THERMOPILE SENSOR FOR CONTACTLESS TEMPERATURE

APPLICATION NOTE

This document is intended to provide an introduction to utilizing thermopile sensors for contactless temperature measurement. Thermopiles are mainly used for contactless temperature measurement in a wide range of applications. Their primary function is to transfer the heat radiation emitted from objects into a voltage output. Major applications include appliances such as microwave ovens, clothes dryers, and automated cooking, medical devices such as ear and fore head thermometers, automotive applications such as car climate control, seat occupancy, blind spot alert, and black ice warning, consumer products such as printers, copiers, mobile phones and many industry applications such as paper and plastics manufacturing.

Thermopile Component
TS305-11C55

Thermopile Function

All objects emit infrared radiation. The amount of radiated power increases with higher surface temperatures. Based on this relationship, thermopiles measure the emitted radiated power and determine the object's temperature precisely. Thermopiles are based on the Seebeck effect, which has historically been utilized for conventional thermocouples. The development of micromechanics and thin film technology has allowed for the design and manufacture of miniaturized and cost-effective thermopile sensor elements.

IR-Radiation

Absorber

measure
ΔT with
Thermopiles

Chip Frame

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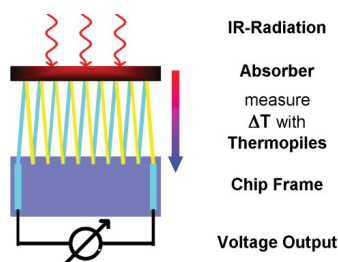
The thermopile voltage V_{TP} is then determined by:

• Object temperature T_{obj}

• Emissivity of the object ε_{obj}

• Ambient temperature Tsen (i.e. temperature of the sensor ≠ air or PCB temperature)

• Instrument factors 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
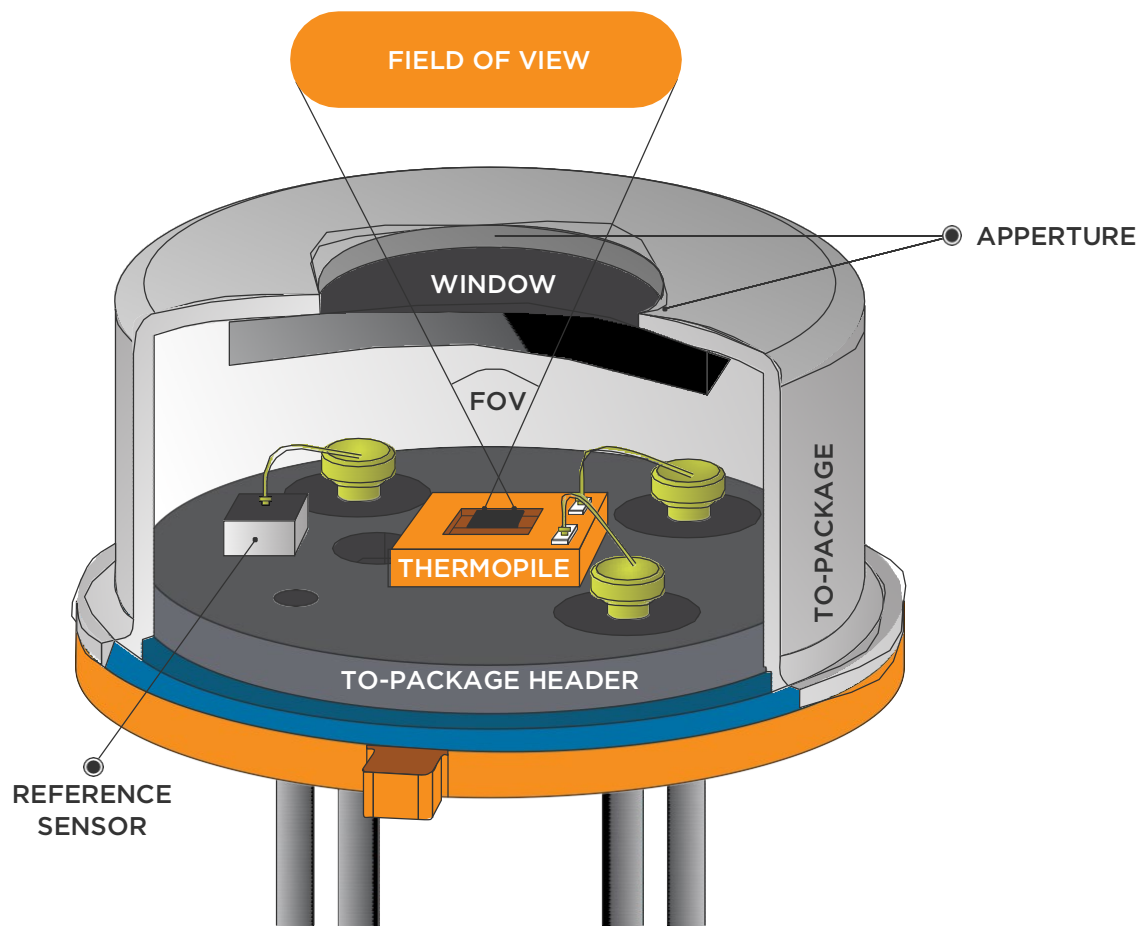
Anatomy of a Thermopile Sensor Component

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

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 the 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 to the component

Table 2: Parts of a thermopile sensor and their function

Package Type

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

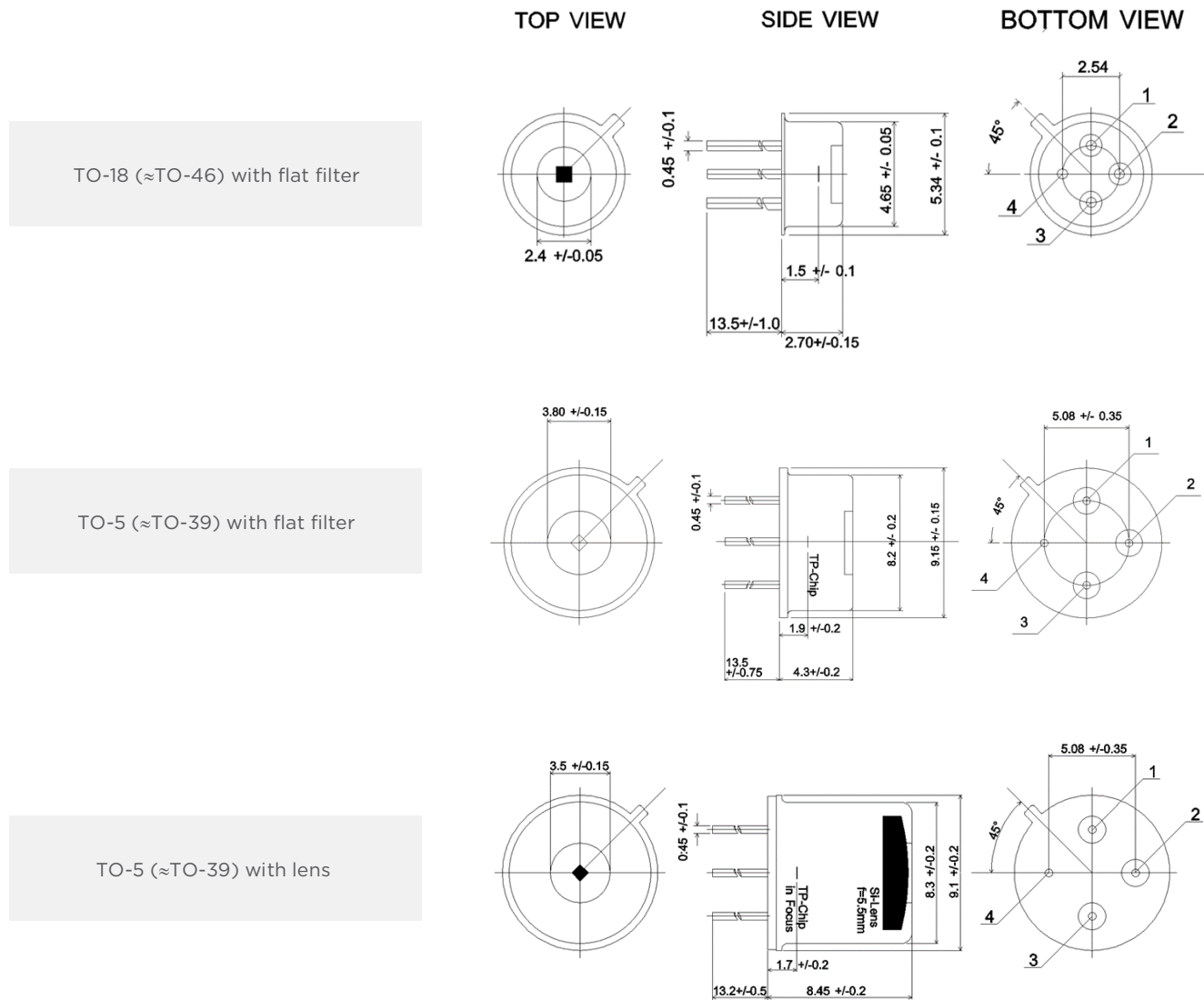|			
TO-18 (≈TO-46) with flat filter			
TO-5 (≈TO-39) with flat filter			
TO-5 (≈TO-39) with lens			

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 utilized for all applications that do not have space limitations. Also, it is the best choice for component customization
- The TO-5 package with lens is best suited 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 itself. It is needed for cold junction compensation according the formula describing the thermopile voltage in Figure 1. To achieve the best overall accuracy, the 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 by an analogue to digital converter (ADC) via a voltage divider without amplification. However, it is highly nonlinear which may cause lower accuracy when applied over a large temperature range. The most common application is for consumer applications over the temperature range from 0-50°C.
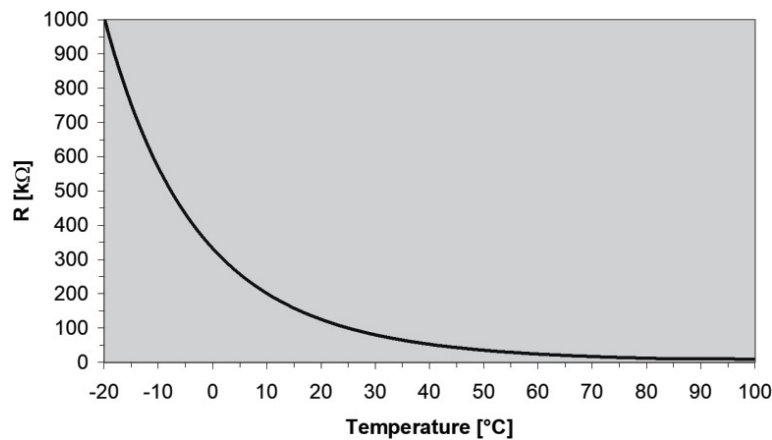
Figure 3: R-T-Curve of an NTC Thermistor

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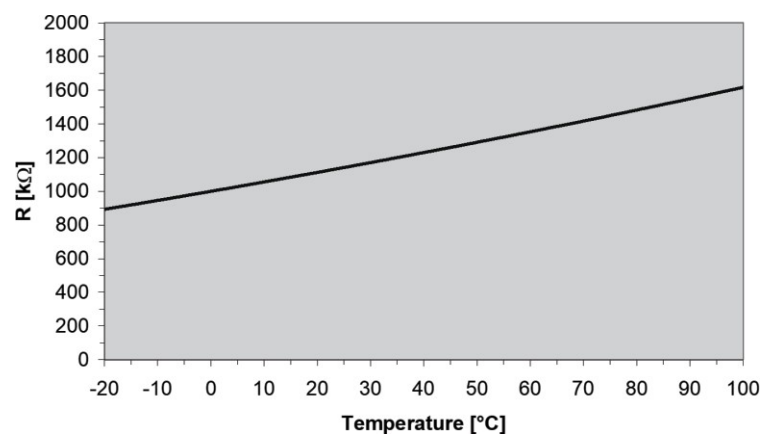
Figure 4: R-T-Curve of a Nickel-RTD type Ni1000

Transport Recommendations

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

Cleaning Recommendations

- Isopropanol (other names: Iso-Propyl-Alcohol (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 the optics and the metal case of the thermopile properly.

- Check for stains after wet cleaning; if necessary, repeat the wet cleaning
- Check for lint after wet cleaning; if necessary, wipe off any lint with a dry tissue

Please Note:
Some cotton swabs have the cotton attached to the stick with glue. In some cases, this glue may be dissolved by the isopropanol and leave a deposit on the optics. Due the infrared absorption of this deposit the calibration and accuracy may be affected.

Solder Recommendations

Process	Temperature	Max. Duration/s	Comment
Wave Soldering [1]	260°C ±5°C	10	Automated Optical Inspection (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

The user should avoid touching the sensor cap. This can affect the accuracy of the sensor, especially when attempting to measure rapid temperature changes.

Circuitry Examples

This chapter is intended to provide examples of circuitry designed for the measurement of thermopile temperature signals. The examples are separated by the type of temperature sensing element used (NTC thermistor or Nickel RTD).

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 parts of the circuit

• This is not intended to be a ready-to-use circuit diagram!
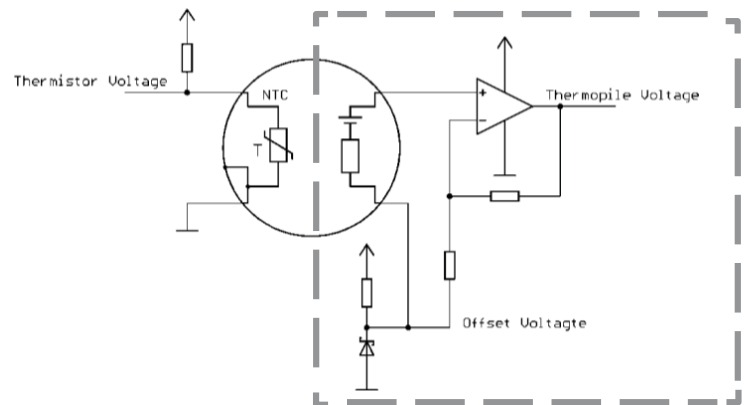
Figure 5: Basic functionality of a TP amplification circuit

NTC Thermistor

A simple voltage divider is used for measurement of the sensor's temperature. Due to the high resistance on the NTC (100kΩ at 25°C) the measurement accuracy is not affected by thermistor self-heating.
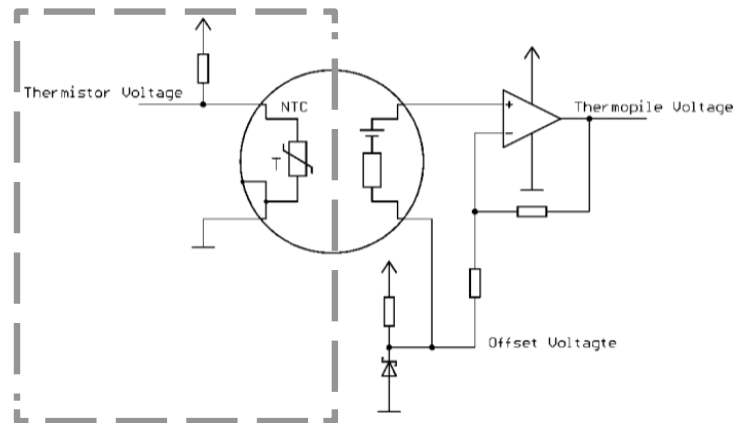
Figure 6: Basic design of an NTC circuit

Nickel RTD (Ni1000)

The additional Op-Amp is used as a Differential Amplifier to achieve a high dynamic range for the RTD output signal. The selection of the resistors for the circuit is dependent upon the ambient operating temperature range and the desired output voltage range.

Figure 7: Basic design 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 manner, regardless of reference sensor selection.

Depending on the desired performance and the accuracy or resistance tolerance of the reference sensor a calibration at one, two, or three ambient temperatures may be necessary. This calibration should be carried out in a temperature-controlled bath.
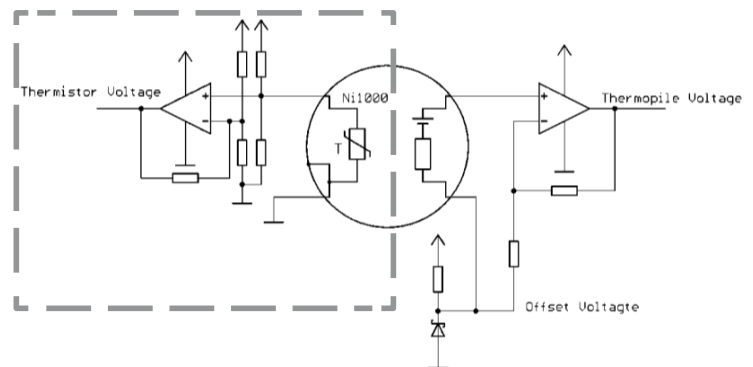
$$V_{TP} = s \cdot \varepsilon_{obj} \cdot \left(T_{obj}^{4-\delta} - T_{sen}^{4-\delta} \right)$$

Reference Sensor Measurement before Calibration

The NTC resistance (or the voltage drop based on the sensor's resistance) is measured at a fixed calibration temperature (i.e. 25°C). Calibration parameters are determined with respect to its reference curve based on the following equation

$$R_{Tx} = R_{25} \cdot e^{\beta \cdot \left(\frac{1}{T_x} - \frac{1}{T_{25}} \right)}$$
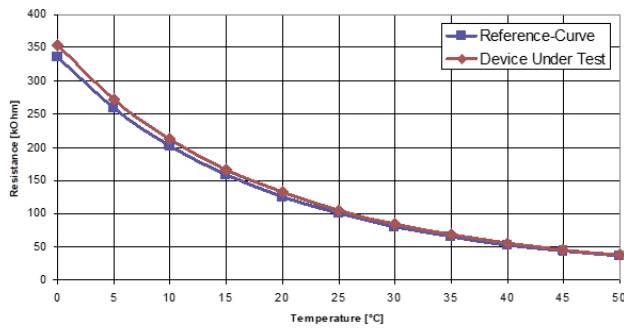
Figure 8: NTC Curve before calibration
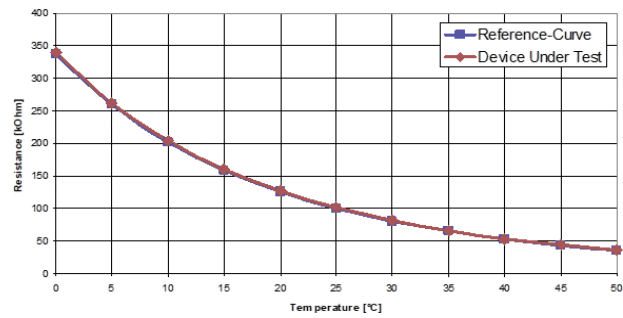
Figure 9: NTC Curve after calibration

Calibration of Thermopile Measurement Temperature

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

• Measurement of the thermopile voltage at a high temperature setpoint to determinate the thermopile sensitivity

• Measurement of the thermopile voltage at a low temperature setpoint to determine the offset voltage caused by electronics and signal processing chain. This step can be skipped if higher accuracy is not required

• The reference curve for the thermopile voltage over temperature must be adjusted or compensated based on the measurement values obtained above

Calculation of Measurement Temperature

This chapter contains a short description of an algorithm used for object (measurement) temperature calculation using Thermopiles and includes:

• Essential facts of Thermopile behavior with respect to 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 during 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 difference between the 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 × T_{CSENS}
- $V_{TP, REF}$ — 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 Behavior of a Thermopile

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 note with regards to ambient temperature variation:
A Thermopile detects infrared radiation. The radiation detected is the difference between the incoming (from the object) and the 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
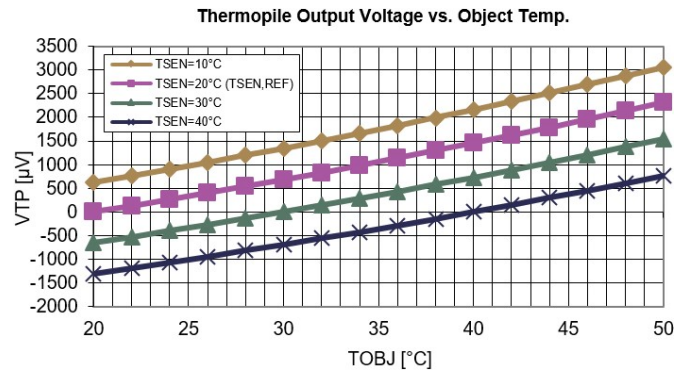
Figure 10: Typical output voltage curve form of Thermopile sensor

1. By increasing the 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 specified as the temperature coefficient TC_{SENS}

2. Consequence of fact No 1 is that the whole curve is shifted at different voltage levels depending upon the ambient temperature. The distance between these curves is listed as an offset V_{OFFS}

Consequence of fact No 2 is that the gradient of the curves (which is proportional to the Thermopile sensitivity) decreases with increasing ambient temperature. The higher the temperature the flatter the curve is. Note that the characteristic curve form isn't affected by both facts. Fact 1 only shifts the curve; fact 2 compresses respective stretches of the curve depending upon the ambient temperature. The curve characteristic is dependent only on the filter characteristic of the Thermopile. In most applications this variation due to the filter characteristic is negligible.

By knowing the sensitivity and the temperature coefficient T_{CSENS} 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 technique used to measure he 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 of an average level.

The measuring should be done in the application. This means that the whole signal path should be measured (including pre-amplification, ...).

An example of typical measuring results is listed in the table to the right.

The step size depends on the desired accuracy after compensation as well as the available memory in the microcontroller.

Two calculations based on this LUT are needed later in the algorithm:
1. V = LUT (T)
2. T = RLUT (V)

Example:

V = LUT (T = 45°C)   = 1.41mV
T = RLUT (V = 3.62mV)   = 70°C

TS305-11C55	
Sensor Temp. = 25°C	
Object Temp. [°C]	VTP [mV]
0	-1.35
5	-1.11
10	-0.86
15	-0.59
20	-0.31
25	0.00
30	0.32
35	0.67
40	1.03
45	1.41
50	1.81
55	2.24
60	2.68
65	3.14
70	3.62
75	4.13
80	4.66
85	5.21
90	5.78
95	6.38
100	7.00

Calibration

Calibration means:
Measuring the Thermopile parameters which are needed afterwards to determine the link between the actual measured Thermopile voltage and the reference Thermopile voltage. These parameters would be stored in the nonvolatile memory of the sensor.

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

In some applications it isn't necessary to know the TC_{SENS} of each individual sensor, which means that the datasheet value can be used. In this case only a "single ambient temperature calibration" to measure the sensitivity is needed.

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

TS305-11C55		TP under Calibration	Conversion
Sensor Temp. = 25°C			
Object Temp. [°C]	VTP [mV]		
		Factor 6.86	**0.980**

Calibration Point: 100 | 7.00

In this example the voltage of the TP under calibration is compared at $T_{SEN} = T_{REF} = 25°C$ **and** $T_{OBJ} = 100°C$ is to the voltage of the reference TP. Result is the sensitivity conversion factor SCONV which is (6.86/7.00) = 0.980. 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

TP Voltage	mV	$8.0_{\pm 2.0}$	±25°C, BB + 100°C, DC, totally filled field of view
TC of sensitivity	%/K	$-0.45_{\pm 0.08}$	+25°C $\longrightarrow$ +75°C ambient
NEV	$nV/Hz^{1/2}$	30	+25°C ambient

b) The TC_{SENS} is available in the microcontroller (the datasheet value)

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

Measuring and calculate temperatures:

- Measuring V_{TP} and V_{RTD}

- V_{TP} sensitivity correction: $\quad V_{TP, CORR} = \dfrac{V_{TP}}{S_{CONV}}$

- Calculating T_{SEN} $\qquad$ Measure the reference sensors resistance and calculate sensor temperature

- Auxiliary step: calculating TCF $\quad TCF = 1 + (DeltaT \times TC_{SENS})$

- V_{OFFS} calculation $\qquad V_{OFFS} = LUT(T_{SEN})$

- Temperature compensation of V_{OFFS} $\quad V_{OFFS, TC} = V_{OFFS} \times TCF$

- Adding VOFFS and $V_{TP, CORR}$ $\quad V_{TP. REF} = V_{TP, CORR} + V_{OFFS, TC}$

- Temperature compensation of $V_{TP, REF:}$ $\quad V_{TP, REF, TC} = \dfrac{V_{TP, REF}}{TCF}$

- Object temperature calculation $\quad T_{OBJ} = RLUT(V_{TP, REF, TC})$

Example

- Measuring V_{TP}
  $V_{TP} = 3.00mV$, $S_{conv} = 0.980$

- V_{TP} sensitivity correction:
  $V_{TP, CORR} = 3.00mV / 0.980 = 3.061mV$ $\qquad V_{TP, CORR} = \dfrac{V_{TP}}{S_{CONV}}$

- Calculating T_{SEN}
  $T_{SEN} = 30°C$ $\qquad$ Measure the reference sensors resistance and calculate sensor temperature

- Auxiliary step: calculating
  $TCF = 1 + [(30°C – 25°C) \times -0.0045/K] = 0.9775$ $\qquad TCF = 1 + (DeltaT \times TC_{SENS})$

- V_{OFFS} calculation:
  $V_{OFFS} = LUT(30°C) = 0.32mV$ $\qquad V_{OFFS} = LUT(T_{SEN})$

- Temperature compensation of
  $V_{OFFS, TC} = 0.32mV \times 0.9775 = 0.313mV$ $\qquad V_{OFFS, TC} = V_{OFFS} \times TCF$

- Adding V_{OFFS} and $V_{TP, CORR:}$
  $V_{TP, REF} = 3.061mV + 0.313mV = 3.374mV$ $\qquad V_{TP. REF} = V_{TP, CORR} + V_{OFFS, TC}$

- Temperature compensation of $V_{TP, REF:}$
  $V_{TP, REF, TC} = 3.374mV / 0.9775 = 3.452mV$ $\qquad V_{TP, REF, TC} = \dfrac{V_{TP, REF}}{TCF}$

- Object temperature calculation:
  $T_{OBJ} = RLUT (3.452mV) = 68.25°C$ $\qquad T_{OBJ} = RLUT(V_{TP, REF, TC})$

Note: The object temperature calculation uses a linear interpolation between known values in the lookup table. In the example above V_{OBJ} = 65°C, V_{TP} = 3.14mV, V_{OBJ} = 70°C, V_{TP} = 3.62mV so calculate slope and offset in y = mx + b format,

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 during calibration (in this case 25°C).

TS305-11C55	
Sensor Temp. = 25°C	
Object Temp. [°C]	VTP [mV]
0	-1.35
5	-1.11
10	-0.86
15	-0.59
20	-0.31
25	0.00
30	0.32
35	0.67
40	1.03
45	1.41
50	1.81
55	2.24
60	2.68
65	3.14
70	3.62
75	4.13
80	4.66
85	5.21
90	5.78
95	6.38
100	7.00

Reference Curve

VTP (mV) vs Temperature (°C)

Gradient Correction

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

Formula

$$V_{TPGradient}[T_{Sen}, T_{Obj}] = U_{TPref} \times (1 + \{T_{Sen} - T_{SenRef}\} \times TC$$

Example

T_{Sen}	35°C
T_{obj}	65°C

$V_{TPGradient}$ [65°C, 35°C] = 3.14mV * (1 + {35°C – 25°C} * -0.0045/K)

$V_{TPGradient}$[65°C, 35°C] = **_2.999mV_**

Results

Tobj/°C	Tsen/°C
	0	5	10	15	20	25	30	35	40	45	50
0	-1.502	-1.472	-1.441	-1.411	-1.380	-1.35	-1.320	-1.289	-1.259	-1.229	-1.198
5	-1.235	-1.210	-1.185	-1.160	-1.135	-1.11	-1.085	-1.060	-1.035	-1.010	-0.985
10	-0.957	-0.937	-0.918	-0.899	-0.879	-0.86	-0.841	-0.821	-0.802	-0.783	-0.763
15	-0.656	-0.643	-0.630	-0.617	-0.603	-0.59	-0.577	-0.563	-0.550	-0.537	-0.524
20	-0.345	-0.338	-0.331	-0.324	-0.317	-0.31	-0.303	-0.296	-0.289	-0.282	-0.275
25	0.000	0.000	0.000	0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000
30	0.356	0.349	0.342	0.334	0.327	0.32	0.313	0.306	0.298	0.291	0.284
35	0.745	0.730	0.715	0.700	0.685	0.67	0.655	0.640	0.625	0.610	0.595
40	1.146	1.123	1.100	1.076	1.053	1.03	1.007	0.984	0.960	0.937	0.914
45	1.569	1.537	1.505	1.473	1.442	1.41	1.378	1.347	1.315	1.283	1.251
50	2.014	1.973	1.932	1.891	1.851	1.81	1.769	1.729	1.688	1.647	1.606
55	2.492	2.442	2.391	2.341	2.290	2.24	2.190	2.139	2.089	2.038	1.988
60	2.982	2.921	2.861	2.801	2.740	2.68	2.620	2.559	2.499	2.439	2.379
65	3.493	3.423	3.352	3.281	3.211	3.14	3.069	2.999	2.928	2.857	2.787
70	4.027	3.946	3.864	3.783	3.701	3.62	3.539	3.457	3.376	3.294	3.213
75	4.595	4.502	4.409	4.316	4.223	4.13	4.037	3.944	3.851	3.758	3.665
80	5.184	5.079	4.975	4.870	4.765	4.66	4.555	4.450	4.345	4.241	4.136
85	5.796	5.679	5.562	5.444	5.327	5.21	5.093	4.976	4.858	4.741	4.624
90	6.430	6.300	6.170	6.040	5.910	5.78	5.650	5.520	5.390	5.260	5.130
95	7.098	6.954	6.811	6.667	6.524	6.38	6.236	6.093	5.949	5.806	5.662
100	7.788	7.630	7.473	7.315	7.158	7.00	6.843	6.685	6.528	6.370	6.213

Offset Correction

The thermopile sensor output is related to both the measured object temperature (T_{obj}) and the sensor temperature (T_{sen}).

Therefore, the reference curve (@ T_{sen}=25°C) needs to be shifted by an offset relative to the sensor temperature (T_{sen}).

This offset voltage is also affected by the temperature coefficient.
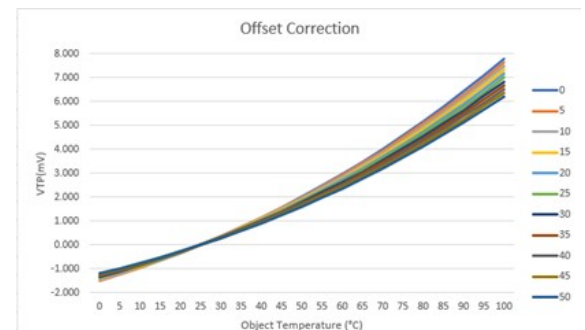
Formula

$$V_{TPGradient}[T_{Sen}, T_{Obj}] = U_{TPref} \times (1 + \{T_{Sen} - T_{SenRef}\} \times TC$$

Example

$$T_{Sen}\ 35°C$$

$$VTP_{Offset}[35°C] = 0.67mV * (1 + \{35°C - 25°C\} * -0.0045/K)\ VTP_{Offset}[35°C] =$$
$$\underline{\textit{\textbf{0.640mV}}}$$

Results

Tobj/°C	Tsen/°C
	0	5	10	15	20	25	30	35	40	45	50
-	-1.502	-1.210	-0.918	-0.617	-0.317	0.000	0.313	0.640	0.960	1.283	1.606

Summation of Signals

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

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] = 2.999mV – 0.640mV

VTP[35°C, 65°C] = ***2.359mV***

Results

Tobj/°C	Tsen/°C										
	0	5	10	15	20	25	30	35	40	45	50
0	0.000	-0.262	-0.523	-0.794	-1.063	-1.350	-1.633	-1.929	-2.219	-2.512	-2.804
5	0.267	0.000	-0.267	-0.543	-0.818	-1.110	-1.398	-1.700	-1.995	-2.293	-2.591
10	0.545	0.273	0.000	-0.282	-0.562	-0.860	-1.154	-1.461	-1.762	-2.066	-2.369
15	0.846	0.567	0.288	0.000	-0.286	-0.590	-0.890	-1.203	-1.510	-1.820	-2.130
20	1.157	0.872	0.587	0.293	0.000	-0.310	-0.616	-0.936	-1.249	-1.565	-1.881
25	1.502	1.210	0.918	0.617	0.317	0.000	-0.313	-0.640	-0.960	-1.283	-1.606
30	1.858	1.559	1.260	0.951	0.644	0.320	0.000	-0.334	-0.662	-0.992	-1.322
35	2.247	1.940	1.633	1.317	1.002	0.670	0.342	0.000	-0.335	-0.673	-1.011
40	2.648	2.333	2.018	1.693	1.370	1.030	0.694	0.344	0.000	-0.346	-0.692
45	3.071	2.747	2.423	2.090	1.759	1.410	1.065	0.707	0.355	0.000	-0.355
50	3.516	3.183	2.850	2.508	2.168	1.810	1.456	1.089	0.728	0.364	0.000
55	3.994	3.652	3.309	2.958	2.607	2.240	1.877	1.499	1.129	0.755	0.382
60	4.484	4.131	3.779	3.418	3.057	2.680	2.307	1.919	1.539	1.156	0.773
65	4.995	4.633	4.270	3.898	3.528	3.140	2.756	2.359	1.968	1.574	1.181
70	5.529	5.156	4.782	4.400	4.018	3.620	3.226	2.817	2.416	2.011	1.607
75	6.097	5.712	5.327	4.933	4.540	4.130	3.724	3.304	2.891	2.475	2.059
80	6.686	6.289	5.893	5.487	5.082	4.660	4.242	3.810	3.385	2.958	2.530
85	7.298	6.889	6.480	6.061	5.644	5.210	4.780	4.336	3.898	3.458	3.018
90	7.932	7.510	7.088	6.657	6.227	5.780	5.337	4.880	4.430	3.977	3.524
95	8.600	8.164	7.729	7.284	6.841	6.380	5.923	5.453	4.989	4.523	4.056
100	9.290	8.840	8.391	7.932	7.475	7.000	6.530	6.045	5.568	5.087	4.607

Compensated Output Graph
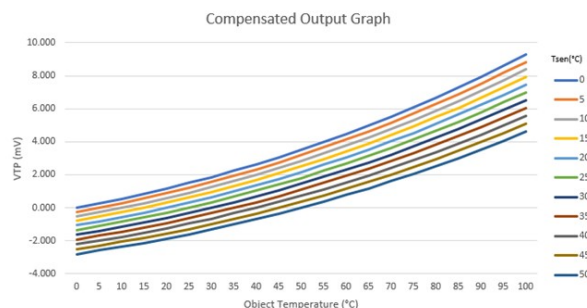
Emissivity

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, that is, transmittance is (1 – emissivity).

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

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

Formula

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 determined.
Emissivity of plastic: ε = 0.95
Uncorrected, measured thermopile voltage: V_{TP} = 5.56mV
Uncorrected temperature (at T_{SEN} = 25°C) T_{TP} = 80.00°C
Thermopile voltage corrected by emissivity: V_{TPCORR} = 5.85mV
Corrected temperature (at T_{SEN} = 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	T/°C	RNI1000/Ohm
0	1000.0	39	1224.1	78	1469.3
1	1005.5	40	1230.1	79	1475.9
2	1011.0	41	1236.1	80	1482.5
3	1016.5	42	1242.2	81	1489.1
4	1022.0	43	1248.2	82	1495.7
5	1027.6	44	1254.3	83	1502.4
6	1033.1	45	1260.4	84	1509.1
7	1038.7	46	1266.5	85	1515.7
8	1044.3	47	1272.6		
9	1049.9	48	1278.8		
10	1055.5	49	1284.9	Values are for reference only	
11	1061.1	50	1291.1		
12	1066.8	51	1297.2		
13	1072.4	52	1303.4		
14	1078.1	53	1309.6		
15	1083.8	54	1315.8		
16	1089.5	55	1322.0		
17	1095.2	56	1328.3		
18	1100.9	57	1334.5		
19	1106.6	58	1340.8		
20	1112.4	59	1347.1		
21	1118.1	60	1353.4		
22	1123.9	61	1359.7		
23	1129.7	62	1366.0		
24	1135.5	63	1372.4		
25	1141.3	64	1378.7		
26	1147.1	65	1385.1		
27	1153.0	66	1391.5		
28	1158.8	67	1397.9		
29	1164.7	68	1404.3		
30	1170.6	69	1410.8		
31	1176.5	70	1417.2		
32	1182.4	71	1423.7		
33	1188.3	72	1430.1		
34	1194.2	73	1436.6		
35	1200.2	74	1443.1		
36	1206.1	75	1449.7		
37	1212.1	76	1456.2		
38	1218.1	77	1462.8		

NTC R25 = 100kOhm B = 3955 / K

T/°C	RNTC/kOhm
0	332.59
1	315.83
2	300.02
3	285.09
4	270.98
5	257.66
6	245.07
7	233.17
8	221.91
9	211.26
10	201.18
11	191.64
12	182.60
13	174.05
14	165.94
15	158.25
16	150.96
17	144.05
18	137.50
19	131.28
20	125.37
21	119.76
22	114.44
23	109.38
24	104.57
25	100.00
26	95.65
27	91.52
28	87.59
29	83.84
30	80.28
31	76.89
32	73.66
33	70.58
34	67.65
35	64.85
36	62.19
37	59.65
38	57.22

T/°C	RNTC/kOhm
39	54.91
40	52.70
41	50.60
42	48.58
43	46.66
44	44.83
45	43.07
46	41.40
47	39.79
48	38.26
49	36.80
50	35.40
51	34.05
52	32.77
53	31.54
54	30.37
55	29.24
56	28.16
57	27.13
58	26.14
59	25.19
60	24.28
61	23.40
62	22.57
63	21.76
64	20.99
65	20.25
66	19.54
67	18.86
68	18.21
69	17.58
70	16.97
71	16.39
72	15.84
73	15.30
74	14.79
75	14.29
76	13.81
77	13.36
78	12.92
79	12.49

T/°C	RNTC/kOhm
80	12.08
81	11.69
82	11.31
83	10.95
84	10.60
85	10.26

Values are for reference only

THERMOPILE SENSOR FOR CONTACTLESS TEMPERATURE

Thermistor Reference Curves TS305-10C50

PN: G-TPCO-023

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

Reference Sensor: NTC

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

Values are for reference only

TS305-10C50

PN: G-TPCO-029

Reference Sensor: NTC

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

Values are for reference only

THERMOPILE SENSOR FOR CONTACTLESS TEMPERATURE

TS318-3B0814
PN: G-TPCO-027

Reference Sensor: NI1000

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

Values are for reference only

THERMOPILE SENSOR FOR CONTACTLESS TEMPERATURE

TS318-5C50

PN: G-TPCO-030

Reference Sensor: NTC

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

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