Contents

1. Introduction

The back end calibration is a feature of the Triaxis position sensors that allows the user to compensate for non-linearity error in the application, improving the linearity performance. It consists of defining a transfer function between the sensor's measurements (after front end error compensation) and the output. Consequently, it defines the behavior of the output vs the magnet position in the application. This is done as part of the End-of-Line programming of the sensor. Different Triaxis products allow for different types of back end calibration methods. Also, the way a certain method works may vary between the different Triaxis generations. Therefore, the purpose of this document is to help the user select the appropriate sensor and method for their application. Note, however, that this guide is dedicated to the calibration methods typically used in rotary or linear displacement applications. Different methods are available for joystick applications, but those are beyond the scope of this document.

2. Calibration Methods

The Triaxis position sensors currently offer four different calibration methods. In general, all methods consist of storing a set of values in the sensor's non-volatile memory which will be used to convert the sensor's angle measurement into an output in %VDD (analog), % duty cycle (PWM) or LSB (SENT or PSI5). This chapter presents an overview of these methods.

2.1. 4-point Calibration

2.1.1. Description

The first generation of Triaxis devices offered a 3 points / 4-slope calibration. With the launch of MLX90360 Melexis introduced a 4 points / 5-slope calibration. It allows the user to define the output transfer curve through a combination of points and slopes. To do so, the user should move the magnet in the application to a number of positions and set the target output for each using the software library provided by Melexis. Depending on the generation the user has the ability to program positive and negative slopes per point, e.g. MLX90316-BCG offers a negative and positive slope **only** for slope C whilst all other slopes per point must be positive. Later generations offer both options per point.

Not all of the points have to be set by the user. Customers looking for better nonlinearity compensation should use at least three calibration points. Customers looking for a cost-effective calibration set-up and shorter calibration time will prefer two-point calibrations. However, the above statement is to be taken into consideration together with the desired angle range i.e. within small-angle ranges 2-points calibration can be as effective as e.g. 3 points or 4 points calibration.

The calibration points can be placed anywhere, which means the user can achieve a better linearization by placing the points where the non-linearity is the highest, as shown in Figure 1. One might notice two extra points in this figure, these are called virtual points. It's the first and last point and they are used typically by the solver to calculate LNR_S0 and LNR_D_S (or LNR_C_S in case of 3 points).

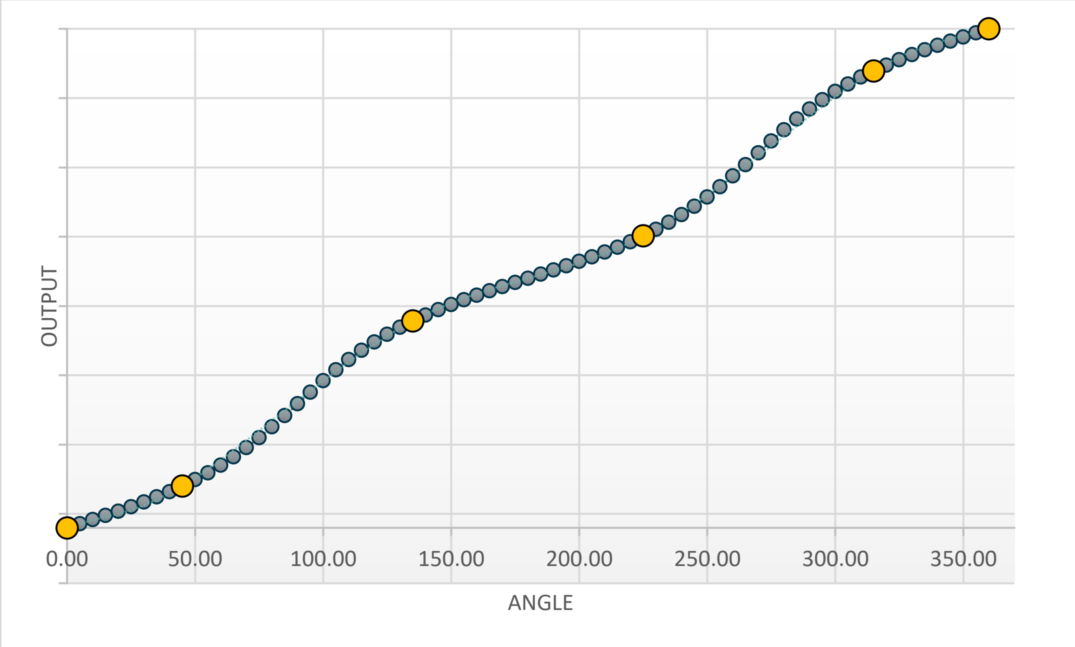

Figure 1 Example of Non-Linearity Error before 4-point calibration; Blue curve resembles the measured angle by the sensor: reality (nonlinear behavior coming from magnet or system); Yellow points resemble the calibration points. First and last points are virtual points typical used by the solver to calculate the first and last slope

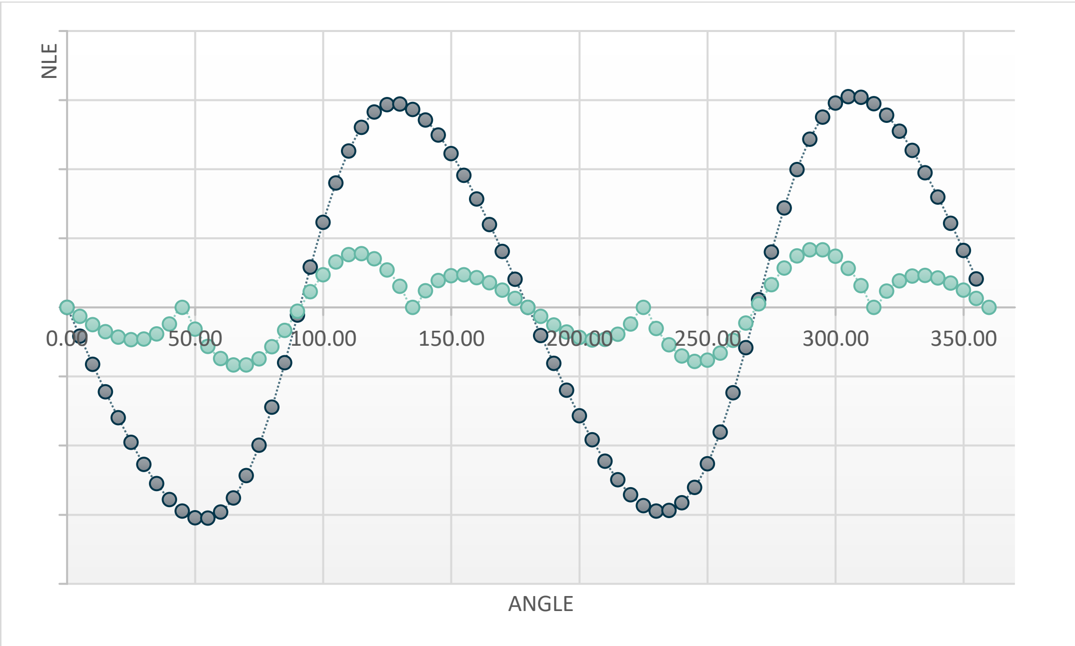

Figure 2 Example of residual error after 4-point calibration. Blue resembles the error without back-end calibration; Green resembles the error after 4 points calibration.

This method can also be used to define transfer curves with different shapes, including discontinuities (e.g. a saw-tooth curve, take note that enable scaling must be set for defining "negative" output values) as shown in Figure 3, by setting the slopes independently from the points. Not applicable to Gen I. Triaxis. For more information, please consult the datasheet.

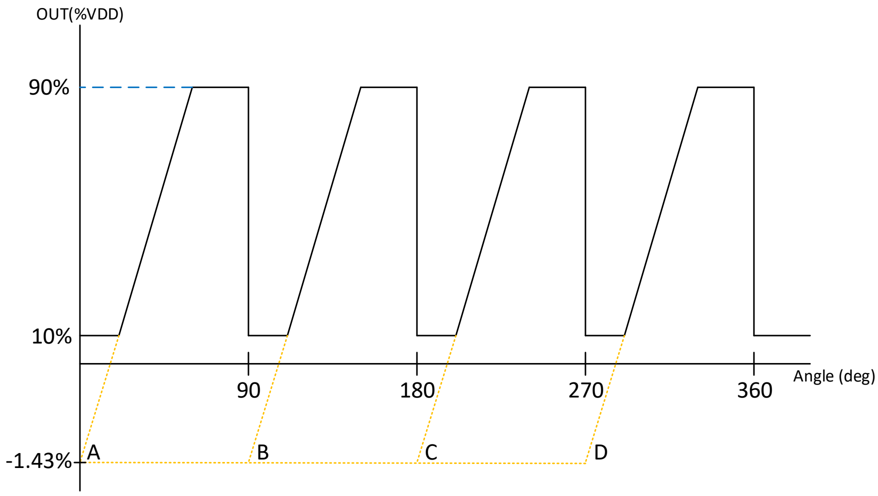

Figure 3 Example of the output transfer curve that can be defined with the 4-points calibration

2.1.2. Typical applications

Typical applications include (but are not limited to):

- Electronic Throttle Body with 2-point calibration;
- Ride height sensors;
- Accelerator pedals;
- Linear actuators;
- Linear displacement applications with limited stroke;

2.2. 8-point Calibration

2.2.1. Description

The 8-point calibration method was introduced in the third Triaxis generation (MLX037x) and is very similar to the 4-point method. It allows the user to define up to 8 calibration points, also in arbitrary positions. However, the user cannot define the slopes independently, so the segments between two points are only calculated by linear interpolation. Different from the 4-point calibration is that the two virtual points are fixed at VP1{0,0%} and VP2{360,100%}. For more information please consult the datasheet.
Having a greater number of calibration points, combined with the freedom to place the points anywhere, this method allows the user to achieve a better linearity performance, as shown in Figure 4.

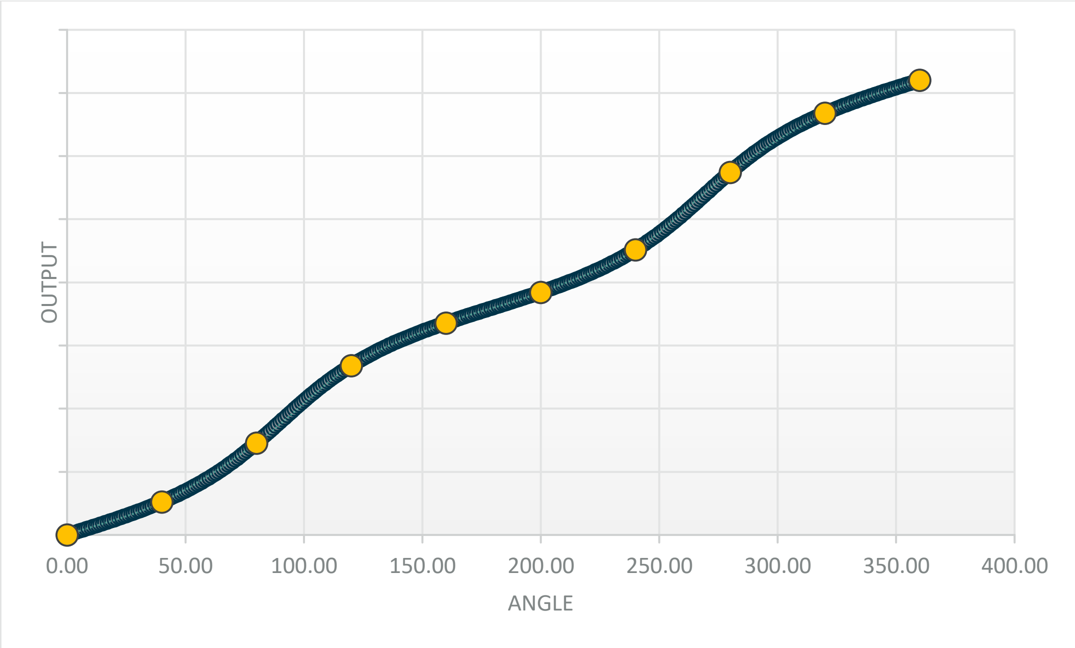

Figure 4 Example of Non-Linearity Error before 8-point calibration; Blue curve resembles the measured angle by the sensor: reality (nonlinear behavior coming from magnet or system); Yellow points resemble the calibration points. The first and last points are virtual points fixed by the sensor.

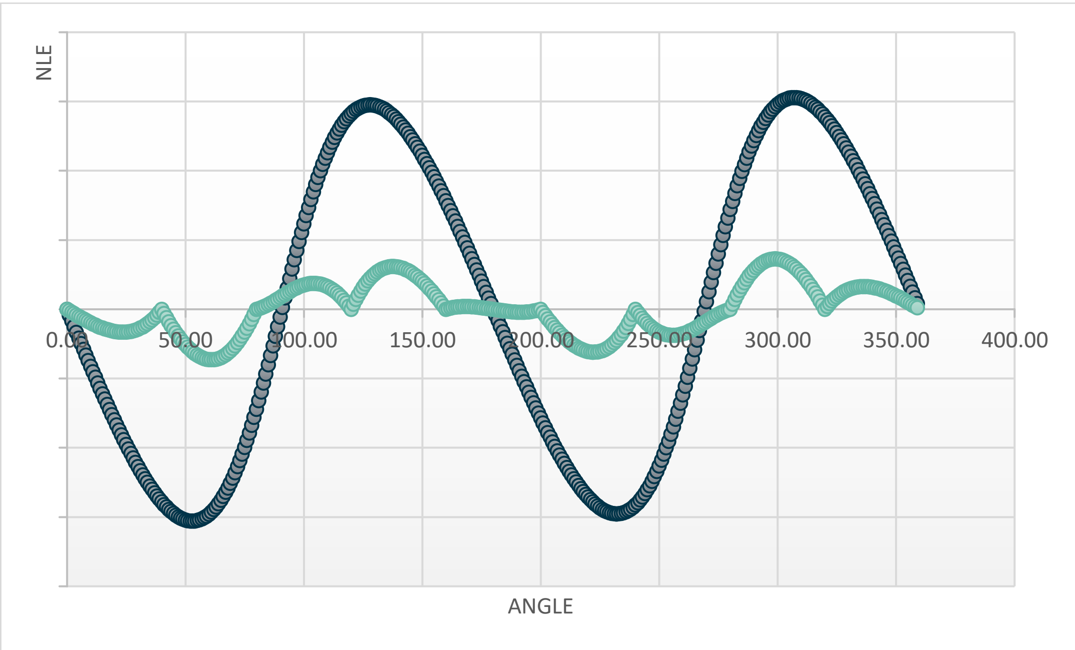

Figure 5 Example of residual error after 8-point calibration. Blue resembles the error without back-end calibration; Green resembles the error after 8 points calibration

2.2.2. Typical applications

Typical applications are the same as listed in paragraph 2.1.2

2.3. 16 / 17-point Calibration

2.3.1. Description

The 17-point calibration method (equal to 16 segments and sometimes also referred to as 16-points calibration) has also been available since the first Triaxis generation (including MLX90324, excluding MLX90316). It allows for a better linearity performance when compared to the previous methods, as shown in Figure 4.

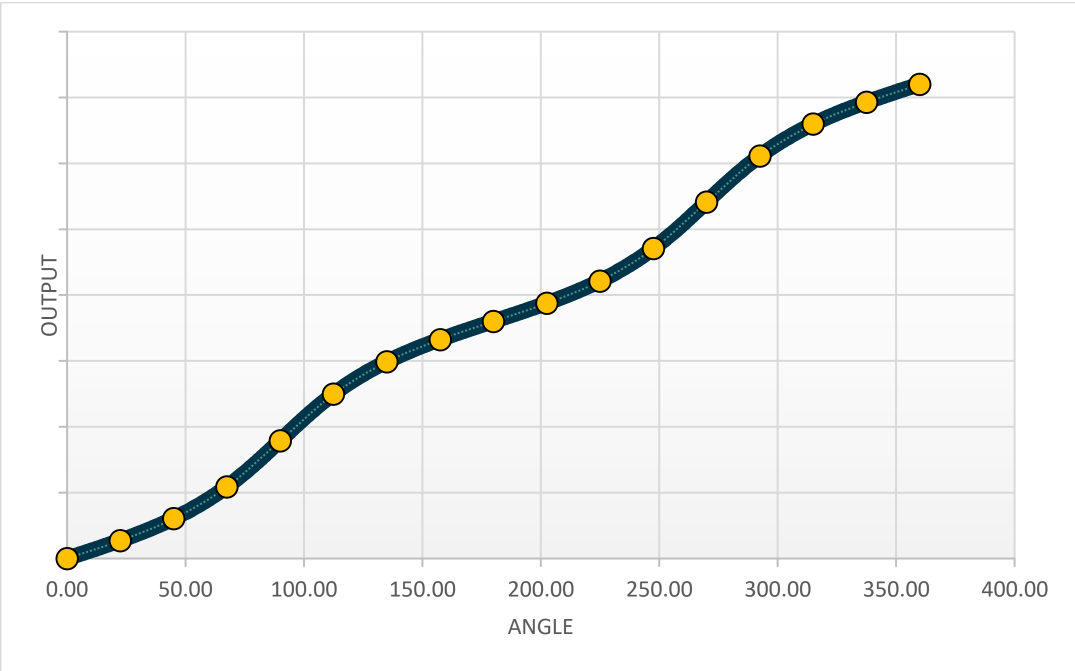

Figure 6 Example of Non-Linearity Error before 17-point calibration. Blue curve resembles the measured angle by the sensor: reality (nonlinear behavior coming from magnet or system); Yellow points resemble the calibration points.

In this method, the transfer curve is defined by 17-points, which are equidistantly spread over the angular working range of the sensor and do not requires any storage space inside the sensor. Between the equidistant distance of sensor angles points, linear interpolation is performed.

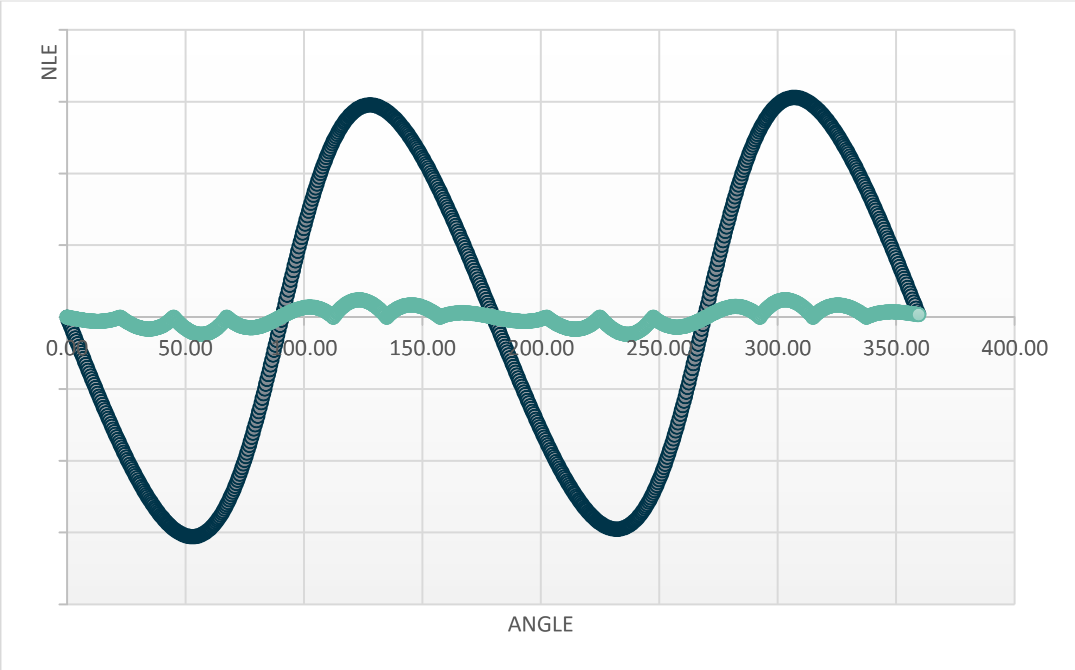

Figure 7 Example of residual error after 17-point equidistant calibration. Blue resembles the error without back-end calibration; Green resembles the error after 17 points calibration.

For the MLX90423, this 17-point calibration method with equidistant points has been adapted to 16 arbitrary points. This allows the user to place 16 points anywhere and can achieve a better linearity performance, as illustrated in fig 9 vs fig 7. The optimized positions of the 16 points are shown in fig 8, where more points are located in the less linear parts of the initial curve and fewer points in the more linear part of the curve.

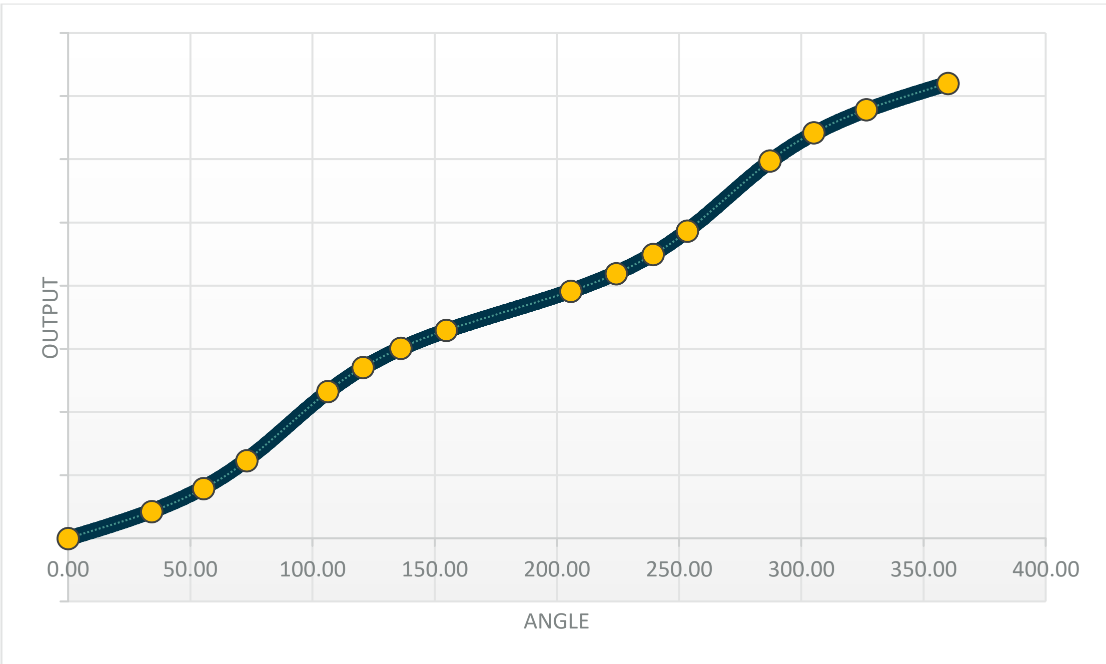

Figure 8 Example of Non-Linearity Error before 16-point calibration. Blue curve resembles the measured angle by the sensor: reality (nonlinear behavior coming from magnet or system); Yellow points resemble the arbitrary calibration points.

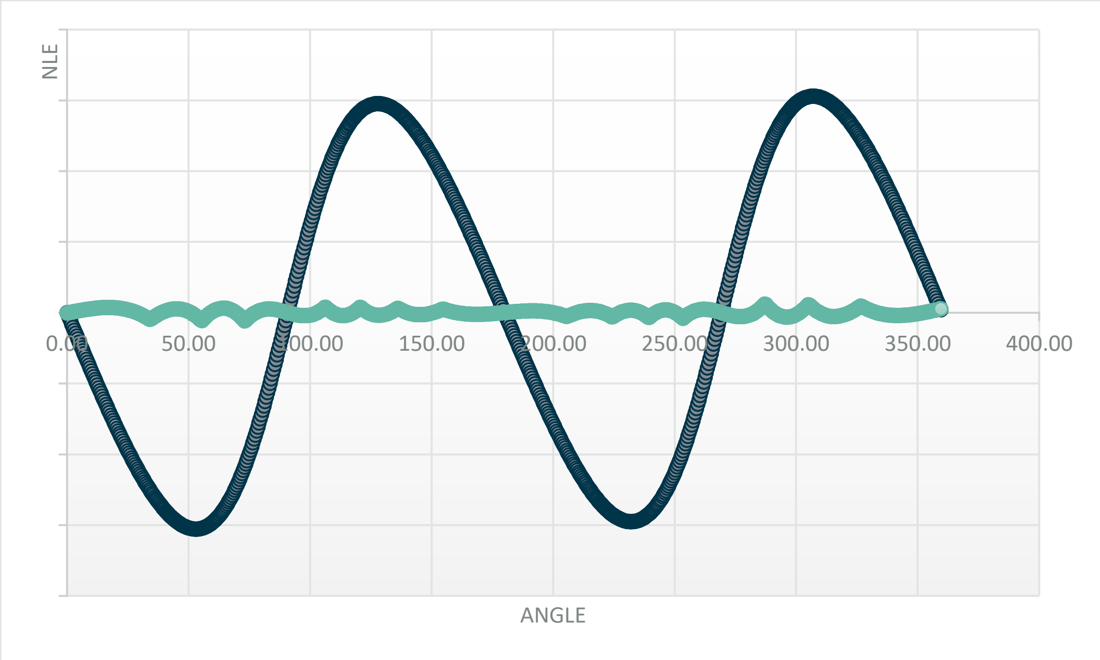

Figure 9 Example of residual error after 16-point arbitrary calibration. Blue resembles the error without back-end calibration; Green resembles the error after 16 points calibration.

There are typically two ways to define the points. The first is to enter the calibration points using the dedicated solver, which is a part of the software library provided by Melexis. In this case, the targets entered by the user are either directly stored in the memory (only for MLX90423) or are interpolated in order to determine the equivalent targets at the equidistant angles. In case of the interpolation, the user can enter as many calibration points as desired, and this will affect the calibration time as well as the linearity performance.

The second way to determine the points is to pre-program the sensor with a default output characteristic, and then characterize the output by comparing it with a reference encoder. Afterwards, the 16/17 points for the piecewise linear approximation function of the correction curve can be directly calculated and stored in the memory. This method is less simple to implement but allows for faster calibration, suitable for production timing.

2.3.2. Typical applications

Typical applications include (but are not limited to):

- Through-shaft rotary applications;
- Rotary knob selector;
- Linear displacement applications with long strokes;

2.4. 32-point Calibration

2.4.1. Description

The 32-point calibration method was introduced in the third Triaxis generation (MLX9037x) and is very similar to the 17-point method. However, by having twice as many points, it allows for an even better linearity performance, as shown in **Figure 10**.

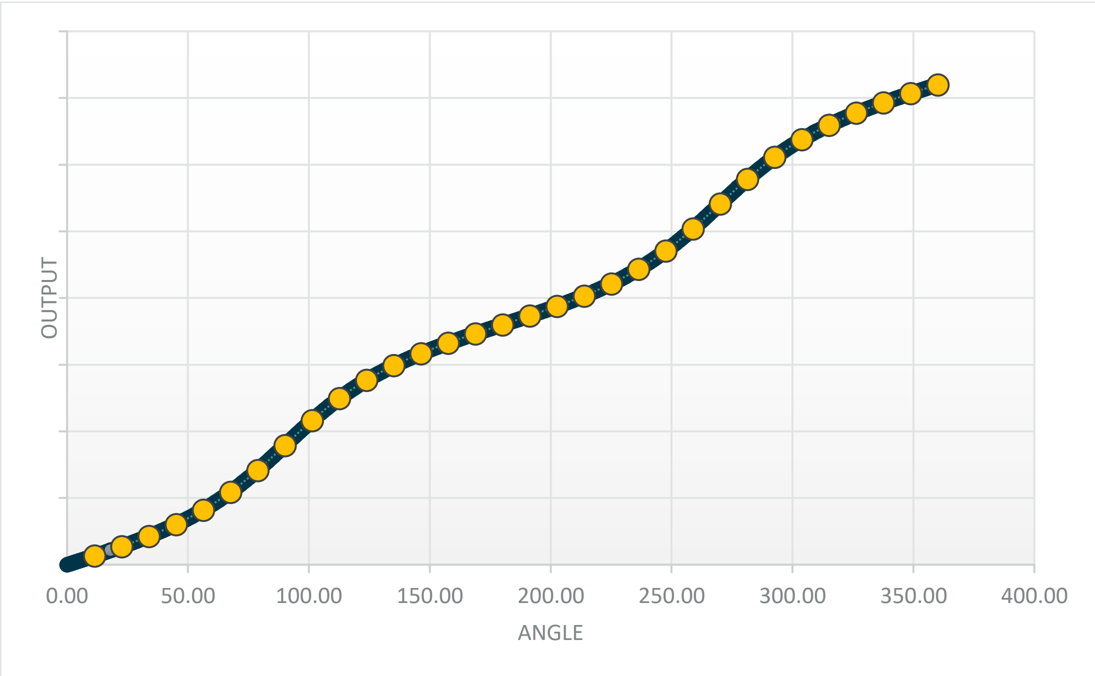

Figure 10 Example of Non-Linearity Error before 32-point calibration. Blue curve resembles the measured angle by the sensor: reality (nonlinear behavior coming from magnet or system); Yellow points resemble the calibration points

In the 32-point method, the points are also equidistantly spread over the angular working range of the sensor. Just as the 17-point method, this method also offers two ways to define the points, one using the dedicated solver and the other calculating the points directly by comparing the sensor's output to a reference.

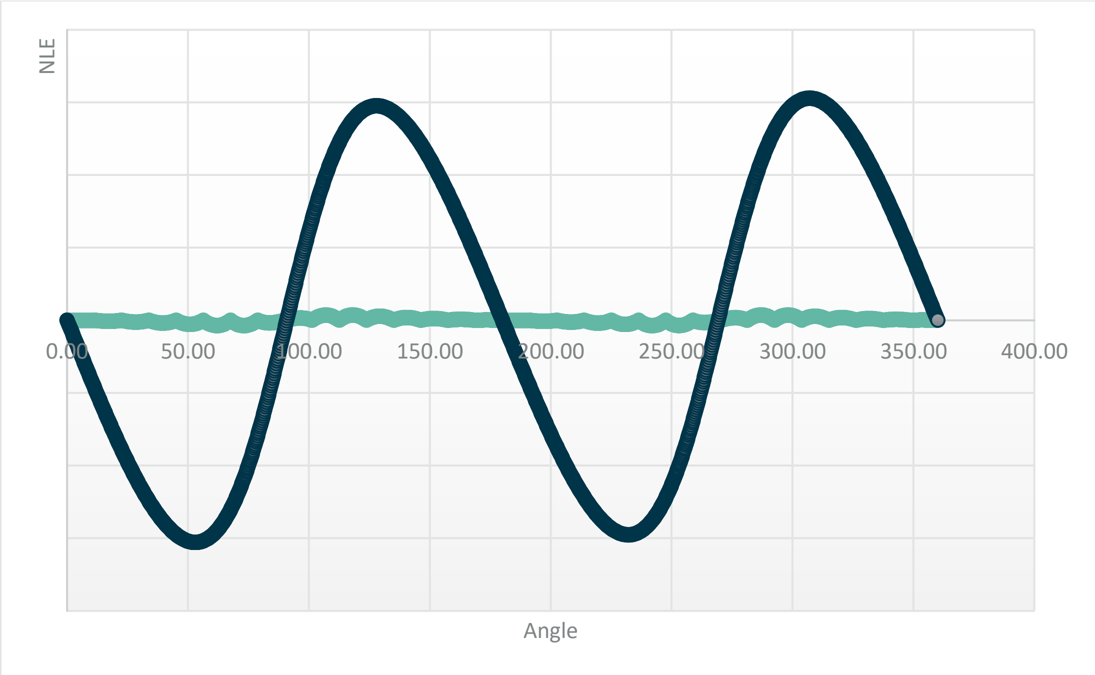

Figure 11 Example of residual error after 32-point calibration. Blue resembles the error without back-end calibration; green resembles the error after 32 points calibration

Therefore, customers that are already familiar with the 17-point method can easily use this method as well, achieving the best linearity performance, as shown in Figure 12, with a reasonable programming time.

Other than the number of points, the main difference this method has is the fact that the points are no longer stored in the memory as absolute values. Instead, a single linear function with a slope and fix reference point is calculated based on the desired output behavior and then only the difference between the calibration points and the values given by the slope are stored in the memory. As there is only one slope, ie one base linear function, the overall output behavior of the application can only be monotonically increasing or decreasing vs the angle position.
The resulting transfer function is formed by these 32 differential points, plus an additional point that is equal to the value given by the slope and that can be either at the start or in the middle of the working range, depending on the product.

2.4.2. Typical applications

Typical applications include (but are not limited to):

- Transmission range sensors;
- Brake pedals;
- Linear displacement applications with long strokes;
- Arc-shaped displacement applications;

3. Parameters

Table 1 shows the programmable parameters related to back-end calibration for the various methods and Triaxis generations. These parameters can be defined either by the solver algorithm or directly by the user. Note that the parameter names may also vary between generations.

Table 1 Programmable parameters related to back end calibration

Parameter	3-pt	4-pt	8-pt	16/17-pt	32-pt
Clockwise (CW)	✓	✓	✓	✓	✓
Discontinuity Point (DP)	✓	✓	✓	✓	✓
LNRAX	✓	✓			
LNRBX	✓	✓			
LNRCX	✓	✓			
LNRDX		✓			
LNRAY	✓	✓			
LNRBY	✓	✓			
LNRCY	✓	✓			
LNRDY		✓			
LNRS0	✓	✓			
LNRAS	✓	✓			
LNRBS	✓	✓			
LNRCS	✓	✓			
LNRDS		✓			
LNRX0…LNRX7			✓		
LNRY0…LNRY7			✓	✓	
LNRY8…LNR15/LNR16				✓	
LNR_DELTAY01…LNR_DELTAY32					✓
Working Range (W)				✓	✓
Clamp Low	✓	✓	✓	✓	✓
Clamp High	✓	✓	✓	✓	✓
Anchor Mid				✓	✓
LNR_DELTA_Y_EXP					✓
WORK_RANGE(GAIN)				✓	✓

4. Selection Guide

Table 2 shows the calibration methods available for each Triaxis product.

Table 2 Calibration methods available for each Triaxis product

Back End Calibration Method	4-point	8-point	17-point	32-point
MLX90316	✓			
MLX90324	✓		✓	
MLX90333	✓(x2)			
MLX90340	✓		✓	
MLX90360	✓		✓	
MLX90364/MLX90365	✓		✓	
MLX90366/MLX90367 See versions	✓(ABT/ABU)		✓(ABS/ABV/ABX)	
MLX90421	✓		✓	
MLX90422	✓		✓	
MLX90423			✓ (16arbitrary)	
MLX90425	✓		✓	
MLX90426	✓		✓	
MLX90371	✓	✓	✓	✓
MLX90372	✓	✓	✓	✓
MLX90373	✓	✓	✓	✓
MLX90374	✓	✓	✓	✓
MLX90378	✓ (x2)			

5. Graphical representation

The graph below shows the relationships between the mechanical position applied, the target output, the measured angle, and the calibration points. The example is given for a 16 point calibration. The measured range is divided into 16 segments of the same length, yielding 17 equidistant points. The target at these points is what will be programmed inside the memory of the IC. The red lines show the position where the output clamping starts. The points before and after are adjusted to set the transition point accordingly. Note the third quadrant. This quadrant is of particular interest when using the sensor in analog mode. The error (gain and offset) introduced by the digital to analog converter (DAC) can be corrected. This is not applicable for PWM and digital outputs

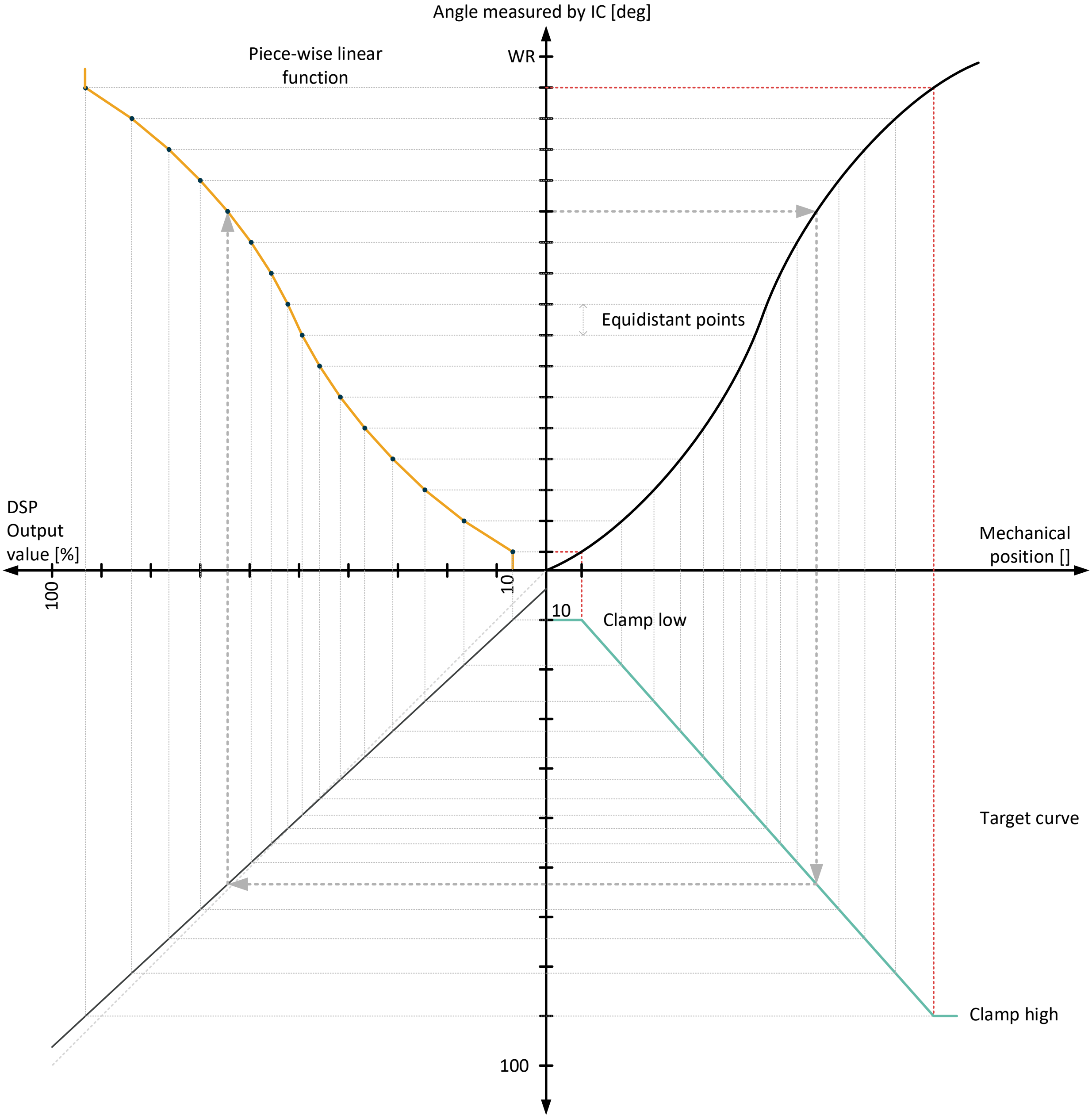

Figure 12 Relation between mechanical position vs target and sensor output

6. Useful Documents

- AN_90360_BackEndCalibration_rev3.1.pdf
- MLX90324-90360-AN_16pts_calibrationVs3Pts.pdf
- AN-MLX90371_MLX90372_32-PointCalibration.pdf

See also our video about back-end calibration: https://youtu.be/S-PT4CkWdVQ.

7. Disclaimer

IATF 16949 and ISO 14001 Certified