IMPROVING THE MEASUREMENT PRECISION OF SMT160-30 TEMPERATURE SENSOR IN 8-PIN MICROCONTROLLER DESIGN

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The paper describes an improved design of the commercially available 4-channal temperature measurement board using the SMT160-30 integrated temperature sensor by Smartec B.V. and an 8-pin microcontroller. Using the new features of PIC12F629 microcontroller the measurement precision is improved, the calculation rounding errors are decreased, the self heating of the sensor is decreased and the measurement range is increased. A detailed study of the discretization error and experimental measurements are done in order to verify the improved precision of the new design.

1. INTRODUCTION

The SMT160-30 integrated temperature sensor measures temperatures from -40°C up to +130°C. It has a duty-cycle coded output. The temperature is calculated according to the formula:

$$\text{Temperature [°C]} = (\text{D.C.} - 0.3200) / 0.0047$$

where:

$$\text{D.C.} = \text{Pulse duration } (t_p) / \text{Period } (T_x).$$

Because the information is coded into the duty cycle ratio of the input signal the only possible measurement method is the period measurement (indirect counting method). According to this method the number of pulses of the high frequency f_0 is counted during one pulse duration t_p and period T_x. Thus in the counter two numbers will be accumulated:

$$N_x = T_x / T_0 \text{ and } N_p = t_p / T_0 \text{ ,}$$

Where the number N_p is equal to the converted pulse duration and the number N_x is equal to the converted period.

Therefore the values of t_p and T_x are equal to:

$$t_p = N_p * T_0 \text{ and } T_x = N_x * T_0$$

and the duty cycle ratio can be calculated as:

$$DC = t_p / T_x = (N_p * T_0) / (N_x * T_0) = N_p / N_x$$

The absolute quantization error because of non-synchronization can be described as:

$$t_p = N_p*T_0 + \Delta t_1 - \Delta t_2 = N_p*T_0 \pm \Delta_{qp}$$
$$T_x = N_x*T_0 + \Delta t_1 - \Delta t_3 = N_x*T_0 \pm \Delta_{qT}$$

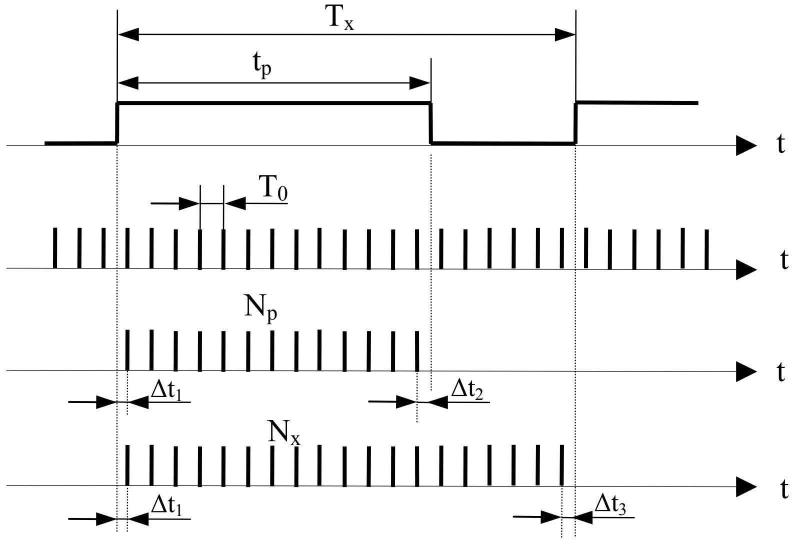

Figure 1. Time Diagrams of SMT160-30 output signal and counting methods

Therefore, distribution laws of this errors $W(\Delta t_1)$, $W(\Delta t_2)$ and $W(\Delta t_3)$ are equiprobable and aasymetrical with probability $1/ T_0$ and with mean values

$$M(\Delta t_1) = 0.5*T_0 \text{ , } M(\Delta t_2) = -0.5*T_0 \text{ and } M(\Delta t_3) = -0.5*T_0$$

The random additive methodical quantization errors Δ_{qp} and Δ_{qT} are determined by the sum of the independent and distributed errors according to the uniform distribution law random errors Δt_1, Δt_2 and Δt_3. The maximum values of the errors are $\Delta_{qp\ max} = \pm T_0$ and $\Delta_{qT\ max} = \pm T_0$. They are distributed according to the triangular distribution law $W(\Delta_q)$ with the null mathematical expectation:

$$M(\Delta_{qp}) = M(\Delta t_1) + M(\Delta t_2) = 0$$
$$M(\Delta_{qT}) = M(\Delta t_1) + M(\Delta t_3) = 0$$

and dispersion:

$$D(\Delta t_1) = D(\Delta t_2) = D(\Delta t_3) = T_0^2 / 12$$

Because of the distribution law symmetry the mean root square error coincides with the standard deviation

$$\sigma(\Delta_{qp}) = \sqrt{\sigma^2(\Delta t_1) + \sigma^2(\Delta t_2)} = \sqrt{\frac{T_0^2}{12} + \frac{T_0^2}{12}} = \pm\frac{T_0}{\sqrt{6}}$$

$$\sigma(\Delta_{qT}) = \sqrt{\sigma^2(\Delta t_1) + \sigma^2(\Delta t_3)} = \sqrt{\frac{T_0^2}{12} + \frac{T_0^2}{12}} = \pm\frac{T_0}{\sqrt{6}}$$

2. EXISTING COMMERCIAL MEASUREMENT SYSTEM

The Microchip's 8-pin single chip microcontroller family is an attractive option for reading the SMT160-30 output. Its small SO8 package, integrated factory pre-calibrated oscillator, build-in reset circuitry and low power consumption are giving the possibility to integrate the sensor and the microcontroller and to use a standard serial interface for data transmission thus receiving an intelligent smart sensor. The only disadvantage of this solution using the first available PIC12C50x devices is the lack of any interrupt capability or build-in capture functions in the microcontroller. That makes software pulling the only possible solution for pulse with and period measurement. In this case using the internal 4 MHz oscillator and the fastest software procedure gives as a result discretization time T_0 = 3µs and $\sigma(\Delta_q)$ = 1,22µs. As mentioned above the maximum values of the errors are $\Delta_{qp\ max} = \pm T_0$ = ±3µs and $\Delta_{qT\ max} = \pm T_0$ = ±3µs. Because the information is coded into the duty cycle ratio of the input signal we have:

$$D.C. = (N_p{*}T_0 \pm \Delta_{qp})/(N_x{*}T_0 \pm \Delta_{qT})$$

so the worst case is:

$$D.C. = (N_p{*}T_0 + T_0)/(N_x{*}T_0 - T_0)$$

If we calculate the maximum error at average value of 3 kHz and duty cycle ratio of 50% we have

$$\Delta = \frac{167\mu s}{333\mu s} - \frac{167\mu s + 3\mu s}{333\mu s - 3\mu s} = -0.01365$$

If we calculate this as temperature drift the result is:

$$\Delta_{max}[°C] = 0.01365 / 0.0047 = 2.9°C$$

This error value is too high for the SMT160-30 temperature sensor that has an absolute accuracy of ±1°C. Because of that the commercially available board based on PIC12C509 microcontroller is using averaging techniques in order to reduce the measurement error. Nevertheless at certain temperatures where the worst case conditions are present we can see fluctuations in the temperature up to ±1°C.

3. THE NEW DESIGN

Another approach for improving the measurement precision still keeping all the advantages of the previous design is to use the next generation PIC12F629 microcontroller. It is offered in the same 8 pin SO package but has a more precisely calibrated internal oscillator, flexible flash program memory, sophisticated digital input pull-ups control and interrupt on pin change capability. In this case using the internal 4 MHz oscillator and the interrupt procedure gives as a result discretization time $T_0 = 1\mu s$ and $\sigma(\Delta_q) = 1{,}40\mu s$. The maximum values of the errors are $\Delta_{qp\,max} = \pm T_0 = \pm 1\mu s$ and $\Delta_{qT\,max} = \pm T_0 = \pm 1\mu s$.

If we calculate the same maximum error at average value of 3 kHz and duty cycle ratio of 50% we have

$$\Delta = \frac{167\mu s}{333\mu s} - \frac{167\mu s + 1\mu s}{333\mu s - 1\mu s} = -0.0045$$

If we calculate this as temperature drift the result is:

$$\Delta_{max}[°C] = 0.01365 / 0.0047 = 0{,}9°C$$

If we use the same averaging techniques we can further reduce the measurement error. The experimental results show no more the picks in the error at the critical temperatures.

4. EXPERIMENTAL RESULTS

Comparative measurements between both designs are given on figure 2.

All the improvements of the new design are:

- The measurement is done with 1µs discretization time thus providing better precision.
- The rising/falling edge detection is done under interrupt instead of software pulling loop of the correspondent pin that result in 3 times better pulse/period measurement accuracy.
- The 16-bit TMR1 is used instead of the 8-bit TMR0 that gives the opportunity to use all the measurement range of the sensor (from -45 °C to +130 °C instead of from -25 °C to +115 °C).
- The final result calculation is done in floating point instead of integer that gives less rounding errors.
- The fluctuation of the result on critical temperatures is removed due to the better measurement and calculation precision.
- The resolution is changed to 0.01 °C instead of 0.1 °C.

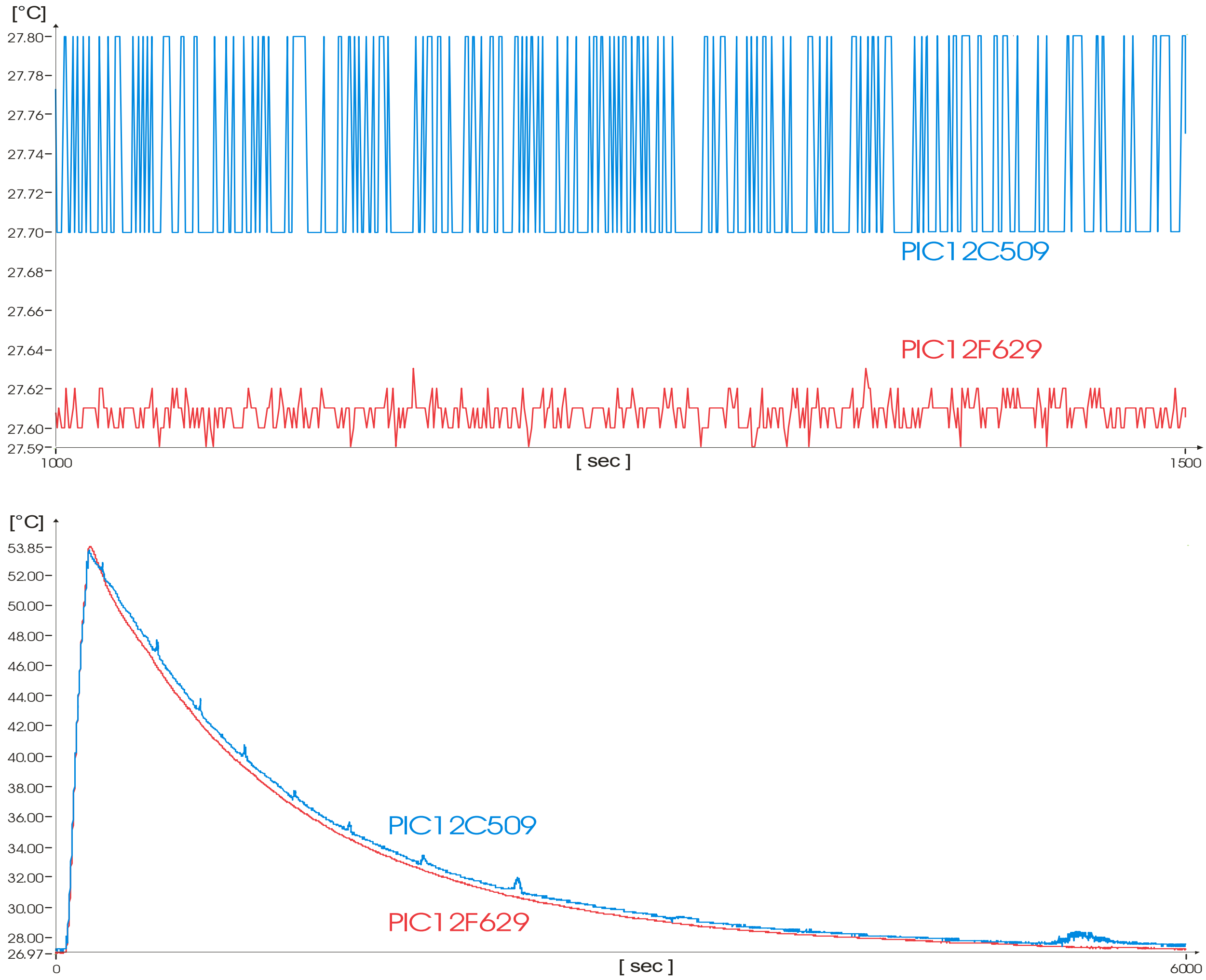

Figure 2. Experimental measurements of PIC12C509 and PIC12F629 designs

- The internal pull-ups of the microcontroller inputs are switched of if a sensor presence is detected (in the new microcontroller the pull-ups are swichable independently one by one) so the self-heating effect is reduced.
- The "*" sign is sent if there is no sensor connected to the correspondent input so it is possible to detect exactly on which input the sensor measured in the moment is connected (this gives the possibility if more sensors are connected and one of them is malfunctioning to detect exactly which one is not working properly).

5. REFERENCES

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