Angle Sensor

GMR Angle Sensor

TLE5009A16D

Data Sheet

Version 1.0, 2016-06

Sense & Control

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1 Product Description

1.1 Overview

The TLE5009A16D is an angle sensor with analog outputs. It detects the orientation of a magnetic field by measuring sine and cosine components with **G**iant **M**agneto **R**esistive (**GMR**) elements. It provides analog sine and cosine output voltages that describe the magnet angle in a range of 0° to 360°.

The differential GMR bridge signals are independent of the magnetic field strength, and the output voltages are designed to use the dynamic range of an A/D-converter using the same supply as the sensor as voltage reference.

The TLE5009A16D is a dual die sensor for safety applications that require redundancy. The two dies are supplied independently by separate supply and ground pins.

1.2 Features

- Dual die sensor with separate supplies for each die
- Low current consumption and very fast power up
- 360° contactless angle measurement
- Immune to airgap variations due to MR based sensing principle
- Operating temperature: -40°C to 125°C (ambient temperature)
- AEC-Q100 automotive qualified
- Green package with lead-free (Pb-free) plating, halogene free

Table 1   Derivate Ordering codes

Product Type	Marking	Ordering Code	Package	Description
TLE5009A16D E1200	09A21200	SP001285628	PG-TDSO-16 (16 pins)	Dual Die 3.3 V supply Without TCO[1] Grade 1[2]
TLE5009A16D E1210	09A21210	SP001296122	PG-TDSO-16 (16 pins)	Dual Die 3.3 V supply With TCO[1] Grade 1[2]
TLE5009A16D E2200	09A22200	SP001296126	PG-TDSO-16 (16 pins)	Dual Die 5.0 V supply Without TCO[1] Grade 1[2]
TLE5009A16D E2210	09A22210	SP001296130	PG-TDSO-16 (16 pins)	Dual Die 5.0 V supply With TCO[1] Grade 1[2]

1) Temperature Compensation Offset
2) Part Operating Temperature Grades according to AEC-Q100

1.3   Target Applications

The TLE5009A16D angle sensor is designed for angular position sensing automotive applications. Its high accuracy and 360° measurement range combined with short propagation delay makes it suitable for systems with high speeds and high accuracy demands such as brush-less DC (BLDC) motors for actuators and electric power steering systems (EPS). At the same time its fast power-up time and low overall power consumption enables the device to be employed for low-power turn counting. Extremely low power consumption can be achieved with power cycling, where the advantage of fast power on time reduces the average power consumption.

The TLE5009A16D is also used in various non-automotive applications.
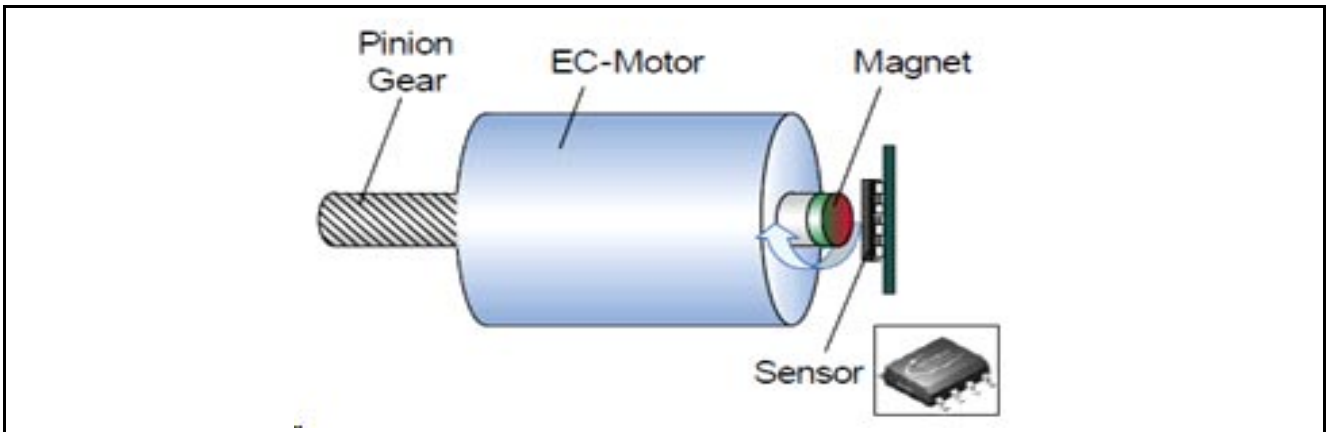

Figure 1   A usual application for TLE5009A16D is the electrically commutated motor

2 Functional Description

2.1 General

The **G**iant **M**agneto **R**esistive (**GMR**) sensors are implemented using vertical integration. This means that the MR sensitive areas are integrated above the analog portion of the ICs. These MR elements change their resistance depending on the direction of the magnetic field.

On each sensor, four individual MR elements are connected in a Wheatstone bridge arrangement. Each MR element senses one of two components of the applied magnetic field:

- X component, V_x (cosine) or the
- Y component, V_y (sine)

The advantage of a full-bridge structure is that the amplitude of the MR signal is doubled and temperature effects cancel out. The output signal of a GMR bridge is unambiguous in a range of 180°. Therefore two bridges are oriented orthogonally to each other to measure 360°.
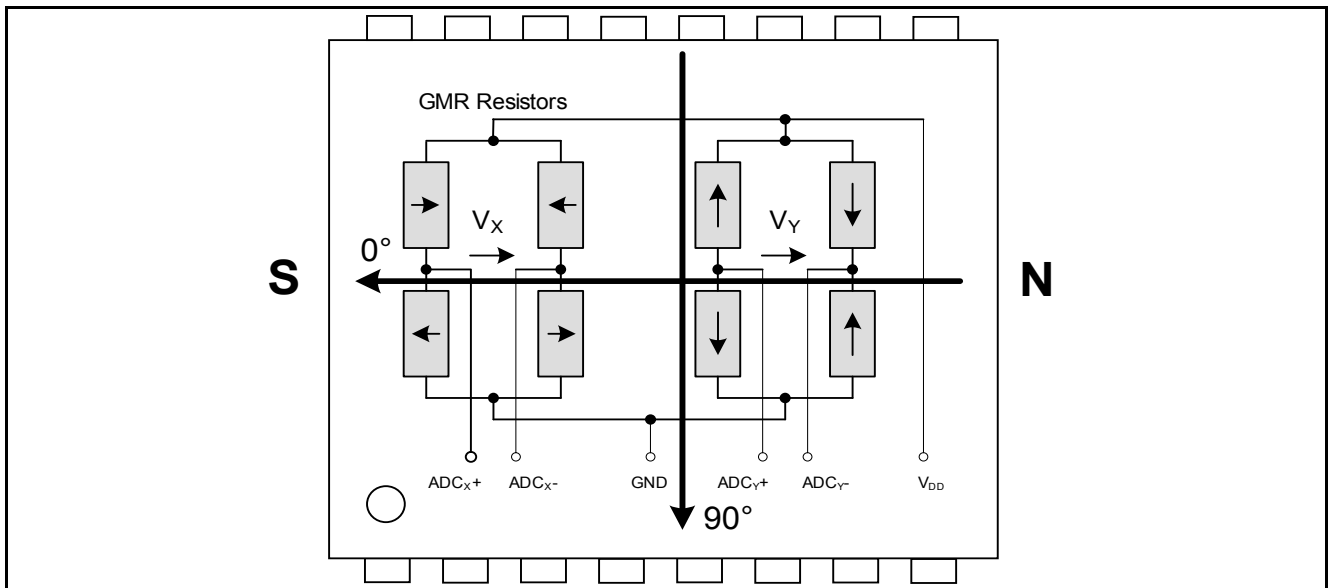

Figure 2   Sensitive bridges of the GMR sensor (one die, not to scale)

Attention: Due to the rotational placement inaccuracy of the sensor IC in the package, the sensors 0°
position may deviate by up to 3° from the package edge direction indicated in Figure 2.

In **Figure 2**, the arrows in the resistors represent the magnetic direction which is fixed in the Reference Layer. On top of the Reference Layer, and separated by a non magnetic layer, there is a Free Layer. When applying an external magnetic field the Free Layer moves in the same direction as the external magnetic field, while the Reference Layer remains fix. The resistance of the GMR elements depends on the magnetic direction difference between the Reference Layer and the Free Layer.

When the external magnetic field is parallel to the direction of the Reference Layer, the resistance is minimal (Reference Layer and Free Layer are parallel). When the external magnetic field and the Reference Layer are anti-parallel (Reference Layer and Free Layer are anti-parallel), resistance is maximal.

The output signal of each bridge is only unambiguous over 180° between two maxima. Therefore two bridges are oriented orthogonally to each other to measure 360°.

With the trigonometric function ARCTAN2, the true 360° angle value is calculated out of the raw X and Y signals from the sensor bridges. The ARCTAN2 function is a microcontroller library function which resolves an angle within 360° using the x and y coordinates on a unit circle.
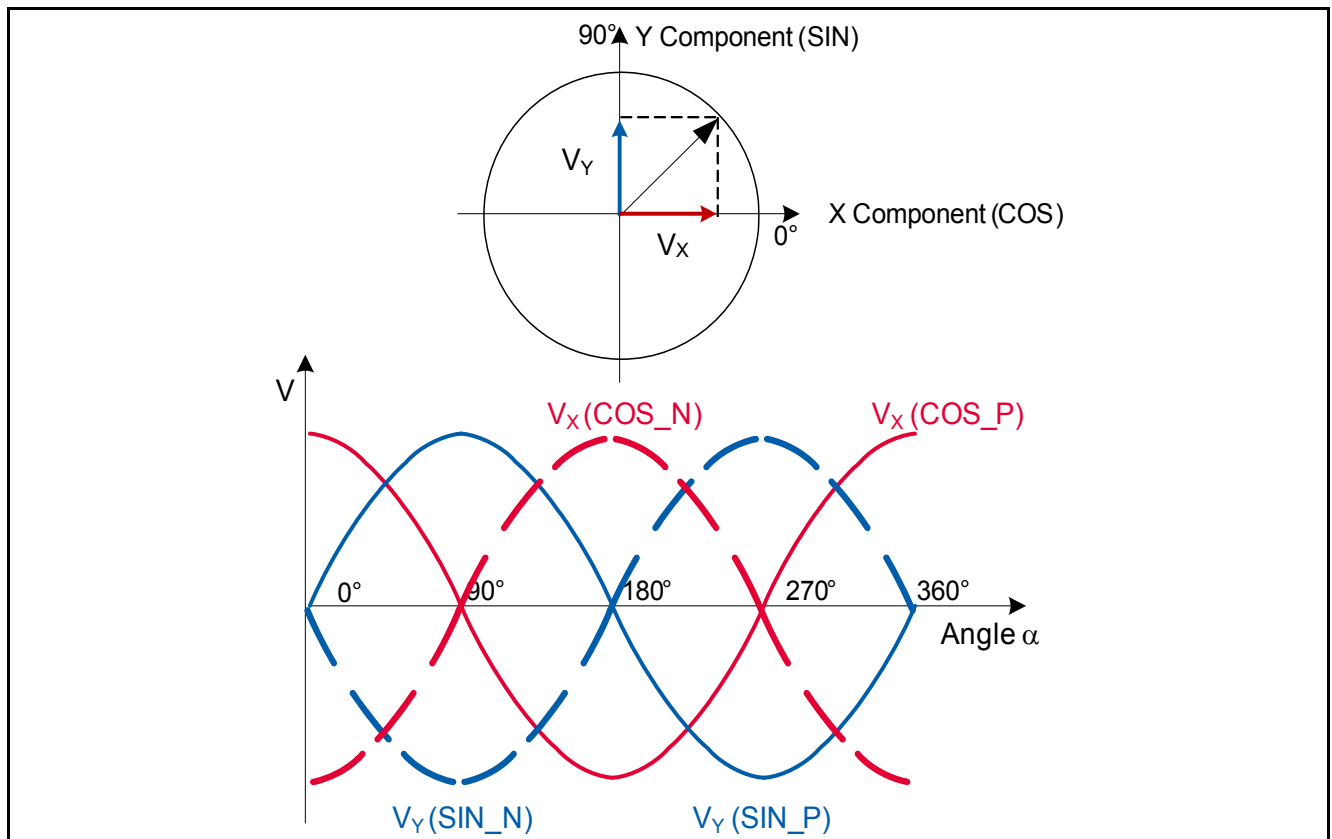
Figure 3   Ideal output of the GMR sensor bridges

2.2   Block Diagram
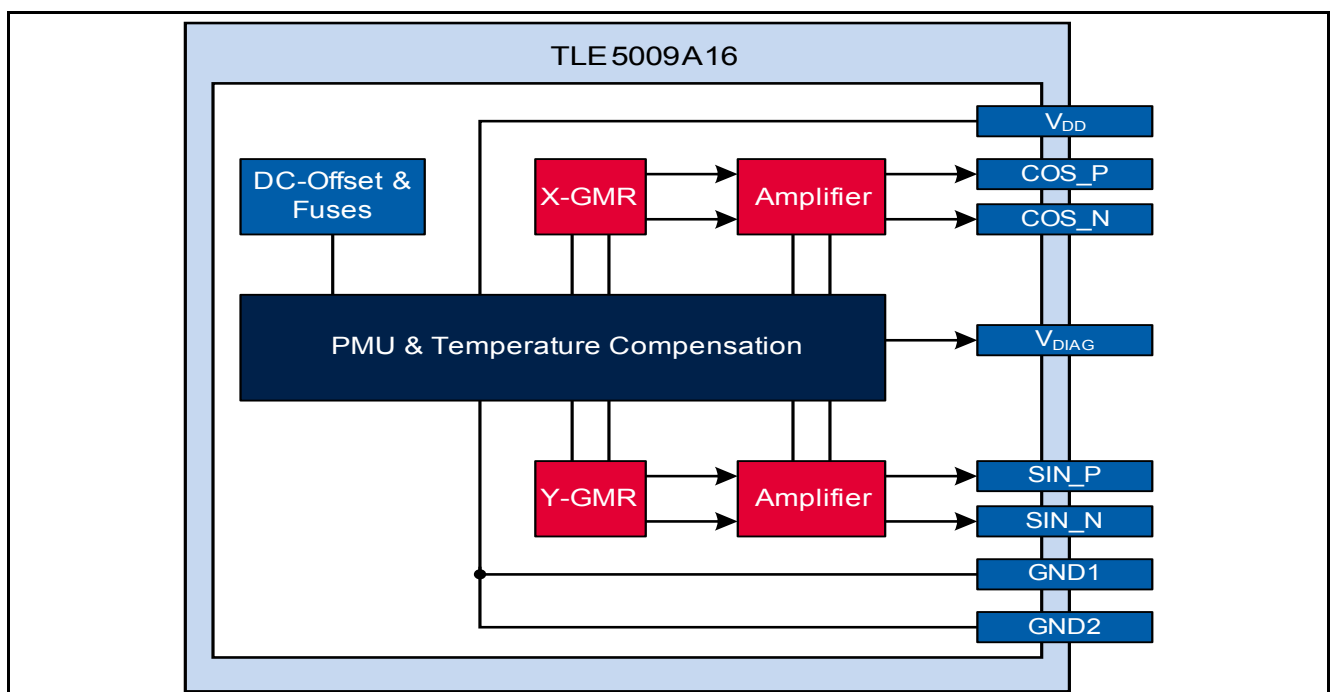
Figure 4   TLE5009A16D block diagram (one die only)

2.3 Pin Configuration

The sensitive area is located at the center of the package.
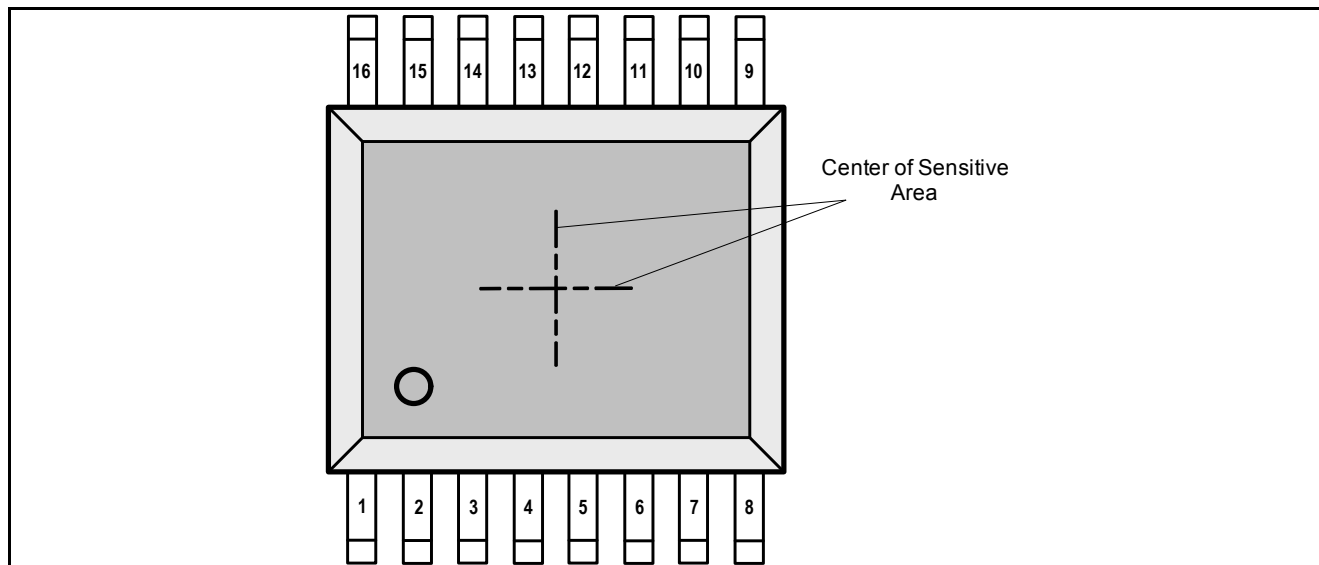
Figure 5   Pin configuration (top view)

2.4 Pin Description

Table 2   Pin description

Pin No.	Symbol	In/Out	TLE5009A16D - Function
1	Die1_V_{DIAG}	O	Die 1 bridge voltage proportional to temperature. Diagnostic function
2	Die1_V_{DD}		Die 1 Supply voltage
3	Die1_SIN_N	O	Die 1 Analog negative sine output
4	Die1_SIN_P	O	Die 1 Analog positive sine output
5	Die2_SIN_P	O	Die 2 Analog positive sine output
6	Die2_SIN_N	O	Die 2 Analog negative sine output
7	Die2_V_{DD}		Die 2 Supply voltage
8	Die2_V_{DIAG}	O	Die 2 bridge voltage proportional to temperature. Diagnostic function
9	Die2_GND		Die 2 Ground
10	Die2_GND		Die 2 Ground
11	Die2_COS_N	O	Die 2 Analog negative cosine output
12	Die2_COS_P	O	Die 2 Analog positive cosine output
13	Die1_COS_P	O	Die 1 Analog positive cosine output
14	Die1_COS_N	O	Die 1 Analog negative cosine output
15	Die1_GND		Die 1 Ground
16	Die1_GND		Die 1 Ground

2.5 Dual Die Angle Output

The TLE5009A16D comprises two GMR sensor ICs mounted on the top and bottom of a package leadframe in a flipped configuration, so the positions of the sensitive elements in the package-plane coincide. This mounting technique ensures a minimum deviation of the magnetic field orientation sensed by the two chips.

Due to the flipped mounting, the two GMR ICs sense opposite rotation directions. This behavior is illustrated in **Figure 6**, which shows the angle calculated afrom the output of the two dies, respectively, for a given external magnetic field orientation.

Figure 6 **Dual die angle output**
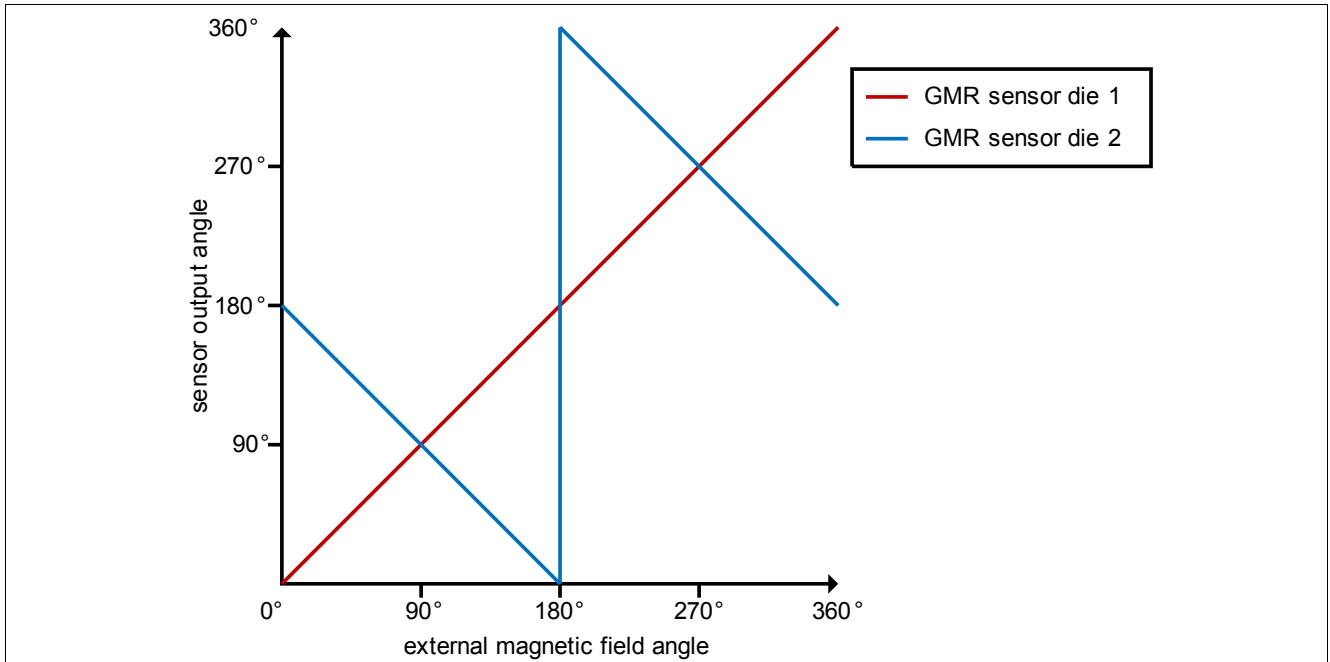
Attention: The positioning accuracy of each sensor IC in the package is ±3°. Thus, the relative rotation of the two sensor ICs can be up to 6°, resulting in a constant offset of the angle output of up to 6°, which has to be measured in an end-of-line calibration and taken into account during operation of the **TLE5009A16D***.*

3 Specification

3.1 Application Circuit

Figure 7 shows a typical application circuit for the TLE5009A16D. The TLE5009A16D has separate supply pins for the two GMR sensor dies. The microcontroller comprises 10 A/D inputs used to receive the sensor output signals. For reasons of EMC and output filtering, the following RC low pass arrangement is recommended.
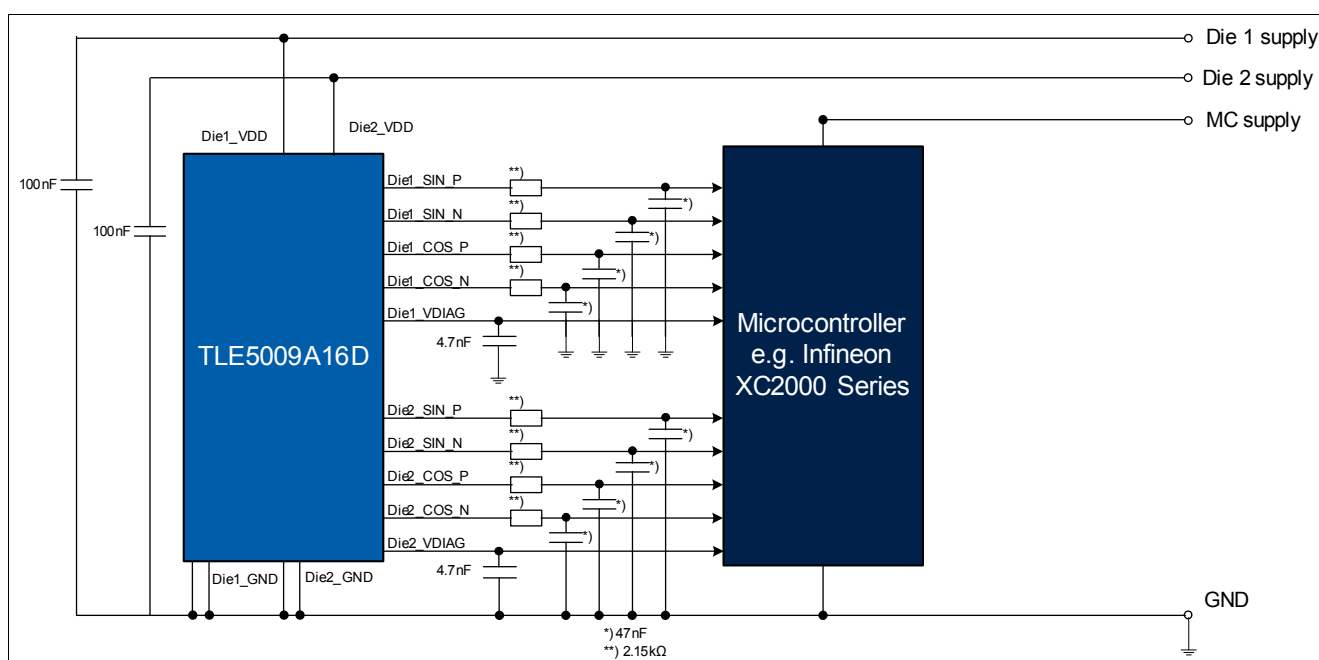
Figure 7 Application circuit for the TLE5009A16D.

3.2 Absolute Maximum Ratings

Table 3 Absolute maximum ratings

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Supply voltage	V_{DD}	-0.5		6.5	V	Max 40 h over lifetime
Ambient temperature[1]	T_A	-40		140	°C	
Magnetic field induction	$\|B\|$			200	mT	Max. 5 min at T_A = 25°C
				150	mT	Max. 5 h at T_A = 25°C

1) Assuming a thermal resistance of the sensor assembly in the application of 150 K/W or less.

Attention: Stresses above the max. values listed here may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. Maximum ratings are absolute ratings; exceeding only one of these values may cause irreversible damage to the device.

3.3 Sensor Specification

The following operating conditions must not be exceeded in order to ensure correct operation of the TLE5009A16D. All parameters specified in the following sections refer to these operating conditions, unless otherwise noted. **Table 4** is valid for -40°C < T_A < 125°C and throught the TLE5009A16D lifetime.

3.3.1 Operating Range

Table 4 Operating range

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Operating temperature[1]	T_A	-40		125	°C	
Supply voltage[2]	$V_{DD, GMR}$	3.0	3.3	3.6	V	E1200, E1210
		4.5	5	5.5	V	E2200, E2210
Output current[3]	I_Q	0		0.5	mA	COS_N; COS_P; SIN_N; SIN_P
		0		0.1	mA	V_{DIAG}
Load capacitance[3][4]	C_L	0		4.7	nF	all output pins
Magnetic field[3][5][6]	B_{XY}	24		60	mT	in X/Y direction, at T_A = 25°C
		26		100	mT	in X/Y direction, at T_A = -40°C
		21		50	mT	in X/Y direction, at T_A = 125°C
Angle range	α	0		360	°	
Rotation speed[3][7]	n			30,000	rpm	
				150,000	rpm	No signal saturation observed in lab

1) Assuming a thermal resistance of the sensor assembly in the application of 150 K/W or less.
2) Supply voltage V_{DD} buffered with 100 nF ceramic capacitor in close proximity to the sensor.
3) Not subject to production test - verified by design/characterization.
4) Directly connected to the pin.
5) Values refer to a homogenous magnetic field (B_{XY}) without vertical magnetic induction (B_Z = 0 mT).
6) Min/Max values for magnetic field for intermediate temperatures can be obtained by linear interpolation.
7) Typical angle propagation delay error is 1.62° at 30,000 rpm.

3.3.2 Electrical Parameters

The indicated electrical parameters apply to the full operating range, unless otherwise specified. The typical values correspond to the specified supply voltage range and 25 °C, unless individually specified. All other values correspond to -40°C < T_A < 125°C and throught the TLE5009A16D lifetime.

Table 5 Electrical parameters

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Supply current	I_{DD}		7	10.5	mA	per sensor IC, without load on output pins
POR level	V_{POR}	2.3	2.65	2.97	V	Power-On Reset
POR hysteresis[1]	V_{PORhy}		50		mV	

Table 5   Electrical parameters

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Power-On time[2]	t_{PON}		40	70	μs	settling time to 90% of full output voltages
Temperature reference voltage	V_{DIAG}	0.5	1.05	2.0	V	**Temperature proportional** output voltage; available on pin **V_{DIAG}**
Diagnostic function	V_{DIAG}	0		0.39	V	**Diagnostic** for internal errors; available on pin **V_{DIAG}**
Temperature coefficient of V_{DIAG}[1]	TC_{VDIAG}		0.4		%/K	

1) Not subject to production test - verified by design/characterization.
2) Time measured at chip output pins.

3.3.3   Output Parameters

All parameters apply over the full operating range, unless otherwise specified.

The following equations describe various types of errors that combine to the overall angle error.

The maximum and zero-crossing of the SIN and COS signals do not occur at the precise angle of 90°. The difference between the X and Y phases is called the **orthogonality** error. In **Equation (1)** the angle at zero crossing of the **X** cosine output is subtracted from the angle at the maximum of the **Y** SIN output, which describes the orthogonality of X and Y.

$$\varphi = \alpha[Y_{max}] - \alpha[X_0] \tag{1}$$

The amplitudes of SIN and COS signals are not equal to each other. The amplitude mismatch is defined as **syncronism**, shown in **Equation (2)**. This value could also be described as amplitude ratio mismatch.

$$k = 100 * \frac{A_X}{A_Y} \tag{2}$$

Differential signals are centered at the mean output voltage V_{MVX}, V_{MVY} given in **Table 6**. The differential voltages for X or Y are defined in **Equation (3)**.

$$V_{Xdiff} = V_{COSP} - V_{COSN}$$
$$V_{Ydiff} = V_{SINP} - V_{SINN} \tag{3}$$

The maximum amplitudes are defined for X or Y as given in **Equation (4)**:

$$A_{Xdiff} = \frac{(X_{diff\_MAX} - X_{diff\_MIN})}{2}$$
$$A_{Ydiff} = \frac{(Y_{diff\_MAX} - Y_{diff\_MIN})}{2} \tag{4}$$

Differential offset is of X or Y is defined in **Equation (5)**.

$$O_{Xdiff} = \frac{(X_{diff\_MAX} + X_{diff\_MIN})}{2}$$

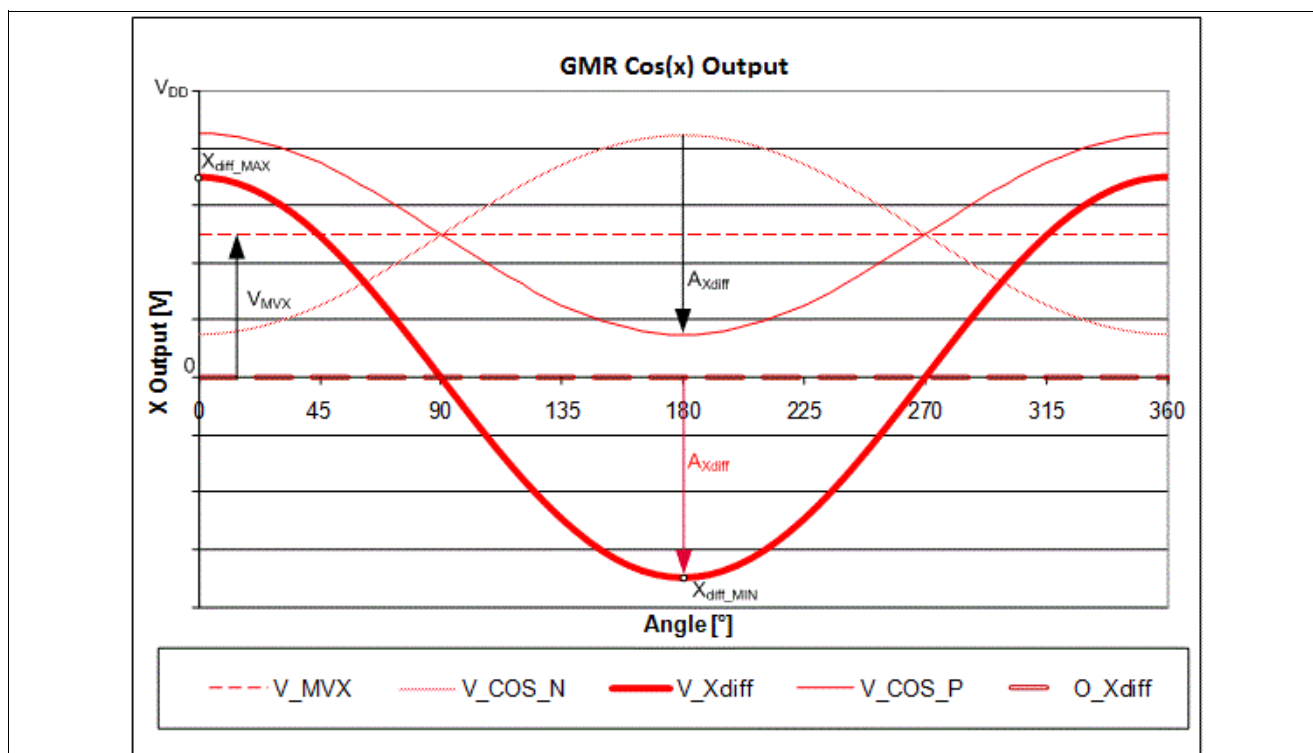$$O_{Ydiff} = \frac{(Y_{diff\_MAX} + Y_{diff\_MIN})}{2}$$

(5)

Figure 8   GMR differential output of ideal cosine

Table 6   Output parameters over temperature and lifetime

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	**Typ.**	**Max.**		
X, Y amplitude (single output pin)	A_X, A_Y	0.7		1.3	V	E1200, E1210
		1.2		1.95	V	E2200, E2210
X, Y differential amplitude	A_{Xdiff}, A_{Ydiff}	1.4		2.6	V	E1200, E1210
		2.4		3.9	V	E2200, E2210
X, Y synchronism	k	94	100	106	%	
X, Y orthogonality error	φ	-12		12	°	
Mean output voltage (single output pin)	V_{MVX}, V_{MVY}	$0.47*V_{DD}$	$0.5*V_{DD}$	$0.53*V_{DD}$	V	$V_{MV}=(V_{max}+V_{min})/2$[1]
X, Y offset	O_{Xdiff}, O_{Ydiff}	-100	0	100	mV	
X,Y cut-off frequency[2]	f_c		30		kHz	-3dB attenuation
X,Y delay time[2]	t_{adel}		9		µs	

Table 6   Output parameters over temperature and lifetime (cont'd)

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Vector Length (V_{VEC} = Sqrt(X_{Diff}^2 + Y_{Diff}^2))[3]	V_{VEC}	1.5		2.8		E1200, E1210
		2.5		3.9		E2200, E2210
Output RMS noise[2]	V_{Noise}		5		mV	

1) V_{max} and V_{min} correspond to the maximum and minimum voltage levels of the X and Y signals respectively.
2) Not subject to production test - verified by design/characterization
3) Vector length check described in the TLE5009 Safety Manual.

3.4   Error diagnosis

Each sensor provides two functions at its V_{DIAG} pin. During normal operation the voltage measured at this pin is temperature dependent. The typical voltage at room temperature and the temperature coefficient are given in **Table 5 "Electrical parameters" on Page 14**.

The second purpose of pin V_{DIAG} is the diagnosis functionality. In case the device detects an internal error, the pin is driven to a low level. The errors that can be detected by monitoring the status of the V_{DIAG} pin are:

- Overvoltage at V_{DD} (supply)
- Undervoltage at V_{DD} (supply)
- Undervoltage at internal nodes (analog voltage regulator and/or GMR voltage regulator)
- Bandgap failure
- Oscillator failure (only tested at startup)
- Parity check of configuration fuses (only tested atstartup)

3.5   Angle Performance

The overall angle error represents the relative angular error. This error describes the deviation from the reference line after zero angle definition. The typical value corresponds to an ambient temperature of 25°C. All other values correspond to the operating ambient temperature range -40°C < T_A < 125°C and throught the TLE5009A16D lifetime.

Fully compensated performance (ongoing calibration)

Using the algorithm described in the application note **"TLE5009 Calibration"**, it is possible to implement an ongoing automatic calibration on the microcontroller to greatly improve the performance of the TLE5009A16D in applications where a rotor is turning continuously.

With this autocalibration algorithm, it is possible to reach an angular accuracy as good as the residual error of the sensing elements, which means the remaining error after perfect compensation of offset, amplitude synchronicity mismatch and orthogonality error.

Table 7   Residual angle error in differential applications over temperature and lifetime[1]

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Fully compensated angle error[2][3]	$\alpha_{ERR,C}$		0.6	0.9	°	

1) After perfect compensation of offset, amplitude synchronicity mismatch and orthogonality error
2) Including hysteresis error
3) Valid for differential readout.

Angle Performance with one-time calibration

After assembly of the TLE5009A16D in a sensor module, the sensor IC(s) in the TLE5009A16D have to be end-of-line calibrated for offset, synchronism and orthogonality error at 25°C and the compensation parameters have to be stored and applied on the microcontroller. For the detailed calibration procedure refer to the application note **"TLE5009 Calibration"**. **Table 8** shows the accuracy of the angle calculated from the differential output of the sensor and the compensation parameters acquired in the end-of-line calibration.

Table 8   Angle error in differential applications over temperature and lifetime

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Angle error[1][2]	α_{ERR}		0.6	3.8	°	E1200, E2200
			0.6	3.0	°	E1210, E2210

1) Including hysteresis error.
2) Valid for differential readout.

3.6   Electrostatic discharge protection

Table 9   ESD protection

Parameter	Symbol	Values		Unit	Notes
		min.	max.		
ESD voltage	V_{HBM}		±4.0	kV	[1] ground pins connected
			±2.0	kV	[1]
	V_{CDM}		±0.5	kV	[2]
			±0.75	kV	[2] for corner pins

1) Human Body Model (HBM) according to: ANSI/ESDA/JEDEC JS-001
2) Charged Device Model (CDM) according to: JESD22-C101

3.7   Electro Magnetic Compatibility (EMC)

The TLE5009A16D is characterized according to the EMC requirements described in the "Generic IC EMC Test Specification" Version 1.2 from November 15, 2007. The classification of the TLE5009A16D is done for local pins.

4 Package Information

The TLE5009A16D comes in a green SMD package with lead-free plating, the **PG-TDSO-16**.

4.1 Package Parameters

Table 10   Package parameters

Parameter	Symbol	Limit Values			Unit	Notes
		min.	typ.	max.		
Thermal Resistance	R_{thJA}		130	150	K/W	Junction-to-Air[1]
	R_{thJC}			35	K/W	Junction-to-Case
	R_{thJL}			70	K/W	Junction-to-Lead
Moisture Sensitivity Level		MSL 3			260°C	
Lead Frame		Cu				
Plating		Sn 100%			> 7 µm	

1) According to Jedec JESD51-7
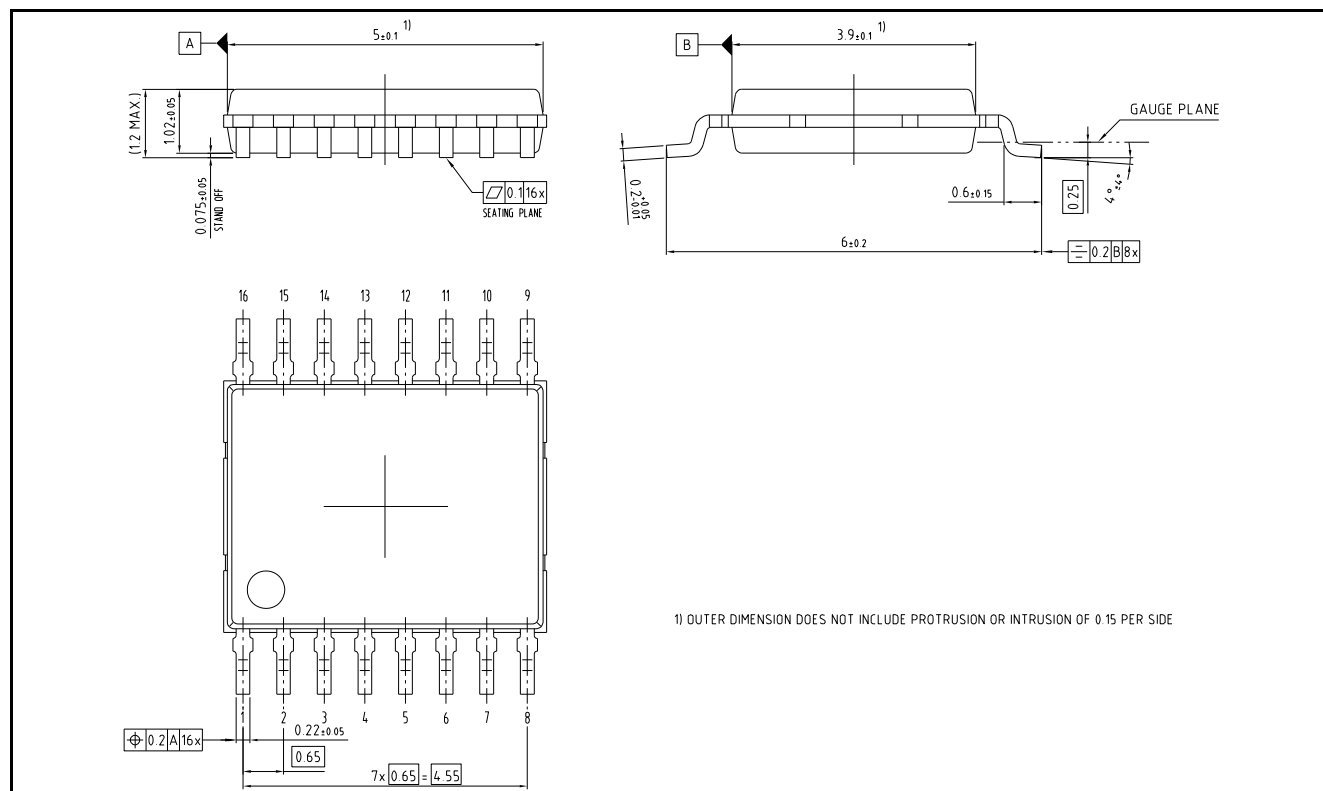
4.2 Package Outline
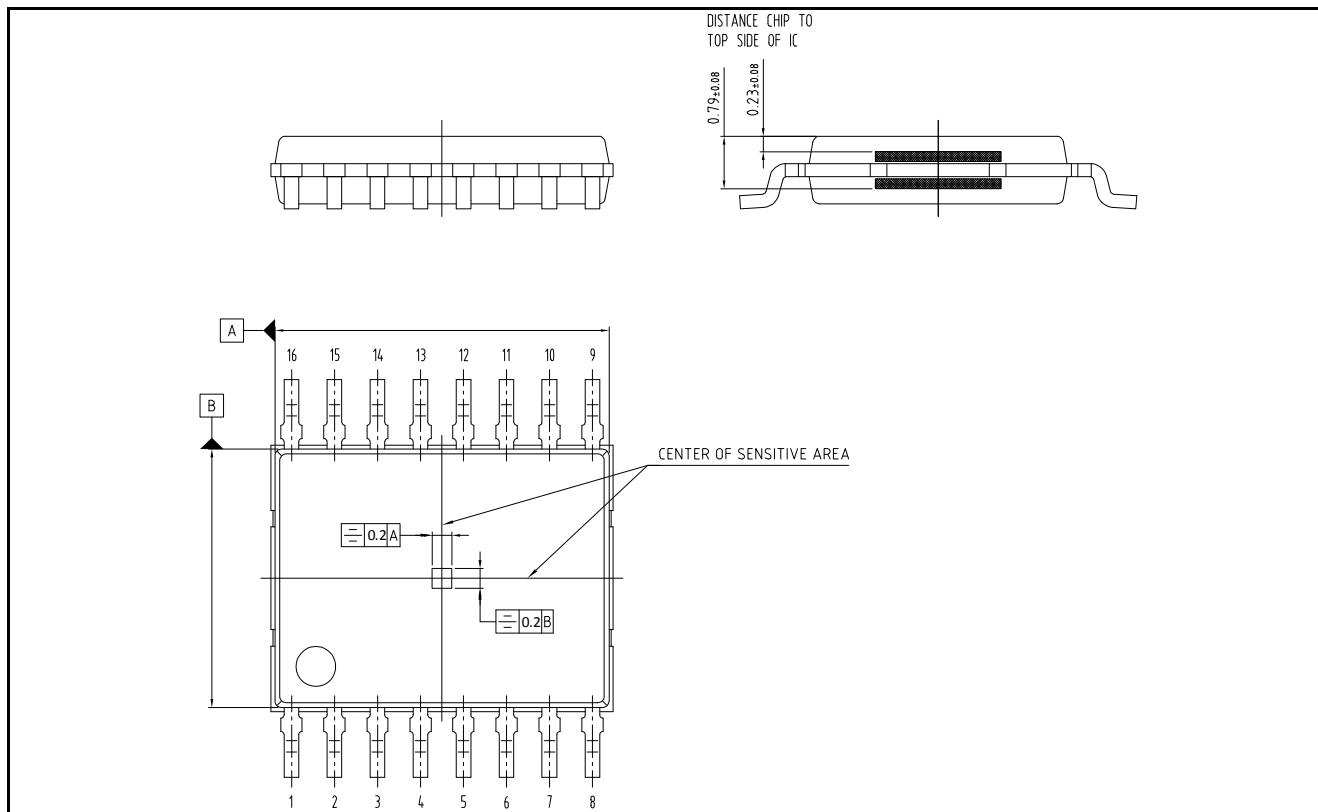

Figure 9   Package dimensions

Figure 10   Position of sensing element

*Note: **Table 10** shows the positioning of the two sensor dies in the TLE5009A16D.*

Table 11   Sensor IC placement tolerances in package

Parameter	Values		Unit	Notes
	Min.	**Max.**		
position eccentricity	-100	100	µm	in X- and Y-direction
rotation	-3	3	°	affects zero position offset of sensor
tilt	-3	3	°	

4.3   Footprint
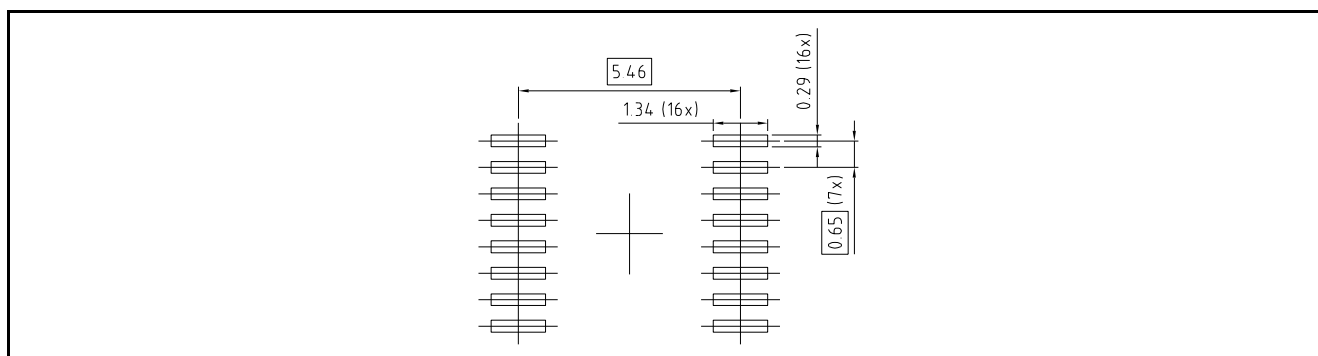
Figure 11   Footprint

4.4 Packing
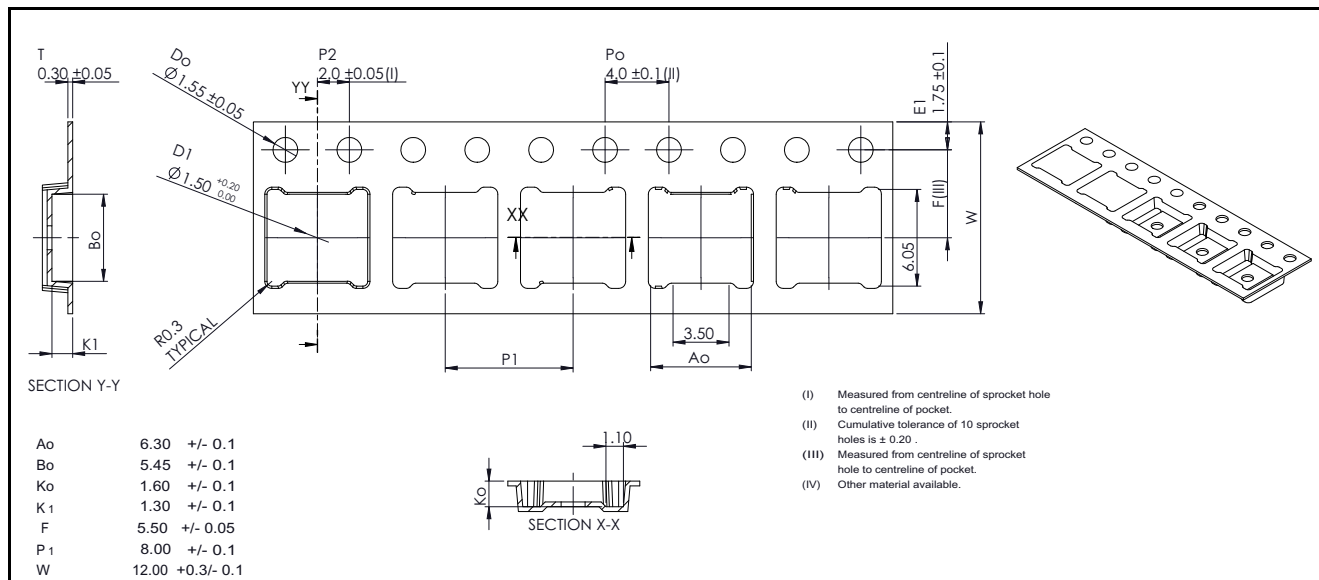
Figure 12 Tape and reel

4.5 Marking

Position	Marking	Description
1st Line	09A2xxxx	dual die
2nd Line	xxx	Lot code
3rd Line	Gxxxx	G..green, 4-digit..date code

References