Keysight 34420A SPRT Measurements and ITS-90 Conversions

Keysight 34420A Revision 2.0 Changes

The *International Temperature Scale of 1990* (ITS–90) is defined in terms of specific fixed points to which temperature values (T_{90}) have been assigned. Table 1 shows the temperature calibration points selected for ITS–90 with their corresponding descriptions.

Table 1 ITS-90 Temperature Calibration Fixed Points

Temperature (T_{90})	Type	Element
-259.3467 °C	Triple Point	(H_2) Hydrogen
-248.5939 °C	Triple Point	(Ne) Neon
-218.7916 °C	Triple Point	(O_2) Oxygen
-189.3442 °C	Triple Point	(Ar) Argon
-38.8344 °C	Triple Point	(Hg) Mercury
+0.01 °C	Triple Point	(H_2O) Water
29.7646 °C	Melting Point	(Ga) Gallium
156.5985 °C	Freezing Point	(In) Indium
231.928 °C	Freezing Point	(Sn) Tin
419.527 °C	Freezing Point	(Zn) Zinc
660.323 °C	Freezing Point	(Al) Aluminum
961.78 °C	Freezing Point	(Ag) Silver

The *Standard Platinum Resistance Thermometer* (SPRT) is the defining standard for temperature interpolation between the fixed temperature calibration points listed above. The sensing element of an SPRT varies resistance with temperature in a known manner. An SPRT normally exhibits a nominal resistance (R_0) of 25.5Ω at the triple point of water (+0.01 °C).

KEYSIGHT TECHNOLOGIES

The 34420A (starting with firmware revision 2.0) incorporates built-in support for precision temperature measurements using SPRT transducers. An SPRT resistance measurement is performed using 1.0 mA of current and offset-compensation — this is a low-frequency (approximately 5 Hz) ac measurement technique which removes thermal offsets in the measurement.

NOTE When making direct resistance measurements of an SPRT, make sure you use the 34420A's low-power resistance mode (use the `SENS:FRES:POW:LIM ON` command).

Calibration values for an SPRT are normally expressed as a ratio, $W(T_{90})$, of the probe resistance at some temperature (T_{90}) divided by the nominal probe resistance (R_0) at the triple point of water. An SPRT must be constructed of pure platinum and must be strain free. The finished probe must meet the following resistance ratio requirements to be acceptable for ITS-90 calibration and use:

$W(+29.7646\ °C) \geq 1.11807$ and $W(-38.8344\ °C) \leq 0.844235$

This is equivalent to a requirement that the alpha coefficient (average normalized temperature coefficient of resistance) meets the following: $\alpha \geq 0.003986\ \Omega / \Omega / °C$ *from 0 °C to +100 °C.*

A single SPRT cannot be used over the entire ITS-90 temperature range. Capsule-type SPRTs are generally usable over the range of approximately –250 °C to +200 °C. Long-stem type SPRTs are generally usable over the range of approximately –200 °C to +660 °C. Often the outer sheath of an SPRT will limit its high-temperature measuring range due to leakage effects shunting the resistive measuring element.

The ITS-90 standard defines reference functions and calibration deviation functions which precisely describe an SPRT's resistance variation with temperature. The ITS-90 reference functions are made up of 9th order and 15th order polynomials which describe the $W(T_{90})$ resistance ratio variation for temperatures above and below the triple point of water, respectively. In addition, ITS-90 deviation function polynomials are used to correct, or calibrate, a particular probe's response over a specified sub-range of temperatures (for example, from 0 °C to the freezing point of aluminum, +660.323 °C). The following sections in this manual list the standard ITS-90 temperature sub-ranges and their corresponding deviation function calibration coefficients.

The conversion routines built into the 34420A implement the ITS-90 temperature conversion equations *directly* for sub-range 4 and sub-range 7, covering the calibrated temperature range of –189.3442 °C to +660.323 °C. The conversion routines allow you to directly enter the following calibration constants:

Table 2 34420A SPRT Calibration Constants

Constant	Description
R_0	Triple Point of Water Probe Resistance Value
A_4, B_4	Sub-Range 4 Calibration Coefficients
A_7, B_7, C_7	Sub-Range 7 Calibration Coefficients

Temperature can be displayed with units of °C, °F, or K.

Calibration Coefficient Substitutions

You can substitute probe calibration data from other temperature sub-ranges for the sub-range 4 and sub-range 7 calibration coefficients as noted in the following sections.

You can enter sub-range 2 or sub-range 3 calibration coefficients in place of sub-range 4 coefficients by applying the following substitutions (see also Table 3):

$A_4 = A_2$, $B_4 = B_2$ or $A_4 = A_3$, $B_4 = B_3$ (Ignore the “C” coefficients)

The calibrated measuring range will be limited to that of sub-range 4 (–189.3442 °C to +0.01 °C) regardless of which sub-range coefficients are used.

Table 3 ITS-90 Sub-Ranges for Temperatures Below the Triple Point (TP) of Water

Temperature Range	Fixed Points	Calibration Coefficients
Sub-Range 2: -248.5939 °C to +0.01 °C	TP of Neon to TP of Water	A_2, B_2, C_1, C_2, C_3
Sub-Range 3: -218.7916 °C to +0.01 °C	TP of Oxygen to TP of Water	A_3, B_3, C_1
Sub-Range 4: -189.3442 °C to +0.01 °C	TP of Argon to TP of Water	A_4, B_4

You can enter sub-range 6 calibration coefficients in place of sub-range 7 coefficients by applying the following substitutions (see also Table 4):

$A_7 = A_6$, $B_7 = B_6$, $C_7 = C_6$ (Ignore the “D” coefficient)

The calibrated measuring range will be limited to that of sub-range 7 (0 °C to +660.323 °C).

For sub-ranges 8 and 9, use the following substitutions (see also Table 4):

$A_7 = A_8$, $B_7 = B_8$ or $A_7 = A_9$, $B_7 = B_9$ ($C_7 = 0$ for both)

For sub-ranges 10 and 11, use the following substitutions (see also Table 4):

$A_7 = A_{10}$ or $A_7 = A_{11}$ ($B_7 = 0$ and $C_7 = 0$ for both)

The calibrated measuring range will be limited to that of the sub-range whose coefficients you entered. For example, if you used sub-range 10 coefficients, then you would enter $A_7 = A_{10}$, $B_7 = 0$, and $C_7 = 0$. The resulting calibrated measuring range would extend from 0 °C to +156.5985 °C (the freezing point of Indium).

Table 4 ITS-90 Sub-Ranges for Temperatures Above 0 °C

Temperature Range	Fixed Points	Calibration Coefficients
Sub-Range 6: 0 °C to +961.78 °C	0 °C to FP of Silver	A_6, B_6, C_6, D
Sub-Range 7: 0 °C to +660.323 °C	0 °C to FP of Aluminum	A_7, B_7, C_7
Sub-Range 8: 0 °C to +419.527 °C	0 °C to FP of Zinc	A_8, B_8
Sub-Range 9: 0 °C to +231.928 °C	0 °C to FP of Tin	A_9, B_9
Sub-Range 10: 0 °C to +156.5985 °C	0 °C to FP of Indium	A_{10}
Sub-Range 11: 0 °C to +29.7646 °C	0 °C to MP of Gallium	A_{11}

When using sub-range 5, calibrated measurements over the restricted range of –38.8344 °C to +29.7646 °C can be performed. The A_5 and B_5 calibration coefficients must be properly substituted as shown below Table 5 to be valid when using sub-range 5 calibration coefficients. Sub-range 5 measurements *are not* valid unless you enter the substitute coefficients for all of A_4, B_4, A_7, B_7, and C_7.

Table 5 ITS-90 Special Sub-Ranges for Temperatures Between –38.8344 °C and +29.7646 °C

Temperature Range	Fixed Points	Calibration Coefficients
Sub-Range 5: -38.8344 °C to +29.7646 °C	TP of Mercury to MP of Gallium	A_5, B_5

You can enter sub-range 5 calibration coefficients in place of the sub-range 4 coefficients by applying the following substitutions (see also Table 5):

$A_4 = A_5$, $B_4 = B_5$

Additionally, sub-range 5 coefficients A_5 and B_5 must be substituted as follows for calibration over the full range of –38.8344 °C to +29.7646 °C (see also Table 5):

$A_7 = A_5$, $B_7 = B_5$, $C_7 = 0$

Temperature Measurement Accuracy

Mathematical conformance to the ITS-90 reference functions and deviation functions yields absolute errors over the approximate range of –190 °C to +660 °C — excluding instrument resistance measuring error and other specified probe calibration errors. Temperature measurement accuracy is limited by the probe resistance measurement error for the 34420A as shown below.

For example, assume the following:

An SPRT exhibits an R_0 of 25.5Ω at the triple point of water.

Alpha (α), the average temperature coefficient of resistance of the probe, is approximated by 0.003986 Ω / Ω / °C x 25.5Ω = ~0.1Ω / °C.

Therefore, when measuring at 100 °C, the probe resistance is approximately R(100 °C) = 25.5Ω + (100 °C – 0 °C) x 0.1Ω / °C = ~ 36Ω.
The meter will use the 100Ω range for this measurement.

The 34420A's 24-day accuracy for a 36Ω measurement is:

0.0015% of Reading + 0.0002% of Range or
0.0015% x 36Ω + 0.0002% x 100 = 0.0005Ω + 0.0002Ω = 0.0007Ω

Translating to Temperature Error:

T_{Error} = 0.0007Ω / 0.1Ω / °C = ~0.007 °C *(Absolute Error)*

Checking the triple point of water probe resistance value (R_0) and entering it into the 34420A in effect relieves the meter of absolute gain accuracy requirements making it simply a resistance ratio measuring device. Performing the triple point check will therefore eliminate the 0.0015% of reading error producing an absolute temperature accuracy of:

0.002 °C (for measurement) + 0.001 °C (for math) = ±0.003 °C

Using 0.0000% of reading error is valid within four hours of performing an R_0 check if the instrument's operating environment is stable to ±1 °C during the measurement period.

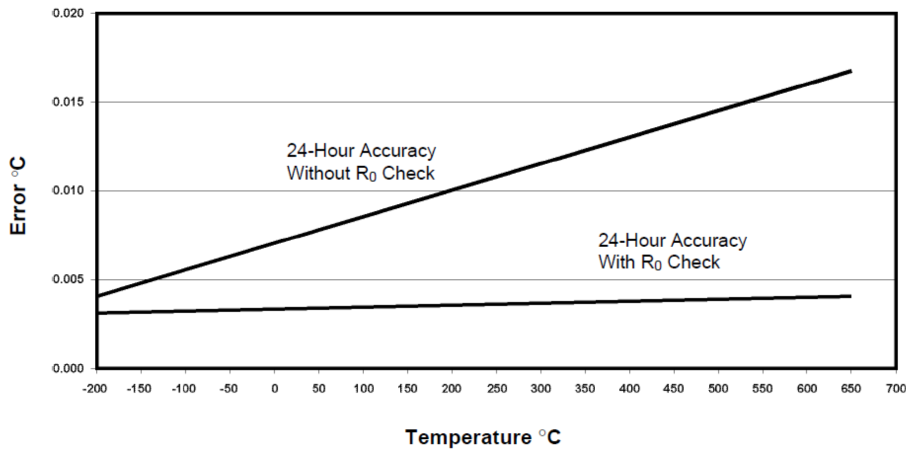

Figure 1 SPRT total measurement error versus temperature before and after checking the triple point of water probe resistance (R_0).

New Front-Panel Menu Entries

A new RTD type (**USER SPRT**) has been added within the **TEMP MENU** as shown below. Select this entry to enable the 34420A to measure SPRT transducers.

.....B: TEMP MENU.....

▼

.....3: RTD TYPE.....

▼

ALPHA = .00385 → ALPHA = .003916 → **USER SPRT** — *New Entry*

After selecting “**USER SPRT**”, a new entry (**SPRT COEF**) will appear on the top level of the **TEMP MENU** as shown below. The new entry is visible only after you select “**USER SPRT**” (see above).

.....B: TEMP MENU.....

▼

.....6: COLD JUNCT → 7: JUNCT TEMP → **8: SPRT COEF** — *New Entry*

▼

EDIT A4	*Press* ENTER
Edit Number	*Press* ENTER
EDIT B4	*Press* ENTER
Edit Number	*Press* ENTER
EDIT A7	*Press* ENTER
Edit Number	*Press* ENTER
EDIT B7	*Press* ENTER
Edit Number	*Press* ENTER
EDIT C7	*Press* ENTER
Edit Number	*Press* ENTER

You are automatically exited from the menu upon completion.

When editing the numeric coefficients shown on the previous page, notice that an engineering units multiplier is also available to edit beyond the smallest (right-most) digit. Multipliers range from:

Tera	=	$x10^{12}$
Giga	=	$x10^{9}$
Megak	=	$x10^{6}$
ilo	=	$x10^{3}$
--	=	x1
milli	=	$x10^{-3}$
micro	=	$x10^{-6}$
nano	=	$x10^{-9}$
pico	=	$x10^{-12}$
femto	=	$x10^{-15}$

In practice, the “micro” ($x10^{-6}$) engineering unit will be most convenient when entering common ITS-90 calibration values.

New SCPI Commands for Remote Interface Programming

New parameters are shown in **bold**.

```
[SENSe:]TEMPerature:
  TRANsducer:FRTD:TYPE {85|91|USER}
```

```
CONFigure:TEMPerature
  FRTD,{85|91|USER|DEF}[,1,{,<resolution>|MIN|MAX|DEF}]
```

```
[SENSe:]TEMPerature:
  TRANsducer:FRTD:USER:COEFficients {<A4>},{<B4>},{<A7>},{<B7>},{<C7>}
```

When using the above command, you must specify all five coefficients; ***default values are not allowed****. Data is stored as double-precision, 64-bit floating-point numbers.*

Additional Temperature Measurement Commands

The 34420A commands for measuring temperature are shown below. Detailed descriptions of these commands are included in the 34420A *User's Guide* but the syntax statements are repeated here for your convenience.

```
[SENSe:]TEMPerature:TRANsducer:TYPE {TCouple|THERmistor|FRTD}
[SENSe:]TEMPerature:TRANsducer:TYPE?
```

```
TEMPerature:TRANsducer:FRTD:RESistance[:REFerence] <value>
TEMPerature:TRANsducer:FRTD:RESistance[:REFerence]?
```

```
UNIT:TEMPerature {C|F|K}
UNIT:TEMPerature?
```


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