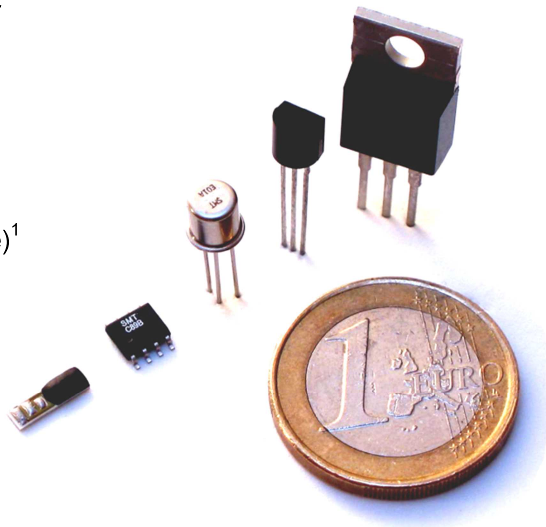
Features and Highlights

- World's most energy efficient temperature sensor
- Wide temperature range: -45 °C to 130 °C
- Extreme low noise: less than 0.001°C
- Low inaccuracy: 0.25°C (-10 °C to 100 °C)
  0.1 °C (TO18)
- Ultra low current (60 μA active or 220 nA average)[1]
- Wide supply voltage range: 2.7 V to 5.5 V
- Excellent long term stability
- Direct interface with Microcontroller (MCU)
- Wide range of package options



Application

- Ultra low power applications: wearable electronics, wireless sensor networks
- Medical applications: body temperature monitoring
- Instrumentation: (Bio)chemical analysis, Precision equipment
- Environmental monitoring (indoor / outdoor)
- Industrial applications: process monitoring / controlling

Introduction

The SMT172 is an ultra-low power, high accuracy temperature sensor that combines the ease of use with the world's leading performance over a wide temperature range. Using the most recent advances in the silicon temperature sensing technology, the SMT172 has applied some really sophisticated IC design techniques as well as high-precision calibration methods, to achieve an absolute inaccuracy of less than 0.25°C in the range of -10 °C to 100 °C
The SMT172 operates with a supply voltage from 2.7 V to 5.5 V. The typical active current of only 60 μA, the high speed conversion over 4000 outputs per second (at room temperature) and an extremely low noise makes this sensor the most energy efficient temperature sensor in the world.
The SMT172 has a pulse width modulated (PWM) output signal, where the duty cycle is proportional to the measured temperature value. This makes it possible that the sensor can interface directly to a MCU without using an Analog-to-Digital Converter (ADC). Today, the hardware Timer in a MCU to read our PWM signal has become available almost universally, fast in speed and low in cost. Therefore it is extremely easy for any user to get started with this sensor and achieve a very quick time to market.

Absolute Maximum Rating

T_A= 25℃. All voltages are referenced to GND, unless o therwise noted.

Power supply voltage	-0.5 V to 7 V
Output Pin load	50 mA
ESD protection (HBM)	+2000 V
Junction temperature	+200 ℃
Soldering temperature (SOIC, SOT)	+260 ℃ (10 s)

Specification

T_A= -45°C to 130°C, Vcc=2.7 V to 5.5 V, unless otherwise noted.

Parameter	Min	Typ	Max	Unit	Conditions
Supply Voltage	2.7		5.5	V	
Active current[1]		50		μA	T_A = -45 °C, Vcc = 2.7 V, no load at the output pin
		60		μA	T_A = 25 °C, Vcc = 3.3 V, no load at the output pin
		70		μA	T_A = 25 °C, Vcc = 5.5 V, no load at the output pin
Average current		220		nA	T_A = 25 °C, Vcc = 3.3 V, one sample per second, each sample is based on average of 16 output periods.
			0	μA	When controlling with Vcc pin
Inaccuracy[2]			0.25	°C	-10 °C to 100 °C (TO18)
			0.8	°C	-45 °C to 130 °C (TO18)
Noise[3]			<0.0002	°C	T_A = 25 °C, Vcc = 5 V, 1 s measurement time
Output frequency	0.5		7	kHz	frequency range is 1 - 4 kHz for Vcc 4.7-5.3 V (-25°C to 110°C).
PSRR at DC			0.1	°C/V	
Repeatability[4]			0.01	°C	T_A = 25°C
Startup time		1	2	ms	after PD and/or Vcc, start measurement on first negative edge
Long term drift			0.05	°C	Measured under 200 °C stress test condition for 48 h
Output impedance			100	Ω	
Operating Temperature	-45		130	°C	
Storage Temperature	-50		150	°C	

[1] Continuous conversion

[2] TO-18 package, all errors included. For other types of package, see section “understanding the specifications”-“package induced error”. For an inaccuracy of 0.1 ℃ another convers ion formula is needed (see page 6).

[3] Noise level will be reduced by averaging multiple consecutive samples, for instance noise can be reduced to 0.0004 °C by taking average in 0.1s, so the measurement time should always be provided when mentioning noise figures. The lower limit of the noise is determined by the flicker noise of the sensor, where further averaging will no longer reduce the noise.

[4] Repeatability is defined as difference between multiple measurements on the same temperature point during multiple temperature cycles.

Output Signal

According to tradition, the Smartec temperature sensors have a duty cycle (PWM) output that can be directly interfaced with a microcontroller without the use of extra components. The output is a square wave with a well-defined temperature-dependent duty cycle. In general, the duty cycle of the output signal is defined by a linear equation:

$$\boldsymbol{DC = 0.32 + 0.0047 \times T}$$

where *DC* = Valid Duty Cycle
T = Temperature in ℃

A simple calculation shows that, i.e. at 0℃, *DC*= 0.32 (32%); at 130℃, *DC*= 0.931 (93.1%).

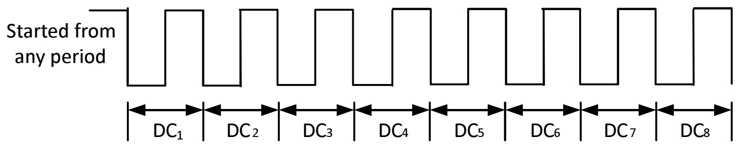
Temperature is then derived from the measured duty cycle by:

$$T = \frac{DC - 0.32}{0.0047} = 212.77 \times DC - 68.085 \qquad (1)$$

The frequency of the output of the sensor is fixed and contains no temperature information. Only the duty cycle contains temperature information in accordance to the formula given above. The output signal may show a low frequency jitter or drift. Therefore most oscilloscopes and counters are not suited for verifying the accuracy of these sensors. However, the duty-cycle value is guaranteed to be accurate within the values specified for each type (housing).
A higher accuracy can be achieved when a second order conversion formula is used, an inaccuracy of 0.1 ℃ can be reached in the range of -20 ℃ to 80 ℃ (see page 6).

Valid Duty Cycle

A valid duty cycle in equation (1) is defined as the average of individual duty cycles from 8 consequent output periods. This is due to the internal working principle of the SMT172 sensor. The difference of duty cycle between individual periods within the 8 period output can be relatively large and also different from sensor to sensor, but the averaged value (valid duty cycle) is very stable and precise.



Therefore a valid duty cycle is: $DC = \frac{\sum_{i=1}^{8} DC_i}{8}$

$DC_i = \frac{t_{Hi}}{t_{Li} + t_{Hi}}$ Where

t_{Hi}: time interval of high cycle

t_{Li} : time interval of low cycle

DC_i duty cycle of individual period i

DC the final duty cycle

For improved noise performance, a measurement of multiples (*N* times) of 8 periods is recommended.

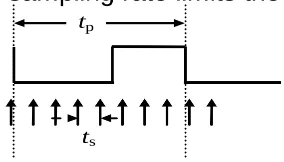
In words:
After each period the duty cycle has to be calculated and stored. The mean duty cycle has to be taken over 8 period or a multiple of 8 periods. This mean duty cycle is used to calculate the temperature.
Measurement always starts on the negative edge of the output signal.

Understanding the specifications

Sampling Noise

From the theory of signal processing it can be derived that there is a fixed ratio between the sensor's signal frequency, the sampling rate and the sampling noise. The sampling rate limits the measurement accuracy to:

$$T_{err} = 200\frac{t_s}{\sqrt{6t_m t_p}}$$



Where T_{err} = measurement uncertainty (= standard deviation of the sampling noise)
t_s = microcontrollers sampling rate
t_p = period of the sensor output
t_m = total measurement time, an integer number of t_p

Note:
The above mentioned error T_{err} is NOT related to the intrinsic accuracy of the sensor. It just indicates how the uncertainty (standard deviation) is influenced when a microcontroller samples a time signal.

Sensor noise

Each semiconductor product generates noise. Also the SMT172 sensor. The lower limit of the noise is determined by the flicker noise of the sensor, where further averaging will no longer reduce it. So the measured noise of the sensor of course depends of the measurement time. The noise of the sensor is about 0.002 ℃ when measuring over 3.6 ms (8 period s). But when measuring over about 1 s period this sensor noise will be better than 0.0004 ℃.

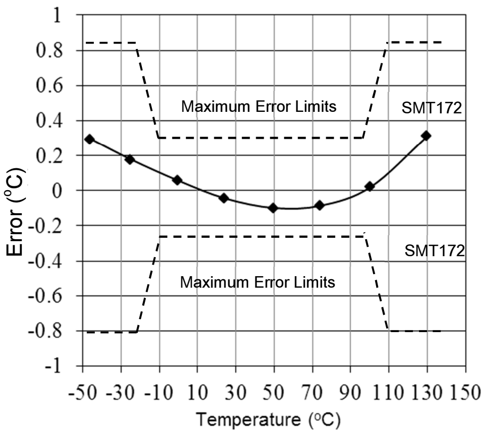
Package induced error

When applying high stress package materials, extra errors will occur and therefore system designers should be aware of this effect. The TO-18 package has the minimum package induced errors. All other packages can have a slightly bigger error on top of the error in the specifications but based on the recent measurements on the plastic versions TO92, SOIC and TO220 the error will be less than 0.35 ℃ (-10 ℃ to 100 ℃) and 1 ℃ over the temperature range of - 45 ℃ – 130 ℃.

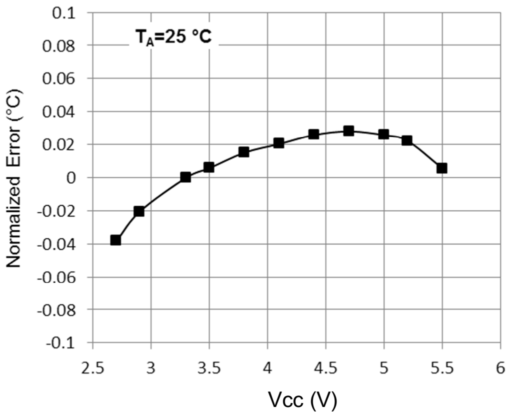
Long-term drift

This drift strongly depends on the operating condition. The measured hysteresis in a thermal cycle (TO-18 packaged samples) is less than 0.01 ℃ over the who le temperature range. Even at extreme condition (TO-18 samples heated to 200 ℃ for 48 hours), the drift is still less than 0.05 ℃ over the whole temperature range.

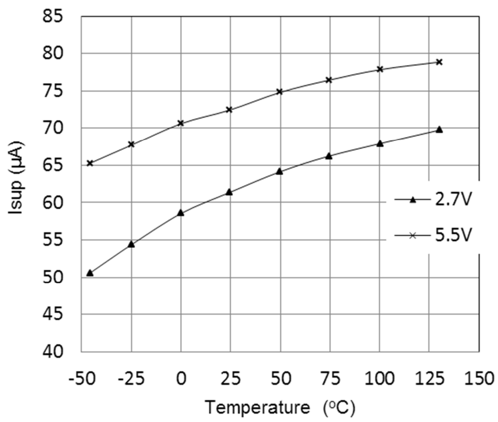
Typical Performance Characteristics



Inaccuracy vs. Temperature(TO18)



Normalized Error vs. Supply Voltage



Supply current vs. Temperature

Measurement with improved accuracy

This addendum to the datasheet of the SMT172 provides information how a temperature can be measured with a higher accuracy than what is specified in the datasheet.

How about

There are two reasons why the accuracy of 0.25°C (-10°C…100°C) has been specified in the SMT172:

1. A linear equation, which is compatible with SMT160 has been used for duty cycle versus temperature. Higher order system errors remain.
2. Due to the special design skill, one complete measurement is the average of 8 periods (or a multiple of 8 periods). The specified accuracy in the datasheet is valid for all kinds of averaging methods.

If a more accurate measurement is required, a more sophisticated interpretation of the output signal is needed. All the specifications of the SMT172 are valid except for the ones given below. The maximum accuracy can be achieved with some extra software.

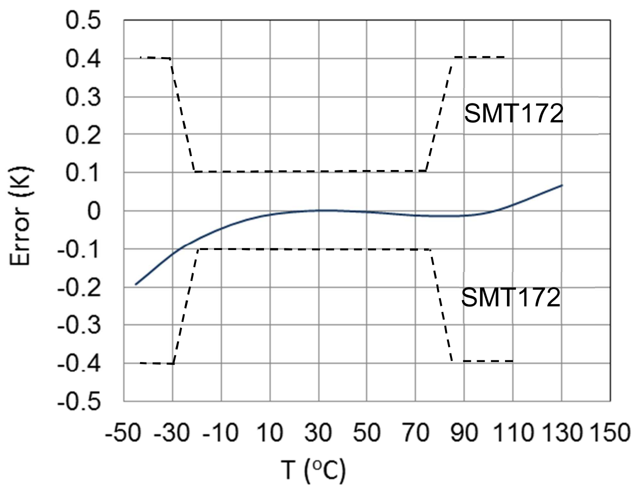
Accuracy			0.1	℃	-20 ℃ to 65 ℃
			0.4	℃	-45 ℃ to 130 ℃

For the plastic types this figures respectively will be 0.25 and 0.8 °C.

This inaccuracy can only be achieved:

1. Accurate method is applied to obtain the average value of the duty cycle
2. A specific second order equation has been applied to translate the averaged duty cycle to a temperature.

Performance characteristic



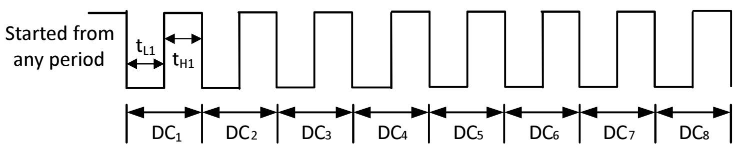
Inaccuracy vs. temperature (TO18)

To obtain the inaccuracy given above, a couple of aspects must be taken into account, like the way of measuring, energy efficiency and package induced errors. Please find below an overview.

Measuring the duty cycle

In general, measuring the duty cycle is relatively simple. The signal is sampled over a certain number of periods, and after that the duty cycle is calculated as the total high time divided by the total time interval. The duty can then be used in the formula to calculate the temperature. This method has advantage of less calculation load for a microcontroller (MCU) and it has been used in the evaluation boards of the SMT160. In the SMT172, it is a little bit different.
For the accurate measurement with the SMT172 the following aspects has to be taken in account:

- **Always start the measurement on the negative edge**



$$DC_i = \frac{t_{Hi}}{t_{Li} + t_{Hi}}$$

t_{Hi}: time interval of high
t_{Li}: time interval of low

- **Measure over 8 periods (or a multiple of eight**)
  The measurement can start at any negative edge.
  After each period (fi. DC1, see above) the duty cycle has to be calculated using the equation given above. After eight periods there are DC_1,…. DC_8

  Therefore the valid duty cycle is: : $DC = \frac{\sum_{i=1}^{8} DC_i}{8}$
  This duty cycle has to be used in the conversion formula between DC and temperature.

  In case the sampling frequency is not high enough, extra measurement noise is introduced. In that case, a measurement can be performed over a multiple of eight periods, and the valid duty cycle is the average of all the duty cycles: $DC = \frac{\sum_{i=1}^{N} DC_i}{N}$ (N should be a multiple of 8)

- F**ormula between Duty Cycle and temperature**
  The temperature can be calculated based on the second order formula below:

$$T = -1.43 \times DC^2 + 214.56 \times DC - 68.6$$

This second order equation can better interpret the averaged duty cycle to temperature, and thus a more accurate result can be achieved. The equation corrects for the typical error curve versus the temperature as in the graph on the previous page.

Application Information

Temperature measurement

The SMT172 measures the temperature of its bipolar transistors with high precision. Due to the great thermal conducting property of single crystalline silicon, we can assume the temperature difference within the sensor die to be negligible. However the thermal property of the package material, the shape and the size of soldering pads, the neighbouring components on the PCB as well as the presence of dedicated thermal sinks are all affecting the die temperature that the sensor is measuring. Therefore a good thermal path between the die and the objects under measurement should be carefully designed and considered.

When measuring temperature of solid or liquid targets, it helps to have a good thermal contact between the sensor and the target. This can be achieved with metals and thermal paste. When measuring air temperatures, it is important to isolate the sensor from the rest of the measurement system, so that the heating from the surrounding circuit components has only a small influence on the sensor temperature.

Self-Heating

All electronic circuits consume power, and all power becomes heat. Depending on the thermal resistance to the environment and the related thermal mass on the heat path, this heat will cause an extra temperature rise of the sensor die and will influence the final reading. Although the ultra-low power consumption of SMT172 sensor minimizes this effect greatly, it is always important to take this into account when designing a temperature measurement system. Design considerations like optimal thermal contact with the environment and powering down the sensors whenever possible (see SMTAS08) are all useful techniques to minimize this effect.

Thermal response time

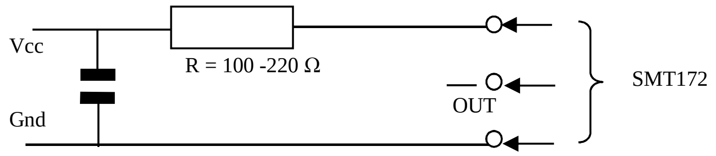
The thermal response time of the temperature sensor is determined by both the thermal conductance and the thermal mass between the heat source and the sensor die. Depending on the packaging material and the immerging substances, this can vary in a wide range from sub-second to hundreds of seconds. The following table illustrates the time constant (the time required to reach 63 % of an instantaneous temperature change) of TO-18 packaged sensors.

Conditions of installation	Time constant (s) (TO-18)
In an aluminium block	0.6
In a bath filled with oil that is stirred constantly	1.4
In air that moves at 3 m/s: - Without heat sink - With heat sink	 13.5 5
In non-moving air: - Without heat sink - With heat sink	 60 100

Supply voltage decoupling/ cable compensation.

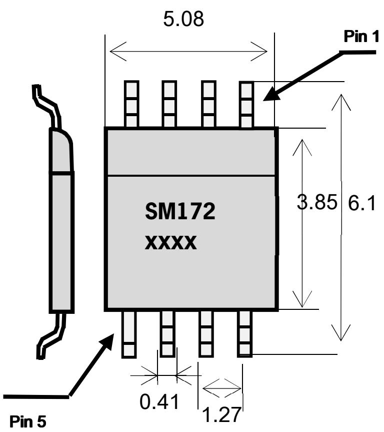
It is common practice for precision analogue ICs to use a decoupling capacitor between Vcc and GND pins. This capacitor ensures a better overall EMI/EMC performance. When applied, this capacitor should be a ceramic type and have a value of approximately 100 nF. The location should be as close to the sensor as possible. The SMT172 has a very accurate output. This means the positive and negative edges of the output signal are very steep, about 5 ns. This means when using longer cables (over 30 cm) there can be an effect of the cable inductance and capacitance which means the pulse is “reflected” and will give a spike on the sensors power supply line and the output of the sensor. These spikes can damage the electronics behind this and also the sensor. Therefor we advise for longer cables to put in series with the Vcc line a resistor of 100 Ohms. This resistor will damp the spikes on the signal as well on the Vcc line.

The capacitor will enhance the EMC performance and the resistor will also limit the maximum current in case of faults or wrong connections.



Packaging

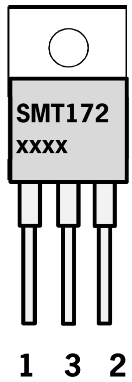
SOIC-8L



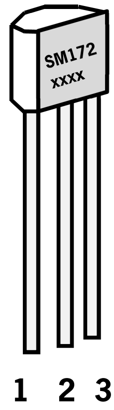
Pin 1 Vcc
Pin 7 Gnd
Pin 8 Out

All sizes in mm

TO220

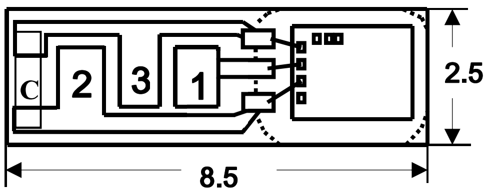


TO92



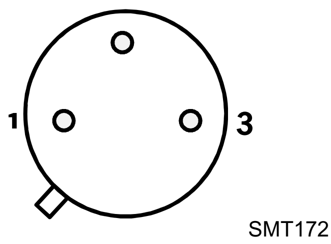
metal backplate = GND

HEC



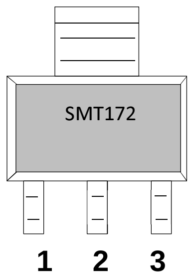
TO18

1 Output
2 + Vcc
3 GND



bottom view

SOT223



1 Vcc
2 Gnd/heatsink
3 Out

Ordering code:

SMT172-SOT223	SMT172 in SOT223 encapsulation
SMT172-TO18	SMT172 in TO-18 encapsulation
SMT172-TO92	SMT172 in TO-92 encapsulation
SMT172-TO220	SMT172 in TO-220 encapsulation
SMT172-SOIC	SMT172 in SOIC-8 encapsulation
SMT172-HEC	SMT172 in HEC encapsulation
SMT172-DIE	SMT172 DIE (die size 1.7 x 1.3 mm)

Related products:

SMTAS04	evaluation board for 4 sensors input (RS232)
SMTAS04USB	evaluation board for 4 sensors input (USB connection)
SMTAS08	evaluation board for 8 sensors input (RS232)
SMTAS08USB	evaluation board for 8 sensors input (USB connection)