Low Power 3D Magnetic Sensor with Digital Output

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3D Magnetic Sensor
TLV493D-A1B6

3D Magnetic Sensor

Technical Product Description

Rev 1.0, 2015-05-26

Sense & Control

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1 Product Description

1.1 Target Applications

This product is suitable for e.g. joystick, controll elements in white goods or anti tampering functionality in electric meter applications.

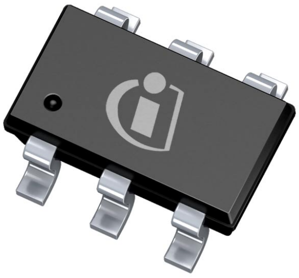

Figure 1 Image of TLV493D-A1B6 in TSOP-6

1.2 Features

- 3D magnetic sensing
- Very low power consumption = 10µA during operations (10Hz)
- Power down mode with 7nA power consumption
- Digital output via 2-wire standard I^2C interface
- 12 bit data resolution for each measurement direction
- Bx, By and Bz linear field measurement up to ±150mT
- Excellent matching of X/Y measurement for accurate angle sensing
- Variable update frequencies and power modes (configurable during operation)
- Supply voltage range= 2.7V…3.5V; Temperature range Tj= -40°C…125°C
- Small, industrial 6 pin TSOP package
- Triggering by external µC possible

Table 1 Overview of Modes

Mode	Update Rate / Hz	I_{DD} (25°C)
Power Down	-	7 nA
Ultra Low Power	10	10 µA
Low Power	100	100 µA
Fast Mode	3300	3.7 mA

Table 2 Ordering Information

Product Name	Marking	Ordering Code	Package
3D Magnetic Sensor	SA (eng. samples) VA (serie)	SP001286056	PG-TSOP-6-6-5

2 Functional Description

2.1 General

Description of the Block diagram and its functions.

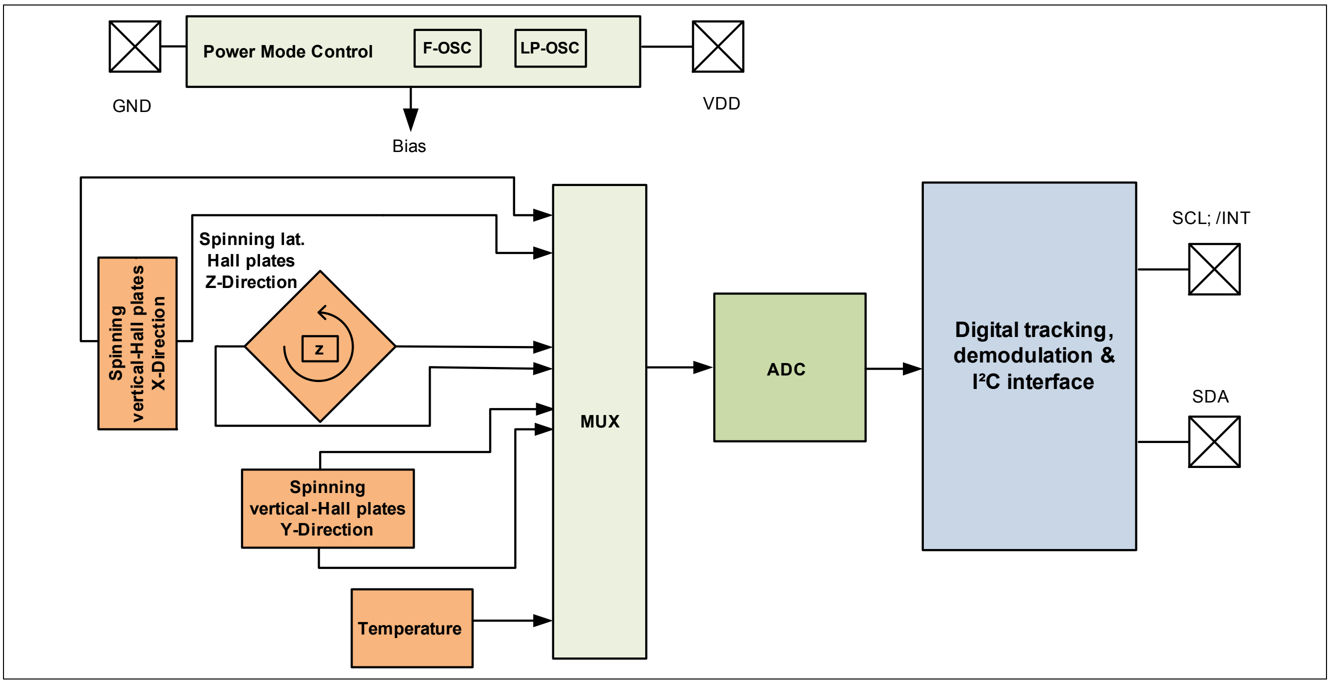

Figure 2 Block Diagram

The IC consists of three main function units containing the 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 successive tracking ADC. Furthermore a temperature sensor is implemented.
- The I^2C interface, containing the register file and I/O pads, see **Chapter 4**.

2.1.1 Power mode control

The power mode control provides 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
  - reads out the voltage level on ADDR pin. The applied voltage represents the address. See also **Chapter 4.2**.
  - initiates sensor power down mode (needs to be configured via I^2C interface)

Note: The sensor is in power down mode after power up

- After re-configuration a measurement cycle is performed, regularly containing of:

- the internal biasing, checks for reset condition and provides the the fast oscillator
- the HALL biasing
- three HALL probe channels sequentially incl. temperature (if activated)

- It then 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 continues its operation afterwards. The functions are also restarted if a reset event occurs in between.

2.1.2 Sensing part

Performs measurements of the magnetic field in X, Y and Z directions. Each X, Y and Z-Hall probe is connected sequentially to a multiplexer, which is then connected to an Analog to Digital Converter (ADC). Optionally, the temperature is determined after the three Hall channels. The current consumption decreases by -25% when temperature measurement is deactivated.

2.1.3 Communication Unit

See **Chapter 4** for detailled information on communication.

2.2 Pin Configuration (top view)

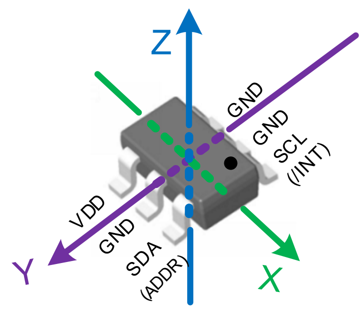

Figure 3 Pin Configuration

Table 3 TSOP-6 **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
2	GND	connect to GND (recommended)
3	GND	Ground Pin
4	V_{DD}	Supply Pin
5	GND	connect to GND (recommended)
6	SDA ADDR	Interface serial data pin (input/output), open drain Sensor ID configuration during power up (see **Chapter 4.2**)

2.3 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 resistors of the I^2C bus have to be set in a way to keep the rise- and fall time specification of the interface bus parameters (see specification section) with the parasitic capacitive load of the actual setup.

Please note: too small resistive values have to be prevented to avoid unnecessary power consumption during interface transmissions, especially for low-power applications. Additionally, 100nF decreases the emission.

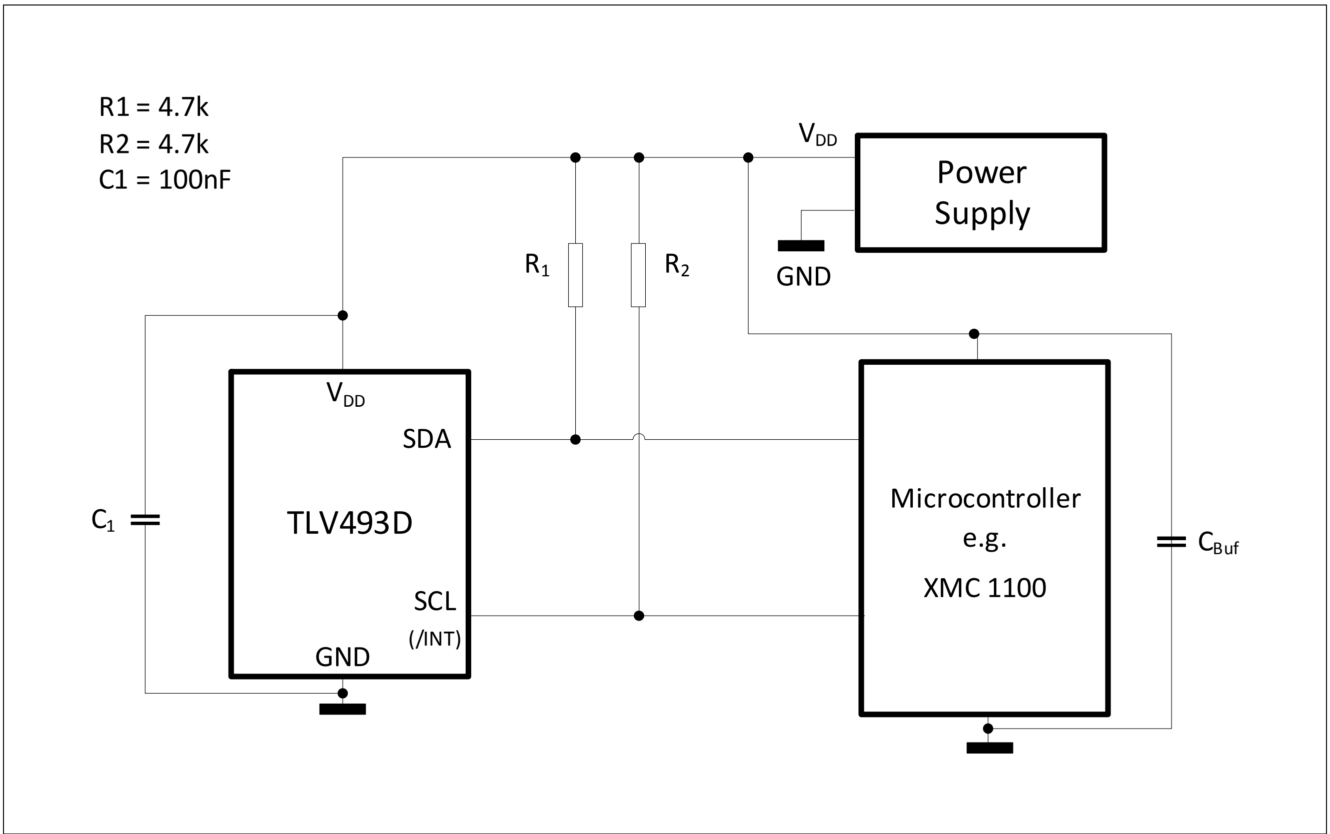

Figure 4 Application circuit with external power supply and µC

3 Specification

3.1 Absolute Maximum Ratings

Note: 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 4 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		-0.1		3.5	V	open-drain outputs are not current limited when forced by a voltage in enabled state!

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 = Ta + 3K in fast mode
Supply voltage	V_{DD}	2.7	3.3	3.5	V	
Reset level	V_{res}		2.2		V	

3.3 Electrical Characteristics

Note: All specification parameters refer to 3.3V ±5% nominal supply Vdd on the pins directly. Typical values refer to 25°C and to 3.3V ±5% nominal supply.

Table 6 Electrical setup

Parameter	min	typ	max	unit	Note/Condition
Supply current I_{DD}[1)]		7		nA	power down mode (default after power on), all off
		10		µA	ultra low power mode, see **Chapter 4.3.3**
		100		µA	low power mode, see **Chapter 4.3.4**
		3.7		mA	fast mode, see **Chapter 4.3.4**.1
Maximum supply current I_{DD_max}		3.7		mA	peak in ULP mode for about 300µs[2)]
Input voltage low threshold	30			%Vdd	all input pads
Input voltage high threshold			70	%Vdd	all input pads
Output voltage low level @ 3 mA load			20	%Vdd	all output pads, static load
Fall time SDA/SCL signal (t_{FALL})[3)]		0.25[4)]	0.3	µs	0.3µs for 400kHz mode (or may require less C load)
Rise time SDA/SCL signal (t_{RISE})[3)]		0.5[4)]		µs	R=4.7k
Output high level		V_{DD}		V	given by ext. pull-up resistor

1) Average values
2) During power down mode the current consumption is about 7nA
3) Dependent on used R-C-combination
4) For given AppCircuit; Capacitive load for each bus line = 400pF (SDA, SCL)

3.4 Magnetic Characteristics

Typical values for 25°C and V_S = 3.3V ±5%

Table 7 Magnetic Characteristics

Parameter	min	typ	max	unit	Note/Condition
Usable magnetic linear range		±150		mT	Bx, By and Bz
Magnetic offset error	-1	+0.2	+1	mT	Bx, By and Bz @ RT
Magnetic gain error	-20	±5	+20	%	
X to Y static channel matching		±2		%	
X/Y to Z static channel matching	-20	±5	+20	%	
Magnetic noise (rms)		0.1		mT	rms = 1 sigma
Resolution 12bit readout		98		µT/ LSB	
Resolution 8bit readout		1.56		mT/ LSB	
Temperature compensation		0[1)]		ppm/K	factory setting for external magnet
Magnetic hysteresis		1		LSB_{12}	only due to quantization effects
DNL		±2		LSB_{12}	Differential Non-Linearity
INL		0.1		%	Integral Non-Linearity

1) Can be changed by programming; further values are -2000, -1000, +500 ppm/K

Conversion register value to magnetic field value:

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

Table 8 Conversion table for 12Bit

		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

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 LSB * 0.098 mT/LSB = -23.6mT

Table 9 Conversion table for 8Bit

	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	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 LSB * 1.56 mT/LSB = 145.1 mT

3.5 Temperature Measurement (only if activated)

Table 10 Temperature Measurement Characteristics

Parameter	min	typ	max	unit	Note/Condition
Digital value @ 25°C[1)]		340		LSB	
Resolution 12bit		1.1		°C/LSB	
Resolution 8bit		17		°C/LSB	not recommended
Accuracy		±5		°C	

1) Theoretical possible measurement range from -50°C to 150°C

4 I²C Interface

4.1 Interface Description

- The I²C interface requires two pins:
  - A serial clock (SCL) input pin.
  - A serial data pin (SDA) for in- & output (open drain)
- The interface does not require the internal oscillators to be active, thus it can operate in any power mode.
- The values of all three axis are stored in separate registers. After a power-on reset these registers will read zero.
- A reset event (operated during an ADC conversion) does not reset these values but only inhibits the ADC conversion. Only a complete supply failure, which is detected by the “zero current” reset block will reset this registers and initiate a new power-on cycle to be executed.
- A 2 bit frame counter checks for a “frozen” sensor condition (e.g. the power unit did not initiate a measurement cycle - which means the frame counter does not get incremented anymore).

4.2 I²C format description

The interface can be accessed in any power mode. It conforms to the I²C fast mode specification (400kBit/sec max.) but allows operation up to at least 1 Mbit/sec in case the electrical setup of the bus is lean enough (which means the amount of devices and thus the parasitic load of the bus line is limited to keep rise/fall time conditions small). The allowed max. clock rate above 400kHz has to be defined on demand given a specific electrical setup.

The protocol uses a standard 7 bit address followed by data bytes to be sent or received. 12bit addressing or any sub-addressing is not implemented, so each start condition always begins with writing the address, followed by reading (or writing) the first byte of the bitmap and continues with reading (or writing) the next byte until all bytes are read (or written) or the communication is simply terminated by a stop condition. The basic initiator for the protocol is the falling SDA edge.

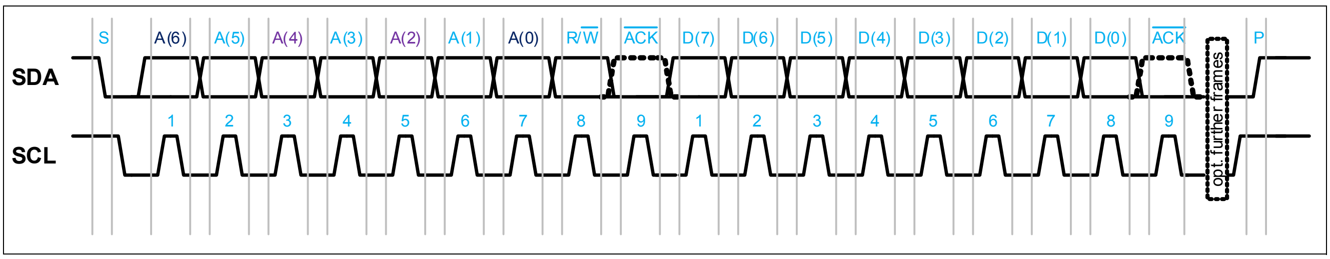

Figure 5 General I²C format

Note: A reset can be triggered with general I²C address 0x00. After this command the sensor will do an power up sequence. (See ***Chapter 4.3.2****)*

The default setting after startup for a read operation is shown below for ADDR=1 and ADDR=0. ADDR=1 is defined by Pin SDA at power up to be high according AppCircuit **Figure 4**. In order to set ADDR=0 SDA must pulled down to low during power up. To set the address the high or low level must be kept 200µs after supplying the sensor.

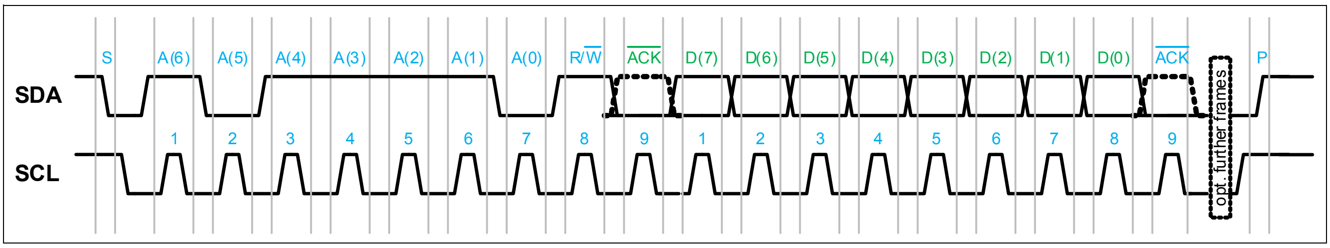

Figure 6 Read example with default setting ADDR=1 (=BD; Write = BC)

For ADDR=1 bit A(6)=1 and A(0)=NOT(Addr) = 0 is used.

After configuration to ADDR=0 following sequence is used.

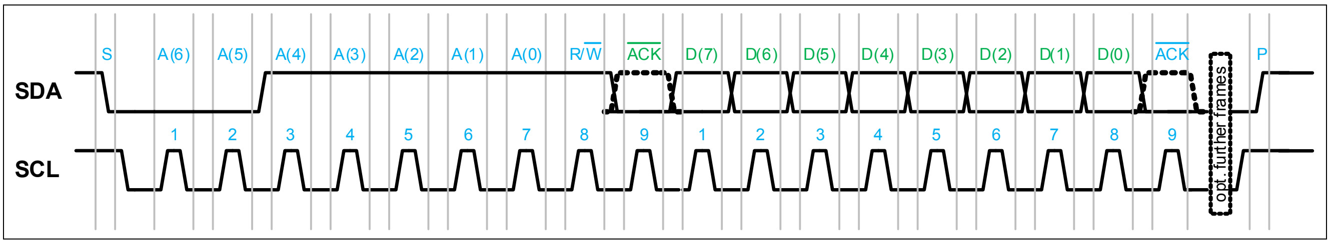

Figure 7 Read example with ADDR=0 (3F; Write = 3E)

For ADDR=0 bit A(6)=0 and A(0)=NOT(Addr) = 1 is used.

4.3 Timing Diagrams and Access Modes

4.3.1 I²C Timing

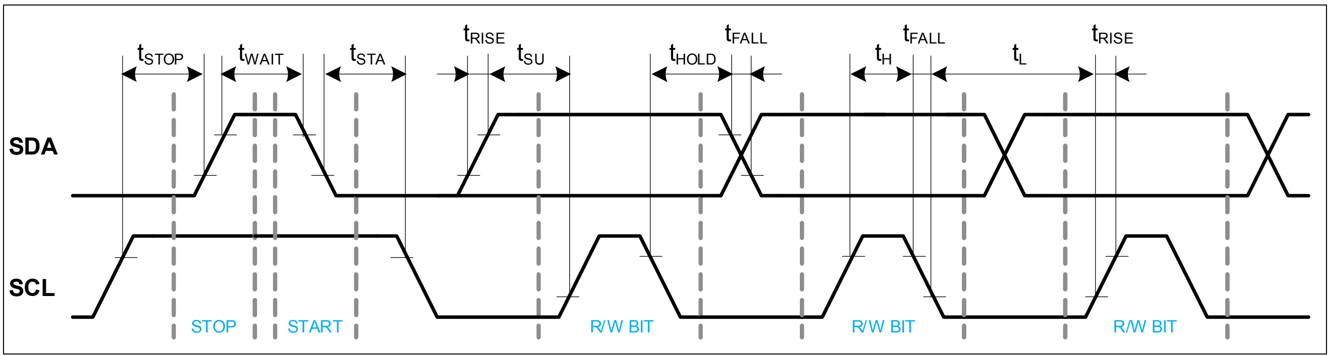

Figure 8 I²C Timing Diagram, see also Table 12

4.3.2 Power Up and Power Down Mode I²C Bus

At power up the sensor starts with the factory configuration and uses this as default mode (= power down).

After power up, the sensor reads out the voltage applied on ADDR pin for 200µs. If the voltage level on ADDR=high then the address is set to "1". If the voltage level on ADDR = low the address is set to "0".

For a short period of time the power consumption increases to 3.7mA. During this short period all functional blocks are active. After this the sensor enters the "power- down mode". In this power down mode all functional blocks are off. Even the low power oscillator is switched off. No magnetic measurement takes place now.

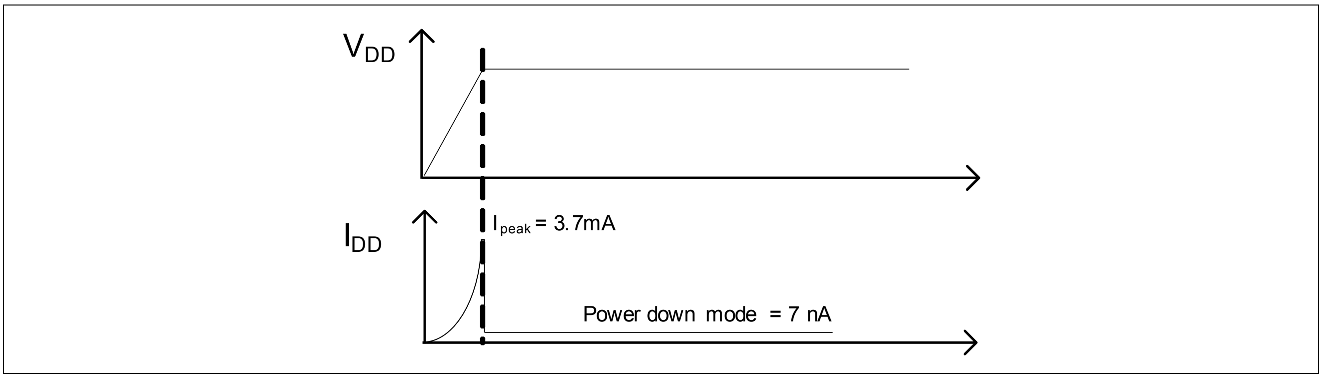

Figure 9 Current consumption during power up

4.3.3 Fast mode

Settings: fastmode=1, lp_mode=0, int_out=1 (byte settings [hex] = 00, x6, xx, xx; keep certain bits)

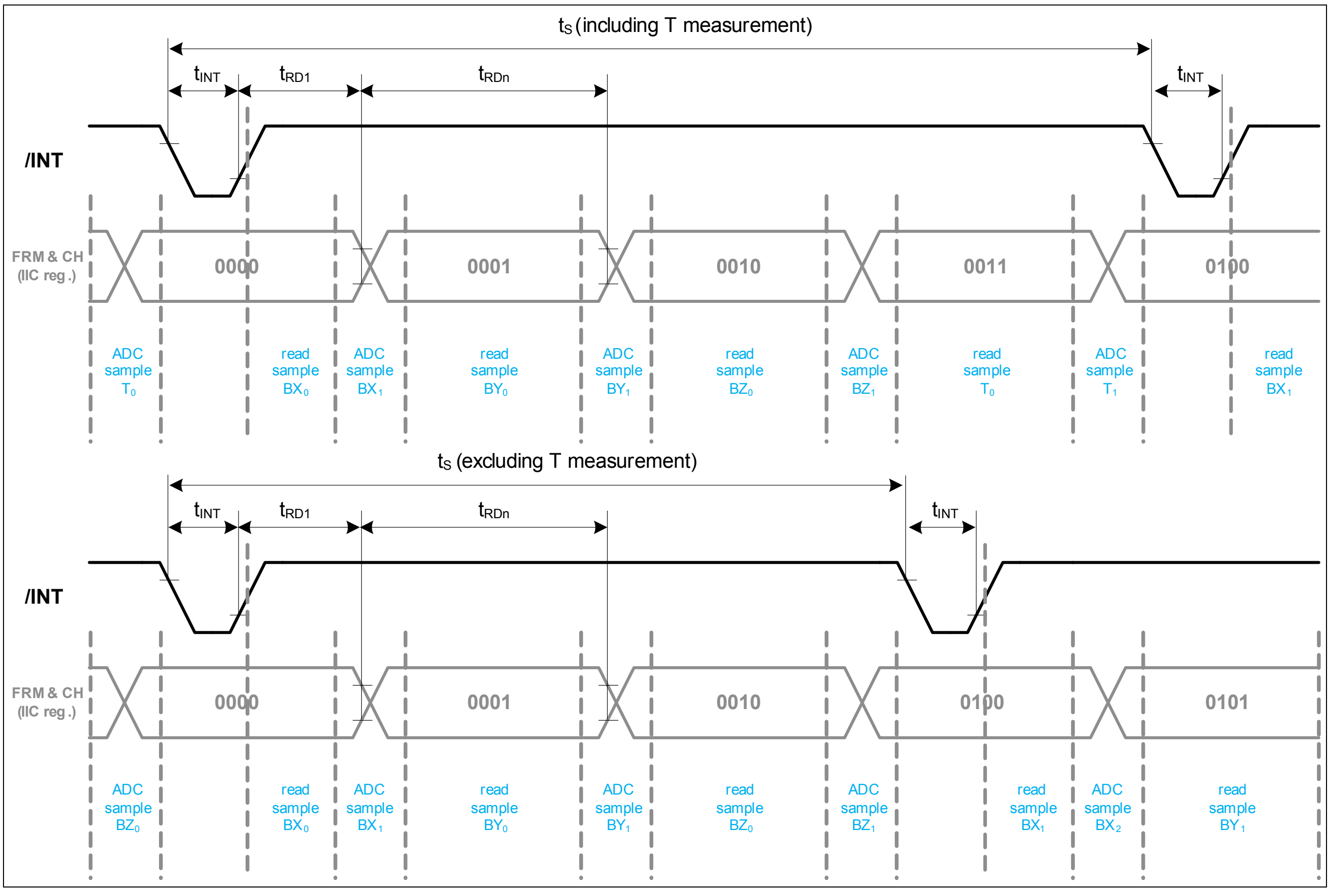

Figure 10 Fast Mode (/w and w/o temp. measurement) in relation to /INT output

It is possible to optimize the readout in a way that the sample of the last conversion can be read while the next conversion is performed. To achieve this, the readout from I²C has to be done faster than the given time when the next value gets overwritten, including any possible clock variance between sensor and master (µC).

Note: This read mode assumes to read only first three 8 bit values via I²C after an /INT pulse.

To read out the 8 bit values for Bx, By and Bz the I²C address write and first byte read needs to be done within t_{RD1} (minus the w.c. accuracy of the sensor clock and the µC clock) after the rising interrupt clock edge. The next byte needs to be read latest within an additional tRDn timeframe (minus tolerances) and so on. Assuming all 3 values are read directly in one I²C sequence, the time for readout of the first byte is the most critical (as two I²C frames are required), reading the remaining bytes should not be a timing issue as here nevertheless more time is available.

Note: Thus, this mode requires a non-standard 1MHz I²C clock to be used to read the data fast enough.

4.3.4 Low Power mode

Settings: fastmode=0, lp_mode=1, int_out=1 (byte settings [hex]: 00, x5, xx, 4x; keep certain bits)

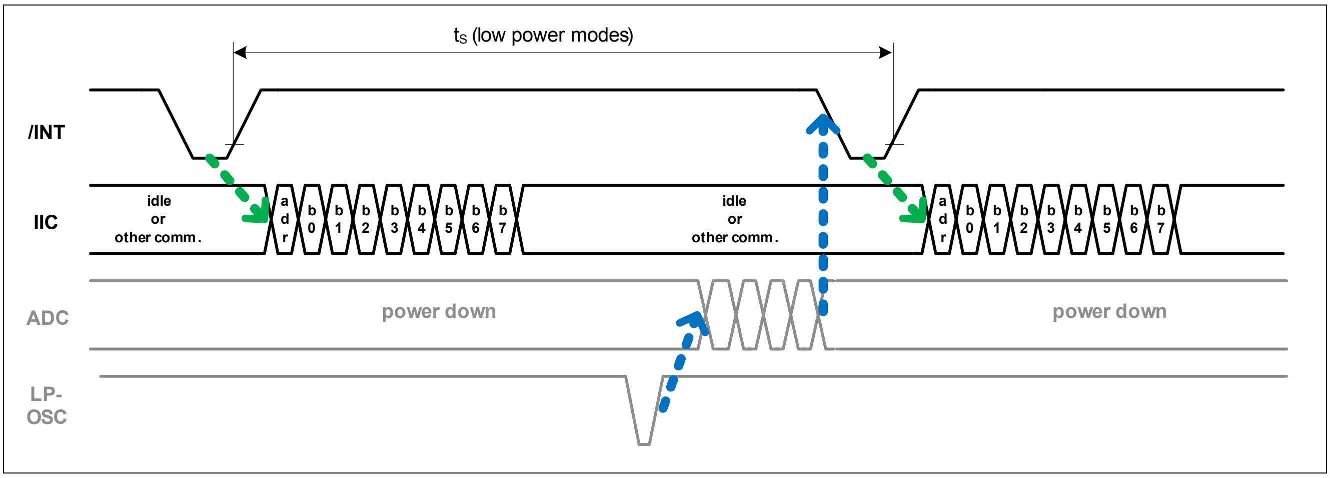

Figure 11 Synchronous, low-power I²C readout using an /INT wake-up pulse

In this low-power mode the sensor goes into power-down mode until it wakes up by itself to perform the next conversion. After the conversion the interrupt line will be pulled (if activated). This means for the low power modes the time window to read out all registers after the rising edge of the /INT pulse is equal one over the sample rate of this low power mode minus the conversion time.

4.3.5 Ultra Low Power Mode

Settings: fastmode=0, lp_mode=1, int_out=1 (byte settings [hex]: 00, x5, xx, 0x; keep certain bits)

In this mode an excellent combination of ultra low power consumption and internal regular wake up function is reached. The basic function is equal to Low Power Mode, but Low Power Mode has about 8 times higher current consumption than Ultra Low Power Mode. As well the interrupt is available, if an even lower power consumption is needed.

4.3.6 Master-controlled mode

Settings: fastmode=1, lp_mode=1, int_out=0/1 (byte settings: 00, x7, xx, xx)

- The fast oscillator is constantly enabled
- One measurement cycle is performed and /INT is pulsed.
- Measurement data is available for read out of the registers.
- The sensor is waiting for read-out and no other measurements are done.
- As soon as the master performs a read-out a new measurment cycle is internally started by the sensor and new values will be stored in the registers. If no further read out takes place no new measurement cycle is initiated.

In the simplest case, periodic read-out of I²C causes a re-run of a new measurement cycle. It only needs to be ensured that the read-out time is larger than the time for the I²C read frame plus the sensor conversion time.

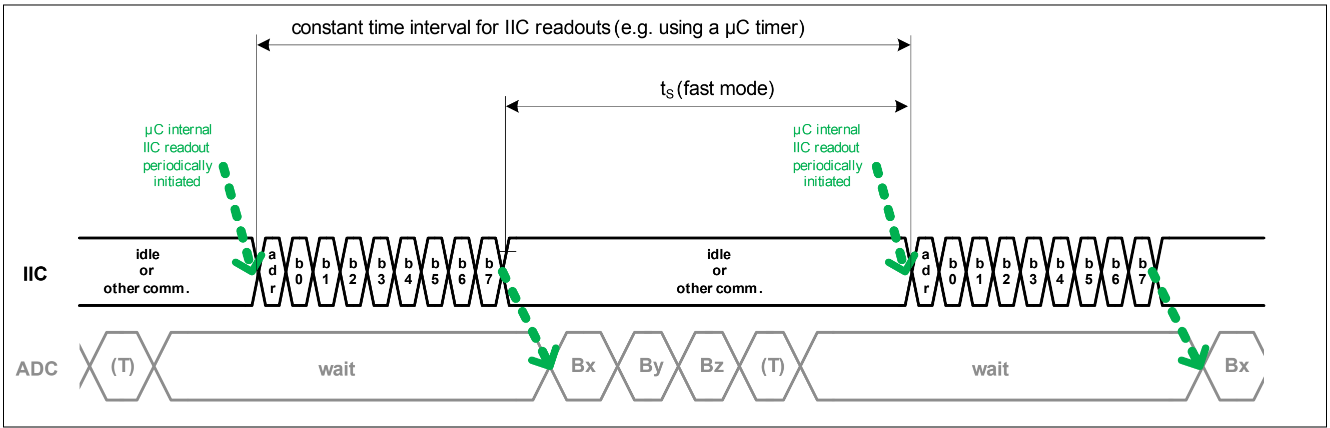

Figure 12 Synchronous, fast I²C access using a periodic I²C read-out

If possible, the /INT output should be activated and used in this mode as well. This will provide the fastest and safest way to read out all axis with a 12bit resolution value, as to be shown next.

This allows a read-out of the sensor to the master (µC) using an interrupt service routine. The sample rate is now basically determined by the ADC conversion time plus the I²C readout time only, and fully avoids the read of inconsistent values. The possible sample rate for this mode at regular 400kHz I²C speed is given in the specification section.

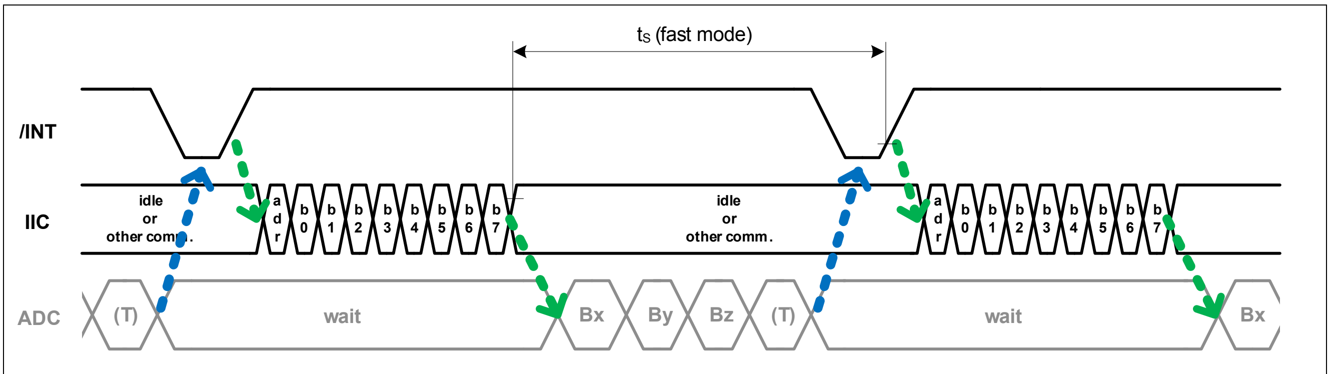

Figure 13 Synchronous, fast I²C access using an /INT trigger for I²C readout

Please be aware that this modes does not switch off the internal biasing and oscillator, it should therefore not be used for low-power operation with large time intervals between measurements.

Table 11 Overview of modes and its corresponding current consumption with sample rates

Mode	Bytehex 0,1,2,3[1)]	Update Rate / Hz	Idd (25°C)	Remark
Power Down	-	-	7 nA	default after power on[2)] [3)]
Ultra Low Power	00, 01, 00, 00	10	10 µA	temp measurement[4)]
Low Power	00, 05, 00, 40	100	100 µA	temp measurement
Fast Mode	00, 06, 00, 00	3300	3.7 mA	temp measurement
Master controlled[5)]	00, 07, 00, 00	variable up to f = 2.2kHz		temp measurement

1) Please use logical Operation: byte 7, 8, 9 (from read out) OR byte 1,2, 3 --> command for mode
2) Configurable after power on via I²C interface. Settings will be lost after power down. Any temporary overwrite via the I²C interface will be lost on a power-on reset.
3) Factory setting, can be changed to any other mode on request
4) I_{DD} increases by +33% for enabled temperature measurement
5) In master controlled mode the oscillator is constantly enabled. For smaller current consumptions the sensor can be set in power down mode after read out.

4.4 Interface and Timing Description

This chapter refers to howthe boundary conditions are set in order to establish a proper interface communication.

Table 12 Interface and timing

Parameter	min	typ	max	unit	Note/Condition
Update rate X, Y, Z in fast mode		3.3		kHz	continuous mode (temp. off)
Update rate I²C master controlled mode	0	2.2		kHz	Sample rate defined by I²C master
Update rate (all axis), ultra low p.		10		Hz	triggered internally, incl. T
Update rate (all axis), low p.		100		Hz	triggered internally, incl. T
End-of-Conversion /INT pulse (t_{INT})		1.2		µs	low-active (when activated)
Time window to read first value (t_{RD1})		32.8		µs	read after rising /INT edge
Time window to read next value. (t_{RDn})		33.6		µs	consecutive reads
Internal clock accuracy	-25		+25	%	all above timing parameters
Allowed I²C bit clock frequency		400	1000	kHz	400kHz is I²C fast mode
Low period of SCL clock (t_L)	0.5			µs	1.3µs for 400kHz mode
High period of SCL clock (t_H)	0.4			µs	0.6µs for 400kHz mode
SDA fall to SCL fall hold time (t_{STA}) (hold time start condition to clock)	0.4			µs	0.6µs for 400kHz mode
SCL rise to SDA rise su. time (t_{STOP}) (setup time clock to stop condition)	0.4			µs	0.6µs for 400kHz mode
SDA rise to SDA fall hold time (t_{WAIT}) (wait time from stop to start cond.)	0.4			µs	0.6µs for 400kHz mode
SDA setup before SCL rising (t_{SU})	0.1			µs	
SDA hold after SCL falling (t_{HOLD})	0			µs	

4.5 I²C read register

The I²C registers can be read at any time. To avoid reading inconsistent values, especially when running the fast mode with significantly changing magnetic input signals, it is recommended to use the sensor interrupt and read the data after an interrupt occurred. Additionally, several flags can be checked to ensure the data values are consistent and the ADC was not running at the time of readout.

Table 13 I²C read register

Description of I²C read register	Byte No.	D(7)	D(6)	D(5)	D(4)	D(3)	D(2)	D(1)	D(0)
Bx value – vertical HALL probe (MSBs)	0	Bx(11…4)							
By value – vertical HALL probe (MSBs)	1	By(11…4)							
Bz value – lateral HALL probe (MSBs)	2	Bz(11…4)							
Selected channel (must be “00” at readout)[1]	3							CH(1…0)	
Frame counter, increments for each X/Y/Z sample	3					FRM(1…0)			
Temperature values (MSB’s, only when enabled)	3	Temp (11..8)							
By value – vertical HALL probe (remaining LSBs)	4					By(3…0)			
Bx value – vertical HALL probe (remaining LSBs)	4	Bx(3…0)							
Bz value – lateral HALL probe (remaining LSBs)	5					Bz(3…0)			
Power-down PD flag (must be “0” at readout)	5	only internal			PD				
Temperature values (only when enabled)	6	Temp (7..0)							
Factory settings	7	to be read out and stored							
Factory settings	8	to be read out and stored							
Factory settings	9	to be read out and stored							

1) If not “00”, a further read-out is necessary

The factory settings (byte7 .. byte 9) should be read out once and stored. Those values are needed for further writing commands and are not allowed to change.

4.6 I²C write register

Configuration Map:

Table 14 I²C write register Configuration Map

Description of I²C write register	Byte No.	D(7)	D(6)	D(5)	D(4)	D(3)	D(2)	D(1)	D(0)
Keep 0x00	0	00000000							
1=low power mode activated (0=lowp. mode off)	1								0/1
1=fast mode activated (0=fast mode off)								0/1	
1=/INT pad activated (0=no /INT pulse given)							0/1		
Keep factory setting (set same as "read" byte 7 D(3))						keep			
Keep factory setting (set same as "read" byte 7 D(4))					keep				
Keep factory setting (se same values as byte 7 D(5) & D(6))			keep	keep					
Parity of configuration map (sum of all 24 bits == odd)[1]		0/1							
Keep factory setting (set same as "read" as byte 8)	2	keep value							
Keep factory setting (set same as "read" as byte 9 D(0) .. D(4))	3				keep value				
1=enable parity test (0=disable);				0/1					
1=12ms LP period (0=100ms ULP period)			0/1						
1=disable T measurement (0=enable T meas.)		0/1							

1) Parity needs to be calculated and set accordingly before a write command is executed. After the write command the sensor (=slave) verifies the parity with the bits in the register. If the parity fails then the sensor sets ACK=high at the next read command

5 Typical Characteristics

5.1 Current Consumption vs. Temperature

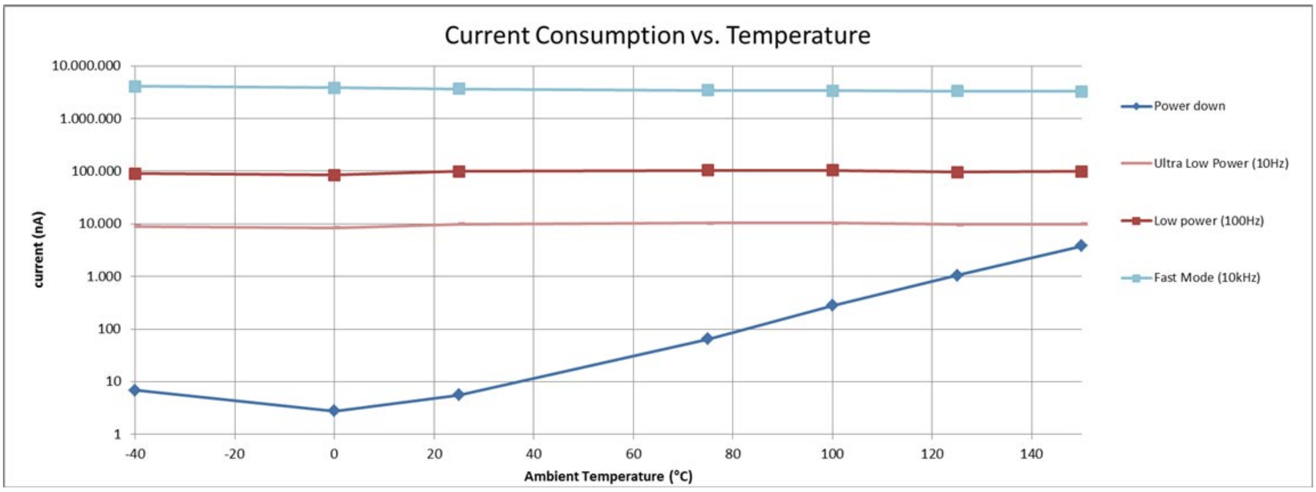

Figure 14 Typical Current Consumption versus Temperature

6 Package Information

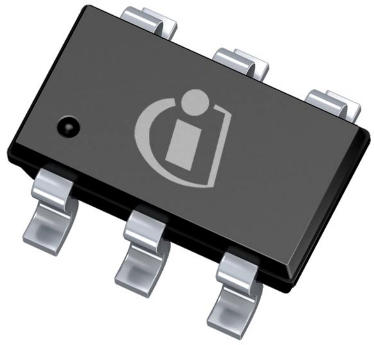

Figure 15 Image of TLV493D-A1B6 in TSOP-6

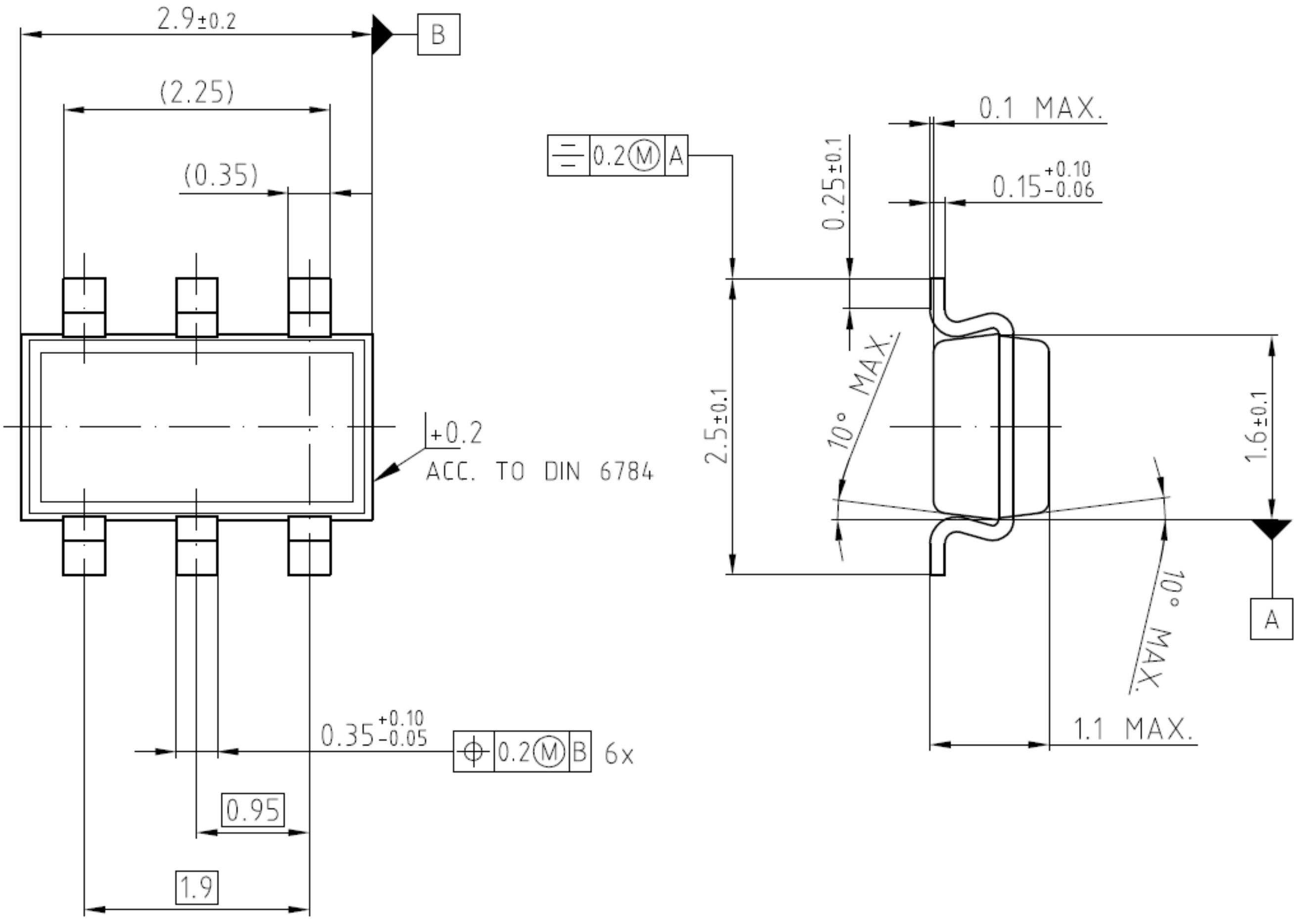

Figure 16 Package Outlines (all dimensions in mm)

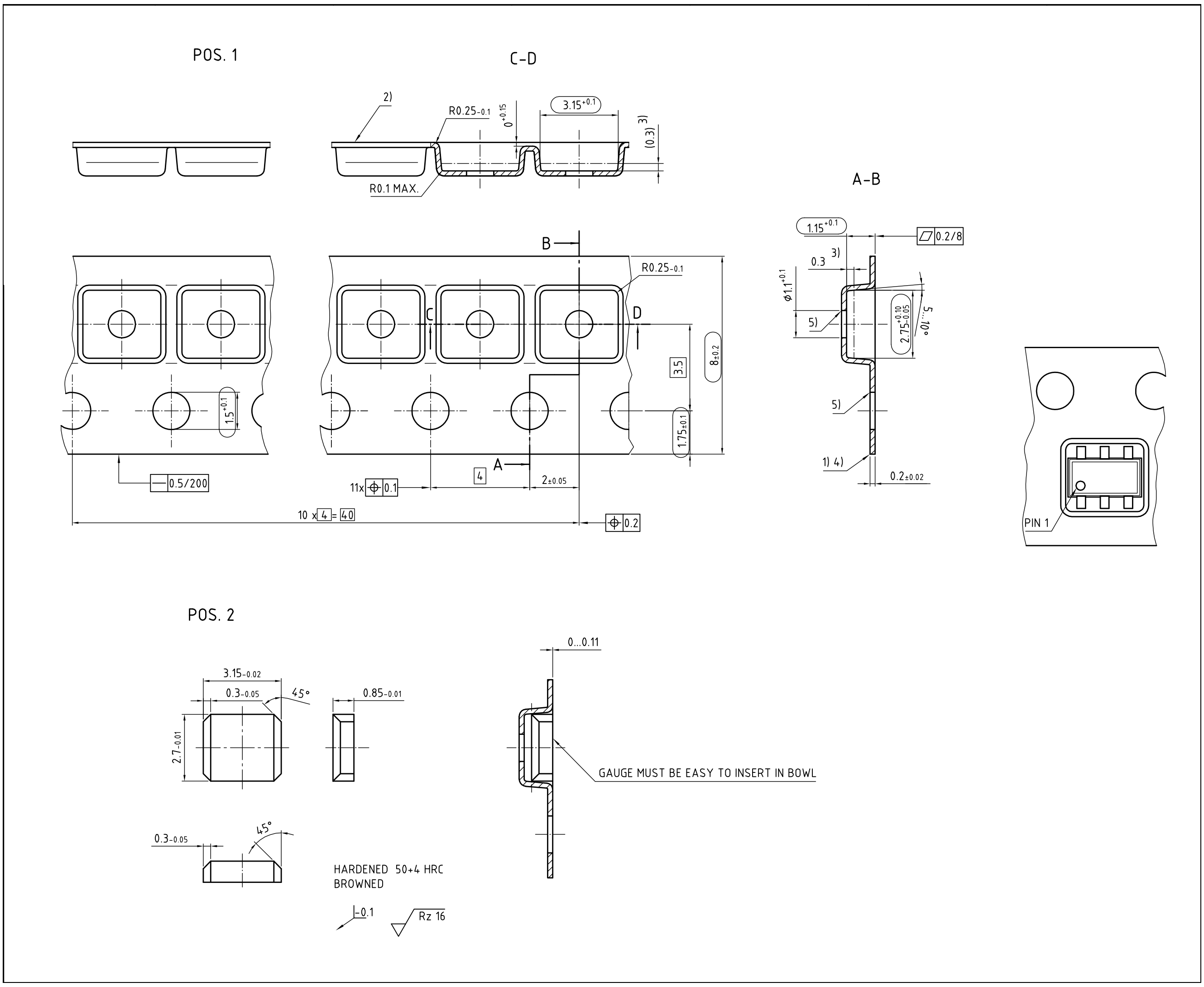

Figure 17 Packing (all dimensions in mm)

7 Revision History

Revision	Date	Changes
1.0	2015-05-26	Initial version

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