Efficient use of the 2nd generation 3D Hall sensors

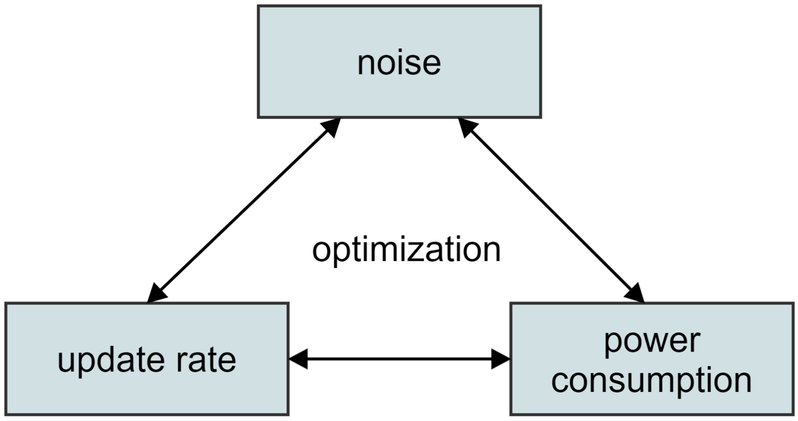
3D magnetic sensors

About this document

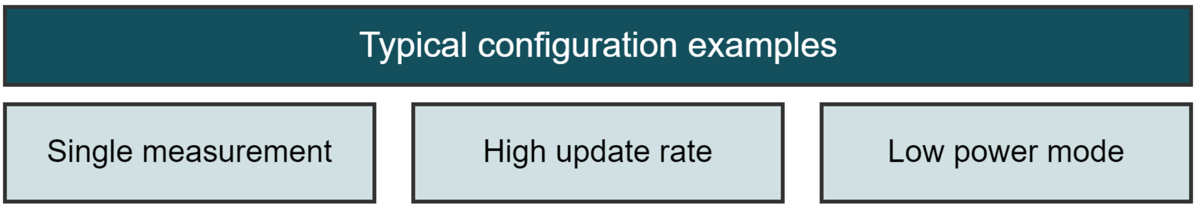
Scope and purpose

The Infineon 3D magnetic sensors are highly configurable devices that fit many applications. A microcontroller is used in a bidirectional I^2C communication to communicate with the sensor and read out the magnetic field measurements. In the firmware it is possible to optimize the measurement for the target applications needs.

In this application note it is explained how a low noise measurement can be performed. It strongly interacts with the update rate and the power consumption of the sensor. The information provides help to find the ideal trade-off for the target application.



To simplify the design-in, three typical sensor configuration and readout schemes are described in detail. It is intended as a starting point to efficiently use the sensor to achieve the desired design targets.



The document is valid for all 3D magnetic sensors of the second generation, including the variants:

- TLE493D-P2B6 A0...A3
- TLE493D-W2B6 A0...A3
- TLE493D-A2B6
- TLI493D-W2BW A0...A3
- TLI493D-A2B6
- TLV493D-A2BW

Intended audience

Any application designer or firmware developer working with Infineon 3D Hall sensors of the 2nd generation.

Table of contents

1 Optimizing the measurement

Depending on the application there are different requirements for the noise, update rate and power consumption. As shown all of these parameters interact with each other. The following sections describe how an average filtering in the microcontroller can reduce the noise and how to find the trade off between current consumption and update rate.

1.1 Improving noise and resolution

The 3D magnetic sensor converts the physical magnetic field via Hall cells and an analog to digital converter into a digital representation thereof. Naturally this process introduces quantification as well as noise errors. While these effects are neglectable with strong magnetic fields, they can have a high impact if very low magnetic fields have to be measured. This chapter describes how an averaging in the microcontroller can significantly improve this measurement.

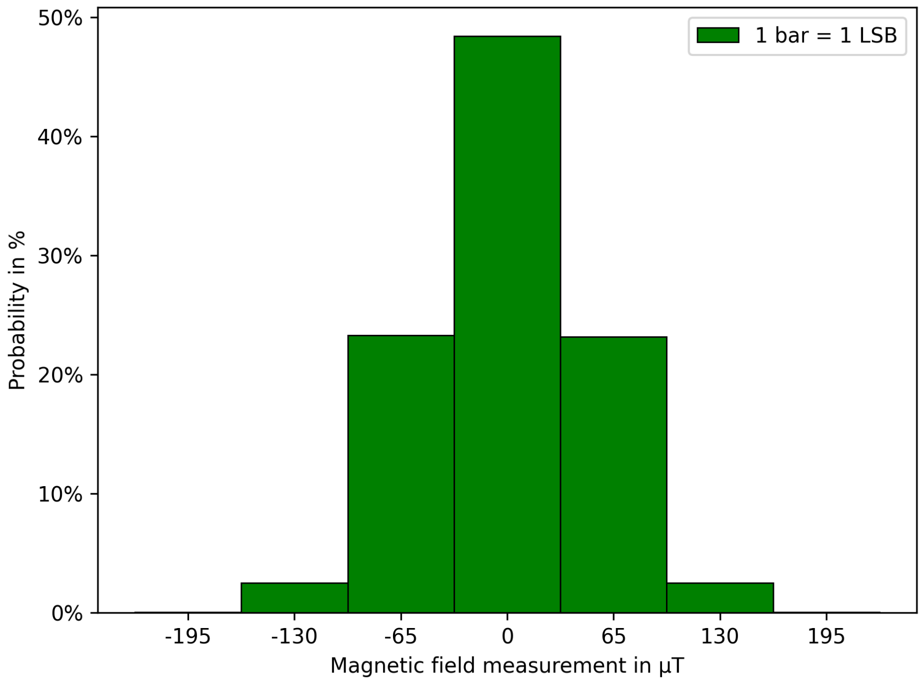
The high output data rate of several kHz provided by the Infineon 3D magnetic sensors allows a high number of averaging if necessary. For a configuration and readout example of the sensor refer to the section High update rate.

Noise without averaging

To analyze the effect of noise on the sensor measurement an example is provided below. The sensor measures the magnetic field in the **Z channel** and is configured to **short range** mode. The sensor has the following typical characteristics:

min. magnetic field range	±100 µT
resolution (1/sensitivity)	65 µT/LSB
magnetic noise rms (B=0mT)	50 µT

The histogram below shows the expected output of the sensor with the effect of quantification and magnetic noise. There is a statistic distribution around zero magnetic field. Due to the magnetic noise it is expected that the sensor reading is typically in the range of -2 to 2 LSB which equals -130 to 130 µT.



Basics of an average filter

To reduce the noise of the measurement a highly efficient possibility is to readout multiple measurements and average the results in the microcontroller.

The average of **N measurements** is calculated with following equation:

$$B_{avg} = \frac{1}{N}\sum_{i=1}^{N} B_i$$

Equation 1

All sensor readings are added up and afterward divided by the number of measurements.

Due to the overlay of noise on the measurement, this methods allows to reduce the quantification steps below the initial resolution. The resulting resolution can be calculated with the following equation:

$$re\,solution\ filtered = \frac{resolution}{N}$$

Equation 2

Additionally the resulting noise of the filtered output is reduced by square root of the number of averaged measurements:

$$magnetic\ noise\ filtered = \frac{magnetic\ noise}{\sqrt{N}}$$

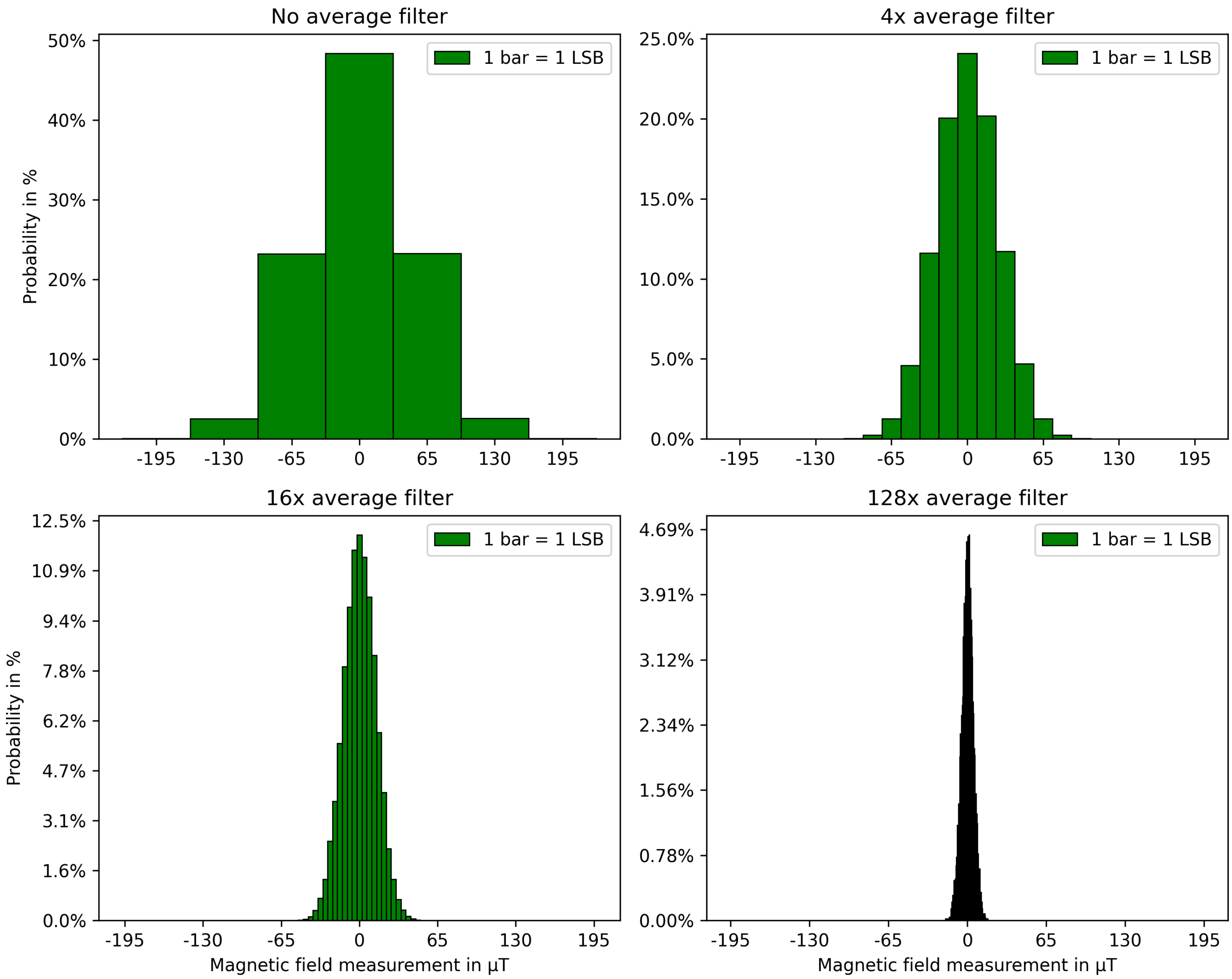
Equation 3

Noise with averaging

According to the previous example the effect of averaging is shown in the table and plots below:

Averaging	**None**	**4x**	**16x**	**128x**
Resolution (1/sensitivity)	65 µT/LSB	16.3 µT/LSB	4.1 µT/LSB	0.51 µT/LSB
Magnetic noise rms (B=0mT)	50 µT	≈ 25 µT	≈ 12.5 µT	≈ 4.4 µT
Approx. measurement time[1)]	194 µs	776 µs	3.1 ms	24.8 ms
Approx. update rate[1)]	5.2 kHz	1.3 kHz	322 Hz	40 Hz

[1] XYZ measurement, configuration according High update rate, 1 MHz I^2C



It can be seen that averaging effectively improves the resolution and the noise and allows very stable measurements also at small magnetic fields.

Tip: *The resolution is improved by the number of measurements included in the average and the noise (distribution width) is reduced by the square root of the number of measurements included in the average.*

Measurement examples

The graphs below show exemplary real measurement results of one sample of the 2nd generation 3D magnetic sensor with different averaging filter length applied.

Reducing the measurement range as well as implementing the averaging filter significantly reduces the magnetic noise of the sensor. Especially in applications that do not require a very high speed (e.g. human machine interfaces) a high number averaging can be implemented.

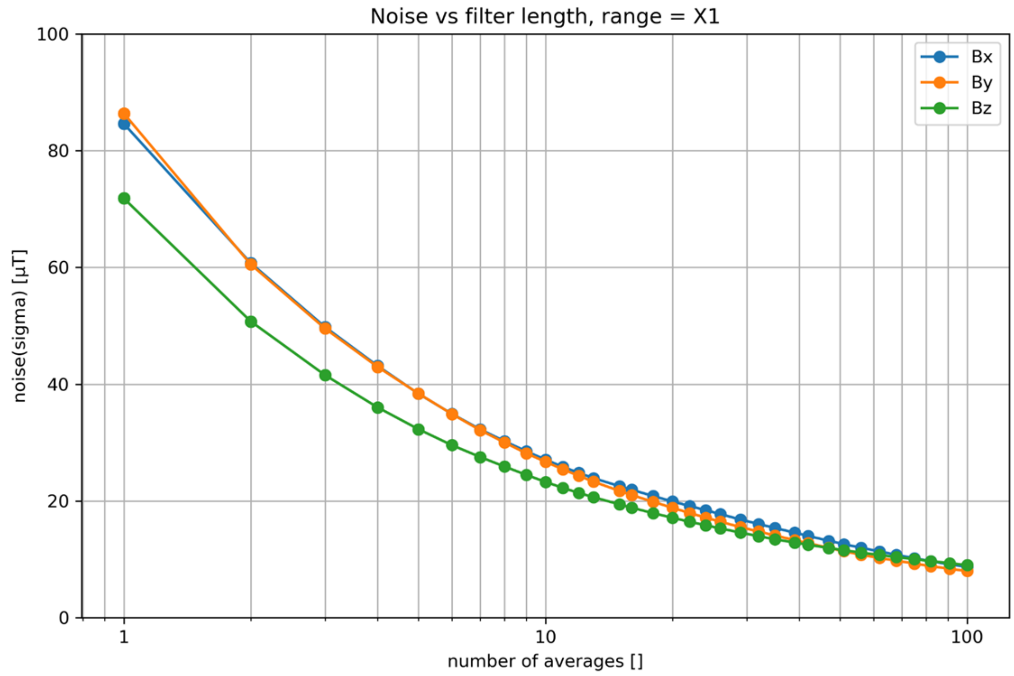


Figure 1 **Noise measurement full range, B = 0 mT**

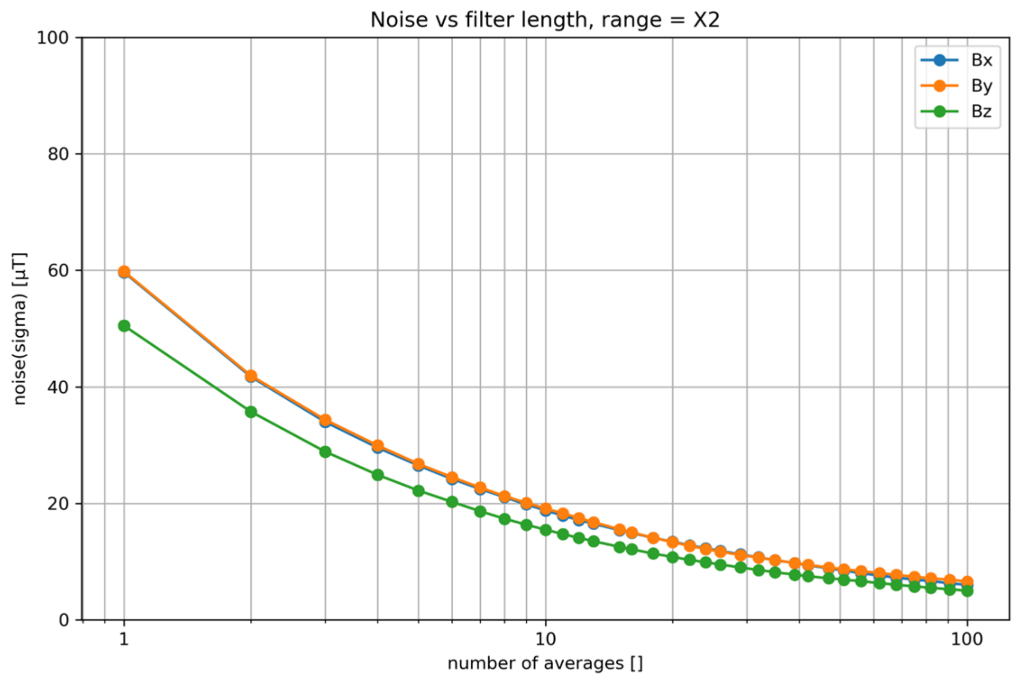


Figure 2 **Noise measurement short range, B = 0 mT**

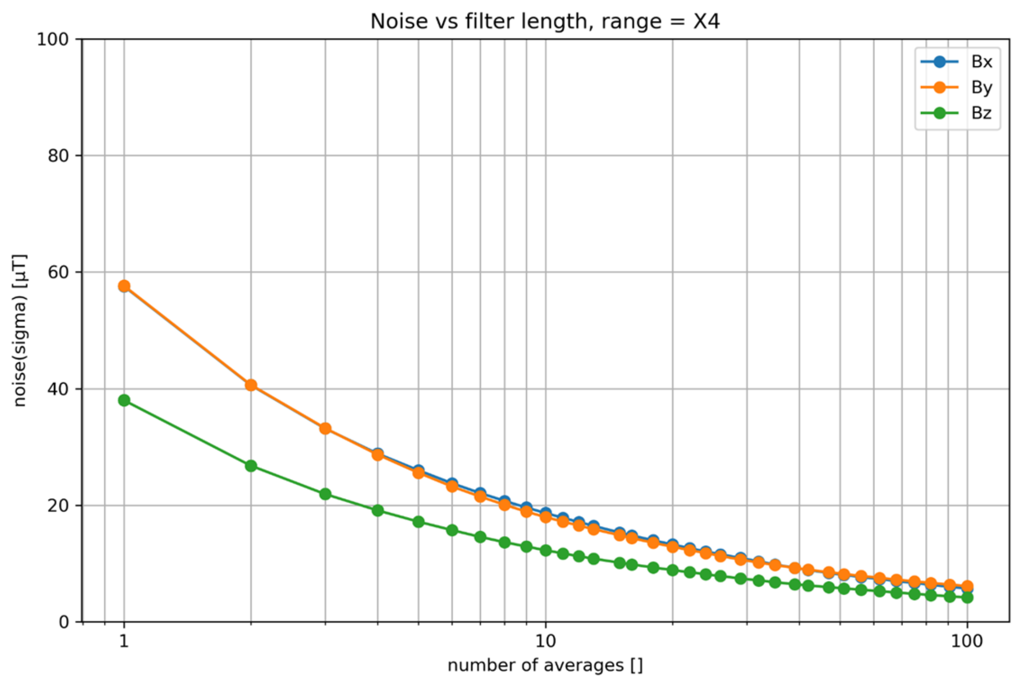
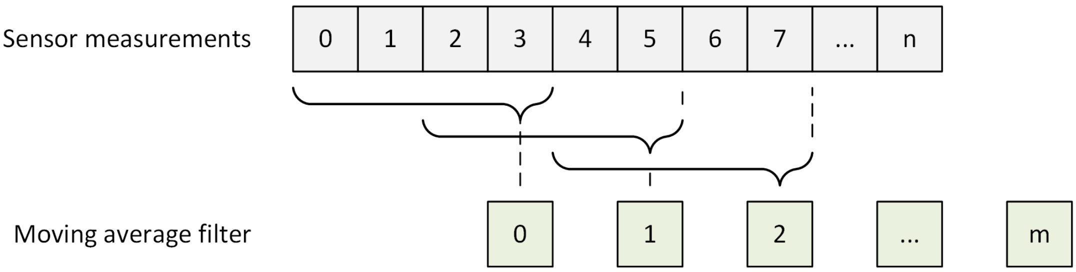


Figure 3 **Noise measurement extra short range, B = 0 mT**

Moving average filter

To still provide a high update rate a moving average filter implementation can be used. An example is shown in the figure below. Here, after two sensor measurements a new average of four readings is calculated. It provides a result that has half of the noise and four times the resolution while the update rate is only reduced by factor two. Note that the step response is slightly reduced.



1.2 Current consumption vs. update rate

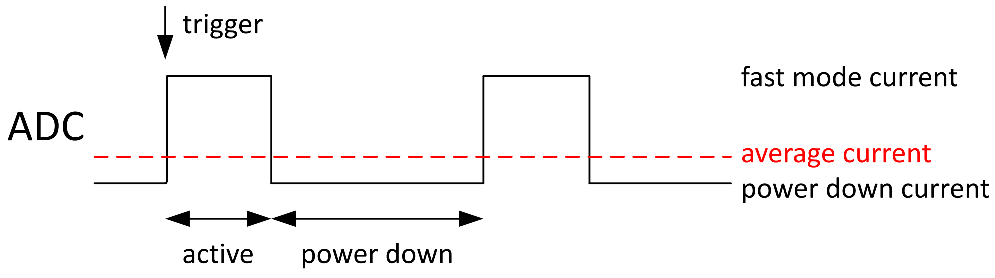
The Infineon 3D magnetic sensors enable applications that require a very low power consumption (e.g. battery powered) as well as applications that require a high output data rate. This chapter describes how to calculate the average current consumption and how to configure the sensor to fit to the target application.

Average current consumption

As described in the product datasheet the average current consumption could be calculated by comparing the active and the power down time of the sensor.

While the active time, the ADC of the sensor is operating converting the magnetic field into digital measurement results. In this time the current consumptions equals approximately the "fast mode current".

In the power down time the sensor is not performing measurements, but the interface is active. In this time the current consumption equals the extremely low "power down current".



Note: *While the sensor can achieve a very low average current consumption, the power supply needs to be designed to support the maximum start up current of the sensor, specified in the datasheet.*

Current consumption in dependence of mode and range setting

The measurement time of the sensor depends on the number of channels that are converted as well as the range setting. The table below gives an indication of the typical average current consumptions that can be expected for each mode.

Update rate vs. current consumption (T=25°C)

	Update rate (typ.)									Unit	≈ Average current consumption (typ.)									Unit
Magnetic range	160 mT			100 mT			50 mT[1]				160 mT			100 mT			50 mT[1]			
Channels	XY	XYZ	XYZT	XY	XYZ	XYZT	XY	XYZ	XYZT		XY	XYZ	XYZT	XY	XYZ	XYZT	XY	XYZ	XYZT	
Fast mode	11.6	7.8	5.8	8.5	5.6	4.5	5.5	3.7	3.2	kHz	3.4									mA
Low power mode	770[2]									Hz	225	338	450	309	463	576	476	715	827	µA
	97									Hz	28	43	57	39	58	73	60	90	104	µA
	24[2]									Hz	7.0	11	14	10	14	18	15	22	26	µA
	12[2]									Hz	3.5	5.3	7.0	4.8	7.2	9.0	7.4	11	13	µA
	6									Hz	1.8	2.6	3.5	2.4	3.6	4.5	3.7	5.6	6.5	µA
	3[2]									Hz	0.88	1.3	1.8	1.2	1.8	2.3	1.9	2.8	3.2	µA
	0.4[2]									Hz	0.12	0.18	0.24	0.17	0.25	0.31	0.25	0.38	0.44	µA
	0.05[2]									Hz	0.02	0.03	0.04	0.03	0.04	0.04	0.04	0.05	0.06	µA
Power down	0									Hz	7									nA
Master controlled mode	power down ... fast mode									kHz	power down ... fast mode									mA

1) only available with the TLI493D-W2BW and TLV493D-A2BW
2) only available with the TLE493D-P2B6, TLE493D-W2B6, TLI493D-W2BW

For example: an application requires the measurement in X, Y and Z direction within a range of 100 mT. In this case it can be extracted from the table that an update rate of **24 Hz** would lead to an average current consumption of only **14 µA**.

2 Configuration examples

The 3D magnetic sensors provide many options for configuration and triggering. The register description can be found in the user manual of the respective sensor. This chapter provides three commonly used examples for a simplified design in.

Tip: *The Infineon 3D magnetic sensor are by default configured to a 2-byte I²C read protocol. This is not supported by all microcontroller and is therefore changed to 1-byte read in all examples.*

2.1 Single measurement

In many cases the application requires a single measurement result from the Infineon 3D magnetic sensor at a specific point in time. In this case the configuration and readout example below shows an efficient way to trigger and read out a single measurement.

Configuration benefits	When not to use
• single measurement with low latency • ideal for scheduler based firmware • no risk of timing violations (data corruption) • provides high flexibility between update rate and power consumption	• if the highest possible update rate should be achieved • if the sensor should trigger new measurements automatically

Sensor configuration

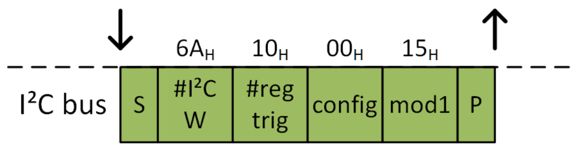
The sensor is configured to master controlled mode in which a new measurement is triggered by the microcontroller. The I²C protocol is changed to 1-byte read. Clock stretching is activated to only readout the sensor data once the conversion is finished. The mod2 register is not needed and can be kept at default values. The fuse parity (FP bit) must be zero to achieve an odd parity of the MOD1 and MOD2 register.

Config (10H)	DT	AM	TRIG		X2	TL_mag		CP
	0	0	0	0	0	0	0	1

MOD1 (11H)	FP	IICadr		PR	CA	INT	MODE	
	0	0	0	1	0	1	0	1

MOD2 (13H)	PRD			Reserved				
	0	0	0	x	x	x	x	x

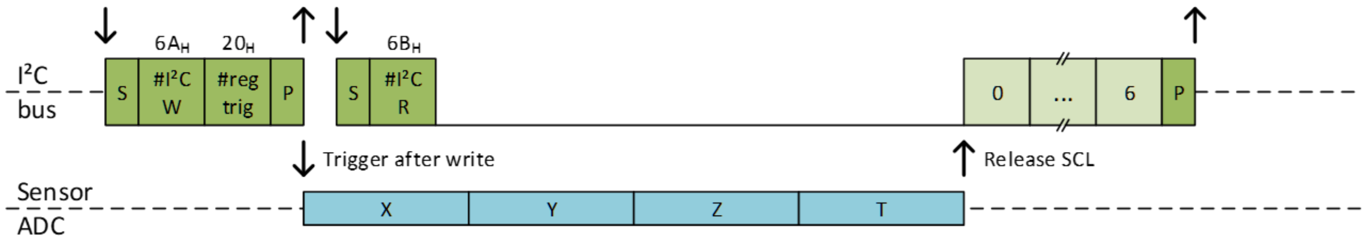
After powering up and complete the reset sequence of the sensor the following I²C write frame is used to configure the sensor to the single measurement example:



Note: *The example configuration frame fits for the default I²C address variants of the sensor (e.g. TLI493D-W2BW A0). In case a different address variant is used the configuration frame needs to be adapted accordingly.*

Readout frame

In the master controlled mode the sensor is by default in the power down state resulting in an ultra low power consumption. The interface is always active and can be used to trigger a new measurement. In this case an empty write frame with accordingly set trigger bits is used to start a new measurement. The readout of the measurement can be initiated any time later. If the measurement conversion is not yet finished, the readout is delayed by the sensor via clock stretching. Once the readout is finished the sensor will be again in power down state and the trigger plus readout frame could be repeated.



Optimization possibilities

Optimization	Description
The microcontroller does not support clock stretching	In this case the clock stretching should be deactivated (CA bit) and a different synchronization method can be used: • Activate the /INT pulse after a finished measurement (INT bit) and only start the readout afterwards • Wait after the measurement trigger for at least the max. conversion time defined in the product datasheet Note: if the bits of the MOD1 register are modified, the fuse parity (FP bit) needs be recalculated (odd parity)
Temperature measurement not required	Deactivate the temperature measurement (DT bit = 1). This reduces the measurement time and current consumption.
Temperature and Bz measurement not required	Deactivate the temperature measurement and activate the angle mode (DT bit = 1 and AM bit = 1). This reduces the measurement time and current consumption even further.
Reduce I²C communication time	Increase the I²C speed up to 1MHZ Note: the possible I²C speed is defined by the bus capacitance and pull up resistors
Removal of dedicated trigger frame	In case of regular measurements without a strict latency requirement the I²C write frame can be removed and replaced with the trigger setting "trigger after read" (TRIG = 10)
Increase the sensitivity	Activate the X2 bit to enable the short range mode. This will increase the measurement time to improve the sensitivity and noise performance. Activate the X2 bit and the X4 bit to enable the extra short range mode. This will increase the measurement time further to improve the sensitivity and noise performance (TLI493D-W2BW and TLV493D-A2BW only)

2.2 High update rate

The Single measurement configuration uses a sequential measurement and readout approach, that can already achieve a high update rate while being inherently robust to timing violations.

To further increase the update rate it possible to measure and readout the sensor data in parallel. In this case it is recommended to apply the master controlled mode with the trigger on read function. Please note that the I²C frequency must be high enough (up to 1 MHz) to finish the readout, before the ADC conversion is finished.

Configuration benefits	When not to use
• Very high update rate • Allows intensive averaging to reduce the sensor noise and increase resolution • Robust to timing violations if I²C speed is fast enough	• if the power consumption should be very low (power down times recommended) • if only a single measurement is needed • the maximum possible output rate is needed (use fast mode, but strict timing requirements need to be fulfilled)

Sensor configuration

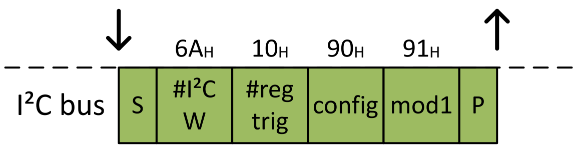
The sensor is configured to master controlled mode in which a measurement is triggered by the microcontroller. The I²C protocol is changed to 1-byte read. The sensor is configured to trigger a measurement, when a new readout is started. The /INT signal is activated to signalize a completed measurement. The mod2 register is not needed and can be kept at default values.

Config (10H)	DT	AM	TRIG		X2	TL_mag		CP
	1	0	0	1	0	0	0	0

MOD1 (11H)	FP	IICadr		PR	CA	INT	MODE	
	1	0	0	1	0	0	0	1

MOD2 (13H)	PRD			Reserved				
	0	0	0	x	x	x	x	x

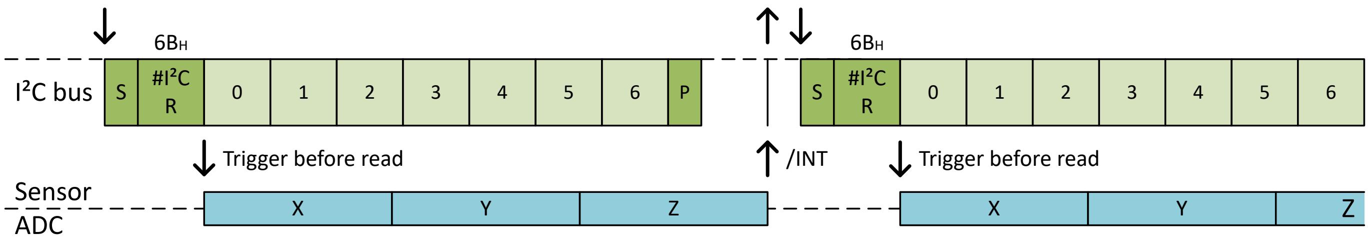
After powering up and complete the reset sequence of the sensor the following I²C write frame is used to configure the sensor to the high update rate example:



Note: The example configuration frame fits for the default I²C address variants of the sensor (e.g. TLI493D-W2BW A0). In case a different address variant is used the configuration frame needs to be adapted accordingly.

Readout frame

The microcontroller continuously reads the sensor data. Each readout triggers a new measurement which runs in parallel to the current communication. After finishing the current readout the microcontroller waits for next /INT pulse which signalizes that new data is available. After that it continues readout and therefore trigger the next measurement.



Optimization possibilities

Optimization	Description
The microcontroller does not support the /INT signal on the SCL line	In this case the /INT signal should be deactivated and clock stretching could be used for synchronizaiton: • Deactivate the /INT signal and activate clock stretching (INT bit =1, CA bit = 0) • Chang the trigger option to "trigger after read" (trigg bits = 10) • The master can repeatedly start new readouts. Each readout is delayed via clock stretching until the current conversion cycle finished and automatically triggers a new readout at the end of the read out. Note: if the bits of the MOD1 register are modified, the fuse parity (FP bit) needs be recalculated (odd parity)
Temperature measurement is required	Activate the temperature measurement (DT bit = 0). This reduces the possible update rate.
Bz measurement i not required	Activate the angle mode (DT bit = 1 and AM bit = 1). This increased the possible update rate-
Reduce I²C communication time	Increase the I²C speed up to 1MHZ. The I²C speed must be fast enough to readout the MSBs of each channel before the ADC finished the conversion of the same channel. Note: the possible I²C speed is defined by the bus capacitance and pull up resistors
Increase the sensitivity	Activate the X2 bit to enable the short range mode. This will increase the measurement time to improve the sensitivity and noise performance. Activate the X2 bit and the X4 bit to enable the extra short range mode. This will increase the measurement time further to improve the sensitivity and noise performance (TLI493D-W2BW and TLV493D-A2BW only)

2.3 Low power mode

The Infineon 3D magnetic sensor provides the possibility to design applications with an ultra low power consumption. If the microcontroller is active the previous configuration examples can be used. However, if the sensor should self trigger the measurements, the low power mode is provided. It allows the sensor to operate autonomous and only notify the microcontroller when there is new data available.

Configuration benefits	When not to use
• The sensor triggers the measurement automatically • Several different update rates can be selected • Very low power consumption • Microcontroller can power down and only read sensor data, if notified by the /INT signal	• if the measurement should be triggered by the microcontroller • if a high update rate is required

Tip: *The lower power mode is especially powerful in combination with the wake up feature (available with the TLE493D-P2B6, TLE493D-W2B6 and TLI493D-W2BW variants only). With the wake up feature the measurement result is compared to configurable thresholds and the /INT signal is only issued if these thresholds are exceeded. This allows the microcontroller to go into a deep sleep mode, while the sensor autonomously operates in the low power mode. When the magnetic field changes to the defined level, the microcontroller gets notified by the INT pulse and can wake up.*

Sensor configuration

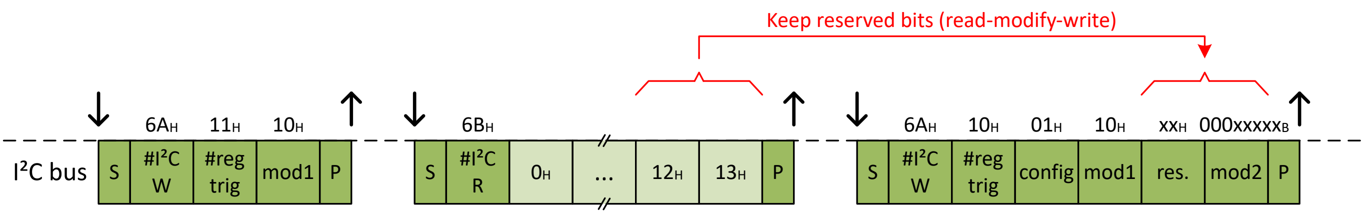
The sensor is configured to low power mode, in which the sensor automatically triggers new measurements. The I²C protocol is changed to 1-byte read. The /INT signal is activated to signalize a completed measurement. The PRD bits allow to configure different update rates as described in the user manual of the product.

Config (10H)	DT	AM	TRIG		X2	TL_mag		CP
	0	0	0	0	0	0	0	0

MOD1 (11H)	FP	IICadr		PR	CA	INT	MODE	
	0	0	0	1	0	1	0	1

MOD2 (13H)	PRD			Reserved				
	0	0	0	x	x	x	x	x

After powering up and complete the reset sequence of the sensor the following I²C write is used to configure the sensor to the low power mode example:



The configuration is done in three steps:

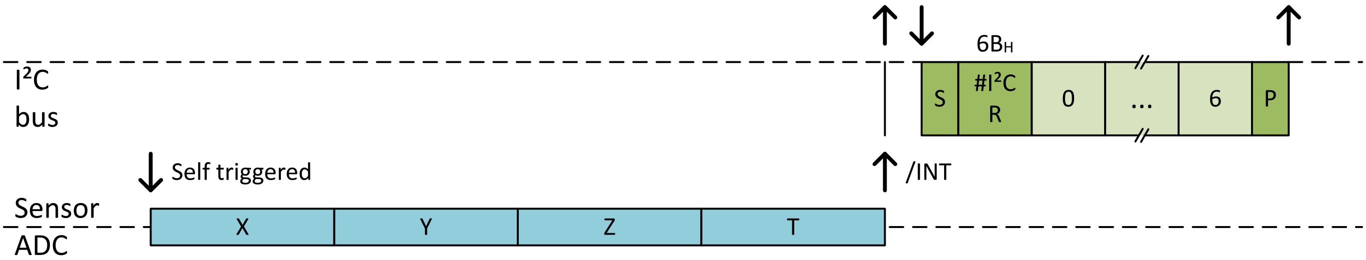
1. The sensor is configured to 1-byte read mode to provide the maximum microcontroller compatibility
2. The initial bitmap is readout
3. The sensor is configured to the described low power mode configuration. The reserved bits are kept from the readout. The fuse parity (FP-bit) is recalculated in dependence of the PRD bits. The complete

configuration (mod1 + mod2) should be done in one write frame to avoid a temporarily wrong FP bit, which would block the sensor communication

Note: The example configuration frame fits for the default I²C address variants of the sensor (e.g. TLI493D-W2BW A0). In case a different address variant is used the configuration frame needs to be adapted accordingly.

Readout frame

In the low power mode the sensor automatically triggers new measurements. Once the measurement is completed an /INT signal is issued and the measurement data can be read out.



Optimization possibilities

Optimization	Description
Use wake up mode	Activate wake up feature to issue a /INT signal only if configurable thresholds are exceeded (available for the TLE493D-P2B6, TLE493D-W2B6 and TLI493D-W2BW only)
Temperature measurement is required	Activate the temperature measurement (DT bit = 0). This increases the measurement time of the sensor and therefore the average current consumption.
Temperature and Bz measurement not required	Activate the angle mode (DT bit = 1 and AM bit = 1). This reduces the measurement time of the sensor and therefore the average current consumption.
Increase pull up resistors	To reduce the interface current consumption the pull up resistor values can be increased. Note that the maximum value depends on the bus capacitance and SCL frequency.
Increase the sensitivity	Activate the X2 bit to enable the short range mode. This will increase the measurement time to improve the sensitivity and noise performance. Activate the X2 bit and the X4 bit to enable the extra short range mode. This will increase the measurement time further to improve the sensitivity and noise performance (TLI493D-W2BW and TLV493D-A2BW only)

Revision history

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1.0	2022-05-31	• Initial release

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Do you have a question about any aspect of this document?

Email: erratum@infineon.com

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