MLX90376

Triaxis® Position Sensor IC
Datasheet

Melexis
INSPIRED ENGINEERING

Features and Benefits

- Triaxis® Hall Technology
- On chip signal processing for robust absolute position sensing
- Programmable measurement range
- Programmable linear transfer characteristic (4 or 8 Multi-points or 16 or 32 Piece-Wise-Linear)
- Selectable output modes
  - (fast) SENT (SAE J2716 APR2016)
  - SPC (Short PWM Code)
  - PWM (Pulse Width Modulation)
  - Ratiometric analog
- AEC-Q100 qualified (Grade-0)
- ISO 26262 SEooC SIL READY
  - ASIL C for (fast) SENT, PWM or SPC output
  - ASIL B for analog output
- Robustness against stray magnetic field up to 5mT (4kA/m) as per ISO 11452-8. Stray-field immune angle sensing up to 360°
- 48 bit ID Number option
- Packages, RoHS compliant
  - SOIC-8 (DC), single die
  - TSSOP-16 (GO), dual die (redundancy)
  - SMP-4 (VD), dual die PCB-less solution

SOIC-8 *TSSOP-16* *SMP-4*

Application Examples

- Throttle Position Sensor
- Ride Height Position Sensor
- Float-Level Sensor
- Steering Wheel Position Sensor

Description

The MLX90376 is a monolithic magnetic position sensor IC. It consists of a Triaxis® Hall magnetic front end, an analog to digital signal conditioner, a DSP for advanced signal processing and an output stage driver.

The MLX90376 is sensitive to the three components of the magnetic flux density applied to the IC (i.e. Bx, By and Bz). This allows the MLX90376 with the correct magnetic circuit to decode the absolute position of any moving magnet (e.g. rotary position from 0 to 360 Degrees or linear displacement). It enables the design of non-contacting position sensors that are frequently required for both automotive and industrial applications.

The MLX90376 provides 4 output modes. Firstly, the IC supports (fast) SENT and SPC frames encoded according to a Secure Sensor format. The output delivers enhanced serial messages providing error codes, and user-defined values. Through programming, the MLX90376 can also be configured to output a PWM (Pulse Width Modulated) or an analog ratiometric output.

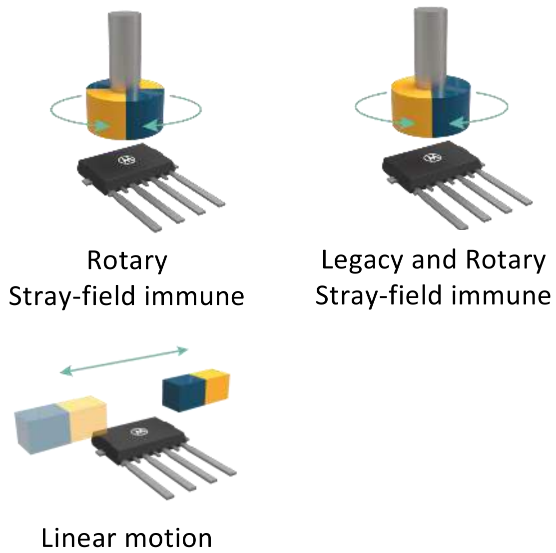

Figure 1 -MLX90376 application modes

Ordering Information

Product	Tempe -rature	Package	Option Code	Packing Form	Definition
MLX90376	G	VD	ABA-110	RE/RX	Rotary Stray-Field Immune Mode Low field variant - 180 degrees Analog / PWM output, High Speed Mode
MLX90376	G	VD	ABA-300	RE/RX	Standard / Legacy Mode Analog / PWM output, Low Power Mode
MLX90376	G	VD	ABA-310	RE/RX	Standard / Legacy Mode Analog / PWM output, High Speed Mode
MLX90376	G	VD	ABA-330	RE/RX	Standard / Legacy Mode SENT output
MLX90376	G	VD	ABA-510	RE/RX	Rotary Stray-Field Immune Mode High field variant - 180 degrees Analog / PWM output, High Speed Mode
MLX90376	G	VD	ABA-530	RE/RX	Rotary Stray-Field Immune Mode High field variant - 180 degrees SENT output
MLX90376	G	VD	ABA-600	RE/RX	Rotary Stray-Field Immune Mode - 360 degrees Analog / PWM output, Low Power Mode
MLX90376	G	VD	ABA-610	RE/RX	Rotary Stray-Field Immune Mode - 360 degrees Analog / PWM output, High-speed Mode

Table 1 - Ordering Codes for SMP-4 package

Product	Tempe-rature	Package	Option Code	Packing Form	Definition
MLX90376	G	GO	ABA-600	RE	Rotary Stray-Field Immune Mode - 360 degrees, Analog / PWM output, Low Power Mode
MLX90376	G	GO	ABA-630	RE	Rotary Stray-Field Immune Mode - 360 degrees, SENT output
MLX90376	G	GO	ABA-680	RE	Rotary Stray-Field Immune Mode - 360 degrees, SPC output
MLX90376	G	DC	ABA-680	RE	Rotary Stray-Field Immune Mode - 360 degrees, SPC output

Table 2 - Ordering Codes for SMD packages

Temperature Code:	**G:** -40°C to 160°C
Package Code:	**VD**: SMP-4 package (PCB-less single mold, see section 19.1) **DC**: SOIC-8 for single die component (see section 19.2.1) **GO**: TSSOP-16_EP for dual die component (see section 19.2.2)
Option Code - Chip revision	**ABA-123: Chip Revision** ▪ ABA: Standard revision
Option Code - Application	ABA-123: **1-Application - Magnetic configuration** ▪ 1: Angular Rotary Strayfield Immune – Low Field – (180 Degrees) ▪ 3: Legacy / Angular Rotary / Linear Position ▪ 5: Angular Rotary Strayfield Immune – High Field – (180 Degrees) ▪ 6: Angular Rotary Strayfield Immune (360 Degrees)
Option Code – SW configuration: output mode, protocol	ABA-123: **2-SW configuration: output mode, protocol** ▪ 0: Analog, PWM compatible output mode, low power mode ▪ 1: Analog, PWM compatible output mode, high speed mode ▪ 3. SENT output mode, 3µs tick time ▪ 8. SPC output mode, 1.5µs tick time **Important:** Product must be ordered by the option code corresponding to the desired output protocol. The output protocols are not interchangeable by reprograming at the end-user.
Option Code	ABA-123: **3-Not used**
Packing Form:	-RE: Tape & Reel ▪ VD: 2500 pcs/reel ▪ DC: 3000 pcs/reel ▪ GO: 4500 pcs/reel -RX: Tape & Reel, similar to RE with parts face-down (VD package)
Ordering Example:	MLX90376GVD-ABA-300-RE For a legacy version in SMP-4 package, low-power analog output, delivered in Reel of 2500 pcs.

Table 3 - Ordering Codes Information

Contents

1. Functional Diagram and Application Modes

1.1. Functional Diagram for PCB-less package

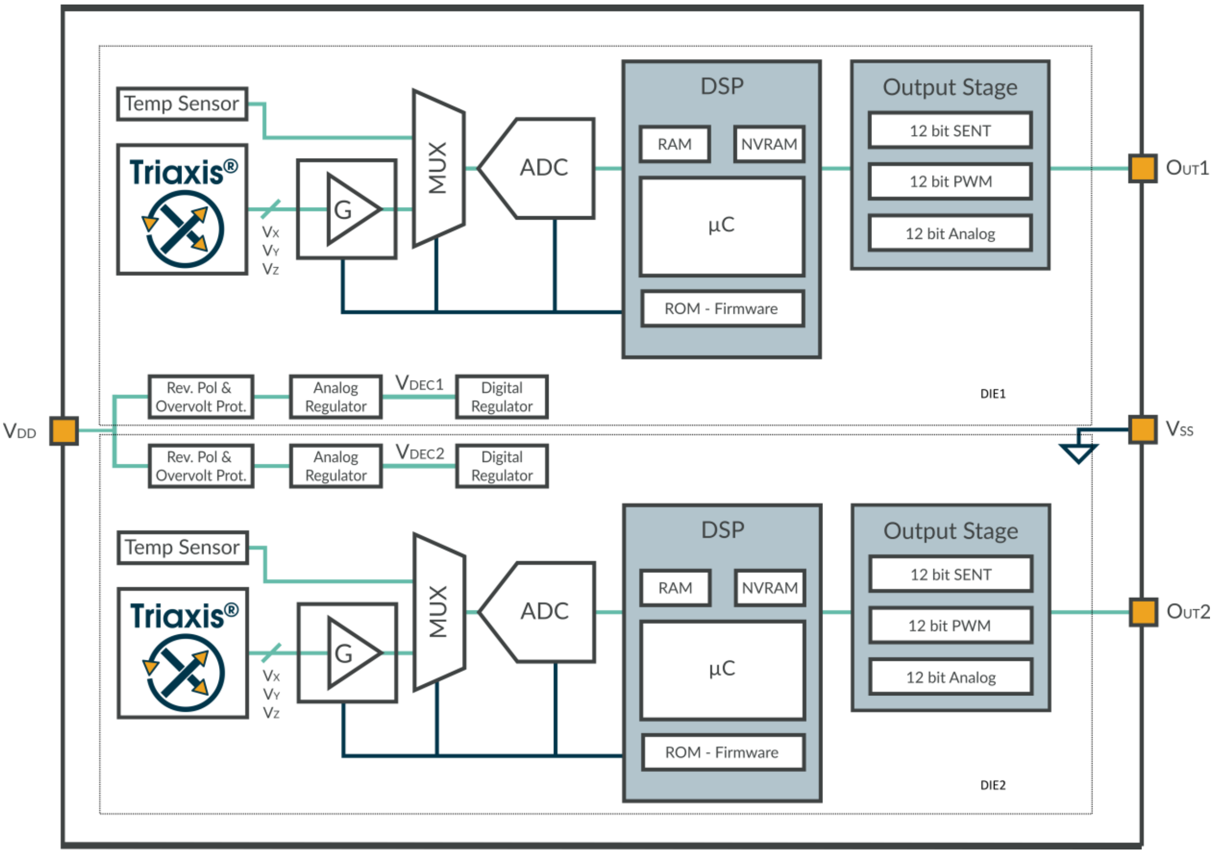

Figure 2 - MLX90376 Block diagram for SMP-4 package

1.2. Functional Diagram for SMD packages

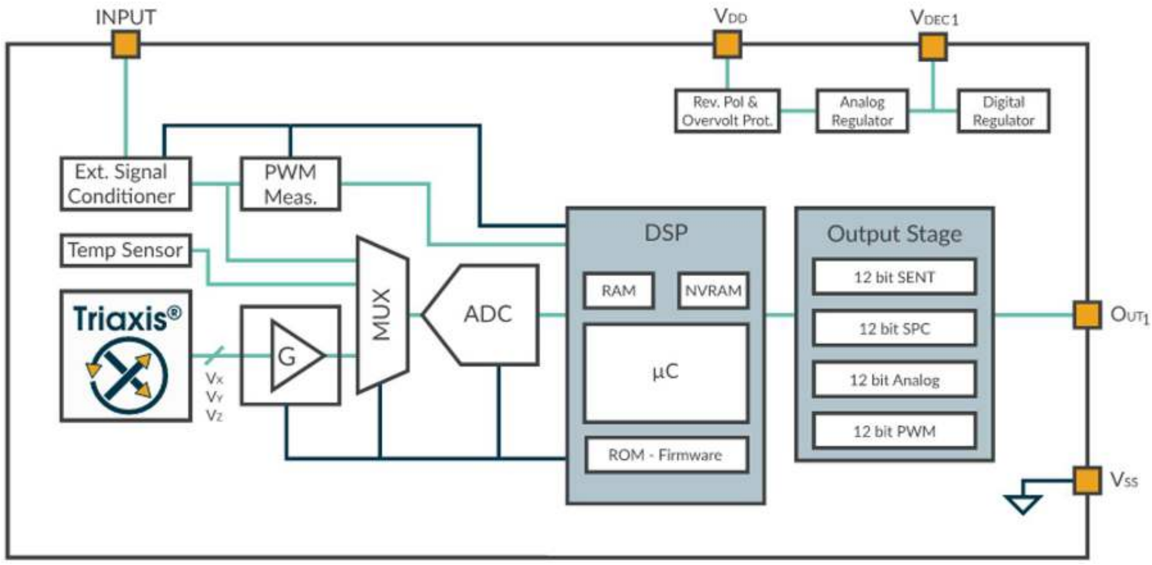

Figure 3 - MLX90376 Block diagram for SMD packages

1.3. Application modes

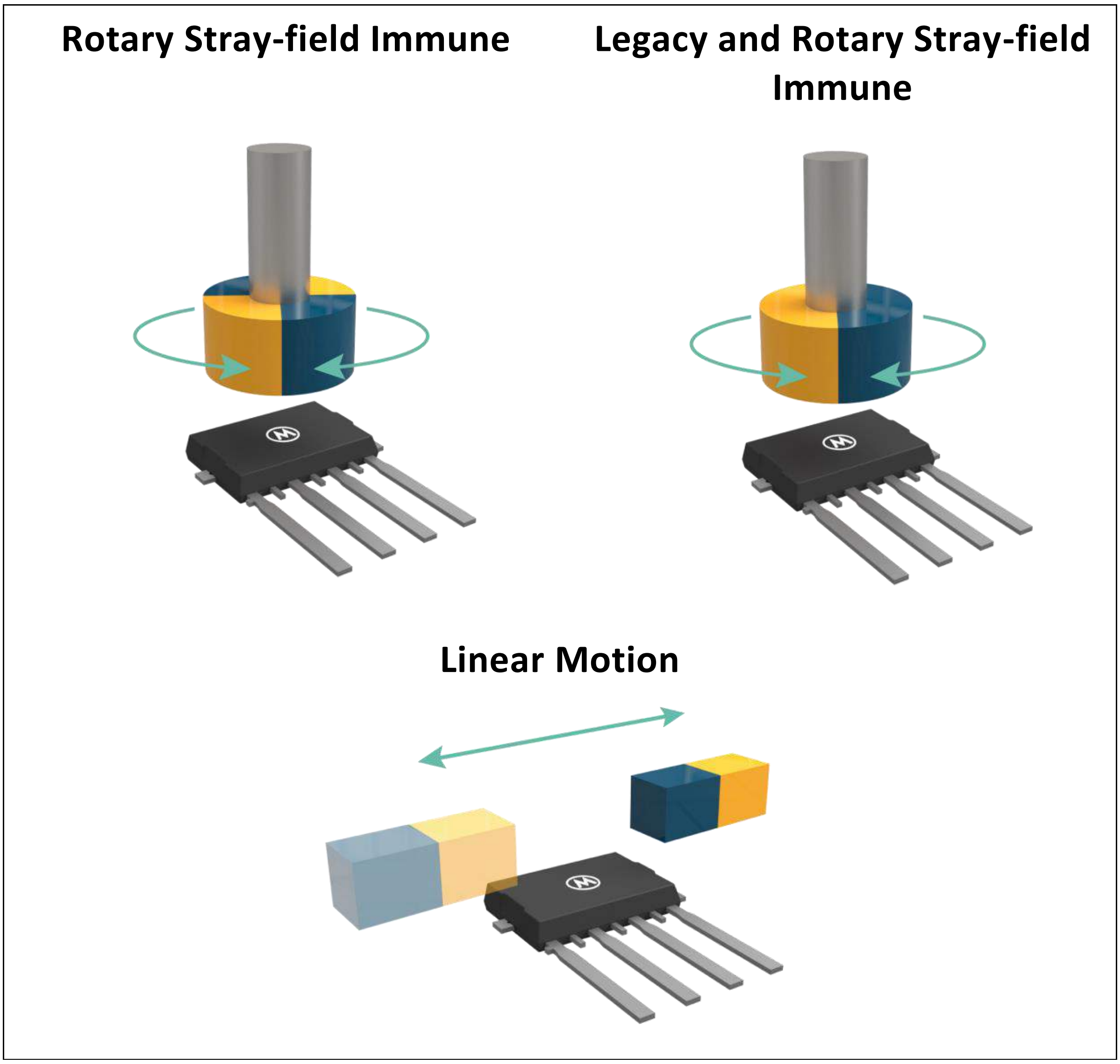

Figure 4 - Application Modes

2. Glossary of Terms

Name	Description
ADC	Analog-to-Digital Converter
AoU	Assumption of Use
ASP	Analog Signal Processing
AWD	Absolute WatchDog
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DC	Duty Cycle of the output signal i.e. T_{ON} /(T_{ON} + T_{OFF})
DP	Discontinuity Point
DSP	Digital Signal Processing
DTI	Diagnostic Test Interval
ECC	Error Correcting Code
EMA	Exponential Moving Average
EMC	Electro-Magnetic Compatibility
EoL	End of Line
EP	Exposed Pad
FIR	Finite Impulse Response
FHTI	Fault Handling Time Interval
Gauss (G)	Alternative unit for the magnetic flux density (10G = 1mT)
HW	Hardware
IMC®	Integrated Magnetic Concentrator
INL/DNL	Integral Non-Linearity / Differential Non-Linearity
IWD	Intelligent WatchDog
LNR	LiNeaRization
LSB/MSB	Least Significant Bit / Most Significant Bit
NC	Not Connected
NVRAM	Non Volatile RAM
PCB	Printed Circuit board
POR	Power On Reset
PSF	Product Specific Functions
PWL	Piecewise Linear
PWM	Pulse Width Modulation
RAM	Random Access Memory
ROM	Read-Only Memory
SPC	Short PWM Code
SCN	Status & Communication Nibble
SEooC	Safety Element out of Context
SMD	Surface Mount Device
SMP	Single Mold Package
TC	Temperature Coefficient (in ppm/°C)
Tesla (T)	SI derived unit for the magnetic flux density (Vs/m2)
TSSOP-16_EP	TSSOP-16 Exposed Pad

Table 4 - Glossary of Terms

3. Pin Definitions and Descriptions

3.1. Pin Definition for SMP-4 package

Pin #	Name	Description
1	OUT1	Output (die 1)
2	VSS	Ground (common to die 1 and die 2)
3	VDD	Supply (common to die 1 and die 2)
4	OUT2	Output (die 2)

Table 5 - SMP-4 Pin definitions and description

3.2. Pin Definition for SMD packages

3.2.1. Pin Definition for SOIC-8 package

Pin #	Name	Description
1	OUT	Output
2	TEST	For test
3	VSS	Ground
4	VDD	Supply
5	INPUT	For test
6	NC	Not connected
7	NC	Not connected
8	VDEC	Decoupling pin

Table 6 - SOIC-8 Pin definitions and description

For optimal EMC behavior, it is recommended to connect the unused pins (NC and the pins for test) to the Ground.

3.2.2. Pin Definition for TSSOP-16_EP Dual-Die package

Pin #	Name	Description
1	NC	Not connected
2	VDEC1	Decoupling pin die1
3	OUT1	Output die1
4	TEST1	For test
5	VSS1	Ground die1
6	VDD1	Supply die1
7	INPUT1	For test
8	NC	Not connected
9	VDEC2	Decoupling pin die2
10	NC	Not connected
11	OUT2	Output die2
12	TEST2	For test
13	VSS2	Ground die2
14	VDD2	Supply die2
15	INPUT2	For test
16	NC	Not connected

Table 7 - TSSOP-16_EP Pin definitions and description

For optimal EMC behavior, it is recommended to connect the unused pins (NC and the pins for test) to the Ground.

Please refer to Section 17.1. for the soldering recommendation of the exposed pad.

4. Absolute Maximum Ratings

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Supply Voltage (1)	V_{DD}			28 37	V	< 48h, T_J < 175°C < 60s, $T_{AMB} \leq 35°C$
Reverse Voltage Protection (1)	$V_{DD\text{-rev}}$	-14 -18			V	< 48h < 1h
Positive Output Voltage (1)	V_{OUT}			28	V	< 48h
Reverse Output Voltage (1)	$V_{OUT\text{-rev}}$	-14 -18			V	< 48h < 1h
Internal Voltage	V_{DEC}			3.6	V	
	$V_{DEC\text{-rev}}$	-0.3			V	
Positive Input pin Voltage	V_{Input}			6	V	
Reverse Input pin Voltage	$V_{Input\text{-rev}}$	-3			V	
Operating Temperature	T_{AMB}	-40		+160	°C	
Junction Temperature	T_J			+175	°C	
Storage Temperature	T_{ST}	-55		+170	°C	
Magnetic Flux Density	B_{max}	-1		1	T	

Table 8 - Absolute maximum ratings

Exceeding any of the absolute maximum ratings may cause permanent damage.

Exposure to absolute maximum ratings conditions for extended periods may affect device reliability.

Derating might occur in TSSOP-16_EP Dual-Die package, if both dies are exposed to the absolute maximum ratings conditions simultaneously.

5. Isolation Specification

Only valid for the TSSOP-16_EP package (code GO, i.e. dual die version).

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Isolation Resistance	R_{isol}	4	-	-	MΩ	Between dice, measured between V_{SS1} and V_{SS2} with +/-20V bias

Table 9 - Isolation specification

[1] *Valid for full operating temperature range.*

6. General Electrical Specifications

General electrical specifications are valid for temperature range [-40; 160] °C and supply voltage range [4.5;5.5] V unless otherwise noted.

Electrical Parameter	Symbol	Min	Typ	Max	Unit	Condition
Supply Voltage	V_{DD}	4.5 6	5 12	5.5 18	V	Powered by regulated supply Powered by vehicle battery (2)
Supply Current for SMP-4 package	I_{DD}	16 20 16 24 18	18 22 18 27 23	22 27 23 30 26	mA	-30x and 60x code (3) -31x and 61x code (3) -33x code (3) -11x and -51x code (3) -53x code (3)
Supply Current for SMD packages (4)	I_{DD}	8 10 8	9 11 9	11 13.5 11.5	mA	-60x code -68x code -63x code
Start-up Level rising	$V_{DDstartH}$ $V_{DDstartHyst}$	3.85	4.0 0.10	4.15	V	
PTC Entry Level	V_{PROV0} (5) $V_{PROV0Hyst}$	5.85 100	6.05 175	6.25 250	V mV	Powered by regulated supply
	V_{PROV1} (5) $V_{PROV1Hyst}$	21.5 1.0	22.5 1.5	23.5 2.0	V	Powered by vehicle battery (2)
Under voltage detection	V_{DDVL} $V_{DDUVHyst}$	3.75	3.90 0.10	4.05	V	
Output Short Circuit Current	$I_{OUTshort}$	-35 10		-10 35	mA	Vout = 0 V Vout = 5 V or 18 V
Output Load	R_L	5	10		kΩ	Analog pull-up/pull-down
		5		100	kΩ	PWM push-pull, pull-up to 5 V, PWM push-pull, pull-down to 0 V
		10	-	55	kΩ	SENT push-pull, pull-up (6)
		3	-	55	kΩ	SPC push-pull and improved emission modes (6)
		1	-	100	kΩ	Open drain pull-up/pull-down

2 The battery mode is exclusively for the PWM protocol in SMD packages
3 Both dies on.
4 IDD refers to the supply current for a single die. In the TSSOP based configurations, the total IDD is doubled because of the presence of two dies.
5 Programming through Connector (PTC) requires rising supply voltage above Vprov0 or Vprov1. This is customer configurable by setting a bit in the NVRAM
6 Output resistance should be selected together with the output capacitive load to correspondingly match the application, i.e. tick time, SPC ID, to allow appropriate time window for the trigger pulse reception. More details see sections 11.2.5 and 11.4.3.

Electrical Parameter	Symbol	Min	Typ	Max	Unit	Condition
Digital open drain output level	$V_{satLoOd}$	0		10	$\%V_{ext}$	Pull-up to any external voltage $V_{ext} \leq 18$ V, $I_L \leq 3.4$ mA
	$V_{satHiOd}$	90		100	$\%V_{ext}$	Pull-down to GND with any supply voltage $V_{DD} \leq 18$ V, $I_L \leq 3.4$ mA
Digital open drain output leakage [7]	$I_{leakpuOd}$			400	µA	$V_{ext} \leq 18$ V, 4.5 V ≤ VDD ≤ 5.5 V, with a pull-up resistor
				100	µA	$V_{vdd} = V_{ext}$, with a pull-up resistor
	$I_{leakpdOd}$			150	µA	with a pull-down resistor
Digital output Ron	R_{on}	27	50	130	Ω	Push-pull mode
Analog Saturation Output Level	V_{satA_lo}		0.5[8] 3.3[8]	1.2[9] 7.4[9]	%VDD	Pull-up load $R_L \geq 10$ kΩ to 5 V Pull-up load $R_L \geq 5$ kΩ to 18 V
	V_{satA_hi}	97[9] 95[9]	99[8] 98[8]		%VDD	Pull-down load $R_L \geq 10$ kΩ Pull-down load $R_L \geq 5$ kΩ
Digital Output Level	V_{satD_lopp}			0.2[9] 0.5[9]	V	Pull-up load $R_L \geq 10$ kΩ Pull-up load 10 kΩ > $R_L \geq 5$ kΩ
	V_{satD_hipp}	VDD -0.2[9] VDD -0.5[9]			V	Pull-down load $R_L \geq 10$ kΩ Pull-down load 10 kΩ > $R_L \geq 5$ kΩ
Active Diagnostic Output Level	Diag_lo		0.5[8] 3.3[8]	1.2[9] 7.4[9]	%VDD	Pull-up load $R_L \geq 10$ kΩ to 5 V Pull-up load $R_L \geq 5$ kΩ to 18 V
	Diag_hi	97[9] 95[9]	99[8] 98[8]		%VDD	Pull-down load $R_L \geq 10$ kΩ Pull-down load $R_L \geq 5$ kΩ
Passive Diagnostic Output Level (Broken-Wire Detection) [10]	BVSSPD		1 2.5	1.6 4	%VDD	Broken VSS & Pull-down load $R_L \leq 10$ kΩ Pull-down load $R_L \leq 25$ kΩ
	BVSSPU	99.5	100		%VDD	Broken VSS & Pull-up load $R_L \geq 5$ kΩ
Passive Diagnostic Output Level (Broken-Wire Detection) [10]	BVDDPD		0	0.5	%VDD	Broken VDD & Pull-down load $R_L \geq 5$ kΩ
	BVDDPU	92.5 97	97.5 99		%VDD	Broken VDD & Pull-up load $R_L \leq 25$ kΩ Pull-up load $R_L \leq 10$ kΩ

[7] *The digital output level is thereby defined by the external voltage and pull-up or pull-down resistor.*
[8] *at 35°C and 5V supply voltage with typical process parameters*
[9] *at 160°C and ≥4.5V supply voltage*
[10] *Valid for dual-die configuration as well, where the two dies have the same supply and ground level, while the output of one die is connected with PU and the output of the other one is connected with PD.*

Electrical Parameter	Symbol	Min	Typ	Max	Unit	Condition
Leakage current in fail-safe (HiZ) state [11]	Ileak_HiZ		10[12]	20[12]	µA	Pull-up at output [13]

Table 10 - Electrical Specifications

[11] *In the case of open-drain mode, see the parameters $I_{leakpuOd}$/$I_{leakpdOd}$.*
[12] *As the leakage current significantly increases at high temperature, the typical value is at 35Deg.C, and the maximum value is at 160Deg.C.*
[13] *The worst-case scenario for the leakage occurs when the output is pulled up. The leakage current will be ~30 times smaller if the output is pulled down.*

7. Timing Specification

Timing specifications are valid for temperature range [-40; 160] °C and supply voltage range [4.5; 5.5] V unless otherwise noted.

7.1. General Timing Specifications

Parameter	Symbol	Min.	Typ	Max.	Unit	Condition
Main Clock Frequency [14]	F_{CK}	11.4 22.8	12 24	12.6 25.2	MHz	-30x, -33x, -53x, -60x, -63x code -11x, -31x, -51x, -61x, -68x code
Main Clock initial tolerances at room temperature	$\Delta F_{CK,0}$	11.75 23.5	12 24	12.25 24.5	MHz	-30x, -33x, -53x, -60x, -63x code -11x, -31x, -51x, -61x, -68x code
Main Clock Frequency Thermal Drift	$\Delta F_{CK,T}$	-3.5	-	3.5	$\%F_{ck}$	Relative to 35°C
Main Clock Frequency Total Drift	$\Delta F_{CK,\ TOT}$	-5	-	5	$\%F_{ck}$	Relative tolerances, including thermal and lifetime drift, after factory trimming at Melexis
1MHz Clock Frequency	F_{1M}	0.95	1	1.05	MHz	

Table 11 - General Timing Specifications

[14] *Including thermal and lifetime drift*

7.2. Timing Definitions

7.2.1. Startup Time

In analog mode, the startup time is the time between the power on cycle and the time the first valid angle transmitted on the output. During startup, the sensor output is in High-Z state, and the driver is only enabled when the sensor is able to transmit a valid output.

In SPC mode, the startup time is the time when the device is able to receive the 1st trigger pulse with valid angle information. Prior to it, there is a programmable SPC-SCN_INIT parameter (see section 12) to report an error in the status and communication nibble (SCN, see section 11.4.5.3).

In SENT mode, the startup time consists of two values. The first one, T_{init}, is the time needed for the circuit to be ready to start acquiring an angle. In SENT mode, at that time, the IC starts transmitting initialisation frames. The second value, T_{stup}, is the time when the first valid angle is transmitted.

In PWM mode, startup is defined by three values, $T_{stup[1..3]}$. The first value is reached when the output is ready and starts to drive a voltage. The second value T_2 is the start of the first value angle transmission and the third one T_3 the moment the first angle has been transmitted.

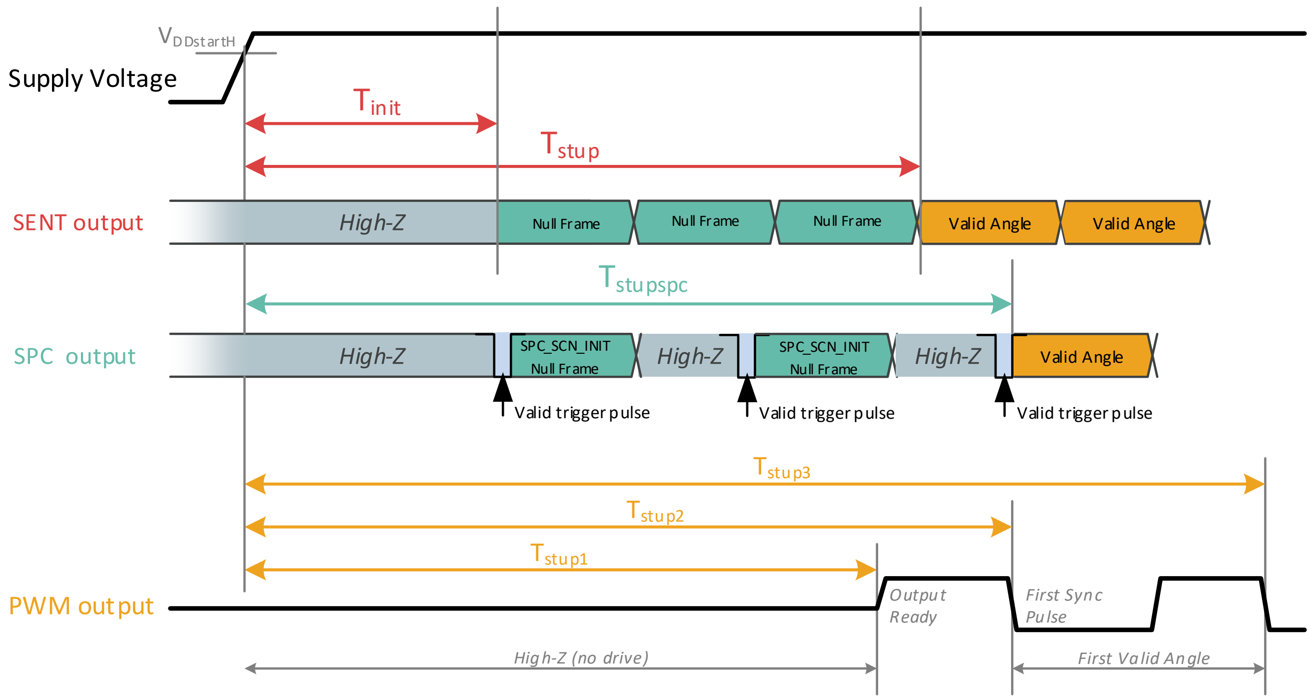

Figure 5 - Startup Time Definition

7.2.2. Latency (average)

Latency is the average lag between the movement of the detected object (magnet) and the response of the sensor output, as shown in Figure 6, where theta_ECU(t) is sampled as the beginning of the synchronization pulse. This value is representative of the time constant of the system for regulation calculations.

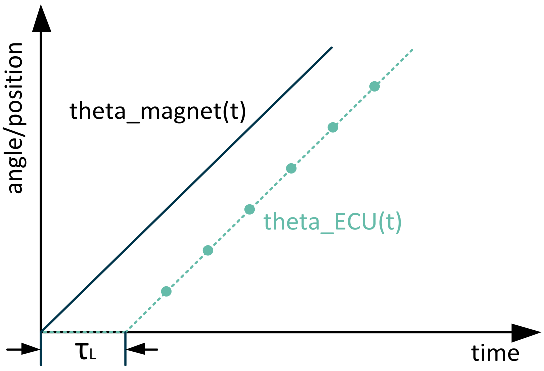

Figure 6 - Definition of Latency

7.2.3. Step Response (worst case)

The step response is a suitable metric for the "delay" of the sensor in case of an abrupt step in the magnetic change, considering 100% settling time without any DSP filter. Full settling is typically achieved in just two steps. The sensor is asynchronous with the magnetic step change: the 100% settling time will fall in a time window; worst case is illustrated in the figure below.

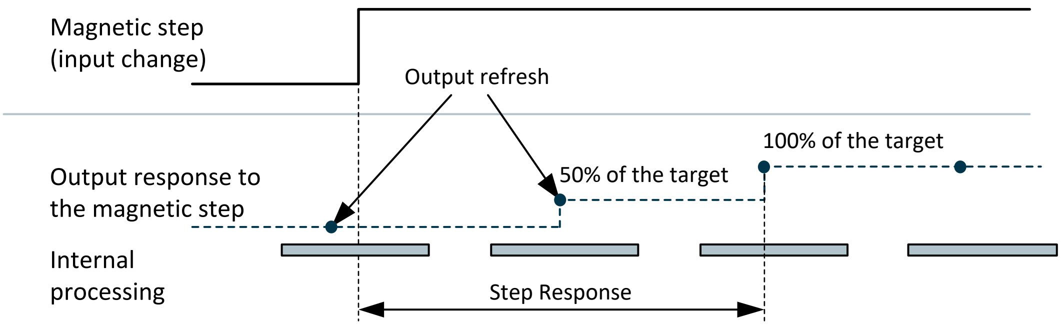

Figure 7 - Step Response Definition

7.3. Analog output timing specifications (-x0x and-x1x code)

For the analog output configurations, specifications are valid for the operational temperature range, and the supply voltage defined in section 6.

7.3.1. High Speed Mode (-11x,-31x,-51x,-61x code)

For the High Speed Mode, the timing specifications are listed in Table 12.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Output refresh period	τ_R	190	200	210	µs	
Latency	τ_L			140	µs	no external load, filter=0
Step response	τ_S			380	µs	no external load, filter=0
Start-up time	τ_{SU}			3.2	ms	
Slew Rate	SR			120 200	V/ms	capacitive load at output is 100nF capacitive load at output is 10nF
Analog Diagnostics Cycle	DTI_{ANA}			7.2	ms	see Table 75, section 15.3
Digital Diagnostics Cycle	DTI_{DIG}			6.1	ms	see Table 75, section 15.3
Safe startup Time [15] [16]				13.3	ms	

Table 12 - Analog General Timing Specifications for High Speed Mode

7.3.2. Low Power Mode (-30x, 60x code)

For the Low Power Mode, the timing specifications are listed in Table 13.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Output refresh period	τ_R	380	400	420	µs	
Latency	τ_L			300	µs	no external load
Step response	τ_S			680	µs	no external load
Start-up time	τ_{SU}		4	4.2	ms	
Slew Rate	SR			120 200	V/ms	capacitive load at output is 100nF capacitive load at output is 10nF
Analog Diagnostics Cycle	DTI_{ANA}			15	ms	see Table 75, section 15.3
Digital Diagnostics Cycle	DTI_{DIG}			9.8	ms	see Table 75, section 15.3
Safe startup Time [15] [16]				21.7	ms	

Table 13 - Analog General Timing Specifications for the Standard/Legacy Low Power Mode

[15] *Fully programmable depending on the power/magnetic/output mode.*
[16] *Time between reset due to digital fault to first valid data transmission. Min. value defined by OUT_DIAG_HIZ_TIME (see section 12).*

7.4. SENT output timing specifications (-x3x code)

The general SENT timing specifications are listed in Table 14.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Tick time [17]			3	6	µs	3µs = Normal SENT (default) 6µs = Slow SENT
SENT edge rise Time	T_{rise}		12.5	18	µs	between 1.1V and 3.8V for 3µs tick time
SENT edge fall Time	T_{fall}		5.3	6.5	µs	
Slow Message cycle length (3µs tick time)			791 475		ms	Extended sequence (40 frames) Short sequence (24 frames)

Table 14 - SENT General Timing Specifications

[17] *The device also supports SENT formats with other tick time, see Table 34.*

7.4.1. Continuous Synchronous Acquisition Mode (-x3x code)

For the SENT output protocol, MLX90376 with the default factory calibration operates with constant SENT frame length (SENT with pause), where a constant latency and step response time is guaranteed. The length of the SENT frame is defined by the parameter T_FRAME in number of ticks (see section 12). When configured in continuous synchronous timing mode, the sensor permanently provides one new angle/position value for each new transmitted frame, with a fixed frame period.

The detailed default setting of the SENT protocol is as follows:

- Protocol: SENT with pause
- Tick time: 3µs/tick
- SENT format: A.3 (H.4)
- Number of conversions per SENT frame: 2
- ADC clock frequency: 3MHz
- DSP linearization: 16 points

The corresponding timing specifications are listed in Table 15.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
SENT frame tick count	N_{Tframe}	320 [18][19]			ticks	
Output refresh period	τ_R		0.96		ms	
SENT startup time	T_{stup}			6.4	ms	Until first valid angle received
Average Latency	T_{latcy}			1.7 1.9 2.5	ms	Filter = 0 (no filter) [20] Filter = 1 (FIR11), default setting Filter = 2 (FIR1111)
Step Response (worst case)	T_{wcStep}			3.0 3.5 4.4	ms	Filter = 0 (no filter) [20] Filter = 1 (FIR11), default setting Filter = 2 (FIR1111)
Analog Diagnostics Cycle	DTI_{ANA}			10.4	ms	see Table 75, section 15.3
Digital Diagnostics Cycle	DTI_{DIG}			8.5	ms	see Table 75, section 15.3
Safe startup Time [15][16]				12.1	ms	

Table 15 - Synchronous SENT Mode Timing Specifications

[18] Defines the typical Output refresh period (SENT Frame Period).
[19] If the sensor is configured from the default factory setting to have 1 conversion per SENT frame, the minimum tick count is 282.
[20] See section 14.4 for details concerning Filter parameter. It is an option to improve the speed, but will degrade noise performance by a factor of 1.4.

7.4.2. Continuous Asynchronous Acquisition Mode (-x3x code)

Optionally to the default factory setting, the MLX90376 can be configured to operate with variable SENT frame length (SENT without pause), where latency and step response is dependent on the transmitted data. The length of the SENT frame is defined by the data content. The sensor is configured in the continuous asynchronous acquisition mode and periodically acquires a magnetic measurement asynchronously to the SENT transmission.

When configured in the continuous asynchronous acquisition mode, the detailed setting of the SENT protocol is as follows:

- Protocol: SENT without pause
- Tick time: 3µs/tick
- SENT format: A.3 (H.4)
- ADC clock frequency: 3MHz
- DSP linearization: 16 points

The corresponding timing specifications are listed in Table 16.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Internal angle measurement period	τ_R	475	500	525	µs	Asynchronously to the output protocol
SENT startup time	T_{stup}			5.9	ms	Until first valid angle received
Average Latency	T_{latcy}			2.0 2.3 2.8	ms	Filter = 0 (no filter) (20) Filter = 1 (FIR11), default setting Filter = 2 (FIR1111)
Step Response (worst case)	T_{wcStep}			2.7 3.2 4.3	ms	Filter = 0 (no filter) (20) Filter = 1 (FIR11), default setting Filter = 2 (FIR1111)
Analog Diagnostics Cycle	DTI_{ANA}			11	ms	see Table 75, section 15.3
Digital Diagnostics Cycle	DTI_{DIG}			8.8	ms	see Table 75, section 15.3
Safe startup Time (15) (16)				18	ms	

Table 16 - Asynchronous SENT Mode Timing Specifications

7.5. PWM output timing specifications (-x0x and-x1x code)

The factory calibrated parts with order code –x0x and –x1x default to ratiometric analog output, the end user must reprogram the part to use the PWM output. Details can be found in Table 43. The Table 17 below shows the timing specifications for PWM output.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Internal angle measurement period (-x0x code)	τ_R	380	400	420	µs	
Internal angle measurement period (-x1x code)	τ_R	190	200	210	µs	
PWM Frequency	F_{PWM}	100		2000	Hz	Details see section 14.1.4
PWM Frequency Initial Tolerances	$\Delta F_{PWM,0}$	-1		1	$\%F_{PWM}$	T=35°C, can be trimmed at EOL
PWM Frequency Thermal Drift	$\Delta F_{PWM,T}$	-3.5		3.5	$\%F_{PWM}$	
PWM Frequency Drift	ΔF_{PWM}	-5.0		5.0	$\%F_{PWM}$	Over temperature and lifetime
PWM startup Time (up to output ready, x0x code) [21]	T_{stup1}		6.4		ms	
PWM startup Time (up to first sync. Edge, x0x code) [21]	T_{stup2}		8.4		ms	$T_{stup1} + T_{PWM}$, F_{PWM} =1kHz
PWM startup Time (up to first data received, x0x code) [21]	T_{stup3}		10.2		ms	$T_{stup1} + 2^* T_{PWM}$, F_{PWM} =1kHz [22]
PWM startup Time (up to output ready, x1x code) [21]	T_{stup1}		3.2		ms	
PWM startup Time (up to first sync. Edge, x1x code) [21]	T_{stup2}		4.2		ms	$T_{stup1} + T_{PWM}$, F_{PWM} =1kHz
PWM startup Time (up to first data received, x1x code) [21]	T_{stup3}		5.2		ms	$T_{stup1} + 2^* T_{PWM}$, F_{PWM} =1kHz [22]
Rise/Fall Time PWM push-pull mode [23]	T_{rise_pp} T_{fall_pp}	2.5	5.0	7.5	µs	VDD in the range of [4.5V, 5.5V], Cout ≤ 15nF [24]
Fall Time PWM NMOS open-drain mode [25]	T_{fall_od}			200	µs	VDD=4.5V, $V_{pull-up}$ = 18V, R_L = 10kΩ [26]

Table 17 - PWM timing specifications with order code

[21] Typical value specified according to the typical PWM frequency. Max. value can be obtained by scaling with the PWM frequency drift accordingly.
[22] First frame transmitted has no synchronization edge; therefore, the second frame transmitted is the first complete one.
[23] Calculated between 10%-90% voltage level.
[24] The 10nF output capacitor included in the SMP-4 package needs to be considered in the 15nF limit.
[25] Rise time in PWM NMOS open-drain mode is not specified as it depends on external components and the pull-up voltage.
[26] Vpull-up stands for the external pull up voltage. The worst-case scenario for this parameter is in the NMOS open-drain mode, where there is the maximal voltage difference between $V_{pull-up}$ and VDD. Furthermore, this parameter highly depends on the $V_{pull-up}$, the capacitive and resistive load at the output. The rise/fall time should be adjusted accordingly, with a different $V_{pull-up}$ value and RC time constant resulting from the output load.

7.6. SPC output timing specifications (-68x code)

In SPC mode, the MLX90376 starts data acquisition once the trigger pulse has been received, regardless of the configured mode. It will send the acquired data in the same SENT frame. This feature is available for any tick time greater than or equal to 1.5µs. Please check the section 11.4 for more details on the configuration options.

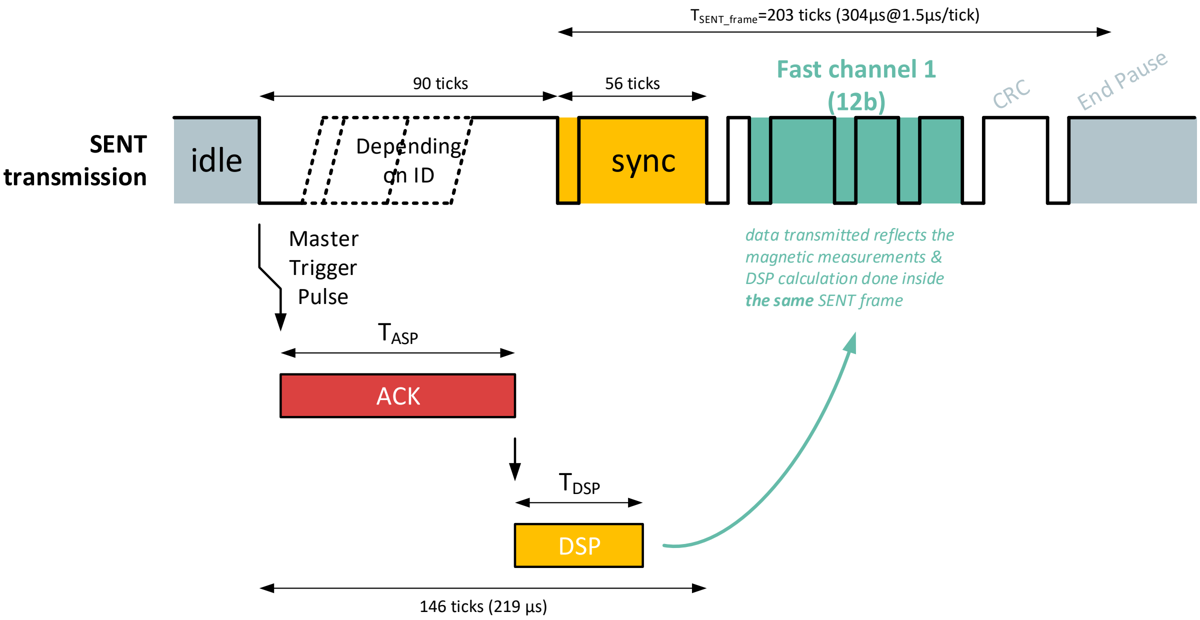

Figure 8 - SPC timing illustration in 1.5µs tick time mode and H.2 format

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Time between trigger received & acquisition started	T_{tr2acq}		10		µs	Tick: 1.5 µs SPC_RX_FILT_TIME [27]: 6 SPC_TRIG_TH: 0
Startup time	$T_{stupspc}$		3.9		ms	
Latency	T_{latcy}		450		µs	
Step Response [28]	T_{wcStep}		1		ms	
Jitter between the acquisition	J_{acq}			5	µs	
Inter-die synchronicity [29]		8.45	9.08	9.71	µs	
Analog Diagnostics Cycle [30]	DTI_{ANA}			9	SPC triggers	
Digital Diagnostics Cycle [30]	DTI_{DIG}			9	SPC triggers	

Table 18 - SPC Mode Timing Specifications

[27] *SPC_RX_FILT_TIME is the parameter for the SPC trigger pulse filtering. Its unit is tick time. It must be aligned with the longest NIBBLE low time on the bus, in order to separate SENT pulses from SPC trigger pulses (NIBBLE_PULSE_FIXED[]).*
[28] *The worst-case step response time is specified, which is equal to twice a SPC trigger plus its SENT response time, when the field change happens right after the trigger pulse, see Figure 9. It is then 1 ms if the SPC trigger period is 0.5 ms.*
[29] *The absolute time difference of the magnetic information acquisition between the two dice in bus transmission mode, see section 11.4, based on 1.5 µs tick time*
[30] *Diagnostics response time, detailed description see section 15.2, e.g. with 500µs ECU frame time, the max. value is 4.5ms*

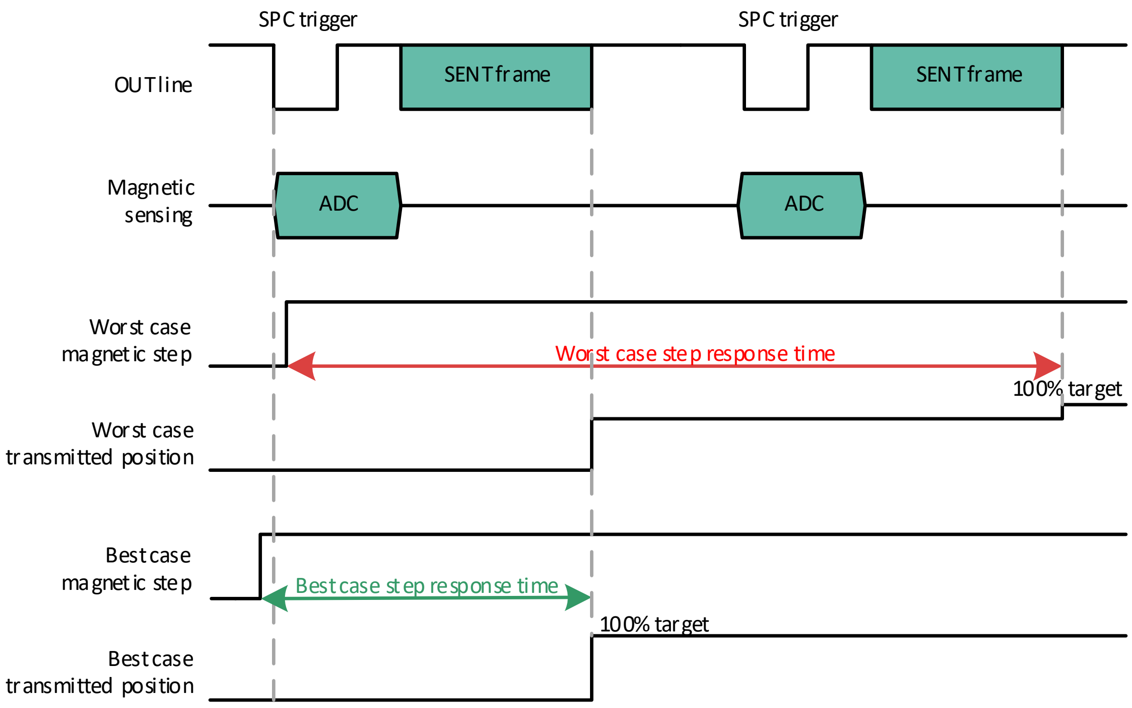

Figure 9 - Illustration of the best- and worst-case step response in SPC mode

8. Magnetic Field Specifications

Magnetic field specifications are valid for temperature range [-40; 160] °C unless otherwise noted.

8.1. Rotary Stray-field Immune Mode- Low Field variant (-1xx code)

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Number of magnetic poles	N_P	4[31]	-	-		
Magnetic Flux Density in X-Y plane	B_X, B_Y[32]			25[33]	mT	$\sqrt{B_X^2+B_Y^2}$ (this is not the useful signal)
Magnetic Flux Density in Z	B_Z			100	mT	(this is not the useful signal)
Magnetic in-plane gradient of in-plane field component	$\frac{\Delta B_{XY}}{\Delta XY}$	4.2	10		$\frac{mT}{mm}$	$\frac{1}{2}\sqrt{\left(\frac{dB_X}{dX}-\frac{dB_Y}{dY}\right)^2+\left(\frac{dB_X}{dY}+\frac{dB_Y}{dX}\right)^2}$ this is the useful signal (see Figure 10)
Magnet Temperature Coefficient	TC_m	-2400		0	$\frac{ppm}{°C}$	
Field Strength Resolution [34]	$\frac{\Delta B_{XY}}{\Delta XY}$	0.075	0.100	0.125	$\frac{mT}{mm\ LSB}$	Magnetic field gradient norm (12bits data)
Field too Low Threshold	B_{TH_LOW}	0.8	1.2	[35]	$\frac{mT}{mm}$	Typ is recommended value to be set by user (see 14.5.4)
Field too High Threshold [36]	B_{TH_HIGH}	70	100	102	$\frac{mT}{mm}$	

Table 19 - Magnetic specification for rotary stray-field immune mode - 180 degrees

Nominal performances apply when the useful signal $\Delta B_{XY}/\Delta XY$ is above the typical specified limit. Under this value, limited performances apply. See 9.2 for accuracy specifications. Stray-field immunity is tested according to ISO 11452-8:2015.

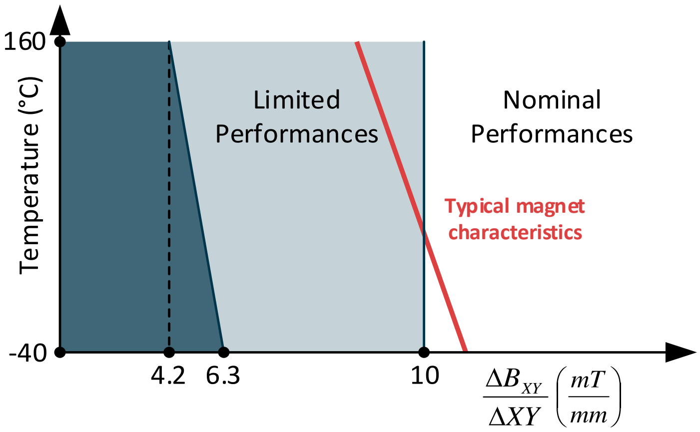

Figure 10 - Minimum useful signal definition for rotary stray-field immune application – 180 degrees

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[31] Due to 4 poles magnet usage, maximum angle measurement range is limited to 180°
[32] The condition must be fulfilled for all combinations of BX and BY.
[33] Above this limit, the IMC® starts to saturate, yielding to an increase of the linearity error.
[34] Only valid with default MAGNET_SREL_T[1..7] configuration
[35] Higher values of Field too Low threshold are not recommended by Melexis and shall only been set in accordance with the magnetic design and taking a sufficient safety margin to prevent false positive.
[36] Due to the saturation effect of the IMC®, the FieldTooHigh monitor detects only defects in the sensor

8.2. Standard/Legacy Mode (-3xx code)

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Number of magnetic poles	N_P	-	2	-		
Magnetic Flux Density in X-Y plane	B_x, B_y[32]			70	mT	$\sqrt{B_x^2 + B_y^2}$
Magnetic Flux Density in Z	B_z			100	mT	in absolute value
Useful Magnetic Flux Density Norm	B_{Norm}	10[37]	20		mT	$\sqrt{B_x{}^2 + B_y{}^2}$ (x-y mode) $\sqrt{B_x{}^2 + \left(\frac{1}{G_{IMC}} B_z\right)^2}$ (x-z mode) $\sqrt{B_y{}^2 + \left(\frac{1}{G_{IMC}} B_z\right)^2}$ (y-z mode) see 14.3.1 for sensing mode description.
IMC® gain	G_{IMC}		1.19			see [38]
Magnet Temperature Coefficient	TC_m	-2400		0	$\frac{\text{ppm}}{°\text{C}}$	
Field Strength Resolution [34]	B_{Norm}	0.075	0.100	0.125	$\frac{\text{mT}}{\text{LSB}}$	Magnetic field gradient norm expressed in 12bits words
Field Too Low Threshold	B_{TH_LOW}	0.4	4.0	[35]	mT	Typ is recommended value to be set by user (see 14.5.4)
Field Too High Threshold [36]	B_{TH_HIGH}	70	100	100	mT	

Table 20 - Magnetic specifications for Standard application

Nominal performances apply when the useful signal B_{Norm} is above the typical specified limit. Under this value, limited performances apply. See Table 25 in section 9.3 for accuracy specifications.

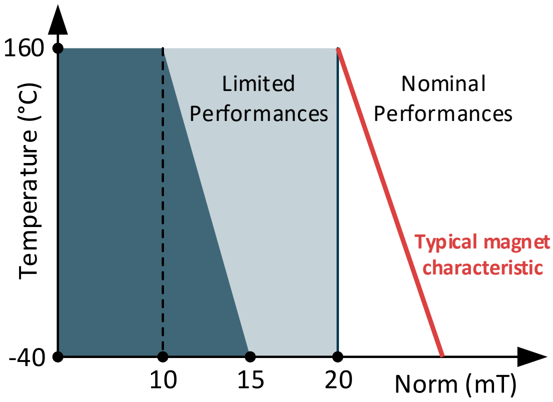


Figure 11 - Minimum useful signal definition for Standard/Legacy application

[37] *Below this value, the performances are degraded due to a reduction of the signal-to-noise ratio, signal-to-offset ratio.*
[38] *IMC® has better performance for concentrating in-plane (x-y) field components, resulting in a better magnetic sensitivity. A correction factor, called IMC gain has to be applied to the z field component to account for this difference.*

8.3. Rotary Stray-field Immune Mode- High Field Variant (-5xx code)

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Number of magnetic poles	N_P	4 (31)	-	-		
Magnetic Flux Density in X-Y plane	B_X, B_Y (32)			67 (33)	mT	$\sqrt{B_X^2 + B_Y^2}$ (this is not the useful signal)
Magnetic Flux Density in Z	B_Z			100	mT	(this is not the useful signal)
Magnetic in-plane gradient of in-plane field component	$\frac{\Delta B_{XY}}{\Delta XY}$	8.5	17		$\frac{\text{mT}}{\text{mm}}$	$\frac{1}{2}\sqrt{\left(\frac{dB_X}{dX} - \frac{dB_Y}{dY}\right)^2 + \left(\frac{dB_X}{dY} + \frac{dB_Y}{dX}\right)^2}$ this is the useful signal.
Magnet Temperature Coefficient	TC_m	-2400		0	$\frac{\text{ppm}}{°\text{C}}$	
Field Strength Resolution (34)	$\frac{\Delta B_{XY}}{\Delta XY}$	0.075	0.100	0.125	$\frac{\text{mT}}{\text{mm LSB}}$	Magnetic field gradient norm (12bits data)
Field too Low Threshold	B_{TH_LOW}	1.2	2	(35)	$\frac{\text{mT}}{\text{mm}}$	Typ is recommended value to be set by user (see 14.5.4)
Field too High Threshold (36)	B_{TH_HIGH}	80	100		$\frac{\text{mT}}{\text{mm}}$	

Table 21 - Magnetic specification for rotary stray-field immune

Nominal performances apply when the useful signal $\Delta B_{XY}/\Delta XY$ is above the minimum specified limit. See section 9.4 for accuracy specifications. Stray-field immunity is tested according to ISO 11452-8:2015.

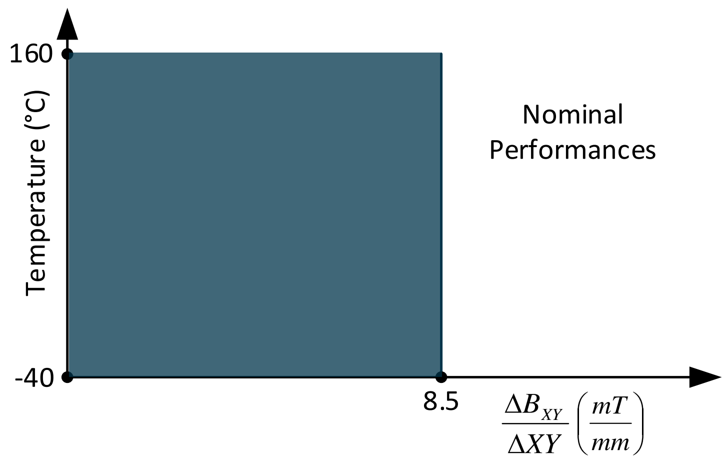


Figure 12 - Minimum useful signal definition for rotary stray-field immune application – 180 degrees

8.4. Rotary Stray-field Immune Mode- 360 degrees (-6xx code) for PCB-less package

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Number of magnetic poles	N_P	-	2	-		
Magnetic Flux Density in Z	B_Z			200	mT	
Magnetic in-plane gradient of Z field component	$\frac{\Delta B_Z}{\Delta XY}$	20			$\frac{mT}{mm}$	$\sqrt{\left(\frac{dB_Z}{dX}\right)^2 + \left(\frac{dB_Z}{dY}\right)^2}$ this is the useful signal.
Magnet Temperature Coefficient	TC_m	-2400		0	$\frac{ppm}{°C}$	$\frac{\Delta B_Z}{\Delta XY} \frac{(mT)}{(mm)}$
Field Strength Resolution [34]	$\frac{\Delta B_Z}{\Delta XY}$	0.075	0.100	0.125	$\frac{mT}{mm\ LSB}$	Magnetic field gradient norm (12bits data)
Field too Low Threshold	B_{TH_LOW}	5	8	[35]	$\frac{mT}{mm}$	Typ is recommended value to be set by user (see 14.5.4)
Field too High Threshold [36]	B_{TH_HIGH}	80	100	102	$\frac{mT}{mm}$	

Table 22 - Magnetic specification for rotary stray-field immune -360degrees

Nominal performances apply when the useful signal $\Delta B_Z/\Delta XY$ is above the minimum specified limit. See section 9.5 for accuracy specifications. Stray-field immunity is tested according to ISO 11452-8:2015.

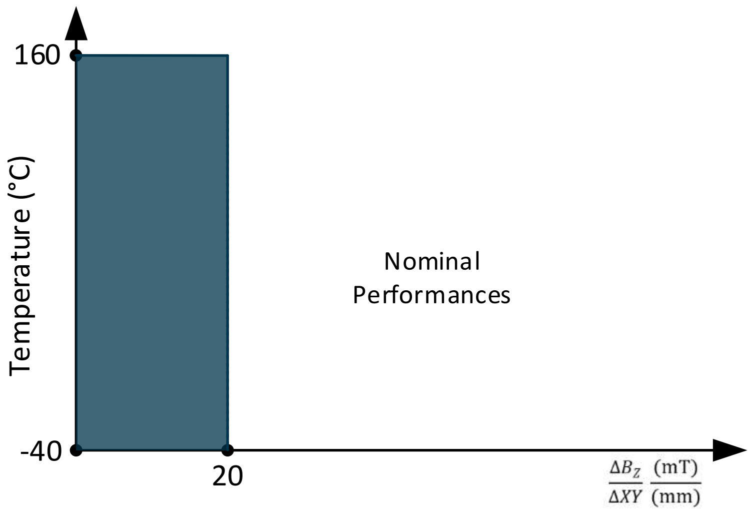


Figure 13 - Minimum useful signal definition for rotary stray-field immune application – 360 degrees

8.5. Rotary Stray-field Immune Mode - 360 degrees (-6xx code) for SMD packages

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Number of magnetic poles	N_P	2		-		
Magnetic Flux Density in Z	B_Z			100	mT	
Magnetic in-plane gradient of Z field component	$\frac{\Delta B_Z}{\Delta XY}$	10	20		$\frac{mT}{mm}$	$\sqrt{\left(\frac{dB_Z}{dX}\right)^2 + \left(\frac{dB_Z}{dY}\right)^2}$ this is the useful signal.
Magnet Temperature Coefficient	TC_m	-2400		0	$\frac{ppm}{°C}$	
Field Strength Resolution	$\frac{\Delta B_Z}{\Delta XY}$	0.075	0.100	0.125	$\frac{mT}{mm\ LSB}$	Magnetic field gradient norm (12bits data)
Field too Low Threshold	B_{TH_LOW}	5	8		$\frac{mT}{mm}$	Typ is recommended value to be set by user (see 14.5.4)
Field too High Threshold	B_{TH_HIGH}	80	100		$\frac{mT}{mm}$	

Table 23 - Magnetic specification for rotary stray-field immune mode – 360 degrees

Nominal performances apply when the useful signal $\Delta B_Z/\Delta XY$ is above the typical specified limit. Under this value, limited performances apply. See section 9.6 for accuracy specifications. Stray-field immunity is tested according to ISO 11452-8:2015.

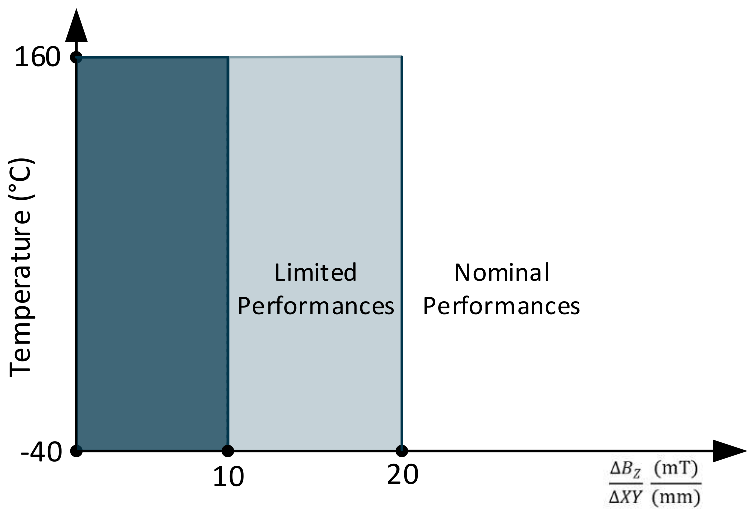


Figure 14 - Minimum useful signal definition for rotary stray-field immune application – 360 degrees

9. Accuracy Specifications

Accuracy specifications are valid for temperature range [-40;160] °C and supply voltage range [4.5; 5.5] V unless otherwise noted.

9.1. Definitions

This section defines several parameters, which will be used for the magnetic specifications.

9.1.1. Intrinsic Linearity Error

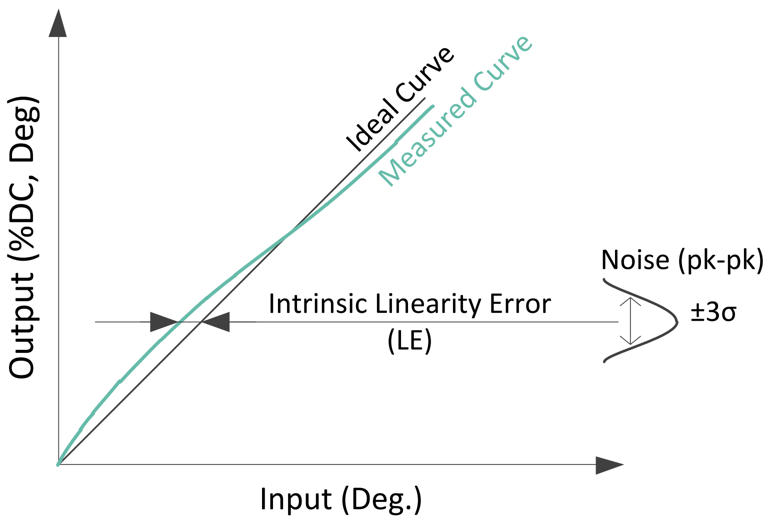


Figure 15 - Sensor accuracy definition

Figure 15 depicts the intrinsic linearity error in new parts. The Intrinsic Linearity Error refers to the IC itself (offset, sensitivity mismatch, orthogonality) considering an ideal magnetic field. Once associated to a practical magnetic construction and the associated mechanical and magnetic tolerances, the output linearity error increases. However, it can be significantly reduced with the multi-point end-user calibration (see 14.2).

9.1.2. Total Angle Drift

After calibration, the output angle of the sensor might still change due to temperature change, aging, etc. This is defined as the total drift $\partial\theta_{TT}$:

$$\partial\theta_{TT} = |\max\{\theta(\theta_{IN}, T, t) - \theta(\theta_{IN}, T_{RT}, t_0)\}|$$

where θ_{IN} is the input angle, T is the temperature, T_{RT} is the room temperature, and t is the elapsed lifetime after calibration. t_0 represents the status at the start of the operating life. Note the total drift $\partial\theta_{TT}$ is always defined with respect to the angle at room temperature. In this datasheet, T_{RT} is typically defined at 35°C, unless stated otherwise. The total drift is valid for all angles along the full mechanical range. The total drift is expressed as an unsigned value, to indicate the ideal minimum drift should be 0. In reality, the drift can happen in both positive and negative directions.

9.2. Rotary Stray-field Immune Mode- Low Field Variant (-1xx Code)

Valid before EoL calibration and for all applications under limited performances conditions described in section 8.1.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
XY - Intrinsic Maximum Error	L_E	-1		1	Deg.	
Noise [39]				0.5 0.35 0.25	Deg.	Filter = 0 Filter = 1 Filter = 2
XY - Total Drift	$\partial\theta_{TT\_XY}$			0.65	Deg.	Relative to 35°C
Hysteresis			0.1		Deg.	
Output Stray Field Immunity [40]	$\partial\theta_{FF}$			0.6	Deg.	In accordance with ISO 11452-8:2015, at 30°C, with 10mT/mm magnetic In-plane gradient of In-plane field component, and with stray-field strength of 4000A/m from any direction

Table 24 - Rotary stray-field immune magnetic performances

[39] $\pm 3\sigma$
[40] *Stray field induced error is linearly proportional to the stray field strength.*

9.3. Standard/Legacy Mode (-3xx Code)

Valid before EoL calibration and for all applications under nominal performance conditions described in section 8.2.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
XY - Intrinsic Linearity Error	L_{E_XY}	-1		1	Deg.	
XZ - Intrinsic Linearity Error	L_{E_XZ}	-2.5		2.5	Deg.	
YZ - Intrinsic Linearity Error	L_{E_YZ}	-2.5		2.5	Deg.	
Noise for nominal performance in section 8.2 in low power mode (-30x, -33x code) (39)				0.1	Deg.	Filter = 0, $\sqrt{B_x^2 + B_y^2}$ > 40mT
				0.2		Filter = 0
				0.1		Filter = 2
Noise for limited performance in section 8.2 in low power mode (-30x, -33x code) (39)				0.4	Deg.	Filter = 0
				0.28		Filter = 1
				0.2		Filter = 2
Noise for nominal performance in section 8.2 in high speed mode (-31x code) (39)				0.28	Deg.	Filter = 0
Noise for limited performance in section 8.2 in high speed mode (-31x code) (39)				0.56	Deg.	Filter = 0
XY - Total Drift	$\partial\theta_{TT\_XY}$			0.45	Deg.	for nominal performance
				0.6		for limited performance
XZ - Total Drift	$\partial\theta_{TT\_XZ}$			0.6	Deg.	for nominal performance
				0.8		for limited performance
YZ - Total Drift	$\partial\theta_{TT\_YZ}$			0.6	Deg.	for nominal performance
				0.8		for limited performance
Hysteresis				0.1	Deg.	for nominal performance
				0.2		for limited performance

Table 25 - Standard Mode Nominal Magnetic Performances

9.4. Rotary Stray-field Immune Mode- High Field Variant (-5xx Code)

Valid before EoL calibration and for all applications under nominal performance conditions described in section 8.3.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
XY - Intrinsic Linearity Error	L_{E_XY}	-1		1	Deg.	
Noise in high speed mode (-51x code) (39)				0.65 0.46 0.33	Deg.	Filter = 0 Filter = 1 Filter = 2
Noise in low power mode (-53x code) (39)				0.4 0.28 0.2	Deg.	Filter = 0 Filter = 1 Filter = 2
XY - Total Drift	$\partial\theta_{TT\_XY}$			0.5	Deg.	
Hysteresis			0.1		Deg.	
Output Stray Field Immunity (40)	$\partial\theta_{FF}$			0.3	Deg.	In accordance with ISO 11452-8:2015, at 30 °C, with typical magnetic In-plane gradient of In-plane field component, and stray-field strength of 4000A/m from any direction

Table 26 - Rotary stray-field immune magnetic performance – High Field Variant

9.5. Rotary Stray-field Immune Mode- 360 degrees (-6xx Code) for PCB-less package

Valid before EoL calibration and for all applications under nominal performances conditions described in section 8.4.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
XY - Intrinsic Linearity Error	L_{E_XY}	-1.8		1.8	Deg.	
Noise (39)				0.8 0.6 0.4	Deg.	Filter = 0 Filter = 1 Filter = 2
XY - Total Drift	$\partial\theta_{TT\_XY}$			1.0	Deg.	
Output Stray Field Immunity (40)	$\partial\theta_{FF}$			0.5	Deg.	In accordance with ISO 11452-8:2015, at 30°C, with 30mT/mm magnetic In-plane gradient of Z field component, and with stray-field strength of 4000A/m from any direction

Table 27 - Rotary stray-field immune magnetic performances for PCB-less package

9.6. Rotary Stray-field Immune Mode - 360 degrees (-6xx Code) for SMD packages

Valid before EoL calibration and for all applications under nominal performances conditions described in section 8.5.

Parameter	Symbol	Min	Typ	Max	Unit	Condition		
XY - Intrinsic Linearity Error	L_{E_XY}	-1.8		1.8	Deg.			
Noise [39]				0.6	Deg.	20mT/mm	Filter = 0	[-40,125] °C
				0.45			Filter = 1	
				0.3			Filter = 2	
				0.8	Deg.		Filter = 0	[-40,160] °C
				0.6			Filter = 1	
				0.4			Filter = 2	
				1.2	Deg.	10mT/mm	Filter = 0	[-40,125] °C
				0.85			Filter = 1	
				0.6			Filter = 2	
				1.7	Deg.		Filter = 0	[-40,160] °C
				1.2			Filter = 1	
				0.85			Filter = 2	
XY - Total Drift	$\partial\theta_{TT\_XY}$			0.7	Deg.	20mT/mm		[-40,125] °C
				1				[-40,160] °C
				0.9	Deg.	10mT/mm		[-40,125] °C
				1.4	Deg.			[-40,160] °C
Output Stray Field Immunity [40]	$\partial\theta_{FF}$			0.5	Deg.	In accordance with ISO 11452-8:2015, at 30°C, with 30mT/mm magnetic In-plane gradient of Z field component, and with stray-field strength of 4000A/m from any direction		

Table 28 - Rotary stray-field immune magnetic performances for SMD packages

10. Memory Specifications

Parameter	Symbol	Min	Typ	Max	Unit	Note
ROM	ROMsize		32		KB	1 bit parity check per 32bits word (single error detection)
RAM	RAMsize		1024		B	1 bit parity check per 16bits word (single error detection)
NVRAM	NVRAMsize		256		B	6 bits ECC per word 16b (single error correction, double error detection)

Table 29 - Memory Specifications

11. Output Accuracy and Protocol

11.1. Analog Output

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Thermal analog output Drift				0.2 0.3	%VDD	up to 125 °C up to 160 °C
Analog Output Resolution	R_{DAC}		12		bit	12bit DAC (Theoretical)
		-4		+4	LSB_{12}	INL (before EoL calibration), output clamped between 3-97%VDD
		-1.0		1.5	LSB_{12}	DNL
Ratiometric Error		-0.1		0.1	%VDD	

Table 30 - Analog output accuracy

11.2. SENT (Single Edge Nibble Transmission) Output

The MLX90376 provides a digital output signal compliant with SAE J2716 Revised APR2016.

11.2.1. Sensor message definition

The MLX90376 repeatedly transmits a sequence of pulses, corresponding to a sequence of nibbles (4 bits), with the following sequence:

- Calibration/Synchronization pulse period 56 clock ticks to determine the time base of the SENT frame
- One 4-bit Status and Serial Communication nibble pulse
- A sequence of one up to six 4-bit data nibbles pulses representing the values of the signal(s) to be transmitted. The number of nibbles will be fixed for each application of the encoding scheme (i.e. Single Secure sensor format A.3, Throttle position sensor A.1)
- One 4-bit Checksum nibble pulse- One optional pause pulse

See also SAE J2716 APR2016 for general SENT specification.

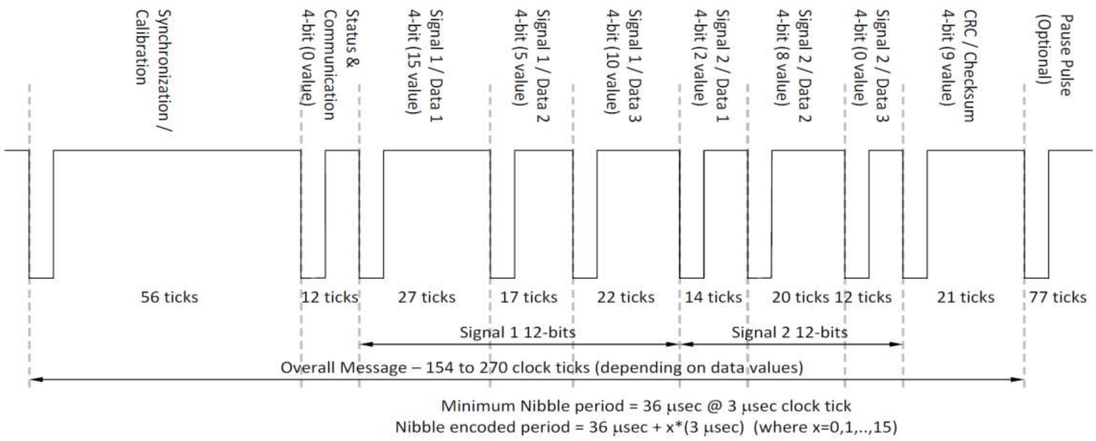


Figure 16 - SENT message encoding example for two 12bits signals

11.2.2. Sensor message frame contents

The SENT output transmits a sequence of data nibbles, according to the following configurations:

Description	Symbol	Min	Typ	Max	Unit	Description
Clock tick time	Tick Time		3	6	µs	Main use cases: Normal SENT, 3µs tick time Slow SENT, 6µs tick time
Number of data nibbles	Xdn	3	6			
Frame duration (no pause pulse)	Npp	154		270	ticks	6 data nibbles
Frame duration with pause pulse	Ppc	282	320	922	ticks	
Sensor type			A.1 A.3			Dual Throttle Position sensors Single Secure sensors

Table 31 - SENT Protocol Frame Definition

11.2.3. SENT Format Option

The default SENT format option of MLX90376 is Single Secure Sensor A.3 (H.4). The MLX90376 SENT transmits a sequence of data nibbles; according to single secure sensor format defined in SAE J2716 appendix H.4 [41]. The frame contains 12-bit angular value, an 8 bit rolling counter and an inverted copy of the most significant nibble of angular value.

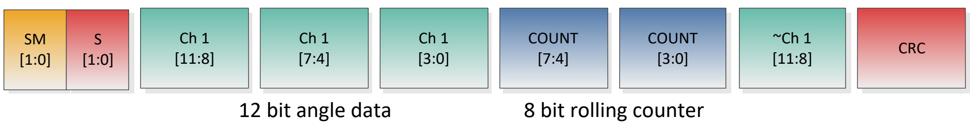


Figure 17 - H.4 Single Secure Sensor Frame Format

Shorthand Description	Tick time	Data nibbles	Pause Pulse	Serial message	Data format
SENT2016-03.0us-6dn-ppc(366.0)-esp-A.3	3µs	6	Y	Enhanced	H.4
SENT2016-03.0us-6dn-ppc(366.0)-nsp-A.3	3µs	6	Y	None	H.4
SENT2016-03.0us-6dn-npp-nsp-A.3	3µs	6	N	None	H.4
SENT2016-##-#us-#dn-###()-###-A.3	1..12	6	Y/N	En/None	H.4

Table 32 - H.4 Single Secure Sensor Shorthand examples

[41] *As referenced from section A.3 Single Secure Sensor of the standard.*

11.2.4. Start-up behaviour

The circuit will send initialisation frames once start-up is done but angle measurement initialisation sequence is not yet complete. These initialisation frames content can be chosen by user with the following option:

SENT_INIT_GM	Initialisation frame value	Comments
0	0x000	SAE compliant
1	0xFFF	OEM requirement

Table 33 - Initialization Frame Content Definition

11.2.5. Output configuration

In SENT mode, the MLX90376 can be configured in open drain mode, normal push-pull mode, as well as an enhanced emission mode, which is the default configuration, see also section 14.1.1.

The tick time is the unit reference for SENT. The default tick time value is 3µs.

The output resistive load, e.g. the external pull-up or pull-down resistor should be carefully selected, because the MLX90376 has a built-in high order low pass filter. A large resistive load will deteriorate the generated SENT signal, and could make the output signal not comply with the SENT specifications, such as the fall times and the minimum output voltages, e.g. parameters $V_{satD\_lopp}/V_{satD\_hipp}$ in Table 10 in chapter 6. In principle, the values in Table 10 in chapter 6 should be considered, which means it is not recommended to have a resistive load value smaller than 10kΩ, and a resistive load value smaller than 3kΩ should be avoided. The maximum output resistive load value should be less than 55kΩ to avoid unexpected impact from leakage current.

11.2.6. SENT Output Timing configuration

Different SENT output timing configurations are listed in the following tables

SENT_TICK_TIME	Tick time configuration	Description
0	6 µs	
1	1 µs	Not recommended
2	2 µs	Not recommended
3	3 µs	Standard SENT
4	4 µs	Not recommended
5	5 µs	Not recommended
6	12 µs	Do not use
7	24 µs	Do not use

Table 34 - SENT Tick Time Configuration (-x30 code)

NIBBLE_PULSE_CONFIG	High/low time configuration
2	Fixed low time (5 ticks)
3	Fixed high time (6 ticks)

Table 35 - SENT Nibble configuration (high/low times)

11.2.7. Serial message channel (slow channel)

Serial data is transmitted sequentially in bit number 3 and 2 of the status and communication nibble. A serial message frame stretches over 18 consecutive SENT data messages from the transmitter. All 18 frames must be successfully received (no errors, calibration pulse variation, data nibble CRC error, etc.) for the serial value to be received.

11.2.7.1. Enhanced Serial Message (ESM)

Enhanced serial message with 12-bit data and 8-bit message ID is used (SAE J2716 APR2016 5.2.4.2, Figure 5.2.4.2-2). According to the standard, SM[0] contains a 6bits CRC followed by a 12-bits data. Message content is defined by a 8-bit message ID transmitted in the SM[1] channel. Correspondence between ID and message content is defined in the tables below (Table 36, Table 37 and Table 38).

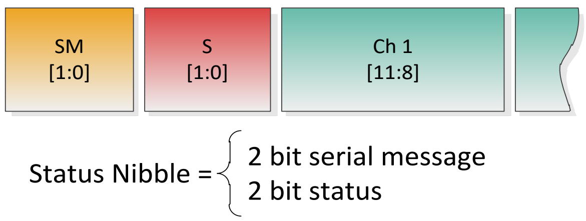


Figure 18 - SENT Status Nibble and Serial Message

By default, the short sequence consisting of a cycle of 24 data is transmitted (Table 36). An extended sequence can be used through configuration of SENT_SLOW_EXTENDED (Table 37). Additionally, the norm of the B field detected by the sensor can be returned at the end of the sequence by setting SENT_SLOW_BFIELD (Table 38)

#	8-bit ID	Item	Source data
1	0x01	Diagnostic error code	Current status code from RAM
2	0x06	SENT standard revision	SENT_REV from NVRAM
3	0x01	Diagnostic error code	Current status code from RAM
4	0x05	Manufacturer code	SENT_MAN_CODE from NVRAM
5	0x01	Diagnostic error code	Current status code from RAM
6	0x03	Channel 1 / 2 Sensor type	SENT_SENSOR_TYPE from NVRAM
7	0x01	Diagnostic error code	Current status code from RAM
8	0x07	Fast channel 1: X1	SENT_CHANNEL_X1 from NVRAM
9	0x01	Diagnostic error code	Current status code from RAM
10	0x08	Fast channel 1: X2	SENT_CHANNEL_X2 from NVRAM
11	0x01	Diagnostic error code	Current status code from RAM
12	0x09	Fast channel 1: Y1	SENT_CHANNEL_Y1 from NVRAM
13	0x01	Diagnostic error code	Current status code from RAM
14	0x0A	Fast channel 1: Y2	SENT_CHANNEL_Y2 from NVRAM
15	0x01	Diagnostic error code	Current status code from RAM
16	0x23	(Internal) temperature	Current temperature from RAM
17	0x01	Diagnostic error code	Current status code from RAM
18	0x29	Sensor ID #1	SENT_SENSOR_ID1 from NVRAM
19	0x01	Diagnostic error code	Current status code from RAM
20	0x2A	Sensor ID #2	SENT_SENSOR_ID2 from NVRAM
21	0x01	Diagnostic error code	Current status code from RAM
22	0x2B	Sensor ID #3	SENT_SENSOR_ID3 from NVRAM
23	0x01	Diagnostic error code	Current status code from RAM
24	0x2C	Sensor ID #4	SENT_SENSOR_ID4 from NVRAM

Table 36 - SENT Enhanced Slow Channel Standard Data Sequence

#	8bit ID	Item	Source data
25	0x01	Diagnostic error code	Current status code from RAM
26	0x90	OEM Code #1	SENT_OEM_CODE1 from NVRAM
27	0x01	Diagnostic error code	Current status code from RAM
28	0x91	OEM Code #2	SENT_OEM_CODE2 from NVRAM
29	0x01	Diagnostic error code	Current status code from RAM
30	0x92	OEM Code #3	SENT_OEM_CODE3 from NVRAM
31	0x01	Diagnostic error code	Current status code from RAM
32	0x93	OEM Code #4	SENT_OEM_CODE4 from NVRAM
33	0x01	Diagnostic error code	Current status code from RAM
34	0x94	OEM Code #5	SENT_OEM_CODE5 from NVRAM
35	0x01	Diagnostic error code	Current status code from RAM
36	0x95	OEM Code #6	SENT_OEM_CODE6 from NVRAM
37	0x01	Diagnostic error code	Current status code from RAM
38	0x96	OEM Code #7	SENT_OEM_CODE7 from NVRAM
39	0x01	Diagnostic error code	Current status code from RAM
40	0x97	OEM Code #8	SENT_OEM_CODE8 from NVRAM

Table 37 - SENT Slow Channel Extended Data Sequence

#	8bit ID	Item	source data
25	0x80	Field Strength	SENT_SLOW_EXTENSION 0: Disabled. No further extension 1: NTC value 2: field-strength temperature compensated, before magnet sensitivity compensation 3: field-strength temperature and gain independent (standard sequence)
41	0x80	Field Strength	SENT_SLOW_EXTENSION 0: Disabled. No further extension 1: NTC value 2: field-strength temperature compensated, before magnet sensitivity compensation 3: field-strength temperature and gain independent (extended sequence)

Table 38 - SENT Slow Channel Magnetic Field Norm ID and position

For Field Strength encoding, see section 14.5.4.

11.2.7.2. Short Serial Message (SSM)

Short serial message with 8-bit data and 4-bit message ID is used (SAE J2716 APR2016 5.2.4.1, Figure 5.2.4.1-1). According to the standard, it contains a 8-bit data followed by a 4-bit CRC.

#	4-bit ID	Item	Source data
1	0x01	Diagnostic error code	Current status code from RAM
2	0x06	SENT standard revision	SENT_REV from NVRAM
3	0x01	Diagnostic error code	Current status code from RAM
4	0x05	Manufacturer code	SENT_MAN_CODE from NVRAM
5	0x01	Diagnostic error code	Current status code from RAM
6	0x03	Channel 1 / 2 Sensor type	SENT_SENSOR_TYPE from NVRAM
7	0x01	Diagnostic error code	Current status code from RAM
8	0x07	Fast channel 1: X1	SENT_CHANNEL_X1 from NVRAM
9	0x01	Diagnostic error code	Current status code from RAM
10	0x08	Fast channel 1: X2	SENT_CHANNEL_X2 from NVRAM
11	0x01	Diagnostic error code	Current status code from RAM
12	0x09	Fast channel 1: Y1	SENT_CHANNEL_Y1 from NVRAM
13	0x01	Diagnostic error code	Current status code from RAM
14	0x0A	Fast channel 1: Y2	SENT_CHANNEL_Y2 from NVRAM
15	0x01	Diagnostic error code	Current status code from RAM
16	0x02	(Internal) temperature	Current temperature from RAM
17	0x01	Diagnostic error code	Current status code from RAM
18	0x0B	Sensor ID #1	SENT_SENSOR_ID1 from NVRAM
19	0x01	Diagnostic error code	Current status code from RAM
20	0x0C	Sensor ID #2	SENT_SENSOR_ID2 from NVRAM
21	0x01	Diagnostic error code	Current status code from RAM
22	0x0D	Sensor ID #3	SENT_SENSOR_ID3 from NVRAM
23	0x01	Diagnostic error code	Current status code from RAM
24	0x0E	Sensor ID #4	SENT_SENSOR_ID4 from NVRAM
25	0x01	Diagnostic error code	Current status code from RAM
26	0x04	Field Strength	Field Strength (mapped to 8 bit)

Table 39 - SENT Short Serial Slow Channel Standard Data Sequence

11.2.8. Serial Message Error Code

11.2.8.1. Enhanced Serial Message (ESM)

The list of error and status messages transmitted in the 12-bit Serial Message data field when Serial Message 8-bit ID is 0x01, is given in the Table 40. The error is one-hot encoded and therefore each bit is linked to one or several diagnostics. Only the first error detected during a diagnostics cycle is reported, and serial message error code will be updated at every diagnostics cycle. The serial message error code will only be cleared out once all the errors disappear. This mechanism ensures only one error at a time takes control of the error debouncing counter (see 14.5.2).

The MSB acts as an error Flag when SENT_DIAG_STRICT is set. This bit will be high only when an error is present. This bit can be kept high even if no error is present (SENT_DIAG_STRICT = 0).

Bit Nb	12 Bit Data (hex)	Diagnostic	Comments
-	0x000 / 0x800	No error	Programmable (see SENT_DIAG_STRICT in section 12)
0	0x801	GAINOOS	Magnetic Signal Conditioning Gain Clamping
1	0x802	FieldTooLow	Fieldstrength is below defined low threshold (see section 14.5.4)
2	0x804	FieldTooHigh	Fieldstrength is above defined low threshold (see section 14.5.4)
3	0x808	ADCclip	ADC is saturated, either low or high
4	0x810	ADC_test	ADC made wrong conversion
5	0x820	Analog Supply Monitors	Detects VDDA (VDEC) over and under voltage or VDD under voltage
6	0x840	Digital Supply Monitors	Detects VDDD (1.8V internal digital supply) overvoltage
7	0x880	RoughOffset	Hall Element offset monitor
8	0x900	Over/Under Temp / ADCdrop	Temperature sensor monitor (see section 14.5.3) / ADC conversion interruption
9	0xA00	DSP overflow / HE_Bias / Analog Front End	DSP overflow / Hall Element biasing issue / Analog front end self-test
10	0xC00	Supply Bias Current / Stress Range	Current biasing system monitor / Stress Sensor Readout
11	0x800	Extra Error Flag	set to one if any error present (only when SENT_DIAG_STRICT = 1). Otherwise, always high.

Table 40 - SENT Serial Message Error Code for Enhanced Serial Message

11.2.8.2. Short Serial Message (SSM)

The list of error and status messages transmitted in the 8-bit Serial Message data field when Serial Message 8-bit ID is 0x01, is given in the Table 41. The error is one-hot encoded and therefore each bit is linked to one or several diagnostics. Only the first error detected is reported and serial message error code will not be updated until all the errors have disappeared. This mechanism ensures only one error at a time takes control of the error debouncing counter (see 14.5.2).

Bit Nb	8 Bit Data (hex)	Diagnostic	Comments
-	0x00	No error	
0	0x01	GAINOOS	Magnetic Signal Conditioning Gain Clamping
1	0x02	FieldTooLow	Fieldstrength is below defined low threshold (see 14.5.4)
2	0x04	FieldTooHigh	Fieldstrength is above defined high threshold (see 14.5.4)
3	0x08	ADCclip / ADC_test	ADC is saturated, either low or high / ADC made wrong conversion
4	0x10	Analog Supply Monitors / Digital Supply Monitors / Supply Bias Current / Stress Range	Detects VDDA (VDEC) over and under voltage or VDD under voltage / Detects VDDD (1.8V internal digital supply) overvoltage / Current biasing system monitor / Stress Sensor Readout
5	0x20	RoughOffset	Hall Element offset monitor
6	0x40	Over/Under Temp / ADCdrop	Temperature sensor monitor (see 14.5.3) / ADC conversion interruption

Table 41 - SENT Serial Message Error Code for Short Serial Message

11.2.9. SENT configuration shorthand definition

Shorthand description	Format	Req	90376 programmable setting
SENT SAE J2716 Rev	SENT xxxx	2007 2008 2010 2016	CRC_2007 0 > 2007 1 2007
Clock Tick length [µs]	XX.X µs	1<xx<12	SENT_TICK_TIME 0 SENT 6µs 1 SENT 1µs 2 SENT 2µs 3 SENT 3µs 4 SENT 4µs 5 SENT 5µs
SENT format option	H.x	SENT format	SENT_FC_FORMAT 0: format H.1 1: format H.1 2: format H.2 3: format H.3 4: format H.4 5: format H.5 6: format H.6 7: format H.7
Pause Pulse Option	npp ppc (xxx.0) xxx	No pause Pulse Pause Pulse with const. frame length Frame Length (in clock ticks)	PROTOCOL 0 = npp 2 = ppc T_FRAME xxx > 282…922
Use of Serial protocol	nsp ssp esp	No serial protocol Short serial protocol Enhanced serial protocol	SERIAL_CONFIG 1 nsp 2 ssp 3 esp

Table 42 - SENT Shorthand Description

11.3. PWM (pulse width modulation) Output

11.3.1. Definition

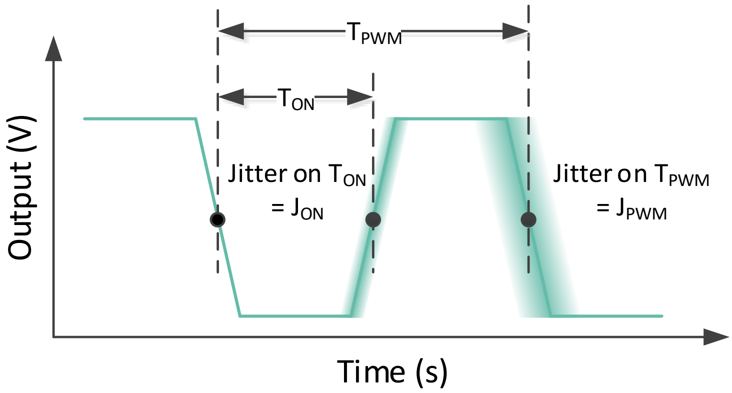


Figure 19 - PWM Signal definition

Parameter	Symbol	Test Conditions
PWM period	T_{PWM}	Trigger level = 50% V_{DD}
Rise time, Fall time	t_{rise}, t_{fall}	Between 10% and 90% of V_{DD}
Jitter	J_{ON}, J_{PWM}	±3σ for 1000 successive acquisitions with clamped output
Duty Cycle	%DC	100 * T_{ON} / T_{PWM}

Table 43 - PWM Signal definition

11.3.2. PWM performances

Parameter	Symbol	Min	Typ	Max	Unit	Condition
PWM Output Resolution	R_{pwm}		12		bit	
PWM %DC Jitter	J_{DC}			0.03	%DC	Push-Pull, 2kHz, C_L=10nF, R_{LPU} =10kΩ
PWM Period Jitter	J_{pwm}	-	-	500	ns	Push-Pull, 2kHz, C_L=10nF, R_{LPU}=10kΩ
PWM %DC thermal drift			0.02	0.05	%DC	Push-Pull, 2kHz, C_L=10nF, R_{LPU}=10kΩ

Table 44 - PWM Signal Specifications

11.4. SPC (Short PWM Code) Output

11.4.1. General Definition

The MLX90376 configured in SPC output mode (see Table 3) provides an SPC frame according to the SPC2015 rev1.0. It is an extension of the SAE J2716 SENT protocol. It allows on-demand transmission of one data frame where the master triggers the transfer of data. The transmission of the SPC frame is always triggered by the master in every mode (synchronous and with ID selection).

The SPC output of the MLX90376 transmits a sequence of data nibbles, according to the following configurations:

Description	Symbol	Min	Typ	Max	Unit	Description
Clock tick time	tickTime	1.5[42]		12	µs	Main use cases: SPC, 1.5µs tick time (default) Normal SENT, 3µs tick time Slow SENT, 6µs tick time (see section 12)
Number of data nibbles	Xdn	3		6		
Frame duration (no pause pulse)	Npp	154		270	ticks	6 data nibbles
Frame duration with pause pulse	Ppc	282	320	922	ticks	
Sensor type	A.3					Single Secure sensors

Table 45 - SENT Protocol Frame Definition

11.4.2. Tick Time requirements

The basic SPC protocol unit time is defined as 1.5 µs. The protocol standard requires a tick time variation of no more than 20% for legacy applications and 10% for general applications.

11.4.3. Output Configuration

In SPC mode, the MLX90376 can be configured in open drain or push-pull mode with enhanced emission mode, see section 14.1.1.

The default output driver configuration is to send the SENT frame in push-pull mode.

Users can select three options (see parameter SPC_PP_Option, in section 12):

- IC is always in open drain
- IC sends the SENT frame from a pre-defined timer (SPC_OUT_ON_TH) to CRC in push-pull. It then returns to high-Z
- IC sends the SENT frame from a pre-defined timer (SPC_OUT_ON_TH) until end of a pre-defined timer (SPC_OUT_OFF_TH). It then returns to high-Z.

[42] *Please contact our Direct Sales Team if other options then main use cases are required.*

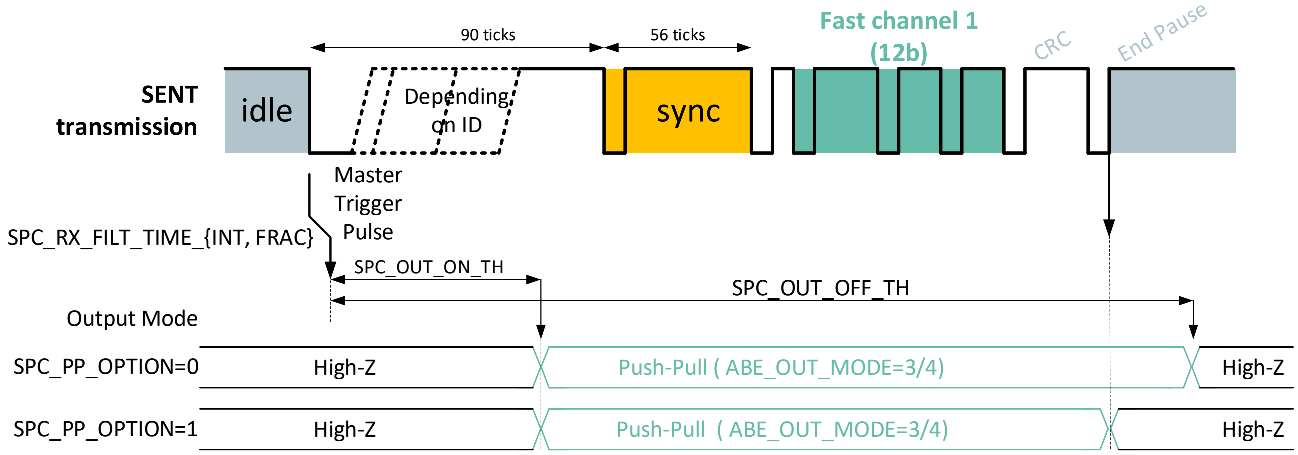


Figure 20 - SPC output driver state switching

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Push-Pull Duration	$T_{push\text{-}pull}$	280		550	µs	Configurable Duration how long IC stays in push-pull once sync pulse of SENT frame starts.

Table 46 - Push-pull duration in SPC mode

The sensor output driver can also be configured as open-drain to enable the master to drive the line. Initially the line is at high level, the chip is waiting for the master to pull it low. This state is called ‘Idle state’, meaning the sensor is not transmitting any data. At a given time, the master will send a trigger low pulse along the line. The embedded CPU of the sensor will measure this master pulse length. If it is recognized as a valid trigger, the chip will answer by sending back an SPC frame containing the current data. Several configurations of the SPC frame are available. If the trigger pulse is not valid, the chip will not transmit any data, keeping the line free. In order to set up the permanent open-drain mode (NV_ABE_OUT_MODE=1), it is important to configure the parameters NV_SPC_OUT_ON_TH and NV_SPC_OUT_OFF_TH thresholds according to the FRAME settings.

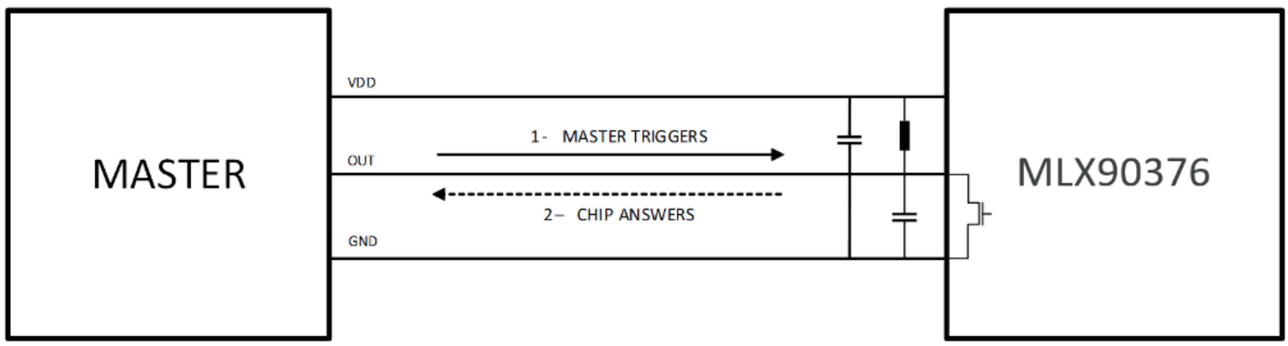


Figure 21 - SPC standard master-slave configuration

Like in SENT, the tick time is the unit reference for SPC. It can be as low as 0.5µs enabling fast transmission rate and short frames. However, the default tick time value is 1.5µs in SPC mode, to benefit from the fast acquisition and magnetic processing of the device.

For the MLX90376, the output resistance, e.g. the external pull-up or pull-down resistor should be carefully selected, because the MLX90376 has a built-in high order low pass filter, too heavy resistive load will deteriorate the generated SPC signal, and could make the output signal not comply to the SPC specifications, such as the fall times and the minimum output voltages, i.e. parameters V_{satD_lopp}/V_{satD_hipp} and V_{satD_loie}/V_{satD_hiie} in section 6. In principle, the values section 6 should be considered, which means it is not recommended to have a resistive load value smaller than 10kΩ, and a resistive load value smaller than 3kΩ should be avoided. The maximum output resistive load value should be less than 55kΩ to avoid unexpected impact from leakage current.

Furthermore, the output capacitance should also be properly chosen together with the output resistive load to correspondingly match the application, e.g. tick time, SPC ID, etc. to allow appropriate time window for the trigger pulse reception. The worst case scenario occurs for SPC ID0, where the trigger pulse should be recognized within only 4 ticks (refer to Table 50 and Figure 26 in section 11.4.7), resulting in 6 µs time window for 1.5 µs tick time SPC protocol. Therefore, RC time constant should be less than 6 µs in such application. When the time window for the trigger pulse reception changes, the resistive and capacitive load on output can be scaled correspondingly. It is also important to note that the mentioned capacitive load refers to the total load on the bus, meaning the value should be equally divided if there are multiple sensors connected, also the load on the ECU side should be taken into account and scaled properly.

11.4.4. SPC Output Timing configuration

Different SPC output timing configurations are listed in the following table:

SENT_TICK_TIME	Tick time configuration	Description
0	3 µs	
1	0.5 µs	
2	1 µs	
3	1.5 µs	Default SPC
4	2 µs	
5	2.5 µs	
6	6 µs	
7	12 µs	

Table 47 - SPC Tick Time Configuration

11.4.5. Frame Content

11.4.5.1. Global Definition

A message frame consists of the following sequence:

- Trigger pulse
- Synchronization pulse
- Status and communication nibble
- Data nibbles
- Checksum nibble
- End Lone pulse

The overall scheme of the SPC frame transmission is described in the following figure.

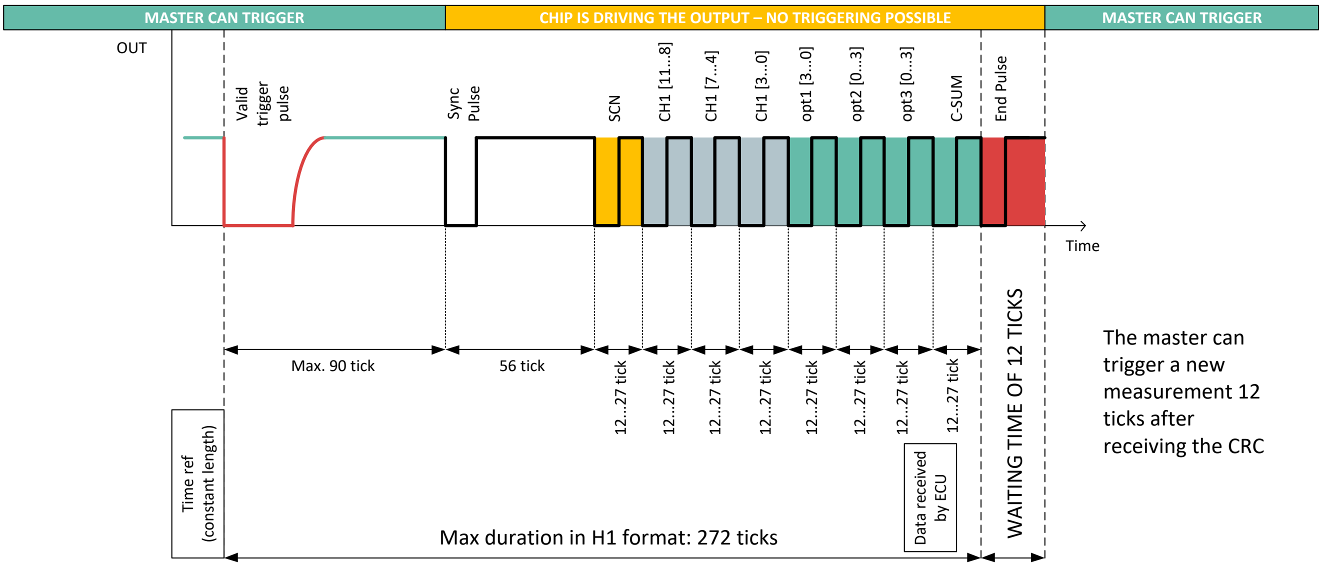


Figure 22 - SPC Frame description

11.4.5.2. Trigger Pulse

The trigger pulse is considered to be part of the SPC frame. The timing related to this trigger pulse is critical as it is initializing the data transfer. The sensor is monitoring the line and computes the duration the line is kept low by the master. This time is called "master low time".

Parameter	Symbol	Min	Typ	Max	Unit
Falling edge threshold	V_{thfSPC}	1.1	1.32	1.7	V
Rising Edge Threshold	V_{thrSPC}	1.25	1.52	1.8	V

Table 48 - SPC Master Trigger Pulse Specifications

The falling edge of the trigger pulse is considered to be the reference of the protocol. The master low time is quantized using clock ticks.

After a non-valid trigger detected, a blanking time of five unit times (counted from the detected rising edge of the trigger pulse) is used by the sensor, before the next trigger measurement is performed. This concept improves EMC robustness and avoids unwanted answer from the chip if the line is subject to spikes.

After detection of a valid trigger and expiration of the trigger pulse time according to the selected transmission mode the sensor starts with the remaining protocol frame.

11.4.5.3. Status and communication nibble (SCN)

The status nibble contains information for error reporting and some optional information like the chip ID or slow channel data.

The position of the 2 status bits and 2 ID bits in SPC mode of MLX90376 complies with the one specified in the SPC standard, but can be reversed if the SENT-standard definition is preferred.

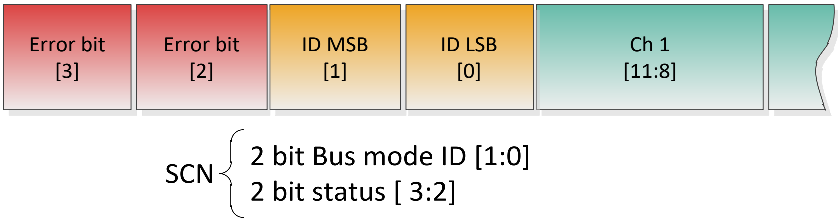


Figure 23 - SPC Bus Transmission Mode Multiplex Example (SPC_SCN_BIT_ORDER=1)

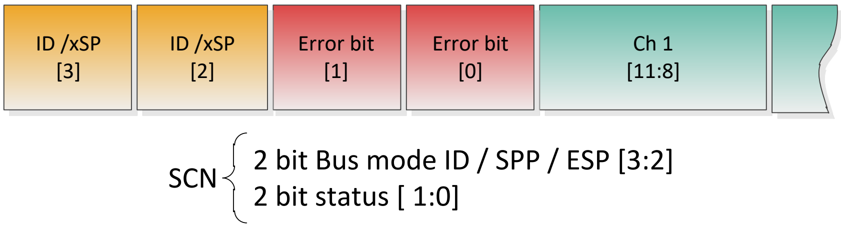


Figure 24 - SENT Transmission Mode Multiplex Example (SPC_SCN_BIT_ORDER=0)

11.4.5.4. Data Nibble

The definition of the data nibbles in SPC matches with SENT. The number of data nibbles transmitted is determined by frame format configured. The data content is programmable. By default, 12 bits of data are transmitted in 3 nibbles.

11.4.5.5. Checksum Nibble

SPC protocol allows transmission of error/warning flags in the status and communication nibble. Then it is highly recommended to take this nibble into the checksum calculation. This option is programmable in the MLX90376. Nevertheless, to be SENT compatible, it is possible to limit the checksum input data to data nibbles only.

MLX90376 also supports the SPC improved nibble checksum algorithms (for the SENT nibbles), method-E and method-O.

11.4.5.6. Pause Pulse

The MLX90376 generates a pulse with a length of 12 clock ticks after transmission of checksum nibble. In that case the master cannot trigger the chip. During that period, MLX90376 is still holding the line. The blanking time is programmable, see parameters SPC_OUT_ON_TH, SPC_OUT_OFF_TH in section 12.

11.4.5.7. Temperature encoding

The temperature field in the SPC frames shall be encoded on 8bits (least significant nibble transmitted first), according to the SENT standard section A.5.3.2 and E.2.2.1.

11.4.6. Synchronous Transmission Mode

In the SPC synchronous mode, the sensor responds to a low pulse of duration between 1.5 and 4 tick times. When using this mode, the time between the end of the trigger pulse and the start of the SENT frame shall be set properly [43], in order to ensure the synchronisation between the master and the chip, and the data gets acquired in the same frame, which is guaranteed with the condition of 3 µs tick time.

[43] *Please contact Melexis application service for detailed support.*

Parameter	Symbol	Min	Typ	Max	Unit
SPC Synchronous Mode Trigger Low Time	$t_{mlowSPC}$	1.5	2.75	4	ticks

Table 49 - SPC Synchronous Timings

11.4.7. Bus Transmission Mode

In the on-demand timing modes, the sensor responds to SPC trigger pulses from the master when its low pulse time corresponds to its pre-programmed ID. The selection of the ID is done with the parameter SPC_ID.

Parameter	Symbol	SPC_CHIP_ID	Min	Typ	Max	Unit	Remark
Bus Mode Master Low Time	$t_{mlowSPC}$	0	8		15	ticks	
		1	16		28	ticks	
		2	29		49	ticks	
		3	50		82	ticks	
Total trigger time	t_{mtrSPC}	-	-	90	-	ticks	master trigger pulse, independent of SPC_ID, not programmable

Table 50 - Bus Transmission Mode Timings

The ECU is able to trigger only one chip on a bus. The maximum amount of chip on the bus line is 4. Each chip must have its output configured to open-drain with a different ID.

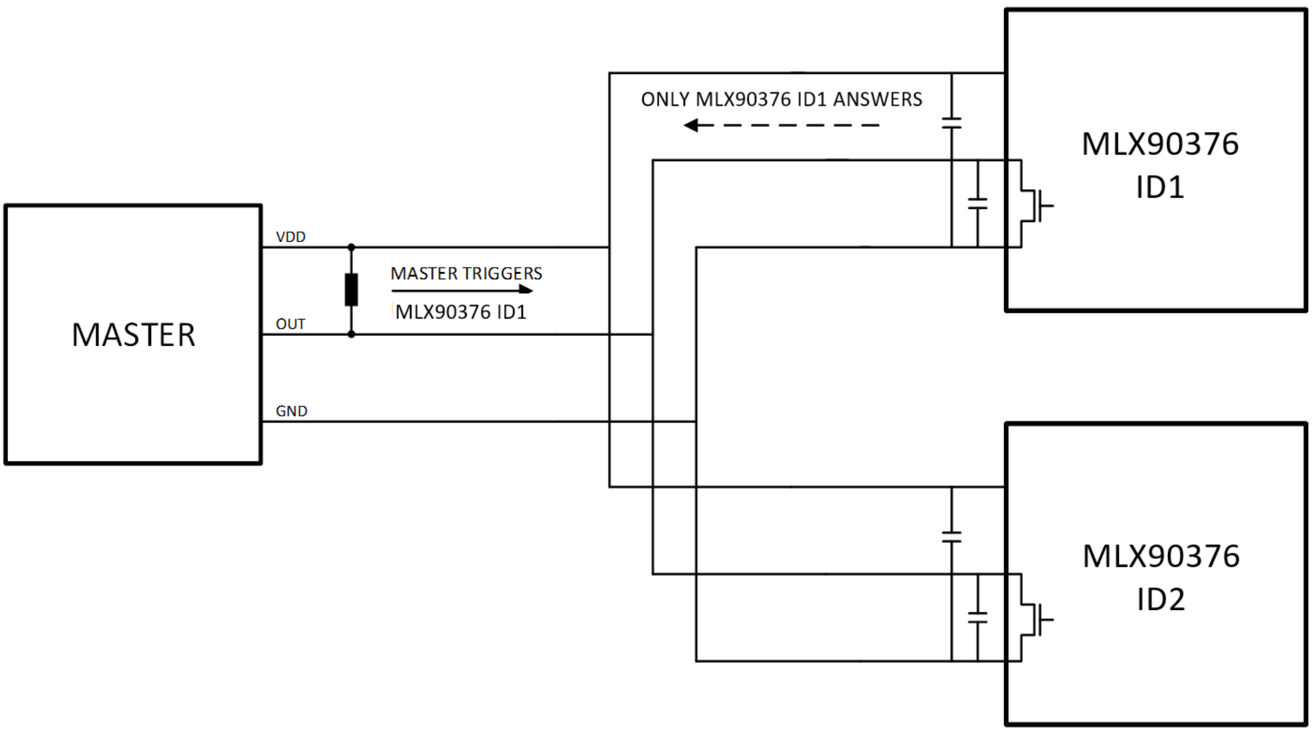


Figure 25 - SPC Bus Transmission Mode Multiplex Example

Figure 26 shows the timing diagram of the trigger pulse reception depending on the SPC ID.

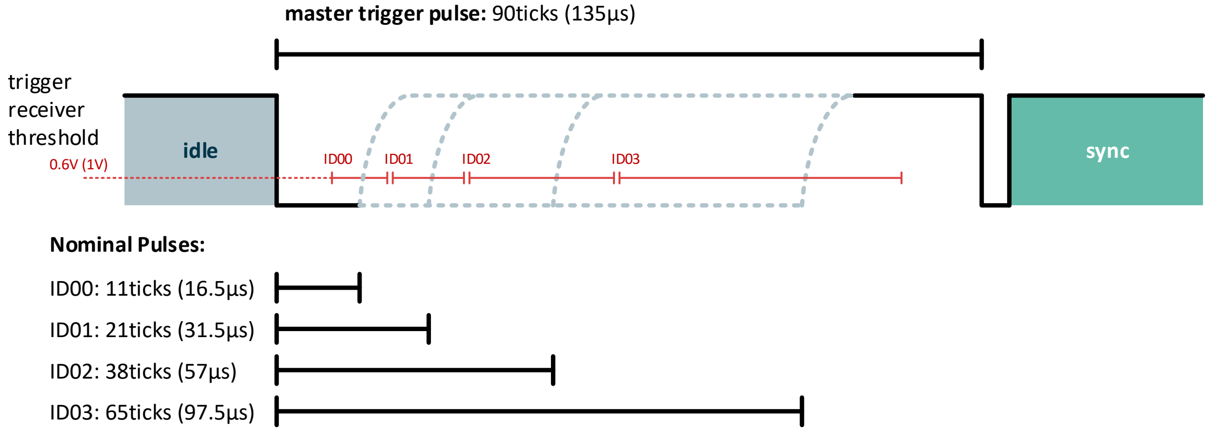


Figure 26 - Time Window for the Trigger Pulse Reception

Notes:

- ID01 and ID03 are advised when only 2 sensors are on the bus
- For correct trigger pulse reception, the clock tolerance of the sensor, the time constant of the rising edge and the receiver threshold shall be considered
- The ECU may adjust the low trigger time to account for the time constant of the rising edge
- Example timings are calculated for the default 1.5µs tick time

Bus Transmission Mode allows two configurations for acquiring data and sending data:

- The IC for which SPC ID matches acquires its data and sends in the same frame the data.
- All IC's on the bus acquire the data when a specific SPC ID is sent. Each IC buffers and transmits when called upon, see Figure 27.

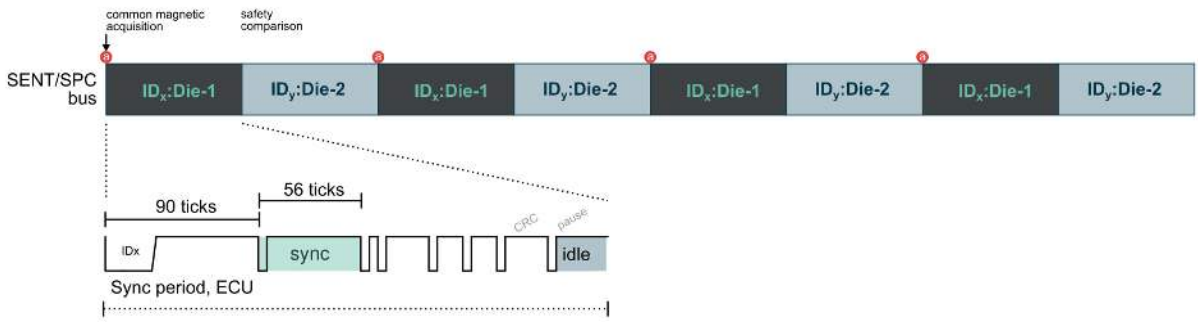


Figure 27 - Acquire Data during one SPC ID on all ICs on the same bus. Buffer and send when SPC ID matches.

11.4.8. Programming in Bus Mode

The EoL programming can be executed even if 4 chips are connected to the same bus. The protocol is capable of selective communication with one chip connected in bus configuration together with other chips (up to 4 on the same line). It uses the MUPET_ADDRESS stored in NVRAM to select the chip to be programmed. When programming 4 chips in parallel, external serial resistors shall be avoided, and are in fact not needed, as the improved emission mode is addressing the additional filtering via a resistance implemented on chip. It enables EoL programming even if 4 chips are connected to the same bus. The SPC ID must be programmed up front. Discuss with your local sales representative for this option.

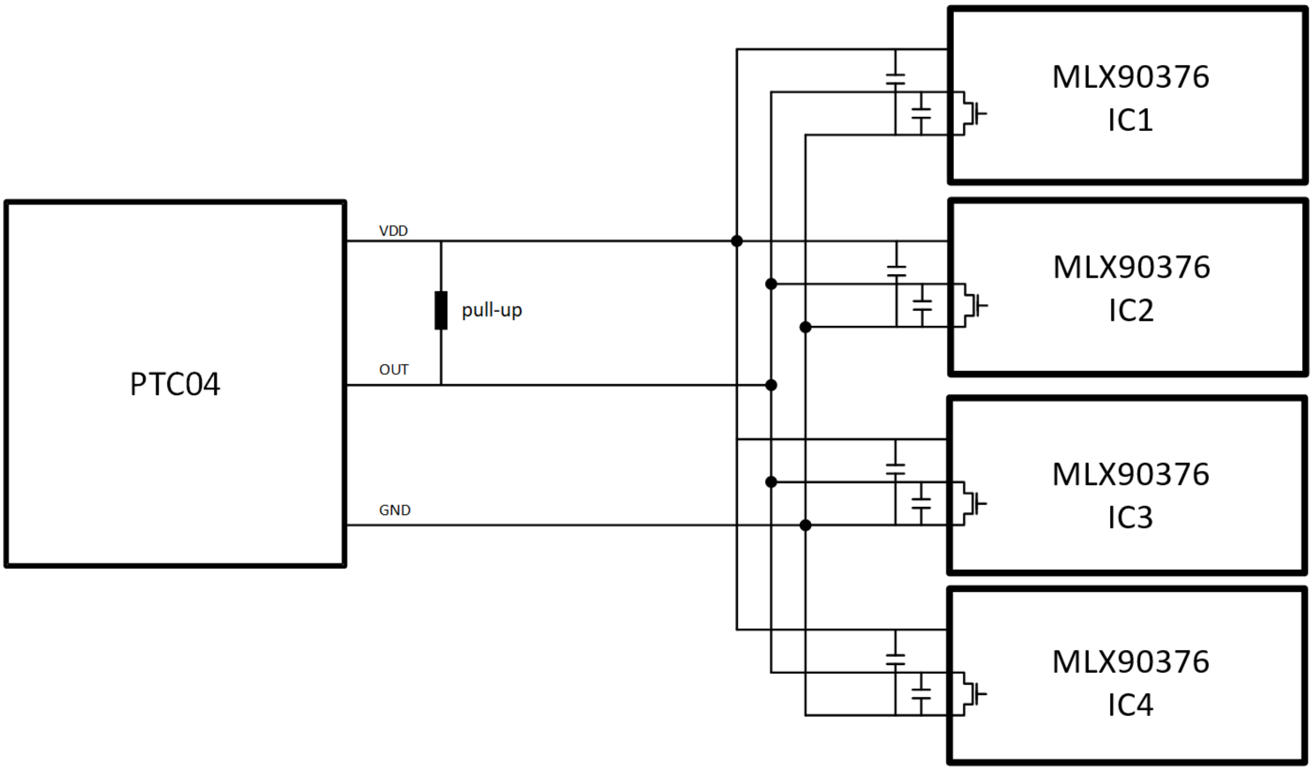


Figure 28 - Example of multiple units programming

12. End User Programmable Items

Parameter	Description	Default Values				
		SENT	SPC	Analog /PWM	#bits
	GENERAL CONFIGURATION				
USER_ID[0..5]	User Id. Reference, details see Table 52 in chapter 13	see Table 52 in chapter 13			8
WARM_TRIGGER_LONG	Add delay for PTC Entry Level	0	0	0	1
WARM_ACT_HIGHV	Select PTC Entry Level Default 0 = V_{PROV0}	0	0	0	1
ROUT_LOW	Select output impedance for PTC communication	1	1	1	1
MUPET_ADDRESS_MODE	Configuration for PTC address. **Do not modify!**	0	0	0	1
MUPET_ADDRESS	PTC address for which the slave will communicate	0/1	0/1	0/1	2
MEMLOCK	Enable NVRAM write protection	0	0	0	2
	SENSOR FRONT END				
GAINMIN GAINMAX	Minimum virtual gain code [0..63] Maximum virtual gain code [0..63]	0 63	0 63	0 64	8
SENSING_MODE	Rotary position stray-field Immune 180 deg Rotary position stray-field immune 360 deg X-Y Angular Rotary (standard / legacy) Y-Z Angular Rotary (standard / legacy) X-Z Angular Rotary (standard / legacy) Linear position, stray-field Immune	0 1 1 2 3 4	0 1 1 2 3 4	0 1 1 2 3 4	3
	FILTERING				
FILTER	FIR filter bandwidth selection	1	0	0	2
HYST	Hysteresis of the denoising filter (hides the small variations but lowers the resolution) Denoising and FIR filtering are applied before the linearization step.	0	0	0	8
DENOISING_FILTER_ALPHA_SEL	Select the alpha parameter of the EMA (IIR) filter	0	0	0	2
SPC_RX_FILT_TIME_INT SPC_RX_FILT_TIME_FRACT	Filtered SPC trigger pulse: Min pulse tick time = (8* SPC_RX_FILT_TIME_INT + SPC_RX_FILT_TIME_FRACT)/8	N/A	6 0	N/A	4 3
SPC_BLANKING_TIME	SPC blanking time (= 5+2*SPC_BLANKING_TIME tick) in case of invalid SPC -ID pulse detected, counted from the rising edge of the trigger pulse. Any other (parasitic) pulse occurring during that time will be ignored.	N/A	0	N/A	2
	LINEAR TRANSFER CHARACTERISTIC				

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
DP	DSP discontinuity point: New Angle = Angle - DP	0	0	0	16
CW	Magnet rotation direction, see section 14.2.2	0	0	0	1
4POINTS	Enable 4 points PWL linearization	0	0	0	1
DSP_LNR_RESX2	Enable a doubled LNR method 0: 4-points or 16-segments 1: 8-points or 32-segments	0	0	0	1
WORK_RANGE_GAIN	Post DSP Gain stage, applied just before linearization	16	16	16	8
GAIN_ANCHOR_MID	Select 50 % position as anchor point Post DSP Gain stage	1	1	1	1
USEROPTION_SCALING	Enables output scaling x2 0 = [0..100%] 1 = [-50%..150%]	1	1	1	1
LNR_S0	4-pts - Slope coefficient before reference point A	N/A	N/A	N/A	16
LNR_A_X, LNR_B_X, LNR_C_X, LNR_D_X	4-pts - X Coordinate for reference points A,B,C,D	N/A	N/A	N/A	16
LNR_A_Y, LNR_B_Y, LNR_C_Y, LNR_D_Y	4-pts - Y Coordinate for reference points A,B,C,D	N/A	N/A	N/A	16
LNR_A_S, LNR_B_S, LNR_C_S, LNR_D_S	4-pts - Slope coefficient for reference points A,B,C,D	N/A	N/A	N/A	16
LNR_Y00	17-pts / 16 segments - Y coordinate point 0	0x4009	0x4009	0x4CCD	16
LNR_Y01	17-pts / 16 segments - Y coordinate point 1	0x4804	0x4804	0x5334	16
LNR_Y02	17-pts / 16 segments - Y coordinate point 2	0x5000	0x5000	0x599A	16
LNR_Y03	17-pts / 16 segments - Y coordinate point 3	0x57FC	0x57FC	0x6000	16
LNR_Y04	17-pts / 16 segments - Y coordinate point 4	0x5FF8	0x5FF8	0x6667	16
LNR_Y05	17-pts / 16 segments - Y coordinate point 5	0x67F4	0x67F4	0x6CCD	16
LNR_Y06	17-pts / 16 segments - Y coordinate point 6	0x6FF0	0x6FF0	0x7334	16
LNR_Y07	17-pts / 16 segments - Y coordinate point 7	0x77EC	0x77EC	0x799A	16
LNR_Y08	17-pts / 16 segments - Y coordinate point 8	0x7FE8	0x7FE8	0x8000	16
LNR_Y09	17-pts / 16 segments - Y coordinate point 9	0x87E4	0x87E4	0x8667	16

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
LNR_Y10	17-pts / 16 segments - Y coordinate point 10	0x8FE0	0x8FE0	0x8CCD	16
LNR_Y11	17-pts / 16 segments - Y coordinate point 11	0x97DC	0x97DC	0x9333	16
LNR_Y12	17-pts / 16 segments - Y coordinate point 12	0x9FD8	0x9FD8	0x999A	16
LNR_Y13	17-pts / 16 segments - Y coordinate point 13	0xA7D4	0xA7D4	0xA000	16
LNR_Y14	17-pts / 16 segments - Y coordinate point 14	0xAFD0	0xAFD0	0xA667	16
LNR_Y15	17-pts / 16 segments - Y coordinate point 15	0xB7CC	0xB7CC	0xACCD	16
LNR_Y16	17-pts / 16 segments - Y coordinate point 16	0xBFC8	0xBFC8	0xB333	16
LNR_X[00..07]	8-pts - X coordinate point 0..7	N/A	N/A	N/A	16
LNR_DELTA_Y[00..32]	33-pts / 32 segments - Delta Y coordinate point 0..32	N/A	N/A	N/A	8
LNR_DELTA_Y_EXPAND_LOG2	Adjust the span of 32 segments NV_LNR_DELTA_Y{n} offsets	0	0	0	2
CLAMPLOW	Low clamping value of angle output data	16	16	32767	16
CLAMPHIGH	High clamping value of angle output data	65408	65408	32767	16
OUTSLOPE_SEL	Possible output offset correction within the post-DSP chain: 0: disabled (default) 1: enabled, applied after discontinuity point stage 2: enabled, applied before clamping stage 3: disabled (unused)	0	0	0	2
OUTSLOPE_COLD	Slope coefficient at cold of the programmable temperature-dependent offset. Used only if NV_OUTSLOPE_SEL enabled	0	0	0	8
OUTSLOPE_HOT	Slope coefficient at hot of the programmable temperature-dependent offset. Used only if NV_OUTSLOPE_SEL enabled	0	0	0	8
DIAGNOSTICS					
DIAG_GLOBAL_EN	Diagnostics global enable. **Do not modify!** (see section 15.2 Safety Mechanisms)	1	1	1	1
DIAG_TEMP_THR_LOW	Temperature threshold & limiter for lower-temperature diagnostic. Default=08 -> -57 deg.C	8	8	8	8

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
DIAG_TEMP_THR_HIGH	Temperature threshold & limiter for over-temperature diagnostic. Default=128 -> 183 deg.C	128	128	128	8
DIAG_FIELDTOOLOWTHRES	Field strength limit under which a fault is reported. (see 14.5.4)	6	6	0	8
DIAG_FIELDTOOHIGHTHRES	Field strength limit over which a fault is reported. (see 14.5.4)	255	255	255	8
DIAG_DEBOUNCE_STEPDOWN	Diagnostic debouncing stepdown time used for recovery time setting	1	1	1	4
DIAG_DEBOUNCE_STEPUP	Diagnostic debouncing step-up time used for hold time setting	1	1	1	4
DIAG_DEBOUNCE_THRESH	Diagnostic debouncing threshold	1	1	1	6
COLD_SAFE_STARTUP_EN	Normal (0) or safe start-up (1) after power-on reset	0	0	0	1
OUT_ALWAYS_HIGHZ	Forces the OUT pin in high-Z mode (for test mode. **Do not modify!)**	0	0	0	1
SENT_REPORT_MODE_ANA	1: Enables the error message within SENT/SPC frame in ANA diagnostic mode. See DIAG_FAULT_CODE	0	0	N/A	2
DIAG_FAULT_CODE	Defines the error message = DIAG_FAULT_CODE + FF9	6	6	N/A	3
DAC_REPORT_MODE_ANA	Defines the DAC state in analog-fault report mode	N/A	N/A	0	2
SENT_INIT_GM	Initialization frame definition until first valid data 0: 000 1: DIAG_FAULT_CODE + FF9	0	0	N/A	1
SPC_SCN_INIT	SCN nibble Initialization contents until first valid data	N/A	0	N/A	0
OUT_DIAG_HIZ_TIME	Output Digital failure (HiZ) recovery time. = 6 + OUT_DIAG_HIZ_TIME ms	0	0	0	5
	OUTPUT CONFIGURATIONS				
PROTOCOL	0: SENT without pause 1: PWM 2: SENT with pause 3: SPC (with or without ID) 4: Analog output 5: SENT-B (SENT rev 5) - reserved for future use	2	3	4	3
ABE_OUT_MODE	HW backend output-amplifier mode selection 0: Analog output (12 bit) 1: Digital output with open-drain-Nmos	4	4	0	3

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
	2: Digital output with open-drain-Pmos 3: Digital output with Push-Pull 4: Digital output with improved emission				
ABE_DAC_SEQ_BYPASS	DAC sequencer bypass option	0	0	1	1
DAC_SEQ_LUT_SEL	DAC Sequence LUT, default for 3µs tick time. **Do not modify!**	6	1	N/A	4
NV_DAC_SEQ_CLK_DIV	DAC Sequence LUT, default for 3µs tick time. **Do not modify!**	0	0	N/A	3
NIBBLE_PULSE_CONFIG	Sets the SENT nibble high/low-time configuration 2: 5 fixed ticks low time (Default) 3: 6 fixed ticks high time	2	2	N/A	2
SPC_PP_OPTION	SPC push-pull and high-Z switching option 0: switch on Push-pull mode @ SPC_OUT_ON_TH, switch it off @ SPC_OUT_OFF_TH (PROTOCOL = 3) 1: switch on Push-pull mode @ SPC_OUT_ON_TH, switch it off right after the last rising edge of the pause pulse. (PROTOCOL = 3) 2: Permanent High-Z (do not use) 3: Permanent state defined by NV_ABE_OUT_MODE (to be used for analog, PWM & SENT)	3	0	3	2
SPC_OUT_ON_TH	Tick delay between the SPC trigger falling edge and the output mode switch: open-drain -> push-pull. Note: tmlowSPC - SPC_RX_FILT_TIME_INT < SPC_OUT_ON_TH < 90	0x32	0x32	N/A	9
SPC_OUT_OFF_TH	Tick delay between the SPC trigger falling edge (filtered) and the output mode switch: push-pull -> open-drain.	450	450	N/A	9
	PWM PROTOCOL OPTIONS				
PWM_POL	Invert the PWM polarity 0: PWM Period start = falling edge, % DC active low	N/A	N/A	0	2
PWM_REPORT_MODE_ANA	Error message within PWM frame 0x0: PWM DC_FAULT 0x1: HiZ 0x2: V_{SS} 0x3: V_{DD}	N/A	N/A	0	2
PWM DC_FAULT	PWM Duty Cycle in case of Fault	N/A	N/A	N/A	8

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
PWM DC_ FIELDTOOLOW	PWM Duty Cycle in case of Field Strength Too Low	N/A	N/A	N/A	8
SPC PROTOCOL OPTIONS					
SENT_TICK_TIME	SPC mode	N/A	3	N/A	3
SPC_ID_EN	0: SPC without ID selection 1: SPC with ID selection. See SPC_CHIP_ID (default)	N/A	1	N/A	1
SPC_CHIP_ID	SPC trigger ID upon which the SENT response will be transmitted on the bus.	N/A	0: Die1 1: Die2	N/A	2
SPC_MEAS_ID	SPC trigger ID upon which the ADC measurement will be done	N/A	1	N/A	2
SERIAL_CONFIG	1: NSP 2: SSP 3: ESP	3	1 [44]	N/A	2
ID_IN_STATUS	Enable SPC ID in SCN (status and communication nibble)	N/A	1	N/A	1
SPC_SCN_BIT_ORDER	Enables SCN bit order according to SPC 1: [b3:2] = Error indication, [b1:0] = SPC_CHIP_ID	N/A	1	N/A	1
SPC_TRIGGER_MODE	SPC trigger pulse treatment mode: 0: Synchronous Transmission Mode 1: Bus mode with constant length trigger pulse (default)	N/A	1	N/A	2
SPC_FORMAT	SPC frame sequence: 8: see SENT_FC_FORMAT[2:0]	8	0	N/A	4
SPC_FC_CSUM_CFG	Fast-channel checksum calculation method 0: checksum in line with SAE J2716 (default) 1: Method “O” in line with SPC2014 Specification 2: Method “E” in line with SPC2014 Specification	N/A	0	N/A	2
SENT_LEGACY_CRC	Enable legacy CRC calculation 0: The SAE J2716 recommended CRC is calculated	0	0	N/A	1
STATUS_IN_CRC	1: Add SCN in checksum calculation	0	1	N/A	1
SPC_CSUM_MODE	Checksum nibble calculation mode in SPC: 0: checksum only (default) 1: Add ID in checksum 2: Add ID & RC in checksum	N/A	0	N/A	2
SPC_BLANK_SENT_FRAME	reserve	N/A	0	N/A	1

[44] *Used for SCN configuration,* ***do not modify!*** *See parameter “ID_IN_STATUS”. 2 bits are overlaid with parameter “SPC_CHIP_ID”.*

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
SPC_TRIG_TH	Delay between the filtered SPC trigger falling edge and the ADC start of sequence, given in number of tick.	N/A	0	N/A	9
	SENT PROTOCOL OPTIONS				
SENT_TICK_TIME	Normal SENT low power mode	3	N/A	N/A	3
SENT_FC_FORMAT	SENT format option (only if SPC_FORMAT = 8) 1: Format H.1 (A.1, Two 12-bit Fast Channels) 2: Format H.2 (One 12-bit Fast Channel, 3 x 4 bit) 3: Format H.3 (One 12-bit fast channel, 4 x 3 bit) 4: Format H.4 (A.3, 12-bit Fast Channel & Single secure) 5: Format H.5 (12-bit Fast Channel & zero values) 6: Format H.6 (14-bit Fast Channel1 & 10-bit Fast Channel2) 7: Format H.7 (16-bit Fast Channel & 8-bit Fast Channel2)	4	N/A	N/A	3
SENT_FC_FORMAT_EN	SENT format enable	1	0	N/A	1
TWO_ANGLES_FRAME	Enable 2 fields measure per output frame (SENT with pulse)	1	N/A	N/A	1
T_FRAME	SENT w/ PP frame length PWM period (4µs/LSB)	320	N/A	N/A	12
T_SYNC_DELAY	SENT - ADC synchronization delay - used in SENT-with-pause only	27	N/A	N/A	12
SENT_FAST_CHANNEL_2	Definition of data transmitted in the SENT fast channel 2 in case SENT_FC_FORMAT=1, 6 or 7 0 Temperature sensor (SP ID 0x23) 1 0xFF9(d4089) - CH1 2 RAM data (RAMPROBE_PTR) 3 0xFFF(d4095) - CH1	0	N/A	N/A	2
SENT_SLOW_EXTENDED	ESM length configuration	0	N/A	N/A	1
SENT_SLOW_EXTENSION	ESM length configuration	0	N/A	N/A	2
SENT_DIAG_STRICT	ESM length configuration	0	N/A	N/A	1
	SERIAL MESSAGE CONFIGURATION				
SENT_SENSOR_TYPE	Part of SSM/ESM: Channel 1/2 sensor type	0x050	0x050	N/A	12
SENT_MAN_CODE	Part of SSM/ESM: Manufacturer code	0x000	0x000	N/A	12
SENT_REV	Part of SSM/ESM: SENT standard revision	0x4	0x4	N/A	4
SENT_CHANNEL_X1	Part of SSM/ESM: Fast-channel 1 - X1	0	0	N/A	12
SENT_CHANNEL_X2	Part of SSM/ESM: Fast-channel 1 - X2	0	N/A	N/A	12

Parameter	Description	Default Values			
		SENT	SPC	Analog /PWM	#bits
SENT_CHANNEL_Y1	Part of SSM/ESM: Fast-channel 1 - Y1	0	N/A	N/A	12
SENT_CHANNEL_Y2	Part of SSM/ESM: Fast-channel 1 - Y2	0	N/A	N/A	12
SENT_SENSOR_ID1	Part of SSM/ESM: Sensor ID-1	0	N/A	N/A	12
SENT_SENSOR_ID2	Part of SSM/ESM: Sensor ID-2	0	N/A	N/A	12
SENT_SENSOR_ID3	Part of SSM/ESM: Sensor ID-3	0	N/A	N/A	12
SENT_SENSOR_ID4	Part of SSM/ESM: Sensor ID-4	0	N/A	N/A	12
SENT_OEM_CODE1	Part of SSM/ESM: OEM code 1	0	N/A	N/A	12
SENT_OEM_CODE2	Part of SSM/ESM: OEM code 2	0	N/A	N/A	12
SENT_OEM_CODE3	Part of SSM/ESM: OEM code 3	0	N/A	N/A	12
SENT_OEM_CODE4	Part of SSM/ESM: OEM code 4	0	N/A	N/A	12
SENT_OEM_CODE5	Part of SSM/ESM: OEM code 5	0	N/A	N/A	12
SENT_OEM_CODE6	Part of SSM/ESM: OEM code 6	0	N/A	N/A	12
SENT_OEM_CODE7	Part of SSM/ESM: OEM code 7	0	N/A	N/A	12
SENT_OEM_CODE8	Part of SSM/ESM: OEM code 8	0	N/A	N/A	12

Table 51 - MLX90376 End-User Programmable Items Table

Performances described in this document are only achieved by adequate programming of the device. To ensure desired functionality, Melexis recommends following its programming guide and to contact its technical or application service.

13. End User Identification Items

Parameter	Description	Default Values	#bits
USER_ID0	Bin1 from production test, can also be reserved for end-user to program information to keep traceability	1	8
USER_ID1	Reserve for end-user to program information to keep traceability	N/A	8
USER_ID2	Reserve for end-user to program information to keep traceability	0x20	8
USER_ID3	Reserve for end-user to program information to keep traceability	N/A	8
USER_ID4	Reserve for end-user to program information to keep traceability	N/A	8
USER_ID5	Reserve for end-user to program information to keep traceability	N/A	8
IMC_VERSION	IMC® / application type: 0: Sun (rotary stray field robust 180deg, low-field variant) 1: Clover (standard/legacy) 2: Dual-disk (linear stray field robust) 4: Bubble (rotary stray field robust 180deg, high Field Variant) 5: DBz mode (rotary stray field robust 360deg)	0 for -1xx order code 1 for -3xx order code 2 for -2xx order code 4 for -5xx order code 5 for -6xx order code	6
TEST_STATUS	Bin 1 verification bit	1	1
MLX_ID0	X-Y position on the wafer (8 bit each)	MLX	16
MLX_ID1	Wafer ID [b15..11] Lot ID [b10..0]	MLX	16
MLX_ID2	Fab ID (4 bits) Test Database ID (6 bits)	MLX	16

Table 52 - Melexis and Customer ID fields description

User identification numbers (48 bits) are freely usable by customers for traceability purpose. Other IDs are read only.

14. Description of End-User Programmable Items

14.1. Output Modes

14.1.1. OUT mode

Defines the Output Stage mode (outside fail-safe state) in application.

ABE_OUT_MODE	ABE_DAC_SEQ_BYPASS	Description	Comments
0	1	Analog output (12-bit DAC)	
1	1	Digital output with open-drain-Nmos	Requires a pull-up resistor on output.
2	1	Digital output with open-drain-Pmos	Requires a pull-down resistor on output.
3	1	Digital output with Push-Pull	
4	0	Digital output with improved emission	

Table 53 - Output Mode Selection

14.1.2. Digital OUT protocol

Selection of the measurement timing mode and the corresponding output protocol

PROTOCOL	Descriptions
0	Continuous asynchronous angle acquisition, SENT without pause
1	Continuous asynchronous angle acquisition, PWM
2	Continuous synchronous angle acquisition, SENT with pause
3	Master-triggered angle transmission, SPC (with or without ID)
4	Continuous synchronous angle acquisition, analog output (DAC)

Table 54 - Protocol Selection

14.1.3. Serial Channel Configuration

Slow Channel configuration:

SERIAL_CONFIG	Descriptions
0	Slow Channel isn't present, the whole nibble is skipped => violating the protocol. Do not use.
1	No serial message
2	Short serial message
3	Enhanced serial message

Table 55 - SENT Serial channel Configuration

14.1.4. PWM Output Mode

If PWM output mode is selected, the output signal is a digital signal with Pulse Width Modulation (PWM). The PWM polarity is selected by the PWMPOL parameter:

- PWM_POL = 0 for a low level at 100%
- PWM_POL = 1 for a high level at 100%

The PWM frequency is selected in the range [100, 2000] Hz by the T_FRAME parameter (12bits), defining the period time in the range [0.5; 10] ms. Minimum allowed value for T_FRAME is therefore 125 (0x7d).

$$T_{PWM} = \frac{4}{10^6} \times T\_FRAME$$

The PWM period is subject to the same tolerances as the main clock (see ΔF_{ck}).

14.1.5. SPC Frame Formats

The SPC frame formats (see section 11.4.1) can be defined by the parameter "SPC_FORMATS", with the following overview:

Figure 29 - SPC Frame Format details

14.2. Output Transfer Characteristic

Figure 30 gives the simplified digital signal processing chain from the position after ADC to the output. This section explains the compensation capability of the IC. The remainder of this chapter explains every parameter in more detail.

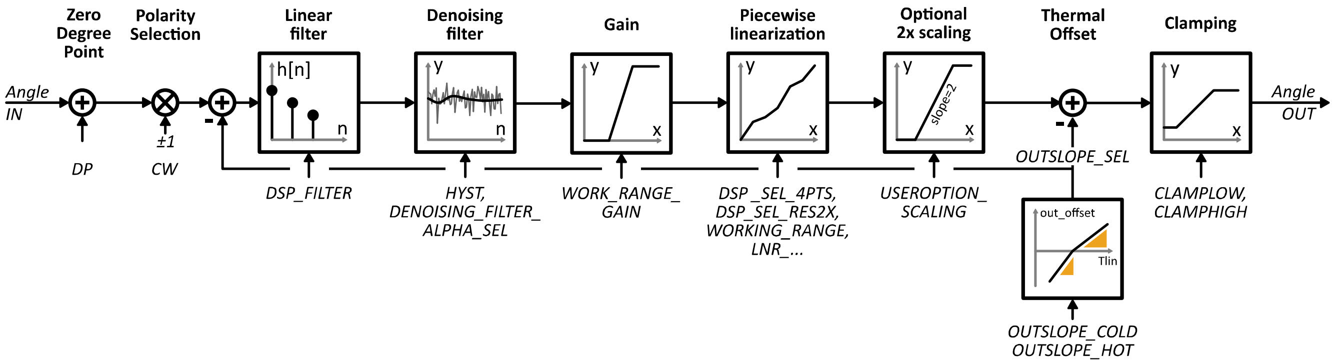


Figure 30 - Digital Signal Process Chain from raw angle calculation to the Output data

There are 4 different possibilities to define the transfer function (LNR) as specified in the Table 56.

- With 4 arbitrary points (defined by X and Y coordinates) and 5 slopes
- With 8 arbitrary points (defined by X and Y coordinates)
- With 17 equidistant points for which only the Y coordinates are defined
- With 32 equidistant points for which only offset of Y compared to the average value is defined

Output Transfer Characteristic	4 POINTS	DSP_LNR_RESX2
4 Arbitrary Points	1	0
8 Arbitrary Points	1	1
17 Equidistant Points	0	0
32 Equidistant Points	0	1

Table 56 - Output Transfer Characteristic Selection Table

Parameter	LNR type	Value	Unit
CW	All	0 → counterclockwise 1 → clockwise	LSB
DP	All	0 … 359.9999	deg
LNR_A_X LNR_B_X LNR_C_X LNR_D_X	4 pts, X coordinates	0 … 359.9999	deg
LNR_A_Y LNR_B_Y LNR_C_Y LNR_D_Y	4 pts, Y coordinates	0 … 100 -50 … + 150	%
LNR_S0 LNR_A_S LNR_B_S LNR_C_S LNR_D_S	4 pts, slopes	-17 … 0 … 17	%/deg
LNR_X00..X07	8 pts, X coordinates	0 … 359.9999	deg
LNR_Y00..Y16	8,17 pts, Y coordinates	0..100 -50 … + 150	%
LNN_DELTA_Y00..Y32	33 pts offsets	+/-3.125% +/-6.25% +/-12.5% +/-25%	%
WORKING RANGE	17/33 pts	65.5 … 360 32.75 … 180	deg
CLAMPLOW	All	0 … 100	%
CLAMPHIGH	All	0 … 100	%

Table 57 - Output linearization and clamping parameters

14.2.1. Enable scaling Parameter

This parameter enables to double the scale of Y coordinates linearisation parameters from [0 .. 100]% to [-50 .. 150]% according to the following table (Table 58). This is valid for all linearisation schemes except the 32 points.

USEROPTION_SCALING	LNR_Y min value	LNR_Y max value
0	0%	100%
1	-50%	150%

Table 58 - USEROPTION_SCALING parameter

14.2.2. CW (Clockwise) Parameter

14.2.2.1. CW (Clockwise) Parameter for PCB-less package

The CW parameter defines the magnet rotation direction.

- 0 or counter clockwise is defined by the 1-2-3-4 pin order direction for the SMP-4 package.
- 1 or clockwise is defined by the reverse direction: 4-3-2-1 pin order direction for the SMP-4 package.

Refer to the drawing in the sensitive spot positioning section (19.1.3).

14.2.2.2. CW (Clockwise) Parameter for SMD packages

The CW parameter defines the magnet rotation direction.

- 0 or counter clockwise is the defined by 1-4-5-8 pin order direction for the SOIC-8 package, 1-8-9-16 pin order direction for the TSSOP-16 package.
- 1 or clockwise is defined by the reverse direction: 8-5-4-1 pin order direction for the SOIC-8 package, 16-9-8-1 pin order direction for the TSSOP-16 package.

Refer to the drawing in the sensitive spot positioning sections (19.2.1.3 and 19.2.2.319.1.3).

14.2.3. Discontinuity Point (or Zero Degree Point)

The Discontinuity Point defines the 0° point on the circle. The discontinuity point places the origin at any location of the trigonometric circle. The DP is used as reference for all the angular measurements.

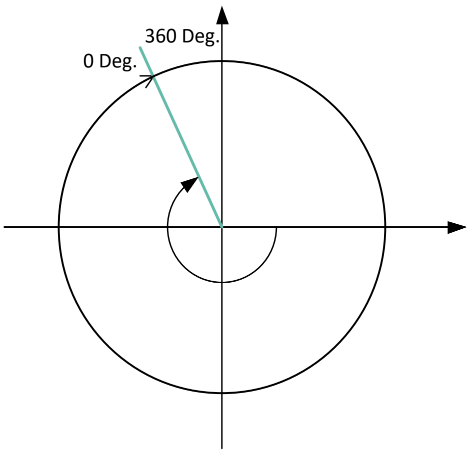


Figure 31 - Discontinuity Point Positioning

14.2.4. 4-pts LNR Parameters

The LNR parameters, together with the clamping values, fully define the relation (the transfer function) between the digital angle and the output signal.

The shape of the MLX90376 4-pts transfer function from the digital angle value to the digital output is described in Figure 32. Seven segments can be programmed but the clamping levels are always flat.

Two to six calibration points are available, reducing the overall non-linearity of the IC by almost an order of magnitude each time. Three or more calibration points will be preferred by customers looking for excellent non-linearity figures. Two-point calibrations will be preferred by customers looking for a lower cost calibration set-up and shorter calibration time.

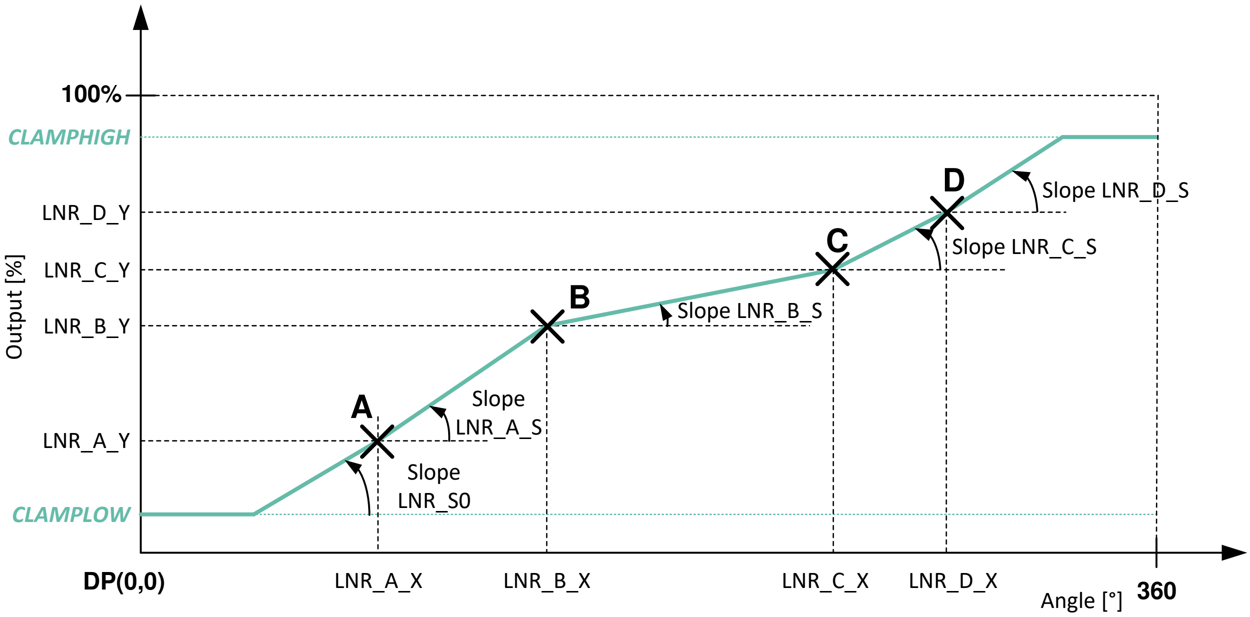


Figure 32 - 4-pts Linearization Parameters Description

14.2.5. 8-pts LNR Parameters

The LNR parameters, together with the clamping values, fully define the relation (the transfer function) between the digital angle and the output signal.

The shape of the MLX90376 8-pts transfer function from the digital angle value to the output voltage is described in Figure 33. Eight calibration points [LNR_X0...7, LNR_Y0...7] together with 2 fixed points at the extremity of the range ([0°, 0%] ; [360°, 100%]) divides the transfer curve into 9 segments. Each segment is defined by 2 points and the values in between is calculated by linear interpolation.

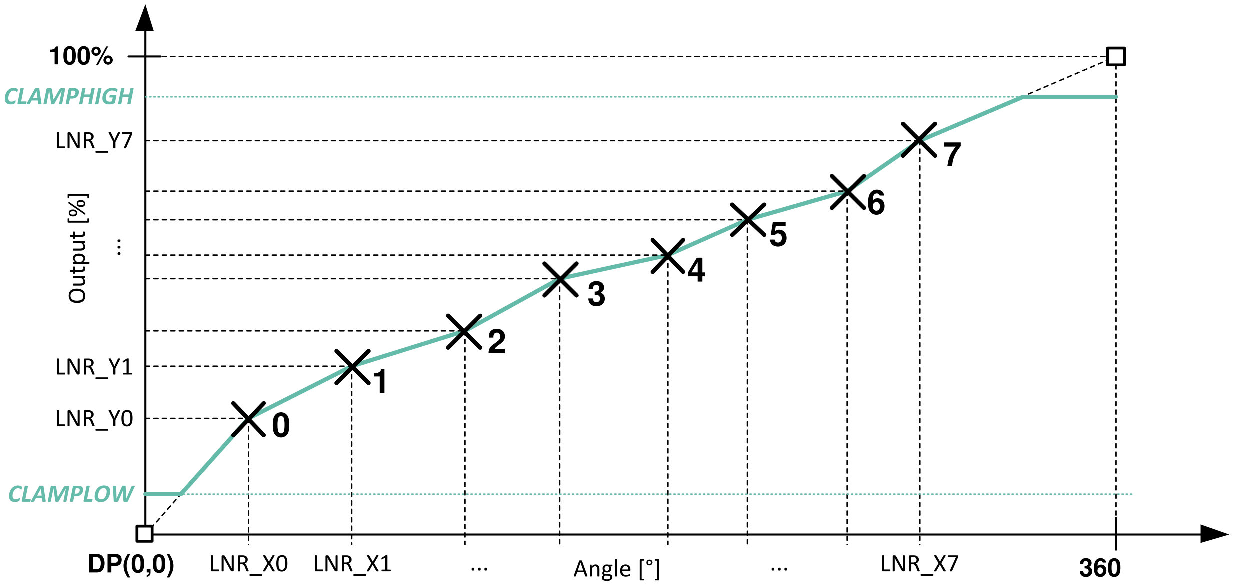


Figure 33 - 8-pts Linearization Parameters Description

14.2.6. 17-pts LNR Parameters

The LNR parameters, together with the clamping values, fully define the relation (the transfer function) between the digital angle and the output signal.

The shape of the MLX90376 17-pts transfer function from the digital angle value to the output voltage is described in Figure 34. In the 17-pts mode, the output transfer characteristic is Piece-Wise-Linear (PWL).

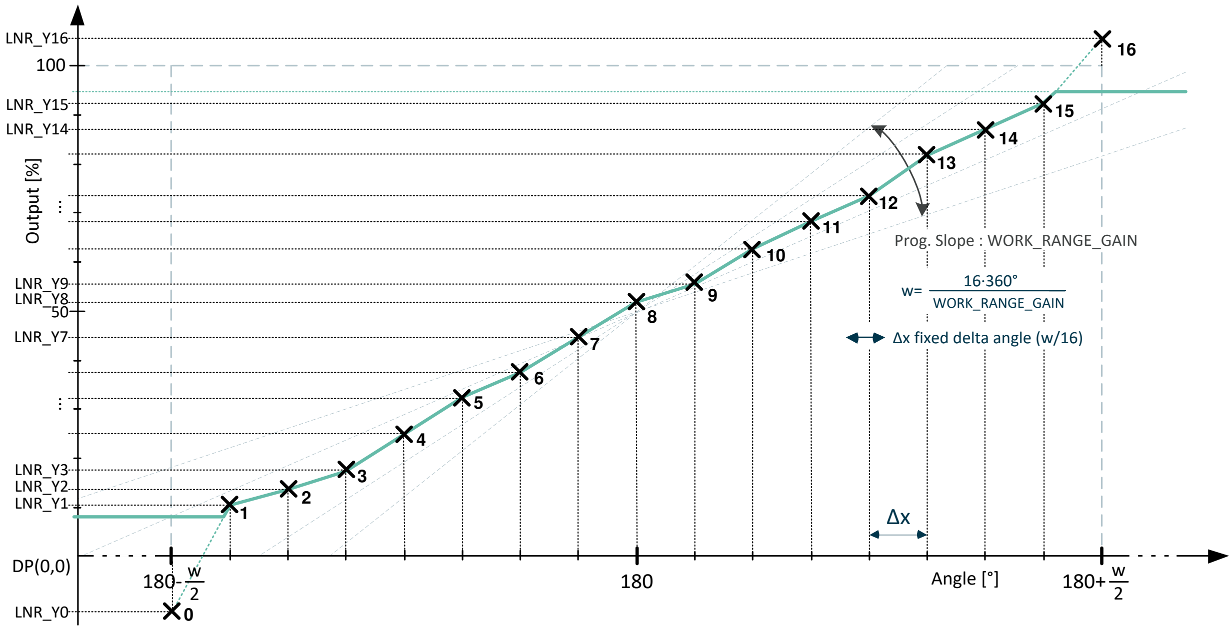


Figure 34 - 17-pts Linearization Parameters Description

All the Y-coordinates can be programmed from -50% up to +150% to allow clamping in the middle of one segment (like on the figure), but the output value is limited to CLAMPLOW and CLAMPHIGH values.

Between two consecutive points, the output characteristic is interpolated.

14.2.7. 33-pts LNR parameters

The LNR parameters, together with the clamping values, fully define the relation (the transfer function) between the digital angle and the output signal.

The shape of the MLX90376 33-pts transfer function from the digital angle value to the output voltage is described in Figure 35 below. In the 33-pts mode, the output transfer characteristic is Piece-Wise-Linear (PWL).

The points are spread evenly across the working range (see. 14.2.8 and 14.2.9 for working range selection). The Y-coordinates can be offset from the ideal characteristic within an adjustable range defined by LNR_DELTA_Y_EXPAND_LOG2. The available values are summarized in Table 59. All LNR_delta_Y## parameters are encoded in a fractional signed 8-bit value.

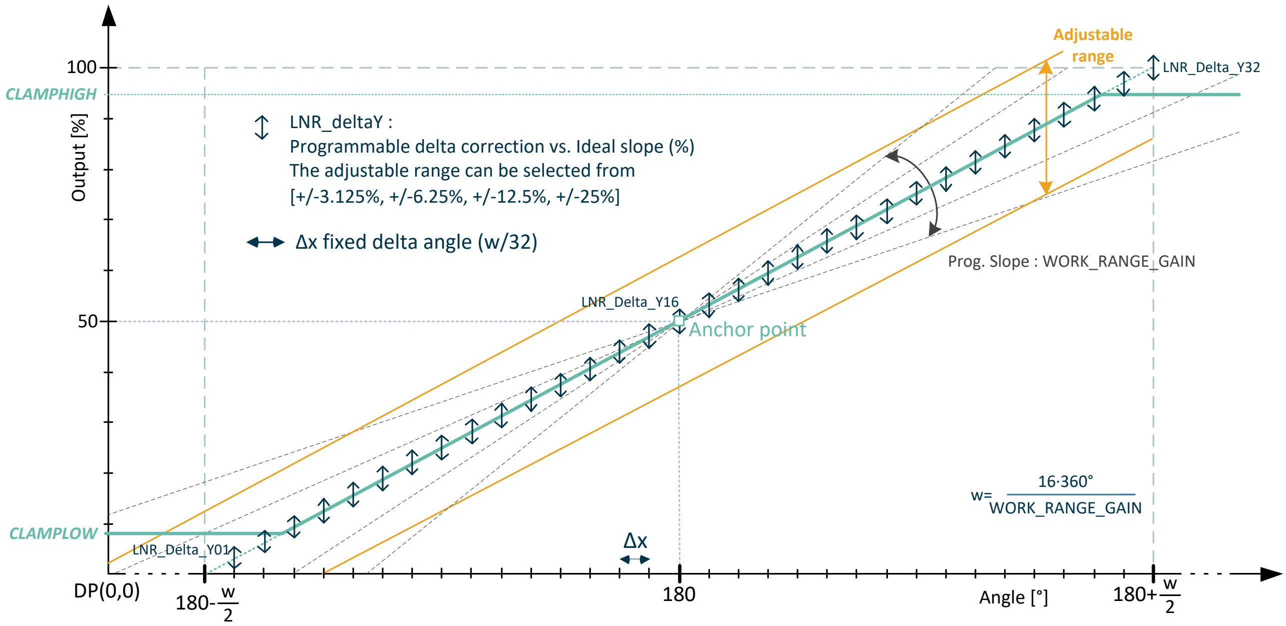


Figure 35 - 33-pts Linearization Parameters Description

LNR_DELTA_Y_EXPAND_LOG2	Adjustable Range	Correction resolution
0	±3.125%	0.024%
1	±6.25%	0.049%
2	±12.5%	0.098%
3	±25%	0.20%

Table 59 - LRN_DELTA_Y_EXPAND_LOG2 values and correction resolution

14.2.8. WORK_RANGE Parameter for Angle Range Selection

The parameter WORK_RANGE determines the input range on which the 16 or 32 segments are uniformly spread. This parameter is provided for compatibility with former versions of Melexis Triaxis sensors. For full featured working range selection, see 14.2.9. For WORK_RANGE parameter, following table applies.

WORK_RANGE	Range	Δx 17pts	Δx 32pts	WORK_RANGE	Range	Δx 17pts	Δx 32pts
0	180.0°	11.3°	5.6°	8	90.0°	5.6°	2.8°
1	160.0°	10.0°	5.0°	9	72.0°	4.5°	2.3°
2	144.0°	9.0°	4.5°	10	60.0°	3.8°	1.9°
3	131°	8.2°	4.1°	11	51.45°	3.2°	1.6°
4	120.0°	7.5°	3.8°	12	45.0°	2.8°	1.4°
5	221.5°	6.9°	3.5°	13	40.0°	2.5°	1.3°
6	103°	6.4°	3.2°	14	36.0°	2.3°	1.1°
7	96°	6.0°	3.0°	15	32.75°	2.0°	1.0°

Table 60 - Work range for 180° periodicity (ordering code -1xx, -5xx)

WORK_RANGE	Range	Δx 17pts	Δx 32pts	WORK_RANGE	Range	Δx 17pts	Δx 32pts
0	360.0°	22.5°	11.3°	8	180.0°	11.3°	5.6°
1	320.0°	20.0°	10.0°	9	144.0°	9.0°	4.5°
2	288.0°	18.0°	9.0°	10	120.0°	7.5°	3.8°
3	261.8°	16.4°	8.2°	11	102.9°	6.4°	3.2°
4	240.0°	15.0°	7.5°	12	90.0°	5.6°	2.8°
5	221.5°	13.8°	6.9°	13	80.0°	5.0°	2.5°
6	205.7°	12.9°	6.4°	14	72.0°	4.5°	2.3°
7	192.0°	12.0°	6.0°	15	65.5°	4.1°	2.0°

Table 61 - Work range for 360° periodicity (ordering code -2xx, -3xx, -6xx)

Outside of the selected range, the output will remain at clamping levels.

14.2.9. WORK_RANGE_GAIN Parameter for Angle Range Selection

Alternatively, the range for the angle can be selected using the WORK_RANGE_GAIN parameter, which applies a fixed gain to the transfer characteristics. WORK_RANGE_GAIN is coded on 8 bits where the 4 MSB defines the integer part and the 4 LSB the fractional part (in power of twos). Therefore, the following equation applies to define the angle range *w*:

$$w = \frac{16 * MaxRange}{WORK\_RANGE\_GAIN}$$

MaxRange depends on the application. It is 360° for ordering code -2xx / -3xx / -6xx, and 180° for ordering code -1xx / -5xx (rotary stray-field immune). Both minimal and maximal angles are then defined by:

$$\theta_{min} = \frac{MaxRange - w}{2} \; ; \; \theta_{max} = \frac{MaxiRange + w}{2}$$

where θ_{min} corresponds to the angle yielding 0% output and θ_{max} the angle giving a 100% output.

Using WORK_RANGE_GAIN parameter, the anchor point is kept at *MaxRange*/2 and the range is symmetrically set around this value. It creates a zoom-in of the angle around this point.
Following tables give some values as example:

GAIN	Factor	Range (w)	θmin	θmax	Δx 17pts	Δx 32pts
0x10	1	180°	0°	180°	11.25°	5.63°
0x20	2	90°	45°	135°	5.63°	2.81°
0x40	4	45°	67.5°	112.5°	2.81°	1.41°
0xFF	15.94	11.3°	78.7°	101.3°	0.71°	0.35°

Table 62 - Working range defined by WORK_RANGE_GAIN parameter (ordering code -1xx, -5xx)

GAIN	Factor	Range (w)	θmin	θmax	Δx 17pts	Δx 32pts
0x10	1	360°	0°	360°	22.5°	11.3°
0x20	2	180°	90°	270°	11.3°	5.6°
0x40	4	90°	135°	225°	5.6°	2.8°
0xFF	15.94	22.6°	168.7°	191.3°	1.41°	0.71°

Table 63 - Working range defined by WORK_RANGE_GAIN parameter (ordering code -2xx, -3xx, -6xx)

Outside of the working range, the output will remain at clamping levels.

14.2.10. Thermal OUTSLOPE offset correction

Two parameters, OUTSLOPEHOT and OUTSLOPECOLD, are used to add a temperature dependent offset. This feature is enabled by the parameter OUTSLOPE_SEL that apply this modification either directly to the angle or after the linearisation function. The MLX90376 uses its internal linearized temperature to compute the offset shift as depicted in the figure below (Figure 36).

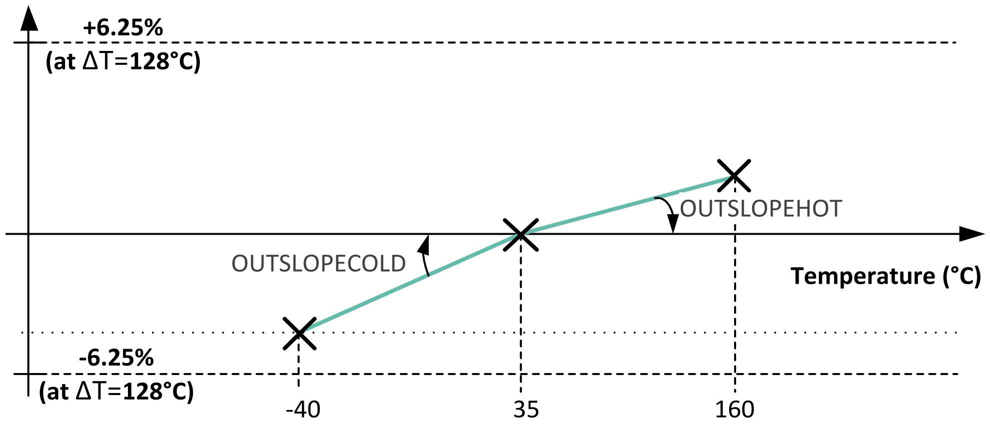


Figure 36 - Temperature compensated offset

The thermal offset can be added or subtracted to the output, before the clamping. The span of this offset is ±6.25% of the full output scale for a temperature difference of 128°C. The added thermal offset varies with temperature following the equations below. The two thermal coefficients are encoded in signed two's complement 8bit format (-128..127) and defined separately below 35°C (OUTSLOPECOLD) and above 35°C (OUTSLOPEHOT).

OUTSLOPE_SEL	Description
0	No thermal offset correction
1	Thermal offset enabled, applied after angle calculation, i.e. after discontinuity point (θ_{r2p})
2	Enabled, applied after output calculation and before clamping (θ_{out})

Table 64 - Temperature compensated offset selection parameter

If IC internal temperature is higher than 35°C then:

$$\theta_{Tcomp} = \theta_{in} - \Delta T \cdot \text{OUTSLOPEHOT}$$

If IC internal temperature is lower than 35°C then:

$$\theta_{Tcomp} = \theta_{in} - \Delta T \cdot \text{OUTSLOPECOLD}$$

where θ_{in} is either θ_{r2p} or θ_{out} depending on OUSLOPE_SEL value.

14.2.11. CLAMPING Parameters

The clamping levels are two independent values to limit the output voltage range. The CLAMPLOW parameter adjusts the minimum output level. The CLAMPHIGH parameter sets the maximum output. Both parameters have 16 bits of adjustment and are available for all four LNR modes. As output data resolution is limited to 12 bits, both in SENT and in PWM, the 4 LSB of this parameter will have no significant effect on the output. The value is encoded in fractional code, from 0% to 100%

14.3. Sensor Front-End

Parameter	Value
SENSING MODE	[0..7]
GAINMIN	[0..63]
GAINMAX	[0..63]
GAINSATURATION	[0, 1]

Table 65 - Sensing Mode and Front-End Configuration

14.3.1. SENSING MODE

The SENSING_MODE parameter defines which sensing mode and fields are used to calculate the angle. The different possibilities are described in the tables below. This 3-bit value selects the first (B1) and second (B2) field components according to the Table 66 content.

MAPXYZ	B1	B2	Angular
0	X	Y	Rotary position, stray-field Immune, 180 degrees, order code -1xx and -5xx
1	X	Y	X-Y Angular Rotary, order code -3xx Rotary position, stray-field Immune, 360 degrees, order code -6xx
2	Y	Z	Y-Z Angular Rotary, order code -3xx
3	X	Z	X-Z Angular Rotary, order code -3xx
4	ΔX	ΔZ	Linear position, stray-field Immune, order code -2xx

Table 66 - Sensing Mode Description

14.3.2. GAINMIN and GAINMAX Parameters

GAINMIN and GAINMAX define the thresholds on the gain code outside which the fault “GAIN out of Spec.” is reported. If GAINSATURATION is set, then the virtual gain code is clamped at GAINMIN and GAINMAX, and no diagnostic fault will be set since the clamping will prevent the gain from exceeding GAINMIN and GAINMAX.

14.4. Filtering

The MLX90376 includes 2 types of filters:

- Exponential moving average (EMA) Filter: programmable by the HYST parameter
- Low Pass FIR Filters controlled with the FILTER parameter

Parameter	Value
FILTER	0 … 2
HYST	0 … 255

Table 67 - Filtering configuration

14.4.1. Exponential Moving Average (IIR) Filter

The HYST parameter is a hysteresis threshold to activate / de-activate the exponential moving average filter. The output value of the IC is updated with the applied filter when the digital step is smaller than the programmed HYST parameter value. The output value is updated without applying the filter when the increment is bigger than the hysteresis. The filter reduces therefore the noise but still allows a fast step response for bigger angle changes. The hysteresis must be programmed to a value close to the internal magnetic angle noise level ($1\text{LSB} = 8 \cdot 360/2^{16}$).

$$y_n = a * x_n + (1-a) * y_{n-i} \qquad \begin{aligned} x_n &= Angle \\ y_n &= Output \end{aligned}$$

The filters characteristic is given in the following table (Table 68):

DENOISING_FILTER_ALPHA_SEL	0	1	2	3
Coefficients a	0.75	0.5	0.25	0.125
Efficiency RMS (dB)		2.4	4.2	

Table 68 - IIR Filter characteristics

14.4.2. FIR Filters

The MLX90376 features 2 FIR filter modes controlled with Filter = 1…2. Filter = 0 corresponds to no filtering. The transfer function is described by:

$$y_n = \frac{1}{\sum_{i=0}^{j} a_i} \sum_{i=0}^{j} a_i x_{n-i}$$

This filter characteristic is given in the Table 69.

FILTER value	0	1	2
Type	Disable	Finite Impulse Response (FIR)	
Coefficients a_i	1	11	1111
Title	No filter	Extra light	Light
DSP cycles (#taps)	1	2	4
Efficiency RMS (dB)	0	3.0	6.0

Table 69 - FIR Filter Characteristics

14.5. Programmable Diagnostics Settings

14.5.1. Diagnostics Global Enable

DIAG_EN must be kept to its default value (1) to retain all functional safety abilities of the MLX90376. This feature shall not be disabled.

14.5.2. Diagnostic Debouncer

A debouncing algorithm is available for analog diagnostic reporting (see chapter 15). Enabling this debouncer will increase the FHTI of the device. Therefore, Melexis recommends keeping the debouncing of analog faults off, by not modifying below described values. The factory default settings mentioned in chapter 12 should be used.

NVRAM Parameter	Description
DIAGDEBOUNCE_STEPDOWN	Decrement values for debouncer counter
DIAGDEBOUNCE_STEPUP	Increment value for debouncer counter
DIAG_DEBOUNCE_THRESH	Threshold for debouncer counter to enter diagnostic mode

Table 70 - Diagnostic debouncing parameters

Once an analog monitor detects an error, it takes control of the debouncing counter. This counter will be incremented by STEPUP value each time this specific monitor is evaluated and the error is still present. When the debouncing counter reaches the value defined by DEBOUNCE_THRESH, an error is reported on the error channel, and the debouncing counter stays clamped to this DEBOUNCE_THRESH value (see section 11.2.8 for SENT error message codes, and 14.5.5 for PWM error reporting). Once the error disappears, each time its monitor is evaluated, the debouncing counter is decremented by STEPDOWN value. When the debouncing counter reaches zero, the error disappears from the reporting channel and the debouncing counter is released. To implement proper reporting times, one should refer to the FHTI, see chapter 15.3. The reporting and recovery time are defined in the table below (valid for THRESH≠0).

Parameter	Min	Max
Reporting Time	$DCT \cdot \left(\left\lceil\frac{THRESH}{STEPUP}\right\rceil - 1\right)$	$DCT \cdot \left(\left\lceil\frac{THRESH}{STEPUP}\right\rceil\right)$
Recovery Time	$DCT \cdot \left(\left\lceil\frac{THRESH}{STEPDOWN}\right\rceil\right)$	$DCT \cdot \left(\left\lceil\frac{THRESH}{STEPDOWN}\right\rceil + 1\right)$
	$\left\lceil\frac{x}{y}\right\rceil$	is the ceiling function of x divided by y

Table 71 - Diagnostic Reporting and Recovery times

14.5.3. Over/Under Temperature Diagnostic

DIAG_TEMP_THR_HIGH defines the threshold for over temperature detection and is compared to the linearized value of the temperature sensor T_{LIN}. DIAG_TEMP_THR_LOW defines the threshold for under temperature detection and is compared to the linearized value of the temperature sensor T_{LIN}

T_{LIN} is encoded using the SENT standard for temperature sensor. One can get the physical temperature of the die using following formula:

$$T_{PHY}[°C] = \frac{T_{LIN}}{8} - 73.15$$

DIAG_TEMP_THR_LOW/HIGH are encoded on 8-bit unsigned values with the following relationship towards T_{Lin}

$$DIAG\_TEMP\_THR\_(LOW/HIGH) = \frac{T_{LIN}}{16}$$

The value of T_{LIN} is clamped between the thresholds defined by DIAG_TEMP_THR_LOW and DIAG_TEMP_THR_HIGH.

Following table summarizes the characteristics of the linearized temperature sensor and the encoding of the temperature monitor thresholds.

Parameter	Symbol	Min	Typ	Max	Unit	Condition
T_{LIN} resolution	Res_{TLIN}	-	0.125	-	°C/LSB	
T_{LIN} refresh rate	$F_{S,TLIN}$	-	200	-	Hz	
T_{LIN} linearity error	T_{LinErr}	-8	-	8	°C	from -40 to 160°C
T_{LIN} linearity error	T_{LinErr}	-2	-	6	°C	from 35 to 125°C
High temperature threshold	DIAG_TEMP _THR_LOW	-	8	-	LSB	Recommended value, corresponds to -57°C
Low temperature threshold	DIAG_TEMP _THR_HIGH	-	128	-	LSB	Recommended value, corresponds to 183°C
High/low temperature threshold resolution	Res_{Tthr}		2		°C/LSB	

Table 72 - Linearized Temperature Sensor characteristics

14.5.4. Field Strength and Field Monitoring Diagnostics

Field Strength is compensated over the circuit operating temperature range and represents a reliable image of the field intensity generated by the magnet. Field Strength value is optionally available in SENT secondary fast channel.

14.5.5. PWM Diagnostic

DC_FAULT - This parameter defines the duty-cycle that is present on the PWM output in case of diagnostic reporting.

DC_FIELDTOOLOW - This parameter defines the duty-cycle that is output in case of Field Too Low, from 0% till 100 % by steps of (100/256) %.

15. Functional Safety

15.1. Safety Manual

The safety manual, available upon request, contains the necessary information to integrate the MLX90376 component in a safety related item, as Safety Element Out-of-Context (SEooC). A safety manual addendum is also proposed for the dual-die products integration.

In particular, it includes:

- The description of the Product Development lifecycle tailored for the Safety Element.
- An extract of the Technical Safety concept.
- The description of Assumptions-of-Use (AoU) of the element with respect to its intended use, including:
    - assumption on the device safe state;
    - assumptions on fault tolerant time interval and multiple-point faults detection interval;
    - assumptions on the context, including its external interfaces;
- The description of safety analysis results (at the device level, to be used for the system integration), HW architectural metrics and description of dependent failures initiators.
- The description and the result of the functional safety assessment process; list of confirmation measures and description of the independency level.

15.2. Safety Mechanisms

The MLX90376 provides numerous self-diagnostic features (safety mechanisms). Those features increase the robustness of the IC functionality either by preventing the IC from providing an erroneous output signal or by reporting the failure according to the SENT protocol definition.

Legend
● High coverage
○ Medium coverage
ANA: Analog hardware failure reporting, described in the safety manual
High-Z: Special reporting, output is set in high impedance mode (no HW fail-safe mode/timeout, no SW safe startup)
DIG: Digital hardware failure reporting, described in the safety manual
At Startup: HW fault present at time zero is detected before a first frame is transmitted.
DIAG_EN: This safety mechanism can be disabled by setting DIAG_EN = 0 (see chapter 12 End User Programmable Items). This option should not be used in application mode!

Table 73 - Self Diagnostic Legend

Category and safety mechanism name	Front-end	ADC	DSP	Back-end	Support. Func.	Module & Package	Reporting mode	At startup	DIAG EN
Signal-conditioning (AFE, External Sensor) Diagnostic									
Magnetic Signal Conditioning Voltage Test Pattern	●	○	○				ANA	NO	●
Magnetic Signal Conditioning Rough Offset Clipping check	●		○				ANA	NO	●
Magnetic Signal Conditioning Gain Monitor	●		○			●	ANA	YES	●
Magnetic Signal Conditioning Gain Clamping	●		○			●	ANA	YES	●
Mag. Sig. Cond. Failure control by the chopping technique	●						n/a	YES	
External Sensor Sig. Cond. Voltage Valid Range Check	●					●	ANA	YES	●
External Sensor Sig. Cond. Frequency Valid Range Check	●					●	ANA	YES	●
A/D Converter Test Pattern		●					ANA	NO	●
ADC Conversion errors & Overflow Errors		●					ANA	YES	●
Flux Monitor (Specific to Rotary mode)	●	○				●	ANA	NO	●
HE Switching Circuitry Symmetry Check	●						ANA	NO	●
HE Bias Current Supply Monitor	●						ANA	NO	●
Stress Sensor Valid Range Check	●						ANA	YES	●
Digital-circuit Diagnostic									
RAM Parity, 1 bit per 16 bits word, ISO D.2.5.2			●				DIG	YES	●
ROM Parity, 1 bit per 32 bits word, ISO D.2.5.2			●				DIG	YES	●

Category and safety mechanism name	Front-end	ADC	DSP	Back-end	Support. Func.	Module & Package	Reporting mode	At startup	DIAG EN
"NVRAM 16 bits signature (run-time) ISO D.2.4.3, by means of SW CRC-CCITT16"			●				DIG	NO	●
NVRAM Double Error Detection ECC ISO			●				DIG	YES	
Logical Monitoring of program sequence ISO D.2.9.3 via Watchdog "IWD" (cpu clock) ISO D2.9.2			●		○		DIG	NO	●
Watchdog "AWD" (separate clock) ISO D2.9.1			●		○		DIG	YES	
CPU Errors "Invalid Address", "Wrong opcode"			●		○		DIG	YES	
ADC Interface Checksum		●	○				DIG	NO	●
DSP Test Pattern (atan2)			●		○		DIG	NO	●
Critical ports monitoring			●				DIG	NO	●
DSP Overflow	○	○	●				DIG	YES	●
ADC data adder test		○	●				DIG	YES	●
SENT Fall Collision detection (SENT pulse generator)			●				DIG	NO	●
DAC Overflow			●				DIG	NO	●
Communication Interface Diagnostic									
SENT parity check over Configuration registers				●			DIG	NO	●
SENT block: Protection against re-configuration at run-time				●			DIG	NO	●
SENT Frame Counter & Redundant Nibble				●			n/a	n/a	
System-level diagnostic									

Category and safety mechanism name	Front-end	ADC	DSP	Back-end	Support. Func.	Module & Package	Reporting mode	At startup	DIAG EN
Supply Voltage Monitors (all supply domains) except VS_OV & POR					●	●	ANA	YES	●
External Supply Overvoltage Monitor VS_OV					●	●	High-Z	YES	
Digital Supply under-voltage monitor (Power-on reset)					●	●	High-Z	YES	
Supply Bias Current Monitor					●		ANA	NO	●
Overheating monitor	○	○	○	○	○	●	ANA	YES	●
Warning/Reporting Mechanisms									
HW Error Controller			●	●	●		DIG	YES	
HW Fail-safe mode with timeout			●	●	●		DIG	YES	
Analog-type Error management	●	●			●		ANA	NO	●
Safe start-up mode			●		●		DIG	n/a	
Mechanisms executed at start-up only									
RAM March-C HW Test at start-up			●		●		DIG	YES	

Table 74 - MLX90376 List of Self Diagnostics with Characteristics

15.3. Fault Handling Time Interval

Name	Definition
DTI_{ANA}	Time to run one full analog diagnostic cycle (programmable value)
DTI_{DIG}	Time to run one full nvram BIST cycle (programmable value)
τ_R	Output refresh period in analog output mode (see "Timings definition" chapter)
T_{pwm_input}	the period of the incoming PWM signal on gateway pin
$T_{trigger}$	the time between 2 SPC trigger pulses
DTI	Diagnostic Time Interval: worst-case time between 2 consecutive runs of a specific diagnostic
EXE	Execution Time: worst-case time between the measurement start of a given diagnostic and the availability of the result of this measurement
REP	Reporting Time: worst-case time needed between an internal diagnostic error event and a switch of the output to fail-safe state
FHTI	Fault Handling Time Interval: the time interval between the start of the first frame with invalid position value without notice, and the end of the last frame preceding a fail-safe state of the IC. It is calculated as the sum of DTI, EXE, and REP figures. The following equation is valid for any diagnostic: $FHTI = DTI + EXE + REP$

Table 75 – Glossary of Terms for the Definition Regarding Fault Handling Time Interval

The following table details the cycle time, execution time and reporting time for all monitors included in MLX90376. In all cases, the worst-case timing values are provided in the table below:

Category and safety mechanism name	DTI	EXE	REP
Signal-conditioning (AFE, External Sensor) Diagnostic			
Magnetic Signal Conditioning Voltage Test Pattern	**$1 * DTI_{ANA}$**	**$1 * \tau_R$**	**$1 * \tau_R$**
Magnetic Signal Cond. Rough Offset Clipping check	2.5 ms	$1 * \tau_R$	$1 * \tau_R$
Magnetic Signal Conditioning Gain Monitor & clamp	2.5 ms	$1 * \tau_R$	$1 * \tau_R$
External Sensor Sig. Cond. Voltage Valid Range Check	$9 * \tau_R$	0	$1 * \tau_R$
External Sensor Sig. Cond. Frequency Valid Range Check	$1*T_{pwm\_input}$	$1 * \tau_R$	$1 * \tau_R$
A/D Converter Test Pattern	$1 * DTI_{ANA}$	0	$1 * \tau_R$
ADC Conversion errors & Overflow Errors	$1 * \tau_R$	0	$1 * \tau_R$
Flux monitor	2.5 ms	$1 * \tau_R$	$1 * \tau_R$
Hall-element & Mechanical-stress Tests	$1 * DTI_{ANA}$	0	$1 * \tau_R$
Digital-circuit Diagnostic			
RAM Parity, 1 bit per 16 bits word, ISO D.2.5.2	$< 1 * DTI_{ANA}$	0	0
ROM Parity, 1 bit per 16 bits word, ISO D.2.5.2	$< 1 * DTI_{ANA}$	0	0
NVRAM Double Error Detection ECC ISO D.2.4.1	< 10µs	0	0
NVRAM 16 bits signature (run-time) ISO D.2.4.3	**$1 * DTI_{DIG}$**	**0**	**0**

Category and safety mechanism name	DTI	EXE	REP
Logical Monitoring of program sequence ISO D.2.9.3 via Watchdog "IWD" (cpu clock) ISO D2.9.2	4 ms	0	0
Watch-dog "AWD" (separate clock) ISO D2.9.1	**5ms**	**0**	**0**
CPU error detection	1 * τ_R	0	0
ADC Interface Checksum	1 * DTI_{ANA}	0	0
DSP Test Pattern (atan2)	1 * DTI_{ANA}	0	0
Critical ports monitoring	1 * DTI_{ANA}	0	0
DSP overflow	1 * τ_R	0	0
ADC data adder test	1 * τ_R	0	0
SENT Fall Collision detection & DAC Overflow	1 * τ_R	0	0
SENT H/W Interface Diagnostic			
SENT parity check over Configuration registers	1 * $T_{trigger}$	0	0
SENT HW: Protection against re-configuration	1 * $T_{trigger}$	0	0
System-level diagnostic			
Supply Voltage Monitors except VS_OV & POR	1 * DTI_{ANA}	0	1 * τ_R
External Supply Overvoltage Monitor VS_OV	1 * DTI_{ANA}	0	1 * τ_R
Supply Bias Current Monitor	1 * DTI_{ANA}	0	1 * τ_R
Overheating monitor	9 * τ_R	1 * τ_R	1 * τ_R

Table 76 - Timings of the cyclic detection mechanism

Note:

- **The orange colour coding** shows the worst-case FHTI for analog and digital diagnostics
- The ROM and RAM parity mechanism trigger a fail-safe state on the failing ROM or RAM word is accessed. (It is assumed that it will be accessed within one full diagnostic cycle in worst case)
- EXE/REP time = 0 means that the execution or reporting time is negligible compared to the FHTI value

16. Recommended Application Diagrams

16.1. Wiring with the MLX90376 in SMP-4 Package (built-in capacitors)

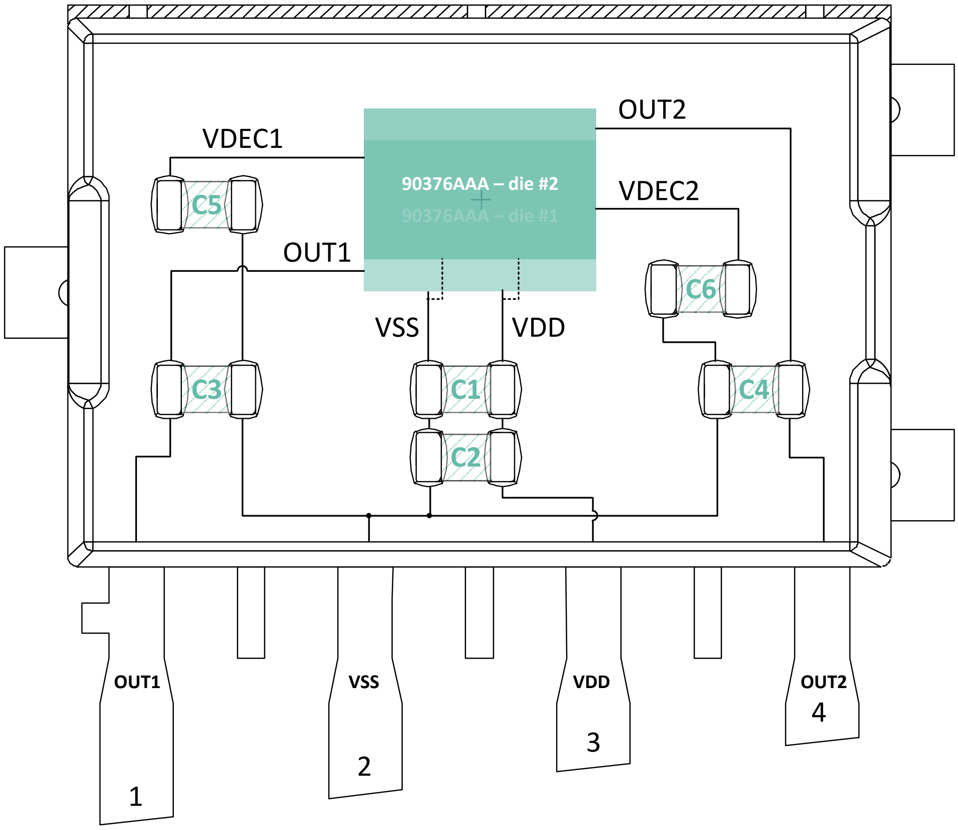


Figure 37 - Internal wiring of the MLX90376 in SMP-4 package

Component	Value	Output Protocol	Remark
C1	220 nF	Analog/PWM/SENT	VDD-VSS decoupling capacitor die 1 (bottom)
C2	220 nF	Analog/PWM/SENT	VDD-VSS decoupling capacitor die 2 (top)
C3	10 nF	Analog/PWM/SENT	OUT1-VSS decoupling capacitor die 1 (bottom)
C4	10 nF	Analog/PWM/SENT	OUT2-VSS decoupling capacitor die 2 (top)
C5	100 nF	Analog/PWM/SENT	VDEC-VSS decoupling capacitor die 1 (bottom)
C6	100 nF	Analog/PWM/SENT	VDEC-VSS decoupling capacitor die 2 (top)

Table 77 - SMP-4 Capacitors configurations

16.2. Wiring with the MLX90376 in SMD packages

16.2.1. SOIC-8 Package

Figure 37 shows the typical recommended application circuit for the MLX90376 in SOIC-8 package, and Table 77 shows the corresponding value of the external components.

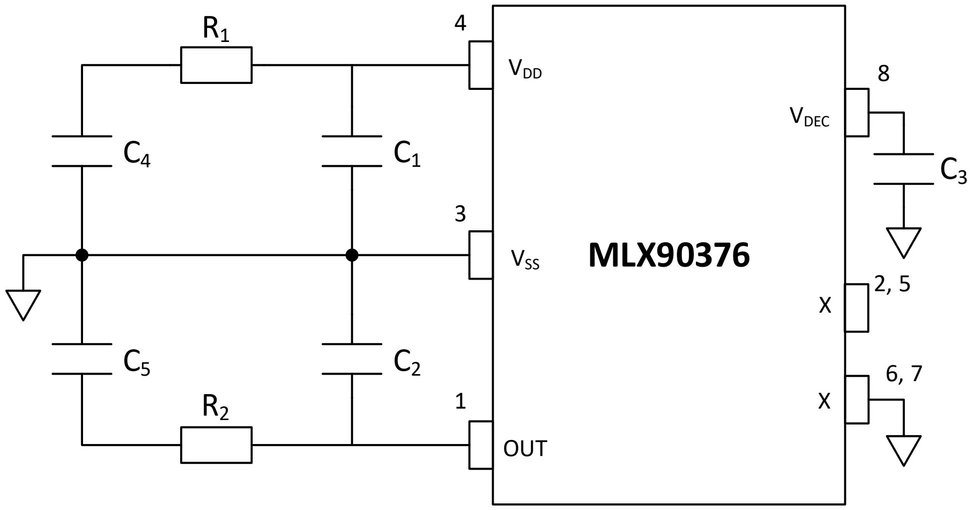


Figure 38 - Recommended wiring for the MLX90376 in SOIC-8 package

Component	Value	Remark
C_1	220nF	Place close to the IC pin
$C_2(C_L)$	100nF 10nF 2.2nF	for analog output for SENT and PWM output for SPC output
C_3	100nF	Place close to the IC pin
C_4	0nF	Place close to the connector
C_5	0nF	Place close to the connector
R_1	0Ω	
R_2	0Ω	

Table 78 - Recommended Values for the MLX90376 in SOIC-8 Package

C_2 should consider the total capacitance on the bus. C_4, C_5, R_1, R_2 are not needed under typical conditions. They are only needed, when extremely high electromagnetic immunity (EMI) compliance is required, but the value of the resistors and capacitors should not exceed 10Ω and 1nF.

In SENT protocol, an external pi-filter to improve radiated emission performance is not needed. The MLX90376 has a built-in high order low pass filter. Therefore, any additional external filter will deteriorate the generated SENT signal, and could make the output signal not comply to the SENT specifications, such as the fall times and the minimum output voltages.

16.2.2. Wiring with the MLX90376 in TSSOP-16_EP Package

Figure 39 shows the typical recommended application circuit for the MLX90376 in TSSOP-16_EP package, and Table 79 shows the corresponding value of the external components.

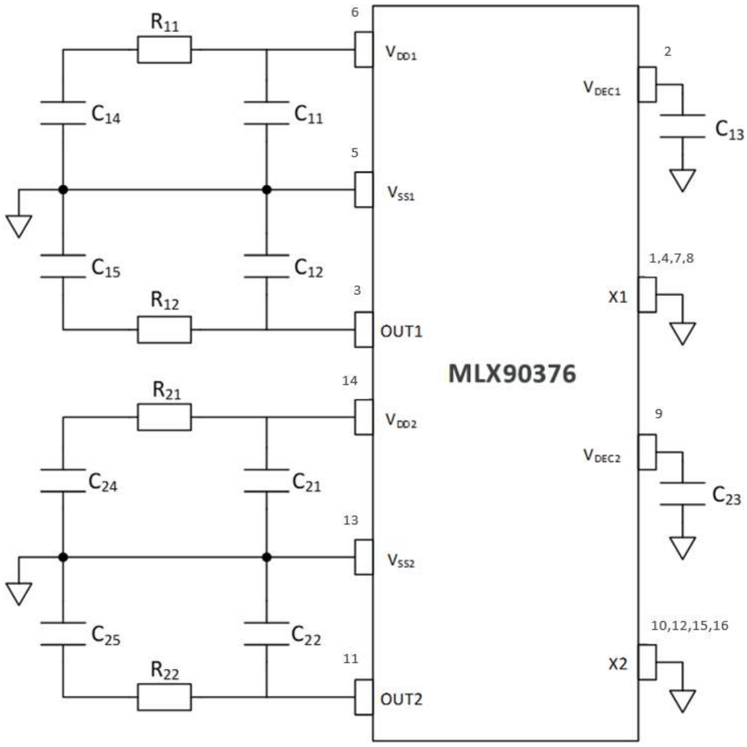


Figure 39 - Recommended wiring for the MLX90376 in TSSOP-16_EP dual-die package

Component	Value	Remark
C_{x1}	220nF	Place close to the IC pin
C_{x2}	100nF 10nF 2.2nF	for analog output for SENT and PWM output for SPC output
C_{x3}	100nF	Place close to the IC pin
C_{x4}	0nF	Place close to the connector
C_{x5}	0nF	Place close to the connector
R_{x1}	0Ω	
R_{x2}	0Ω	

Table 79 - Recommended Values for the MLX90376 in TSSOP-16_EP dual-die Package

C_{x2} should consider the total capacitance on the bus. C_{x4}, C_{x5}, R_{x1}, R_{x2} are not needed under typical conditions. They are only needed, when extremely high electromagnetic immunity (EMI) compliance is required, but the value of the resistors and capacitors should not exceed 10Ω and 1nF.

In SENT or SPC protocol, an external pi-filter to improve radiated emission performance is not needed. The MLX90376 has a built-in high order low pass filter. Therefore, any additional external filter will deteriorate the generated output signal, and could make the output signal not comply to the SENT or SPC specifications, such as the fall times and the minimum output voltages.

17. Standard Information Regarding Manufacturability of Melexis Products with Different Soldering Processes

Our products are classified and qualified regarding soldering technology, solderability and moisture sensitivity level according to standards in place in Semiconductor industry.

For further details about test method references and for compliance verification of selected soldering method for product integration, Melexis recommends reviewing on our web site the General Guidelines soldering recommendation (http://www.melexis.com/en/quality-environment/soldering)

For all soldering technologies deviating from the one mentioned in above document (regarding peak temperature, temperature gradient, temperature profile etc), additional classification and qualification tests have to be agreed upon with Melexis.

For package technology embedding trim and form post-delivery capability, Melexis recommends consulting the dedicated trim & form recommendation application note : "Lead Trimming and Forming Recommendations" (http://www.melexis.com/en/documents/documentation/application-notes/lead-trimming-and-forming-recommendations).

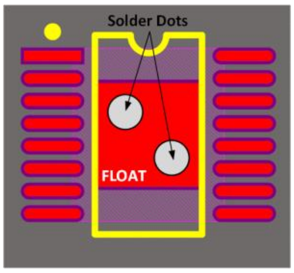
Melexis is contributing to global environmental conservation by promoting lead free solutions. For more information on qualifications of RoHS compliant products (RoHS = European directive on the Restriction Of the use of certain Hazardous Substances) please visit the quality page on our website: http://www.melexis.com/en/quality-environment.

17.1. Soldering recommendations for the Exposed Pad (EP) in TSSOP-16

The MLX90376ABA in a stacked die configuration come in a TSSOP package with an exposed pad. This package is used to enable sufficient space for the die stacking. The exposed pad is **not** used to improve the thermal dissipation of the IC. Consequently, the dice are isolated with regards to the exposed pad, both electrically and thermally. To guarantee product performance and electrical safety, the following guidelines shall be followed when designing the PCB.

A copper pad of adequate size shall be placed under the exposed pad on the PCB. For electrical safety and optimal EMC and noise performance, the copper pad on the PCB shall remain electrically inactive (FLOAT, not connected to any electrical net). It is not necessary to solder the package exposed pad to the PCB.
When soldered, the following remarks shall be taken into consideration:

- a stencil of minimal thickness of 150um shall be used
- dispensing shall be limited to two dots of 1mm maximum diameter
- a limited force of 1N to 2 N should be applied to the TSSOP package to secure wetting contact of the exposed pad to solder paste



18. ESD Precautions

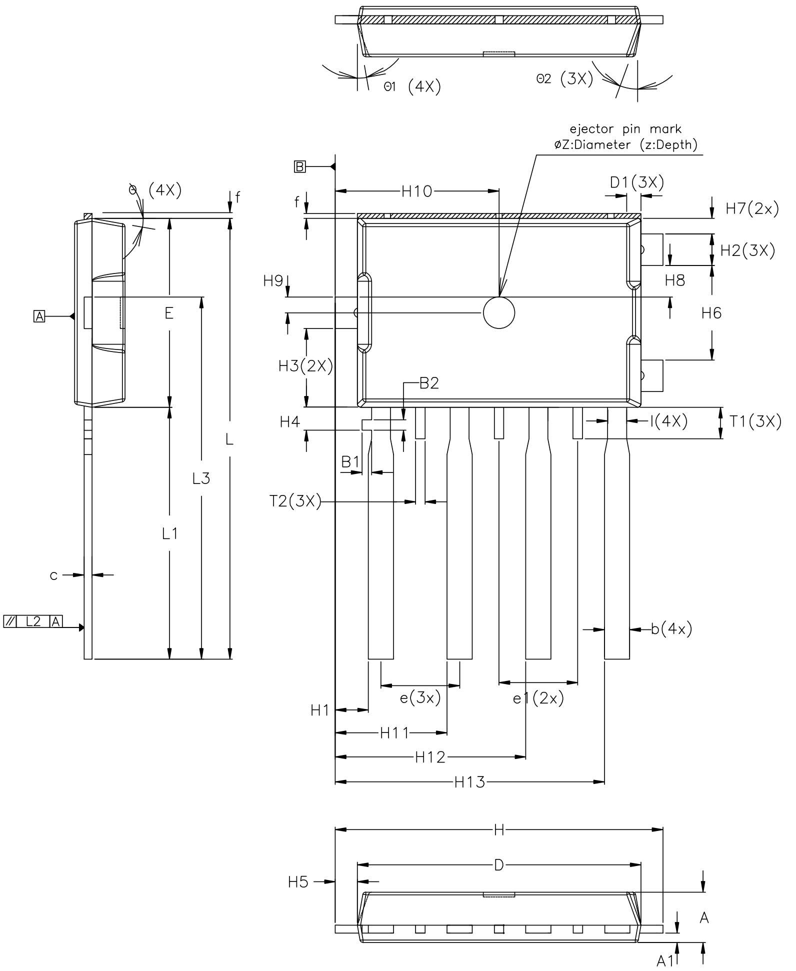
Electronic semiconductor products are sensitive to Electro Static Discharge (ESD).

Always observe Electro Static Discharge control procedures whenever handling semiconductor products.

19. Package Information

19.1. SMP-4 Package

19.1.1. SMP-4- Package Outline Dimensions (POD)



Dimension	MIN.	NOM.	MAX.
A	1.550	1.600	1.650
A1	0.250	0.290	0.330
B1	0.235	0.300	0.365
B2		0.33 REF	
c	0.250	0.280	0.310
D	8.920	9.000	9.080
D1		0.450 REF	
E	5.920	6.000	6.080
f	0.000	- - -	0.150
H	10.300	10.400	10.500
H1	0.900	1.050	1.200
H2	0.975	1.050	1.125
H3	2.380	2.475	2.570
H4	0.635	0.730	0.825
H5	0.605	0.700	0.795
H6	2.875	2.950	3.025
H7		0.475 REF	
H8	0.875	0.950	1.025
H9	0.410	0.525	0.640
H10	5.085	5.200	5.315
H11	3.400	3.550	3.700
H12	5.900	6.050	6.200
H13	8.400	8.550	8.700

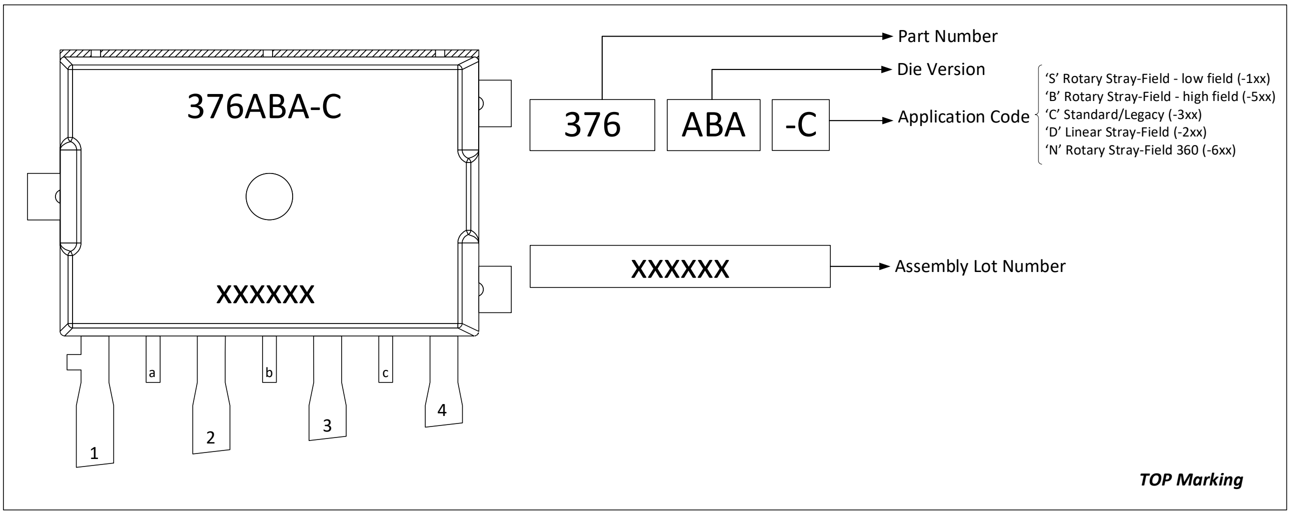
Dimension	MIN.	NOM.	MAX.
L	13.870	14.000	14.130
L1	7.870	8.000	8.130
L2	-0.250	0.000	0.250
L3	11.375	11.525	11.675
I	0.525	0.600	0.675
b	0.770	0.820	0.870
e1		2.500 BSC	
e		2.500 BSC	
Θ	8°	10°	12°
Θ1	8°	10°	12°
Θ2	18°	20°	22°
øZ	0.900	1.000	1.100
z	0.025	- - -	0.150
T1	0.870	1.000	1.130
T2	0.225	0.300	0.375

NOTES:

1. DIMENSIONS ARE IN MILLIMETER UNLESS NOTED OTHERWISE.
2. PACKAGE WIDTH DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.15MM PER END. PACKAGE LENGTH DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25MM PER SIDE.
3. THE PACKAGE TOP MAY BE SMALLER THAN THE PACKAGE BOTTOM. PACKAGE WIDTH AND LENGTH ARE DETERMINED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY EXCLUSIVE OF MOLD FLASH, TIE BAR BURRS, GATE BURRS AND INTERLEAD FLASH.
4. PLATING SPECS: MATTED TIN, ELECTROPLATED, 12 ± 5 MICROMETER (μm) THICKNESS
5. ALL "EARS" ARE CONNECTED TO ELECTRIC GROUND.

Figure 40 - SMP-4 Package Outline Dimensions

19.1.2. SMP-4- Pinout and Marking



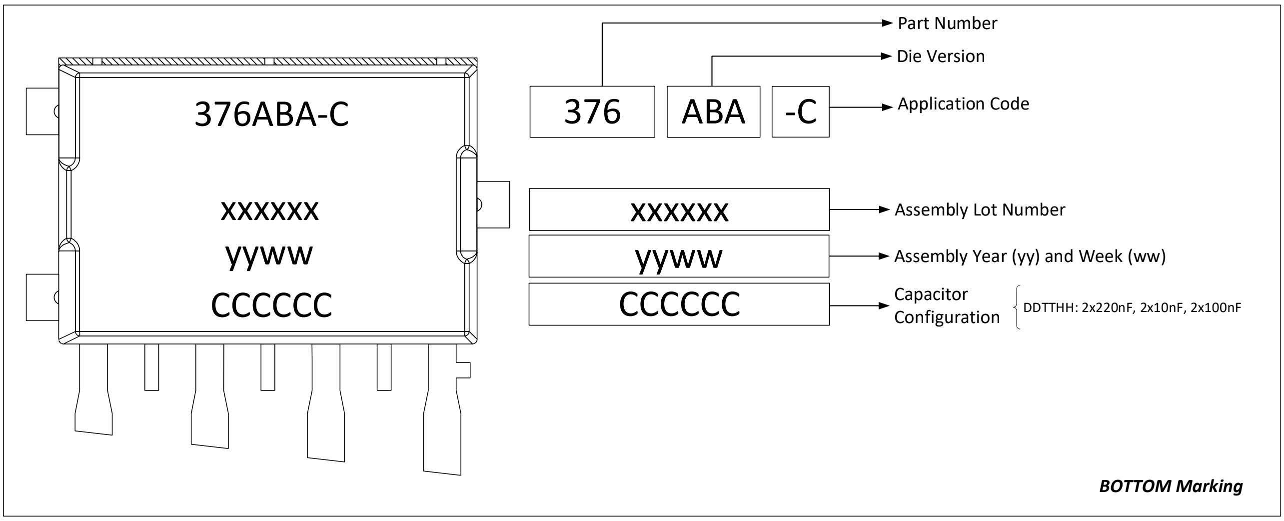


Figure 41 - SMP-4 Pinout and Marking

19.1.3. SMP-4- Sensitive spot positioning

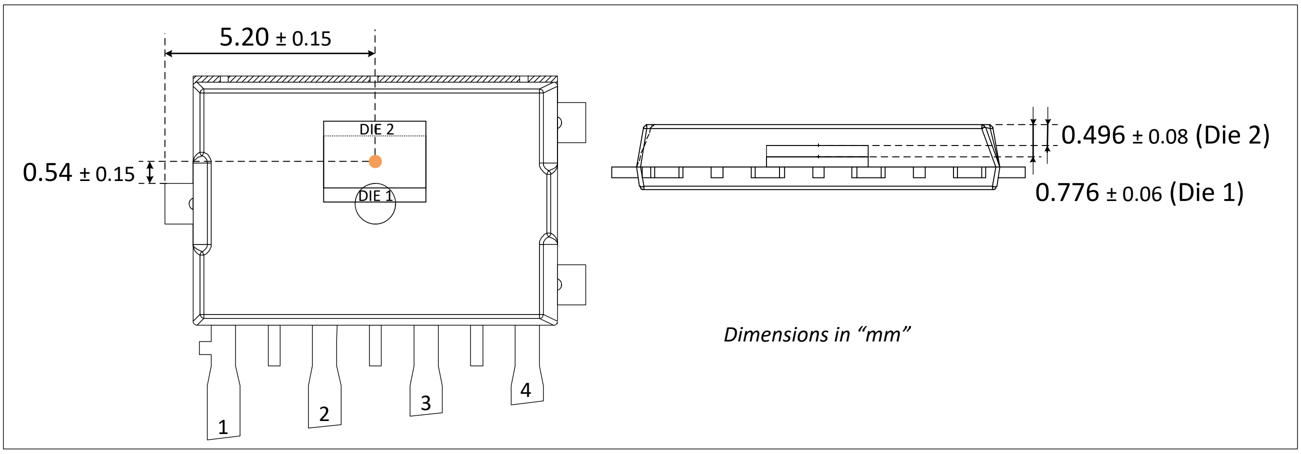


Figure 42 - SMP-4 sensitive spot for rotary Stray-Field immune and standard/legacy modes

19.1.4. SMP-4- Angle detection

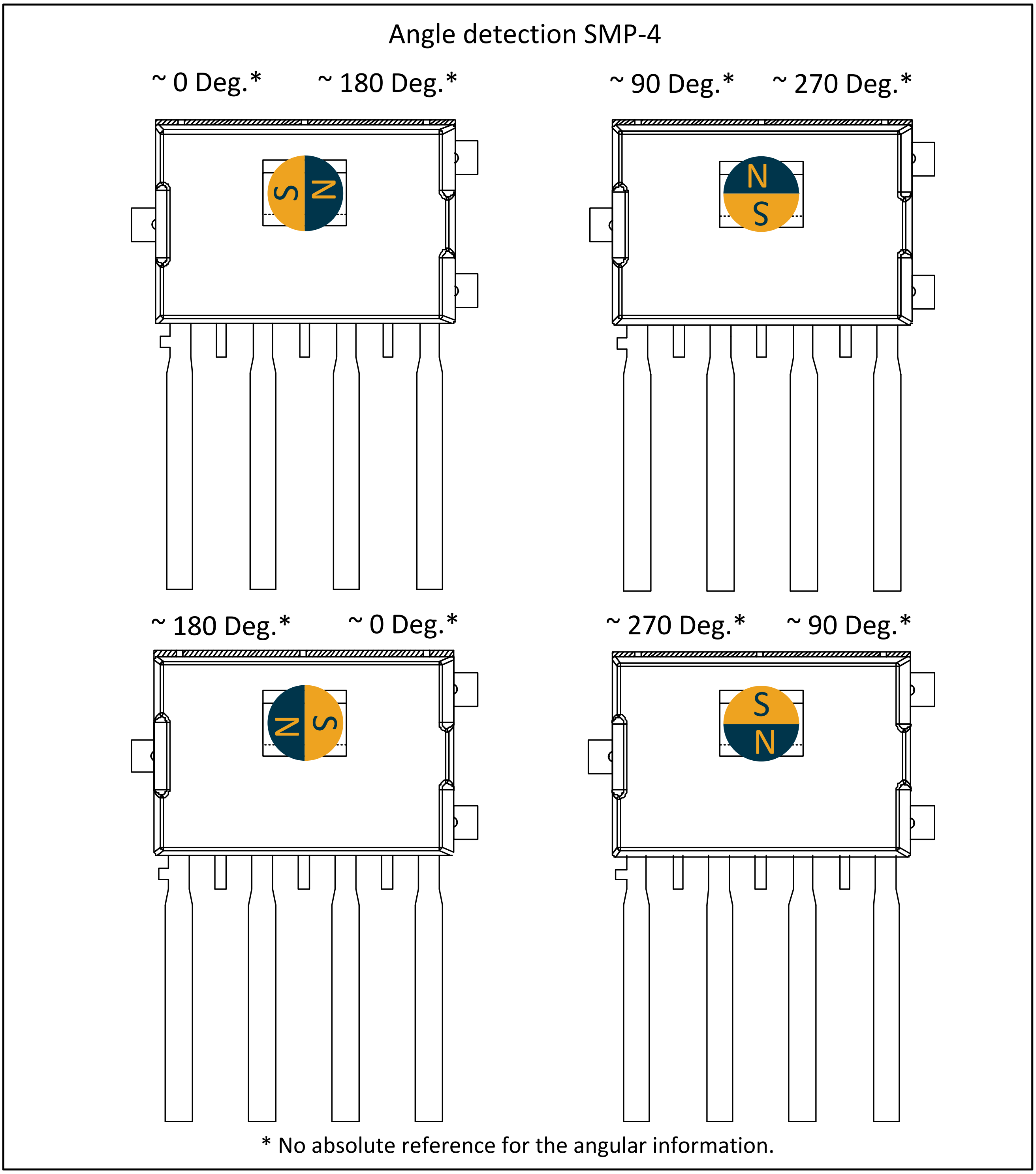


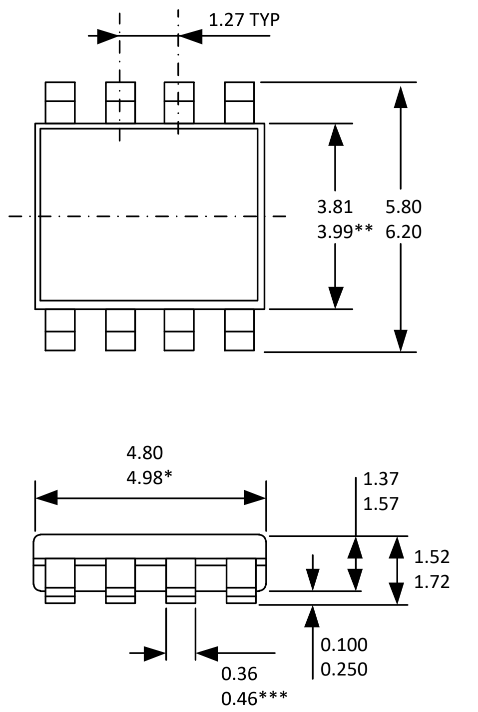
Figure 43 - SMP-4 Angle Detection

The MLX90376 is an absolute angular position sensor but the linearity error (See section 9) does not include the error linked to the absolute reference 0 Deg (which can be fixed in the application through the discontinuity point).

19.2. SMD packages

19.2.1. SOIC-8 Package

19.2.1.1. SOIC-8- Package Outline Dimensions (POD)



NOTES:

All dimensions are in millimeters (angles in degrees).
* Dimension does not include mold flash, protrusions or gate burrs (shall not exceed 0.15 per side).
** Dimension does not include interleads flash or protrusion (shall not exceed 0.25 per side).
*** Dimension does not include dambar protrusion. Allowable dambar protrusion shall be 0.08 mm total in excess of the dimension at maximum material condition. Dambar cannot be located on the lower radius of the foot.

Figure 44 - SOIC-8 Package Outline Dimensions

19.2.1.2. SOIC-8- Pinout and Marking

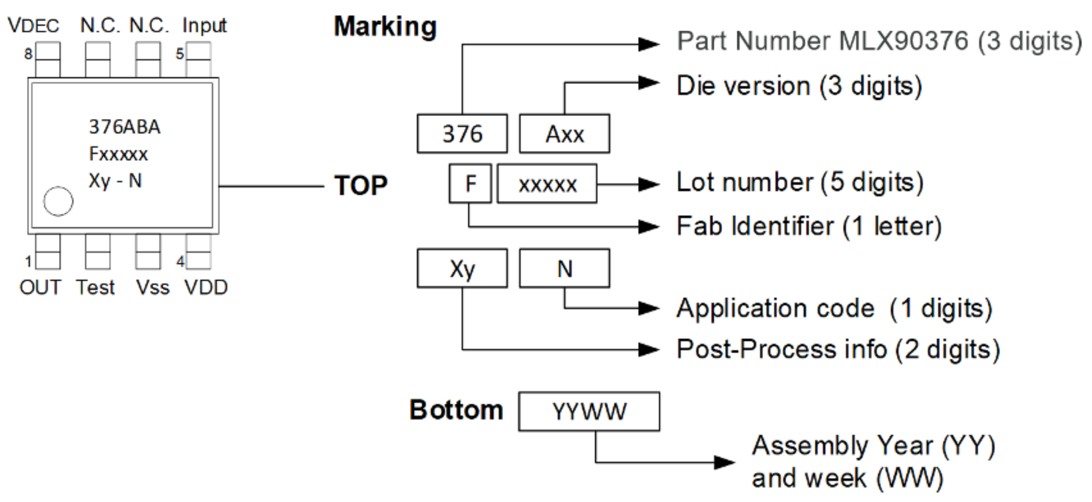


Figure 45 - SOIC-8 Pinout and Marking

19.2.1.3. SOIC-8- Sensitive spot positioning

19.2.1.3.1. Rotary Stray-field Immune

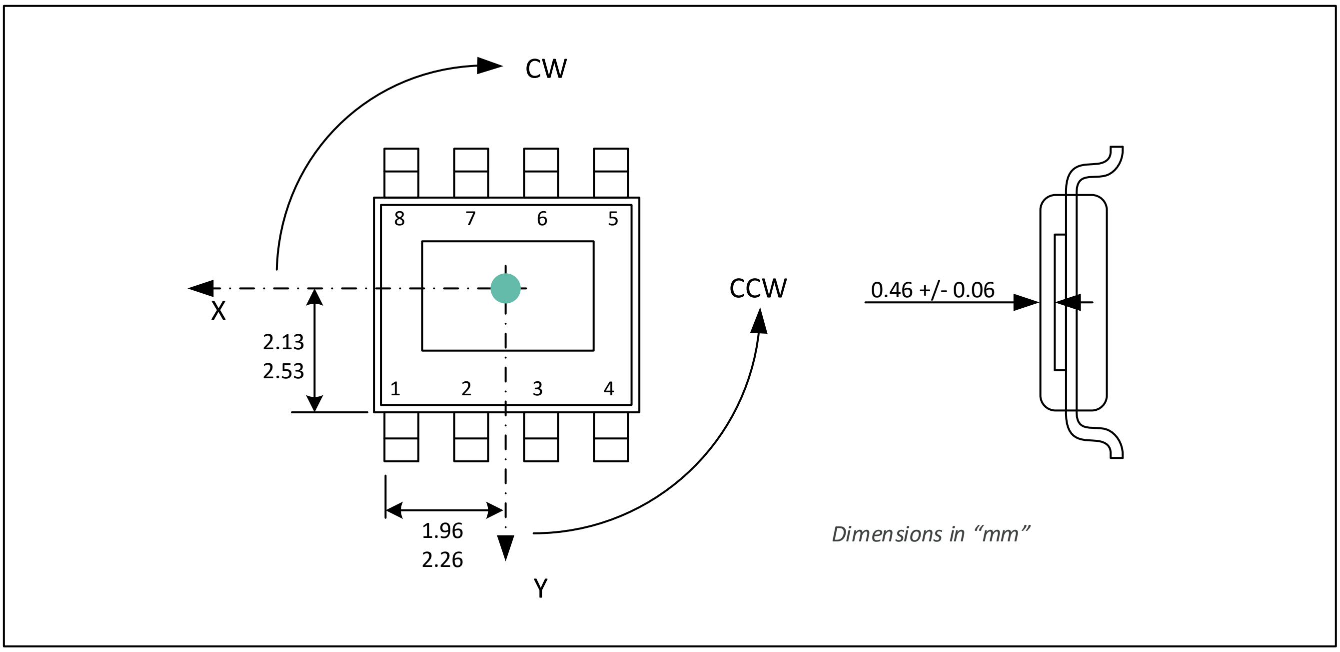


Figure 46 - SOIC-8 sensitive spot for rotary Stray-Field immune and standard/legacy modes

19.2.1.4. SOIC-8- Angle detection

The MLX90376 is an absolute angular position sensor but the linearity error (See section 9) does not include the error linked to the absolute reference 0 Deg (which can be fixed in the application through the discontinuity point).

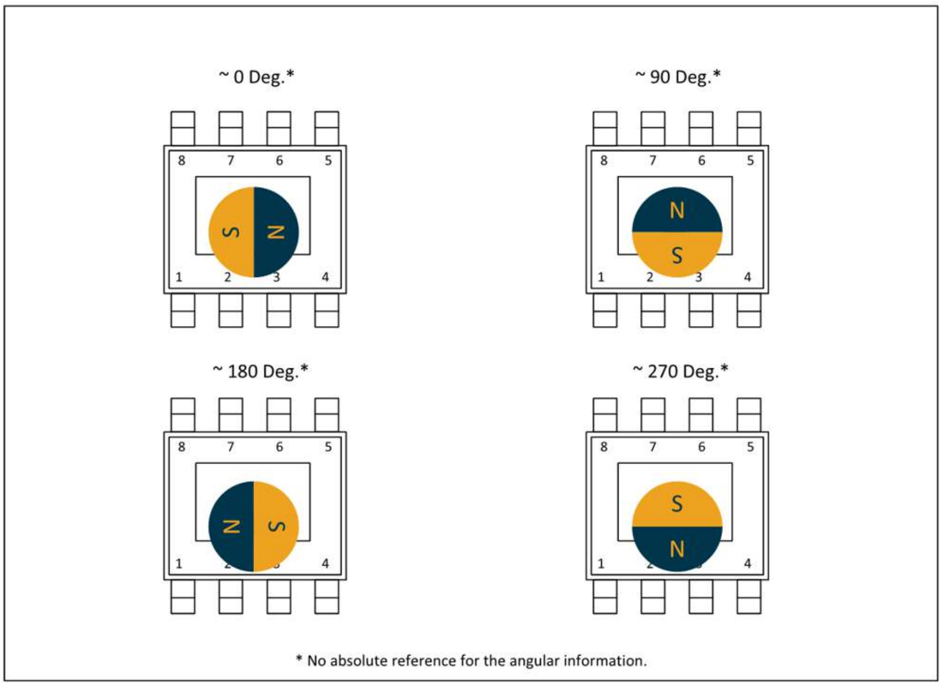
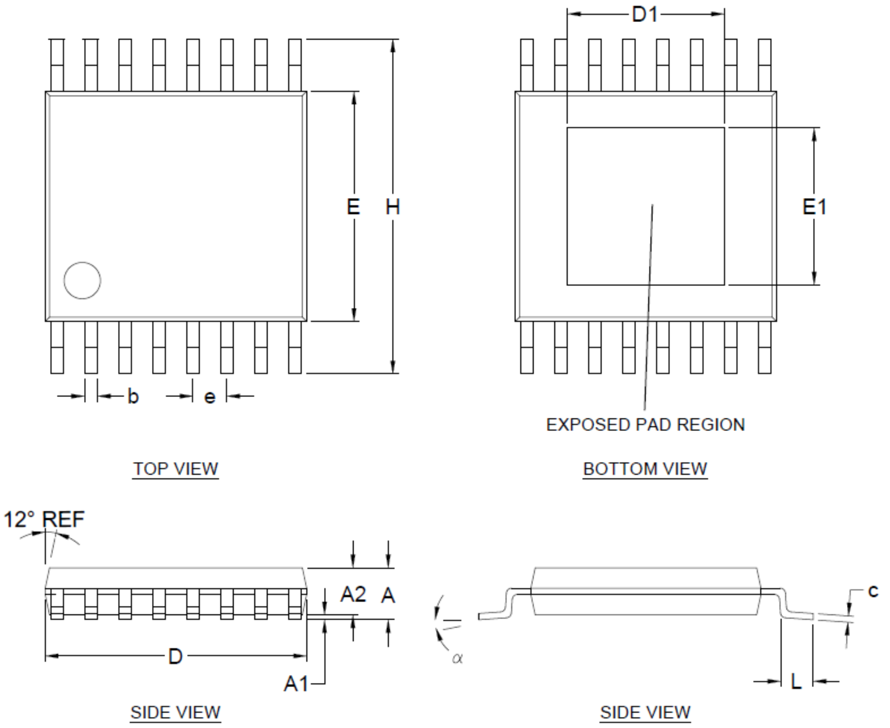


Figure 47 - SOIC-8 Angle Detection for MLX90376ABA

19.2.2. TSSOP-16_EP Package

19.2.2.1. TSSOP-16_EP- Package Outline Dimensions (POD)



SYMBOL	MINIMUM	MAXIMUM
A	---	1.10
A1	0.05	0.15
A2	0.85	0.95
D	4.90	5.10
E	4.30	4.50
D1	2.90	3.10
E1	2.90	3.10
H	6.40 REF	
L	0.50	0.75
b	0.19	0.30
c	0.09	0.20
e	0.65 BSC	
α	0°	8°

NOTE :
1. ALL DIMENSIONS IN MILLIMETERS (mm) UNLESS OTHERWISE STATED.
2. DIMENSION D DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS OF MAX 0.15 mm PER SIDE.
3. DIMENSION E DOES NOT INCLUDE INTERLEADS FLASH OR PROTRUSIONS OF MAX 0.25 mm PER SIDE.
4. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION OF MAX 0.08 mm.
5. LEAD COPLANARITY SHALL BE MAXIMUM 0.1 mm.

Figure 48 - TSSOP-16_EP Package Outline Dimensions

19.2.2.2. TSSOP-16_EP- Pinout and Marking

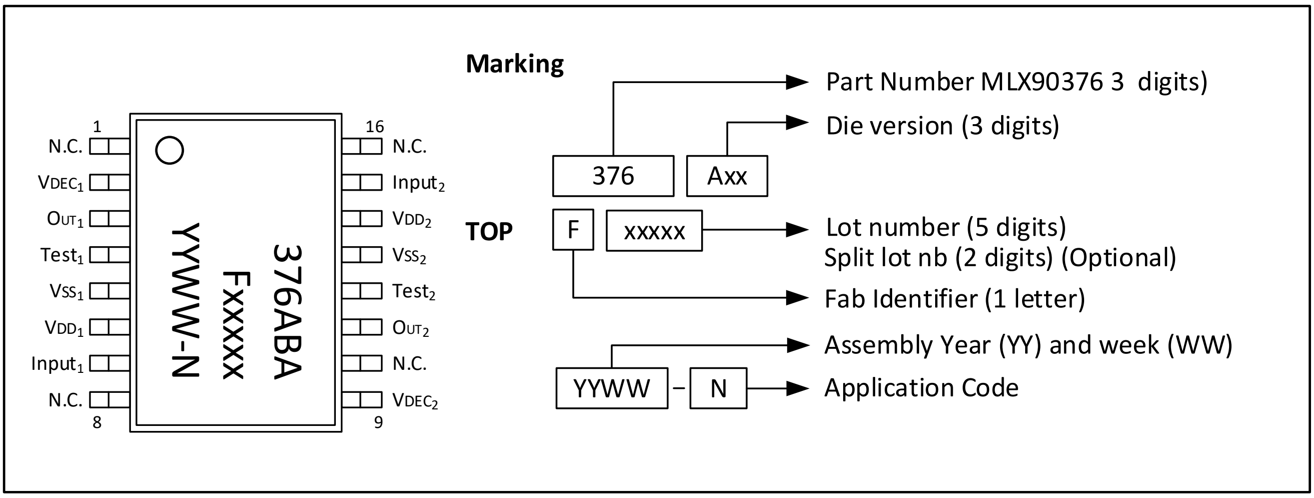


Figure 49 - TSSOP-16_EP Pinout and Marking

19.2.2.3. TSSOP-16_EP- Sensitive spot positioning

19.2.2.3.1. Rotary Stray-field Immune

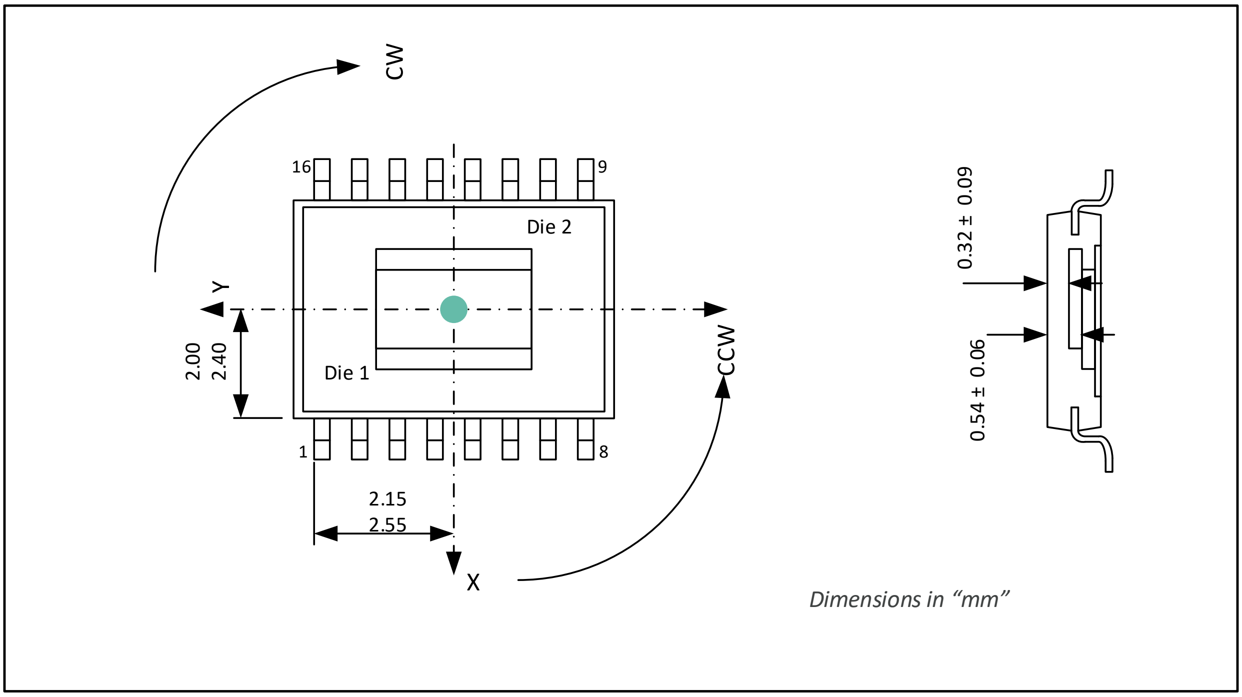


Figure 50 - TSSOP-16_EP sensitive spot for rotary Stray-Field immune and standard/legacy modes

19.2.2.4. TSSOP-16_EP- Angle detection

The MLX90376 is an absolute angular position sensor but the linearity error (See section 9) does not include the error linked to the absolute reference 0 Deg (which can be fixed in the application through the discontinuity point).

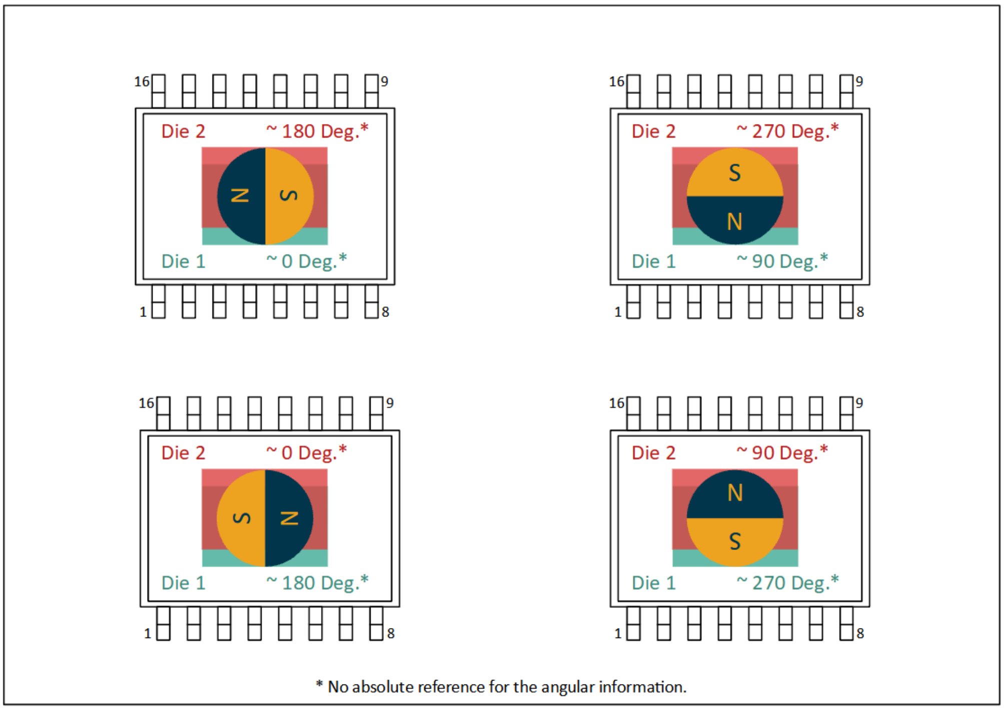


Figure 51 - TSSOP-16_EP Angle Detection for MLX90376ABA

19.3. Package Thermal Performances

19.3.1. Package Thermal Performances for SMP-4 package

The table below describe the thermal behaviour of available packages following JEDEC EIA/JESD 51.X standard.

Package	Junction to case - θjc	Junction to ambient - θja (JEDEC 1s2p board)	Junction to ambient - θja (JEDEC 1s0p board)
SMP-4 Stacked Die	25.7 K/W	-	144.6 K/W

Table 80 - SMP-4 Package Thermal Performances

19.3.2. Package Thermal Performances for SMD packages

The table below describe the thermal behaviour of available packages following JEDEC EIA/JESD 51.X standard

Package	Junction to case - θjc	Junction to ambient - θja (high effective board)	Junction to ambient - θja (JEDEC 1s0p board)
SOIC-8 Single Die	38.8 K/W	112 K/W	153 K/W
TSSOP-16_EP Dual Die	26 K/W	42 K/W	150 K/W

Table 81 - SOIC-8 and TSSOP-16_EP Package Thermal Performances

20. Contact

For the latest version of this document, go to our website at www.melexis.com.

For additional information, please contact our Direct Sales team and get help for your specific needs:

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	Email : sales_europe@melexis.com
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2. civil firearms, including spare parts or ammunition for such arms;

3. defense related products, or other material for military use or for law enforcement;

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