Application note
MLX90380 resolver

1. Scope

This application note describes the functionality of the MLX90380 resolver evaluation / demonstration board and software.

The document also explains the front end calibration / signal processing to compensate the non-ideal magnetic field angle components of the application.

The MLX90380 resolver demo board demonstrates an embedded application for the MLX90380 paired with a Micro Controller.

The embedded micro controller performs a resolver to digital conversion on the angle information, the SIN/COS signal, from the MLX90380.

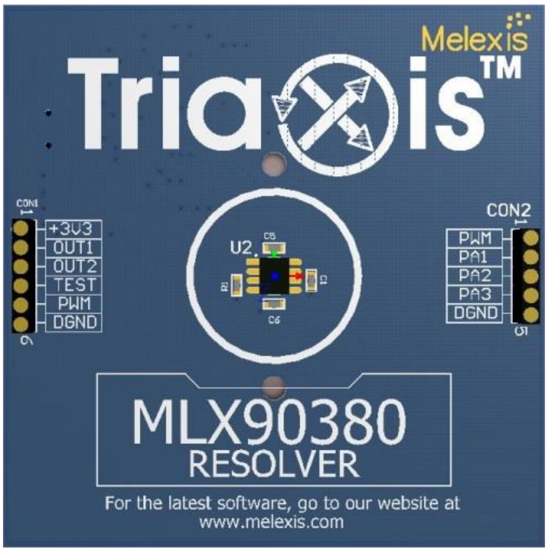


Figure 1: MLX90380 Resolver Evaluation/Demonstration board

2. Related Documents, Products and Tools

The documentation and information on the products and tools listed below can be found on www.melexis.com.

2.1. Related Products

MLX90380 Triaxis® Resolver

2.2. Related Documents

Datasheet MLX90380

Application Note AN_90363_FrontEndCalibration

Application Note MLX90316_AN_Front-endCalibration

2.3. Related Tools

GUI MLX90380 Demonstration Evaluation Board: Demo_Board_MLX90380_Concept_UI.xlsm

3. Contents

4. Glossary of Terms

Gauss (G) Tesla (T)	Units for the magnetic flux density: 1 mT = 10 G
NLE	Nonlinearity Error
SMM	Sensitivity Mismatch: Difference in sensitivity between OUT1 and OUT2 signal of the sensor.
OMM	Offset Mismatch: Difference in offset (V_{OQ}) of OUT1 and OUT2 vs. 50%VDD offset level.
PHI	Signal phase shift
ORTH	Orthogonality
V_{OQ}	Output Quiescent Voltage (%VDD): output level when magnetic flux density = 0mT
S	Sensitivity of the hall element times the gain of the amplifier (%VDD/mT)
SPAN	Peak to peak value of the output signal after one full 360 degree period.
OFFSET	Mean or average value of the output signal after one full 360 degree period ≈ V_{OQ}
µC	Micro controller
RPM	Revolutions per minute

5. Demo board hardware

The MLX90380 resolver evaluation / demonstration board demonstrates an embedded application for the MLX90380 paired with a Micro Controller.

The embedded micro controller performs the signal processing on the magnetic field angle information, the SIN/COS signal, from the MLX90380.

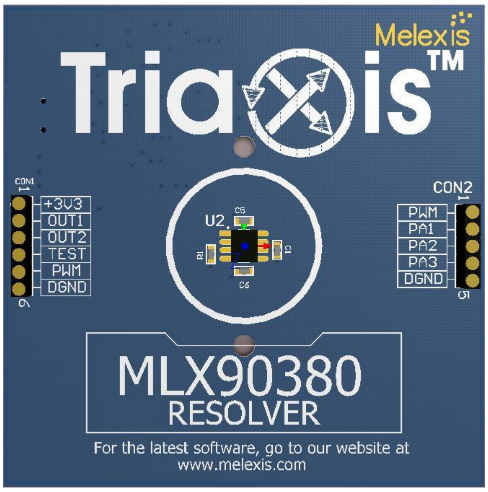


Figure 2: MLX90380 resolver on the top

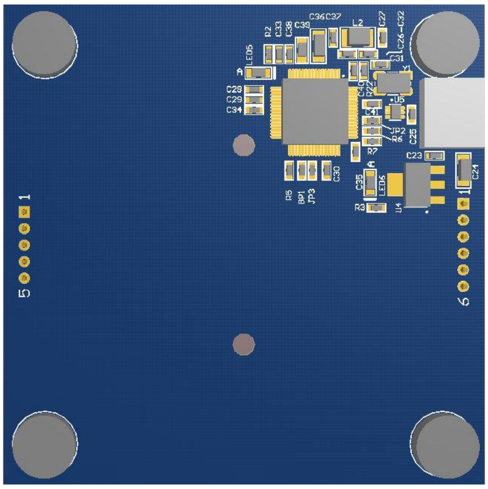


Figure 3: µC for signal processing on the bottom.

The signal processing of the µC consists in the acquisition of the SIN/COS information, the signal corrections for sensitivity mismatch and offset to compensate the non-ideal magnetic field angle components of the application, the angular position calculation (arctangent interpolation) and the translation to a digital output signal (in this case a 2kHz PWM signal). The signals can be measured on CON1 of the demo board.

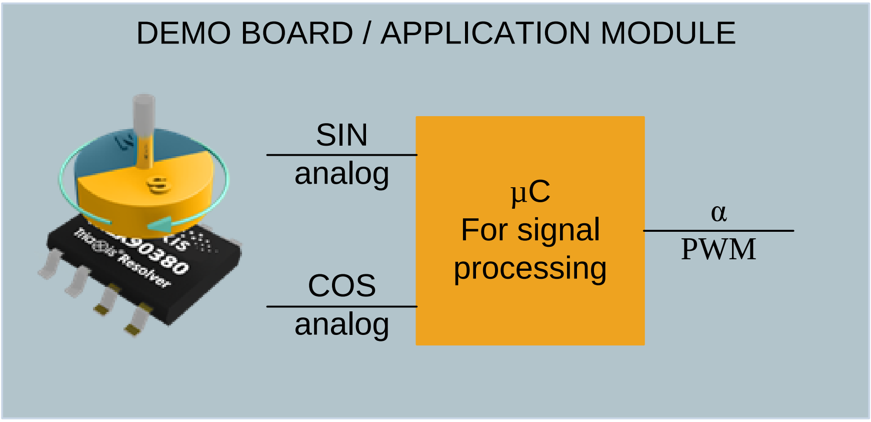


Figure 4: Application mode

When the board is powered up via the USB, the µC will start the acquisition of the SIN/COS signal from the MLX90380, compute the angular position and translate it to a PWM signal.

The signal correction parameters to compensate the mismatch in the magnetic field angle components are calculated on the fly / dynamically. After the first full 360 degree turn of the magnet, the necessary data is acquired for the angle correction.

The technique that is applied is explained later on in the chapter Angle Nonlinearity Correction – Front end calibration

6. Demo board software

The MLX90380 resolver evaluation / demonstration board is equipped with a USB interface to a PC. This allows us to collect data from the OUT1 and OUT2 of the MLX90380 sensor to demonstrate the functionality of the SMM and OMM angle nonlinearity corrections.

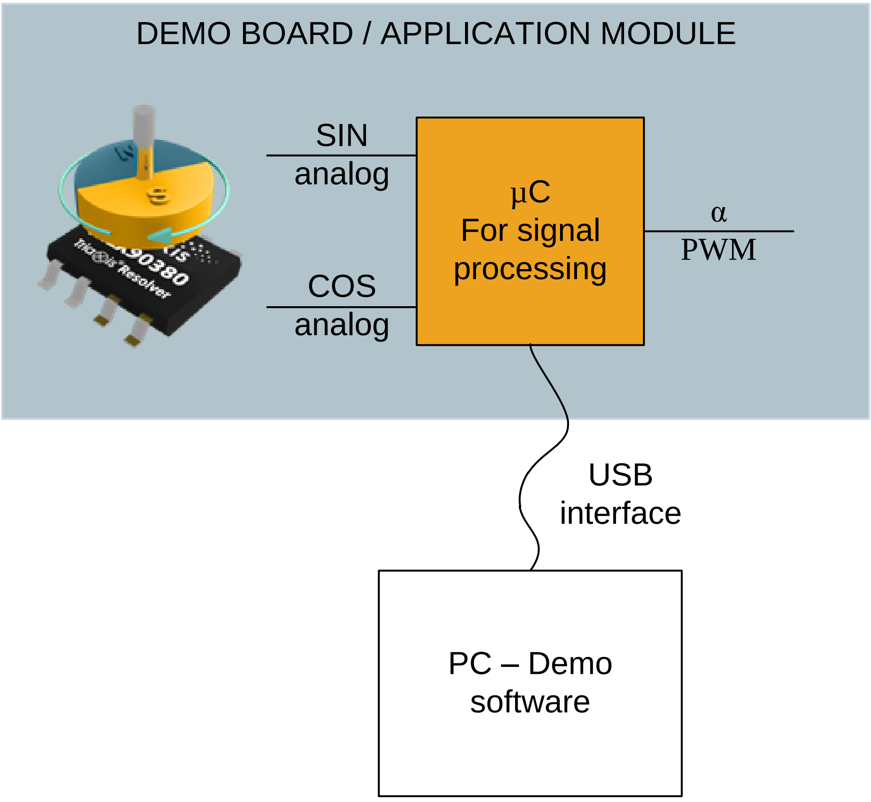


Figure 5: Interface mode

6.1. Software Package

MLX90380 user interface	Demo_Board_MLX90380_Concept_UI.xlsm
EVB Product Specific Functions library (dll)	PSF00TEVBAAMLX.exe

6.1.1.1. To install the software package

Run the installation of the PSF (double click on PSF00TEVBAAMLX.exe). Please follow the instructions to complete the installation.

6.1.1.2. When starting the software for the first time

Please follow the instructions:

- Connect the MLX90380 Resolver Demo Board if still not connected. If you are using the board for the first time, Windows will take some time to install the USB drivers.

- Open the Demo_Board_MLX90380_Concept_UI.xlsm excel sheet.

Go to the Connect to Demo Board and click on the connect button. When the connection is established you will get a message that the MLX90380 Resolver Demo Board has been found.

The software is now ready for work.

Note: The PSF library (dll) is a 32bit type library. This will run on a 32 bit or 64 bit operating system. But for the excel sheet to work you the 32bit Microsoft Office package installation on your PC. The 64bit excel version cannot connect with 32bit libraries.

6.2. User Interface Demo Board MLX90380

The excel UI has 5 sheets:

- MLX90380 Angle nonlinearity Theory

  In this sheet you will find an example on the different components of which the angle nonlinearity is build up and the technique to correct the angle nonlinearity. The chapter Angle Nonlinearity Theory – Front end description describes in more detail the different components of which the angle nonlinearity is build up.

- Connect to Demo Board

  This sheet is only used to establish a connection between the PC (excel sheet) and the MLX90380 Resolver Demo Board.

- DAQ + calculations

  In this sheet we demonstrate the simplified nonlinearity corrections technique which is also implemented in the companion Micro Controller of the MLX90380 Resolver Demo Board.

- Plot Results

  Plots with the results of the nonlinearity corrections

- DAQ plot

  This sheet contains a plot of the Data Acquisition from the MLX90380 Resolver Demo Board.

6.2.1. Connect to Demo Board

To establish a link between the PC and the PTC04:

- Connect the MLX90380 Resolver Demo Board if still not connected. If you are using the board for the first time, Windows will take some time to install the USB drivers.

Open the Demo_Board_MLX90380_Concept_UI.xlsm excel sheet.

Go to the Connect to Demo Board and click on the connect button. When the connection is established you will get a message that the MLX90380 Resolver Demo Board has been found.

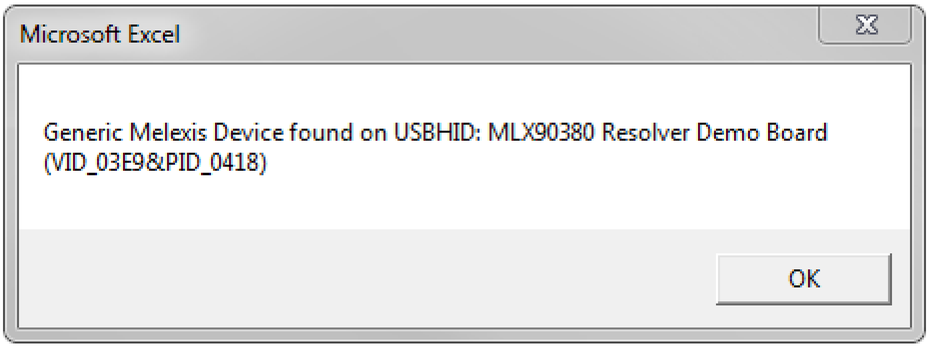


Figure 6: Successful connect to the demo board.

6.2.2. DAQ + calculations

On the sheet you will find 4 data block: DAQ raw data, Calculations of SMM and OMM, DAQ normalized data – recalculated w/ SMM and OMM and NLE (nonlinearity error).

Calculation of SMM and OMM			
OMM	1.5		Bit
SMM	0.655		%
SMM	1.007		Ratio
	OUT1	OUT2	
Span	768	763	Bit
Mean	511	509.5	Bit
Min	127	128	Bit
Max	895	891	Bit

Four measurements required for the MIN-MAX method

DAQ RAW DATA			
Angle	OUT1	OUT2	Radius
73.403	619	871	374.606
71.420	631	866	373.466
69.193	645	862	374.418
67.062	658	857	374.621
64.807	671	850	373.530
62.889	683	846	375.229

NLE
0.065
0.090
0.117
0.142
0.168
0.189

DAQ NORMALIZED DATA - RECALCULATED w/ SMM and OMM				
Angle	OUT1	OUT2	ATAN	Radius
73.469	108	364	1.282	379.558
71.509	120	359	1.248	378.369
69.310	134	355	1.210	379.270
67.205	147	350	1.173	379.411
64.975	160	343	1.134	378.239
63.078	172	339	1.101	379.875

On the left side you will find 4 buttons:

6.2.2.1. DAQ High Rate:

Is a high speed DAQ to be used for a high speed motor setup. The software captures 5000 raw ADC data samples in one block from the micro controller, processes the data for SMM and OMM in one block and updates the plots.

6.2.2.2. DAQ Medium Rate:

Is a medium speed DAQ to be used for a low speed motor setup or with the magnet knop delivered with the demo board. The software sends 500 measurements requests to the micro controller and processes the data for SMM and OMM in one block and updates the plots.

6.2.2.3. DAQ Low Rate:

Is low speed DAQ to be used with the magnet knop delivered with the demo board. The software sends 500 measurements requests to the micro controller and processes the data sample by sample for SMM and OMM. With each sample the plots are updated.

6.2.2.4. Single measurements:

To be used with the magnet knop delivered with the demo board. The software sends a single measurement requests to the micro controller and processes the data sample with the existing SMM and OMM data.

6.2.3. Plots Results

This sheet shows a plot of the raw data, the normalized data for sensitivity mismatch and offset mismatch and the nonlinearity compensation, the difference between raw and normalized data.

For the DAQ medium or low rate the measurements and plots are in volt. For the DAQ high rate the measurements and plots are binary ADC readings.

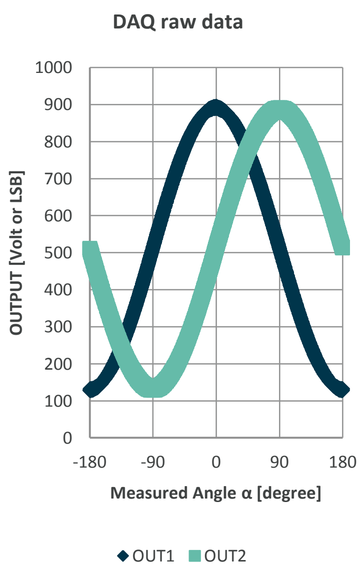


Figure 7: DAQ w/ ADC data

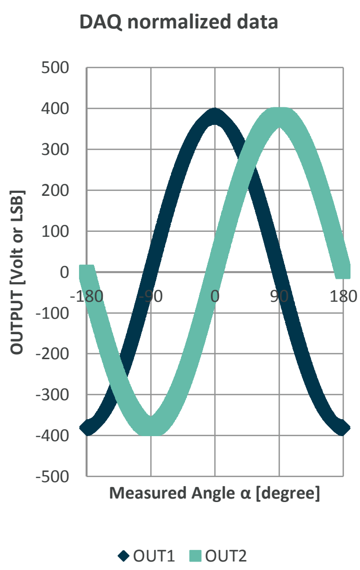


Figure 8: DAQ w/ ADC data

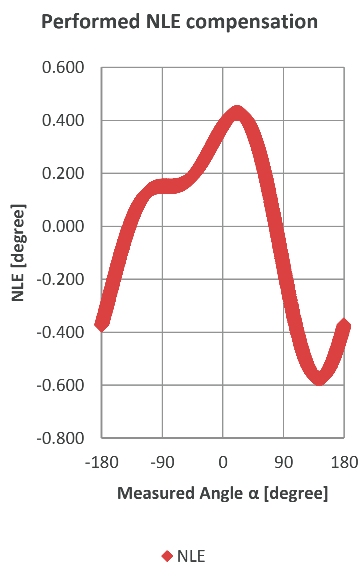


Figure 9: DAQ w/ ADC data

7. Angle Nonlinearity Theory – Front end description

7.1. Introduction

This section of the application note explains the different components of the angular nonlinearity.

It will help you understand how to calculate the total error budget of your application and the MLX90380, how to recognize the different nonlinearity components and how to correct/compensate the angular nonlinearity.

The MLX90380 is a monolithic sensor IC sensitive to the flux density applied orthogonally and parallel to the IC surface. The MLX90380 can sense the magnetic flux density in 3 directions: X-Y-Z.

The 2 outputs can be assigned to either X, Y or Z making the sensor compatibility with end-of-shaft and through-shaft magnetic configurations.

In this application note we mainly focus on the End of shaft (XY) application as it is demonstrated on the demo board. But the theory on the angular nonlinearity components also counts for the trough shaft (XZ or ZY) application.

More information on the axis configuration can be found in the datasheet of the MLX90380.

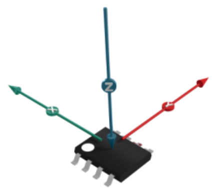


Figure 10: Intrinsic magnetic axis

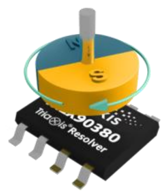


Figure 11: Option Code AAA-x0x

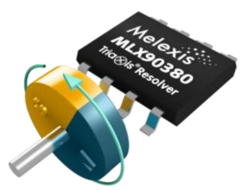


Figure 12: Option Code AAA-x1x

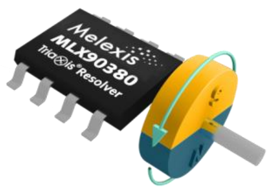


Figure 13: Option Code AAA-x2x

7.2. Description

As demonstrated above, the embedded micro controller or ECU of the module performs the signal processing on the angle information, the SIN/COS signal from the MLX90380. The angle α is calculated from the arctangent of SIN over COS:

$$\alpha = \arctan\left(\frac{SIN}{COS}\right) \text{ Or } \alpha = \arctan\left(\frac{OUT_2}{OUT_1}\right)$$

The sensors OUT_1 and OUT_2 output voltages are proportional to the applied magnetic field, the B_X and B_Y components of the magnetic field angle.

$OUT_1 = V_{OQ1} + S_1 * B_x$ and $OUT_2 = V_{OQ2} + S_2 * B_Y$.

Where:
V_{OQ} is the offset level of the analogue signal.
S is the sensitivity of the hall element times the gain of the amplifier (%VDD/mT).

So:

$$\alpha = \arctan\left(\frac{By}{Bx}\right)$$

To have the optimum linearity with respect to a magnet position α, the signals B_x and B_y: should be described as follows:

$$B_X \div \sin(90° - \alpha) \div \cos\alpha$$

$$B_Y \div \sin\alpha$$

In reality, they can be described according to the following formulas:

$$B_x = B_{x,0}(T) + A_x(\alpha)\sin(90° - \alpha + \beta)$$

$$B_y = B_{y,0}(T) + A_y(\alpha)\sin(\alpha)$$

Where:
T is the temperature.
B (T) X,0 is the component X offset (temperature dependent).
B (T) Y,0 is the component Y offset (temperature dependent).
β is the orthogonality error or phase error between the 2 components of the field.
A_X is the component X amplitude.
A_Y is the component Y amplitude.

The MLX90380 is pre-programmed by Melexis for a certain Magnetic/sensitivity range. So a very important step during final test is the magnetic calibration of the sensor. This calibration is performed at Melexis i.e. the S_1, S_2, Voq_1 and Voq_2 are calibrated for a minimum SMM and OMM at sensor level.

At module level remains a residual SMM and OMM of the sensor plus the none ideal behaviour B_X and B_y induced by B_{X0}, $B_{Y0,}$ $A_{X,}$ A_{Y+} and β.

Before the arctangent calculation, the ECU needs to perform some signal corrections to compensate the non-ideal behaviour of the sine and cosine signals.

Those non ideal behaviours can be split in four main categories:

Offset (B (T) X,0 ≠ 0, B (T) Y,0 ≠ 0)
Sensitivity Mismatch ($A_X \neq A_Y$)
Orthogonality Error ($\beta \neq 0$)
Signal Non Linearity ($A_X = A_X(\alpha)$ and $A_Y = A_Y(\alpha)$)

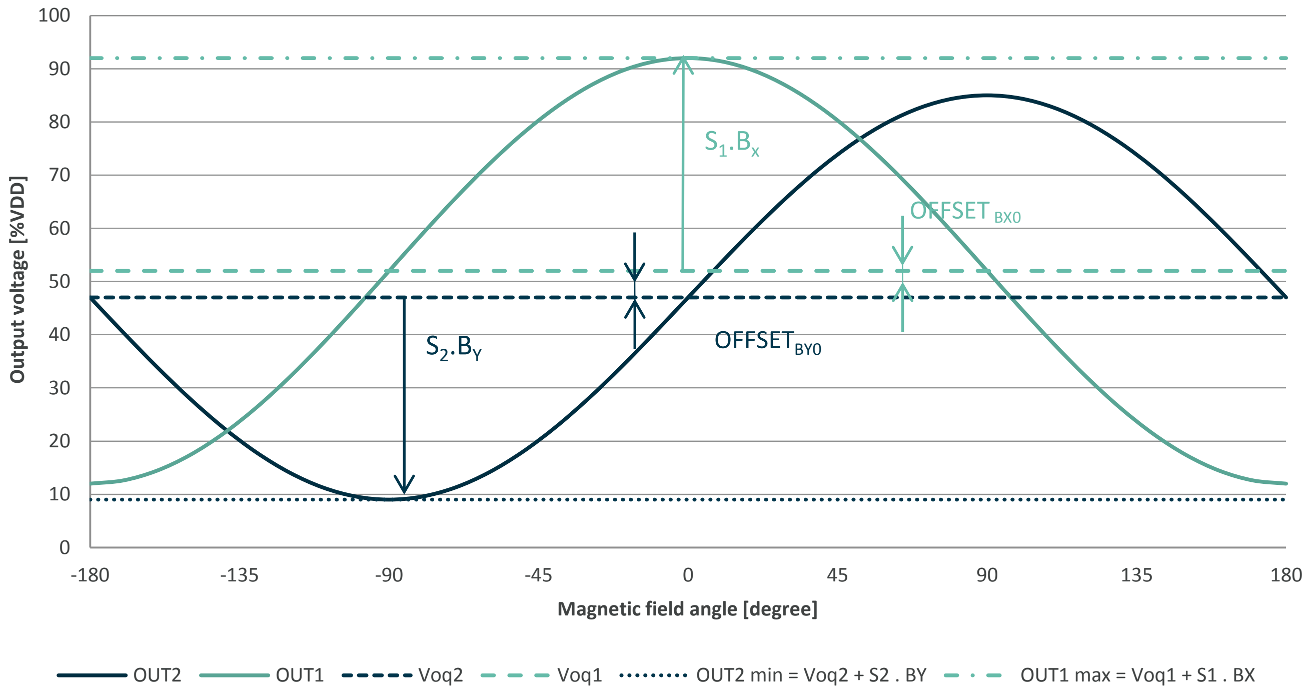


Figure 14: Non ideal behaviours of the sine and cosine signals

The non-ideal behaviour of the sine and cosine signals depends on the type of application, magnetic construction of the application and the magnetization of the magnet.

For end of shaft applications the non-ideal behaviours are relatively small as the flux density and the curve of the field lines remain fairly stable at the sensing point of the magnetic field angle while the magnet turns. “The sensor always measures the angle of the same field lines”.

For trough shaft applications the non-ideal behaviours are larger as the variation in flux density and the curve of the field lines are larger at the sensing point of the magnetic field angle while the magnet turns. “The sensor crosses different field lines”.

The following sections are critical in the use of the MLX90380 sensor, since they represent very useful information to anybody interested in improving the performance in term of angular nonlinearity.

7.3. Signal Phase Shift

The Signal Phase Shift error or PHI is a tracking delay between the B_X - B_Y components of the magnetic field and the analogue output signal, OUT_1 - OUT_2.

The tracking delay is determined by the Output Update Period and the bandwidth settings of the filter. The tracking delay T_{PHI} is a constant delay expressed in µSec. Please refer to the MLX90380 datasheet for the specifications of the tracking delay.

The signal phase shift error PHI is the absolute angle offset error (Magnet angle vs. Sensors output angle) in function of the magnet rotation speed.

$$a_0 = T_{PHI} * RPM / 166666.6667$$

Figure 15 shows the phase shift error for 25, 250, 2500 and 25000RPM for high bandwidth.

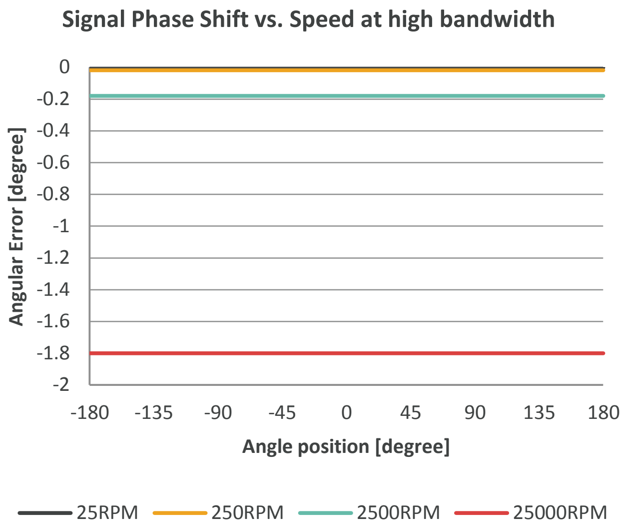


Figure 15: Phase shift vs. rotation speed

7.4. Orthogonality

The orthogonality error, also called the quadrature error, is a phase error between the sine and cosine signals, OUT_2 and OUT_1. This means that the phase separation of these two signals is not exactly 90 degrees.

The figure below shows the effect on the nonlinearity error (the angular error is equal to the phase error). It translates into a double-period signal like the sensitivity mismatch error but in this case it is unipolar, either positive or negative depending on the rotation direction of the magnet (CW or CCW) and the assignment of sine and cosine to OUT_2 and OUT_1 of the MLX90380 sensor.

The phase delay between the OUT_2 and OUT_1 signal T_{orth} is a constant of 2µS.

$$a_4 = T_{orth} * RPM / 166666.6667$$

$$a_4 * Cos(\alpha)^2$$

Figure 16 shows the Orthogonality error for 25, 250, 2500 and 25000RPM

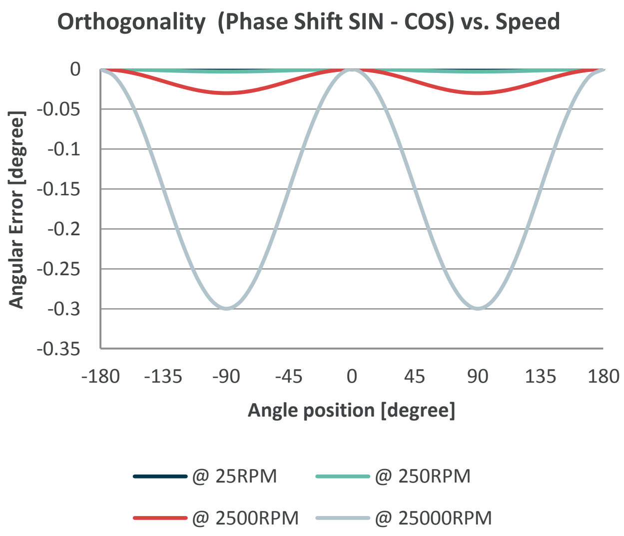


Figure 16: Orthogonality vs. rotation speed

7.5. Offset Mismatch

Though the on-chip dynamic offset cancellation mechanism (Hall plate quadrature spinning and chopper stabilized amplifier) and the calibration of the signal offset OUT_2 and OUT_1 (V_{OQ1} = V_{OQ2} = 50%VDD), the analogue signals may show a residual offset and an offset of the magnetic design.

Figure 17 and Figure 18 show the influence of the offset error (OMM vs. 50%VDD) on the angular nonlinearity for various values of OMM= 0.2, 0.5, 1, 1.5 and 2.5 %VDD. The signature of the offset error is one period over 360 degrees, i.e.

$$a_1 * Sin(\alpha) \quad \text{and} \quad a_2 * Cos(\alpha)$$

Figure 19 shows the angle nonlinearity when both OUT_1 and OUT_2 have an offset error.

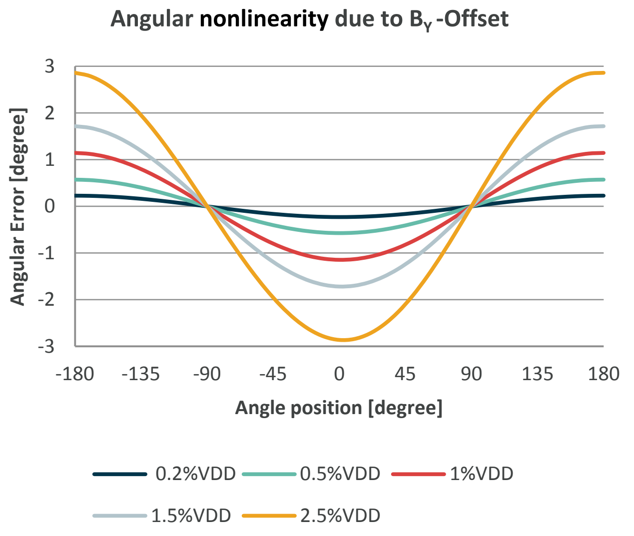


Figure 17: Offset on B_Y

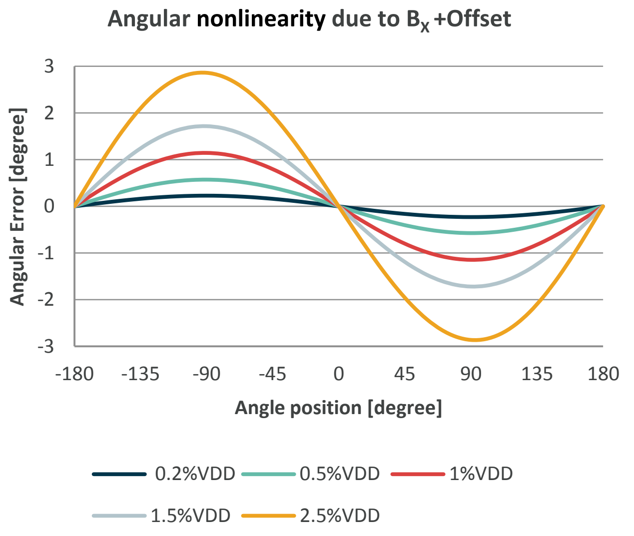


Figure 18: Offset on B_X

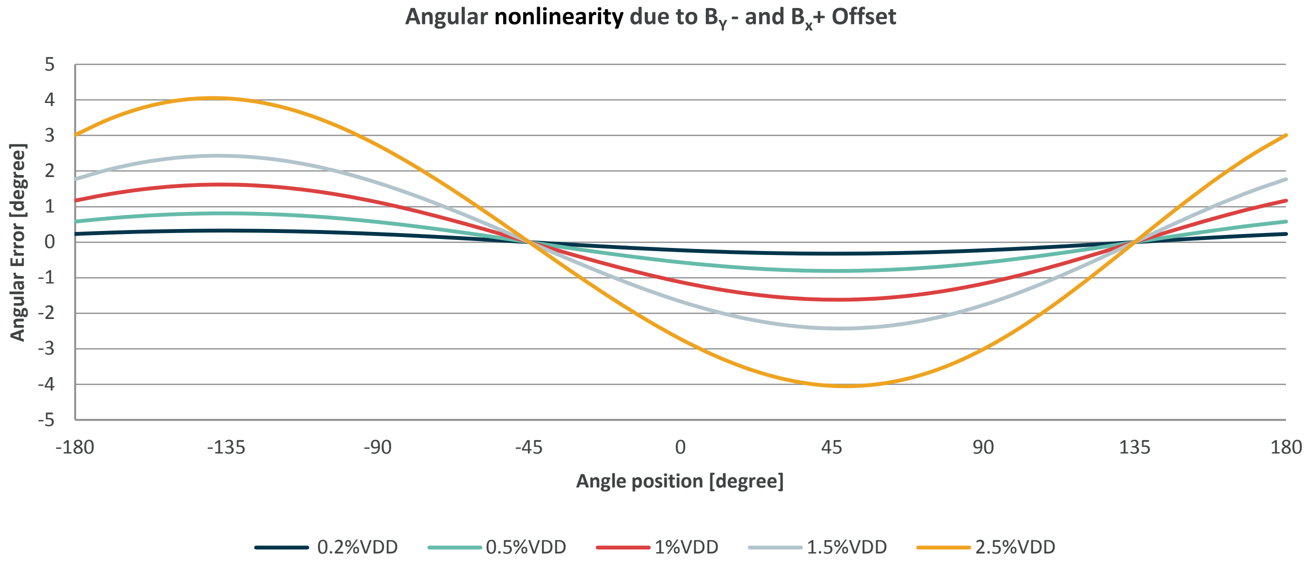


Figure 19: Offset on B_X and B_Y

7.6. Sensitivity Mismatch

The sensitivity mismatch depends on the selected magnetic axis configuration (see option code of the sensor) and the type of application. See illustration in Figure 20 and Figure 21.

7.6.1. End of shaft applications B_x - B_y

(Option code: BAx-x0x)

For end of shaft applications the (sensitivity mismatch) amplitude mismatch of B_X - B_Y components is relatively small as the flux density and the curve of the field lines remain fairly stable at the sensing point of the magnetic field angle while the magnet turns. “The sensor always measures the angle of the same field lines”.

7.6.2. Trough shaft applications B_x or B_y - B_z

(Option code: BAx-x1x or BAx-x2x)

For trough shaft applications the (sensitivity mismatch) amplitude mismatch of B_X - B_Y components is larger as the variation in flux density and the curve of the field lines are larger at the sensing point of the magnetic field angle while the magnet turns. “The sensor crosses different field lines”.

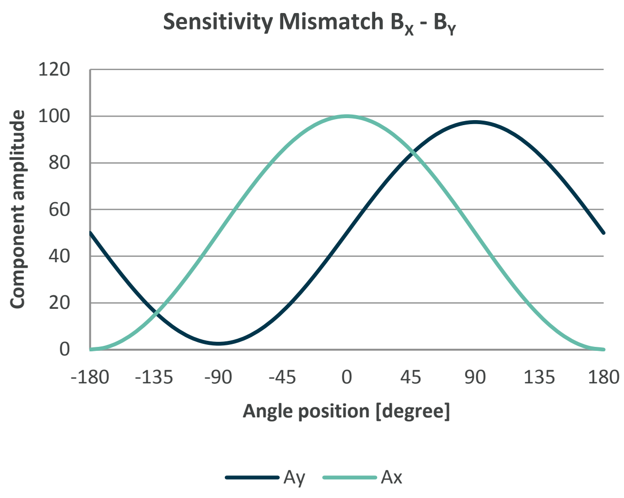


Figure 20: Sensitivity Mismatch AAA-x0x

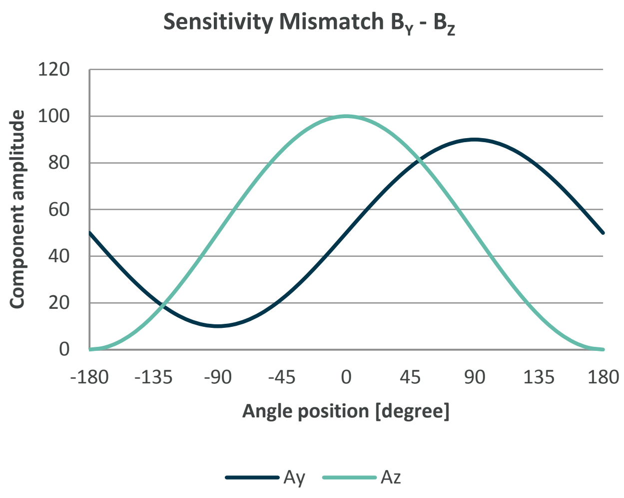


Figure 21: Sensitivity Mismatch AAA-x1x or -x2x

Next to the amplitude mismatch of B_X - B_Y components, there is also a residual sensitivity mismatch of the two output signals of the sensor. Although all Hall signals (Vx, Vy and Vz) are generated by matched Hall Plates and amplified though a calibrated amplification chain, the two signals may show a residual difference in amplitude. The three main reasons for this mismatch are the non-perfect alignment of the Integrated Magneto Concentrator (IMC) with respect to the Hall Plates constellation, a difference between the sensitivity of the different Triaxis® Hall Plates and the application dependant absence/presence of the IMG magnetic gain.

An illustration of the amplitudes mismatch impact on angle nonlinearity is shown in Figure 22 and Figure 23. The signature is a double period and bipolar over 360 degrees, i.e. The thermal variation of sensitivity mismatch is negligible.

$$\text{a3} * \ Sin(2 * \alpha).$$

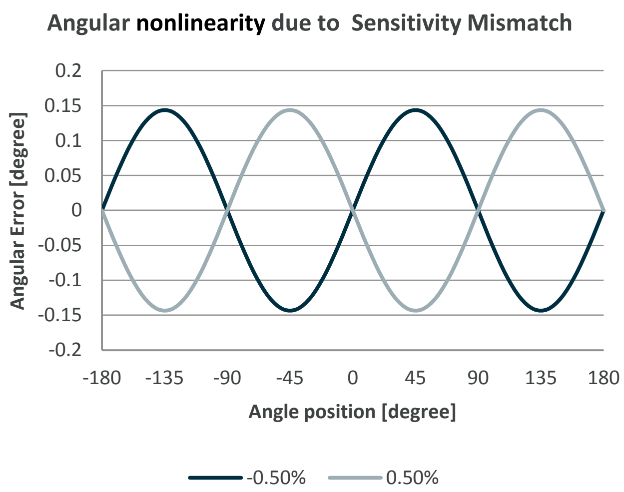


Figure 22: Angle nonlinearity due to sensitivity Mismatch

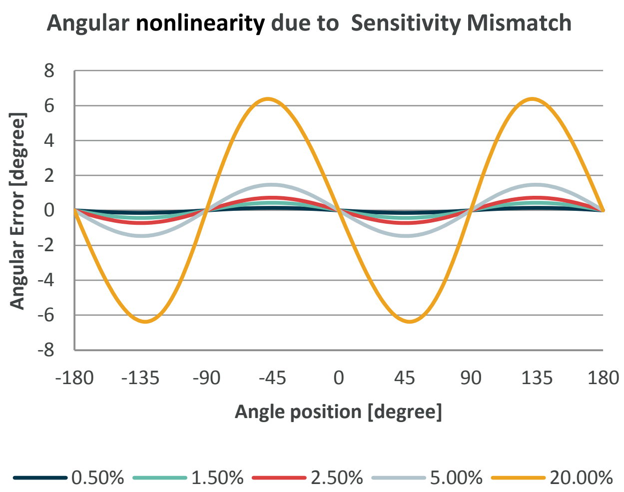


Figure 23: Angle nonlinearity due to sensitivity Mismatch

7.7. Signal Nonlinearity

In normal operation, the signal non linearity is negligible. Its signature is easily recognizable: four periods over 360 degrees, i.e.

$$a_5 * \mathrm{Sin}\,(4*\alpha\,)$$

There are three sources of nonlinearity, i.e. the magnetic saturation, the applied field on the IMC location in X or Y direction is greater than 70mT, electrical saturation, the gain of the sensor is set to high for the applied magnetics flux density, and the nonlinearity of the two output amplifiers.

Figure 24 and Figure 25 illustrate an (exaggerated) electrical saturation of the output signals and the resulting angle nonlinearity.

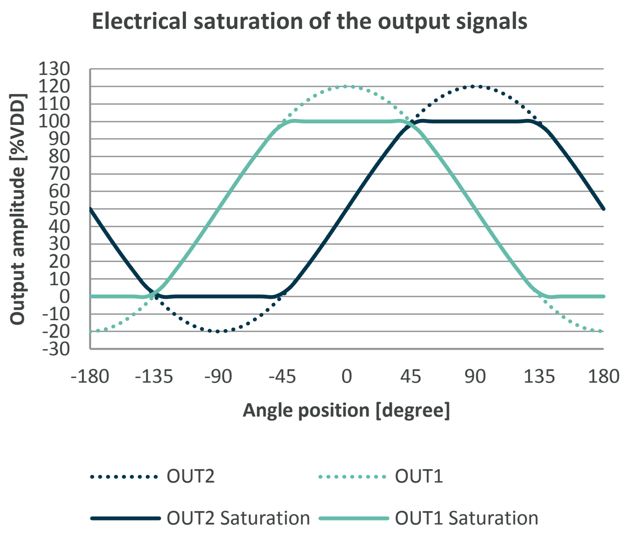


Figure 24: Electrical output signal saturation

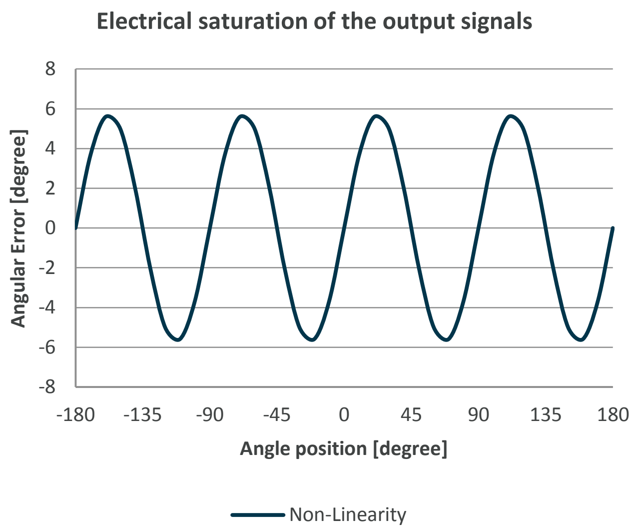


Figure 25: Angle nonlinearity due to signal saturation.

8. Angle Nonlinearity Correction – Front end calibration

This chapter explains how to determine the MLX90380 front-end correction parameters such as offset, SMM and orth. There are different methods to find the optimum values for the correction parameters, which are explained in more detail in the next sections.

The calculations are demonstrate in the sheet MLX90380 Angle NLE Theory of the Demo_Board_MLX90380_Concept_UI.xlsm

8.1. Least-Square Linear Fit method

This technique requires a full rotation of the magnet with an absolute angle reference for the least-square linear fit calculation. This method calculates SMM, OMM, ORTH, PHI based on measurements. To analyse the linearity error we first calculate the NLE as α_{90380} - α_{magnet} (sensor angle – reference angle).

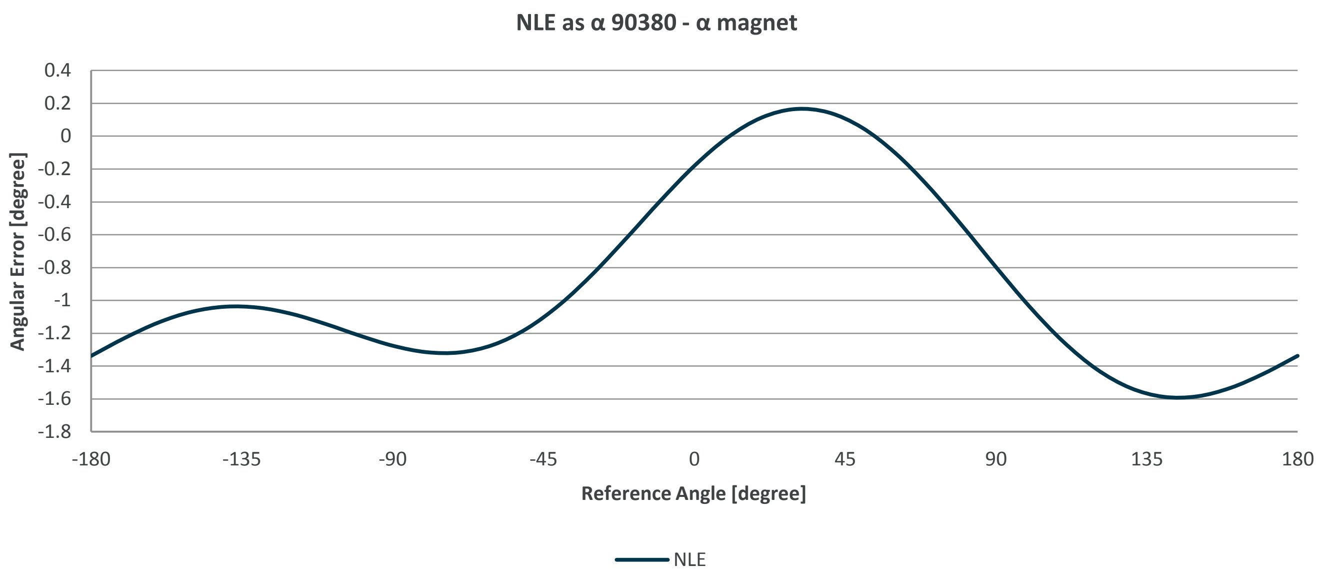


Figure 26: Calculate Nonlinearity Error

Secondly we find the basic components from the nonlinearity error using a general LS Linear Fit, which finds the k-dimension linear curve values and the set of k-dimension linear fit coefficients, which describe the k-dimension linear curve that best represents the input data set using the least-squares solution...

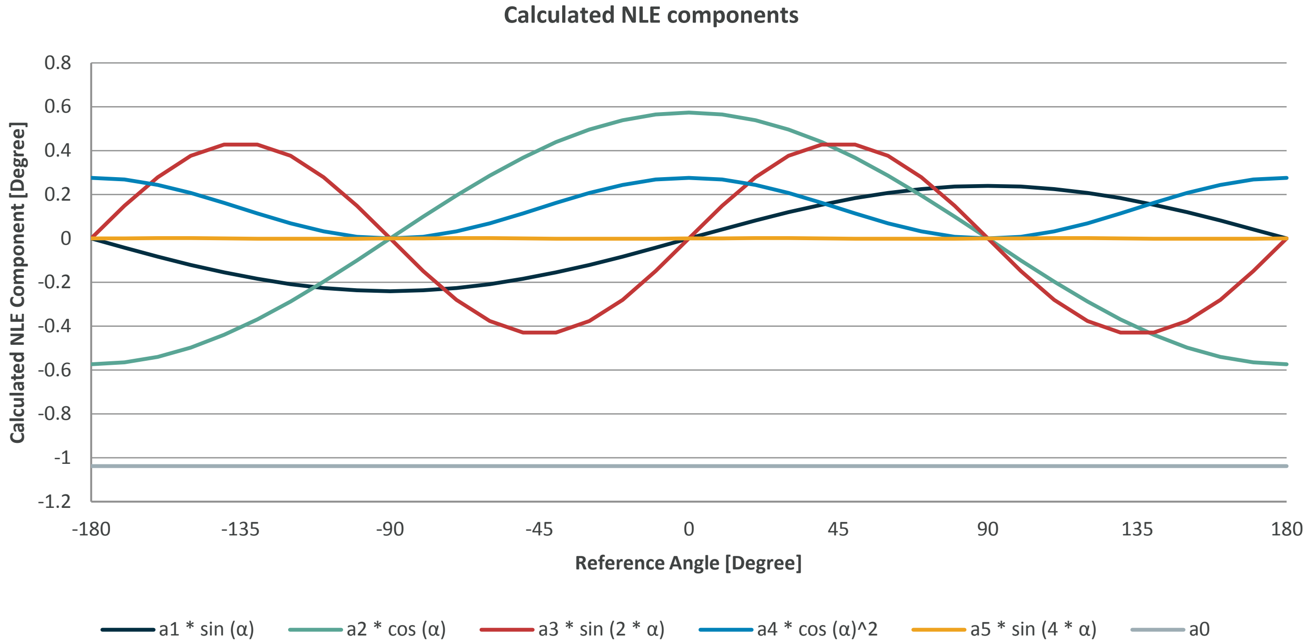


Figure 27: Calculated Nonlinearity Error components

The purpose is to find the set of least square coefficients "a" that best represent the set of data points (α_m,NLE). The relationship between α_m and NLE is of the form:

NLE = $a_0 + a_1 * Sin\ (\alpha) + a_2 * Cos\ (\alpha) + a_3 * Sin\ (2 * \alpha) + a_4 * Cos\ (\alpha)^2 + a_5 * Sin\ (4 * \alpha)$

Where:
a_0 = absolute angle offset error (Phase Shift vs. absolute 0 degree position)
a_1 = amplitude of error created by Offset BX
a_2 = amplitude of error created by Offset BY
a_3 = amplitude of error created by SMM
a_4 = amplitude of error created by ORT
a_5 = amplitude of error created by signal non linearity

8.2. Min-Max method

The technique requires a full rotation of the magnet with or without an absolute angle reference.

The SMM and OMM are calculated based on measurements. The Phase shift and Orthogonality error are corrected with the theoretical constant from the formulas explained in the front end description above.

This method basically normalizes two signals by matching the SPAN and the OFFSET of the two signals.

The span of the OUT2 is corrected to match the SPAN of OUT1. The OFFSET of each signal is normalized to zero. It is a Simple technique which only requires four measurements.

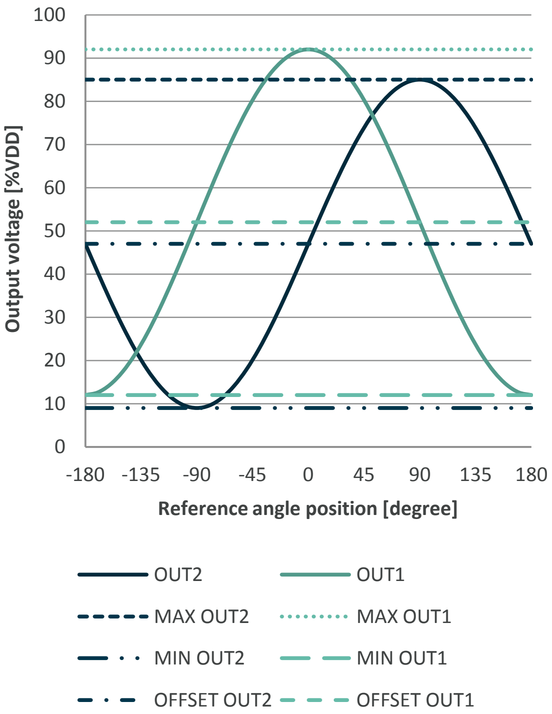


Figure 28: Raw data

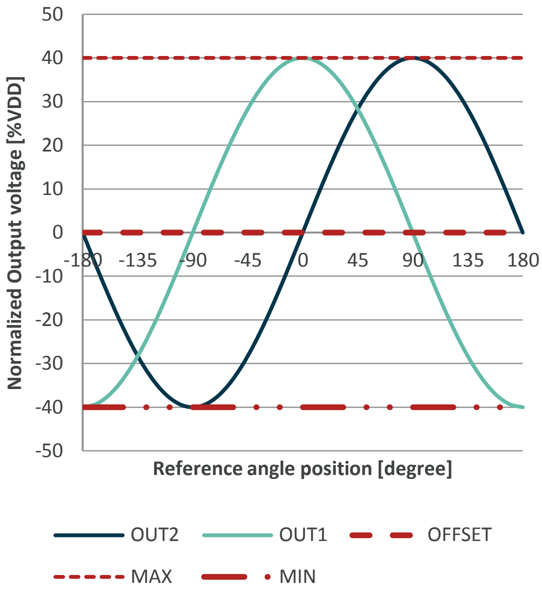


Figure 29: Normalized data

For the calculation of the sensitivity mismatch and the offset mismatch we need to measure the MIN and MAX output level of the two output signals (Marked in orange).

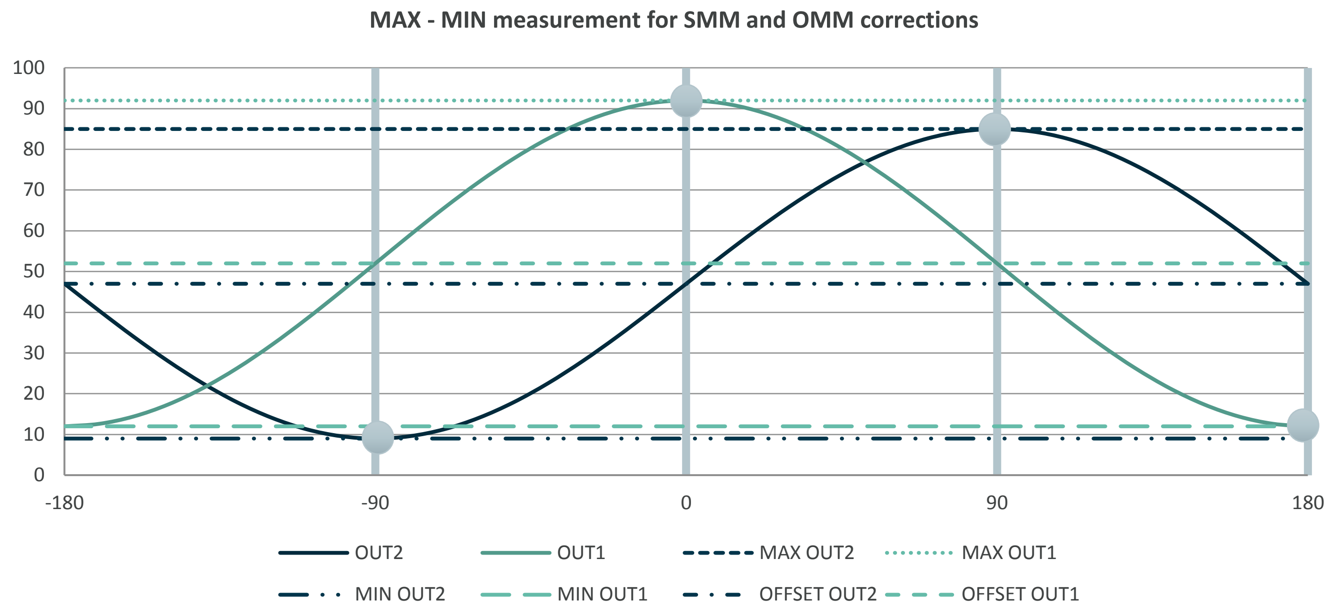


Figure 30: Only four measurements are required

There are two techniques to obtain the measurements.

8.2.1. Absolute positioning

With an absolute angle reference, four fix angles positioned at 0, 90, 180, 270 (or -90) degree are measured. For the measurement, an accurate reference angle is important to ensure that the actual MIN and MAX level is measured.

8.2.2. Min-Max tracking via data acquisition

The DAQ technique searches for the MIN-MAX level of the two output signals.

While the magnet turns the micro controller or DAQ setup keeps track on the SIN/COS signal and extracts the MIN and MAX level of OUT1 and OUT2.

This method can also be performed by the micro controller start-up as demonstrated by the evaluation / demonstration board or on the fly.

At start-up the µC searches the MIN-MAX levels of the two output signals. After one full 360 degree turn of the magnet, all data is collected to start the signal corrections to normalize both output signals. This allows the µC to perform dynamic angle corrections in the application.

8.2.3. Calculation

Sensitivity mismatch:

$$SMM = \frac{S_2 * B_Y}{S_1 * B_X} = \frac{SPAN_{OUT2}}{SPAN_{OUT1}}$$

Where:
$SPAN_{OUT1} = MAX_{OUT1} - MIN_{OUT1}$
$SPAN_{OUT2} = MAX_{OUT2} - MIN_{OUT2}$

Offset mismatch:

$$OFFSET_{OUT1} = \frac{(MAX_{OUT1} + MIN_{OUT1})}{2}$$

$$OFFSET_{OUT2} = \frac{(MAX_{OUT2} + MIN_{OUT2})}{2}$$

The angle α is calculated from the arctangent of SIN over COS:

$$\alpha = ATAN2\left(\frac{SIN}{COS}\right)$$

Where:
$SIN = (OUT2 - OFFSET_{OUT2}) * SMM$
$COS = OUT1 - OFFSET_{OUT1}$

If desired the angle α can be corrected for Phase shift and Orthogonality with the theoretical constant for the nominal speed of the application:

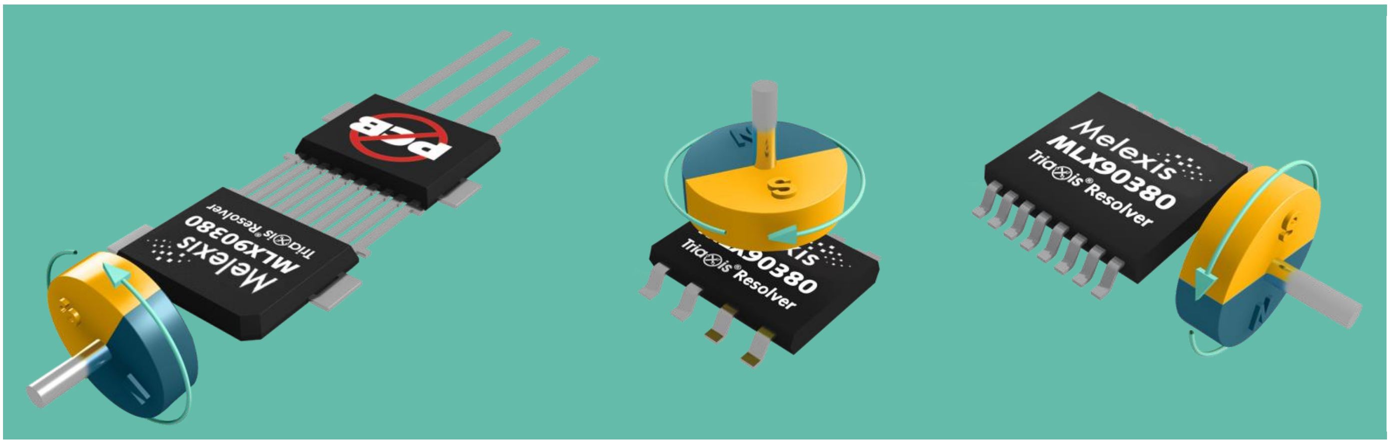
Phase shift:

$$\alpha_0 = a_0 = T_{PHI} * RPM / 166666.6667$$

Orthogonality:

$$a_4 = T_{ORTH} * RPM / 166666.6667$$

$$\alpha_4 = a_4 * Cos2(\alpha)$$



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