Application Note

MLX90129 Acquisition Chain

Scope

The goal of this application note is to provide to the MLX90129 users more information on how to set-up its embedded analog acquisition chain. The document will provide detailed information concerning the implementation of the MLX90129 acquisition chain, as well as some calculations to better understand how to set it up. Finally, the document will also provide information related to the embedded temperature sensor of the MLX90129 and an example of calibration.

Applications

- Temperature sensor tag
- Asset management and monitoring (security and integrity)
- Industrial, medical and residential control and monitoring

Related Melexis Products

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<thead>
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<th>Product No.</th>
<th>Temperature Suffix</th>
<th>Package Code</th>
<th>Option Code</th>
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<tbody>
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<td>R (-40°C to 105°C)</td>
<td>GO [TSSOP 20]</td>
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General Description

The MLX90129 is an RFID sensor tag. It embeds a fully configurable acquisition chain used to convert differential voltage information coming from an external resistive sensor, to a digital value. This value could be stored in the internal EEPROM memory of the MLX90129 for further processing (e.g. data-logger application) or directly transmitted through RFID like in the case of a full passive sensor TAG. The acquisition chain is composed of two gain stages PGA1 and PGA2, an offset compensation DAC and a 16bits analog to digital converter ADC. Each component is parameterized by the user depending on the resistive sensor used. Moreover, the MLX90129 is embedding an internal temperature sensor which can be used to sense ambient temperature.
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1. Acquisition chain

1.1. Block diagram

The MLX90129 is embedding a fully configurable differential acquisition chain for the conversion of the sensor voltage to digital information, the acquisition chain of the MLX90129 is illustrated in the following block diagram.

![Figure 1: MLX90129 acquisition chain](image)

1.2. First amplifier PGA1

The first amplifier PGA1 is used to amplify the differential input voltage $V_{SENSOR}$ according to the Equation 1 below.

Equation 1:

$$\Delta V_{PGA1\text{OUT}} = GAIN_{PGA1} \cdot \Delta V_{sensor}$$

With:

- $PGA1\text{OUT}$ = Differential output voltage of the PGA1 amplifier
- $V_{sensor}$ = Differential voltage from the sensor

The gain of the PGA1 amplifier could be adjusted from 8 up to 75 [V/V] by configuring the bytes “SensorN_Pga1Gain” defined in the “Sensor N: Signal Conditioner configuration words” at the EEPROM addresses #18, #1E and #24 bits [11:8]. For more information please refer to the datasheet on page 45.

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<td>30.8</td>
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<td>0x0111 (0x07)</td>
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<td>0x1000 (0x08)</td>
<td>47.6</td>
</tr>
<tr>
<td>0x1001 (0x09)</td>
<td>59.4</td>
</tr>
<tr>
<td>0x1010 0x0A</td>
<td>75</td>
</tr>
</tbody>
</table>

*Table 1: Gain of PGA1 amplifier*
1.3. DAC compensation

The acquisition chain of the MLX90129 is featuring a DAC used to compensate for any differential offset voltage of the sensor and the first amplification stage PGA1. The differential offset voltage is measured during calibration process.

\[ \Delta \text{PGA2}_{\text{IN}} = (\text{GAIN}_{\text{PGA1}} \cdot \Delta V_{\text{sensor}}) \pm \Delta V_{\text{DAC}} \]

The DAC is an 8-bit converter with one bit of sign with a compensation step of +/-VREF/128. The maximum compensation range is therefore equal to +/-½*VREF. The Equation 2 above could be modified as shown below:

\[ \Delta \text{PGA2}_{\text{IN}} = (\text{GAIN}_{\text{PGA1}} \cdot \Delta V_{\text{sensor}}) \pm N_{10} \cdot \frac{\text{V}_{\text{REF}}}{128} \]

With:
- PGA2IN = Differential input of the PGA2 amplifier
- Vsensor = Differential voltage from the sensor
- N10 = decimal number programmed into the DAC, defined in EEPROM #18, #1E and #24 bit [7:0] (for more information please refer to the datasheet page 45):
- VREF = Reference voltage of the MLX90129

1.4. Second amplifier PGA2

The second amplifier PGA2 will amplify the signal provided by the first amplification gain already compensated with the DAC compensation value. Using the Equation 3 above, it is possible to calculate the output voltage of PGA2:

\[ \Delta \text{PGA2}_{\text{OUT}} = \left[ (\text{GAIN}_{\text{PGA1}} \cdot \Delta V_{\text{sensor}}) \pm N_{10} \right] \cdot \frac{\text{V}_{\text{REF}}}{128} \cdot \text{GAIN}_{\text{PGA2}} \]

With:
- PGA2OUT = Differential output of the PGA2 amplifier
- Vsensor = Differential voltage from the sensor
- N10 = decimal number programmed into the DAC
- VREF = Reference voltage of the MLX90129

The gain of the PGA2 amplifier could be adjusted from 1 to 8 [V/V] by configuring the bytes “SensorN_Pga2Gain” defined in the “Sensor N: Signal Conditioner configuration words” at the EEPROM addresses #18, #1E and #24 bits [14:12] (for more information please refer to the datasheet on page 45).

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</table>

*Table 2: Gain of PGA2 amplifier*
1.5. Analog to Digital Converter (ADC)

The MLX90129 is featuring a 16bits ADC converting the analog sensor conditioned signal to digital information. This digital information could then be stored into the EEPROM memory of the MLX90129 or directly downloaded through the RFID interface. The information provided by the ADC is always on 16bits but, the effective number of bits (ENOB) is limited to maximum 11-bits. Moreover, if the resolution could be sacrificed to acquisition time by reducing the ENOB down to 8-bits, for more information, please refer to the datasheet on page 8.

<table>
<thead>
<tr>
<th>ADC parameters #15 [15:14]</th>
<th>Mode 00</th>
<th>Mode 01</th>
<th>Mode 10</th>
<th>Mode 11</th>
<th>Units</th>
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<tr>
<td>ENOB : effective number of bits</td>
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<td>9</td>
<td>10</td>
<td>11</td>
<td>Bit</td>
</tr>
<tr>
<td>Conversion time in normal operation mode</td>
<td>3.2</td>
<td>5.8</td>
<td>11.3</td>
<td>21</td>
<td>ms</td>
</tr>
<tr>
<td>Conversion time in low power mode</td>
<td>6.4</td>
<td>11.6</td>
<td>22.6</td>
<td>42</td>
<td>ms</td>
</tr>
</tbody>
</table>

*Table 3: ADC ENOB & Conversion time*

Each single input of the ADC is limited to a maximum voltage of ¾*VREF and a minimum voltage of ¼*VREF, leading to a full differential voltage of ±½*VREF (e.g. ADCinput+ = ¾*VREF and ADCinput- = ¼*VREF).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Δ_ADCInput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential ADC input</td>
<td>±½*VREF</td>
</tr>
</tbody>
</table>

*Table 4: ADC differential input range*

Taking into consideration that a differential value of -½*VREF correspond an ADC code of 0x0000 and a differential value of ½*VREF correspond to an ADC code of 0xFFFF, the conversion formula of the ADC could be expressed as following:

\[
\Delta V_{ADC_{IN}} = \left( \frac{V_{REF}}{2^{ENOB} \cdot D_{10}} \right) - \frac{V_{REF}}{2}
\]

*Equation 5:*

The Equation 6 below represents the formula of the full acquisition chain of the MLX90129:

\[
\left( \frac{V_{REF}}{2^{ENOB} \cdot D_{10}} \right) - \frac{V_{REF}}{2} = \left( \frac{\left( GAIN_{PGA1} \cdot \Delta V_{sensor} \right) + N_{10} \cdot \frac{V_{REF}}{128} }{2^{ENOB}} \right) \cdot GAIN_{PGA2}
\]

*Equation 6:*

With:
- \( ENOB \) = Effective Number of Bits
- \( D_{10} \) = ADC output code
- \( V_{REF} \) = Reference voltage of the MLX90129 (depends on the Low-voltage option)
- \( \Delta V_{SENSOR} \) = Differential voltage from the sensor

1.6. Common mode (CM) consideration

The common mode (CM) is the offset value generated by the external sensor. The CM is not amplified by the acquisition chain which is fully differential but has to be properly set to ½*VREF to allow the maximum dynamic for the acquisition. The *Equation 7* below expressed this statement.

\[
V_{CM} = \frac{V_{REF}}{2}
\]

*Equation 7:*
As a consequence, to allow the maximum dynamic of the acquisition chain, the user will have to take care that the CM value of the external sensor is equal to $\frac{1}{2} \cdot V_{REF}$. This is normally the case for a classical symmetric Weston bridge sensor. In case of a simple resistor would be used as a sensor (e.g. PTC1000), the internal adjustable resistors Rv1, Rv2 (adjusted between 500- and 32k- with a step of 1k-) could be used to create a resistive divider. In order to satisfy the Equation 7 above, the internal resistance the MLX90129 has to be equal to the resistor of the sensor.

2. Example of calibration procedure

This chapter provides an example how to perform a two points calibration with the MLX90129. More complex procedure could be implemented which are out of the scope of this application note.

A good understanding of each parameter is needed to be sure that the correct physical value is sensed. The following parameters will be used later in this document:

- **Full scale (FS)**: The total range of the physical value to be sensed ($FS = \Delta Sens_{max} - \Delta Sens_{min}$)
- **Sensor Sensitivity (SS)**: Sensitivity of the sensor to be used (e.g. expressed in [mV/°C])
- **Output scale (OS)**: Full dynamic output of the acquisition chain ($\Delta ADC_{Input} = \frac{1}{2} \cdot V_{REF}$)
- **Offset (OF)**: Residual value at minimum sensed voltage $\Delta V_{MIN}$
- **Gain (G)**: amplification needed to reach the desired output span ($Gain = Gain_{PGA1} \cdot Gain_{PGA2}$)

The following chart illustrates the different definition values defined just above:

![Diagram](chart.png)

The chapters below provide an example of a calibration procedure in five steps, performed at the temperature of the application (most of the time ambient temperature).

2.1. Common mode definition

The first step is to insure that the sensor is generating a common mode voltage as close as possible to $\frac{1}{2} \cdot V_{REF}$, allowing the maximum dynamic range for the acquisition chain. This is normally the case of all Weston bridges like the internal temperature sensor included in the MLX90129.

Of course it is possible to use a CM voltage different from $\frac{1}{2} \cdot V_{REF}$ but in this case you will lose in dynamic range affecting...
the final precision of your measurements. This is why it is recommend to center the common mode voltage on $\frac{1}{2}V_{REF}$ using additional resistors (internal Rv1 or Rv2 or external ones).

There is no specific measurements to be performed for this step but simply verifying that your sensor is providing a CM of $\frac{1}{2}V_{REF}$.

The second step would be to calculate the approximate value of Gain and DAC compensation offset to be programmed into the MLX90129 to get the maximum dynamic over the range of the physical value to be sensed.

The following formulas could be used to calculate the gain (Gain) of the acquisition chain equal to the multiplication of the Gain of both PGA1 and PGA2 amplifiers.

\[
\text{Equation 8: } (SS \cdot FS) \cdot \text{Gain} = V_{REF}
\]

- $SS$ = Sensitivity of the Sensor (e.g. 1.06[mV/°C])
- $FS$ = Full Scale of physical value to be sensed
- $Gain$ = Gain of the analog chain (PGA1*PGA2)
- $V_{REF}$ = Reference voltage of the MLX90129

Then the formula expressed in Equation 6 above could be used to determine the required DAC compensation value:

\[
\text{Equation 9: } \left[ (SS \cdot \Delta V_{Sensor}) + \Delta \text{Offset} \right] \cdot \text{GAIN}_{PGA1} = \frac{V_{REF}}{128} \cdot \text{N}_{10}\cdot \text{PGA2} \cdot \text{Gain} = -\frac{V_{REF}}{2}
\]

With:
- $SS$ = Sensitivity of the Sensor (e.g. 1.06[mV/°C])
- $\Delta V_{Sensor}$ = Differential voltage provided by the sensor
- $\Delta \text{Offset}$ = Differential offset of the sensor (e.g. 45mV)
- $N_{10}$ = decimal number programmed into the DAC
- $V_{REF}$ = Reference voltage of the MLX90129

2.2. Calibration

Once the parameters of the analog chain are defined, the real calibration process could be performed. This could be done with only three steps:

**Offset verification**: This will be used to fine adjust the DAC offset compensation value which may vary from device to device. This could be done by measuring the ADC code at the minimum sensing value (or any other suitable value) and fine adjust to DAC to reach as close as possible the theoretical ADC code value. The value obtained will be stored as SENS1 and use to calculate the parameters of the linear calibration curve.

**Second value acquisition**: A second value is required to get the linear parameters; this could be done at the most optimized value according to the sensor characteristics. This value has to be stored as SENS2 and will be used to calculate the parameters of the linear calibration curve.

**Linear approximation**: The two points measured above will be used to determine the linear parameters. It has to be noted that the MLX90129 does not embed any microcontroller and digital state machine. Consequently, this operation has to be implemented in the RFID reader by downloading the two values SENS1 & SENS2 previously stored into the EEPROM of the MLX90129. The following formulas will be used to calculate the linear parameters:

\[
\text{Equation 10: } \text{Slope} = \frac{SENS1 - SENS2}{S_1 - S_2}
\]
With:
- \( S_1 \) = Physical sensing value at which \( SENS_1 \) is measured
- \( S_2 \) = Physical sensing value at which \( SENS_2 \) is measured
- \( SENS_1 \) = ADC code obtained under \( S_1 \) condition
- \( SENS_2 \) = ADC code obtained under \( S_2 \) condition

**Equation 11:**

\[
\text{Offset} = \frac{\text{ADC}_{MAX} - S_{MAX}}{\text{Slope}}
\]

**Note:** Some sensors may present a certain error of linearity reducing the accuracy of the measured value. In this case, another point could be measured after the step four above (e.g. middle of the range) to be able to define a second order polynomial formula instead of linear approach. Of course this would increase the time of calibration due to the additional measurement point.

### 2.3. Temperature compensation

The measurements above have been performed at fix temperature e.g. room temperature). The variation of the temperature may have an effect on the sensor and on the acquisition chain of the MLX90129. Therefore, to optimize the calibration, a temperature compensation process can be implemented to identify the possible variation of the slope and of the offset over the temperature.

One simple solution will be to perform the same measurements as above without changing the settings of the acquisition chain (gain and offset compensation) at high temperature. Based on the new points measured, it is possible to perform a linear approximation of the variation of the slope and offset over the temperature:

If the sensor shows a too strong variation at low temperature, it is possible to make one more measurement at low temperature and perform the same linear regression as above. Then the application will have to change from one curve to the other according if the temperature is above of below the temperature used for the calibration (most of the time 25 degrees).

### 3. Calibration examples

#### 3.1. Internal temperature sensor

This shows an example of calibration performed with the MLX90129 and its internal temperature sensor. The objective is to measure the temperature from -30°C up to 30°C with an accuracy of at least +/-1°C.

**Applicative information**
- Value to be sensed = Temperature
- Full Scale FS \( (T_{MAX} - T_{MIN}) = 60°C \)
- Normal voltage operation (low-volt option deactivated)

**Sensor information** (internal temperature sensor, refer to datasheet page 7)
- Sensor Sensitivity = 1.06mV/°C ()
- Offset = 45mV
- None-linearity = +/-2.65mV

**Type of calibration & expected accuracy**
- Two points \( T_{MIN} \) and \( T_{MAX} \)
- Expected accuracy = +/-1°C

The internal temperature sensor is built as Weston bridge and features a common mode (CM) of \( 1/2 \times V_{REF} \) allowing the maximum dynamic of the acquisition chain. Consequently, the first condition is obtained.
The second step would be to calculate the Offset and Gain using the sensor parameters as defined above (typical values). The calculation is performed using Equation 8 and Equation 9 above.

\[
\text{Gain} = \frac{V_{\text{REF}}}{(\text{SS}_{\text{internal}} \cdot \text{FS})} = \frac{3[\text{Volt}]}{(1.06[\text{mV/}^{\circ}\text{C}] \cdot 60[\circ\text{C}]}) = 47.2[\text{V/V}]
\]

This leads to the following settings of the two stage amplifier gain, \(\text{Gain}_{\text{PGA1}} = 19.6\) and \(\text{Gain}_{\text{PGA2}} = 2\), giving an overall gain of 38.4 with a margin from the calculated gain of about 23%. Knowing the overall gain of the acquisition chain, the DAC compensation value could be calculated as follow:

\[
\text{DAC}_{10} = \left(\left(\text{SS}_{\text{internal}} \cdot \text{Sens}_{\text{MIN}} + \text{Offset}_{\text{internal}}\right) \cdot \text{Gain}_{\text{PGA1}} + \frac{V_{\text{REF}}}{2 \cdot \text{Gain}_{\text{PGA2}}}\right) \cdot 128 = -43 = 0\text{xAB}
\]

Here again, enough margin should be taken to avoid saturation, a reduction of the offset of 10% would be taken leading to a value of 0xA7 (-39\_10).

As a resume, the following parameters will be used for the calibration.

- \(\text{PGA1}_{\text{Gain}} = 19.6\)
- \(\text{PGA2}_{\text{Gain}} = 2\)
- \(\text{DAC}_{\text{Offset}} = 0\text{xA7}\)

**Note:** The third step would be to fine adjust the offset at the minimum temperature value (or other suitable temperature). The internal temperature sensor of the MLX90129 shows some none linearity and to reduce as much as possible to accuracy, some specific points have to be chosen. The following table is an example of some specific points based on simulation and the accuracy which could be obtained:

<table>
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<tr>
<th>Tmin [\degree\text{C}]</th>
<th>Tmax [\degree\text{C}]</th>
<th>Full Scale [\degree\text{C}]</th>
<th>T1 [\degree\text{C}]</th>
<th>T2 [\degree\text{C}]</th>
<th>Accuracy [\degree\text{C}]</th>
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<tr>
<td>+5</td>
<td>+40</td>
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<td>+10</td>
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<td>95</td>
<td>-20</td>
<td>+55</td>
<td>+/- 2.5</td>
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<td>-30</td>
<td>+30</td>
<td>60</td>
<td>-20</td>
<td>+20</td>
<td>+/- 1</td>
</tr>
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</table>

**Table 5: Recommended calibration temperature vs Full scale**

**Note:** The accuracy could be strongly improved by using a third calibration point.

Consequently, the adjustment of the DAC compensation offset will be made at -20\degree\text{C}, using the Equation 6 above to calculate the ADC code to obtain.

\[
D_{10} = \left(\left((\text{Gain}_{\text{PGA1}} \cdot \Delta V_{\text{sensor}}) + N_{10} \cdot \frac{V_{\text{REF}}}{128}\right) \cdot \text{Gain}_{\text{PGA2}} + \frac{V_{\text{REF}}}{2} \right) \cdot 2^{16} = 13213
\]

The DAC code giving the value as close as possible to the ADC code calculated above, will be stored and used for the linearization (ADC-20deg). A second point would be used for the linearization at +20\degree\text{C} (ADC+20deg). In the samples measured for this example, the following values have been found:

- \(\text{DAC code N}_{10} = 0\text{x009716}\) (fine adjust at @ -20deg)
- \(\text{ADC-20deg} = 0\text{x341C16}\)
- \(\text{ADC+20deg} = 0\text{xB7F216}\)

Providing the following linear parameters using Equation 10 and Equation 11 defined above:

- Slope = 0x034816
- Offset = 0x760716

The chart below shows the error obtained between the real temperature set and the measured ones using the...
MLX90129 device and its internal temperature sensor. It could be observed that accuracy of ±1°C could be obtained.

![Chart 1: Calibration over -30 up to +30 degrees example](image)

4. Conclusion

In this application note, the full acquisition chain has been described in detail and the required calculation formula provided. An example of simple calibration has also been discussed with an example using the internal temperature sensor of the MLX90129.
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