FLUKE®

Calibration

1594A/1595A Super-Thermometer Uncertainty Analysis

Application Note

Metrologists should be proud of their uncertainties. A lot of effort goes into maintaining and improving them, especially in an accredited laboratory. The Fluke Calibration temperature laboratory in American Fork, Utah is well known its performance, not only for some of the lowest uncertainties in the industry, but also for educating other labs about how they can do the same.

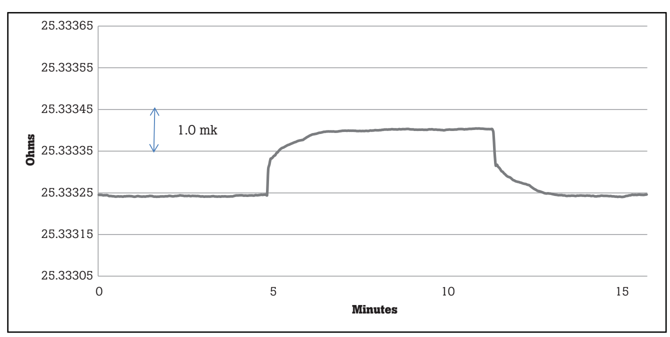
When Fluke Calibration developed the 1594A/1595A Super-Thermometer, the temperature calibration laboratory in American Fork became one of the first customers by installing four instruments in the lab.

The calibration laboratory in American Fork uses the 1595A for fixed-point calibrations and comparison calibrations. It comes as no surprise that calibration customers today demand lower and lower uncertainties. It is sometimes hard to accommodate these needs. Calibration laboratories are often up against the wall of their capabilities in trying to provide what the customer wants. This puts the laboratory under a heavy burden, because any little thing that goes wrong will delay calibrations and put the staff in fire-fighting mode.

One of the benefits cited by the Fluke Calibration laboratory staff is that the 1595A gave them the breathing room they needed to be able to keep their processes under statistical control even while maintaining the low uncertainties demanded by customers. Also, because the 1595A significantly reduced the amount of measurement noise, the lab became more confident in their results, which reduced the amount of time spent troubleshooting when there was a problem.

The improved specification and lower noise had another interesting side effect. It was now easy to distinguish resistance values at two very similar excitation currents, such as 1 mA and 1.414 mA. This and a new zero-power measurement feature allowed the laboratory to remove self-heating from their reference SPRT measurements, which further reduced measurement uncertainties. For example, it made it easier to calibrate precision thermistors by comparison with uncertainties as low as ± 1.5 mK.

Given their familiarity with the 1595A Super-Thermometer, we asked the calibration laboratory to show us how they would calculate their uncertainty budgets for two common applications: SPRT calibration by fixed point and PRT calibration by comparison.



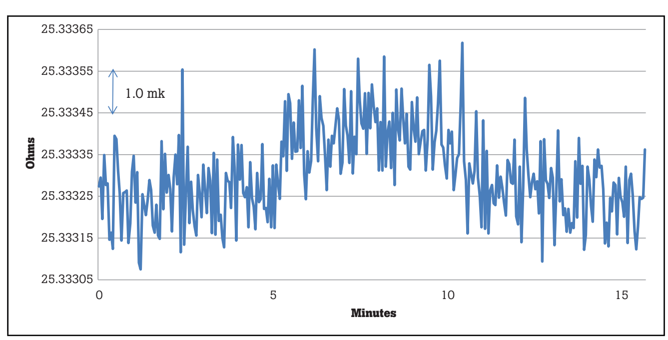


Figure 1. A new generation of Super-Thermometer with 10 times better noise characteristics than the previous generation clearly shows the effect of self-heating when excitation current is raised from 1 mA to 1.414 mA.
Test conditions: An SPRT in a triple point of water cell was connected to a 1595A (above) and a 1590A (below). A procedure typical of a zero power measurement was followed. The readout was set to sample over a period of two seconds per data point with the digital filter turned off. Current was set to 1 mA for 5 minutes, then 1.414 mA for 5 minutes of stability. Finally the current was set back to 1 mA.

Uncertainty analysis example 1: SPRT calibration by fixed-point

The following uncertainty budget is based on an SPRT calibrated by measuring its W_{T90} value at each fixed-point temperature listed in Table 1. The fixed-point points include the triple point of Argon (TPAr), the melting point of Mercury (MPHg), the triple point of water (TPW), the freezing point of Tin (FPSn), and the freezing point of Zinc (FPZn). W_{T90} is a ratio of two resistance measurements specified by the ITS-90 (International Temperature Scale of 1990). The numerator in W_{T90} is the resistance of the SPRT when measured at an ITS-90 fixed point temperature and the denominator is always the resistance of the same SPRT when measured at the temperature of the triple point of water. In the following uncertainty budget a 1595A is used to measure the ITS-90 resistance ratio W_{T90} of the SPRT. Each source of uncertainty is explained in detail after the table. Following the uncertainty budget is a description of each source of uncertainty.

Process variability
This is the standard deviation of the check standard measurements. It is important to monitor the measurement system through the use of a check standard SPRT. For best results a different SPRT is used for each fixed-point temperature.

Measurement precision
This is the estimated standard deviation of the mean of the resistance measurement in the fixed-point cell. Measurement precision is primarily affected by stability of the fixed-point temperature, readout noise, and influences from the fixed-point furnace. Measurement precision is monitored automatically in the 1594A and 1595A using the built-in Standard Error statistics value.

Fixed-point cell temperature
This is the uncertainty of the temperature produced by the fixed-point cell. It may be based on a calibration uncertainty or manufacturer's specification depending on the situation.

Self-heating correction
This is the uncertainty of the estimated zero-power resistance of the SPRT. Zero-power measurement reduces most of the self-heating error caused by measurement current. It is estimated by measuring the SPRT at nominal current and a current at which twice the dissipated power is achieved. The 1594A and 1595A have built-in zero-power measurement functionality to make this measurement easy and automatic.

Hydrostatic head correction
This is the uncertainty associated with correction of temperature error caused by hydrostatic head pressure inside the fixed-point cell. If corrections are not applied the error or uncertainty will be much larger.

Non-ideal immersion
This is the uncertainty associated with the immersion error of the SPRT in the fixed-point cell.

RTPW error propagation
Since this calibration model is based on measuring the W_{T90} value of the SPRT, the RTPW is part of each W_{T90} measurement. Therefore, uncertainty in RTPW measurement contributes to uncertainty of W_{T90} at each fixed-point measurement.

Shunt losses
This is the estimated error caused by parallel resistances in the SPRT measurement circuit. This effect exists in both metal-sheath and glass-sheath SPRTs. In most cases it cannot be measured directly and is estimated based on published information.

			TPAr	MPHg	TPW	FPSn	FPZn
Uncertainty sources	**Type**	**Distribution**	**mK**	**mK**	**mK**	**mK**	**mK**
Process variability	A	Normal	0.30	0.20	0.20	0.30	0.50
Measurement precision	A	Normal	0.02	0.02	0.02	0.04	0.06
Fixed-point cell temperature	B	Normal	0.087	0.110	0.035	0.250	0.300
Self-heating correction	B	Rectangular	0.006	0.006	0.006	0.012	0.012
Hydrostatic head correction	B	Normal	0.021	0.021	0.006	0.006	0.008
Non-ideal immersion	B	Normal	0.087	0.009	0.000	0.002	0.014
RTPW error propagation	B	Normal	0.021	0.085	0.000	0.189	0.257
Shunt losses	B	Rectangular	0.000	0.000	0.000	0.000	0.000
1595A linearity	B	Normal	0.008	0.018	0.008	0.041	0.059
Reference resistor stability	B	Rectangular	0.003	0.012	0.014	0.029	0.042
Total (k=2):			0.65	0.49	0.41	0.88	1.29

Table 1. Uncertainty budget of an SPRT fixed-point calibration

1595A linearity

This uncertainty is based on the ability of the 1595A Super-Thermometer to measure W_{T90} which is the ratio between R_{T90} (resistance at an ITS-90 fixed-point temperature) and RTPW. This uncertainty is based on three components. First, the ratio measurement between the SPRT at the fixed-point temperature and the reference resistor, second, the ratio measurement between the SPRT at the triple-point of water and the reference resistor, and the drift of the reference resistor during the elapsed time between the two measurements. This uncertainty is categorized separately in the following uncertainty.

Reference resistor stability

This is the third component of the 1595A's ability to measure W_{T90}. In this measurement scheme an external resistor is used and is maintained in a stable resistor bath. The resistor stability is based on an 8 hour period since both measurements that contribute to W_{T90} occur within 8 hours. The internal resistor can be used if necessary with minimal overall impact on measurement uncertainty. For more information regarding uncertainty associated with the internal resistor see the specifications section of the 1594A/1595A Super-Thermometer Technical Guide.

Uncertainty analysis example 2: PRT calibration by comparison

In this example, a calibrated reference SPRT provides the actual temperature of the bath while the UUTs (unit under test) resistance is measured. Both the SPRT and UUT are measured by the 1595A. Typically PRT calibrations are based on the resistance of the PRT at each temperature point as in this uncertainty analysis.

Process variability

The standard deviation of the check standard measurements. It is important to monitor the measurement system through the use of a check standard PRT. If possible the check standard should be similar in design and characteristics to the UUT.

UUT precision

The standard deviation of the mean of the unit under test measurement (also often referred to as standard error). In this calibration scheme a measurement point is the average of 20 samples. Measurement precision is primarily affected by bath stability and readout measurement noise. Measurement precision is monitored automatically in the 1594A and 1595A using the built-in standard error statistics value.

Reference SPRT precision

The standard deviation of the mean of the reference SPRT measurement (also often referred to as standard error). In this calibration scheme a measurement point is the average of 20 samples. Measurement precision is primarily affected by bath stability and readout measurement noise. Measurement precision is monitored automatically in the 1594A and 1595A using the built-in standard error statistics value.

Reference SPRT calibration

This is the calibration uncertainty of the SPRT. It is found on the SPRT calibration report.

Reference SPRT drift

This is uncertainty caused by SPRT drift. It is estimated by using the allowed RTPW drift of SPRT. In this example the allowed SPRT drift is 1.5 mK. This uncertainty affects all measured temperatures. RTPW is measured and entered into the Super Thermometer before each calibration run to reduce the error.

			-80 °C	-40 °C	0 °C	100 °C	200 °C
Uncertainty sources	**Type**	**Distribution**	**mK**	**mK**	**mK**	**mK**	**mK**
Process variability	A	Normal	1.8	1.3	1.0	2.2	2.6
UUT precision	A	Normal	0.3	0.3	0.3	0.3	0.3
Reference SPRT precision	A	Normal	0.3	0.3	0.3	0.3	0.3
Reference SPRT calibration	B	Normal	0.5	0.4	0.3	0.6	0.8
Reference SPRT drift	B	Rectangular	0.5	0.7	0.9	1.2	1.6
Measurement of SPRT	B	Normal	0.1	0.1	0.1	0.1	0.2
Measurement of UUT	B	Normal	0.4	0.5	0.6	0.9	1.2
Bath uniformity	B	Rectangular	1.2	1.2	0.9	1.2	1.2
Immersion error – SPRT	B	Rectangular	0.0	0.0	0.0	0.0	0.0
Immersion error – UUT	B	Rectangular	0.0	0.0	0.0	0.0	0.0
Repeatability of the UUT	B	Rectangular	0.8	3.7	4.3	6.0	8.2
Total (k=2):			**4.9**	**8.4**	**9.4**	**13.5**	**18.0**

Table 2: Uncertainty budget of a PRT comparison calibration in stirred-liquid baths

Measurement of SPRT
This is the ability of the Super-Thermometer to measure the SPRT. To achieve best measurement performance the chosen measurement scheme is based on the linearity of the Super-Thermometer measurement circuit. This requires measuring the RTPW of the SPRT before each calibration run and entering it into the Super-Thermometer. This uncertainty includes 1595A ratio accuracy of the measurement point, the 1595A ratio accuracy of the RTPW measurement, uncertainty of the TPW cell, measurement precision of the RTPW measurement. For more information see the Applying the Specifications section of the 1594A/1595A Super-Thermometer Technical Guide.

Measurement of UUT
The ability of the Super-Thermometer to measure the UUT. In this example the UUT measurement is based on the absolute resistance accuracy. The 1595A absolute resistance accuracy is converted to units of mK at each measurement point based on the resistance and sensitivity (dR/dT) of the UUT. For more information see the Applying the Specifications section of the 1594A/1595A Super-Thermometer Technical Guide.

Bath uniformity
The uncertainty caused by non-uniformity of the stirred-liquid bath. In this example, it is based on the temperature uniformity of the bath in the area where the SPRT and UUTs are inserted, not the manufacturer's uniformity specification of the bath. The SPRT and UUTs are inserted in the bath to the same depth and in close proximity. The uncertainty is based on measurements that verified bath uniformity in the area where the probes are inserted.

Immersion error – SPRT
In this example the uncertainty is 0 mK because the SPRT is sufficiently immersed due to the depth of the bath. It is important to verify immersion error by performing an immersion profile test.

Immersion error – UUT
In this example the uncertainty is 0 mK because the UUT is sufficiently immersed due to the depth of the bath. It is important to verify immersion error by performing an immersion profile test.

Repeatability of the UUT
During calibration the UUT is monitored for repeatability by measuring the RTPW multiple times and calculating the change in RTPW. This uncertainty is based on the drift or repeatability of the RTPW during calibration. The impact of RTPW shift on other measured temperatures is estimated using an error propagation model.

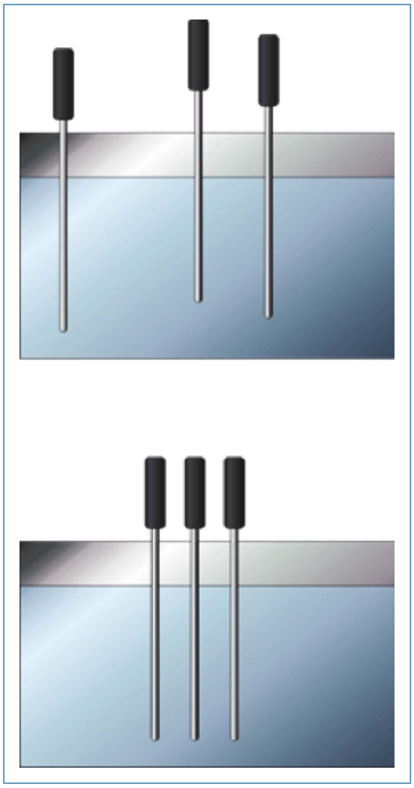


Figure 2. Though calibration baths are designed to provide excellent temperature uniformity, proper probe placement can further improve measurement uncertainty. Placing the probes in the bath at the same depth, close together and in the center of the bath will reduce the error caused by bath non-uniformity. Avoid letting the probes come in contact with the sides and bottom of the bath.

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