Time-to-Digital-Converter

Application Note

Metrological Investigations of TDC-GP2

Temperature Measurement Unit

18th August 2010
Document-No.: AN024_en V1.0

Introduction

The EN1434 standard's general requirements of temperature measurement systems in heat meters calls for at least +/- 0.01 °C repeatability. This requires accurate temperature sensors. So heat meters typically utilize a pair of platinum RTD's to compare the temperature difference of the entering and exiting fluid.

Besides the sensor accuracy, the signal conditioning circuit that is used to digitize the RTD's output signal also plays an important role. Here the TDC-GP2 offers an accurate but low current solution, that ideally suits to temperature measurement in heatmeters.

This application note delves into the TDC-GP2 temperature measurement unit in conjunction with the DIN EN1434 standard and characterizes the relevant performance parameters. Starting with a short introduction into temperature measurement with PICOS-TRAIN and RTD's, a test setup is introduced. It is followed by a detailed description how to measure these parameters. Finally an in depth discussion of the different error types, particularly with respect to DIN EN 1434 specification for heat meters, complements this application note.

Since this paper focuses on the TDC-GP2 circuit solution, errors that are produced by the sensor itself, such as hysteresis, repeatability, stability, and aging are not considered.

Due to their incompatibility to the GP2 temperature measurement unit, PT100 sensors are also beyond the scope of this document.

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1   Background

1.1   Introduction to PICOSTRAIN and Temperature Measurement with RTD's

The TDC-GP2 uses the PICOSTRAIN method to measure the temperature with RTD's. PICOSTRAIN transfers the temperature dependent resistance variation of an RTD in an accurate time interval measurement, by measuring the timing constant of an RC low pass filter.
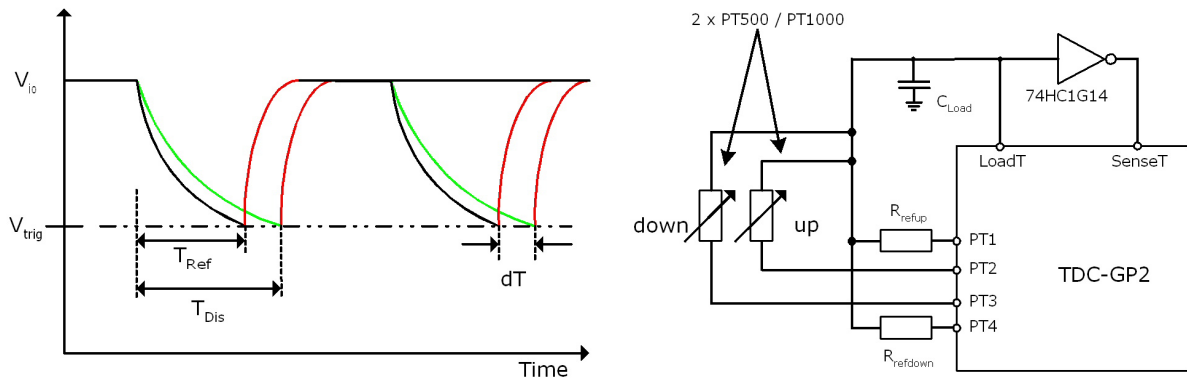

Figure 1: Temperature measurement with PICOSTRAIN

For that reason a capacitor is discharged alternately through the RTD sensor and a temperature stable reference resistor. The discharge time is set typically between 100µs to 250 µs and measured with picosecond resolution. The ratio of the discharge time shows the deviation of the sensor resistance relative to the reference resistor.

According to the four GP2 temperature port pins PT1 to PT4, the discharge time is measured four times. Finally each result is stored in the corresponding result register 0 to 3.

1.2   Calculating the Temperature from the GP2 Result

As mentioned in the previous section the measured discharge times are stored in the appropriate GP2 result register. They are given in multiples of the reference clock. Henceforth a microcontroller can calculate the resistance value by the following equation:

$$R_{RTD} = \left(\frac{T_{RTD}}{T_{Ref}} - 1 \right) * R_0 \qquad [1]$$

Where:

T_{RTD} is the discharge time through the RTD sensor

T_{Ref} is the discharge time through the fixed reference R_{Ref}

R_0 is the RTD resistance at 0 °C (e. g. 1000 Ohm for a PT1000 Sensor)

R_{RTD} is the RTD resistance as function of temperature

The temperature then can be calculated by the RTD transfer function. For t ≥ 0 °C it is

$$R_{RTD}(t) = R_0 * \left(1 + A*t + B*t^2\right) \qquad [2]$$

Where:

t is the RTD temperature

R_0 is the RTD resistance at 0 °C

$A = 3,9083 \times 10^{-3}$ °C^{-1}

$B = -5,775 \times 10^{-7}$ °C^{-1}

$R_{RTD}(t)$ is the RTD resistance as function of the RTD temperature

Equatgion [2] shows the RTD resistance as a function of its temperature. It is possible to turn the equation around and solve it for the RTD temperature, as a function of its resistance. For temperatures above 0 °C the following equation is the result:

$$t = \frac{-R_0 * A + \sqrt{(R_0 * A)^2 - 4*R_0 * B * (R_0 - R)}}{2*R_0 * B} \qquad [3]$$

Where:

R is the resistance measured in Ohm

t is the temoerature calculated in°C

R_0, A, B are parameters as specified in EN60 751

Now t gives the temperature as a function of the RTD resistance.

2   Test Hardware Description

The basic test setup includes the ATMD-GP2 evaluation system and a test board. The test hardware is used to adjust different resistance values in order to simulate the behaviour of an RTD sensor at different temperatures. It is connected to the ATMD-GP2 temperature unit by a five wired cable. To adjust the appropriate resistance value, a jumper is set on the test board. The ATMD-GP2 is connected to a PC, for data acquisition the ATMD-GP2 software is used. The following picture shows the typical setup.
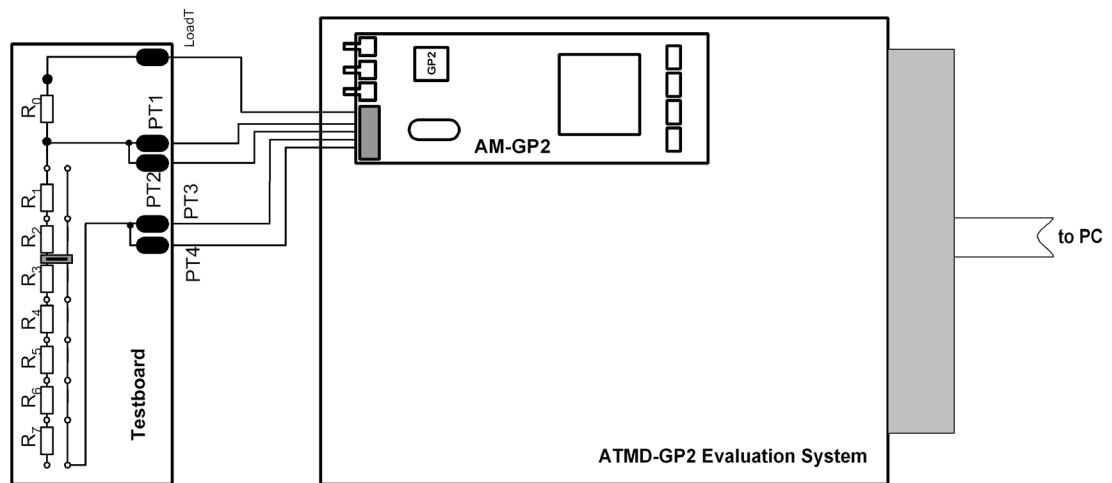
Figure 2: Basic test setup

R_0: RTD resistance at 0°C

$R_1...R_7$: Resistors, that can be added to R_0 to simulate the RTD resistance at different temperatures

Note:

Investigating small temperature differences requires accurate and temperature stable resistors, with an accuracy in the milliohm range. As they are not available at reasonable costs, the problem was solved easily by doing a reference measurement. There we determined the absolute resistance values at different jumper settings of the test hardware. The reference measurements were done with acam's PSO81-Evaluation system. This system offers the possibility of resistance measurement with up to 29-Bit resolution. Even compared to the resistance variation of a PT100 this equals to an accuracy better than 0.001 K. Additionally, the test hardware was put into a cardboard box to prevent it from temperature variation during thermal drift investigations.

The adjustment of the different resistance values is manually done by setting a jumper on the test board. Therefore we also investigated the contact resistance in order to be sure that this will not affect the accuracy of the measured results. These tests were also done with the PSO81-Evaluation system and showed that the influence can be neglected.

2.1   Investigated Properties

This application note focuses on three main properties of the TDC-GP2 temperature unit.

▪ **Total system accuracy**

Here the accuracy of the complete system was investigated, simulating a medium temperature difference from 1K to 160K. The measurements were done with 3 diffe-

rent AM-GP2 hardware modules at 2.5V, 3.0V, and 3.6V supply voltage

- **Offset and gain drift of the electronic**

  The electronics temperature drift and its dependency from the supply voltage was investigated for a temperature range from 0 °C … +75 °C. Offset and gain drift of three modules was measured, each at 2.5 V, 3 V, and 3,6 V.

- **Cable capacitance investigation**

  The GP2 temperature measurement unit uses AC excitation, so the cable capacitance may have an influence on the result. Therefore, we made investigations about that. Additionally, we examined the effect of different cable lengths.

3 Total System Accuracy

The total system accuracy of the TDC–GP2 temperature measurement unit was investigated by means of three different AM-GP2 modules. They were measured at 2.5V, 3V, and 3.6V supply voltage with the PT1000 and PT500 test board.

The tests were made according to EN1434, but we reduced the minimum temperature difference to 1K.

3.1 Selecting the appropriate Ports

The electrical properties of the four GP2 temperature ports are not exactly the same. Different bond wire lengths and different distances from the pins to the next power supply pin result in a a quite small error which cannot be neglected. A good port assignment solves this issue and improves the total system accuracy. Some tests in advance of these investigations showed, that the following port assignement provides best accuracy:

    PT1: not used
    PT2: Tref (fixed reference)
    PT3: Tup (hot)
    PT4: Tdown (cold)

Important recommendation:

If you use only one reference resistor, connect it to PT2 and do not use temperature port PT1!

3.2 Choosing the Number of Reference Resistors

Heatmeter with AD-converters sometimes use 2 reference resistor instead of one. The main reason is to compensate the converter's poor gain drift by a two point gain calibration over the full temperature range. The GP2 temperature unit offers excellent gain drift

properties so a second calibration point has not to be taken into consideration.
All measurements in this appication note were done with only one reference resistor.
However, the TDC-GP2 also operates with two reference resistors. Bit 9 in register 0 offers the possibility to choose between two and four measurement ports. If you use four measurement ports but only one reference resistor, it is mandatory that you also connect the unused reference port to a resistor. Otherwise a timout will occur.

3.3 Determine the individual offset value for each module

The initial offset value of each GP2 temperature port is different. This is mainly caused by the RDSON, that slightly differs for each port, and small differences in the bond wire lengths of the port pins. To compensate for that, the offset of each port has to be measured during production process. Then store the value in the microprocessor to use it for later corrections.

The offset values of the different ports are fairly easy to measure. Just connect the same resistor to each port, by shorting them. The below shows the results:

# Module	Differential offset relative to PT2 [mOhm]	
	PT3	PT4
Module 1	-0,3	-3,8
Module 2	24,0	29,7
Module 3	20,1	24,5

Table 1: Differential offset values of the relevant ports

3.4 PT1000 Measurements

According to the above recommendations we used the following setup:

PT1: not used

PT2: Tref (fixed reference)

PT3: Tup (cold)

PT4: Tdown (hot)

Now, PT2 was used as fixed reference for the temperature measurement. The diagram in figure 3 shows the the total accuracy of the three AM-GP2 modules at 2.5V, 3V and 3.6 V supply voltage.
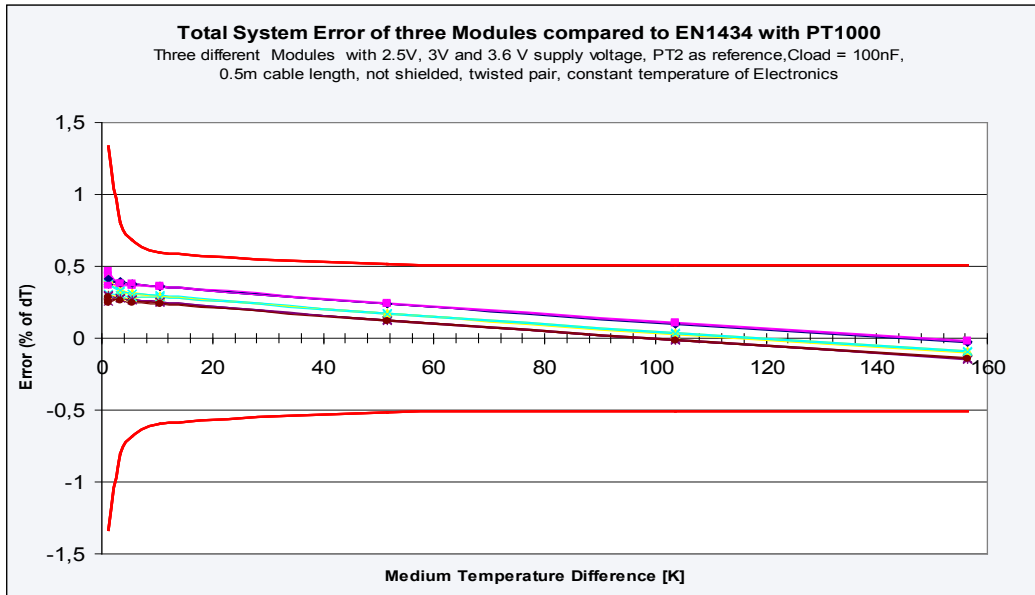
Figure 3: Total system error of three GP2 modules at 2.5V, 3V, and 3.6V supply voltage compared to EN1434 standard

With PT2 as reference the TDC-GP2 temperature measurement unit comfortably meets the EN1434 standard for heatmeters. There is no real need to do any additional correction of the result. The different supply voltages also cause no problems.

3.5   Mathematical Correction for Gain and Offset

However, the above investigations can be improved by a linear mathematical correction. It corrects the gain of the temperature unit that is not exactly 1.0. The reason is the delay time of the Schmitt-trigger, that introduces a deviation from the ideal gain. This is a systematic error, so it can be calculated and compensated by means of a linear correction with two constant correction values, K1and K2. Factor K2 corrects the overall gain loss over full scale, factor K1 the value dependend gain error. The calculation is done as follows:

As described in section 2.2 the RTD resitance is calculated by the following equation:

$$R_{RTD} = \left(\frac{T_{RTD}}{T_{Ref}} - 1 \right) * R_0 \qquad [4]$$

Adding a linear y = m*x +b correction and two correction factors K1 and K2 gives the following term:

$$R_{RTD-corr} = R_{RTD} * \left(1 - \frac{R_{RTD} * K1}{1000000}\right) * K2 \qquad [5]$$

R_{RTD}: uncorrected result, calculated from equation [4]

K1: correction factor for gain error

K2: correction factor for mathematical offset

$R_{RTD-corr}$: mathematically corrected result

Tests with (three) different modules showed that the mathematical correction can be generally admitted. If the correction factor is determinded once, it can be used in general for each device, if the same hardware is used. A recalculation of the factors K1 and K2 is necessary if the following components were changed:

- value of discharge capacitor (e.g. 100nF → 200nF)
- RO value (e.g. PT500 → PT1000)
- Type of schmitt-trigger

For PT1000 with 100 nF discharge capacitor and a 74HC14 Schmitt-trigger we determined the foolowing values:

K1= 7.0

K2 =1.003

With this correction we achieved a significat improvement of the accuracy for all modules. EN1434 standard is now (very) deeply fullfilled, as shown in the following diagram.

Corrected System Error of three Modules compared to EN1434 with PT1000
Three different Modules with 2.5V, 3V and 3.6 V supply voltage, PT2 as reference, Cload = 100nF, 0.5m cable length, not shielded, twisted pair, constant temperature of Electronics
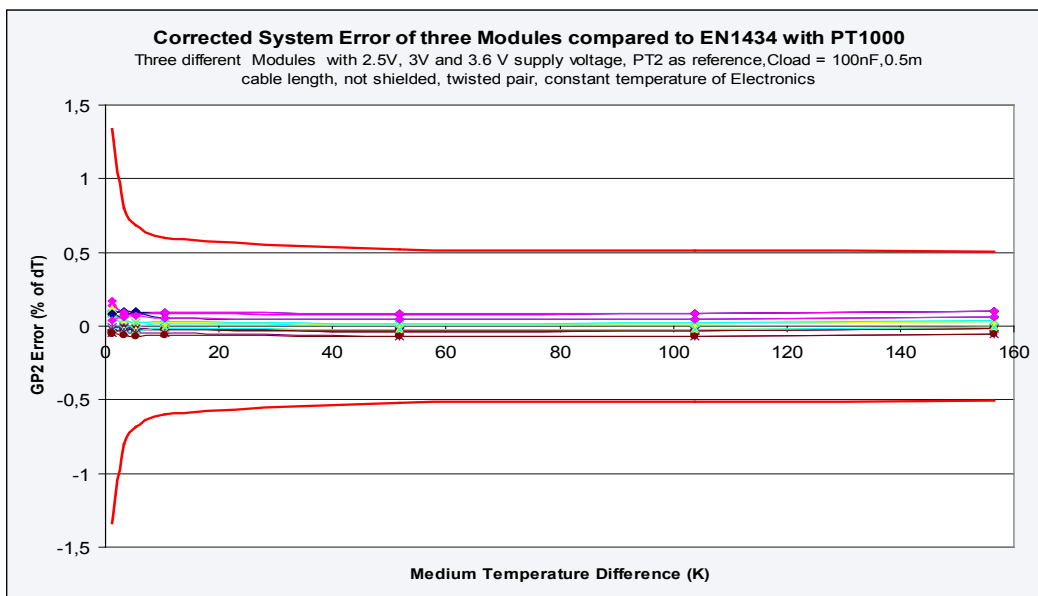

Figure 4: System accuracy of three different GP2 modules with 2.5V, 3V, and 3.6V supply voltage compared to EN1434 standard

Note:

PT1000 sensors require no additional corrections. But it is necessary for PT500, to meet the EN1434 specification.

3.6 PT500 Measurements

Similar to the PT1000 measurements the overall system accuracy was also investigated for PT500 Sensors. The same three AM-GP2 modules were used with PT2 as fixed reference for the measurements. The discharge capacitor was changed to 200nF.

According to our theoretical expectations the overall system accuracy behaves inversely proportional to the RTD's base resistance. It increased compared to the PT1000 results. Because of that all 3 Modules failed EN1434 requirements.

In order to improve the accuracy to achieve EN1434 specification also with PT500 a mathematical correction of the results is necessary. The simplest solution introduces a correction factor K that simply scales the GP2 results by an additional multiplication. The diagram below shows the results for the three AM-GP2 Modules with K = 1.006 at 2.5V, 3V and 3.6V supply voltage.

Total System Error of three Modules compared to EN1434 with PT500
Three different GP2 modules at 2.5V, 3V and 3.6V supply voltage with simple correction
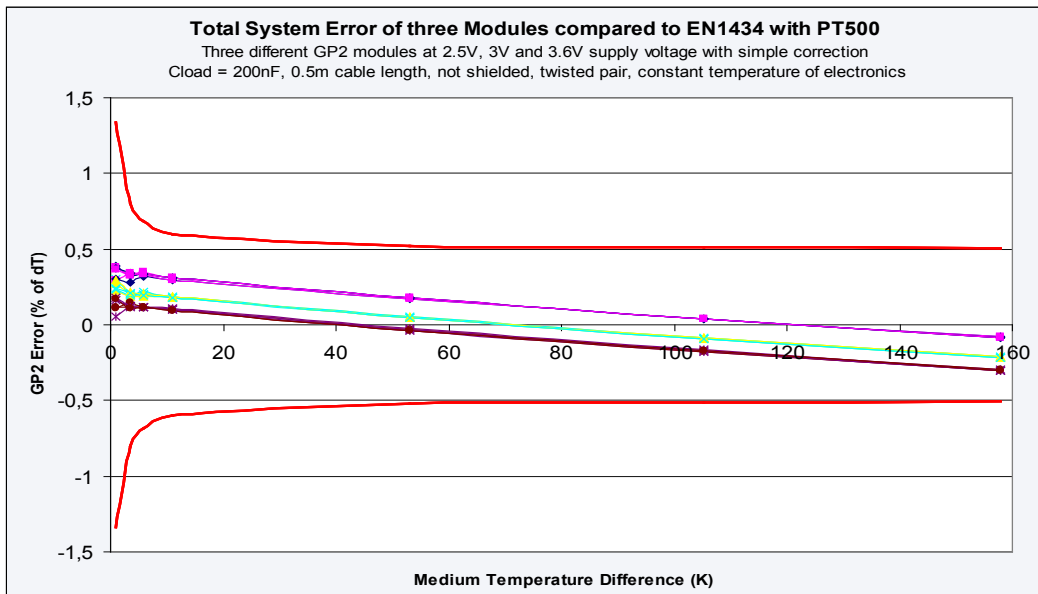Cload = 200nF, 0.5m cable length, not shielded, twisted pair, constant temperature of electronics

Figure 5: System accuracy compared to EN1434 with PT500 and simple mathematical correction

Now all modules meet the EN1434 specification, also with PT500. But they still show a moderate gain error over the total measurement range. Applying the same linear

correction as introduced in chapter 3.4.1 corrects the results for this value dependent gain error. With K1 = 14 and K2 = 1,008 we got the following diagram.

Total System Error of three Modules compared to EN1434 with PT500
Three different GP2 modules at 2.5V, 3V and 3.6V supply voltage with linear correction
Cload = 200nF, 0.5m cable length, not shielded, twisted pair, constant temperature of electronics
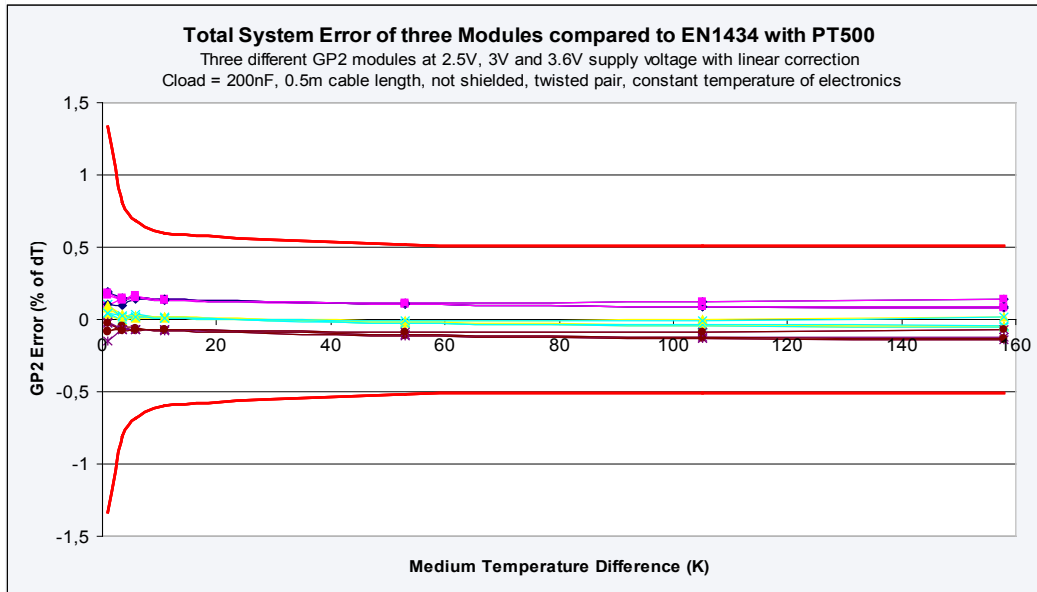
Figure 6: System accuracy compared to EN1434 with PT500 sensor and linear correction of the results

All three modules are now deeply within the limits, independent from their supply voltage. The results show the great performance of this gain correction. Also in combination with PT500 sensors there is no need for an individual and separate correction of each system. Again, the correction factors can be generally admitted to all GP2 hardware.

3.7 Discussion of the Results

The overall system accuracy was investigated because it represents the dominant system errors which are offset-, gain- and linearity errors. As the linearity errors originate primarily in the sensor they are not in the scope of this discussion.

The main considerable error sources of the TDC–GP2 temperature measurement unit are

- The Rdson of each temperature measurement port's input buffer that introduces an additional offset error.
- The propagation delay of the Schmitt Trigger, that adds an additional gain error to the result.

The Rdson as well as the Schmitt Trigger's propagation delay significantly dependend from the GP2 supply voltage. Because of that the investigations were made at 2.5V, 3V, and 3.6 V.

Due to the high stability of the TDC-GP2 temperature measurement unit over the total measurement range there's no need for two reference pins in order to separately measure the cold vs. hot temperature differences. Only PT2 should be used as reference port. Under these conditions all results showed a significant improvement of their quality. In combinations with PT1000 and PT500 sensors the GP2 temperature measurement unit now comfortably meets EN1434. With PT500 sensors a mathematical correction of the results is necessary to correct the gain error of the electronic.

We have measured the overall system accuracy down to a temperature difference of 1K, which is a 3 times lower difference than EN1434 requires.

4 Temperature Drift Investigations

The AM-GP2 module was placed into a climate chamber and the sensor (here we used an 1 k resistor with 0,1% accuracy and 3ppm/K temperature drift) was left ouside in a cardboard box, to prevent it for any temperature variation (constant environmental temperature of 26°C).
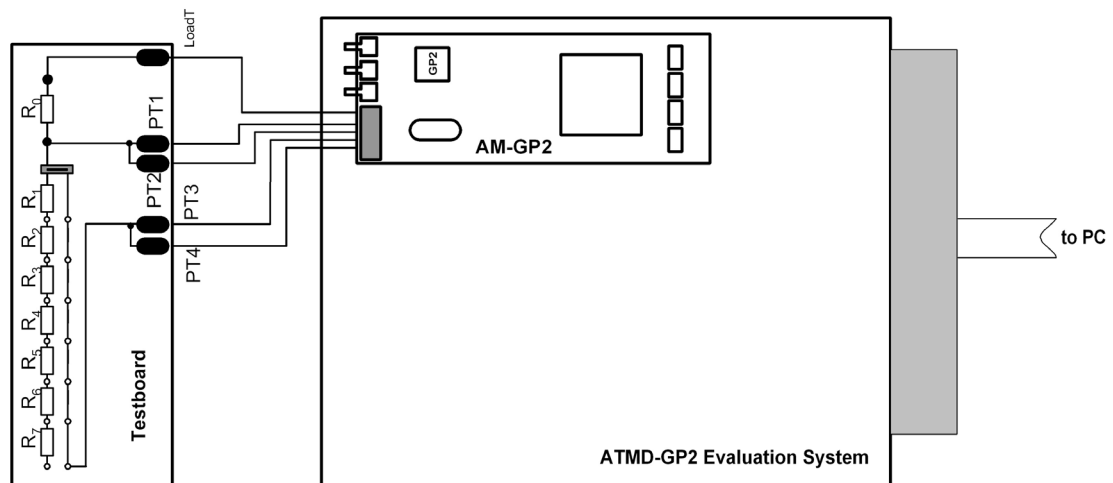
Figure 7: Basic test setup for temperature drift measurements

The tests were done as follows:

1. Heat up the climate chamber to 75°C. During this step it is useful to run the ATMD-GP2 measurement software, and display the results in the graphical display sheet of the software. This ensures that the measurement results are stable due to the temperature gradient during heating-up.

2. Restart the software and collect 500 values at 75°C. Then start cooling-down the climate chamber to 0°C.

3. Wait again, until the last 500 measurement results are stable due to the temperature gradient. Then stop the measurement software and store data in a file.

During the whole measurement data was collected with the ATMD-GP2 software.

4.1   Zero Drift of Electronics with PT1000

A measurement run with PT2 as reference provided the following results:

Offset Drift of three Modules over Temperature with PT1000 U = 2.5V, 3V, and 3.6 V, Cload = 100nF, Temperature Range: 0°C to 75 °C Values are given in mK / °C						
Supply Voltage	**2,5 V**		**3 V**		**3,6 V**	
Port Pins	**PT3/PT2 mK/°C**	**PT4/PT2 mK/°C**	**PT3/PT2 mK/°C**	**PT4/PT2 mK/°C**	**PT3/PT2 mK/°C**	**PT4/PT2 mK/°C**
Modul_1 Ser. No 7070001	0,029	0,016	0,034	0,018	0,021	0,009
Modul_2 Ser. No 9050156	0,028	0,007	0,012	0,021	0,008	0,004
Modul_3 Ser. No 9050160	0,038	0,019	0,032	0,023	0,024	0,004

Table 2: Offset drift results with PT1000 at different supply voltages

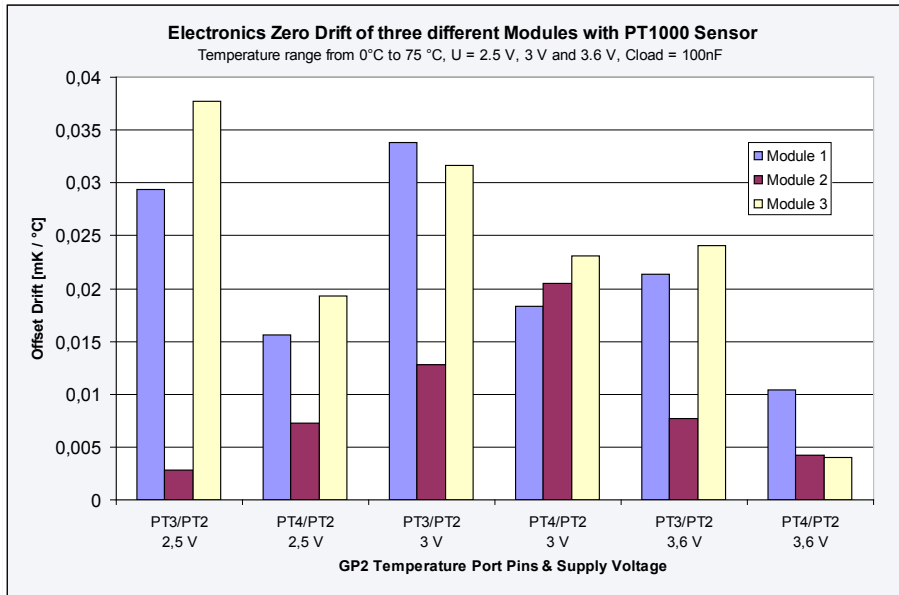The spread of the results is shown graphically in the following diagram:

Figure 8: Zero drift of three modules with PT1000 at different supply voltages

The max. measured drift was about 38 µK /°C. Transfered to the total range from -10°C to 85°C this equals to an overall drift of 3,7 mK. Assumed that the heatmeters minimal temperature difference is specified with 1 K, the max. possible error would be < 0,37 %. Compared to the +/- 1,5 % limitation of EN1434 this not problem at all.

4.2 Zero Drift of Electronics with PT500

The similar test setup was used, only the PT1000 test hardware was replaced by the one with 500 Ohm base resistance. The following results were measured:

Offset Drift of three Modules over Temperature with PT500
U = 2.5V, 3V and 3.6 V, Cload = 100nF, Temperature Range: 0°C to 75 °C
Values are given in mK / °C

Supply Voltage	2,5 V		3 V		3,6 V	
Port Pins	PT3/PT2 mK/°C	PT4/PT2 mK/°C	PT3/PT2 mK/°C	PT4/PT2 mK/°C	PT3/PT2 mK/°C	PT4/PT2 mK/°C
Modul_1 Ser. No 7070001	0,081	0,049	0,068	0,045	0,062	0,046
Modul_2 Ser. No 9050156	0,025	0,044	0,019	0,037	0,022	0,031
Modul_3 Ser. No 9050160	0,086	0,061	0,066	0,050	0,053	0,035

Table 3: Offset drift results with PT500 at different supply voltages

Electronics Zero Drift of three different Modules with PT500 Sensor
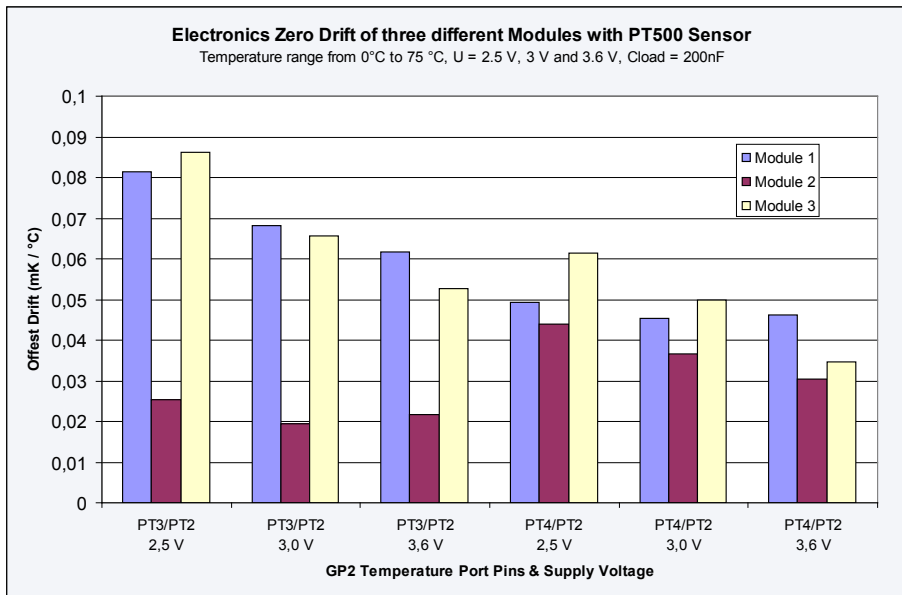Temperature range from 0°C to 75 °C, U = 2.5 V, 3 V and 3.6 V, Cload = 200nF

Figure 9: Zero drift of electronics with PT500

If we again consider the worst case, the max. drift has now increased to about 87 µK/ °C. This equals to 6,6 mK for the total temperature range, and leads to a max error of < 0,7 % with Tmin = 1 K.

4.3   Discussion of the Results

The Offset drift is preliminary caused by the Rdson missmatch and its temperature dependency. It has to be considered because it mainly affects the measurement of small temperature differences, which is of course more critcal than measuring big ones. Theoretically the offset drift should decrease at higher supply voltage, but the measurement over three different modules showed that there is no clear dependency It varies more with hardware, than with voltage.

According to the known issues PT1 is again the most critical pin with the highest zero drift over temperature. PT1 pin should not be used especially in combination with PT500 sensors.

Excursion: **Offset drift considerations covering the overall heatmeter electronics**
At this point we only considered the TDC-GP2 dominant error source of the offset drift. But in real heatmeter electronics, the main error source is the temperature drift of the reference resistor. The following example provides a practical illustration.

> **Example**:
>
> Maximal permissible zerodrift of the heatmeter electronics: 0.15 mK/C
>
> Assumed the GP2 partly introduces 0.05 mK / °C to the overall zero drift, the maximal permissible offset drift of the reference resistor must be 0.1 mK / °C.
>
> For temperature measurement a platinum resistor with a sensivity of typ. 4000 ppm/°C is used. To meet 0.1 mK/ °C, the temperature stability of the reference must be improved by a factor of 10,000, compared to the platinum resistor. This equals to 0.4 ppm/K (or in other words: a max. permissible temperature variation of 0.4 ppm / °C would be required for the reference) . Only with single adjusted, high accurate resistors you would reach such a good value. But their costs would exceed the cost of a GP2.
>
> The offset drift of the GP2 is significantly lower (about 20-30 times) than the offsetdrift, that is caused by the reference resistor. As a consequece the offset drift of the GP2 can practically be neglected.

4.4 Gain Drift of Electronics with PT1000

The same three AM-GP2 module have been used to measure the electronic's gain drift at 2.5V, 3V, and 3.6V supply voltage. According to the test hardware's full span 160 K was specified as as full scale range. The investigations were made within a temperature range of 75 °C to 0 °C, similar to the offset drift measurements. The results are provided in the table below:

Gain Drift of three Modules at different Supply Voltages U = 2.5V, 3V, and 3.6V , Cload = 100nF, Temperature Range: 75 °C to 0 °C Values are given in % / K @ 160 °C FS								
Supply Voltage	**2,5 V**			**3 V**			**3,6 V**		
Port Pins	PT2/ PT1 [%/K]	PT3/ PT1 [%/K]	PT4/ PT1 [%/K]	PT2/ PT1 [%/K]	PT3/ PT1 [%/K]	PT4/ PT1 [%/K]	PT2/ PT1 [%/K]	PT3/ PT1 [%/K]	PT4/ PT1 [%/K]
Modul 1 Ser. No 7070001	0,0023	0,0024	0,0024	0,0018	0,0019	0,0019	0,0017	0,0017	0,0017
Modul 2 Ser. No 9050156	0,0018	0,0019	0,0019	0,0017	0,0017	0,0017	0,0015	0,0015	0,0015
Modul 3 Ser. No 9050160	0,0018	0,0019	0,0019	0,0017	0,0017	0,0017	0,0015	0,0016	0,0016

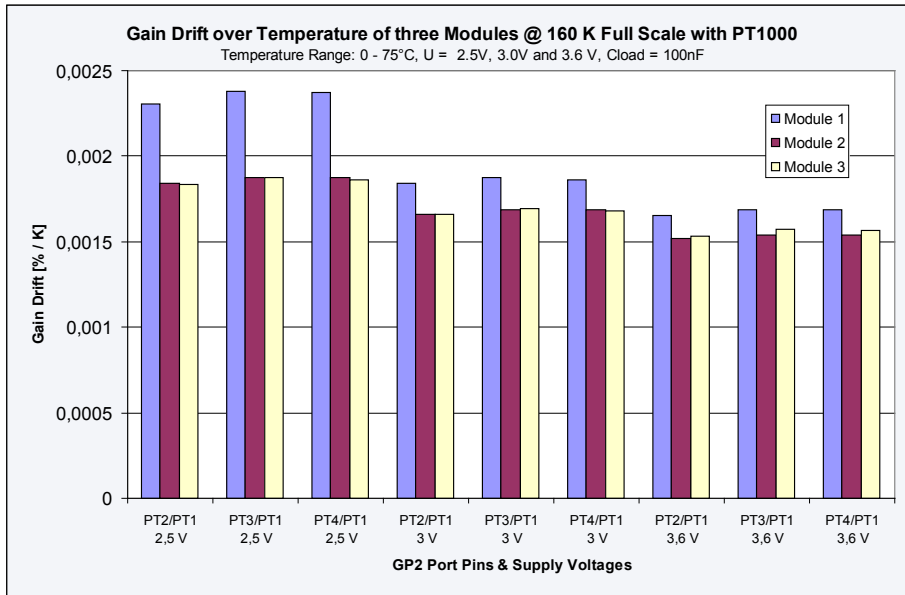Table 4: Gain drift with PT1000 at different supply voltages

Figure 10: Gain drift of electronics with PT1000

The gain drift decreases for higher supply voltage and ranges between 0,0015 and 0,0027 % / K. The max. error is about 0,2 % for the -10° C to 85 °C temperature range which is not a problem for EN1434 standard.

4.5　　　Gain Drift of Electronics with PT500

Offset Drift of Electronics over Temperature with PT2 as reference3 different Modules with PT500 at 2,5 V, 3,0 V and 3,6 V Supply Voltage and 0°C to 75 °C Temperature RangeValues are given in % / °C @ 160 K Full Scale Range						
Supply Voltage	2,5 V		3 V		3,6 V	
Port Pins	PT3/PT2 %/°C	PT4/PT2 %/°C	PT3/PT2 %/°C	PT4/PT2 %/°C	PT3/PT1 %/°C	PT4/PT1 %/°C
Modul_1 Ser. No 7070001	0,0030	0,0030	0,0027	0,0027	0,0025	0,0025
Modul_2 Ser. No 9050156	0,0030	0,0030	0,0027	0,0027	0,0020	0,0020
Modul_3 Ser. No 9050160	0,0030	0,0030	0,0027	0,0027	0,0020	0,0020

Table 5: Gain drift with PT500 at different supply voltages

Gain Drift over Temperature of three Modules @ 160 K Full Scale with PT500
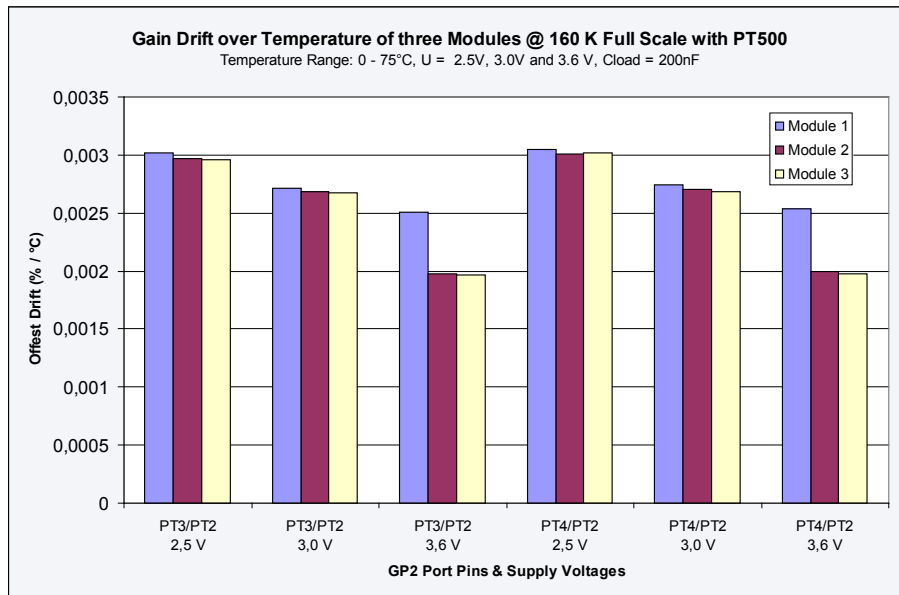Temperature Range: 0 - 75°C, U = 2.5V, 3.0V and 3.6 V, Cload = 200nF

Figure 11: Gain drift of electronics with PT500

As a consequence of the lower RTD resitance, the gain drift has increased for the PT500 measurements. Depending from the supply voltage it ranges now between 0,0025 and 0,003 % / K of full scale range.

4.6   Discussion of the Results

The gain drift is mainly caused by the temperature dependent propagation delay of the Schmitt Trigger. For PT1000 sensors it ranges between 0,0015 … 0,0023 % / K, with PT500 is sligtly increases to 0,003 %/ K of full scale range

The diagrams also show a slight dependency from the supply voltage. Compared to the EN1434 standard that specifies a max permissible error of 0,5 % at full scale, the gain drift of the temperature measurement unit is quite low and of minor importance.

Important Note:

The hardware setup, that was used for evaluating the temperature drift only considered the TD-GP2 and the Schmitt Trigger. A major contributor, the reference resistor, was placed outside the climate chamber on the test hardware. Though it was not exposed to any temperature variation. Considering the overall system temperature drift, the reference resistor has to be taken into account. In fact, a reference resistor with 25 ppm / K increases the gain drift by the same value.

5   Investigations about Cable Capacitance

Similar to acam's PICOSTRAIN products, the TDC-GP2 temperature measurement unit measures discharge curves of a capacitor, and is therfore AC based. Because of that, the cable capacitance is an important parameter, that has to be considered. Crosstalk and dynamic variations of the cable capacitance will also disturb, even the cable laying affects the measurement result. This dependency is investigated in this chapter.

Important Note:

This chapter does no reflect on the cable effects because of the cable's resistance. Here is no difference to the DC based 2-wire temperature measurements. Please also consider that the temperature unit of the TDC-GP2 cannot be used for a 4-wire temperature measurement.

Starting as a worst-case analysis we decided to use a PVC insulated, non-shielded cable with untwisted wires and a length of 1,5 m and 10 m. Of cource 10 m cable length is quite uncommon in practise for 2-wire measurement. However this measurement provides valuable information about the limitation due to cable length.

After an examination of the the offset and gain error, it can be seen, that the cable capacitance mainly affects the offset drift, than the gain drift. Therefore we only focus on the offset error in this section. The gain error is much smaller and can be neglected.

The main properties that have been investigated are
- the offset error that is introduced by the cable
- the capacitance variation due to different cable layings
- the temperature dependent zero drift of the cable

5.1   Offset Error

Before starting the cable investigations we measured the initial offset of each system. For that purpose all temperature ports were shortened, and connencted to LoadT, with an accurate and temperature stable resistor. The resitance value was selected according to the RTD's base resistance.

After that, we connected the resistor via 1.5 m and 10 m cable to the AMTD-GP2 and measured the offset values again. Calculating the difference from the initial offset without cable gives the additional offest that is introduced by the cable. The measurements were done with PT500 and PT1000.

Absolute Cable Offset Error with PT500 and PT1000 at const. Temperature, Modul_1 (Ser. No 7070001) with 1.5m and 10m length, U = 3V Cable Type: Metrofunk LiYY 6 x 0,14/13, PVC coating, 6 wires untwisted, no shield				
	PT500		PT1000	
Cable Length	PT3/PT2 Offset Error [mK]	PT4/PT2 Offset Error [mK]	PT3/PT2 Offset Error [mK]	PT4/PT2 Offset Error [mK]
1,5m	-0,59	-0,08	-0,66	0,60
10 m	-0,95	-17,06	-3,51	-48,39

Table 6: Cable Offset with PT500 and PT1000 at 1,5 m and 10 m cable length

The above table shows, that with 1.5 m length the offset is < 1mK. So basically there's no need to pay attention to the cable's capacitive properties with short cables. The test measurement with a 10 m cable have to be considered as a worst case examination, to show the significant impact on the overall measurement. As a consequence long cables are not recommended and require special considerations of the cable's parasitics.

5.2 Investigations on Cable Laying

An important factor to consider is the effect of different cable layings on the cable capacitance. In order to find out how this affects the measurement uncertainty, we measured the offset error and looked how it sways for the following cable lays.

- Straight: Straight cable connection between the electronics and the temnpearture sensor without any curves.
- Straight_2: Also a straight cable connection, but a little bit modified compared to the previous one.
- Curved_3: Cable laying with three curves
- Curved_5: Cable laying with five curves
- Mixed-up: Cable spaghetti

Cable Offset Error Variation in mK with different cablings at const. Temperature Modul_1 (Ser. No 7070001) with 1.5m and 10m length, U = 3V Cable Type: Metrofunk LiYY 6 x 0,14/13, PVC coating, 6 wires untwisted, no shield					
		PT500		PT1000	
Cable Length	Cable Laying	PT3/PT2 Cable Offset Error [mK]	PT4/PT2 Cable Offset Error [mK]	PT3/PT2 Cable Offset Error [mK]	PT4/PT2 Cable Offset Error [mK]
1,5m	straight	-0,59	0,08	-0,66	0,60
1,5 m	straight2	-0,76	0,23	-0,53	-1,20
1,5 m	currved_3	-0,36	0,53	1,03	-1,58
1,5 m	curved_5	-0,59	0,09	-0,10	-0,94
10 m	straight	-0,95	-17,07	-3,51	-48,39
10 m	straight2	-1,20	-17,43	-3,36	-48,19
10 m	currved_3	-1,14	-17,24	-2,70	-48,08
10 m	curved_5	-0,63	-16,88	-2,50	-48,41
10 m	mixed	-0,91	-16,61	-3,01	-47,89

Table 7: Cable offset error with 1.5 m / 10 m cable length at different cable lays

The cable offset shows a slight dependency from the cable laying. The variation equals a temperature variation is less than 1 mK, even at 10 m cable length. The effect of different cable laying on the cable's capacitive properties is insifignicant.

5.3 Cable Zero Drift

Finally the cable's zero drift over tempertature was determined. During that test, only the cable was placed into the climate chamber and applied to temperature variation from 85°C to -10 °C.

The ATMD-GP2 system and the PT1000 hardware were placed outside the climate chamber and additionally prevented by a cardboard box. Two measurement runs with 1.5 m and 10 m cable length were done. The graphs are shown on the follwing page.
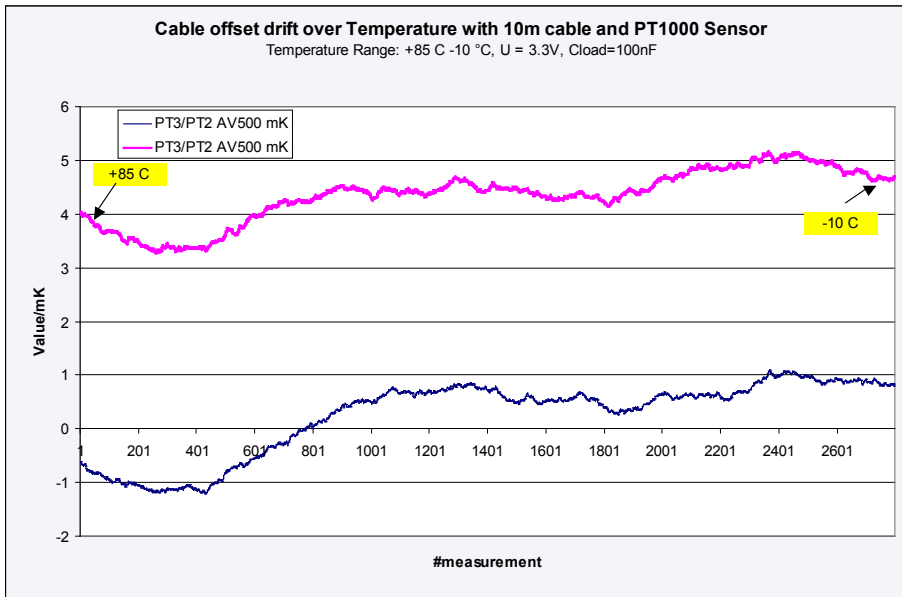
Cable offset drift over Temperature with 10m cable and PT1000 Sensor
Temperature Range: +85 C -10 °C, U = 3.3V, Cload=100nF

Figure 12: Cable offset drift over tenperature with 1,5 m cable length

Cable offset drift over Temperature with 10m cable and PT1000 Sensor
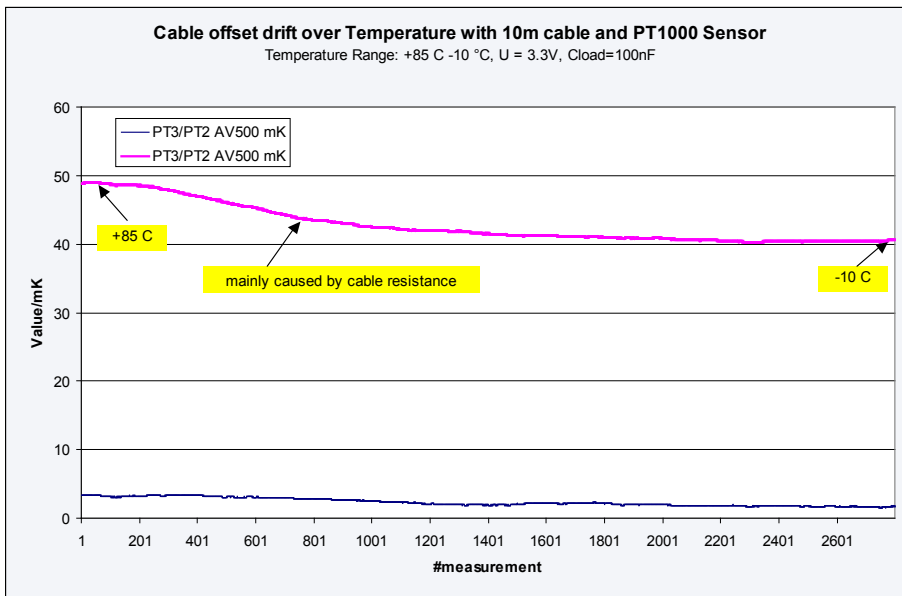Temperature Range: +85 C -10 °C, U = 3.3V, Cload=100nF

Figure 13: Cable offset drift over tenperature with 10 m cable length

Basically the cable's temperature drift analysis showed the expected results. With 1,5 m cable length the overall drift is about 2 mK. This equals to 0,2 % inaccuracy for systems that are specified with Tmin = 1K. With 10 m cables the measurement uncertainty significantly increases, peliminary caused by 2 effects:

- Variation of cable capacitance
- Wiring missmatch, because of different wire length of the cable's wires which result in an unbalanced wire resistance

Both effects cannot be separated. They cause no problems with short cables, but with increasing cable length the influence of the cable's parasitics will also increase. 10 m cable length doesn't make sense at all. It is much to much, especially for 2-wire temperature measurement.

5.4　　　Discussion of the Results

The main important parameter is the length of the cable. It has a considerable influence to the measured results and can have a significant impact to the overall uncertainty of the temperature measurement.

The tests in section 5.2 showed that the capacitive cable properties only have a slight influence. The results are stable at different cable layings, even up to 10 m cable length. Because of that the cable basically causes the same difficulties, as known from other 2-wire temperature measurement systems. Hence, the recommendations from the RTD manufacturers are also valid for GP2 and have to be considerd as well.

6　Tips to achive best Results

In summary, there are many factors that can affect the GP2 temperature measurement, so this paper is meant to provide an overview of the relavant parameterss and to help minimize measurement uncertainty. Thus, the final chapter of this document provides a summary of tips for accurate temperature measurement with the GP2. This helps to avoid pitfalls and shall give you a good start with your GP2 development project.

Select the correct RTD sensor for your application

PT1000 would be the best choice and provides highest accuracy. PT500 is also possible but the measurement quality will decrease. PT100 sensor can not be used in combination with the TDC-GP2.

Use the correct reference port

Poor quality of your reference directly affects the measured results. If possible use only one reference and connect it to PT2. Do not use PT1 as reference port, because it is the most critical port pin of the TDC-GP2 tempearture unit.

Determine the initial offest for each temperature port

The initial offset value of the GP2 temperature ports is different. To compensate for that, the offset of each port has to be measured and stored in the microprocessor.

Mathematical error correction

A mathematical error correction is described in this paper. It can be implemented easily by software, and leads to a significant improvement of the measurement quality.

Hardware layout

A good hardware layout is essential to achieve best result. Because of that, please consider the TDC-GP2 datasheet and its recommendation in chapter 2.5. Also refer to the technical documentation of the ATMD-GP2 evaluation system, and use it as a reference for your hardware design.

7 Literature References
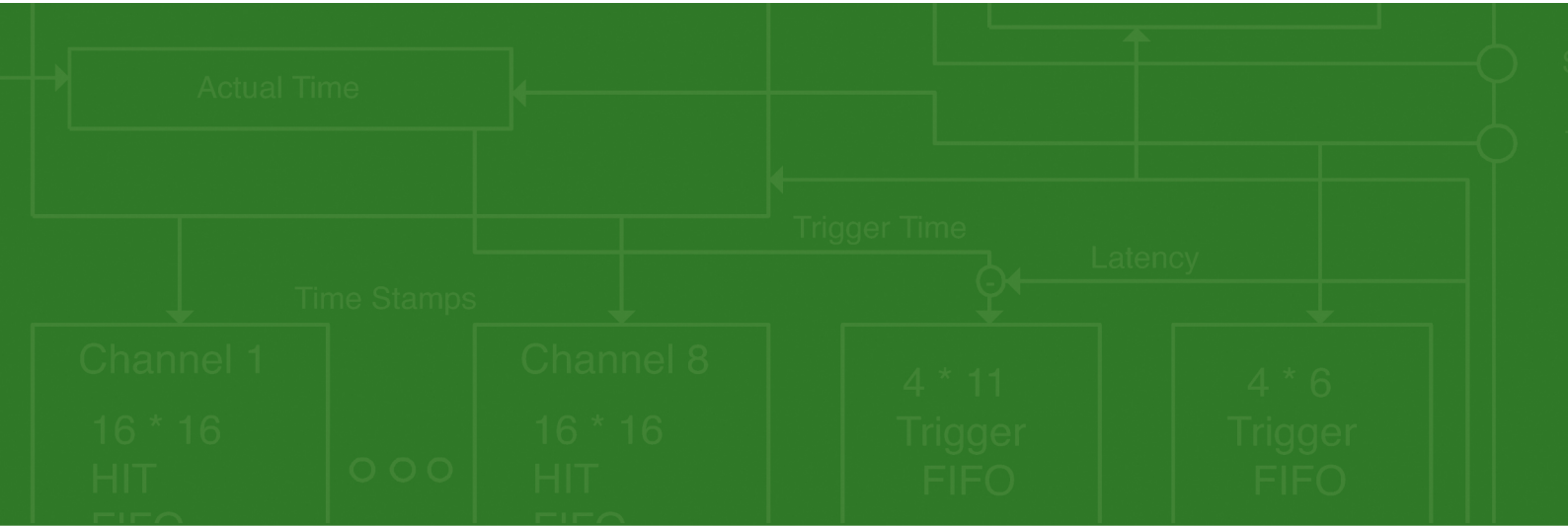
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