than 15 minutes, they can be taken just about anywhere you need to calibrate something, and they are very reasonably priced.

A better solution would be a field dry–well with an external reference thermometer for improved accuracy. A 1523 is a great choice for the readout because it graphs temperature in real–time, letting you know exactly when it's time to take a reading, and it measures PRTs, thermistors and thermocouples.

Table 6. Examples of calibration solutions			
	Good	**Better**	**Best**
Accuracy	1.0 °C to 0.1 °C	0.1 °C to 0.01 °C	0.01 °C to .001 °C
Workload	Dial thermometers	RTDs/PRTs	PRTs
	Thermocouples	Liquid in glass	SPRTs
Typical environment	Mostly on-site	Lab or on-site	Lab
Entry-level solution	Handheld dry-well: 9100S or 9102S	Field Metrology Well: 914X-P 5626 reference PRT	9210 mini Tpw Maintenance Apparatus 5901B mini TPW cell 9260 Mini Furnace 594X Fixed Point Cells 7196 LN2 comparator
Premium solution	Handheld readout: 1523 or 1524	1560 with 256X Module	7012 TPW Maintenance Bath
	PRT : 5616	5699 SPRT	5901D-Q TPW cell
	Field dry-well: 9103 or 9141	70XX or 60XX bath	9114 fixed point furnace
			590X fixed point cells
			7341 TPHg bath
			5900A TpHg cell
			7196 LN2 Comparator
			5681 SPRT
			5581 Resistance bridge

More accurate thermometers like RTDs and LIGs (liquid in glass thermometers) require more accurate equipment to calibrate them. The equipment used to calibrate RTDs and LIGs often bridge the gap between on-site and laboratory calibration work and could be used in either location. For example, 914X Field Metrology Wells can be carried on-site in one hand and are great for speed and versatility. 917X Metrology Wells are portable and yet are sufficiently accurate for laboratory calibration work. On the other hand, certain calibration baths, are sufficiently compact to, be taken on-site (i.e. 6102 or 7102 Micro-Baths), but most calibration baths are used exclusively in the laboratory, because of their size.

For best results, SPRTs and better PRTs can be calibrated by fixed point. Entry-level fixed point calibration is usually done with mini-fixed point cells for high-end PRTs. The maintenance apparatus for these are significantly less expensive than maintenance apparatus for large cells, and the smaller dimensions make it easier to calibrate PRTs than SPRTs (i.e. 9 in to 15 in) and would not be long enough for calibration in the large fixed point cells. Fixed point calibrations do not require a reference thermometer, unless a comparison at the normal boiling point of liquid nitrogen (–197 °C) is substituted for the triple point of Argon (–189.3442 °C).



Conclusion

If you have a new type of thermometer to calibrate, hopefully you now have a better idea of what you are going to need to calibrate it. If you have SPRTs, you are going to need the equipment for fixed point calibration, and if you are doing comparison calibrations of other types of thermometers, your choice of equipment may hinge largely on where you have to go to calibrate them. If it's in the laboratory, you'll probably use baths and SPRTs with thermometer readouts, and if you're calibrating on-site you'll be using a calibrator like a Field Metrology Well or Micro-Bath. Whichever way you decide to go, don't forget to talk to the experts; we'll help you get started and keep you up and running.

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