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Application notes of SMT172

1. Introduction to SMT172

SMT172 is a new designed CMOS temperature sensor, which is based on the same design principle as SMT160. It has also a duty cycle modulated output, where the duty cycle is linearly proportional to temperature.
Compared to SMT160, SMT172 has better performances in:

- Accuracy: ±0.25ºC (-10ºC to 110ºC)
  ±0.1ºC (-20ºC to 60ºC)
- Resolution: 0.002ºC (measurement time 3.6ms)
- Low power consumption: 60μA active, 0.36μJ/measurement

But there is still some difference between SMT172 and SMT160:

1.1. DEM in SMT172: in order to eliminate the error caused by the big component mismatch in CMOS technology, advanced circuit technique DEM (Dynamic Element Matching) has been applied, taking average of the results in one complete DEM cycle can remove the mismatch induced error significantly. One complete DEM cycle consists 8 periods. The averaged duty cycle of 8 periods is a valid duty cycle, and can be further converted to temperature.
Thus, measurement and data processing of SMT172 needs to be updated, see section 2.

- Data processing
- Needs decoupling capacitor

The valid duty cycle is fully compatible to SMT160.

2. Output of SMT172

The sensor SMT172 is implemented in CMOS technology. In order to reduce the effects of the big component mismatches, Dynamic Element Matching (DEM) has been applied. One complete DEM cycle consists 8 periods. Averaging the duty cycles of 8 successive periods will give an accurate result.
Note that the individual values of the duty cycles of the 8 periods show differences corresponding up to ±4ºC at worse cases, as shown in Fig. 1. This indicates the individual component mismatch, and it changes from sensors to sensor. But the moving average of 8 periods removes the big fluctuation and give a stable and accurate reading (see the pink line in Fig. 1).

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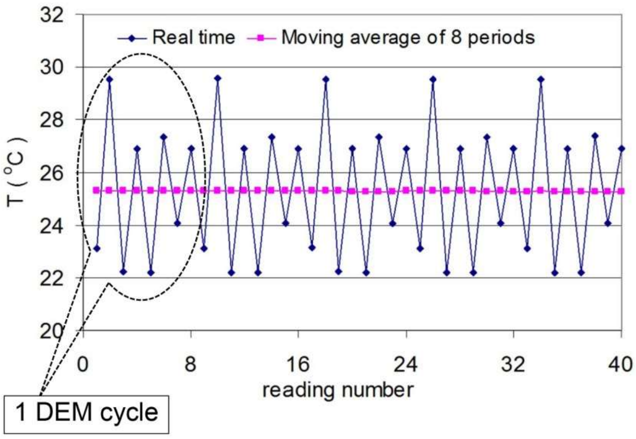

Fig. 1 Measured temperature reading at room temperature, using each individual period and after averaging over eight periods.

Further improvement of the measurement resolution is obtained by averaging over an integer number *N* of DEM cycles (*N* = 1, 2, …, etc.).

3. Connection of SMT172

3.1. Decoupling capacitor

Similar to ICs in general, it is recommended that the power supply lines of the sensor SMT172 are decoupled with a capacitor of 100nF nearby the sensor, as shown in Fig. 2. With decoupling capacitor, the SMT172 will work properly. The serial resistor of 100Ω can protect the sensor when it is connected in wrong way (by limiting the maximum current).

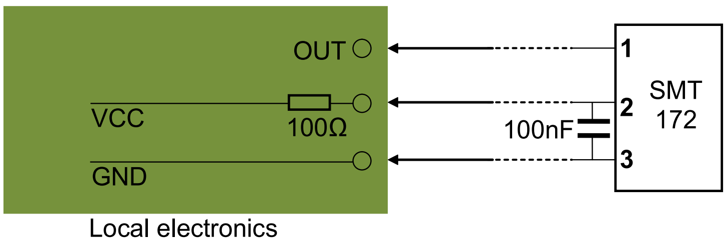

Fig. 2 First suggestion of the sensor connection.

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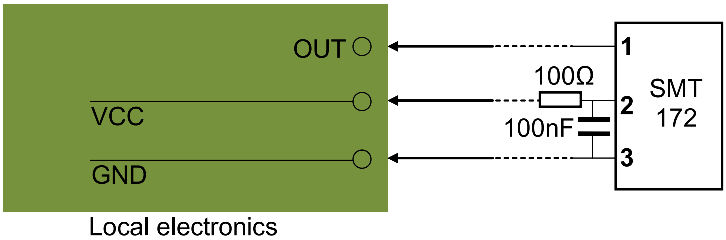

Fig. 3 Serial resistor close to sensor is also OK when a decoupling capacitor is available.

3.2. Without decoupling capacitor

If it is not possible to connect a decoupling capacitor nearby the sensor, then it is suggested to connect the sensor as shown in Fig. 4. When using a shielded cable, its length can be up to 20m. The connection in Figure 5 is also allowed. The shield should be connected to GND both at the sensor side and at local PCB side. The serial resistor of 100 Ω will damp the generated voltage spikes due to the large cable length. For long cable applications, it is recommended that the sensor is powered with supply voltage above 3.3V.

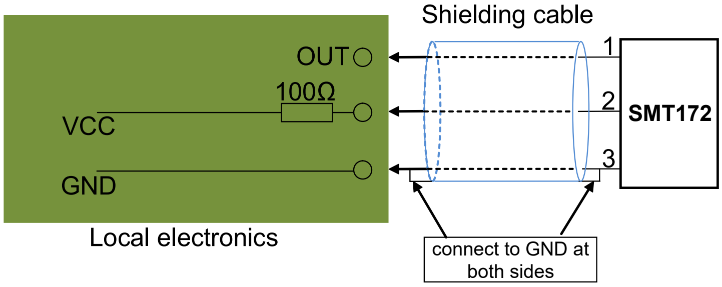

Fig. 4 Second suggestion for the sensor connection.

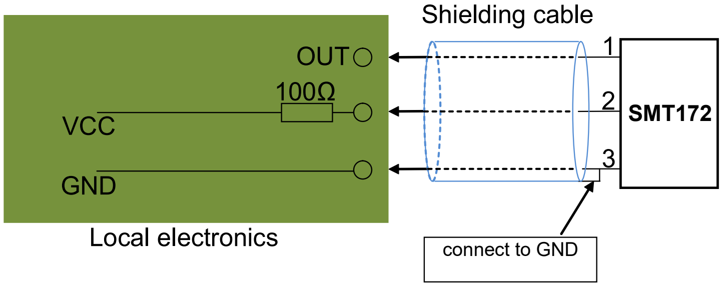

Fig. 5 Connect shielding to GND at sensor side is also ok.

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Another suggestion is add a serial resistor (~100Ω) at OUT, which can effectively reduce the transient current, and thus the voltage spikes (which may cause the sensor fails) at three wires. The connection is shown in Figure 6. This connection is suited for shielding cable up to 20m and twisted wire up to 10m. But there will be some extra error (especially with shielding cable) for lower supply voltages.

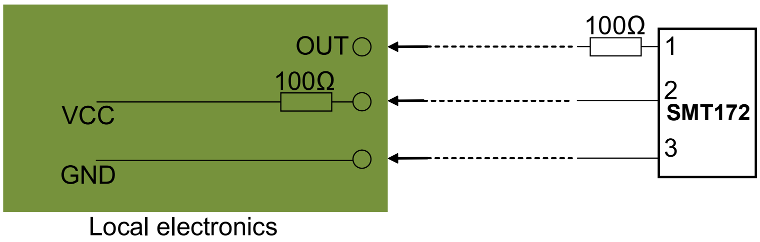

Fig. 6 Serial resistor of 100Ω helps to reduce the transient current.

4. Supply of SMT172

Unlike the former sensor SMT160, the output period of SMT172 changes with the supply voltage. Therefore, a DC supply is needed for SMT172. The DC supply voltage can have any value between 2.7V and 5.5V. Fluctuation in supply voltage with a frequency close to that of the SMT172 output can induce extra measurement error.

5. What happens if an old SMTA08 board is used for new sensor?

If an old SMTA08 evaluation board is used and the software is not updated, the temperature readings can have larger fluctuation than when using the old sensor SMT160. Also since in the evaluation board, the output is taken as the average result over a measurement time (t_m) of about 10ms, which does not correspond to an integer value of 8 periods (at room temperature 8 periods take about 3.6ms for 5V supply), an extra error in the temperature measurement can occur. This error can be up to ±0.2°C, and changes from sample to sample, depending on the specific component mismatching within the sensor. Taking the average of more output readings will reduce such additional error.

6. A new SMTAS08usb board is available

The new SMTA08usb board is available now. The associate document is available in the website.

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7. Measurement noise versus clock frequency of Microcontroller

The time intervals of SMT172 output signal can be measured by a microcontroller, then duty cycles can be derived, finally, temperature is obtained based on the averaged duty cycle.
Quantization noise has been described in the book <<Smart Sensor System>>. For a period t_p, when it is counted with sampling signal with period t_s, the relative error in standard deviation is:

$$\sigma_q^2 = \frac{1}{6}\frac{t_s^2}{t_p^2}$$

In time domain, the standard deviation is:

$$\sigma_t^2 = \frac{1}{6}t_s^2$$

After calculation, is can be concluded that for one DEM cycle (8 periods, t_{p1}, t_{p2} …t_{p8}), the total quantization noise in duty cycle can be described as:

$$\sigma_{\bar{D}}^2 \approx \frac{1}{48}\frac{t_s^2}{t_p^2}$$

Where we suppose that $t_{p1} \approx t_{p2} \ldots \approx t_{p8} \approx t_p$.

For instance, at room temperature, we calculated the quantization noise of one DEM cycle for different clock frequencies for VDD=3.3V and VDD=5V:

VDD=3.3V, T=25°C, t_p=225us, sensor noise≈3mK

CLK frequency	Q noise in duty cycle	Q noise in temp. (mK)	Total noise in temp. (mK)	Meas. noise over ~100ms (27 DEMs) (mK)
5MHz	1.28E-04	27.3	27.5	3.70
10MHz	6.42E-05	13.6	14.0	1.88
20MHz	3.21E-05	6.82	7.45	1.01
48MHz	1.34E-05	2.84	4.13	0.56
72MHz	8.91E-06	1.90	3.55	0.48
100MHz	6.42E-06	1.36	3.30	0.44

VDD=5V, T=25°C, t_p=450us, sensor noise≈2mK

CLK frequency	Q noise in duty cycle	Q noise in temp. (mK)	Total noise in temp. (mK)	Meas. noise over ~100ms (55 DEMs) (mK)
5MHz	6.42E-05	13.6	13.8	2.65
10MHz	3.21E-05	6.82	7.1	1.37
20MHz	1.60E-05	3.41	4.0	0.76
48MHz	6.68E-06	1.42	2.5	0.47
72MHz	4.45E-06	0.95	2.2	0.43
100MHz	3.21E-06	0.68	2.1	0.41

It is clear that the quantization noise is not significant when the clock frequency is above ~50MHz, and negligible when it is above 100MHz. If it is not critical for the measurement speed, even with low frequency microcontroller, low noise can be achieved by taking average of more measurement cycles.
There are huge number of microcontrollers in the market, some popular microcontrollers are:

	Price per piece (€)	Description
STM32F030F4P6	2.07, Farnell, 2393635	48MHz, 32bit, TSSOP-20
STM32F030C8T6	3.51, Farnell, 2393634	48MHz, 32bit, LQFP-48
STM32G031F4P6TR	2.74, Mouser, 511-STM32G031F4P6TR	64MHz, 32bit, TSSOP-20
STM32F103CBT6	8.69, Farnell, 1606327	72MHz, 32bit, LQFP-48
PIC32MX274F256B-I/MM	4.7, Farnell, 2765506	72MHz, 32bit, QFN-28
PIC32MX154F128D-I/PT	5.29, Farnell, 3636623	72MHz, 32bit, TQFP-44
JN5189THN/001Z	7.77, Farnell, 3378947	48MHz, 32bit, HVQFN-40
CC1310F128RGZT	6.96, Farnell, 3123128	48MHz, 32bit, VQFN-48
R7FA4E2B93CFM#AA0	3.79, Mouser, 964-R7FA4E2B93CFMAA0	100MHz, LQFP-64
F280021PTSR	3.38, Mouser, 595-F280021PTSR	100MHz, LQFP-48

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