

Automotive Low Power 3D Magnetic Sensor with I²C Interface

TLE493D-A1B6

3D Hall Sensor

Data Sheet

Rev. 1.2, 2019-04-09

Sense & Control

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Product Description

1 Product Description

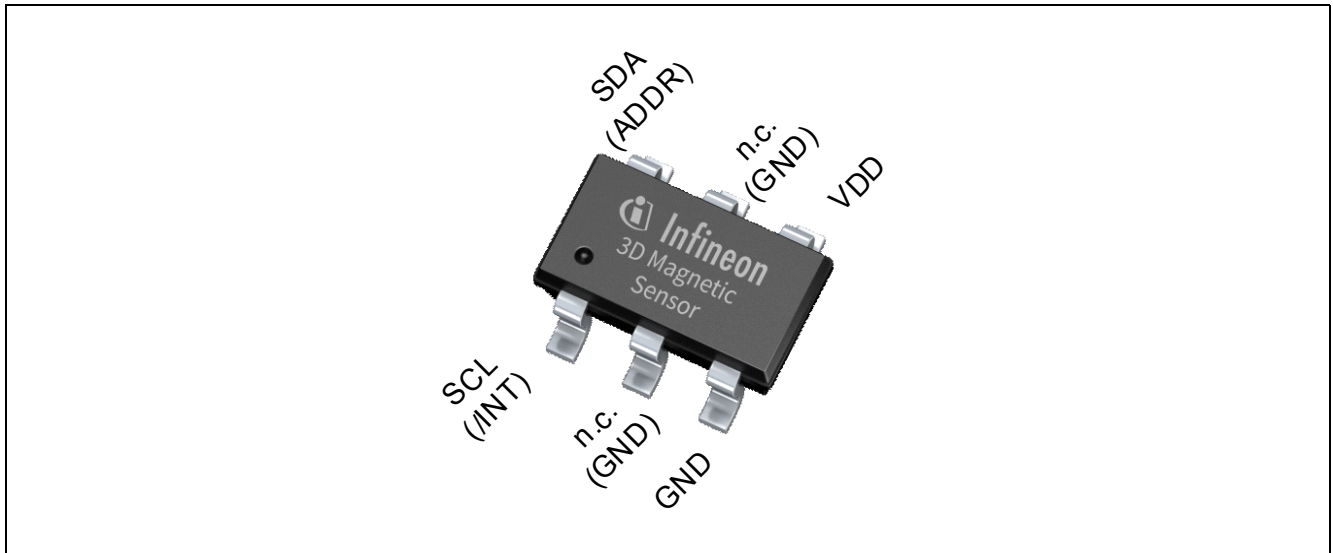
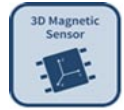


Figure 1 Image of TLE493D-A1B6 in TSOP6 package

1.1 Target Applications

The TLE493D-A1B6 is designed for linear, rotary and 3D position sensing in automotive applications, such as:

- Gear stick
- Turnlight and wiper control elements
- Multi function knobs
- Pedal/valve position sensing
- Integration in the top column module for direction indicator for instance

1.2 Features

- 3D magnetic flux density sensing
- Ultra low power consumption with typical 5 μ A during operation (typical 6Hz)
- Power-down mode with typical 7nA power consumption
- Digital output via 2-wire standard I²C interface
- 12 bit data resolution for each measurement direction incl. chip temperature
- B_x, B_y and B_z linear field measurement of ± 60 mT
- Excellent matching of X/Y measurement for accurate angle sensing
- Variable update frequencies and power modes (configurable during operation)
- Supply voltage range = 2.9V...3.5V
- Temperature range T_j = -40°C...125°C
- Triggering by external μ C possible via I²C protocol
- Interrupt signal to signalise end of measurement cycle
- Temperature measurement

Product Description

- Automotive qualified
- Small 6-pin TSOP package

Table 1 **Ordering Information**

Product Name	Marking	Ordering Code	Package
TLE493D-A1B6	EA	SP001368598	PG-TSOP6-6-5

Functional Description

2 Functional Description

2.1 General

Description of the Block diagram and its functions.

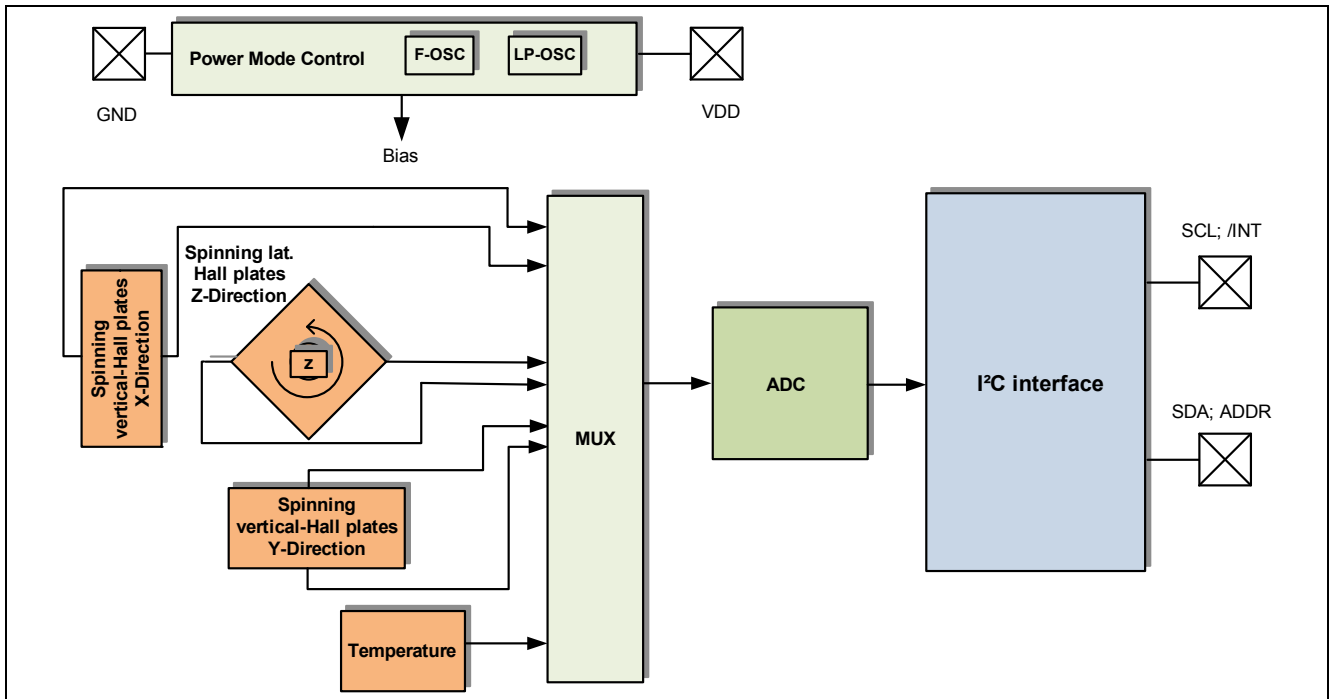


Figure 2 Block Diagram

The IC consists of three main function units containing following building blocks:

- The power mode control system, containing a low-power oscillator, basic biasing, accurate reset, undervoltage detection and a fast oscillator.
- The sensing part, containing the HALL biasing, HALL probes with multiplexers and ADC. Furthermore a temperature sensor is implemented.
- The I²C interface, containing the register files and I/O pads.

2.1.1 Power mode control

The power mode control provides the power distribution in the IC, a power-on reset function and a specialized low-power oscillator as clock source. Additionally it is handling the start-up behavior.

- On start-up this unit:
 - activates the biasing, provides an accurate reset detector and fast oscillator
 - interprets the applied voltage level on ADDR pin as logical “0” or “1”. This represents than the address sensor enters low power mode (and can be configured via I²C interface)
- After re-configuration a measurement cycle is performed regularly containing of:
 - activation the internal biasing, checks for reset condition and provides the fast oscillator
 - the HALL biasing

Functional Description

- the measurement of the three HALL probe channels sequentially incl. temperature (default = activated)
 - and enters the configured mode again
- In any case functions are only executed if the supply voltage is high enough, otherwise the reset circuit will halt the state machine until the level is reached and restarts its operation afterwards. The functions are also restarted if a reset event occurs in between (parameter "Reset Level" in [Chapter 3.2](#)).

2.1.2 Sensing part

Performs the measurements of the magnetic field in X, Y and Z direction. Each X, Y and Z-Hall probe is connected sequentially to a multiplexer, which is then connected to an Analog to Digital Converter (ADC). Optional, the temperature (default = activated) is determined as well after the three Hall channels.

2.2 Pin Configuration (top view)

Figure 3 shows the pinout of the TLE493D-A1B6.

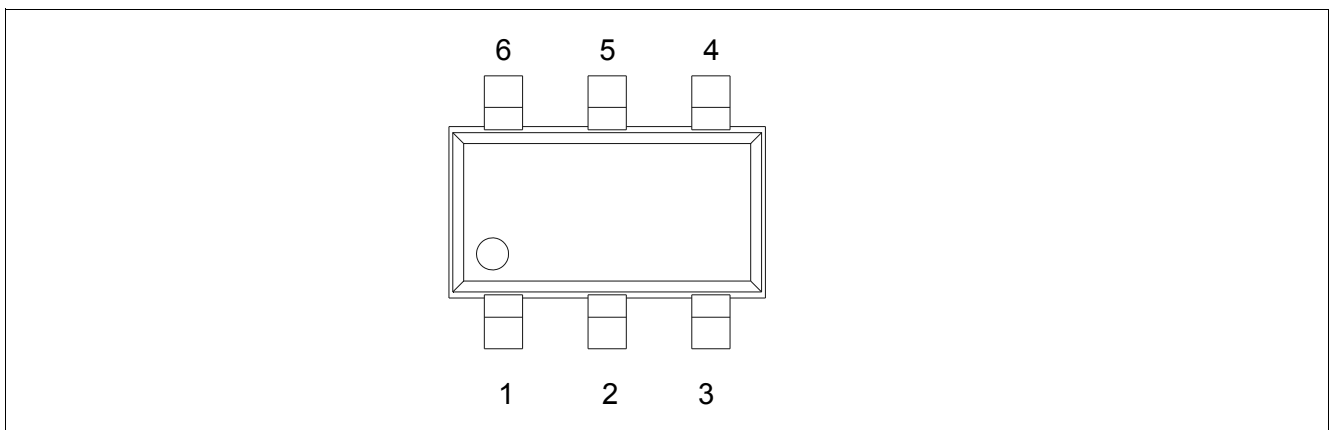


Figure 3 Pinout

Table 2 TSOP6 pin description and configuration (see [Figure 3](#))

Pin No.	Name	Description
1	SCL /INT	Interface serial clock pin (input) Interrupt pin, signals a finished measurement cycle, open drain
2	GND	connect to GND
3	GND	Ground Pin
4	V _{DD}	Supply Pin
5	GND	connect to GND
6	SDA ADDR	Interface serial data pin (input/output), open drain Sensor ID configuration during power up

Functional Description

2.3 Definition of Magnetic Field

A positive field is considered as South-Pole facing the corresponding Hall element.

Figure 4 shows the definition of the magnetic field directions X, Y, Z of the TLE493D-A1B6.

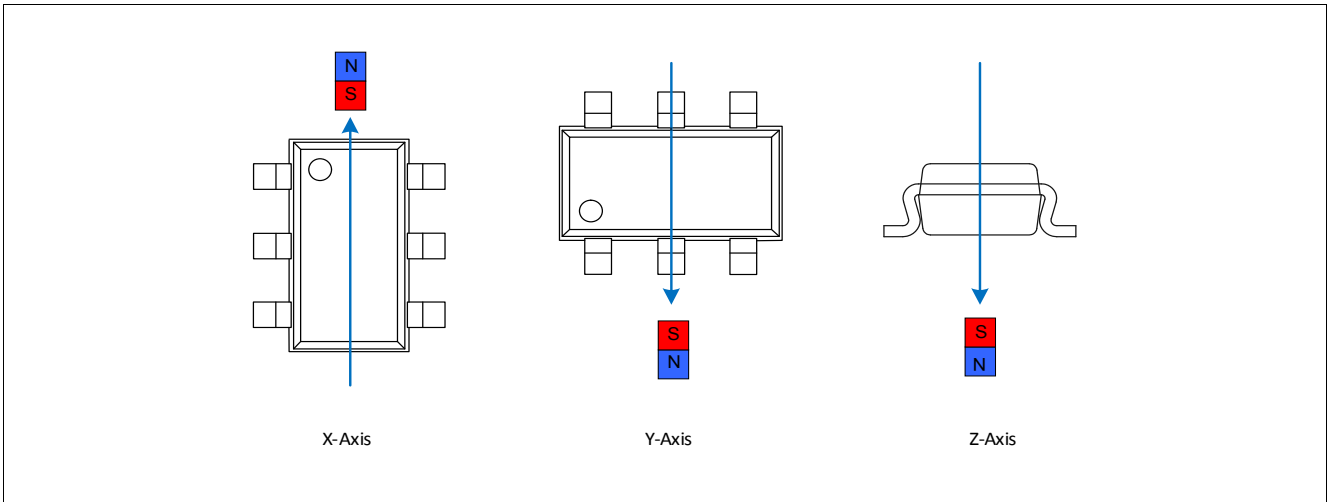


Figure 4 Definition of Magnetic Field Direction

2.4 Sensitive Area

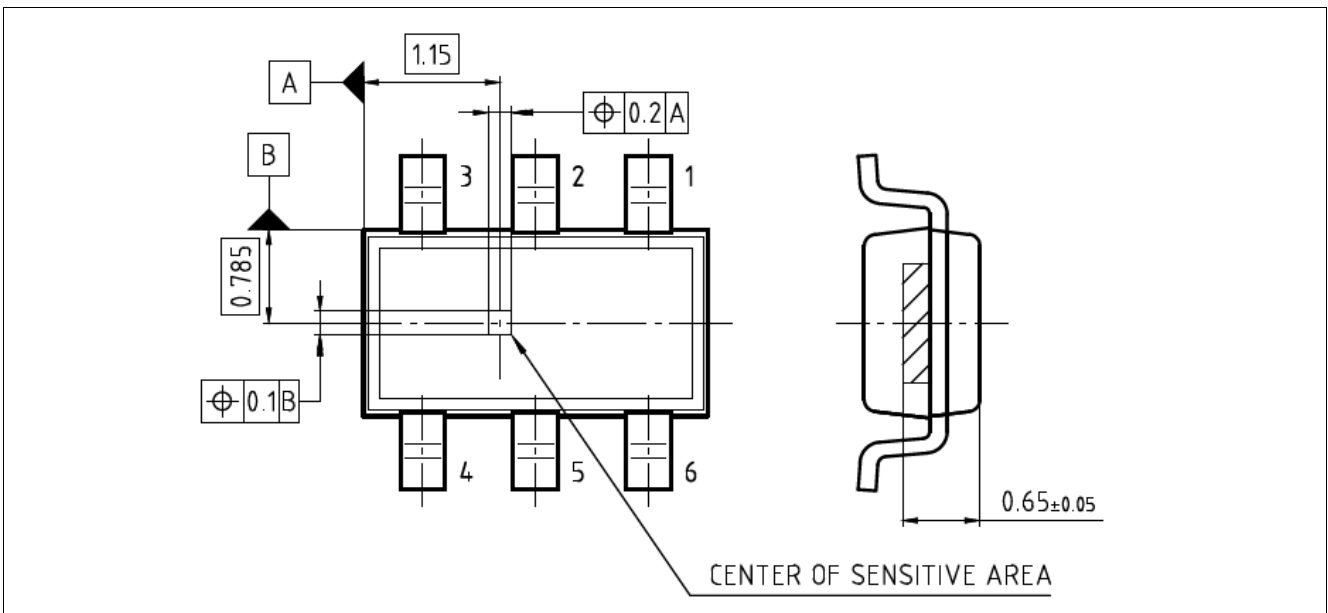


Figure 5 Center of Sensitive Area (all dimensions in mm)

Functional Description

2.5 Application circuit

The use of an interrupt line is optional, but highly recommended to ensure proper and efficient readout of the sensor data.

The pull-up resistor values of the I²C bus have to be calculated in a way to fulfill the rise- and fall time specification of the interface for the given worst case parasitic (capacitive) load of the actual application setup.

Please note: too small resistive values $R_{1/2}$ have to be prevented to avoid unnecessary power consumption during interface transmissions, especially for low-power applications.

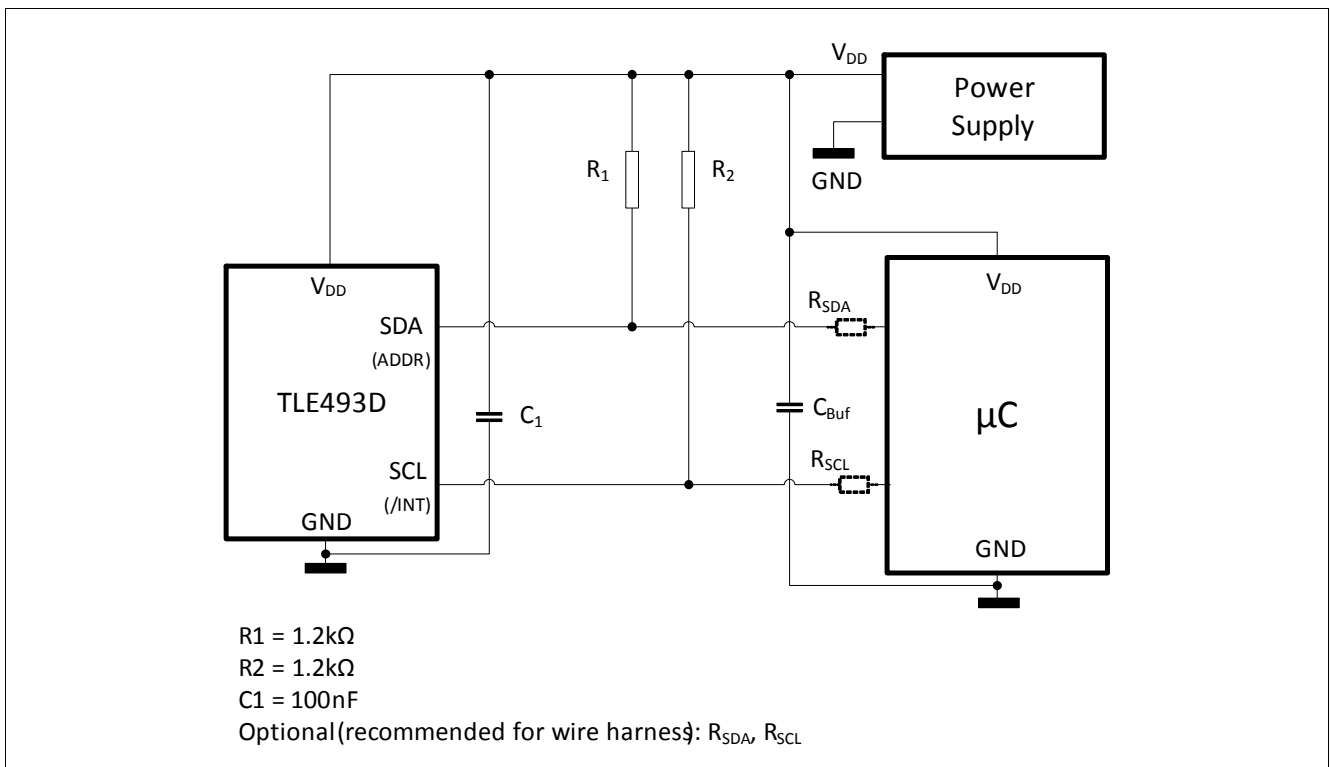


Figure 6 Application circuit with external power supply and µC

For additional EMC precaution in harsh environments, C_1 may be implemented by two 100nF capacitors in parallel, which should be already given by C_{Buf} near the µC and/or power supply.

Specification

3 Specification

3.1 Absolute Maximum Ratings

Attention: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Furthermore, only single error cases are assumed. More than one stress/error case may also damage the device.

Exposure to absolute maximum rating conditions for extended periods may affect device reliability. During absolute maximum rating overload conditions the voltage on VDD pins with respect to ground (VSS) must not exceed the values defined by the absolute maximum ratings.

Table 3 Absolute maximum ratings

Parameter	Symbol	min	typ	max	Unit	Note/Condition
Junction temperature	T_j	-40	–	125	°C	–
Voltage on V_{DD}	V_{DD}	-0.3	–	3.5	V	–
Magnetic field	B_{max}	–	–	± 1	T	–
Voltage range on any pin to GND	V_{max}	-0.1	–	3.5	V	open-drain outputs are not current limited.

Table 4 Electrostatic Discharge Protection

Parameter	Symbol	Values			Unit	Note or Test Condition
		Min.	Typ.	Max.		
ESD voltage	V_{HBM}			± 2.0	kV	¹⁾ R = 1.5 k Ω , C = 100 pF
	V_{CDM}			± 0.5	kV	²⁾
				± 0.75	kV	²⁾ for corner pins

1) Human Body Model (HBM) tests according to ANSI/ESDA/JEDEC JS-001.

2) Charged Device Model (CDM), ESD susceptibility according to JESD22-C101.

3.2 Operating Range

Table 5 Operating Range

Parameter	Symbol	min	typ	max	Unit	Note/Condition
Operating temperature	T_j	-40	–	125	°C	$T_j = T_a + 3^\circ\text{C}$ in fast mode
Supply voltage	V_{DD}	2.9	3.3	3.5	V	Supply voltage must be above reset level
Reset level	V_{Res}	2.2	2.5	2.9	V	min. ADC operating level

Specification

Note: To provide this ultra low power consumption figures, the chip does not use a classic (and current consuming) reset concept. The implemented reset focus on ensuring a proper supply for the ADC operation only (so it inhibits the ADC reliably until the sensor supply is high enough). Thus, the sensor relays on a proper supply ramp incl. 3.3mA current consumption during power-on to ensure it is initialized correctly, typically a monotonic rise of Vdd from zero to 3.3V within less than 10 μ s and without over/undershoots larger than 300mV. The I²C reset feature of the sensor shall be used by the μ C after power-up. If an supply monitoring is used in the system (e.g. brown-out detector etc.), it is also recommended to use the I²C reset of the sensor upon events detected by this monitor. In any case, an external supply switch (either provided by a System-Basis-Chip solution which includes a supply-enable feature, a Bias-Resistor-Transistor device, a capable μ C GPIO pin, etc.) shall allow a power-cycle of the sensor as backup for high availability applications to cope with any form of Vdd ramps (including potential EMC influences).

Specification

3.3 Electrical Characteristics

Note: All specification parameters refer to 3.3V $\pm 5\%$ nominal supply V_{DD} on the pins directly. Typical values refer to 25°C and to 3.3V $\pm 5\%$ nominal supply.

Table 6 Electrical setup

Parameter	Symbol	min	typ	max	Unit	Note/Condition
Supply current ¹⁾	I_{DD}	–	7	–	nA	power-down mode, all off
		–	5	–	μ A	ultra low power mode
		–	57	–	μ A	low power mode (default after power on)
		–	3.3	–	mA	fast mode
Average operating current	I_{DD_op}	–	3.3	–	mA	during active ADC measurement for about 172 μ s ²⁾³⁾
Input voltage low threshold ⁴⁾	V_{IL}	–	–	30	% V_{DD}	all input pads
Input voltage high threshold ⁴⁾	V_{IH}	70	–	–	% V_{DD}	all input pads
Input voltage hysteresis ⁴⁾	V_{L_Hyst}	5	–	–	% V_{DD}	all input pads
Output voltage low level @ 3mA load	V_{OL}	–	–	0.4	V	all output pads, static load
Output high level	V_{OH}	–	V_{DD}	–	V	given by ext. pull-up resistor

- 1) Average values considering measuring period and power-down
- 2) Typical conversion time is 172 μ s with temperature and 129 μ s without
- 3) Current at Pull ups needs to be considered for power supply dimensioning, consider minimum 10mA for the power supply for the sensor only
- 4) Based on I²C standard 1995 for V_{DD} related input levels

Note: The average supply current I_{DD} in the 2 low power modes and I²C triggered mode will decrease by about 25% when the temperature measurement is disabled.

Specification

3.4 Magnetic Characteristics

Table 7 Initial Magnetic Characteristics¹⁾

Values for 25°C, 0h and $V_{DD} = 3.3V$, unless otherwise stated

Parameter	Symbol	min	typ	max	Unit	Note/Condition
Magnetic linear range ²⁾	B_{xyz_LIN}	±60	–	–	mT	Bx, By and Bz for -40°C < $T_{junction}$ < +125°C
Offset	B_{OZ}	-1.8	±0.2	+1.8	mT	Offset of Bz
	B_{OXY}	-0.75	±0.2	+0.75	mT	Offset of Bx and By
Sensitivity	$Sens$	5.5	7.7	10.5	LSB ₁₂ / mT	Bx, By and Bz; (12bit)
X to Y magnetic matching ³⁾	$M_{X/Y}$	-15	–	+15	%	
X/Y to Z magnetic matching ³⁾	$M_{X/YZ}$	-25	–	+25	%	
Resolution 12-bit readout ⁴⁾	Res_{12}	95	130	182	µT/ LSB ₁₂	
Resolution 8-bit readout ⁴⁾	Res_8	1.52	2.08	2.91	mT/ LSB ₈	
Magnetic initial noise (rms)	B_{iNeff}	–	0.1	0.5	mT	rms = 1 sigma
Magnetic hysteresis	B_{HYS}	–	1	–	LSB ₁₂	due to quantization effects

- 1) Magnetic test on wafer level. It is assumed that initial variations are stored and compensated in the external µC during module test and calibration.
- 2) Not subject to production test - verified by design/characterization; magnetic minimum linear range is valid for the specified 0h sensitivity range
- 3) The matching is defined for sensitivity values of Bx (=X), By (=Y) and Bz (=Z) as:
X/Y matching: $100 \cdot 2 \cdot (X-Y)/(X+Y)$ [in %], X/Y to Z matching: $100 \cdot 2 \cdot (X+Y-2 \cdot Z)/(X+Y+2 \cdot Z)$ [in %]
- 4) Resolution is calculated as 1/Sensitivity (and multiplied by 16 for 8-bit value).

Table 8 Sensor Drifts¹⁾

Values for $V_{DD} = 3.3V \pm 5\%$, $T_j = -40$ to 125 °C, static magnetic field within usable linear range

Parameter	Symbol	min	typ	max	Unit	Note/Condition
Sensitivity drift	$Sens_D$	-15	±5	+15	%	Bx, By and Bz
Offset drift	B_{O_DZ}	-1.6	±0.2	+1.6	mT	Bz @ 0mT
	B_{O_DXY}	-0.75	±0.2	+0.75	mT	Bx and By @ 0mT
X to Y magnetic matching drift ²⁾	M_{XY_D}	-9	±1	+9	%	
X/Y to Z magnetic matching drift ²⁾	M_{X/YZ_D}	-15	±10	+15	%	
Temperature compensation ³⁾	TC_0	–	±0	–	ppm/K	Bx, By and Bz (default)
	TC_1	–	-750	–		Bx, By and Bz (option 1)
	TC_2	–	-1500	–		Bx, By and Bz (option 2)
	TC_3	–	+350	–		Bx, By and Bz (option 3)

Specification

Table 8 Sensor Drifts¹⁾

Values for $V_{DD} = 3.3V \pm 5\%$, $T_j = -40$ to $125\text{ }^\circ\text{C}$, static magnetic field within usable linear range

Parameter	Symbol	min	typ	max	Unit	Note/Condition
DNL (Differential Non Linearity)	DNL	–	$\pm 2^4$	–	LSB ₁₂	Bx, By and Bz
INL (Integral Non Linearity)	INL	–	$\pm 2^4$	–	LSB ₁₂	Bx, By and Bz
Magnetic noise (rms)	B_{Neff}	–	–	1	mT	rms = 1 sigma

- 1) Not subject to production test, verified by design/characterization. Drifts are changes from the initial characteristics due to external influences.
- 2) The matching is defined for sensitivity values of Bx (=X), By (=Y) and Bz (=Z) as:
X/Y matching: $100 \cdot 2 \cdot (X-Y)/(X+Y)$ [in %], X/Y to Z matching: $100 \cdot 2 \cdot (X+Y-2 \cdot Z)/(X+Y+2 \cdot Z)$ [in %]
- 3) The temperature sensitivity variation alone is +13%. It is mandatory to set the TC value before performing data readouts of the sensor on given magnetic points or angles for sensitivity trimming (with external microcontroller as zero-hour trim in production).
- 4) Represents 0.1%FSR.

Conversion register value to magnetic field value:

Table 9 Conversion table for 12Bit

	MSB	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	LSB
	-2048	1024	512	256	128	64	32	16	8	4	2	1
e.g.	1	1	1	1	0	0	0	0	1	1	1	1

The conversion is realized by the two's complement. Please use following table for transformation:

Example for 12Bit read out: 1111 0000 1111: $-2048 + 1024 + 512 + 256 + 0 + 0 + 0 + 0 + 8 + 4 + 2 + 1 = -241$ LSB

Calculation to mT: $-241 \text{ LSB} \cdot 0.130 \text{ mT/LSB} = -31.3 \text{ mT}$

Table 10 Conversion table for 8Bit

	MSB	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	LSB
	-128	64	32	16	8	4	2	1
e.g.	0	1	0	1	1	1	0	1

Example for 8-Bit read out: 0101 1101: $0 + 64 + 0 + 16 + 8 + 4 + 0 + 1 = 93$ LSB

Calculation to mT: $93 \text{ LSB} \cdot 2.08 \text{ mT/LSB} = 193.4 \text{ mT}$

Specification

3.5 Temperature measurement (default = activated)

Table 11 Temperature Measurement Characteristics¹⁾

Parameter	Symbol	min	typ	max	Unit	Note/Condition
Digital value @ 25°C ²⁾	T_{25}	974	1217	1460	LSB ₁₂	-
Resolution 12bit	T_{Res12}	0.24	0.28	0.32	°C/LSB ₁₂	-
Resolution 8bit	T_{Res8}	-	4.48	-	°C/LSB ₈	-
Accuracy	T_{ACC}	-	±7	-	°C	-

- 1) The temperature measurement is not trimmed on the sensor. An external μC can measure the sensor during module production and implement external trimming to gain higher accuracies.
- 2) Theoretical possible measurement range from -50°C to 150°C

3.6 Overview of Modes

Table 12 Overview of modes and its corresponding current consumption with sample rates¹⁾

Mode	Register Address	Typ. Update Rate	Typ. IDD	Remark
Power Down	-	-	7 nA	-
Low Power	Reg 11, Bit 0..1 = 00 Reg 13, Bit 7..5= 001	94 Hz	57 μA	Default after Power On
	Reg 11, Bit 0..1 = 00 Reg 13, Bit 7..5= 100	6 Hz	5 μA	Ultra low power mode
Fast Mode	Reg 11: Bit 0..1 = 11 Reg 13: Bit 7..5= x	5.7 kHz	3.3 mA	Temperature enabled (default). 1Mbit example
	Reg 11, Bit 0..1 = 11 Reg 13, Bit 7..5= x	7.5 kHz	3.3 mA	Temperature disabled (Reg 10: Bit 7 = 1). 1Mbit example
MCM (Master Controlled Mode: I ² C triggered)	Reg 11: Bit 0..1 = 01 Reg 13: Bit 6 = x	0 Hz ... 7.5 kHz ~2.8 kHz	<1 μA ... 3.3 mA ~1.7 mA	400 kbit example

- 1) Default low power setting also used to signal a sensor error.

I²C triggered mode typ. consumption (μC triggers every “trigger_period”) estimation formula:

$$I_{DD} [\text{mA}] \approx 3.3 [\text{mA}] * 0.18 [\text{ms}] / \text{trigger_period} [\text{ms}]$$

Interface and Timing Description

4 Interface and Timing Description

This chapter refers to how to set the boundary conditions in order to establish a proper interface communication.

Table 13 Interface and timing¹⁾

Parameter	Symbol	min	typ	max	Unit	Note/Condition
End-of-Conversion /INT pulse	t_{INT}	–	2.5	–	μs	low-active (when activated)
Time window to read first value	t_{RD1}	–	40	–	μs	read after rising /INT edge
Time window to read next value	t_{RDn}	–	43	–	μs	consecutive reads
Internal clock accuracy	t_{clk_E}	-25	–	+25	%	all above timing parameters
Allowed I ² C bit clock frequency	f_{I2C_clk}	–	400	1000	kHz	400kHz is I ² C fast mode
Low period of SCL clock	t_L	0.5	–	–	μs	1.3 μs for 400kHz mode
High period of SCL clock	t_H	0.4	–	–	μs	0.6 μs for 400kHz mode
SDA fall to SCL fall hold time (hold time start condition to clock)	t_{STA}	0.4	–	–	μs	0.6 μs for 400kHz mode
SCL rise to SDA rise su. time (setup time clock to stop condition)	t_{STOP}	0.4	–	–	μs	0.6 μs for 400kHz mode
SDA rise to SDA fall hold time (wait time from stop to start cond.)	t_{WAIT}	0.4	–	–	μs	0.6 μs for 400kHz mode
SDA setup before SCL rising	t_{SU}	0.1	–	–	μs	–
SDA hold after SCL falling	t_{HOLD}	0	–	–	μs	–
Fall time SDA/SCL signal ²⁾	t_{FALL}	–	0.05 ³⁾	0.3	μs	0.3 μs for 400kHz mode (or may require less C load)
Rise time SDA/SCL signal ²⁾	t_{RISE}	–	0.6 ³⁾	–	μs	R = 1.2k

1) Not subject to production test - verified by design/characterization

2) Dependent on used R-C-combination

3) For given AppCircuit; Capacitive load for each bus line = 200pF (SDA, SCL)

Interface and Timing Description

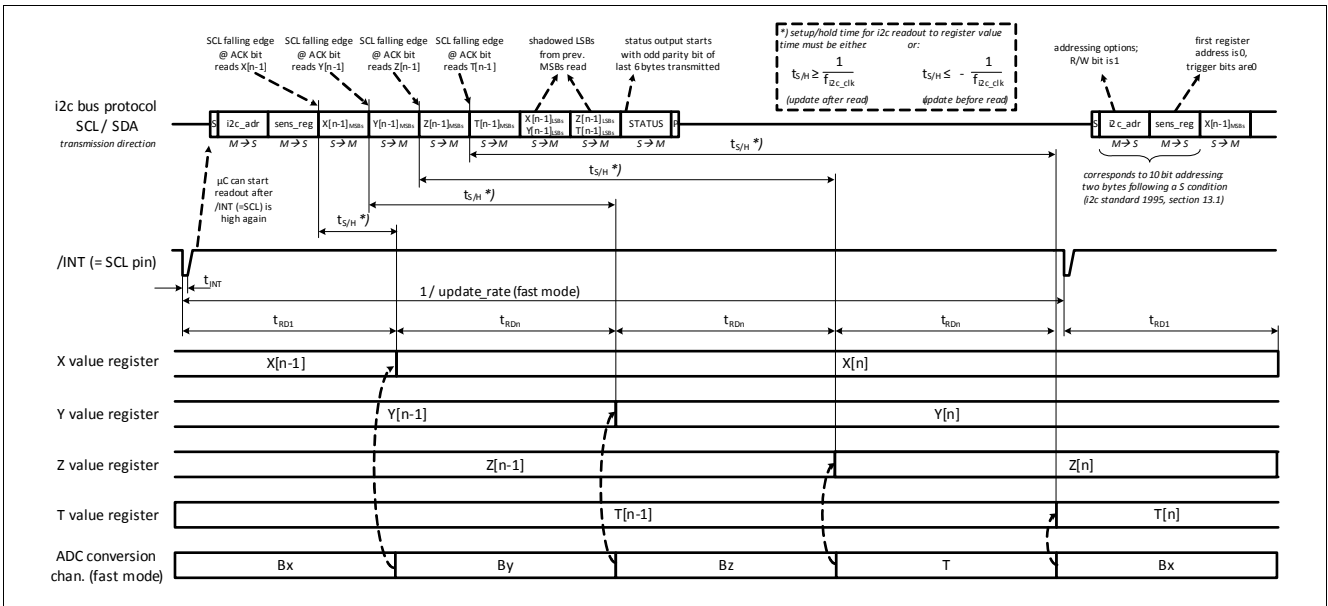


Figure 7 I²C readout frame, ADC conversion and related timing

Note: The fast mode requires a very strict I²C behavior synchronized with the sensor conversions and high bit rates; other modes are available for more relaxed timing and also for a synchronous μ C operation of sensor conversions; in 3-channel mode, the T chan. is not converted and updated (so the cycle starts over with Bx after Bz is finished); in all other modes the conversion stops after the T chan. (or Bz chan. in 3-channel mode) until it is triggered again by an internal or external trigger source (which will start an Bx chan. conv.).

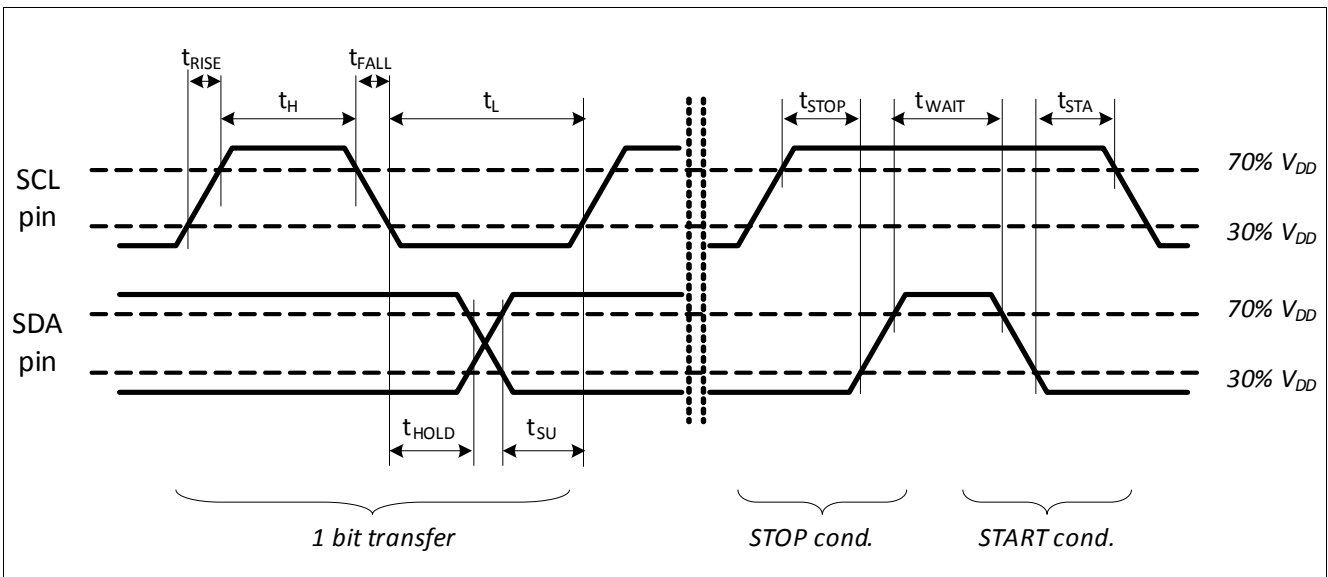


Figure 8 I²C timing specification

Package Information

5 Package Information

5.1 Package Parameters

Table 14 Package Parameters

Parameter	Symbol	Limit Values			Unit	Notes
		Min.	Typ.	Max.		
Thermal resistance Junction ambient	R_{thJA}	-	-	200	K/W	Junction to air ¹⁾ for PG-TSOP-6-6-5
Thermal resistance Junction lead	R_{thJL}	-	-	100	K/W	Junction to lead for PG-TSOP-6-6-5
Moisture Sensitivity Level	MSL 1					260°C ²⁾

1) according to Jeduc JESD51-7

2) suitable for reflow soldering with soldering profiles according to JEDEC J-STD-020D.1 (March 2008)

5.2 Package Outlines

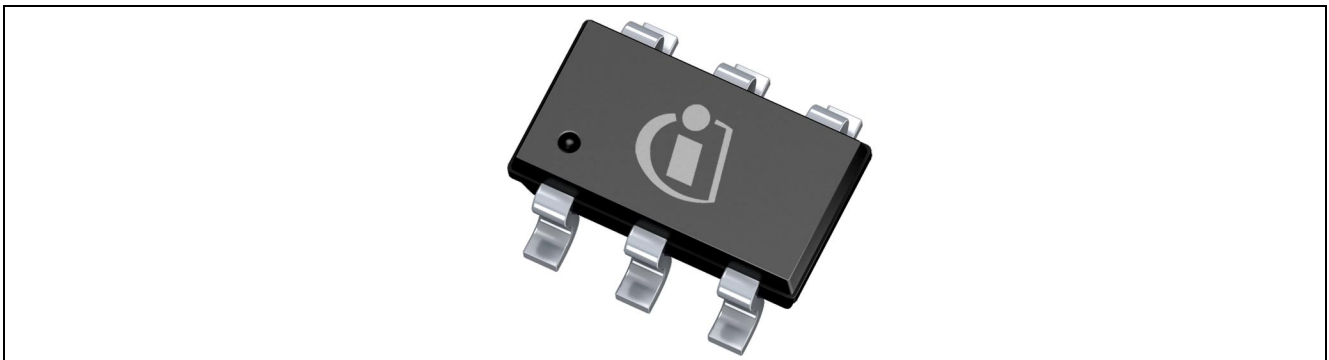


Figure 9 Image of TLE493D-A1B6 in TSOP6

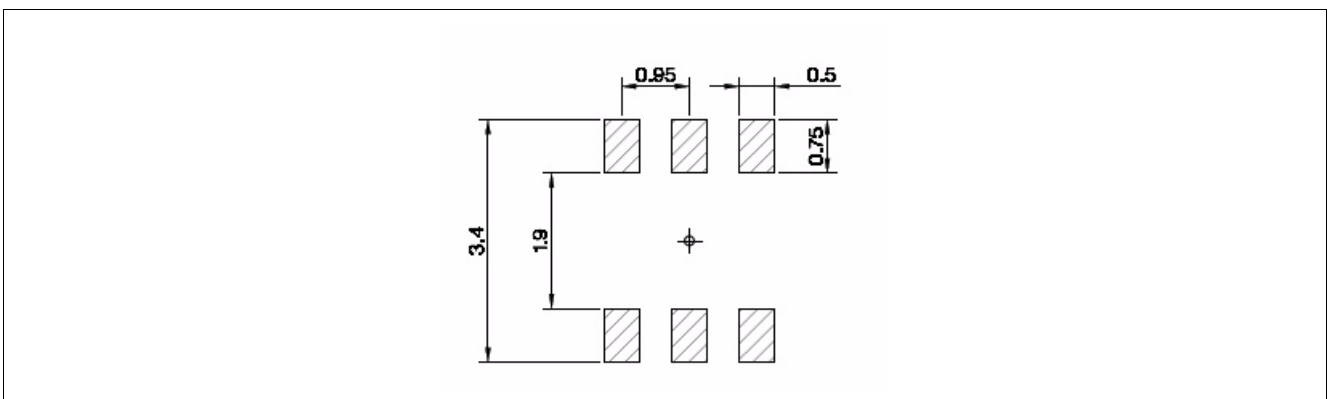


Figure 10 Footprint for PG-TSOP6-6-5 and PG-TSOP6-6-8 (all dimensions in mm)

Package Information

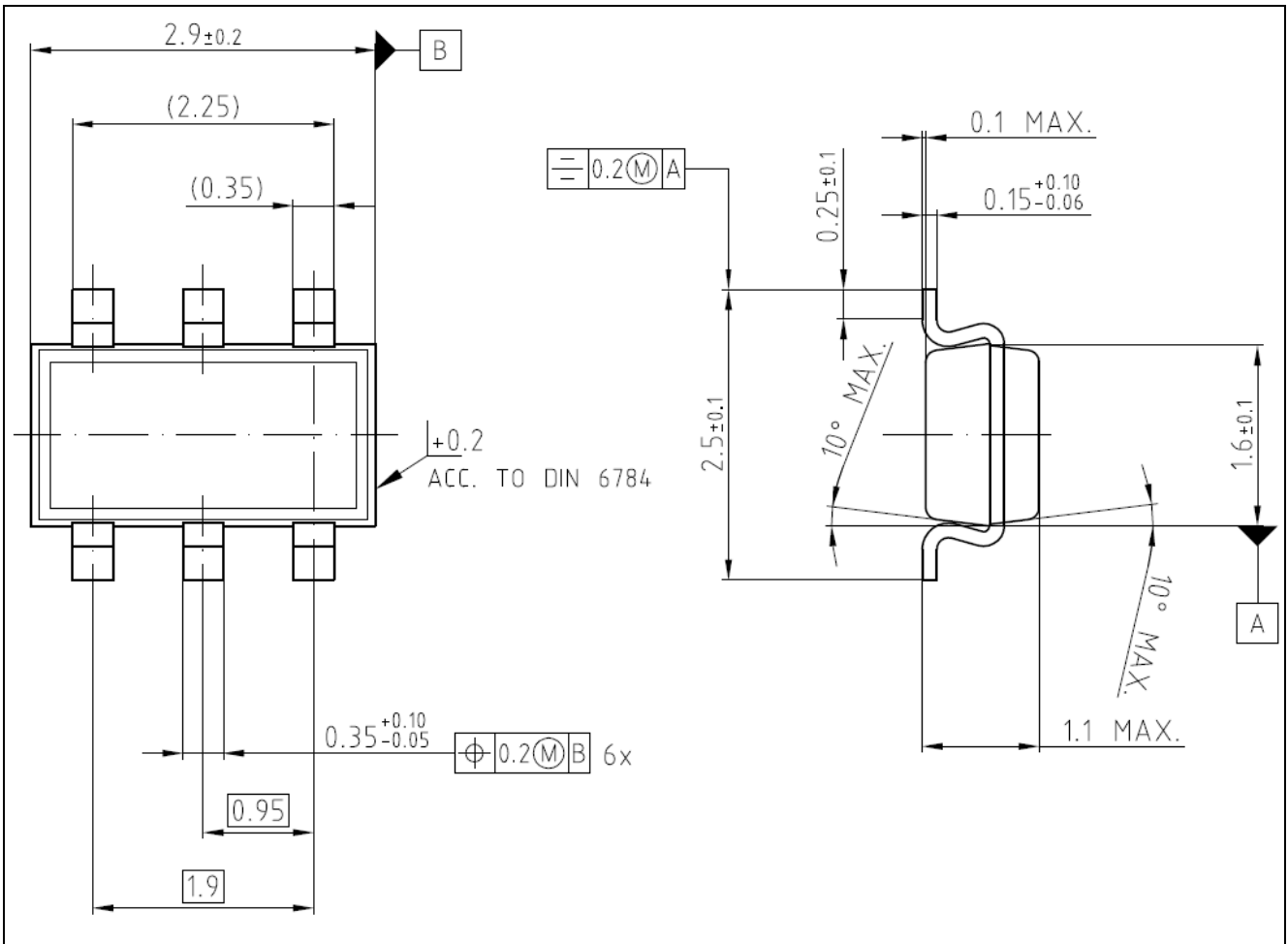


Figure 11 Package Outlines (all dimensions in mm)

Revision History

6 Revision History

Revision	Date	Changes
Rev. 1.2	2019-04-09	Note on Page 12 updated.
Rev. 1.1	2017-11-07	Chapter 1.2 editorial changes. Figure 5 updated. Table 8 Offset drift updated.
Rev. 1.0	2017-02-10	Initial version

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