LZE GMBH • FRAUENWEIHERSTRASSE 15 • 91058 ERLANGEN

FH3D02* DUAL 3D HALL SENSOR **DATASHEET**

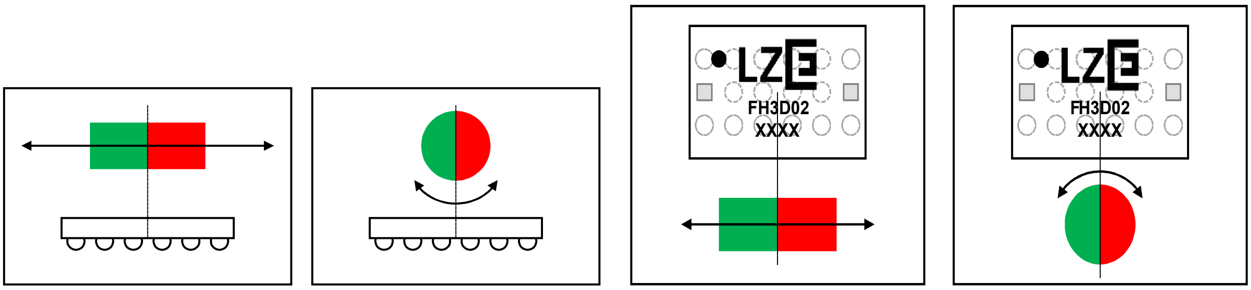
* Equivalent to FH5401c

Content

1
FH3D02 Overview

1.1
General Description

The FH3D02 is a dual 3D magnetic field sensor using two 3D Hall sensors using the HallinOne® technology, which are also called “pixels”. The versatile magnetic field sensor is suited for measuring all magnetic field components in three dimensions. It can be used as a magnetic field probe or a position sensor for linear or rotary movement of permanent magnets. A variety of applications can be evaluated instantly with the standard programming. With specific programming even more applications can be addressed.



Example applications of the FH3D02

1.2
Features

- Integrated hall sensor for 3D magnetic vector measurement with high linearity
- Usage of HallinOne® technology
    - https://www.iis.fraunhofer.de/hallinone
- Two 3D sensors allow for differential measurements to suppress external magnetic fields
- Ready-to-use adjustment for X/Y applications
- Fully corrected offsets
- CORDIC for angle calculation of two magnetic field components
- Four different measurement modes for sequential measurements of different magnetic field compone409nts.
- Integrated temperature sensor
- Measurement rate up to 1 kHz
- PWM output of measurement values
- Internal EEPROM for calibration data and configuration
- Linearization of angle with interpolated look-up- table
- No ferromagnetic components used (no hysteresis, no saturation)
- Low noise, high resolution
- High magnetic and geometric precision
- External field independence following automotive standards
- SPI interface (up 16 Mhz)
- Prepared for self-test and self-monitoring
- Wide operating temperature range from -40°C to 105°C
- Small package and footprint

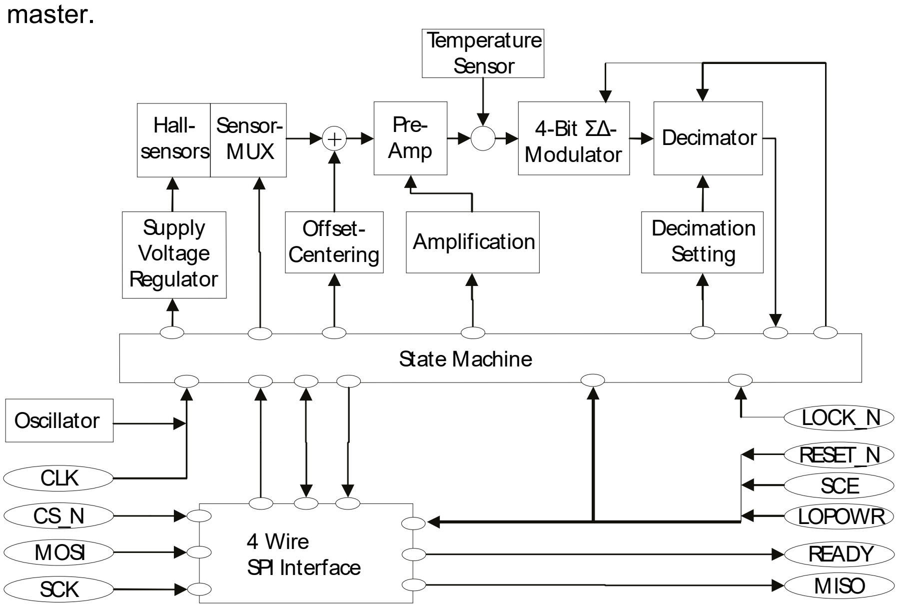
1.3 Applications

- 3D position and orientation determination (using multiple devices)
  - http://www.iis.fraunhofer.de/hallinmotion
- Magnetic field measurement in lab equipment
  - http://www.iis.fraunhofer.de/hallinsight
- Mechanical position sensing in consumer and industrial applications
- Rotary encoder (standalone, PWM output)
- Linear positioning measurement
- Contactless angle measurement
- Current sensing
- Quality control
- Fluid level measurement
- 3D speed sensing
- Utility meters
- Current sensing
- Control knobs and selector switches
- 3D proximity sensing
- 3D valve positioning

REMARK: FH3D02 Dual 3D Hall sensors are not qualified for automotive applications.
If you would like to purchase qualified automotive devices, please contact LZE GmbH.

1.4 Functional Block Diagram

The sensor chip provides two 3D Hall pixels, which are supplied by an voltage regulator and are selected by the sensor MUX. The analogue signal computation channel consists of a programmable gain amplifier and offset centering, ΣΔ-modulator and a decimation register. The state machine controls voltage regulator, sensor MUX, decimation, offset centering and performs a 4-phase measurement cycle and temperature measurement. The decimation results are transmitted via a 4-wire SPI interface to a connected SPI master.



Functional block diagram of the integrated sensor periphery

2
Characteristics

2.1
Absolute Maximum Ratings

Stresses beyond those listed here may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated under “Operating Conditions” is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Parameter	Min	Max	Unit	Note
VDD		5	V	
Input pin voltage	-0.3	VDD+0.3	V	
Input current (latchup immunity)	-100	100	mA	Standard: JEDEC 78
Electrostatic discharge		±2	kV	Standard: MIL 883 E method 3015
Storage temperature	-55	125	°C	
Body temperature		260	°C	Norm: IPC/JEDEC J-Std-020
Humidity non-condensing	5	85	%	
Moisture Sensitive Level (MSL)		1		Unlimited floor time
EEPROM write cycles		40,000	cycles	Single write access to every EEPROM-address

Absolute maximum ratings

2.2
Operating Conditions

Parameter	Min	Max	Unit	Note
Supply Voltage (VDD)	3.0	3.6	V	3.3 typical
Ambient temperature	-40	105	°C	
I/O pin output current		8	mA	
I/O pin input level low		0.3*VDD		
I/O pin input level high	0.7*VDD			
I/O pin output level low		0.4	V	at 8 mA load current
I/O pin output level high	VDD-0.5		V	at 8 mA load current

Operating conditions

2.3 Magnetic Specifications

Parameter	Symbol	Min	Typ	Max	Unit	Note
Magnetic field range	B_{max}	-70		70	mT	-40°C … 105°C
		-100		100	mT	at 25°C
Magnetic sensitivity			250		LSB/mT	
Magnetic resolution			4		µT/LSB	
Magnetic offset	B_{ofs}	-0.25		0.25	mT	at 25°C
Magnetic offset drift		-0.25		0.25	mT	-40°C … 105°C
Sensitivity error X, Y, Z	S_{err}	-20		20	%	at 25°C
Sensitivity drift X, Y, Z	S_{drift}	-5		5	%	-40°C … 105°C
Sensitivity matching X/Y		-0.5		0.5	%	-40°C … 105°C
Sensitivity matching X/Z		-15		15	%	at 25°C
Sensitivity matching drift X/Z, Y/Z		-10		10	%	-40°C … 105°C
Cross-sensitivity X/Y	$S_{crossXY}$	-1		1	%	-40°C … 105°C
Cross-sensitivity X/Z, Y/Z	S_{crossZ}	-10		10	%	-40°C … 105°C

Magnetic specifications

2.4 Current Consumption

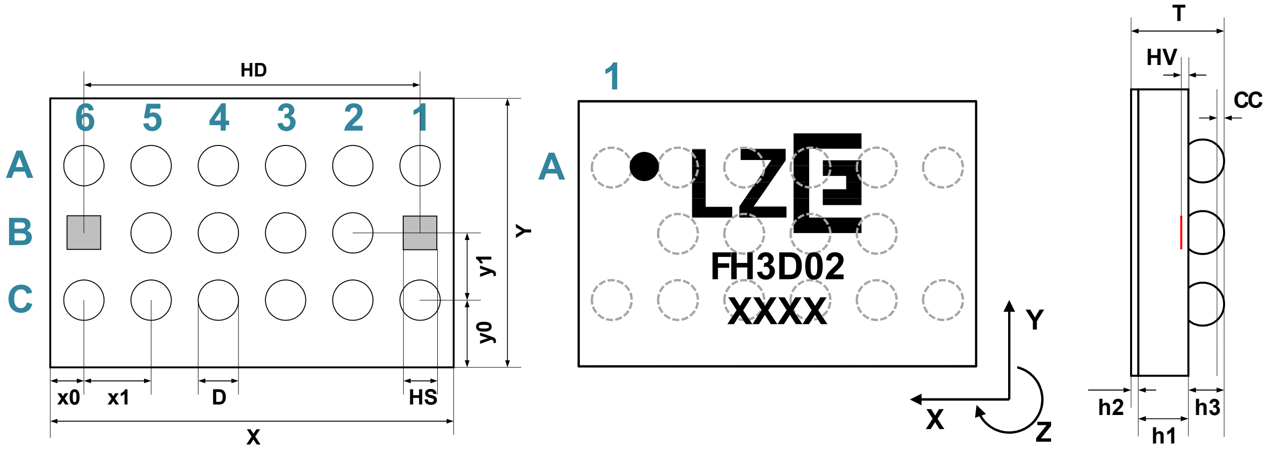
Parameter	Symbol	Min	Typ	Max	Unit	Note
IDD during measurements	IDD_{meas}		10	15.5	mA	
IDD during standby, awaiting a measurement start	$IDD_{standby}$		1	2.25	mA	
IDD during reset	IDD_{reset}		0.6		mA	
IDD in low power mode (2)	$IDD_{lowpower}$			10	µA	

(1) For information on the low power mode refer to 7.1
(2) Output currents on I/O pins are not included
(3) Values are DC mean currents. IDD_x can be temporarily higher.

Current consumption in various operation modes (3) (4)

3
Package and Circuit Connection

3.1
Footprint and Dimensions



Bottom view Top view Side view

Parameter	Symbol	Min	Typ	Max	Unit	Note
Hall Sensor Size	HS		250		µm	
Hall Sensor Distance	HD		2500		µm	
Chip length	X	3015	3035	3055	µm	
Chip width	Y	2015	2035	2055	µm	
Chip thickness	T	570	600	630	µm	
X-Distance chip border to bumps	x0		285		µm	
Bump pitch X-direction	x1		500		µm	
Y-Distance chip border to bumps	y0		535		µm	
Bump pitch Y-direction	y1		500		µm	
Wafer thickness	h1	325	335	355	µm	
Backside Laminate	h2		25		µm	
Bump height	h3		240		µm	
Solder Ball Coplanarity	CC		40		µm	
Hall Sensor vertical position	HV		30		µm	
Bump diameter	D	315	325	335	µm	

Package dimensions

3.2 Pins

Pin	Symbol	Type	Description
A1	MISO	DO_T	Master in / Slave out (SPI interface data output)
A2	CLK	DIO	Clock input / output. Must be connected to VSS if internal clock is used
A3 B3	VSS1	S	Ground (0V) Note: both VSS1 and VSS2 must be connected
A4	SCE	DI_ST	Test pin, must be connected to VSS in normal operation
A5	LOPOW R	DI_ST	Shutdown & Reset input. Connect to VSS in normal operation
A6	CS_N	DI_ST	Chip select (active low)
B2	MOSI	DI_ST	Master out / Slave in (SPI interface data input)
B4 C5	VSS2	S	Ground (0V) Note: both VSS1 and VSS2 must be connected
B5	SCK	DI_ST	SPI clock input
C1	READY	DO_T	Measurement ready signal
C2	RESET_ N	DI_PU	Reset input (active low)
C3	LOCK_N	DI_ST	Test pin, must be connected to VSS in normal operation
C4	VDD	S	Positive supply voltage (3.3 V)
C6	PWM	DO	Linearized angle output in PWM mode.

Pin/Bump list

DIO digital input & output
DI_ST digital Schmitt-Trigger input
DI_PU digital input with pull-up
DO digital output
DO_T digital output /tri-state
S supply pin

Notes:
- Pins LOCK_N and SCE are test pins for factory testing. They must be connected to VSS in normal operation to prevent accidental enabling of a test mode.
- Output READY is set high when a measurement cycle is completed and the results in the output registers are valid. It is cleared by reading data from address 0122h.
- CLK allows to monitor the internal clock or to apply an external clock. Refer to chapter 7.6 for further information.
- Output MISO is only activated when CS_N is low. It is in high impedance state otherwise, this allows for parallel operation of multiple ICs.
- CS_N is active low and activates data transmission. If only a single device is used, CS_N may remain low for several commands, for example while reading the output registers.

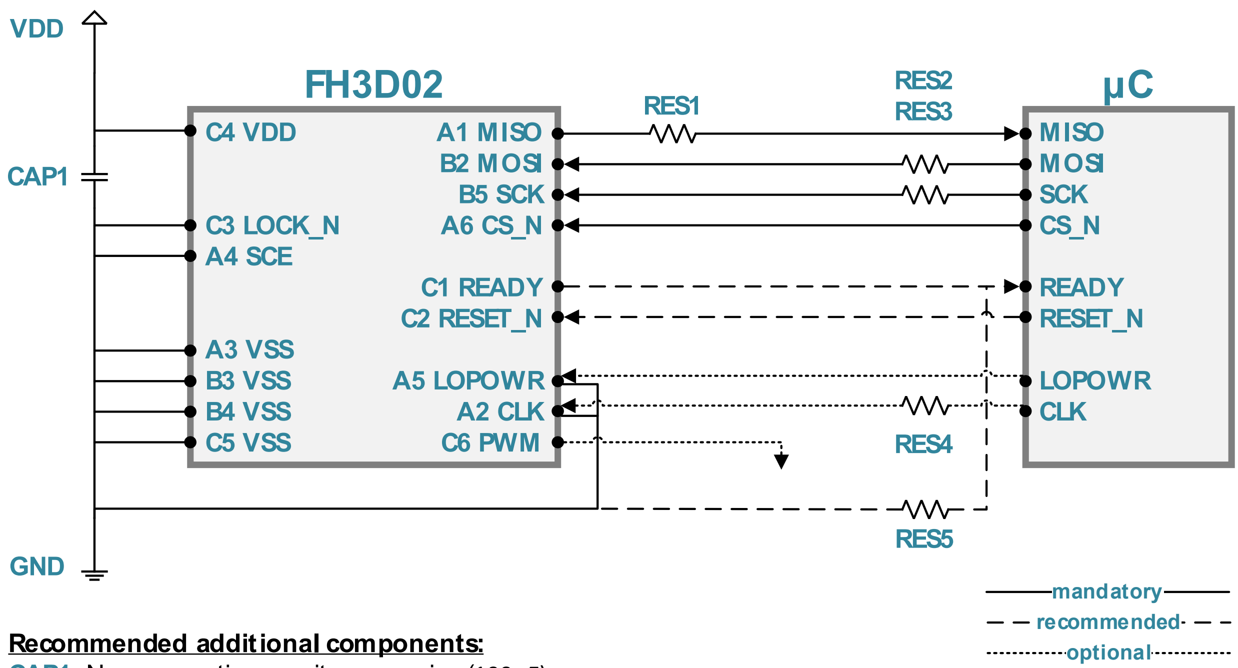
3.3 Electrical Connection

The sensor chip must be connected to a supply of 3.3V via its VDD and VSS pins. All unused pins should be connected to VSS to guarantee proper function. A decoupling capacitor between VDD and VSS close to the sensor chip is strongly recommended as well as the usage of non-magnetic components nearby to prevent magnetic interference.

For communication of a single sensor with a microcontroller, all four SPI signals CS_N, SCK, MOSI and MISO have to be connected. Fast digital signals (like clock and data signals) should be terminated with series resistors near the transmitting device to prevent disturbing signal reflections.

It is recommended to use the two additional signals READY and RESET_N to recognize finished measurements and execute a proper reset cycle of the sensor chip (reset timing see 5.1.2). If multiple sensors are connected to the same lines, a pull-down resistor for the READY signal should be used.

For optional usage of low power mode or an external clock generated by the controller (see 7.1 and 7.6), LOPOWR and CLK have to be wired properly, whereas the CLK signal also should be terminated with a series resistor at the µC. If PMW output is used, the corresponding signal has to be wired to the receiver.



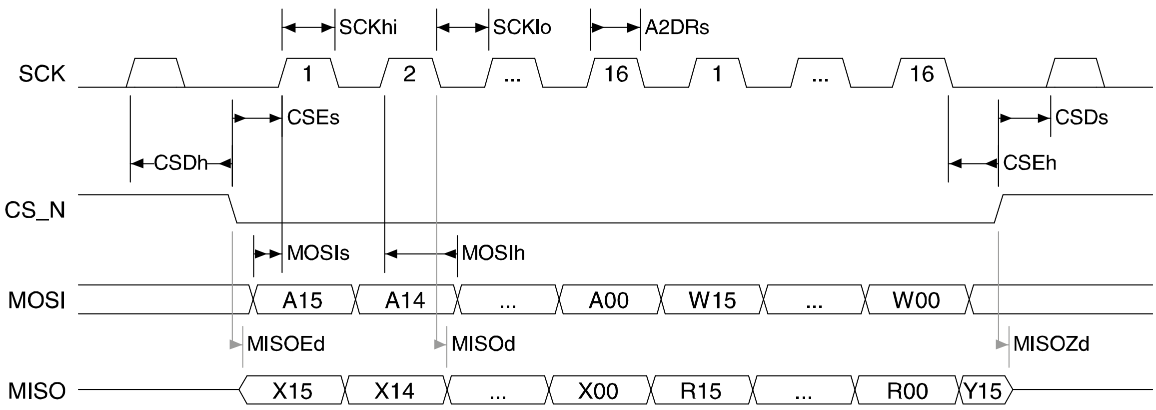
Recommended additional components:
CAP1: Non-magnetic capacitor near pins (100µF)
RES1: Non-magnetic series resistor matching line impedance at sensor (50Ω - 100Ω)
RES2 – RES4: Series resistor matching line impedance at µC (50Ω - 100Ω)
RES5: Pull-down resistor when using multiple sensors on same SPI bus (12kΩ)

Please note:

It is strongly recommended to use a PCB with wide bandwidth, low impedance supply layers and impedance controlled digital signal lines with matching series resistors to the hardware setup.
A stable supply and clean signals are mandatory for low sensor noise and faultless communication at high SPI frequency.

4 SPI Communication

4.1 Protocol and Timing



The transferred data bits via MOSI (Master Out – Slave In) and MISO (Master In – Slave Out) are defined as follows:

A15….A00 = 16-bit register address
W15….W00 = 16-bit write data (in write mode)
X15….X00, Y15 = 16-bit read data or previous command (depending on mode)
R15…R0 = 16-bit read data in read mode or previous data in write mode

Parameter	Symbol	Min	Typ	Max	Unit
SCK frequency		0		16	MHz
SCK pulse width HI	SCKhi	15			ns
SCK pulse width LO	SCKlo	15			ns
SCK setup time before data read	A2DRs	15			ns
CS_N enable setup time before SCK	CSEs	10			ns
CS_N enable hold time after SCK	CSEh	10			ns
CS_N disable setup time before SCK	CSDs	10			ns
CS_N disable hold time after SCK	CSDh	10			ns
MOSI setup time before SCK	MOSIs	10			ns
MOSI hold time after SCK	MOSIh	10			ns
MISO delay after SCK	MISOd			10	ns
MISO enable delay after CS_N	MISOEd			10	ns
MISO high Z delay after CS_N	MISOZd			10	ns
Output edge rise time	Or			3	ns
Output edge fall time	Of			3	ns

SPI timing parameters

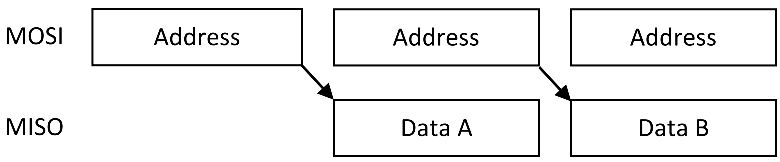
4.2 Read/Write Access

Data is transferred to the device via the MOSI pin with the rising edge of SCK. It should be updated by the master at the falling edge of SCK.
Data is updated at the MISO pin with the falling edge of SCK and can safely be read from the device with the rising edge of SCK.

The data format consists of data streams with 32 bit in length. The first 16 bits define a 16-bit address and the subsequent 16 bits contain read or write data.
The MSB of the address word A<15> defines the direction of data transfer:
A<15> = 0 READ; data transfer from device to an external controller; read measurement data
A<15> = 1 WRITE; data transfer from a controller to the device; write configuration data

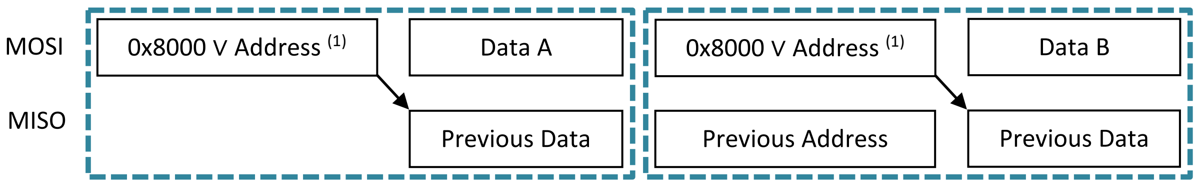
4.2.1 Read

For reading a register, the 16-bit Read address (with A<15>=0) is sent to the MOSI pin. After 16 SCK cycles, data of the specified address is read from the MISO pin. At the same time, the new address may be clocked into the MOSI pin.



4.2.2 Write

For writing to a register, the 16-bit Write address (with A<15>=1) is sent to the MOSI pin. After 16 SCK cycles, data following the address bits is written to the specified address. At the same time, the present data of that register may be read from the MISO pin. Following the 16-bit of data (Data A in figure) a new address may be written to the device. While the new address is written, the address from the previous command is available at the MISO output.

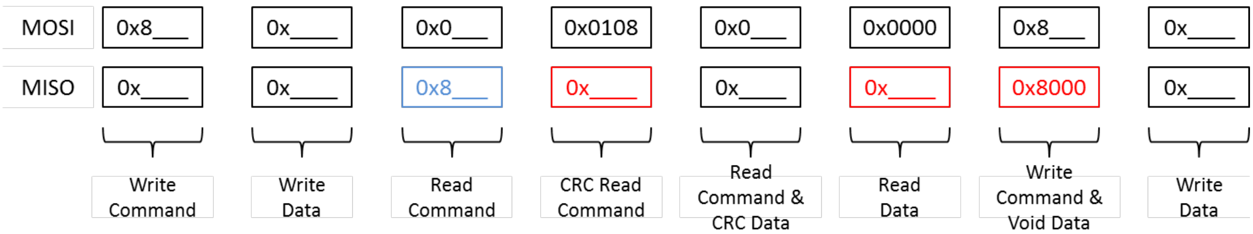


(1) ∨ = bitwise logical OR

4.2.3 CRC Calculation

The CRC value in register 0x0108 is calculated as bitwise XOR operation of the SPI read data and the previous CRC value. It is recommended to implement an identical CRC calculation in the SPI master and compare the CRC value from register 0x0108 to the calculated value.
Please note that the SPI command 0x0000 is regarded as read command, too. Hence its constant result of 0x8000 is also used for the CRC calculation. The read value from 0x0108 itself is not used for the CRC calculation.

The following drawing depicts an SPI cycle where all values used for CRC calculations are marked red.



5 List of Registers

Following table shows all available registers for communication with the sensor via SIP. For detailed description of the register content and respective bit assignment go to the specified chapters.

Register	Read / Write	Description	Refer to chapter
0x0004	Read & Write	Clock configuration register	7.6
0x000B	Read & Write	Measurement control register	5.1.1
0x000D	Read	PWM configuration register	7.4
0x000E	Read & Write	Measurement start register	5.1.2
0x0030	Write	EEPROM write/read address register	7.2
0x0031	Write & Read	EEPROM write/read data register	7.2
0x0107	Write	Magnetic measurement result status	5.1.3
0x0108	Read	CRC calculation result	4.2.3
0x0110	Read	Temperature measurement result	5.1.4
0x0111	Read	Magnetic measurement result Bi0	5.1.5
0x0112	Read	Magnetic measurement result Bi1	5.1.6
0x0113	Read	Magnetic measurement result Bj0	5.1.7
0x0114	Read	Magnetic measurement result Bj1	5.1.8
0x0120	Read	Measurement result magnitude	5.1.9
0x0121	Read	Measurement result angle	5.1.10
0x0122	Read	Measurement result linearized angle / Special function: Magnetic measurement result Bz1	5.1.11
0x0124	Read	Special function: Magnetic measurement result Bz0	5.1.12

Register Overview

5.1 Measurement Register Contents

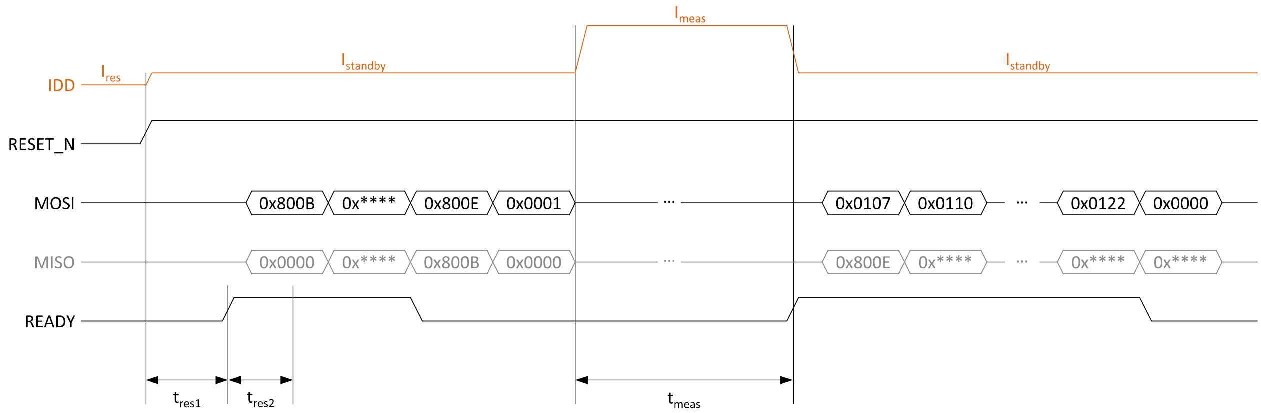
5.1.1 0x000B (read/write) – Measurement Control

Bit	Symbol	Default	Description
D15 (MSB) – D12	r	0	(Reserved. Always set to default state)
D11	*MgnRngExt*	0	"Magnet Range Extension" Only useful if Bit Gradient = 1. Enables the algorithm for an extended position range. Refer to chapter 7.7 for further information. 0 = Magnet Range Extension disabled 1 = Magnet Range Extension enabled
D10	*CoordSel*	0	"Coordinate System Selection" Only useful if Bit MgnDir = 1. The linearized angle can be inverted if the magnet is rotated. 0 = Linearized Angle (0x0122) is not changed 1 = The sign of the Linearized Angle (Register 0x0122) is inverted
D9	*Special<1>*	0	"Special Function" Must be set to 0b11 if TableSelect=0b01. Refer to chapter 6.2 for further explanation.
D8	*Special<0>*	0	
D7	*TableSelect<1 >*	0	"Table Select" These bits allow the selection of 4 different operating modes. Refer to chapters 6.1 to 6.6.
D6	*TableSelect<0 >*	0	
D5	*MgnDir*	0	"Magnet Direction" This Bit allows to switch the magnet direction. 0 = Magnetic north pole must point to the directions indicated in chapters 6.3 to 6.6. 1 = North pole must point to the opposite direction.
D4	*Gradient*	0	"Gradient Mode" 0 = absolute measurement of Hall sensors, 1 = differential measurement of Hall sensors.
D3 – D2	*r*	0	(Reserved. Always set to default state)
D1	*Rdy2hZ*	1	"READY to high Z State" 0 = Pin READY is always active. It must NOT be connected in parallel with other devices. 1 = Several READY pins may be connected in parallel. Important: READY is only set if the sensor chip is selected with CS_N (also see chapter 7.5).
D0 (LSB)	*PWMflags*	0	"State flags in PWM mode" 0 = Normal operation 1 = Enables output of error flags on pins READY (*MagLost*) and MISO (*CalcErr*), see chapter 7.4.

0x000B Bits

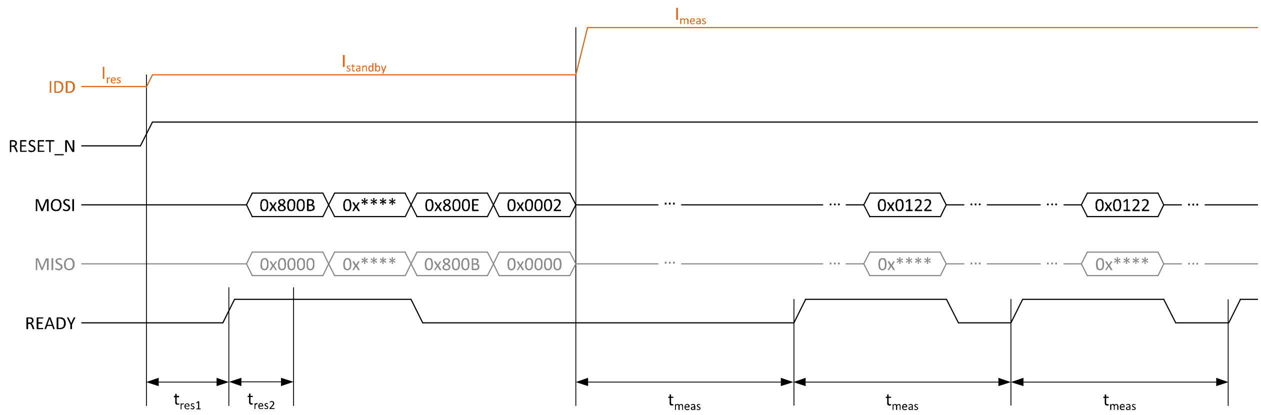
5.1.2 0x000E (read/write) – Measurement Start

Single shot measurements are started by SPI command 0x800E-0x0001. The last rising SCK edge triggers the measurement. The measurement completion is indicated by a READY rise. The same information is available as bit *Ready* of register 0x0107 (see section 5.1.3). It can be polled if connection of pin READY shall be omitted. READY is reset to logical 0 if register 0x0122 is read. A new measurement can be started now.



Timing diagram for single shot measurement cycle. Use CS_N and SCK according to SPI protocol (section 4.1). Values shown as 0x**** depend on settings and results. For IDD values refer to chapter 2.4.

Continuous measurements are started by SPI command 0x800E-0x0002. The last rising SCK edge starts the measurement loop. Every measurement completion is indicated by a READY rise. A new measurement is started immediately. The measurement loop is stopped by SPI command 0x800E-0x0000.



Timing diagram for continuous measurement cycle. Use CS_N and SCK according to SPI protocol (section 4.1). Values shown as 0x**** depend on settings and results. For IDD values refer to chapter 2.4.

Parameter	Symbol	Min	Typ	Max	Unit	Note
Measurement time	t_{meas}	1		1.07	ms	TableSelect: 0b00, 0b10, 0b11
	t_{meas}	2		2.13	ms	TableSelect: 0b01
Startup time	t_{res1}	25	80	200	µs	Do not apply SCK rise before t_{res1}!

Measurement timing values

Settling time	t_{res2}	200	µs	Do not start a measurement before $t_{res1}+t_{res2}$!

Bit	Symbol	Default	Description
D15 (MSB) – D2	r	0	(Reserved. Always set to default state)
D1	*ContMeas*	0	"Continuous Measurement Enable" The measurement cycle is continuously repeated. After every measurement cycle the READY pin or flag (register 0x0107) is set. It must be reset during the next cycle to indicate the next cycle completion.
D0 (LSB)	*SnglLoop*	0	"Single Loop" One single measurement is performed after the last SCK rising edge of the write access. The READY pin or flag (register 0x0107) indicate the completion of the measurement.

0x000E Bits

5.1.3
0x0107 (read only) – Status Register

Bit	Symbol	Description
D15 (MSB)	*Ready*	Indicates completion of a new measurement; same function as the READY output pin. 0 = calculation is in progress or chip not ready 1 = measurement completed
D14	*MagLost*	"Magnet Lost" 0 = Magnetic field magnitude above a minimum value 1 = Magnetic field values are too low for position measurement; the threshold level can be set by an EEPROM setting (1)
D13	*CorrOvfl*	Ambiguous angle correction overflow
D12	*NormOvfl*	Normalizing scale overflow
D11	*SensOvfl*	Overflow during sensitivity correction over temperature
D10	*RngWarn*	ADC overflow
D9	*HistWarn*	Histogram failure during ADC operation
D8	*CalcError*	"Calculation Error" Or wired combination of RngWarn, HistWarn, NormOvfl, SensOvfl. The corresponding measurement values must not be used.
D7 – D2	*r*	(Reserved. Always 0)
D1	*MgnDir*	"Magnet Direction" Chosen orientation of Magnet
D0 (LSB)	*EEDone*	"EEPROM Write Done" 0 = EEPROM access in progress 1 = EEPROM access completed

0x0107 Bits

(1) For more information about setting the Magnet Lost threshold refer to chapter 7.9

5.1.4 0x0110 (read only) – Temperature Sensor

During every measurement cycle the internal temperature is measured sequentially with the magnetic values. The temperature value is used for internal compensation of magnetic sensor offsets and sensitivity drifts and is also available in output register 0x0110.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*T*	"Temperature" Output value of the internal temperature sensor. 16 bit signed integer value in two's complement representation. Conversion (typical): T [°C] = T [LSB] / 200 [LSB/°C] + 25°C

0x0110 Bits

5.1.5 0x0111 (read only) – Bi_0 Magnetic Field

Depending on the table selection (Bits *TableSelect* in register 0x000B) the Bi_0 output register can hold different magnetic field components. For an overview of the Bi_0 contents refer to chapter 5.2.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bi0*	"Bi_0" Output value of magnetic field sensor. 16 bit signed integer value in two's complement representation. For explanation of the actual magnetic direction refer to chapter 5.2. Conversion (typical): Bi_0 [µT] = Bi_0 [LSB] * 4 [µT/LSB]

0x0111 Bits

5.1.6 0x0112 (read only) – Bi_1 Magnetic Field

Depending on the table selection (Bits *TableSelect* in register 0x000B) the Bi_1 output register can hold different magnetic field components. For an overview of the Bi_1 contents refer to chapter 5.2.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bi1*	"Bi_1" Output value of magnetic field sensor. 16 bit signed integer value in two's complement representation. For explanation of the real magnetic direction refer to chapter 5.2. Conversion (typical): Bi_1 [µT] = Bi_1 [LSB] * 4 [µT/LSB]

0x0112 Bits

5.1.7 0x0113 (read only) – Bj_0 Magnetic Field

Depending on the table selection (Bits *TableSelect* in register 0x000B) the Bj_0 output register can hold different magnetic field components. For an overview of the Bj_0 contents refer to chapter 5.2.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bj0*	"Bj_0" Output value of magnetic field sensor. 16 bit signed integer value in two's complement representation. For explanation of the real magnetic direction refer to chapter 5.2. Conversion (typical): Bj_0 [μT] = Bj_0 [LSB] * 4 [μT/LSB]

0x0113 Bits

5.1.8 0x0114 (read only) – Bj_1 Magnetic Field

Depending on the table selection (Bits *TableSelect* in register 0x000B) the Bj_1 output register can hold different magnetic field components. For an overview of the Bj_1 contents refer to chapter 5.2.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bj1*	"Bj_1" Output value of magnetic field sensor. 16 bit signed integer value in two's complement representation. For explanation of the real magnetic direction refer to chapter 5.2. Conversion (typical): Bj_1 [μT] = Bj_1 [LSB] * 4 [μT/LSB]

0x0114 Bits

5.1.9 0x0120 (read only) – Magnetic Field Magnitude

A CORDIC algorithm calculates magnitude and angle of the Bi and Bj field components. The magnitude is available in register 0x0120. Please note that the representation is unsigned integer and a certain factor has to be taken into account for the conversion.
In gradient mode the Bi and Bj differences are used as CORDIC input (see conversion formulas in the table).

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bmag*	"B_{mag}: Magnitude of $\vec{B}$" CORDIC magnitude of Bi and Bj. 16 bit unsigned integer value. Calculation: (absolute mode): $B_{mag} = 0.8234 \cdot \sqrt{{Bi_0}^2 + {Bj_0}^2}$ (gradient mode): $B_{mag} = 0.8234 \cdot \sqrt{(Bi_1 - Bi_0)^2 + (Bj_1 - Bj_0)^2}$

0x0120 Bits

5.1.10 0x0121 (read only) – Magnetic Field Angle

The CORDIC angle of the Bi and Bj field components is available in register 0x0121. In gradient mode the Bi and Bj differences are used as CORDIC input (see conversion formulas in the table).

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*angle*	"$angle_B$: CORDIC angle" CORDIC angle of Bi and Bj. 16 bit signed integer value in two's complement representation. Conversion: (normal mode): $angle_B[°] = \frac{180°}{32768\ LSB} \cdot angle_B[LSB]$ (range extension): $angle_B[°] = \frac{288°}{32768\ LSB} \cdot angle_B[LSB]$ Calculation: (absolute mode): $angle_B = atan2(Bi_0, Bj_0)$ (gradient mode): $angle_B = atan2\left((Bi_1 - Bi_0), (Bj_1 - Bj_0)\right)$

0x0121 Bits

5.1.11 0x0122 (read only) – Linearized Angle / Bz_1 Field (Special Function Mode)

The magnetic angle can be linearized using a user defined look-up-table in the EEPROM. For further information and the definition of the LinTab()-function please refer to chapter 7.8.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*LinAngle*	"$angle_{lin}$: Linearized CORDIC angle" 16 bit signed integer value in two's complement representation. Calculation: $angle_{lin} = LinTab(angle_B)$

0x0122 Bits (normal operation)

By enabling the special function (bits *Special*=0b11 and *TableSelect*=0b01 in 0x000B) it is possible to read all magnetic field components during the same measurement cycle. Then Bz_1 is available in 0x0122 whereas *LinAngle* is not available any more.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bz1*	"Bz_1" Output value of magnetic field sensor. 16 bit signed integer value in two's complement representation. Conversion (typical): Bz_1 [µT] = Bz_1 [LSB] * 4 [µT/LSB]

0x0122 Bits (special function)

5.1.12 0x0124 (read only) – Bz_0 Magnetic Field (Special Function Mode)

By enabling the special function (bits *Special*=0b11 and *TableSelect*=0b01 in 0x000B) it is possible to read all magnetic field components during the same measurement cycle. Then Bz_0 is available in register 0x0124.

Bit	Symbol	Description
D15 (MSB) – D0 (LSB)	*Bz0*	"Bz_0" Output value of magnetic field sensor. 16 bit signed integer value in two's complement representation. Conversion (typical): Bz_0 [µT] = Bz_0 [LSB] * 4 [µT/LSB]

0x0124 Bits (special function)

5.2
Result Register Overview

With different settings in the sequencer register 0x000B the FH3D02 can be used for various applications. Depending on the *TableSelect* settings in register 0x000B the results in registers 0x0111 – 0x0114, 0x0120 – 0x124 can hold different magnetic values. The following table gives an overview about the register content in different configurations.

Register	TableSelect 0b00 (1 kHz)	TableSelect 0b01 (0.5 kHz)	TableSelect 0b10 (1 kHz)	TableSelect 0b11 (1 kHz)
0x0110 (Temp)	Temperature	Temperature	Temperature	Temperature
0x0111 (Bi0)	Pixel 0 Bz_0	Pixel 1 By_1	Pixel 0 Bz_0	Pixel 0 By_0
0x0112 (Bi1)	Pixel 0 Bz_0	Pixel 0 By_0	Pixel 1 Bz_1	Pixel 1 By_1
0x0113 (Bj0)	Pixel 0 Bx_0	Pixel 1 Bx_1	Pixel 0 Bx_0	Pixel 0 Bx_0
0x0114 (Bj1)	Pixel 0 By_0	Pixel 0 Bx_0	Pixel 1 Bx_1	Pixel 1 Bx_1
0x0120 (Mag)	CORDIC Magnitude (1)	CORDIC Magnitude (1)	CORDIC Magnitude (1)	CORDIC Magnitude (1)
0x0121 (Ang)	CORDIC Angle (2)	CORDIC Angle (2)	CORDIC Angle (2)	CORDIC Angle (2)
0x0122	Linearized CORDIC Angle (3)	Pixel 1 Bz_1 (4)	Linearized CORDIC Angle (3)	Linearized CORDIC Angle (3)
0x0124	-	Pixel 0 Bz_0 (4)	-	-

Output Register Overview

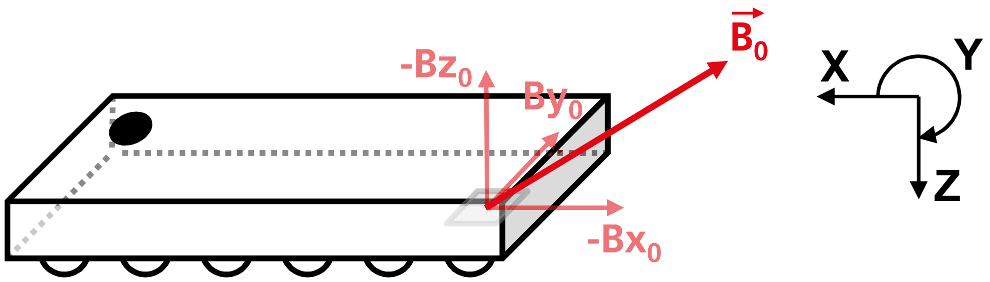
(1) For CORDIC magnitude calculation and input components refer to chapter 5.1.9
(2) For CORDIC angle calculation and input components refer to chapter 5.1.10
(3) For angle linearization refer to chapters 5.1.11 and 7.8.
(4) For magnetic field components in special function mode refer to chapters 5.1.11 and 5.1.12.

6
Measurement Modes

6.1
Single Magnetic Probe

The three magnetic field components Bx_0, By_0 and Bz_0 from pixel 0 can be measured in one measurement cycle by using the single probe mode.

6.1.1
Application Example



Magnetic vector components of Pixel 0 in probe mode.
The actual sensors are placed at the bottom side of the IC.

6.1.2
Settings

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Setting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*Rdy2hZ*	0
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Register 0x000B bit settings (1)

6.1.3
Output Registers

0x0111	0x0112	0x0113	0x0114	0x0120	0x0121	0x0122	
Pixel 0 Bz_0	Pixel 0 Bz_0	Pixel 0 Bx_0	Pixel 0 By_0	Magnitude (3)	Angle (3)	Linearized angle (2)	Output Registers

(3) CORDIC magnitude: $0.8234 \cdot \sqrt{Bx_0{}^2 + Bz_0{}^2}$ CORDIC angle: $atan2(Bz_0, Bx_0)$

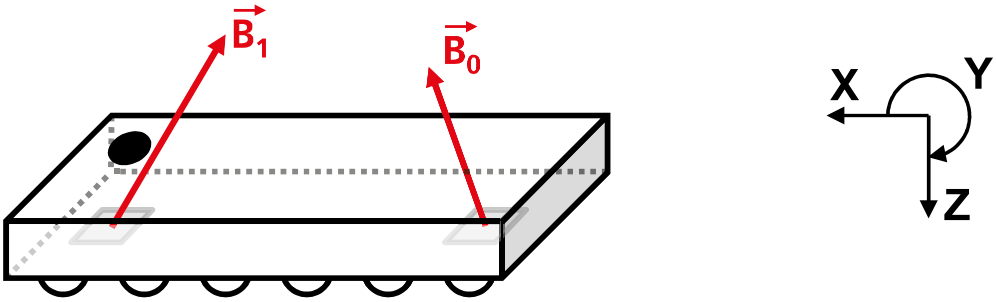
6.1.4
References

(1) see chapter 7.5 for explanation of bit *Rdy2hZ*
(2) see chapter 7.8 for explanation of angle linearization

6.2
Dual Magnetic Probe

All possible magnetic field components can be measured in one measurement cycle by using the dual probe mode.

6.2.1
Application Example



Magnetic vectors in dual probe mode. For exact pixel positions refer to chapter 3.1.

6.2.2
Settings

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Setting	0	0	0	0	0	0	1	1	0	1	0	0	0	0	*Rdy2hZ*	0
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Register 0x000B bit settings (1)

6.2.3
Output Registers

0x0111	0x0112	0x0113	0x0114	0x0122	0x0124	
Pixel 1 By_1	Pixel 0 By_0	Pixel 1 Bx_1	Pixel 0 Bx_0	Pixel 1 Bz_1	Pixel 0 Bz_0	Output Registers

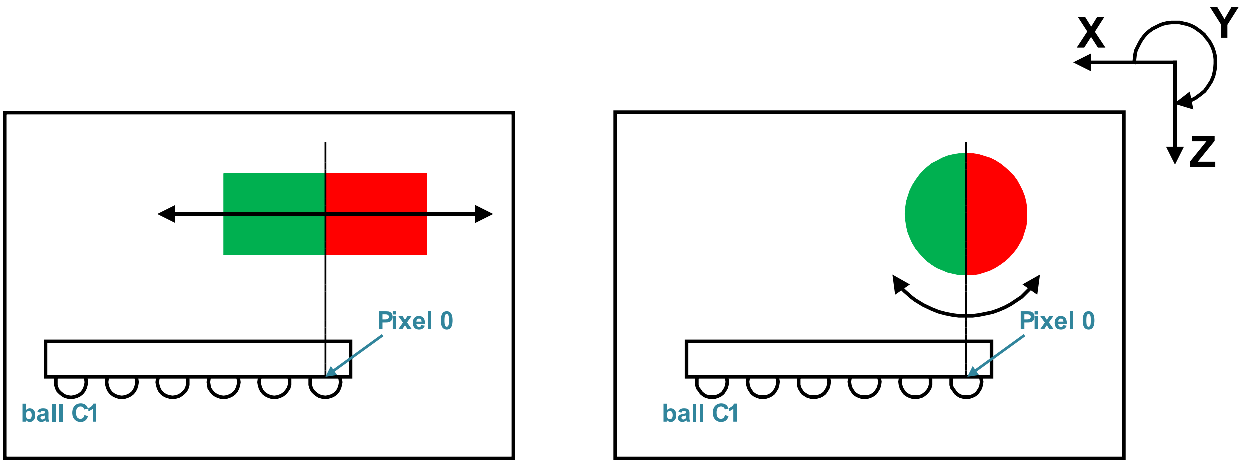
6.2.4
References

(1) see chapter 7.5 for explanation of bit *Rdy2hZ*

6.3
Linear Position or Off-Axis Angle Sensor (Absolute Field Values, Magnet On-Top)

With this setting a linear position measurement or an off-axis angle measurement is feasible. A linearization table can be used for both applications to allow for a linear output curve (see chapter 7.8).

6.3.1 Application Example



Magnet configuration examples in zero position

6.3.2 Settings

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Setting	0	0	0	0	0	0	0	0	1	0	0	0	0	0	*Rdy2hZ*	0
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Register 0x000B bit settings (1)

6.3.3 Output Registers

0x0111	0x0112	0x0113	0x0114	0x0120	0x0121	0x0122	
Pixel 0 Bz_0	Pixel 1 Bz_1	Pixel 0 Bx_0	Pixel 1 Bx_1	Magnitude (3)	Angle (3)	Linearized angle (2)	Output Registers

(3) CORDIC magnitude: $0.8234 \cdot \sqrt{Bx_0{}^2 + Bz_0{}^2}$ CORDIC angle: $atan2(Bz_0, Bx_0)$

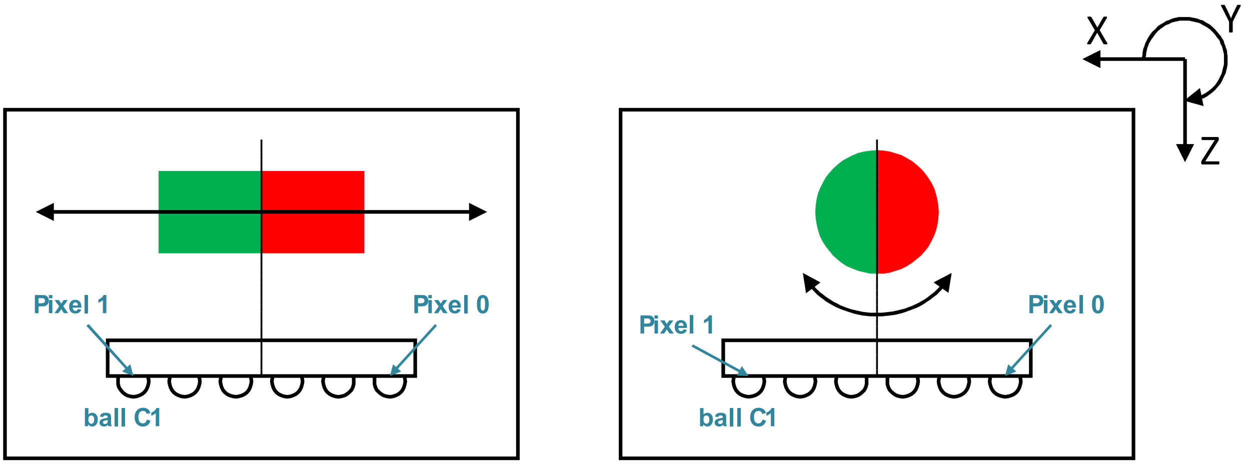
6.3.4 References

(1) see chapter 7.5 for explanation of bit *Rdy2hZ*
(2) see chapter 7.8 for explanation of angle linearization

6.4 Linear Position or Off-Axis Angle Sensor (Gradient Field Values, Magnet On-Top)

With this setting a linear position measurement or an off-axis angle measurement is feasible. The gradient mode makes the angle value independent from homogeneous external fields. A linearization table can be used for both applications to allow for a linear output curve (see chapter 7.8).

6.4.1 Application Example



Magnet configuration examples in zero position for gradient operation mode

6.4.2 Settings

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Setting	0	0	0	0	*MgnRngExt*	0	0	0	1	0	0	1	0	0	*Rdy2hZ*	0
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Register 0x000B bit settings (1) (2)

6.4.3 Output Registers

0x0111	0x0112	0x0113	0x0114	0x0120	0x0121	0x0122	
Pixel 0 Bz_0	Pixel 1 Bz_1	Pixel 0 Bx_0	Pixel 1 Bx_1	Magnitude (4)	Angle (4)	Linearized angle (3)	Output Registers

(4) CORDIC magnitude: $0.8234 \cdot \sqrt{(Bx_1 - Bx_0)^2 + (Bz_1 - Bz_0)^2}$
CORDIC angle: $atan2\big((Bz_1 - Bz_0), (Bx_1 - Bx_0)\big)$

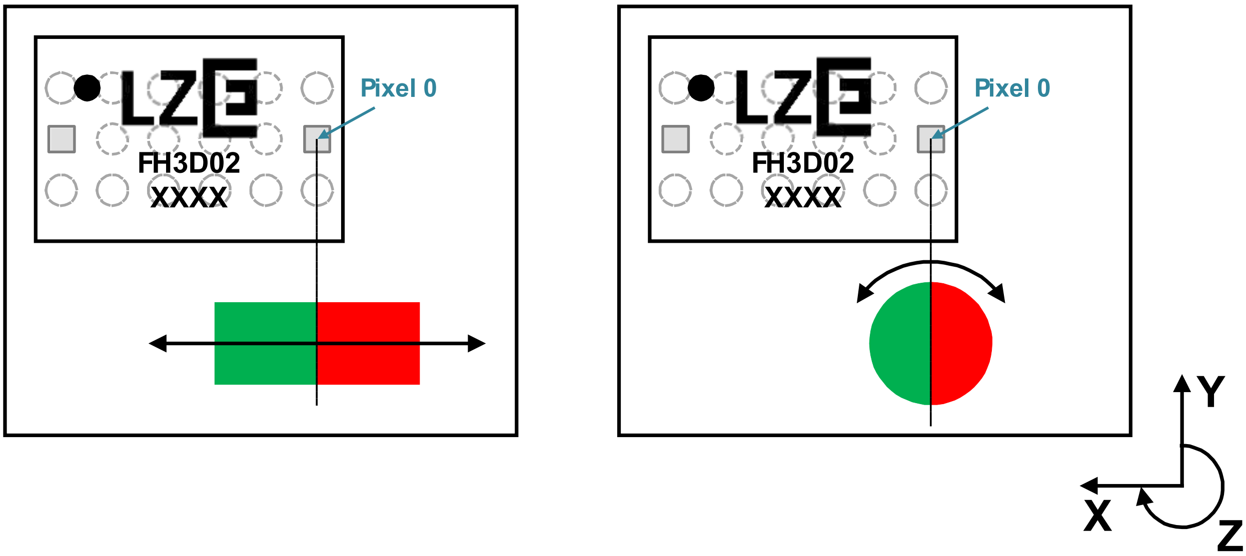
6.4.4 References

(1) see chapter 7.5 for explanation of bit *Rdy2hZ*
(2) see chapter 7.7 for explanation of bit *MgnRngExt*
(3) see chapter 7.8 for explanation of angle linearization

6.5
Linear Position or Off-Axis Angle Sensor (Absolute Field Values, Magnet At-The-Side)

With this setting a linear position measurement or an off-axis angle measurement is feasible. A linearization table can be used for both applications to allow for a linear output curve (see chapter 7.8).

6.5.1 Application Example



Magnet configuration examples in zero position

6.5.2 Settings

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Setting	0	0	0	0	0	0	0	0	1	1	0	0	0	0	*Rdy2hZ*	0
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Register 0x000B bit settings (1)

6.5.3 Output Registers

0x0111	0x0112	0x0113	0x0114	0x0120	0x0121	0x0122	
Pixel 0 By_0	Pixel 1 By_1	Pixel 0 Bx_0	Pixel 1 Bx_1	Magnitude (3)	Angle (3)	Linearized angle (2)	Output Registers

(3) CORDIC magnitude: $0.8234 \cdot \sqrt{{Bx_0}^2 + {By_0}^2}$ CORDIC angle: $atan2(By_0, Bx_0)$

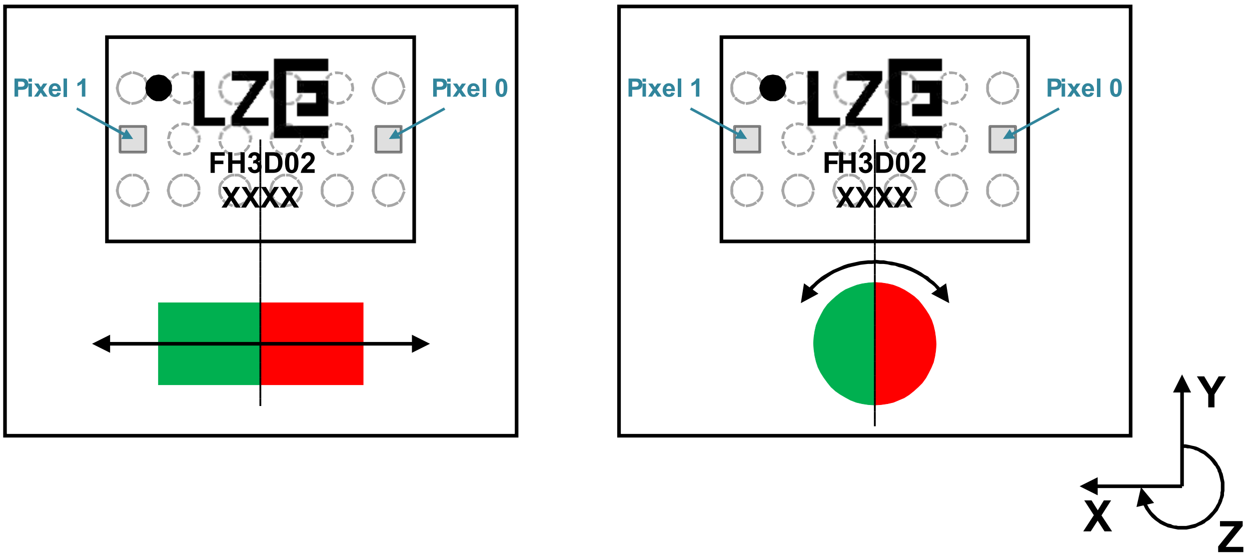
6.5.4 References

(1) see chapter 7.5 for explanation of bit *Rdy2hZ*
(2) see chapter 7.8 for explanation of angle linearization

6.6 Linear Position or Off-Axis Angle Sensor (Gradient Field Values, Magnet At-The-Side)

With this setting a linear position measurement or an off-axis angle measurement is feasible. The gradient mode makes the angle value independent from homogeneous external fields. A linearization table can be used for both applications to allow for a linear output curve (see chapter 7.8).

6.6.1 Application Example



Magnet configuration examples in zero position for gradient operation mode

6.6.2 Settings

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Setting	0	0	0	0	*MgnRngExt*	0	0	0	1	1	0	1	0	0	*Rdy2hZ*	0
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Register 0x000B bit settings (1)

6.6.3 Output Registers

0x0111	0x0112	0x0113	0x0114	0x0120	0x0121	0x0122	
Pixel 0 By_0	Pixel 1 By_1	Pixel 0 Bx_0	Pixel 1 Bx_1	Magnitude (4)	Angle (4)	Linearized angle (2)	Output Registers

(4) CORDIC magnitude: $0.8234 \cdot \sqrt{(Bx_1 - Bx_0)^2 + (By_1 - By_0)^2}$
CORDIC angle: $atan2\left((By_1 - By_0), (Bx_1 - Bx_0)\right)$

6.6.4 References

(1) see chapter 7.5 for explanation of bit Rdy2hZ and chapter 7.7 for bit *MgnRngExt*
(2) see chapter 7.8 for explanation of angle linearization

7
Additional Features

7.1 Low Power Mode

For low power applications the FH3D02 can be set to a low power mode. In this mode all analog components are turned off and the oscillator and digital components are stopped. The low power mode is enabled by logical levels at pin LOPOWR. A logical rise signal will immediately enable the low power mode. Any measurement will be interrupted and the SPI will not return any data. After a logical fall signal at LOPOWR a reset cycle will be performed and the IC will enter its initial condition. All necessary SPI register settings must be rewritten as they return to their initial states during the reset.

Please note:

The reset cycle at leaving the low power mode requires the regular reset wait time t_{res1} before starting the SPI communication (see chapter 5.1.2).

LOPOWR level	State	Current consumption	Note
high	Low power mode	$IDD_{lowpower}$	All internal components are switched off.
low	Normal operation	[depending on operation mode]	The SPI register content is reset when returning to normal operation.

Low power mode information

7.2 EEPROM Access

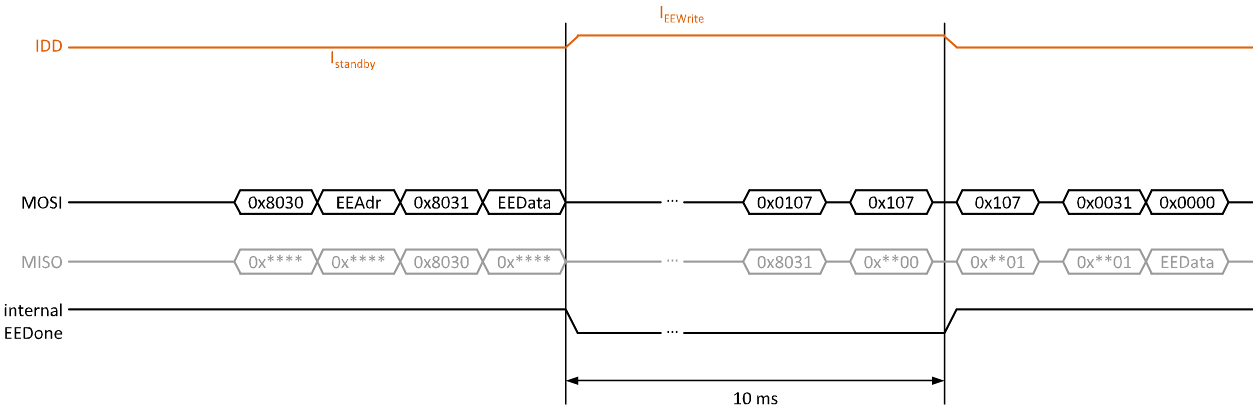
The internal 512 x 16bit EEPROM is a non-volatile memory which holds initialization and calibration data and the definition of internal measurement sequences. Certain address ranges of the EEPROM are accessible and can be modified. Others must not or can not be modified.

Read and write access is performed via the SPI registers 0x0030 and 0x0031. The desired address is written to register 0030h and the stored bits can be read from register 0031h or written to it. The internal write cycle requires 10ms before the data is permanently stored. After completion the status bit *EEDone* in register 0107h is set to 1. This write cycle must not be interrupted by power down, reset or VDD power loss.

SPI address	Symbol	Description
0x0030	*EEAddr*	EEPROM address
0x0031	*EEData*	EEPROM data
0x0107		Status flags

SPI registers for EEPROM access

The following timing diagram shows a typical EEPROM write cycle. After setting *EEAdr* and writing *EEData* the internal write cycle is started. After 10 ms the internal EEDone signal is set and bit 0 in status register 0x0107 will be logical 1. Not before this the EEPROM content can be read and verified by reading from register 0x0031.



Timing diagram of an EEPROM write cycle. Use CS_N and SCK according to SPI protocol (section 4.1). Values shown as 0x**** depend on settings and EEPROM content. $I_{EEWrite}$ is typically $I_{standby}$ + 100 µA.

Please note:

By altering the EEPROM content holding calibration data and measurement sequence definitions the functionality of the device is altered and malfunctions will occur. An access restriction as described in chapter 7.3 can prevent unintended modifications and is strongly recommended.
Do not access the EEPROM during measurements. Read and write access is only allowed during standby. The guaranteed number of write cycles to the EEPROM is 40,000, independent from the chosen address.

The following table gives an overview about the content of different address ranges in the EEPROM.

Address range	Content	Note
0x001 – 0x00F	SPI register initialization	At the reset cycle the content of this EEPROM address range is copied to the SPI accessible volatile memory and will be used during normal operation.
0x010 – 0x01F	Sensor calibration data	Do not access this address range. Any modification will result in device malfunction!
0x020	Lock mode	Definition of EEPROM access restrictions. Refer to 7.3 for further information.
0x021 – 0x026	Reserved	Do not access this address range. Any modification will result in device malfunction!
0x027	Analog calibration data	Write access to this address is prevented.
0x028 – 0x02D	Reserved	Do not access this address range. Any modification will result in device malfunction!
0x02E – 0x02F	Unique ID	Every device of a production lot has a unique 32-bit identification number. It can be used for traceability purposes. The production lot can be identified by the date code on every device. Write access to the ID is prevented.
0x030 – 0x057	Analog and sensor calibration data	Do not access this address range. Any modification will result in device malfunction!
0x058 – 0x05E	Reserved	Do not access this address range.
0x05F – 0x07F	Angle linearization table	Refer to 7.8 for further information.
0x080 – 0x0FF	Sensitivity correction tables	Do not access this address range. Any modification will result in device malfunction!
0x100 – 0x1FF	Measurement sequence definitions	Do not access this address range. Any modification will result in device malfunction!

EEPROM address ranges

7.3 EEPROM Access Restriction (Lock Modes)

The lock mode definition at EEPROM address 0x020 can be used to prevent write and read access to the EEPROM. After setting single bits in the lock mode word and performing a reset cycle the bits can not be set back to 0. The following table gives an overview about the locked EEPROM functions and address ranges.

It is strongly recommended to set the lock mode as soon as possible to the highest possible value to prevent unintended EEPROM access. Only in rare cases it might be necessary to modify the calibration values or the measurement sequence definitions.

Bit	Lock address ranges	Default Value	Recom-mended Value	Description
D15 (MSB)	-	1	1	Reserved
D14	0x010 – 0x01F 0x030 – 0x057 0x080 – 0x0FF	0	1	Sensor calibration data
D13	-	0	0	Reserved
D12	SPI register 0x001, bit 0	0	1	Manual measurements can not be started if this lock bit is set.
D11	-	0	*	Selection bit for PWM mode. 0: off, 1: PWM output can be activated (see 7.4).
D10	-	1	1	Reserved
D9	-	1	1	Reserved
D8	-	0	1	Read protection for sensor calibration data
D7	0x05F – 0x07F	0	*	Linearization table. After modifying the table to the final values this lock bit should be set, too.
D6	0x100 – 0x1FF	0	1	Measurement sequence definitions, part A
D5	0x100 – 0x1FF	0	1	Measurement sequence definitions, part B
D4	0x000 – 0x00F	0	1	SPI register initialization
D3	0x009	0	0	Reserved
D2	SPI registers 0x000 – 0x009 0x00B – 0x027	0	1	Direct access to volatile SPI registers
D1	-	0	0	Reserved
D0 (LSB)	-	0	1	Read protection for measurement sequence definitions, linearization table, SPI register initialization.

Lock mode bits

Recommended lock word for application: 0xD7FD

7.4 PWM Output

From the measured and linearized angle in SPI register 0x0122 a PWM signal can be generated. The base frequency of the PWM is the system clock frequency of typ. 8 MHz. Hence one PWM digit always corresponds to approx. 125 ns.
The PWM signal is available at pin PWM. If one of the error flags *MgnLost* or *CalcErr* occurs the PWM output will be disabled with PWM remaining at the current level (high or low). In that way it is ensured that no false falling edge is generated and an external controller can capture the error event by a timeout counter.
In PWM mode both flags can also be made available at pins READY (*MagLost*) and MISO (*CalcErr*) by setting PWMflags in register 000Bh to 1.
The PWM duty cycle can be limited to a low and high threshold. Even if the measured and linearized angle exceeds these limits, the duty cycle will clip there. The low limit can be set to any value between 0% and 50%, the high limit to any value between 50% and 100%, both with a resolution of 6 bit.
The settings and activation of the PWM output are defined by the 16-bit word at EEPROM address 0x00D.

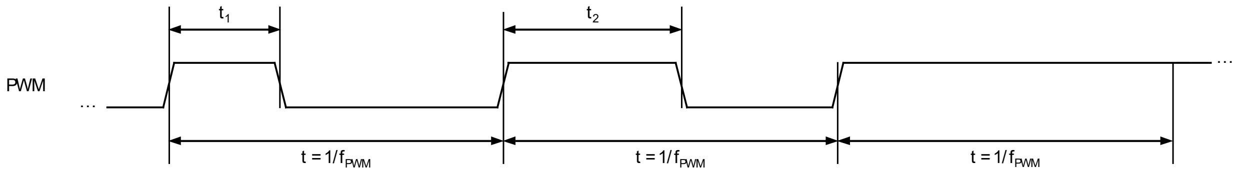
Bit	Symbol	Description
D15 (MSB) – D10	*PWMLimitHi*	"PWM Limit High" Limits the PWM duty cycle to the maximum value $\left(PWMLimitHi \cdot {}^{50}/_{64} + 50\right)\%$
D9 – D4	*PWMLimitLo*	"PWM Limit Low" Limits the PWM duty cycle to the minimum value $\left(PWMLimitLo \cdot {}^{50}/_{64}\right)\%$
D3	*PWMEn*	"PWM Enable" Enables the PWM output.
D2 – D0 (LSB)	*PWMPreScale*	"PWM PreScale" Defines the PWM frequency and resolution. Refer to the following table for further information.

0x00D Bits (PWM setting)

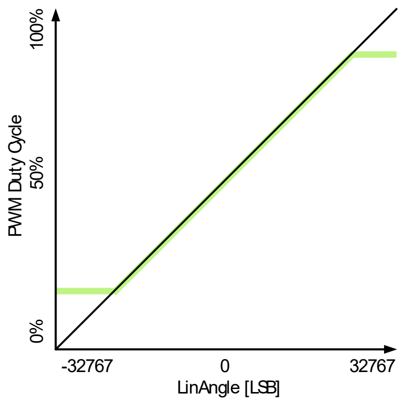
The PWM resolution and update frequency are both set by the 3 bits of *PWMPreScale* which shift the 16 bit wide angle value by 0 to 7 digits. The following table shows the effect of this setting.

PWMPreScale	PWM Resolution	Min. frequency f_{PWM}	Max. frequency f_{PWM}
0b000	16 bit		0.122 kHz
0b001	15 bit		0.244 kHz
0b010	14 bit		0.49 kHz
0b011	13 bit		0.98 kHz
0b100	12 bit		1.95 kHz
0b101	11 bit		3.91 kHz
0b110	10 bit		7.81 kHz
0b111	9 bit		15.63 kHz

PWM frequency



Timing diagram of 3 PWM cycles. t_1/t and t_2/t define the duty cycle. The last cycle represents an error state at which no PWM edge is generated.



Characteristic curve of the PWM duty cycle vs linearized angle value. The black line represents the maximum possible PWM range. The green curve shows limited min and max values.

Please note:

Even if a high PWM frequency is used the output update rate is defined by the internal measurement cycle. Hence several equal output values will be generated. For analog voltage emulation by using a low pass filter at the PWM output this might still be a preferred setting.
At low PWM frequencies the PWM will only represent the currently valid angle. There is no averaging of several measurement values even if the internal measurement rate is higher than the PWM frequency.
The PWM settings can be read by SPI at register 0x000D but only be set at the appropriate EEPROM address 0x00D.
The 0% and 100% levels of the PWM duty cycle are always at ±180° of the linearized angle. Hence the zero-point of the PWM can not be chosen arbitrarily. It is only possible to shift the range around 50% slightly by using the linearization table.
The PWM can only be activated if bit 11 of the lock mode word is set to 1 (refer to 7.3).

7.4.1 Stand-Alone Operation with PWM Output

It is possible to use the FH3D02 as stand-alone sensor with PWM output. In this case the following steps are advised:

1. Set a safe lock mode with PWM mode enabled, e.g. 0xDF68 (see chapter 7.3).
2. Set an appropriate measurement configuration by modifying EEPROM address 0x00B (see 5.1.1).
3. Set magnet lost limit (see 7.9) if a different minimum field strength than 1 mT is needed.
4. Calculate and generate an appropriate linearization table and store it in the EEPROM.
5. Configure and enable the PWM by modifying EEPROM address 0x00D (see above).
6. Enable the continuous measurement mode: EEPROM address 0x00E (see 5.1.2).
7. Set a safe application lock mode with PWM enabled, e.g. 0xDFFD (see chapter 7.3).
8. Reboot the device. After the reset cycle the automatic measurement mode will commence and the PWM output will be activated.

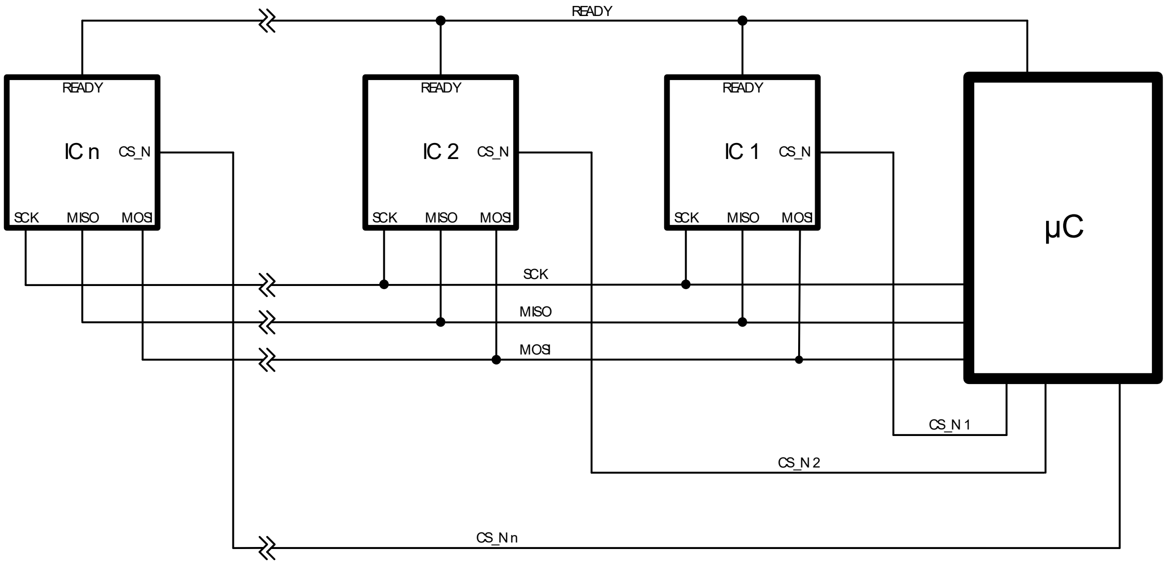
7.5 Parallel Operation of Multiple Devices

For several applications it might be necessary to use several devices with only one master controller.

The simplest way to communicate with several ICs for combined operation is to use separate CS_N wires for every device. Communication with a device is only possible while CS_N is low. Then the output MISO is active, otherwise it is high impedance (see also 4.1).

Please note:

If READY is wired in parallel it must be set to high-Z mode (*Rdy2hZ* = 1). Then the READY signal is active only if the chip is selected.



Example for configuration with several FH3D02 devices and one master controller in chip select mode.

7.6 CLK Input/Output

The system clock of the FH3D02 is generated by an internal RC oscillator if it is used in standard configuration. Due to process variations the clock frequency exhibits certain spread. The characteristics are noted in the following table.

Parameter	Symbol	Min	Typ	Max	Unit	Note
System clock frequency	f_{clk}	7.5		8	MHz	System clock frequency

Several devices in a combined setup can be started synchronously by group addressing (see 7.5) but will complete their measurement cycles at different points in time. For absolutely synchronous measurements a common clock can be used. By disabling the internal oscillator the signal edges at pin CLK will be used as system clock. See the following table for the necessary characteristics of this clock signal.

Parameter	Symbol	Min	Typ	Max	Unit	Note
Clock frequency	f_{clkExt}	7.5		8	MHz	
Edge rise time	t_{rise}				ns	0.3 V to 2.7 V
Edge fall time	t_{fall}				ns	2.7 V to 0.3 V
Duty cycle	tc_{duty}	49		51	%	

External clock characteristics

The clock behavior can be set by setting bits D10 and D11 in SPI register 0x0004.

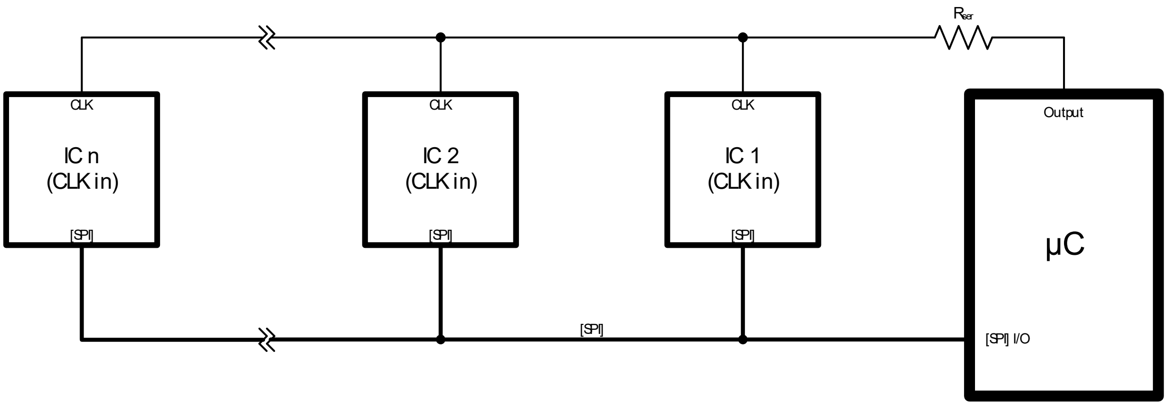
Bit	Symbol	Default Value	Description
D15 (MSB) – D12	*r*	0	(Reserved. Always set to default state)
D11	*OscOut*	0	"Oscillator Output Enable" 0: oscillator output disabled, pin CLK is high impedance 1: oscillator output enabled, pin CLK is active
D10	*OscPD*	0	"Oscillator Power Down" 0: internal oscillator is enabled 1: internal oscillator is disabled, clock signal at pin CLK is used as system clock
D9 – D7	*r*	0	(Reserved. Always set to default state)
D6	*BiasOn*	1	"Internal Bias References Enable" This bit must not be set to 0.
D5 – D0 (LSB)	*r*	0	(Reserved. Always set to default state)

0x0004 Bits

Two different modes of operation are possible and described in the following sections.

Clock signal generated by external source

Write value 0x0440 to register 0x0004 of all devices. Apply the external clock signal to pin CLK.



Example for configuration with several FH3D02 devices and one master controller as clock source.

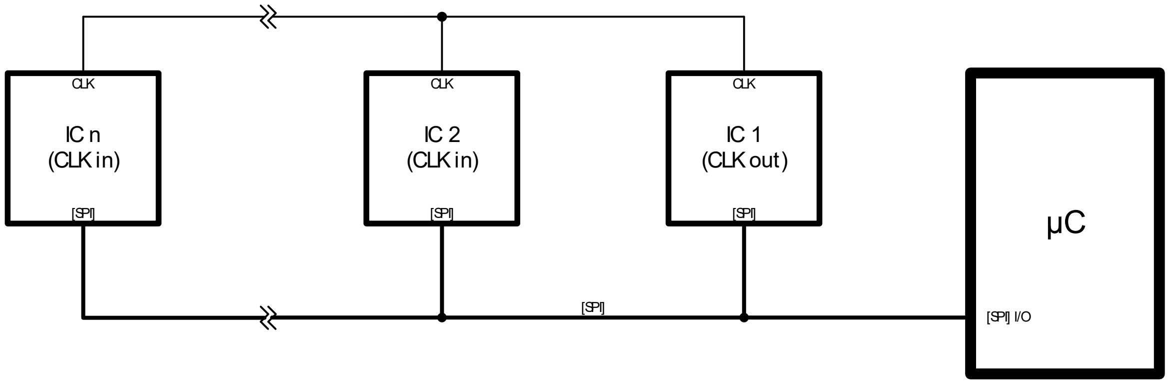
Please note:
It is strongly recommended to use an impedance controlled digital signal line with source resistor (e.g. R_{ser} as shown) for the clock wire.

The reset sequence always uses the internal clock, even if 0x0440 is written to 0x0004 in the EEPROM. For synchronization reasons the external clock will not be used until the first SCK edge. This edge must not occur before the end of the reset cycle and does not need a CS_N=0.

Do not connect more than 16 (32) ICs to one CLK output if a 100 Ω (50 Ω) series resistor is used.

Clock generation by one FH3D02 with CLK output

Write value 0x0840 to register 0x0004 of the CLK output device. Write value 0x0440 to register 0x0004 of all CLK input devices.



Example for configuration with several FH3D02 devices and IC1 as clock source.

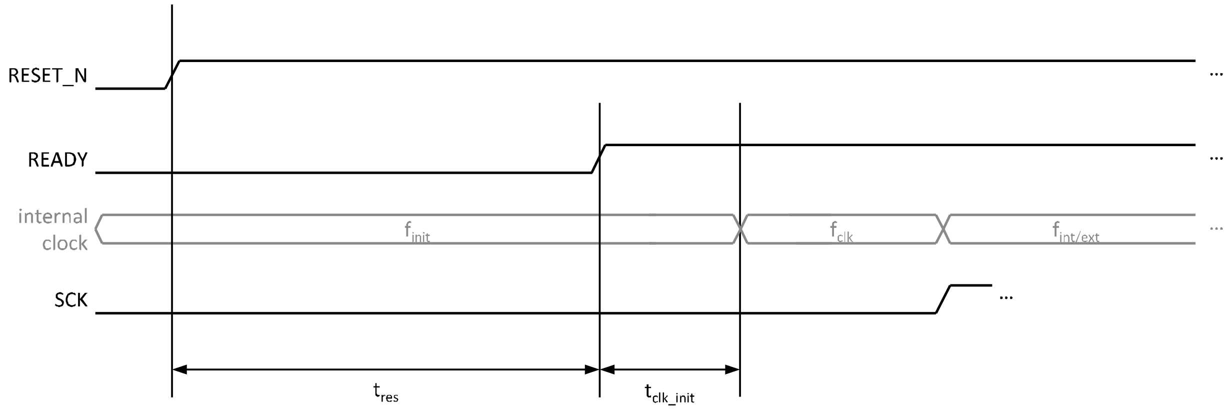
Please note:

Do not connect more than 16 (32) ICs to one CLK output if a 100 Ω (50 Ω) series resistor is used.

The reset sequence always uses the internal clock. For synchronization reasons the external clock will not be used until the first SCK edge. This edge must not occur before the end of the reset cycle and does not need a CS_N=0.

EEPROM Clock Settings

If the oscillator settings from SPI register 0x0004 are stored in the EEPROM attention should be paid to the startup procedure:
During the boot procedure an untrimmed internal clock frequency is used. After a certain time t_{res} the rising READY indicates that the boot procedure is finished and communication on the SPI can commence.
During an additional time t_{clk_init} the internal clock frequency remains at its initial raw value and will change to the nominal f_{clk} afterwards without external indication.
The internal (raw or trimmed) clock will be used until a first SCK rising edge. Any setting of bits *OscOut* and *OscPD* will not take effect until the first SCK rising edge. Only then the CLK output will be active or an external clock source will be used as system clock.



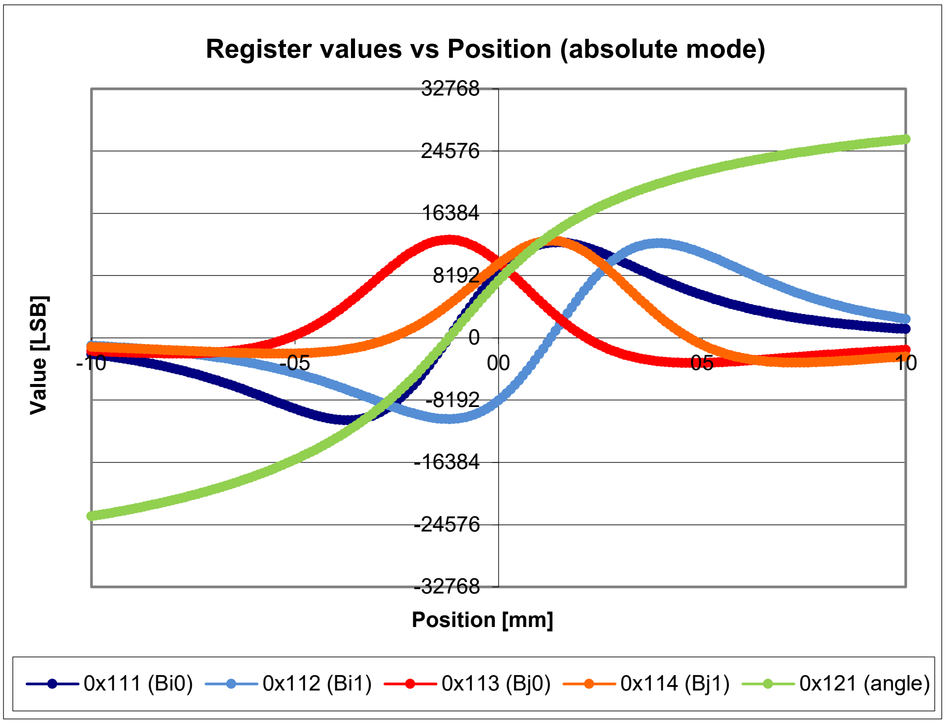
Please note:
A reset can be triggered externally on RESET_N or internally by the VDD-dependent power-on-reset.
The READY behavior depends on bit settings *Rdy2hZ* (see chapter 5.1.1).
For f_{clk} refer to table “System clock frequency” above.
For t_{res} refer to t_{res1} in chapter 5.1.2.

Parameter	Symbol	Min	Typ	Max	Unit	Note
Raw clock frequency	f_{init}	0.85	2	7.3	MHz	
Initial clock delay time	t_{clk_init}	4.5	16	35	µs	

Boot procedure parameters

7.7 Range Extension in Gradient Mode

In any position sensing application an angle value is calculated from two magnetic components Bi and Bj. In rotary and absolute linear applications this angle can vary between +/-180° (see the graph below). For linear magnet movements the magnetic fields become lower at the outside of the movement range. The angle will be correct inside its limits until offsets and noise exceed the magnetic field amplitude. The linearization is properly applicable.



Example data of a real magnet applied for linear position sensing as described in 6.3.1. The angle is calculated from Bi0 and Bj0 (typically pixel 0). Hence the angle is ≠0 if the magnet is placed at the centre of the IC.

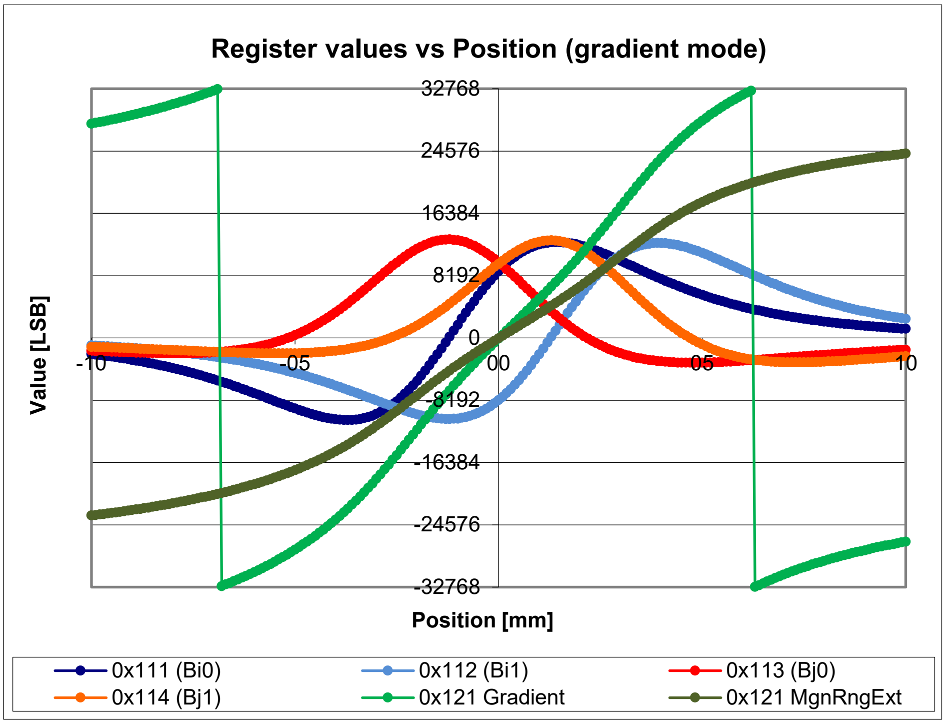
In gradient mode the Bi and Bj components are calculated as differences between the register contents (see 6.4.3 and 6.6.3). Depending on the magnet these Bi and Bj components will exhibit slightly different shapes with additional zero-crossings in Bj. This leads to jumps between +/-180° at the zero crossings. With these angle ambiguities a linearization is not possible.

For movements outside of these points it is possible to extend the angle range to +/-288°. Set bit *MgnRngExt* in register 0x000B. See chapter 5.1.1 and 5.1.10 for further details. Only now a proper angle linearization is applicable.
The graph below shows the output angle in gradient mode with *MgnRngExt* disabled and enabled.

Please note:

The internal algorithm uses absolute field values to separate angles >+180° and <-180°. Strong external fields add up to the permanent magnet's field and will alter the measured absolute field. If $2 \cdot B_{offset}$ > (Bi0 + Bi1) the calculation will give false results.
As Bi depends on the used magnet no absolute limit for magnetic offsets can be told. In the shown example the remaining field at 10 mm displacement is ~1500 LSB or ~6 mT. Hence the acceptable external homogeneous field may vary between +/-6 mT without angle error.

In range extension mode also the linearization table will be applied using +/-288° range. Different tables are needed for absolute mode, gradient mode and gradient mode with range extension.



Example data of real magnet in gradient mode. The standard CORDIC angle “Gradient” jumps between +/-180° if the Bj component crosses 0. “MgnRngExt” shows a valid angle without ambiguity by offering a range of +/-288°.
Please note: Bi and Bj are not directly accessible by SPI.

7.8 Linearization Table

A linearized angle *LinAngle* (register 0x0122) is calculated from the direct CORDIC angle (0x0120) and a static linearization table in the EEPROM. The factory setting is a transparent table where 0x0122 holds the identical content as 0x0120.

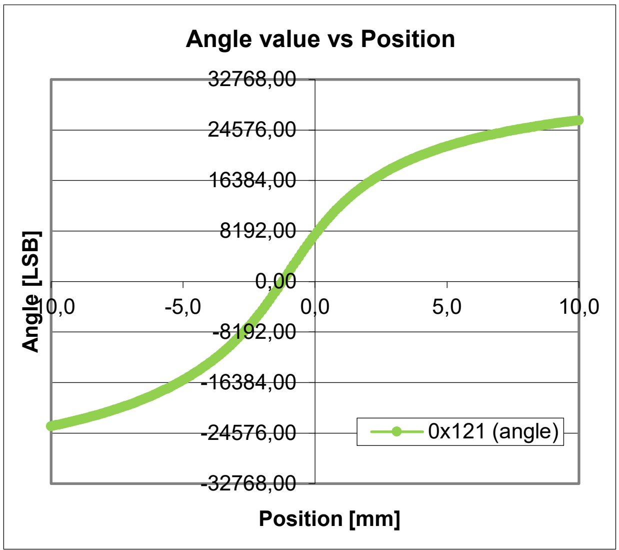
- 33 base points from -16 to +16
- constant x distance of 2048 digits (→ 11.25° in standard mode, 18° in range extension mode) between the base points
- linear interpolation between the base points
- for rotary applications value -16 must be 0x8000 and value +16 must be 0xFFFF
- for linear applications values -16 and +16 can be chosen arbitrarily

Address	Content	Note
0x05F	value 16, base point +32767	
0x060	value 0, base point 0	
0x061	value 1, base point +2048	
…	…	
0x06F	value 15, base point +30720	
0x070	value -16, base point -32768	
0x071	value -15, base point -30720	
…	…	
0x07E	value -2, base point -4096	
0x07F	value -1, base point -2048	

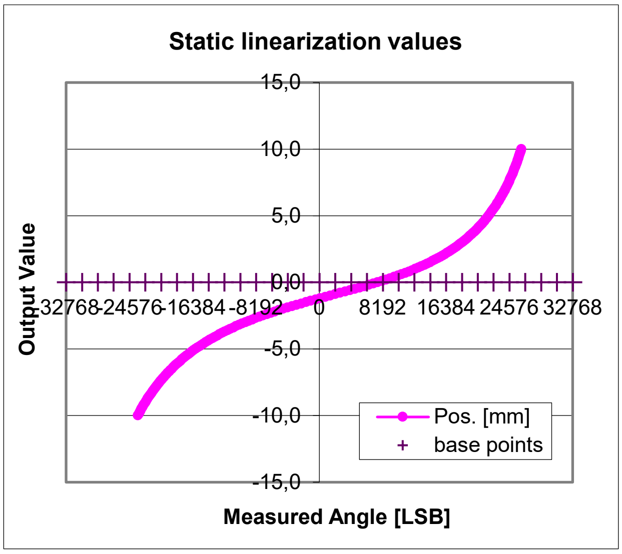
EEPROM addresses for angle linearization

7.8.1 Example

The absolute angle from the magnetic example data shown in 7.7 can be linearized as follows:



Example angle of real magnet at linear movement.

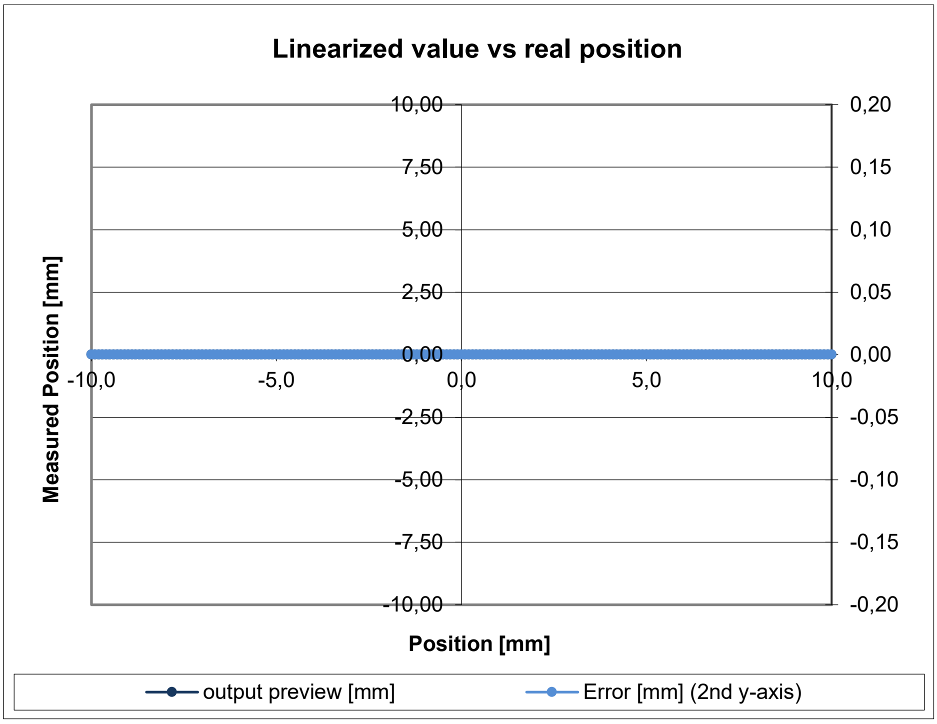


Linearization curve and discrete base points for table.

The linearization table can be generated as follows:

- Record angle data vs movement with the used magnet/IC pair.
- Chose proper factor for movement quantization. (e.g. 2048 LSB/mm for this example)
- Invert the angle curve using this factor.
- Extrapolate the curve to generate (at least) the adjacent base points outside the existing data.
- Interpolate at base points and clip the curve to +/-32767.

This linearization corrects for linearity errors and zero point offsets.
A position error is induced by the interpolation if the linearization is applied. Nonlinear regions in the curve will result in higher errors (see outer regions in example graph below).



Linear output angle as present in register 0x122 using 2048 LSB/mm as gain factor for this example. Depending on the linearization algorithm positive and/or negative position errors will be induced by the linear interpolation between the base points.

7.9
Magnet Lost Setting

At every measurement the magnetic field magnitude is compared to an adjustable value and the flag *MagLost* in register 0x0107 is set if the magnitude falls below this value.
In order to avoid a toggling flag on the edge of this limit a hysteresis can be set.

Bit	Symbol	Description
D15 – D11	*r*	(Reserved. Always 0)
D10 – D8	*Hyst*	"Hysteresis" Hysteresis around the Magnet Lost Limit. It is calculated by $16 \cdot MgnLostLmt \cdot \frac{1}{2^{Hyst}}$ Factory setting is 1, which corresponds to approx. 0.43 mT.
D7 – D0	*MgnLostLmt*	"Magnet Lost Limit" If the bits <13:6> of the Magnetic Field Magnitude (register 0x0120) is lower than *MgnLostLmt* the error flag *MagLost* in register 0x0107 is set. Factory setting is 3, which corresponds to approx. 0.93 mT.

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