THERMOPILE SENSOR FOR CONTACTLESS TEMPERATURE

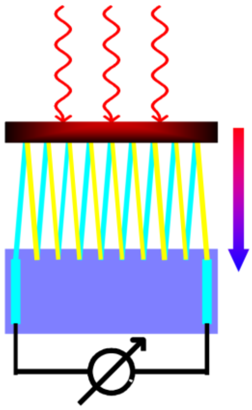
APPLICATION NOTE

This document is meant to provide an introduction in the functionality and usage of thermopile sensors for contactless temperature measurement. Thermopiles are mainly used for contact-less temperature measurement in many applications. Their function is to transfer the heat radiation emitted from the objects into voltage output. Major applications are appliances like microwave oven, clothes dryer, automatic cooking, medical devices like ear and fore head thermometer, automotive applications like car climate control, seat occupancy, blind spot alert, black ice warning, consumer products like printer, copier, mobile phone and many industry applications like paper web, plastic parts etc.

Thermopile Component TS305-11C55

Thermopile Function

Any object emits infrared radiation. The radiation power is increasing with growing surface temperatures. Based on this relation, thermopiles measure the emitted power and determine the object's temperature precisely. Thermopiles are based on the Seebeck effect, which is used since a long time for conventional thermocouples. The application of micromechanics and thin film technology allows the production of miniaturized and cost-effective sensor elements.



The thermopile voltage V_{TP} is then determined by:

- object temperature T_{obj}
- emissivity of the object ε_{obj}
- ambient temperature T_{sen} (i.e. temperature of the sensor ≠ air or PCB temperature)
- instrument factor s
- correction for filter transmission δ

$$V_{TP} = s \cdot \varepsilon_{obj} \cdot \left(T_{obj}{}^{4-\delta} - T_{sen}{}^{4-\delta} \right)$$

Figure 1: Contributions to the thermopile voltage

Anatomy of a thermopile sensor component

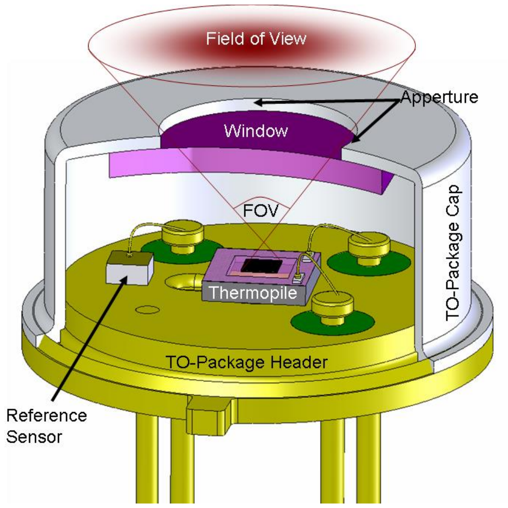


Figure 2: Cross section through a thermopile sensor showing all relevant parts

Table 1: Parts of a thermopile sensor and their function

Part	Function
Thermopile Chip	Sensing element, converts radiation into voltage
Reference Sensor	Measures the temperature of the sensor package, i.e. the temperature of the cold contacts
Window	Filter and/or lens: • defines wavelength range of the component • defines together with the thermopile chip and the package the field of view (FOV) • provides together with the package hermetic sealing
TO-Package	Cap & Header: • defines together with the thermopile chip and the package the field of view (FOV) • provides together with the window hermetic sealing • provides electrical connections of the component

Table 2: Parts of a thermopile sensor and their function

Package Type

TE Sensor Solutions offers thermopile components in a TO-18 (≈TO-46) package and a TO-5 (≈TO-39) package with flat window. A TO-5 (≈TO-39) package with lens is also available.

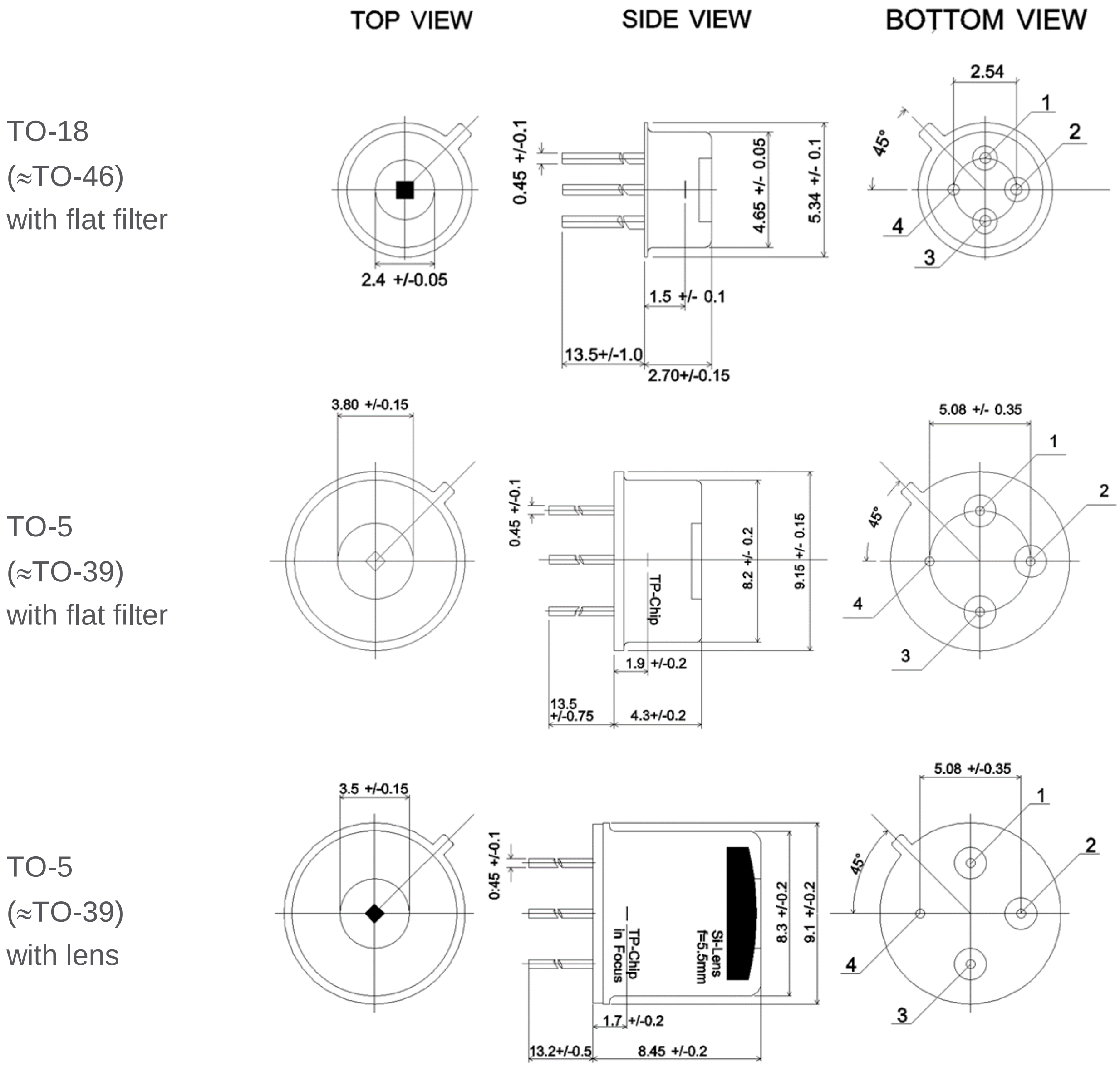


Table 3: Thermopile components package types

- The TO-18 package with flat window is small and therefore suitable for applications where space is an issue, e.g. ear thermometer.
- The TO-5 package with flat window is a good general-purpose package for thermopile sensors. It should be applied to all applications without space limitations. Also, it is the best choice for customization of a component.
- The TO-5 package with lens is best suit for applications where a narrow field of view, i.e. small spot size to distance ratio, is required.

Reference Sensor

The reference sensor is used to measure the temperature of the sensor. It is needed according the formula describing the thermopile voltage in Figure 1. To reach enough accuracy a reference sensor in a thermopile component must be calibrated.

NTC Thermistor

The most common reference sensor type is a negative temperature coefficient (NTC) thermistor. It has a very high temperature coefficient of resistance, low self-heating and can be read out by an analogue to digital converter (ADC) via a voltage divider without amplification. However, it is strongly nonlinear which may cause lower accuracy when applied in a large temperature range. The most common application range is for consumer applications 0-50°C.

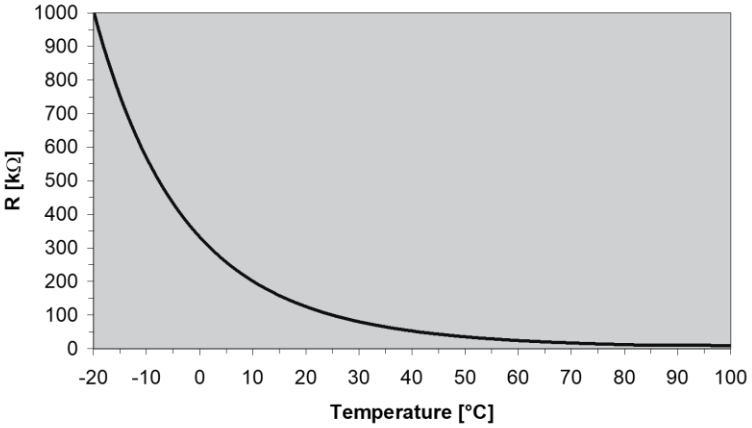


Figure 3: R-T-Curve of a NTC Thermistor

Nickel RTD

TE also provides Nickel resistance temperature detectors (RTD) as reference sensors. These have the advantage of an almost linear resistance-temperature-curve over a large range.

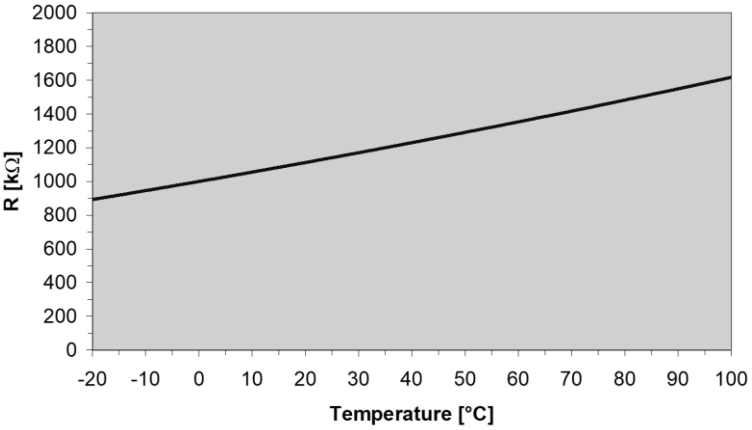


Figure 4: R-T-Curve of a Nickel-RTD type Ni1000

Transport Recommendations

- Avoid touching of silicon window
- Avoid contamination of silicon window
- Avoid damage of silicon window (scratches, etc.)
- Avoid pin deformation
- Avoid compression of component housing

Cleaning Recommendations

- Isopropanol (other names: Iso-Propyl-Acohol (IPA), 2-Propanol),
  use medical grade, pro analysis grade or purer
- Scratch and lint free cleaning tissue (e.g. Bemcot M-3II)

Using the wet tissue:
Clean from the center of the window or lens to the outside.
Take care that you also clean the tiny step between optics and metal case of the thermopile properly

- Check for stains after wet cleaning, if necessary repeat the wet cleaning
- Check for lints after wet cleaning, if necessary wipe of lints with a dry tissue
- Please Note:
  Some Q-tips have the cotton attached to the stick with glue. In some cases, this glue is dissolved by the isopropanol and leaves a deposit on the optics. Due the infrared absorption of this deposit the calibration may be compromised.

Solder Recommendations

Process	Temperature	Max. Duration / s	Comment
Wave Soldering [1]	260°C ±5°C	10	AOI recommended
Hand Soldering [1]	375°C ±10°C	4	Control for flux residue and other contamination on the surface of the PCBA recommended
Reflow Soldering	Not recommended		

[1] Parameter valid only for PB-free soldering process.

Touching the Sensors Cap

User should avoid touching the sensors cap. There will still be a measurement deviation after changing the sensors temperature rapidly.

Circuitry Examples

This chapter is meant to illustrate examples of circuitry for measurement of thermopile temperature signals. The examples are separated with respect to the used thermistor (NTC or Nickel).

Thermopile Output Signal Processing

The Op-Amp is used as a non-inverting amplifier with a shifted virtual ground ("Offset Voltage"). This additional voltage is required to keep the output voltage positive even in case of negative sensor output voltages. Due to the very low output voltage level of Thermopiles (µV up to mV level) the Op-Amp should be selected carefully with respect to the following parameters:

- Low offset voltage, low offset voltage drift
- Low leakage current, low leakage current drift
- Low noise

NOTE:

This drawing shows only the basic functionality.

This is not a ready to use circuit diagram!

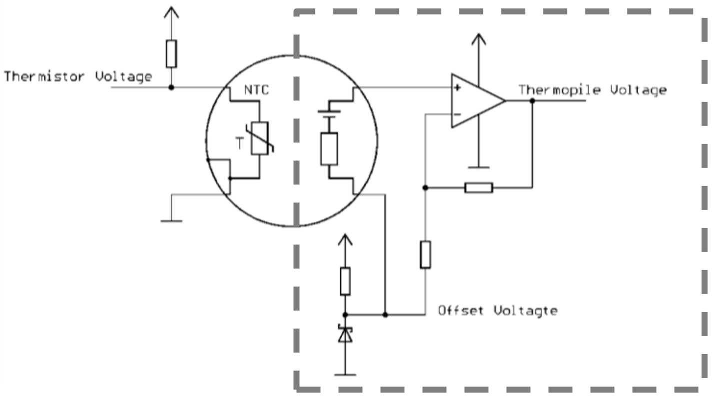


Figure 5: Basic functionality of a TP amplification circuit

NTC Thermistor

A simple voltage divider is used for measurement of the sensor's temperature. Due to the high resistance on the NTC (100kΩ) self-heating due to measurement current has no reasonable influence on measurement accuracy.

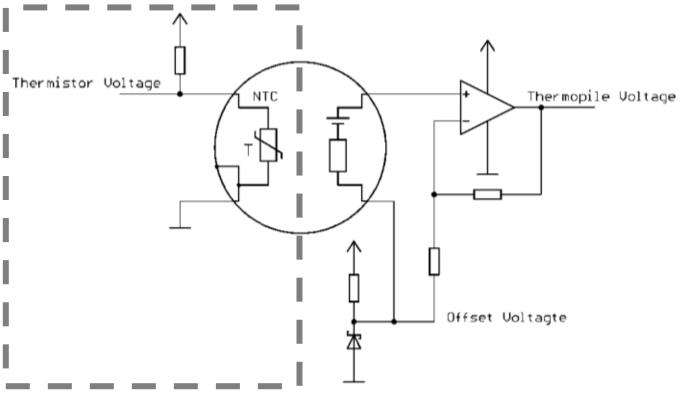


Figure 6: Basic functionality of a NTC circuit

Nickel RTD (Ni1000)

The additional Op-Amp is used as a Differential Amplifier to achieve high dynamic range of thermistor output signal. The selection of the resistors depends on the occurring ambient temperatures and the expected output voltage range.

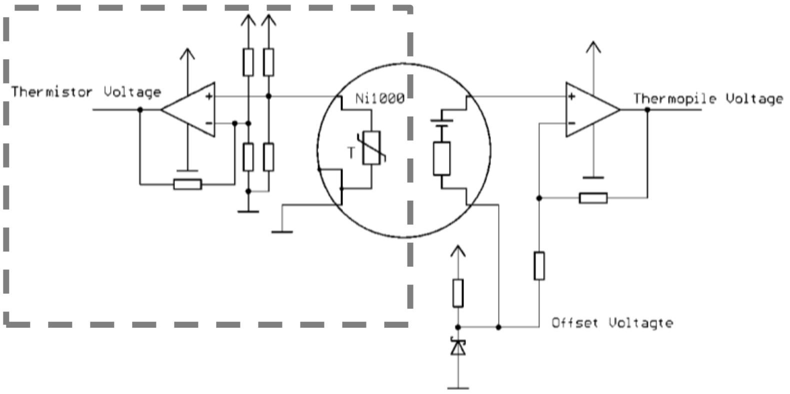


Figure 7: Basic functionality of a Ni-RTD circuit

Calibration of Reference Sensor

The reference sensor must be calibrated to achieve adequate overall measurement accuracy. The process of calibration is carried out in the same way regardless of reference sensor selection.

Depending on the desired performance and the tolerance of the reference sensor a calibration at one, two, or three ambient temperatures is necessary. This can be carried out in a bath.

$$V_{TP} = s \cdot \varepsilon_{obj} \cdot \left(T_{obj}^{4-\delta} - T_{sen}^{4-\delta}\right)$$

Reference Sensor Measurement before Calibration

The NTC resistance (or the voltage drop over its resistance) is measured at a fixed calibration temperature (i.e. 25°C). Calibration parameter are determinate with respect to its reference curve.

$$R_{Tx} = R_{25} \cdot e^{\beta \cdot \left(\frac{1}{T_x} - \frac{1}{T_{25}}\right)}$$

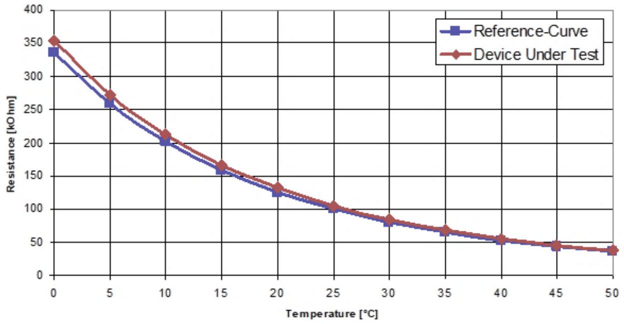


Figure 8: NTC Curve before calibration

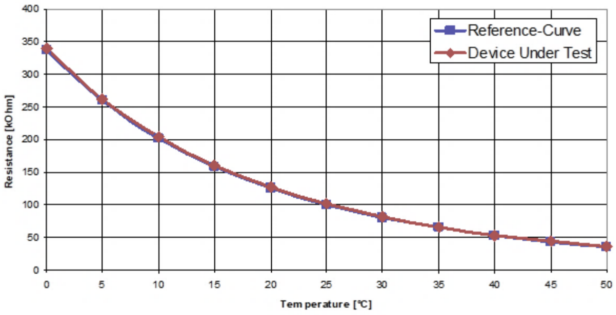


Figure 9: NTC Curve after calibration

Calibration of Thermopile Measurement Temperature

The calibration of the thermopile output signal can be carried out in these process steps:

- Measurement of thermopile voltage at high temperature setpoint to determinate the thermopile sensitivity s.
- Measurement of thermopile voltage at low temperature setpoint to determinate offset voltage caused by electronics and signal processing chain. This step can be skipped in dependence of accuracy demands.
- The reference curve of thermopile voltage over temperature must be fitted in dependence to the measurement values.

Calculation of Measurement Temperature

This chapter contains a short description of an algorithm for object (measurement) temperature calculation using Thermopiles.

The focus is on the description of

- essential facts of Thermopile behavior concerning ambient temperature variation
- the necessary steps to create a "calibrated and temperature compensated sensor" which includes the calibration itself and an algorithm for object temperature calculation which can be implemented in a microcontroller

Nomenclature

- TP — Thermopile
- T_{OBJ} — Object Temperature
- T_{SEN} — Sensor Temperature
- $T_{SEN,REF}$ — Reference Sensor Temperature while calibration
- Delta T — $Delta\ T = T_{SEN} - T_{SEN,REF}$
- V_{TP} — Thermopile Voltage
- TC_{SENS} — Temperature Coefficient of Thermopile Sensitivity
- S_{CONV} — Sensitivity Conversion Factor
- $V_{TP,CORR}$ — Thermopile Voltage corrected by S_{CONV}
- V_{OFFS} — Offset, which is the voltage distance between reference curve (stored in LUT) and the actual $V_{TP}(T_{SEN})$
- $V_{OFFS,TC}$ — V_{OFFS} (Offset) corrected by T_{CF}
- T_{CF} — TC Factor which is $T_{CF} = 1 + Delta\ T \times TC_{SENS}$
- $V_{TP,REF}$ — Calculated Thermopile Voltage at $T_{SEN,REF}$
- $V_{TP,REF,TC}$ — $V_{TP,REF}$ corrected by T_{CF}
- LUT — Look-Up-Table

Table 4: Nomenclature

Characteristic Thermopile Behavior

The figure on the right shows the typical Thermopile output voltage (in this case with 5 µm-cut-on filter) as a function of object and ambient temperature.

There are two essential effects which are important to notice in context with ambient temperature variation:

1. A Thermopile detects infrared radiation. This radiation is the difference between incoming (from the object) and outgoing (from the sensor itself) radiation. Therefore, the Thermopile output voltage is
   a. $V_{TP} > 0$ if object temperature > sensor temperature
   b. $V_{TP} < 0$ if object temperature < sensor temperature

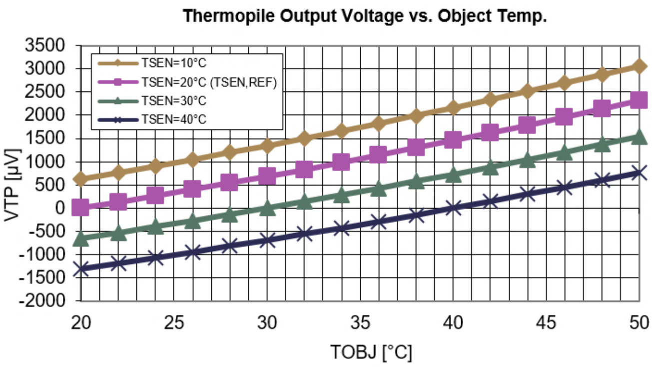


Figure 10: Typical output voltage curve form of Thermopile sensor

2. By increasing ambient temperature, the sensitivity decreases. Due to material properties (thermocouple material, membrane material) the sensitivity - Volt per absorbed radiation - is lower at higher ambient temperatures. This Thermopile property is given as the temperature coefficient TC_{SENS}.

Consequence of fact No 1 is that the whole curve is shifted at different voltage levels depending on the ambient temperature. The distance between these curves is here called offset V_{OFFS}.

Consequence of fact No 2 is that the gradient of the curves (which is proportional to the Thermopile sensitivity) decreases by increasing ambient temperature. The higher the temperature the flatter is the curve form.

Note that the characteristic curve form isn't affected on both facts. Fact 1 only shifts the curve, fact 2 compresses resp. stretches the curve in dependence on the ambient temperature. The curve characteristic only depends on the filter characteristic of the Thermopile. In most applications this variation of filter characteristic is negligible.

By knowing the sensitivity and the temperature coefficient TC_{SENS} of a particular Thermopile it is possible to determine the relation to a reference Thermopile and - as a result - to calculate the object temperature.

Look-Up-Table and Reverse-Look-Up-Table

This chapter gives a short description of the way how to measure the reference values which are needed for the Reference Look-Up-Table. The essential operations on this LUT are described.

The reference TP should be a Thermopile with a sensitivity at an average level. The measuring should be done in the application. This means that the whole signal path should be measured (including pre-amplification, ...).

The measuring result could be the table on the right.

The step size depends on the required accuracy of later temperature detection and on the available memory in the microcontroller.

Two operations on this LUT are needed later in the algorithm:

1. **V = LUT (T)**
2. **T = RLUT (V)**

Example:

V = LUT (T = 45°C) = 1.70mV

T = RLUT (V = 4.34mV) = 70°C

TS118-1	
Sensor Temp. = 25°C	
Object Temp. [°C]	**VTP [mV]**
0	-1.63
5	-1.35
10	-1.04
15	-0.72
20	-0.37
25	0.00
30	0.39
35	0.81
40	1.24
45	1.70
50	2.18
55	2.69
60	3.21
65	3.76
70	4.34
75	4.94
80	5.56
85	6.21
90	6.88
95	7.58
100	8.30

Calibration

Calibration means:

Measuring the Thermopile parameter which are later needed to determine the link between the actual measured Thermopile voltage and the reference Thermopile voltage. Storing these parameters in the nonvolatile memory of the sensor.

The required parameters are the TC_{SENS} and the sensitivity in comparison to the reference sensor, the sensitivity conversion factor S_{CONV}.

In some applications it isn't necessary at all to know the TC_{SENS} of each sensor exactly which means that the datasheet value should be considered. In this case only a "one ambient temperature calibration" to measure the sensitivity is needed.

See following example how to measure the S_{CONV}.

	TS118-1			
	Sensor Temp. = 25°C			
	Object Temp. [°C]	**VTP [mV]**	**TP under Calibration**	**Conversion Factor**
Calibration Point	100	8.30	**8.15**	**0.982**

In this example the voltage of the TP under calibration is compared at $\mathbf{T_{SEN} = T_{REF} = 25°C}$ and $\mathbf{T_{OBJ} = 100°C}$ is to the voltage of the reference TP. Result is the sensitivity conversion factor S_{CONV} which is 0.982. This value must be stored in the non-volatile memory of the sensor under calibration.

Algorithm

Here is described – step by step – how to calculate the object temperature in the microcontroller.

a) Reference LUT as shown above is available in the non-volatile memory (or as a constant array) in the microcontroller
b) The TC_{SENS} is available in the microcontroller (the datasheet value)

TP Voltage	mV	8.0±2.0	+25°C BB +100°C DC, totally filled field of view
TC of sensitivity	%/K	-0.45±0.08	+25°C → +75°C ambient
NEV	nV/Hz^½	30	+25°C ambient

c) The sensitivity conversion factor S_{CONV} of the actual sensor is available in the microcontroller

Measuring and calculate temperatures:

1. Measuring V_{TP} and V_{RTD}
2. V_{TP} sensitivity correction: $$V_{TP,CORR} = \frac{V_{TP}}{S_{CONV}}$$
3. Calculating T_{SEN} — Measure the reference sensors resistance and calculate sensor temperature
4. Auxiliary step: calculating TCF $$TCF = 1 + (DeltaT \times TC_{SENS})$$
5. V_{OFFS} calculation $$V_{OFFS} = LUT(T_{SEN})$$
6. Temperature compensation of V_{OFFS} $$V_{OFFS,TC} = V_{OFFS} \times TCF$$
7. Adding VOFFS and $V_{TP,CORR}$ $$V_{TP.REF} = V_{TP,CORR} + V_{OFFS,TC}$$
8. Temperature compensation of $V_{TP,REF}$: $$V_{TP,REF,TC} = \frac{V_{TP,REF}}{TCF}$$
9. Object temperature calculation $$T_{OBJ} = RLUT(V_{TP,REF,TC})$$

Example

1. Measuring VTP
   V_{TP} = 3.00mV, S_{conv} = 0.982
2. V_{TP} sensitivity correction:
   $V_{TP,CORR}$ = 3.00mV / 0.982 = 3.055mV $$V_{TP,CORR} = \frac{V_{TP}}{S_{CONV}}$$
3. Calculating T_{SEN}
   T_{SEN} = 30°C — Measure the reference sensors resistance and calculate sensor temperature
4. Auxiliary step: calculating
   TCF = 1 + [(30°C – 25°C) x -0.0045/K] = 0.955 $$TCF = 1 + (DeltaT \times TC_{SENS})$$
5. V_{OFFS} calculation:
   V_{OFFS} = LUT(30°C) = 0.39mV $$V_{OFFS} = LUT(T_{SEN})$$
6. Temperature compensation of
   $V_{OFFS,TC}$ = 0.39mV x 0.955 = 0.372mV $$V_{OFFS,TC} = V_{OFFS} \times TCF$$
7. Adding V_{OFFS} and $V_{TP,CORR}$:
   $V_{TP,REF}$ = 3.055mV + 0.372mV = 3.427mV $$V_{TP.REF} = V_{TP,CORR} + V_{OFFS,TC}$$
8. Temperature compensation of $V_{TP,REF}$:
   $V_{TP,REF,TC}$ = 3.427mV / 0.955 = 3.588mV $$V_{TP,REF,TC} = \frac{V_{TP,REF}}{TCF}$$
9. Object temperature calculation:
   T_{OBJ} = RLUT (3.588mV) = 63.44°C $$T_{OBJ} = RLUT(V_{TP,REF,TC})$$

Creation of a 2-dimensional Look-Up-Tables for Thermopile Voltage

This chapter is meant to describe and illustrate the numerical calculation of the thermopile sensor voltage for different sensor and object temperatures.

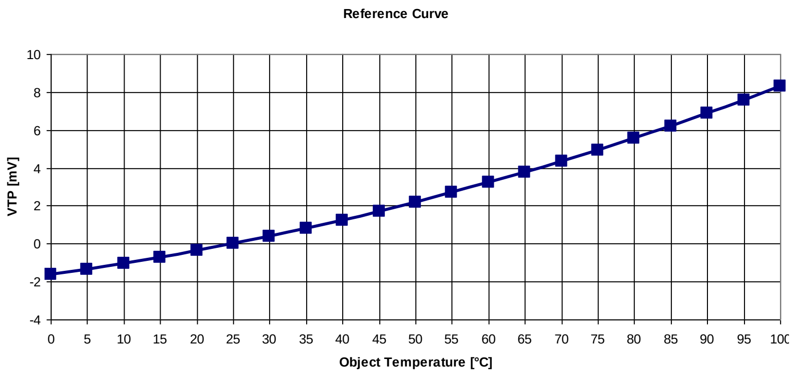
To describe the numerical calculation, thermopile signals are calculated for different object temperatures at different sensor temperatures.

Constants

- TC_{SENS} -0.0045/K
- $T_{SEN,REF}$ 25°C

Reference / Calibration Curve

Given is a reference or calibration curve of the TP under test. This calibration curve was created by measurement of the TP signal at one or more setpoints. The sensor temperature was recorded while calibration (in this case 25°C).



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60	3.21
65	3.76
70	4.34
75	4.94
80	5.56
85	6.21
90	6.88
95	7.58
100	8.30

Gradient Correction

Due to the temperature coefficient of the TP, the gradient of the TP signal output curve is depending on the sensor temperature.

Formula

$$V_{TPGradient}[T_{Sen},T_{Obj}] = U_{T\,\mathrm{Pref}} \times (1+\{T_{Sen} - T_{Sen\mathrm{Re}\,f}\} \times TC$$

Example

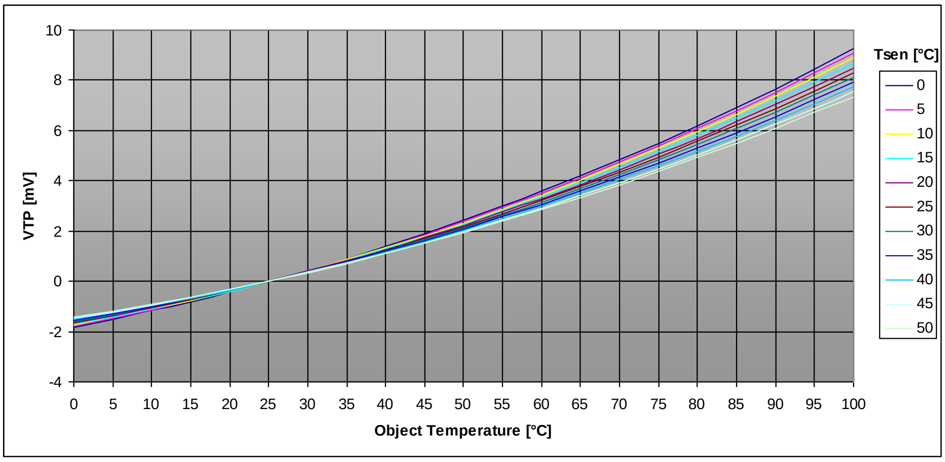
- T_{Sen} 35°C
- T_{obj} 65°C

$V_{TPGradient}$[65°C, 35°C] = 3.76mV * (1 + {35°C – 25°C} * -0.0045/K)

$V_{TPGradient}$ [65°C, 35°C] = ***3.591mV***

Results

Tobj / °C	Tsen / °C										
	0	5	10	15	20	25	30	35	40	45	50
0	-1.813	-1.777	-1.740	-1.703	-1.667	-1.630	-1.593	-1.557	-1.520	-1.483	-1.447
5	-1.502	-1.472	-1.441	-1.411	-1.380	-1.350	-1.320	-1.289	-1.259	-1.229	-1.198
10	-1.157	-1.134	-1.110	-1.087	-1.063	-1.040	-1.017	-0.993	-0.970	-0.946	-0.923
15	-0.801	-0.785	-0.769	-0.752	-0.736	-0.720	-0.704	-0.688	-0.671	-0.655	-0.639
20	-0.412	-0.403	-0.395	-0.387	-0.378	-0.370	-0.362	-0.353	-0.345	-0.337	-0.328
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.434	0.425	0.416	0.408	0.399	0.390	0.381	0.372	0.364	0.355	0.346
35	0.901	0.883	0.865	0.846	0.828	0.810	0.792	0.774	0.755	0.737	0.719
40	1.380	1.352	1.324	1.296	1.268	1.240	1.212	1.184	1.156	1.128	1.101
45	1.891	1.853	1.815	1.777	1.738	1.700	1.662	1.624	1.585	1.547	1.509
50	2.425	2.376	2.327	2.278	2.229	2.180	2.131	2.082	2.033	1.984	1.935
55	2.993	2.932	2.872	2.811	2.751	2.690	2.629	2.569	2.508	2.448	2.387
60	3.571	3.499	3.427	3.354	3.282	3.210	3.138	3.066	2.993	2.921	2.849
65	4.183	4.098	4.014	3.929	3.845	3.760	3.675	3.591	3.506	3.422	3.337
70	4.828	4.731	4.633	4.535	4.438	4.340	4.242	4.145	4.047	3.949	3.852
75	5.496	5.385	5.273	5.162	5.051	4.940	4.829	4.718	4.607	4.495	4.384
80	6.186	6.060	5.935	5.810	5.685	5.560	5.435	5.310	5.185	5.060	4.935
85	6.909	6.769	6.629	6.489	6.350	6.210	6.070	5.931	5.791	5.651	5.511
90	7.654	7.499	7.344	7.190	7.035	6.880	6.725	6.570	6.416	6.261	6.106
95	8.433	8.262	8.092	7.921	7.751	7.580	7.409	7.239	7.068	6.898	6.727
100	9.234	9.047	8.860	8.674	8.487	8.300	8.113	7.927	7.740	7.553	7.366



Offset Correction

The thermopile sensor output is related to the measured object temperature (T_{obj}) and the sensor temperature (T_{sen}) itself. Therefore, the reference curve (@ T_{sen}=25°C) needs to be shifted by an offset in dependence to the sensor temperature (T_{sen}). This offset voltage is also affected by the temperature coefficient.

Formula

$$V_{TPOffset}[T_{Sen}] = V_{TPref}[T_{Sen}] \times (1 + \{T_{Sen} - T_{SenRef}\} \times TC)$$

Example

- T_{Sen} 35°C

VTP_{Offset}[35°C] = 0.81mV * (1 + {35°C – 25°C} * -0.0045/K)

VTP_{Offset} [35°C] = ***0.774mV***

Results

Tobj / °C	Tsen / °C										
	0	5	10	15	20	25	30	35	40	45	50
---	-1.813	-1.472	-1.110	-0.752	-0.378	0.000	0.381	0.774	1.156	1.547	1.935

Summation of Signals

To calculate the thermopile sensor output at different object temperatures and sensor temperature, the difference between gradient corrected curve (0) and offset value (0) has to determinated.

Formula

$$V_{TP}(T_{Sen}, T_{Obj}) = V_{TPGradient}[T_{Sen}, T_{Obj}] - V_{TPOffset}[T_{Sen}]$$

Example

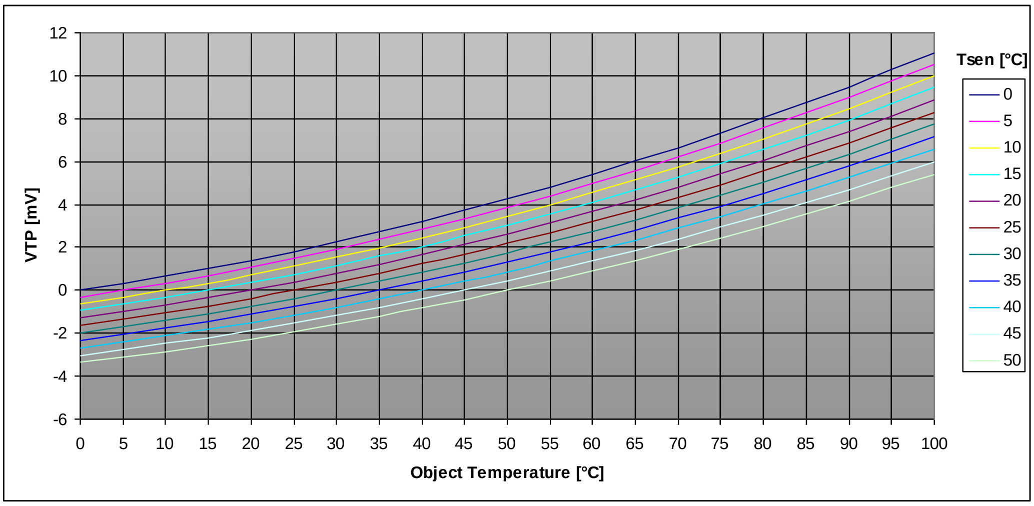
- T_{Sen} 35°C
- T_{obj} 65°C

VTP[35°C, 65°C] = 3.591mV – 0.774mV

VTP[35°C, 65°C] = **2.817mV**

Results

	Tsen / °C										
Tobj / °C	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
0	0.000	-0.305	-0.630	-0.951	-1.288	-1.630	-1.975	-2.330	-2.676	-3.030	-3.381
5	0.312	0.000	-0.331	-0.658	-1.002	-1.350	-1.701	-2.063	-2.415	-2.776	-3.133
10	0.656	0.338	0.000	-0.334	-0.685	-1.040	-1.398	-1.767	-2.126	-2.493	-2.858
15	1.012	0.687	0.342	0.000	-0.358	-0.720	-1.085	-1.461	-1.828	-2.202	-2.574
20	1.402	1.068	0.715	0.366	0.000	-0.370	-0.743	-1.127	-1.501	-1.884	-2.263
25	1.813	1.472	1.110	0.752	0.378	0.000	-0.381	-0.774	-1.156	-1.547	-1.935
30	2.247	1.897	1.527	1.160	0.777	0.390	0.000	-0.401	-0.793	-1.192	-1.589
35	2.715	2.354	1.975	1.599	1.207	0.810	0.411	0.000	-0.401	-0.810	-1.216
40	3.193	2.823	2.434	2.048	1.646	1.240	0.831	0.411	0.000	-0.419	-0.834
45	3.705	3.325	2.925	2.529	2.117	1.700	1.281	0.850	0.429	0.000	-0.426
50	4.239	3.848	3.437	3.031	2.607	2.180	1.750	1.308	0.877	0.437	0.000
55	4.806	4.404	3.982	3.563	3.129	2.690	2.248	1.795	1.352	0.901	0.453
60	5.385	4.970	4.537	4.107	3.661	3.210	2.757	2.292	1.837	1.374	0.914
65	5.996	5.570	5.124	4.682	4.223	3.760	3.294	2.817	2.350	1.875	1.402
70	6.642	6.202	5.743	5.288	4.816	4.340	3.861	3.371	2.891	2.402	1.917
75	7.309	6.856	6.384	5.915	5.429	4.940	4.448	3.944	3.450	2.948	2.450
80	7.999	7.532	7.046	6.563	6.063	5.560	5.054	4.536	4.028	3.513	3.000
85	8.722	8.240	7.739	7.242	6.728	6.210	5.689	5.157	4.635	4.104	3.577
90	9.467	8.971	8.455	7.942	7.413	6.880	6.344	5.797	5.259	4.714	4.171
95	10.246	9.734	9.202	8.674	8.129	7.580	7.028	6.465	5.912	5.351	4.793
100	11.047	10.519	9.970	9.426	8.865	8.300	7.732	7.153	6.583	6.006	5.432



Emissivity

Definition

The efficiency of a material to emit infrared radiation is called emissivity (ε).

In most cases, thermopile sensors are calibrated with respect to a high accuracy black body heater which has an emissivity close to 1 (or 100%). Under real life circumstances most surfaces (materials) have an emissivity <1.

Any object with an emissivity <1 will transmit or reflect infrared radiation which is sourced by the surrounding objects. If the transmittance is negligible, the reflection is the balance of emissivity to 1.

Therefore, the resulting measurement failure do not only depend on the emissivity of the object to be measured itself but also on the sensor temperature itself and the temperature of the environment.

Overall, the less the emissivity of an object is, the more infrared radiation creating by the environment will be reflected.

Formular

Thermopile formula:

$$V_{TP} = s \cdot \varepsilon_{obj} \cdot \left(T_{obj}{}^{4-\delta} - T_{sen}{}^{4-\delta} \right)$$

Emissivity correction formula

$$VTPcorr = VTP \cdot \frac{1}{\varepsilon_{obj}}$$

i.e.: The temperature of an object made of plastic should be determinated.

Emissivity of plastic: ε = 0.95

Uncorrected, measured thermopile voltage: V_{TP} = 5.56mV

Uncorrected temperature (at Tsen = 25°C) T_{TP} = 80.00°C

Thermopile voltage corrected by emissivity: V_{TPcorr} = 5.85mV

Corrected temperature (at Tsen = 25°C) T_{TPcorr} = 82.23°C

Table of Emissivity

Material	Emissivity ε
Aluminum	
Polished	0.10 – 0.05
Oxidized	0.10 – 0.40
Rough	0.10 – 0.30
Anodized	0.60 – 0.95
Asphalt	0.90 – 1.00
Brass	
Polished	0.05
Oxidized	0.50 - 0.60
Burnished	0.30
Ceramic	0.90 – 0.95
Copper	
Polished	0.10
Oxidized	0.20 - 0.80
Foods	0.85 – 1.00
Gold	0.05
Glass	
Plate	0.90 – 0.95
Fused quartz	0.75

Material	Emissivity ε
Human Skin	0.99
Iron	
Polished	0.20
Oxidized	0.50 - 0.95
Rusted	0.50 – 0.70
Paint	
Aluminum paint	0.50
Bronze paint	0.80
Paint on metal	0.60 – 0.90
Paint on plastic or	0.80 – 0.95
Paper	0.85 – 1.00
Plastic	0.95 – 1.00
Stainless Steel	
Polished	0.10 – 0.15
Oxidized	0.45 - 0.95
Water	
Liquid	0.90 – 0.95
Ice	0.95 – 1.00
Snow	0.80 – 1.00

Appendix

Thermistor Reference Curves

NI1000

T / °C	RNI1000 / Ohm	T / °C	RNI1000 / Ohm
0	1000.0	45	1260.4
1	1005.5	46	1266.5
2	1011.0	47	1272.6
3	1016.5	48	1278.8
4	1022.0	49	1284.9
5	1027.6	50	1291.1
6	1033.1	51	1297.2
7	1038.7	52	1303.4
8	1044.3	53	1309.6
9	1049.9	54	1315.8
10	1055.5	55	1322.0
11	1061.1	56	1328.3
12	1066.8	57	1334.5
13	1072.4	58	1340.8
14	1078.1	59	1347.1
15	1083.8	60	1353.4
16	1089.5	61	1359.7
17	1095.2	62	1366.0
18	1100.9	63	1372.4
19	1106.6	64	1378.7
20	1112.4	65	1385.1
21	1118.1	66	1391.5
22	1123.9	67	1397.9
23	1129.7	68	1404.3
24	1135.5	69	1410.8
25	1141.3	70	1417.2
26	1147.1	71	1423.7
27	1153.0	72	1430.1
28	1158.8	73	1436.6
29	1164.7	74	1443.1
30	1170.6	75	1449.7
31	1176.5	76	1456.2
32	1182.4	77	1462.8
33	1188.3	78	1469.3
34	1194.2	79	1475.9
35	1200.2	80	1482.5
36	1206.1	81	1489.1
37	1212.1	82	1495.7
38	1218.1	83	1502.4
39	1224.1	84	1509.1
40	1230.1	85	1515.7
41	1236.1		
42	1242.2		
43	1248.2		
44	1254.3		

NTC R25 = 100kOhm B = 3955 / K

T / °C	RNTC / kOhm	T / °C	RNTC / kOhm
0	332.59	45	43.07
1	315.83	46	41.40
2	300.02	47	39.79
3	285.09	48	38.26
4	270.98	49	36.80
5	257.66	50	35.40
6	245.07	51	34.05
7	233.17	52	32.77
8	221.91	53	31.54
9	211.26	54	30.37
10	201.18	55	29.24
11	191.64	56	28.16
12	182.60	57	27.13
13	174.05	58	26.14
14	165.94	59	25.19
15	158.25	60	24.28
16	150.96	61	23.40
17	144.05	62	22.57
18	137.50	63	21.76
19	131.28	64	20.99
20	125.37	65	20.25
21	119.76	66	19.54
22	114.44	67	18.86
23	109.38	68	18.21
24	104.57	69	17.58
25	100.00	70	16.97
26	95.65	71	16.39
27	91.52	72	15.84
28	87.59	73	15.30
29	83.84	74	14.79
30	80.28	75	14.29
31	76.89	76	13.81
32	73.66	77	13.36
33	70.58	78	12.92
34	67.65	79	12.49
35	64.85	80	12.08
36	62.19	81	11.69
37	59.65	82	11.31
38	57.22	83	10.95
39	54.91	84	10.60
40	52.70	85	10.26
41	50.60		
42	48.58		
43	46.66		
44	44.83		

Values are for reference only

Thermopile Reference Curves

Conditions: Tsen = 25°C Emissivity Black Body ε > 0.99

TS305-10C50

PN: G-TPCO-023 Reference Sensor: NTC

T / °C	VTP / mV	T / °C	VTP / mV
0	-1.421	50	1.827
1	-1.371	51	1.909
2	-1.320	52	1.993
3	-1.269	53	2.077
4	-1.218	54	2.161
5	-1.166	55	2.247
6	-1.113	56	2.333
7	-1.060	57	2.421
8	-1.006	58	2.509
9	-0.952	59	2.597
10	-0.897	60	2.687
11	-0.841	61	2.777
12	-0.785	62	2.869
13	-0.728	63	2.961
14	-0.671	64	3.053
15	-0.613	65	3.147
16	-0.555	66	3.242
17	-0.496	67	3.337
18	-0.436	68	3.433
19	-0.375	69	3.530
20	-0.314	70	3.628
21	-0.253	71	3.727
22	-0.191	72	3.826
23	-0.128	73	3.927
24	-0.064	74	4.028
25	0.000	75	4.131
26	0.065	76	4.234
27	0.130	77	4.338
28	0.196	78	4.443
29	0.263	79	4.548
30	0.331	80	4.655
31	0.399	81	4.763
32	0.468	82	4.871
33	0.537	83	4.981
34	0.607	84	5.091
35	0.678	85	5.203
36	0.750	86	5.315
37	0.822	87	5.428
38	0.895	88	5.542
39	0.969	89	5.657
40	1.043	90	5.773
41	1.118	91	5.890
42	1.194	92	6.008
43	1.270	93	6.127
44	1.348	94	6.247
45	1.426	95	6.368
46	1.504	96	6.490
47	1.584	97	6.613
48	1.664	98	6.737
49	1.745	99	6.862
		100	6.988

TS318-10C50

PN: G-TPCO-029 Reference Sensor: NTC

T / °C	VTP / mV	T / °C	VTP / mV
0	-1.897	50	2.440
1	-1.831	51	2.550
2	-1.763	52	2.661
3	-1.695	53	2.773
4	-1.626	54	2.886
5	-1.557	55	3.001
6	-1.487	56	3.116
7	-1.416	57	3.233
8	-1.344	58	3.350
9	-1.271	59	3.469
10	-1.198	60	3.588
11	-1.124	61	3.709
12	-1.049	62	3.831
13	-0.973	63	3.954
14	-0.896	64	4.078
15	-0.819	65	4.203
16	-0.741	66	4.329
17	-0.662	67	4.456
18	-0.582	68	4.585
19	-0.501	69	4.714
20	-0.420	70	4.845
21	-0.338	71	4.977
22	-0.255	72	5.110
23	-0.171	73	5.244
24	-0.086	74	5.380
25	0.000	75	5.516
26	0.087	76	5.654
27	0.174	77	5.793
28	0.262	78	5.933
29	0.352	79	6.074
30	0.442	80	6.217
31	0.533	81	6.360
32	0.624	82	6.505
33	0.717	83	6.652
34	0.811	84	6.799
35	0.906	85	6.948
36	1.001	86	7.098
37	1.098	87	7.249
38	1.195	88	7.401
39	1.293	89	7.555
40	1.393	90	7.710
41	1.493	91	7.866
42	1.594	92	8.024
43	1.696	93	8.183
44	1.800	94	8.343
45	1.904	95	8.504
46	2.009	96	8.667
47	2.115	97	8.831
48	2.222	98	8.997
49	2.330	99	9.164
		100	9.332

Values are for reference only

TS318-3B0814

PN: G-TPCO-027 Reference Sensor: NI1000

T / °C	VTP / mV	T / °C	VTP / mV
0	-1.066	50	1.370
1	-1.028	51	1.432
2	-0.990	52	1.495
3	-0.952	53	1.558
4	-0.914	54	1.621
5	-0.874	55	1.685
6	-0.835	56	1.750
7	-0.795	57	1.816
8	-0.755	58	1.882
9	-0.714	59	1.948
10	-0.673	60	2.015
11	-0.631	61	2.083
12	-0.589	62	2.152
13	-0.546	63	2.221
14	-0.503	64	2.290
15	-0.460	65	2.360
16	-0.416	66	2.431
17	-0.372	67	2.503
18	-0.327	68	2.575
19	-0.282	69	2.648
20	-0.236	70	2.721
21	-0.190	71	2.795
22	-0.143	72	2.870
23	-0.096	73	2.945
24	-0.048	74	3.021
25	0.000	75	3.098
26	0.049	76	3.175
27	0.098	77	3.253
28	0.147	78	3.332
29	0.197	79	3.412
30	0.248	80	3.492
31	0.299	81	3.572
32	0.351	82	3.654
33	0.403	83	3.736
34	0.455	84	3.819
35	0.509	85	3.902
36	0.562	86	3.986
37	0.617	87	4.071
38	0.671	88	4.157
39	0.726	89	4.243
40	0.782	90	4.330
41	0.839	91	4.418
42	0.895	92	4.507
43	0.953	93	4.596
44	1.011	94	4.686
45	1.069	95	4.776
46	1.128	96	4.868
47	1.188	97	4.960
48	1.248	98	5.053
49	1.309	99	5.147
		100	5.241

TS318-5C50

PN: G-TPCO-030 Reference Sensor: NTC

T / °C	VTP / mV	T / °C	VTP / mV
0	-1.897	50	2.440
1	-1.831	51	2.550
2	-1.763	52	2.661
3	-1.695	53	2.773
4	-1.626	54	2.886
5	-1.557	55	3.001
6	-1.487	56	3.116
7	-1.416	57	3.233
8	-1.344	58	3.350
9	-1.271	59	3.469
10	-1.198	60	3.588
11	-1.124	61	3.709
12	-1.049	62	3.831
13	-0.973	63	3.954
14	-0.896	64	4.078
15	-0.819	65	4.203
16	-0.741	66	4.329
17	-0.662	67	4.456
18	-0.582	68	4.585
19	-0.501	69	4.714
20	-0.420	70	4.845
21	-0.338	71	4.977
22	-0.255	72	5.110
23	-0.171	73	5.244
24	-0.086	74	5.380
25	0.000	75	5.516
26	0.087	76	5.654
27	0.174	77	5.793
28	0.262	78	5.933
29	0.352	79	6.074
30	0.442	80	6.217
31	0.533	81	6.360
32	0.624	82	6.505
33	0.717	83	6.652
34	0.811	84	6.799
35	0.906	85	6.948
36	1.001	86	7.098
37	1.098	87	7.249
38	1.195	88	7.401
39	1.293	89	7.555
40	1.393	90	7.710
41	1.493	91	7.866
42	1.594	92	8.024
43	1.696	93	8.183
44	1.800	94	8.343
45	1.904	95	8.504
46	2.009	96	8.667
47	2.115	97	8.831
48	2.222	98	8.997
49	2.330	99	9.164
		100	9.332

Values are for reference only

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