# A Study of the Impact of $R_{TPW}$ Shift on SPRT and PRT Accuracy

*Michael Coleman, Thomas J. Wiandt, Thomas G. Harper*

Fluke Corporation, Temperature Calibration Division, American Fork, Utah, USA
mike.coleman@fluke.com, tom.wiandt@fluke.com, tom.harper@fluke.com

**Abstract:** At Fluke's Primary Temperature Calibration Laboratory, we recommend that our calibration customers monitor SPRT and PRT drift by tracking each thermometer's resistance at the triple-point of water ($R_{TPW}$). We also encourage our customers to update their temperature readout with the thermometer's $R_{TPW}$ value measured by the same readout whenever it is possible. This is important since $R_{TPW}$ is used by the readout to calculate temperature. In response to these instructions, our customers often ask how much an SPRT or PRT should be allowed to drift at the triple-point of water (TPW) before it needs to be annealed or recalibrated. The answer to this question is complicated because it is difficult to know how much $R_{TPW}$ can change before $W_{T90}$ changes. In order to answer this question, $R_{TPW}$ and $W_{T90}$ drift data from a variety of SPRT and PRT models is presented to show how $R_{TPW}$ drift affects accuracy over the entire range of calibration. Also, a concise description of the mathematics and process involved in ITS-90 temperature calculation is given to demonstrate the reason why $R_{TPW}$ is so important for measurement accuracy. The intent is to present data and information that allow the reader to determine appropriate $R_{TPW}$ drift guidelines for their measurement needs.

## 1. INTRODUCTION

The $W_{T90}$ ratio of an SPRT (Standard Platinum Resistance Thermometer) is the base value of the SPRT range of the ITS-90 (International Temperature Scale of 1990). It is the ratio of an SPRT's resistance at some temperature $T_{90}$ to the resistance at the triple-point of water (1).

$$W_{T90} = \frac{R_{T90}}{R_{TPW}} \qquad (1)$$

The ITS-90 equations are based on $W_{T90}$ values rather than resistance values of the SPRT for two main reasons. First, the resistance of an SPRT may drift but the ratio of resistance, or $W_{T90}$ value, will exhibit very little drift or remain constant. Thus, a new value of $R_{TPW}$ will essentially restore the initial uncertainty of the $W_{T90}$ for the thermometer. Second, since $W_{T90}$ is a ratio between two resistances, it is possible to remove most if not all the resistance error found in a temperature measurement by properly using the $R_{TPW}$ value with the readout measurements. Additionally, this feature of ITS-90 facilitates removal of the traceability (thus, the uncertainty) of the ohm from temperature calculations. In essence, mainly the linearity of the readout will affect the ability of the readout to measure a temperature. However, this concept requires careful consideration to understand the uncertainties that are involved in the measurement and it may be best to consult with the readout manufacturer to understand all of the uncertainties involved in the readout's measurement capability.

Per ITS-90 literature[1], an SPRT is characterized or calibrated by measuring the $W_{T90}$ value at prescribed fixed-point temperatures. This is done by measuring the SPRT resistance at the required ITS-90 fixed-points directly followed with an $R_{TPW}$ measurement. $W_{T90}$ is calculated for each temperature point by dividing the measured resistance by the corresponding $R_{TPW}$ . The $W_{T90}$ values are then entered into calculations to determine calibration coefficients that describe the deviation of the thermometer from the reference ITS-90 equation.

In theory, the same procedure is followed when using the SPRT as a reference thermometer in some type of temperature measurement. That is to say the $R_{TPW}$ would be measured after any measurement at $T_{90}$ and calculations made before the temperature of the SPRT is known. However, most working laboratories today are not using this procedure due to the modern equipment used in the laboratories.

Modern day instrumentation has been designed to automatically calculate ITS-90 temperatures by allowing the user to enter calibration coefficients and the $R_{TPW}$ value into the readout. The readout is able to perform all of the necessary ITS-90 calculations to display a temperature value based on the measured resistance. The $R_{TPW}$ must be handled correctly to ensure the best results when using this type of readout. We recommend that the user measures the thermometer's $R_{TPW}$ on a routine basis and updates the readout with the most recently measured $R_{TPW}$ value.

Regardless of the method used, the same question of SPRT resistance drift applies. How much can an SPRT's resistance drift before $W_{T90}$ is no longer considered valid and the SPRT should be annealed or re-characterized? To help answer this question concisely, it is necessary to first review the method in which temperatures are calculated when using the ITS-90.

## 2. HOW ITS-90 TEMPERATURES ARE CALCULATED IN MOST MODERN READOUTS

As explained in the previous section, $W_{T90}$ is the basis for the SPRT function set. It is also the base unit that a modern thermometer readout uses to calculate and display a temperature reading when measuring an SPRT.

To calculate and display a temperature reading, the readout first measures the resistance of the SPRT. After this, the resistance value is divided by the $R_{TPW}$ value stored in the readout to calculate $W_{T90}$. The $W_{T90}$ value is then used along with the deviation function coefficients also stored in the readout to calculate $\Delta W_{T90}$. This is done using an ITS-90 deviation function equation such as (2) shown below.

$$W(T_{90}) - W_r(T_{90}) = a[W(T_{90}) - 1] + b[W(T_{90}) - 1]^2 + c[W(T_{90}) - 1]^3 + d[W(T_{90}) - W(660.323°C)]^2 \quad (2)$$ [1]

$\Delta W_{T90}$ is used to correct $W_r$ so it can be entered into the corresponding ITS-90 reference function equation to arrive at a temperature reading. (3) is the reference function used for 0 °C to 961.78 °C.

$$W_r(T_{90}) = C_0 + \sum_{i=1}^{9} C_i \left[\frac{T_{90}/K - 754.15}{481}\right]^i \quad (3)$$ [1]

## 3. EXAMPLES OF RTPW AND $W_{T90}$ DRIFT

In order to demonstrate how $R_{TPW}$ drift affects $W_{T90}$, we have presented data from the calibrations of different types of SPRTs and secondary PRTs. The $\Delta W_{T90}$ data shown in the following graphs are based on values calculated from updated $R_{TPW}$. This allows the data to demonstrate how much $W_{T90}$ changes even though $R_{TPW}$ is continually updated as the thermometer drifts.

The secondary PRTs are of different models but all made by the same manufacturer and have partially supported platinum sensing elements of α = 0.003925 wire. The SPRT data represent a variety of models that are commercially available and the type of construction is represented in each graph.

The PRTs were measured by comparison with a calibrated SPRT while the SPRTs were all measured in reference fixed-point cells at all temperatures except -189.344 °C. The corresponding fixed-point or comparison temperature points and $k = 2$ measurement uncertainties are shown in the legend of each graph.

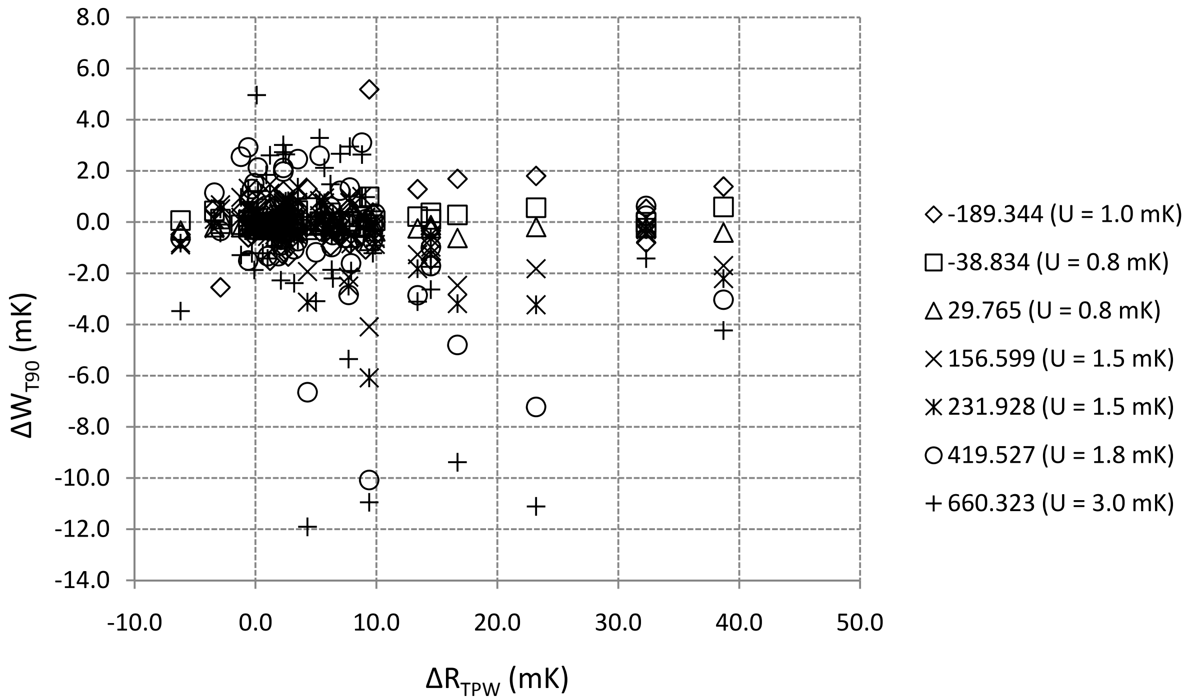


**Fig. 1. $W_{T90}$ drift of metal-sheath SPRTs with different amounts of change in $R_{TPW}$**

| Temperature Point (ºC) | Average $\Delta W_{T90}$ (mK) | Std. Dev. Of $\Delta W_{T90}$ (mK) |
|---|---|---|
| -189.344 | 0.0 | 1.1 |
| -38.834 | 0.1 | 0.3 |
| 29.765 | -0.1 | 0.3 |
| 156.599 | -0.3 | 1.0 |
| 231.928 | -0.3 | 1.4 |
| 419.527 | -0.4 | 2.5 |
| 660.323 | -1.0 | 3.6 |

**Table 1. Average and standard deviation of the $\Delta W_{T90}$ values at each temperature point shown in Figure 1**

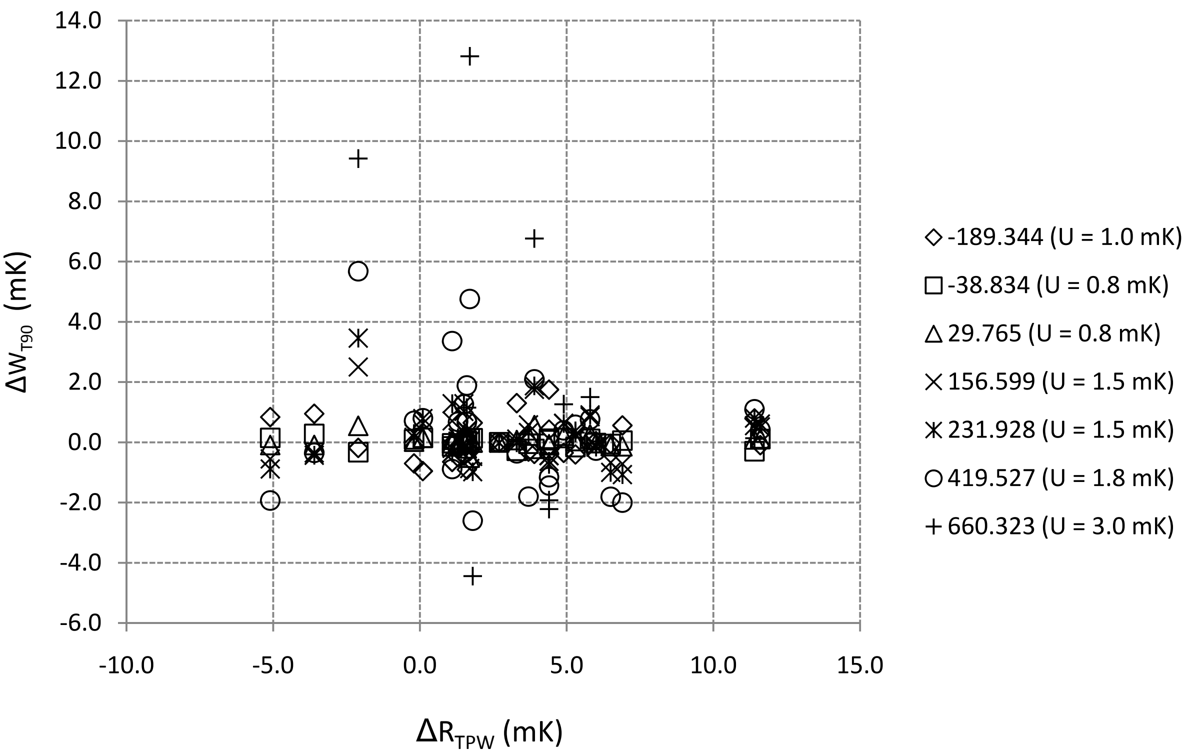


**Fig. 2.** ***$W_{T90}$*** **drift of quartz-sheath SPRTs with different amounts of change in** ***$R_{TPW}$***

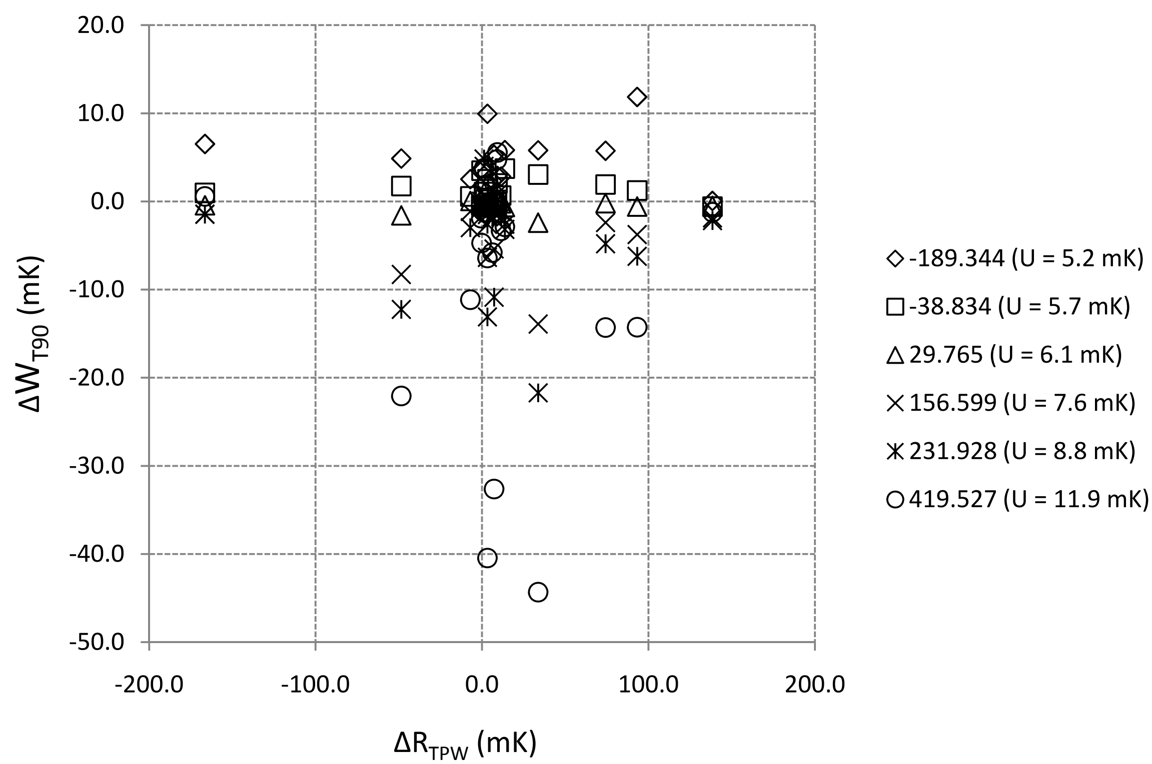


**Fig.3.** ***$W_{T90}$*** **drift of 100 Ω secondary PRTs with different amounts of change in** ***$R_{TPW}$***

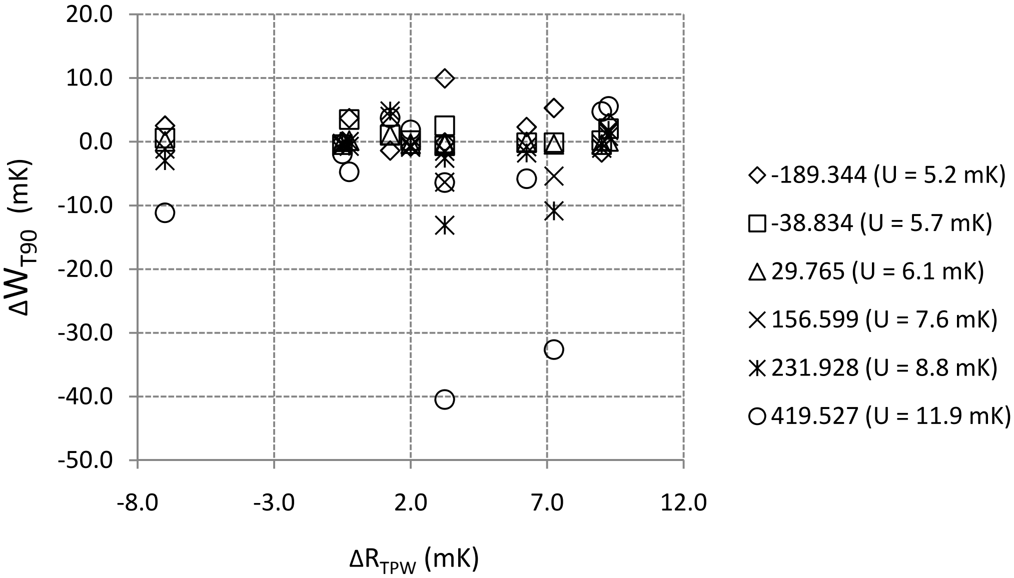


**Fig. 4.** $W_{T90}$ **drift of 100 Ω secondary PRTs with changes in** $R_{TPW}$ **of less than 10 mK**

The data indicate that SPRT $W_{T90}$ can change as much as ±13 mK when $R_{TPW}$ only changes by about 2 mK. However, this is not usually the case. Most SPRTs that drift in $R_{TPW}$ as much as 10 mK only change in terms of $W_{T90}$ by about ±2 mK or less depending on the temperature. The quartz-sheath SPRTs appear to have slightly lower $W_{T90}$ drift but the data population would need to be a bit larger to solidify this possibility. It is important to note that the $\Delta W_{T90}$ calculations are based on updated $R_{TPW}$ values. It has been observed that $\Delta W_{T90}$ would be much larger without updated $R_{TPW}$.

A few of the SPRTs exhibit changes in $W_{T90}$ that are much larger than expected considering the measurement uncertainties and the statistics of the data. We intend to investigate these SPRTs individually in an attempt to better understand this behavior.

Not surprisingly, the PRT data indicate much larger changes in both $R_{TPW}$ and $W_{T90}$. The PRTs are not strain-free and since they are all working instruments they are exposed to many different conditions. With that said, the $W_{T90}$ performance is quite good considering the intended accuracy limits of these types of devices. With rare exception, PRTs that shift in $R_{TPW}$ as much as 10 mK exhibit shifts in $W_{T90}$ of 10 mK or less. The data are sufficient to show that $R_{TPW}$ updates are important for PRTs as well.

## 4. CONCLUSION

Answering the question of how much an SPRT or PRT $R_{TPW}$ should be allowed to drift before it needs to be annealed or recalibrated is a bit difficult. In most cases an SPRT could drift as much as 10 mK with a fairly small change in $W_{T90}$ at temperatures of 231.928 °C and lower. However, since some SPRTs inexplicably deviate from this pattern, it would be prudent to analyze the SPRT calibration history for $W_{T90}$ stability. Also, periodically checking the SPRT at a higher temperature fixed-point such as zinc would be another way to verify the stability of $W_{T90}$ as $R_{TPW}$ drifts and is updated. This same procedure applies to PRTs as well especially since smaller fixed-point cells are available for use with PRTs. It may also be necessary to consider an additional uncertainty that covers the change in $W_{T90}$.

## 5. RECOMMENDATIONS

The data presented in this paper suggest but do not conclusively confirm a reliable (predictive) relationship between $R_{TPW}$ and $W_{T90}$. Thus, the authors recommend the following. First, evaluate the stability of the thermometer each time the instrument is calibrated to determine if the thermometer appears to show a relationship between $R_{TPW}$ and $W_{T90}$.

Second, for routine applications of SPRT usage, a limit of 2 mK to 3 mK can be established for allowable SPRT $R_{TPW}$ drift before recalibration or annealing is required. Within this range of $R_{TPW}$ drift, $W_{T90}$ appears stable.

Third, for special applications in which the drift needs to be known more precisely, or in cases where the risk of out-of tolerance usage must be minimized, it is advisable to use a higher temperature fixed point cell to monitor a specific $W_{T90}$ to ensure stability across the entire range. In all cases the $R_{TPW}$ value should be updated at regular intervals to remove resistance error.

The relationship between $R_{TPW}$ and $W_{T90}$ for PRTs does not suggest that an $R_{TPW}$ error increases as temperature increases, thus, it may be acceptable to allow $R_{TPW}$ to drift by the maximum allowed at any temperature before recalibration. Again, in applications in which the drift needs to be known more precisely, or in cases where the risk of out-of tolerance usage must be minimized, it is advisable to use a higher-temperature evaluation (secondary fixed-point system or comparison to an SPRT) to monitor a specific $W_{T90}$ to ensure stability across the entire range. In all cases the $R_{TPW}$ value should be updated at regular intervals to remove resistance error.

## 6. REFERENCES


[1] The International Temperature Scale of 1990 (ITS-90), Preston-Thomas, H., pp 6-8

[2] Zhao, Mingjian, Walker, Rick, Fluke-Hart Scientific, Inc., MSC 2006 Proceedings, Long-Term Resistance and Ratio Stability of SPRTS, Comparing Metal Sheaths vs. Fused Silica Sheaths