Data sheet

BMC050
Electronic Compass

Bosch Sensortec

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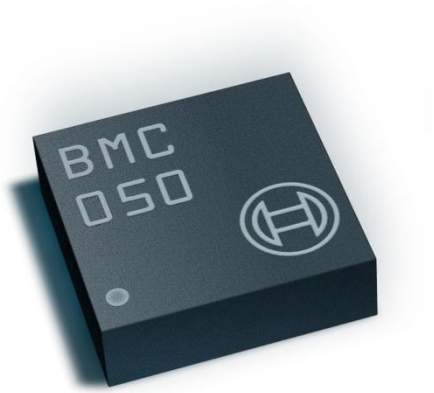

BMC050: Data sheet

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BMC050

ELECTRONIC COMPASS WITH THREE-AXIS MAGNETIC FIELD SENSOR AND THREE-AXIS ACCELEROMETER

Key features

Three-axis magnetic field sensor and three-axis accelerometer in one package

- Accelerometer can still be used independently from magnetometer operation
- Ultra-Small package — LGA package (16 pins), footprint 3mm x 3mm, height 0.95mm
- Digital interface — SPI (4-wire, 3-wire), I²C, 4 interrupt pins
(2 acceleration sensor, 2 magnetic sensor interrupt pins)
- Low voltage operation — V_{DD} supply voltage range: 1.62V to 3.6V
V_{DDIO} interface voltage range: 1.2V to 3.6V
- Flexible functionality — Acceleration ranges ±2g / ±4g / ±8g / ±16g
Acceleration Low-pass filter bandwidths 1 kHz - <8Hz
Magnetic field range typical ±1000µT
Magnetic field resolution of ~0.3µT
- On-chip interrupt controller — Motion-triggered interrupt-signal generation for
- new data (separate for accelerometer and magnetometer)
- any-motion (slope) detection
- tap sensing (single tap / double tap)
- orientation recognition
- flat detection
- low-g/high-g detection
- magnetic Low-/High-Threshold detection
- Ultra-low power — Low current consumption (190µA @ 10 Hz including accelerometer and magnetic sensor in low power preset), short wake-up time, advanced features for system power management
- Temperature range — -40 °C ... +85 °C
- RoHS compliant, halogen-free

Typical applications

- Tilt-compensated electronic compass for map rotation, navigation and augmented reality
- 6-axis orientation for gaming
- Display profile switching
- Menu scrolling, tap / double tap sensing
- Pedometer / step counting
- Free-fall detection
- Drop detection for warranty logging
- Advanced system power management for mobile applications

General Description

The BMC050 is an integrated electronic compass solution for consumer market applications. It comprises a leading edge triaxial, low-g acceleration sensor and an ultra-low power, high precision triaxial magnetic field sensor. It allows measurements of acceleration and magnetic field in three perpendicular axes. Performance and features of both sensing technologies are carefully tuned and perfectly match the demanding requirements of all 6-axis mobile applications such as electronic compass, navigation or augmented reality.
An evaluation circuitry (ASIC) converts the output of the micromechanical sensing structures (MEMS) to digital results which can be read out over the industry standard digital interfaces.

Package and interfaces of the BMC050 have been designed to match a multitude of hardware requirements. As the sensor features an ultra-small footprint and a flat package, it is ingeniously suited for mobile applications.

The BMC050 offers ultra-low voltage operation (V_{DD} voltage range from 1.62V to 3.6V, V_{DDIO} voltage range 1.2V to 3.6V) and can be programmed to optimize functionality, performance and power consumption in customer specific applications. The programmable interrupt engine sets new standards in terms of flexibility.

The BMC050 senses orientation, tilt, motion, shock, vibration and heading in cell phones, handhelds, computer peripherals, man-machine interfaces, virtual reality features and game controllers.

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1. Specification

If not stated otherwise, the given values are over lifetime and full performance temperature and voltage ranges, minimum/maximum values are ±3σ. The specifications are split into accelerometer part and magnetometer part of BMC050.

1.1 Compass electrical specification

Table 1: Compass electrical parameter specification

COMPASS OPERATING CONDITIONS						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Unit**
Supply Voltage Internal Domains	V_{DD}		1.62	2.4	3.6	V
Supply Voltage I/O Domain	V_{DDIO}		1.2	1.8	3.6	V
Voltage Input Low Level	$V_{IL,a}$	SPI & I²C			$0.3V_{DDIO}$	-
Voltage Input High Level	$V_{IH,a}$	SPI & I²C	$0.7V_{DDIO}$			-
Voltage Output Low Level	$V_{OL,a}$	V_{DDIO} = 1.62V I_{OL} = 3 mA, SPI & I²C			$0.2V_{DDIO}$	-
		V_{DDIO} = 1.2V I_{OL} = 3 mA, SPI & I²C			$0.23\ V_{DDIO}$	-
Voltage Output High Level	$V_{OH,a}$	V_{DDIO} = 1.62V I_{OL} = 2 mA, SPI & I²C	$0.8V_{DDIO}$			-
		V_{DDIO} = 1.2V I_{OL} = 2 mA, SPI & I²C	$0.62\ V_{DDIO}$			-

1.2 Accelerometer specification

Table 2: Accelerometer parameter specification

ACCELEROMETER OPERATING CONDITIONS						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Unit**
Acceleration Range	g_{FS2g}	Selectable via serial digital interface		±2		g
	g_{FS4g}			±4		g
	g_{FS8g}			±8		g
	g_{FS16g}			±16		g
Supply Current in Normal Mode	$I_{DD,a}$	Nominal V_{DD} supplies T_A=25°C, bw = 1kHz		139		µA
Supply Current in Low-Power Mode	$I_{DDlp,a}$	Nominal V_{DD} supplies T_A=25°C, bw = 1kHz sleep duration ≥ 25ms		7		µA
Supply Current in Suspend Mode	$I_{DDsm,a}$	Nominal V_{DD} supplies T_A=25°C		0.5		µA

Wake-Up Time	$t_{w\_up,a}$	from Low-Power Mode or Suspend Mode, bw = 1kHz		0.8		ms
Start-Up Time	$t_{s\_up,a}$	POR, bw = 1kHz		2		ms
Operating Temperature	T_A	Same for accelerometer and magnetometer	-40		+85	°C
ACCELEROMETER OUTPUT SIGNAL						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Unit**
Device Resolution	$D_{res,a}$	g_{FS2g}		3.91		mg
Sensitivity	S_{2g}	g_{FS2g}, T_A=25°C		256		LSB/g
	S_{4g}	g_{FS4g}, T_A=25°C		128		LSB/g
	S_{8g}	g_{FS8g}, T_A=25°C		64		LSB/g
	S_{16g}	g_{FS16g}, T_A=25°C		32		LSB/g
Sensitivity Temperature Drift	TCS_a	g_{FS2g}, -40°C ≤ T_A ≤ +85°C Nominal V_{DD} supplies		±0.02		%/K
Zero-g Offset	Off_a	g_{FS2g}, T_A=25°C Nominal V_{DD} supplies		±80		mg
Zero-g Offset Temperature Drift	TCO_a	g_{FS2g}, -40°C ≤ T_A ≤ +85°C Nominal V_{DD} supplies		±1		mg/K
Bandwidth	bw_8	1st order filter, selectable via serial digital interface		8		Hz
	bw_{16}			16		Hz
	bw_{31}			31		Hz
	bw_{63}			63		Hz
	bw_{125}			125		Hz
	bw_{250}			250		Hz
	bw_{500}			500		Hz
	bw_{1000}			1000		Hz
Nonlinearity	$NL_{,a}$	best fit straight line		±0.5		%FS
Output Noise	$n_{rms,a}$	g_{FS2g}, T_A=25°C Nominal V_{DD} supplies Normal mode		0.8		mg/√Hz
Power Supply Rejection Rate	$PSRR_a$	T_A=25°C Nominal V_{DD} supplies			20	mg/V
Temperature Sensor Measurement Range	T_S	T_A=25°C Nominal V_{DD} supplies	-40		+87.5	°C
Temperature Sensor Slope	dT_S	T_A=25°C Nominal V_{DD} supplies		0.5		LSB/K
Temperature Sensor Offset	OT_S	T_A=25°C Nominal V_{DD} supplies		±5		K

ACCELEROMETER MECHANICAL CHARACTERISTICS						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Unit**
Cross Axis Sensitivity	S_a	relative contribution between any two of the three axes		1		%
Alignment Error	$E_{A,a}$	relative to package outline		±0.5		°

1.3 Magnetometer specification

Table 3: Magnetometer parameter specification

MAGNETOMETER OPERATING CONDITIONS						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Unit**
Magnetic field range	$B_{rg,xy}$	T_A=25°C, full active measurement range		±1000		µT
	$B_{rg,z}$			2500		µT
Magnetometer heading accuracy[1]	$Am_{heading}$	30µT horizontal geomagnetic field component, T_A=25°C			±2.5	degree
System heading accuracy[2]	$As_{heading}$	30µT horizontal geomagnetic field component, T_A=25°C			±3.5	degree
Supply Current in Active Mode (average)[3]	$I_{DD,lp,m}$	Low power preset Nominal V_{DD} supplies T_A=25°C, ODR=10Hz		170		µA
	$I_{DD,rg,m}$	Regular preset Nominal V_{DD} supplies T_A=25°C, ODR=10Hz		0.5		mA
	$I_{DD,eh,m}$	Enhanced regular preset Nominal V_{DD} supplies T_A=25°C, ODR=10Hz		0.8		mA
	$I_{DD,ha,m}$	High accuracy preset Nominal V_{DD} supplies T_A=25°C, ODR=20Hz		4.9		mA
Supply Current in Suspend Mode	$I_{DDsm,m}$	Nominal V_{DD}/V_{DDIO} supplies, T_A=25°C		1		µA
Peak supply current in Active Mode	$I_{DDpk,m}$	In measurement phase Nominal V_{DD} supplies T_A=25°C		18		mA

[1] Theoretical heading accuracy of the 3-axis magnetometer alone, assuming ideal accelerometer and calibration with Bosch Sensortec eCompass software. Average value over various device orientations (typical device usage).
[2] Heading accuracy of the tilt-compensated 6-axis eCompass system, assuming calibration with Bosch Sensortec eCompass software. Average value over various device orientations (typical device usage).
[3] For details on magnetometer current consumption calculation refer to chapter 4.3.2 and 4.3.3.

Peak logic supply current in active mode	$I_{DDIOpk,m}$	Only during measurement phase Nominal V_{DDIO} supplies T_A=25°C		210		µA
POR time	$t_{w\_up,m}$	from OFF to suspend; time starts when VDD>1.5V and VDDIO>1.1V			1.0	ms
Start-Up Time	$t_{s\_up,m}$	from suspend to sleep		3		ms

MAGNETOMETER OUTPUT SIGNAL

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Device Resolution	$D_{res,m}$	T_A=25°C (x,y,z)		0.3		µT
Sensitivity	S_m	After temperature compensation T_A=25°C Nominal V_{DD} supplies		1		µT sensor output per µT applied field
Sensitivity Temperature Drift	TCS_m	After temperature compensation -40°C ≤ T_A ≤ +85°C Nominal V_{DD} supplies		±0.01		%/K
Zero-B offset	OFF_m	T_A=25°C		±10		µT
ODR (data output rate), normal mode	odr_{lp}	Low power preset		10		Hz
	odr_{rg}	Regular preset		10		Hz
	odr_{eh}	Enhanced regular preset		10		Hz
	odr_{ha}	High accuracy preset		20		Hz
ODR (data output rate), forced mode	odr_{lp}	Low power preset	0		>300	Hz
	odr_{rg}	Regular preset	0		100	Hz
	odr_{eh}	Enhanced regular preset	0		60	Hz
	odr_{ha}	High accuracy preset	0		20	Hz
Full-scale Nonlinearity	$NL_{m,\ FS}$	best fit straight line			1	%FS
Output Noise	$n_{rms,lp,m,xy}$	Low power preset x-, y-axis, T_A=25°C Nominal V_{DD} supplies		1.0		µT
	$n_{rms,lp,m,z}$	Low power preset z-axis, T_A=25°C Nominal V_{DD} supplies		1.4		µT
	$n_{rms,rg,m}$	Regular preset T_A=25°C Nominal V_{DD} supplies		0.6		µT

	$n_{rms,eh,m}$	Enhanced regular preset T_A=25°C Nominal V_{DD} supplies		0.5		µT
	$n_{rms,ha,m}$	High accuracy preset T_A=25°C Nominal V_{DD} supplies		0.3		µT
Power Supply Rejection Rate	$PSRR_m$	T_A=25°C Nominal V_{DD} supplies		±0.5		µT/V

2. Absolute maximum ratings

The absolute maximum ratings provided in Table 4 apply to both the accelerometer and magnetometer part of BMC050.

Table 4: Absolute maximum ratings

Parameter	Condition	Min	Max	Unit
Voltage at Supply Pin	V_{DD} Pin	-0.3	4.0	V
	V_{DDIO} Pin	-0.3	4.0	V
Voltage at any Logic Pad	Non-Supply Pin	-0.3	VDDIO + 0.3	V
Operating Temperature, T_A	Active operation	-40	+85	°C
Passive Storage Temp. Range	≤ 65% rel. H.	-50	+150	°C
Mechanical Shock	Duration ≤ 200µs		10,000	g
	Duration ≤ 1.0ms		2,000	g
	Free fall onto hard surfaces		1.8	m
ESD	HBM, at any Pin		2	kV
	CDM		500	V
Magnetic field	Any direction		> 7	T

3. Block diagram

Figure 1 shows the basic building blocks of the BMC050:

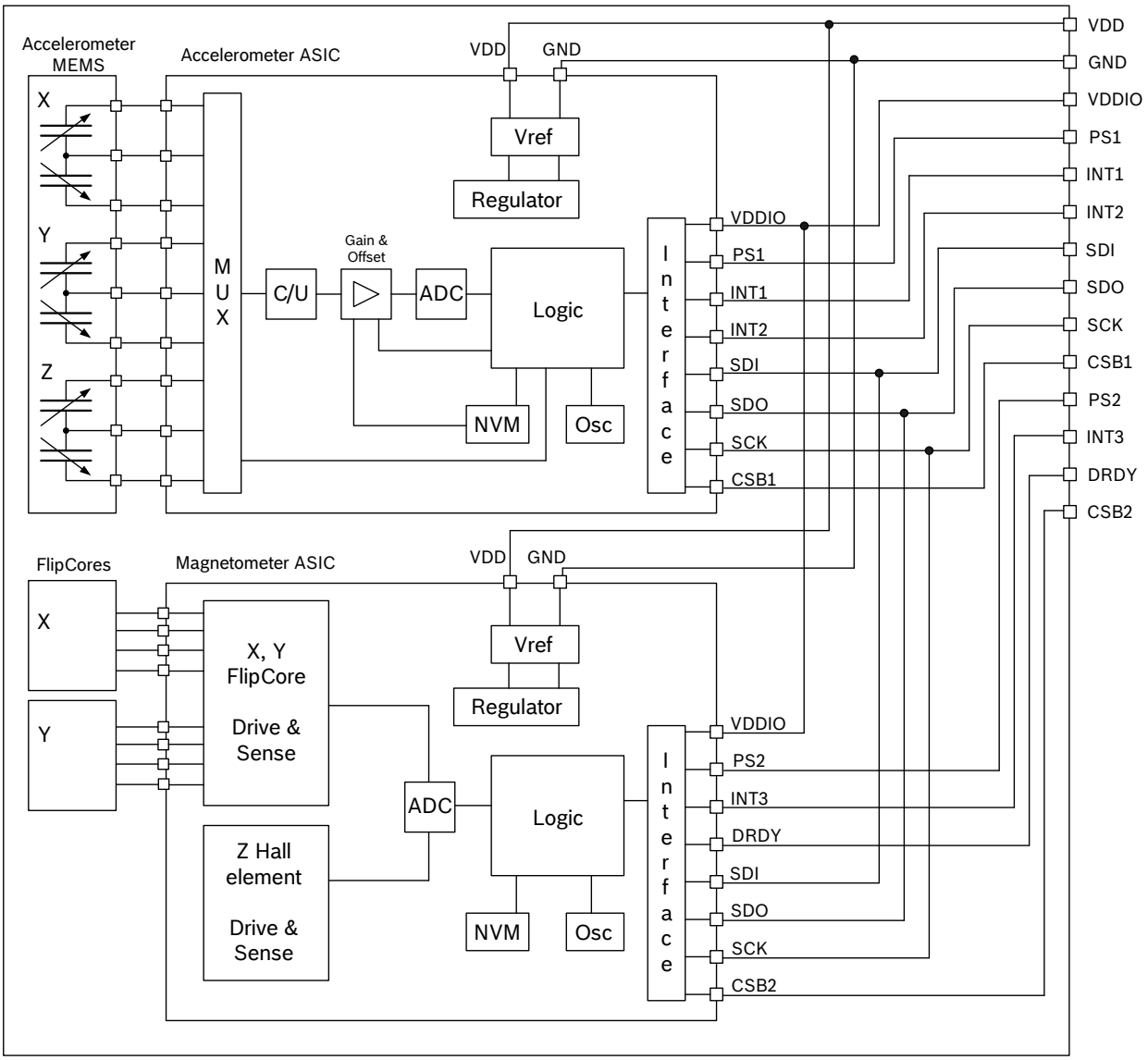


Figure 1: Block diagram of BMC050

4. Functional description

BMC050 is a SiP (system in package) integration of a triaxial accelerometer (Sensing element and ASIC) and a triaxial geomagnetic sensor (Sensing element and ASIC) in one package. The two ASICs act as two separate slave devices on the digital bus (with different I²C address in I²C mode, or separate CSB lines in SPI mode, respectively), which allows an almost independent operation of accelerometer and magnetometer parts in order to fit into a wide range of usage scenarios.

Note: Default values for registers can be found in chapters 5 and 6.

4.1 Power management

The BMC050 has two distinct power supply pins which supply both the acceleration sensor part and the magnetometer sensor part:

- V_{DD} is the main power supply for all internal analog and digital functional blocks;
- V_{DDIO} is a separate power supply pin, used for the supply of the digital interface as well as the magnetic sensor's logic.

There are no limitations on the voltage levels of both pins relative to each other, as long as each of them lies within its operating range. Furthermore, the device can be completely switched off (V_{DD} = 0V) while keeping the V_{DDIO} supply on (V_{DDIO} > 0V). To switch off the interface supply (V_{DDIO} = 0V) and keep the internal supply on (V_{DD} > 0V) is safe only in normal mode of the accelerometer part (magnetic sensor will switch to off mode automatically). If the accelerometer part of the device is in low-power mode or suspend mode while V_{DDIO} = 0V, there is a risk of excess current consumption on the V_{DD} supply (non-destructive).

It is absolutely prohibited to keep any interface at a logical high level when V_{DDIO} is switched off. Such a configuration will permanently damage the device (i.e. if V_{DDIO} = 0 → [SDI & SDO & SCK & CSB1 & CSB2] ≠ high).

The device contains a power on reset (POR) generator for each of the sensor parts, accelerometer part and magnetometer part. It resets the logic part and the register values of the concerned ASIC after powering-on V_{DD} and V_{DDIO}. There is no limitation on the sequence of switching on both supply voltages. In case the I²C interface is used, a direct electrical connection between V_{DDIO} supply and the PS pins (PS1 and PS2) is needed in order to ensure reliable protocol selection (see chapter 4.2).

4.2 Protocol selection

The BMC050 acts as two separate slave devices (i.e. accelerometer part and magnetometer part), on a digital interface (SPI or I²C) which is controlled by the external bus master (e.g. µC). The master obtains measurement data and status information from the device through the digital interface. In particular, the master can configure the interrupt controllers and read out the interrupt status registers. Moreover, it can freely configure and use the interrupt pins (INT1, INT2, INT3 and DRDY).

All pads are in input mode (no output driver active) during the start-up sequence until the interface type is selected. The start-up sequence is run after power-up and after reset.

Note: It is not possible to select mixed interfaces (I²C for accelerometer part and SPI for magnetometer part or vice versa), because the digital interface uses shared pins.

Figure 2 illustrates the protocol selection:

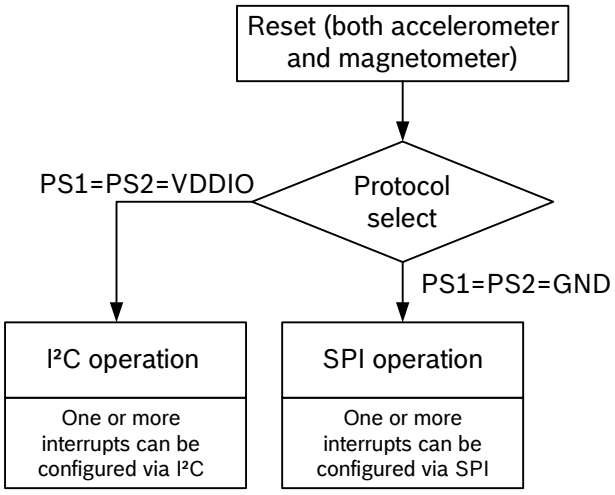


Figure 2: Protocol selection

4.3 Power modes

The BMC050 features separately configurable power modes for the accelerometer and the magnetometer part. The advantage is that different characteristics regarding optimum system power saving of the two sensor types are exploited, and that the accelerometer part may also be used alone in certain usage scenarios where no magnetic field data is required. In such an example, the magnetometer part is able to suspend and save power during the time in which it is not required.
In the following chapters, power modes for both accelerometer and magnetometer part are described.

4.3.1 **Accelerometer power modes**

The BMC050 accelerometer part has four different power modes (see Figure 4). Besides normal mode, which represents the fully operational state of the device, there are two special energy saving modes: low-power mode and suspend mode.

The possible transitions between the power modes are illustrated in Figure 3:

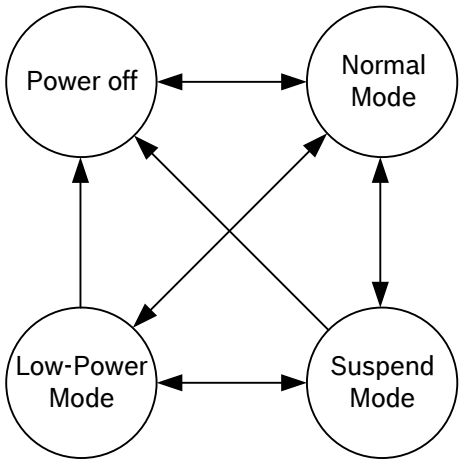


Figure 3: Accelerometer power mode transition diagram

Power off mode is enabled when V_{DD} and/or V_{DDIO} are unpowered. In this state, the accelerometer does not operate. Power on reset is performed after both supply voltages have risen above their detection thresholds.

In **normal mode**, all parts of the electronic circuit are held powered-up and data acquisition is performed continuously.

In contrast to this, in **suspend mode** the whole analog part, oscillators included, is powered down. No data acquisition is performed, the only supported operations are reading registers (latest acceleration data are kept) and writing to the *(0x11) suspend* bit or *(0x14) softreset* register. Suspend mode is entered (left) by writing “1” (“0”) to the *(0x11) suspend* bit.

In **low-power mode**, the device is periodically switching between a sleep phase and a wake-up phase. The wake-up phase essentially corresponds to operation in normal mode with complete power-up of the circuitry. During the sleep phase the analog part except the oscillators is powered down. Low-power mode is entered (left) by writing “1” (“0”) to the *(0x11) lowpower_en* bit.

During the wake-up phase the number of samples required by any enabled interrupt is processed. If an interrupt is detected, the device stays in the wake-up phase as long as the interrupt condition endures (non-latched interrupt), or until the latch time expires (temporary interrupt), or until the interrupt is reset (latched interrupt). If no interrupt is detected, the device enters the sleep phase.

The duration of the sleep phase is set by the *(0x11) sleep_dur* bits as shown in the following table:

Table 5: Sleep phase duration settings

(0x11) sleep_dur	Sleep Phase Duration t_{sleepa}
0000b	0.5ms
0001b	0.5ms
0010b	0.5ms
0011b	0.5ms
0100b	0.5ms
0101b	0.5ms
0110b	1ms
0111b	2ms
1000b	4ms
1001b	6ms
1010b	10ms
1011b	25ms
1100b	50ms
1101b	100ms
1110b	500ms
1111b	1s

The current consumption of the BMC050 accelerometer part can be calculated according to this formula:

$$I_{DDlp,a} \approx \frac{t_{sleep,a} \cdot I_{DDsm,a} + t_{active,a} \cdot I_{DD,a}}{t_{sleep,a} + t_{active,a}}.$$

In this formula, the subfix “a” indicates that the current and time variables refer to the accelerometer part of BMC050, to distinguish from the magnetometer part.
When making an estimation about the length of the wake-up phase $t_{active,a}$, the wake-up time, $t_{w\_up,a}$, has to be considered. Therefore, $t_{active,a} = t_{u,at} + t_{w\_up,a}$, where $t_{u,at}$ is given in Table 9. During the wake-up phase all analog modules are held powered-up, while during the sleep phase most analog modules are powered down. As a consequence, a wake-up time of less than 1ms (typ. value 0.8ms) is needed to settle the analog modules in order to get reliable acceleration data.

Table 6 gives an overview of the resulting average supply currents for the different sleep phase durations and a selected bandwidth of 1000Hz, assuming no interrupt is active and thus only one sample per wake-up phase is taken:

Table 6: Accelerometer part average current consumption in low-power mode

Sleep phase duration	Average current consumption
0.5ms	100.5 µA
1ms	78.8 µA
2ms	55.0 µA
4ms	34.5 µA
6ms	25.2 µA
10ms	16.4 µA
25ms	7.4 µA
50ms	4.0 µA
100ms	2.3 µA
500ms	0.9 µA
1s	0.7 µA

4.3.2 **Magnetometer power modes**

The BMC050 magnetometer part has four power modes:

Power off mode

In Power off mode, V_{DD} and/or VDDIO are unpowered. The magnetometer part does not operate in this mode. When only one of V_{DD} or V_{DDIO} is supplied, the magnetic sensor will still be in Power off mode. Power on reset is performed after both V_{DD} and V_{DDIO} have risen above their detection thresholds.

Suspend mode

Suspend mode is the default power mode of BMC050 magnetometer part after the chip is powered. When VDD and VDDIO are turned on the POR (power on reset) circuits operate and the device's registers are initialized. After POR becomes inactive, a start up sequence is executed. In this sequence NVM content is downloaded to shadow registers located in the device core. After the start up sequence the device is put in the Suspend mode. In this mode only registers supplied directly by VDDIO which store I^2C slave device address, power control bit information and some others can be accessed by the user. No other registers can be accessed in Suspend mode. All registers lose their content, except the control register (*0x4B*). In particular, in this mode a Chip ID read (register *0x40*) returns "0x00h" (I²C) or high-Z (SPI).

Sleep mode

The user puts device from suspend into Sleep mode by setting the Power bit to "1", or from active modes (normal or forced) by setting OpMode bits to "11". In this state the user has full access to the device registers. In particular, the Chip ID can be read. Setting the power control bit to "0" (register *0x4B bit0*) will bring the device back into Suspend mode. From the Sleep mode the user can put the device back into Suspend mode or into Active mode.

Active mode

The device can switch into Active mode from Sleep mode by setting OpMode bits (register *0x4C*). In active mode the magnetic field measurements are performed. In active mode, all registers are accessible.

In active mode, two operation modes can be distinguished:

- Normal mode: selected channels are periodically measured according to settings set in user registers. After measurements are completed, output data is put into data registers and the device waits for the next measurement period, which is set by programmed output data rate (ODR). From normal mode, the user can return to sleep mode by setting OpMode to “11” or by performing a soft reset (see chapter 6.6). Suspend mode can be entered by setting power control bit to “0”.
- Forced mode (single measurement): When set by the host, the selected channels are measured according to settings programmed in user registers. After measurements are completed, output data is put into data registers, OpMode register value returns to “11” and the device returns to sleep mode. The forced mode is useful to achieve synchronized operation between host microcontroller and BMC050. Also, different data output rates from the ones selectable in normal mode can be achieved using forced mode.

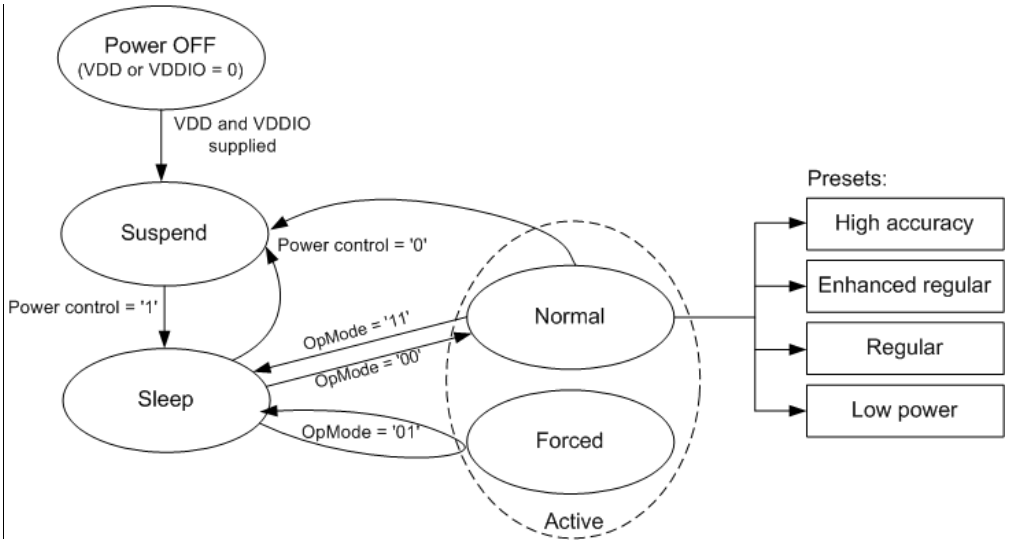


Figure 4: Magnetometer power mode transition diagram

In Active Mode and normal operation, in principle any desired balance between output noise and active time (hence power consumption) can be adjusted by the repetition settings for x/y-axis and z-axis and the output data rate ODR. The average power consumption depends on the ratio of high current phase time (during data acquisition) and low current phase time (between data acquisitions). Hence, the more repetitions are acquired to generate one magnetic field data point, the longer the active time ratio in one sample phase, and the higher the average current. Thanks to longer internal averaging, the noise level of the output data reduces with increasing number of repetitions.

By using forced mode, it is possible to trigger new measurements at any rate. The user can therefore trigger measurements in a shorter interval than it takes for a measurement cycle to complete. If a measurement cycle is not allowed to complete, the resulting data will not be written into the data registers. To prevent this, the manually triggered measurement intervals must not be shorter than the active measurement time which is a function of the selected number of repetitions. The maximum selectable read-out frequency in forced mode can be calculated as follows:

$$f_{\max,ODR} \approx \frac{1}{145\mu s \times nXY + 500\mu s \times nZ + 980\mu s}$$

Hereby nXY is the number of repetitions on X/Y-axis (not the register value) and nZ the number of repetitions on Z-axis (not the register value) (see description of XY_REP and Z_REP registers in chapter 6).

Although the repetition numbers for X/Y and Z axis and the ODR can be adjusted independently and in a wide range, there are four recommended presets (High accuracy preset, Enhanced regular preset, Regular preset, Low power preset) which reflect the most common usage scenarios, i.e. required output accuracy at a given current consumption, of the BMC050 magnetometer part.

The three presets consist of the below register configurations, which are automatically set by the BMC050 API or driver provided by Bosch Sensortec when a preset is selected. Table 7 shows the recommended presets and the resulting magnetic field output noise and magnetometer part current consumption:

Table 7: Magnetometer presets in Active operation and normal mode:

Preset	X/Y rep	Z rep	ODR	ODR_{max} (forced mode)	RMS Noise x/y/z	Average current consumption
Low power preset	3	3	10 Hz	>300 Hz	1.0/1.0/1.4 µT	170 µA
Regular preset	9	15	10 Hz	100 Hz	0.6/0.6/0.6 µT	0.5 mA
Enhanced regular preset	15	27	10 Hz	60 Hz	0.5/0.5/0.5 µT	0.8 mA
High accuracy preset	47	83	20 Hz	20 Hz	0.3/0.3/0.3 µT	4.9 mA

4.3.3 **BMC050 overall power consumption**

Below, Table 8 shows the overall current consumption of BMC050 (sum of accelerometer and magnetometer part) in typical scenarios such as a tilt-compensated electronic compass application.

Table 8: BMC050 overall current consumption in typical usage scenarios:

Compass preset	Acc. Active / sleep interval	Mag. DOR	Acc. BW / DOR	Mag. avg. current	Acc. avg. current	Total average current
Low power preset	8 / 50 ms	10 Hz	62.5 / 17 Hz	170 µA	20 µA	190 µA
Regular preset	16 / 50 ms	10 Hz	31 / 15 Hz	0.5 mA	35 µA	0.54 mA
Enhanced regular preset	16 / 50 ms	10 Hz	31 / 15 Hz	0.8 mA	35 µA	0.84 mA
High accuracy preset	16 /25 ms	20 Hz	31 / 24 Hz	4.9 mA	55 µA	5.0 mA

4.4 Sensor data

4.4.1 **Acceleration data**

The width of acceleration data is 10 bits given in two´s complement representation. The 10 bits for each axis are split into an MSB upper part (one byte containing bits 9 to 2) and an LSB lower part (one byte containing bits 1 and 0 of acceleration and a *(0x02, 0x04, 0x06) new_data* flag). Reading the acceleration data registers shall always start with the LSB part. The content of an MSB register is updated by reading the corresponding LSB register (shadowing procedure). The shadowing procedure can be disabled (enabled) by writing “1” (“0”) to the bit *shadow_dis*. With disabled shadowing, the content of both MSB and LSB registers is updated by a new value immediately. Unused bits of the LSB registers are fixed to 0. The *(0x02, 0x04, 0x06) new_data* flag of each LSB register is set if the data registers are updated, it is reset if either the corresponding MSB or LSB part is read.

Two different streams of acceleration data are available, unfiltered and filtered. The unfiltered data is sampled with 2kHz. The sampling rate of the filtered data depends on the selected filter bandwidth; it is twice the bandwidth. Which kind of data is stored in the acceleration data registers depends on bit *(0x13) data_high_bw*. If *(0x13) data_high_bw* is “0” (“1”), then filtered (unfiltered) data is stored in the registers. Both data streams are separately offset-compensated. Both kinds of data can be processed by the interrupt controller.

The bandwidth of filtered acceleration data is determined by setting the *(0x10) bw* bit as follows:

Table 9: Bandwidth configuration

bw	Bandwidth	Update Time t_{ut}
00xxx	*)	-
01000	7.81Hz	64ms
01001	15.63Hz	32ms
01010	31.25Hz	16ms
01011	62.5Hz	8ms
01100	125Hz	4ms
01101	250Hz	2ms
01110	500Hz	1ms
01111	1000Hz	0.5ms
1xxxx	*)	-

*) Note: Settings 00xxx result in a bandwidth of 7.81 Hz; settings 1xxxx result in a bandwidth of 1000 Hz. It is recommended to actively use the range from “01000b” to “01111b” only in order to be compatible with future products.

The BMC050's accelerometer part supports four different acceleration measurement ranges. A measurement range is selected by setting the *(0x0F)* range bits as follows:

Table 10: Range selection

Range	Acceleration measurement range	Resolution
0011	±2g	3.91mg/LSB
0101	±4g	7.81mg/LSB
1000	±8g	15.62mg/LSB
1100	±16g	31.25mg/LSB
others	reserved	-

4.4.2 **Temperature data**

The width of temperature data is 8 bits given in two´s complement representation. Temperature values are available in the *(0x08) temp* register.

The slope of the temperature sensor is 0.5K/LSB, its center temperature is 24°C [*(0x08) temp* = 0x00]. Therefore, the typical temperature measurement range is -40°C up to 87.5°C.

4.4.3 **Magnetic field data**

The representation of magnetic field data is different between X/Y-axis and Z-axis. The width of X- and Y-axis magnetic field data is 13 bits each and stored in two's complement.
DATAX_LSB (*0x42*) contains 5-bit LSB part [4:0] of the 13 bit output data of the X-channel.
DATAX_MSB (*0x43*) contains 8-bit MSB part [12:5] of the 13 bit output data of the X-channel.
DATAY_LSB (*0x44*) contains 5-bit LSB part [4:0] of the 13 bit output data of the Y-channel.
DATAY_MSB (*0x45*) contains 8-bit MSB part [12:5] of the 13 bit output data of the Y-channel.

The width of the Z-axis magnetic field data is 15 bit word stored in two's complement.
DATAZ_LSB (*0x46*) contains 7-bit LSB part [6:0] of the 15 bit output data of the Z-channel.
DATAZ_MSB (*0x47*) contains 8-bit MSB part [14:7] of the 15 bit output data of the Z-channel.

For all axes, temperature compensation on the host is used to get ideally matching sensitivity over the full temperature range. The temperature compensation is based on a resistance measurement of the hall sensor plate. The resistance value is represented by a 14 bit unsigned output word.
RHALL_LSB (*0x48*) contains 6-bit LSB part [5:0] of the 14 bit output data of the RHALL-channel.
RHALL_MSB (*0x49*) contains 8-bit MSB part [13:6] of the 14 bit output data of the RHALL-channel.

All signed register values are in two´s complement representation. Bits which are marked "reserved" can have different values or can in some cases not be read at all (read will return 0x00 in I²C mode and high-Z in SPI mode).

Data register readout and shadowing is implemented as follows:
After all enabled axes have been measured, complete data packages consisting of DATAX, DATAY, DATAZ and RHALL are updated at once in the data registers. This way, it is prevented

that a following axis is updated while the first axis is still being read (axis mix-up) or that MSB part of an axis is updated while LSB part is being read.
While reading from any data register, data register update is blocked. Instead, incoming new data is written into shadow registers which will be written to data registers after the previous read sequence is completed (i.e. upon stop condition in I²C mode, or CSB going high in SPI mode, respectively). Hence, it is recommended to read out at all data at once (*0x42* to *0x49* or *0x4A* if status bits are also required) with a burst read.
Single bytes or axes can be read out, while in this case it is not assured that adjacent registers are not updated during readout sequence.

The “Data ready status” bit (register *0x48 bit0*) is set “1” when the data registers have been updated but the data was not yet read out over digital interface. Data ready is cleared (set “0”) directly after completed read out of any of the data registers and subsequent stop condition (I²C) or lifting of CSB (SPI).

In addition, when enabled the “Data overrun” bit (register *0x4A bit7*) turns “1” whenever data registers are updated internally, but the old data was not yet read out over digital interface (i.e. data ready bit was still high). The “Data overrun” bit is cleared when the interrupt status register *0x4A* is read out. This function needs to be enabled separately by setting the “Data overrun En” bit (register *0x4D bit7*)).

Note: Please also see chapter 6 for detailed register descriptions.

4.4.4 **Magnetic field data temperature compensation**

The raw register values DATAX, DATAY, DATAZ and RHALL are read out from the host processor using the BMC050 API/driver which is provided by Bosch Sensortec. The API/driver performs an off-chip temperature compensation and outputs x/y/z magnetic field data in 16 LSB/µT to the upper application layer:

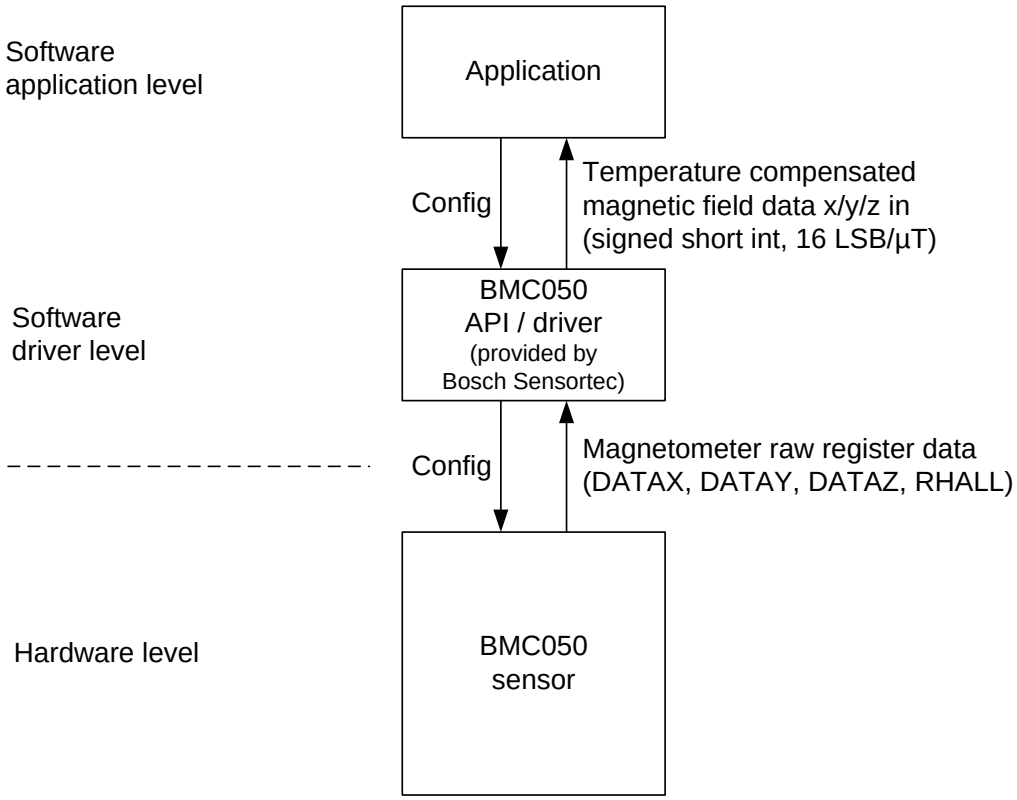


Figure 5: Calculation flow of magnetic field data from raw BMC050 register data

The API/driver performs all calculations using highly optimized fixed-point C-code arithmetic. For platforms that do not support C code, a floating-point formula is available as well.

4.5 Self-test

4.5.1 **Accelerometer self-test**

This feature permits to check the BMC050's accelerometer part functionality by applying electrostatic forces to the sensor core instead of external accelerations. By actually deflecting the seismic mass, the entire signal path of the sensor can be tested. Activating the self-test results in a static offset of the acceleration data; any external acceleration or gravitational force applied to the sensor during active self-test will be observed in the output as a superposition of both acceleration and self-test signal.

The self-test is activated individually for each axis by writing the proper value to the *(0x32) self_test_axis* bits ("01b" for x-axis, "10b" for y-axis, "11b" for z-axis, "00b" to deactivate self-test). It is possible to control the direction of the deflection through bit *(0x32) self_test_sign*. The excitation occurs in positive (negative) direction if *(0x32) self_test_sign* = "0" ("1").

In order to ensure a proper interpretation of the self-test signal it is recommended to perform the self-test for both (positive and negative) directions and then to calculate the difference of the resulting acceleration values. Table 11 shows the minimum differences for each axis. The actually measured signal differences can be significantly larger.

Table 11: Self-test difference values

	x-axis signal	y-axis signal	z-axis signal
resulting minimum difference signal	+0.8 g	+0.8 g	+0.4 g

It is recommended to perform a reset of the device after self-test. If the reset cannot be performed, the following sequence must be kept to prevent unwanted interrupt generation: disable interrupts, change parameters of interrupts, wait for at least 600 µs, enable desired interrupts.

4.5.2 **Magnetometer self-test**

BMC050 supports two self-tests modes for the magnetometer part: Normal self-test and advanced self-test.

Normal self test

During normal self-test, the following verifications are performed:

- FlipCore signal path is verified by generating signals on-chip. These are processed through the signal path and the measurement result is compared to known thresholds.
- FlipCore (X and Y) bondwires to ASIC are checked for connectivity
- FlipCore (X and Y) bondwires and MEMS are checked for shorts
- Hall sensor connectivity is checked for open and shorted connections
- Hall sensor signal path and hall sensor element offset are checked for overflow.

To perform a self test, the sensor must first be put into sleep mode (OpMode = "11"). Self-test mode is then entered by setting the bit "Self test" (register *0x4C bit0*) to "1". After performing self

test, this bit is set back to “0”. When self-test is successful, the corresponding self-test result bits are set to “1” (“X-Self-Test” register *0x42 bit0*, “Y-Self-Test” register *0x44 bit0*, “Z-Self-Test” register *0x46 bit0*). If self-test fails for an axis, the corresponding result bit returns “0”.

Advanced self test

Advanced self test performs a verification of the Z channel signal path functionality and sensitivity. An on-chip coil wound around the hall sensor can be driven in both directions with a calibrated current to generate a positive or negative field of around 100 µT.

Advanced self test is an option that is active in parallel to the other operation modes. The only difference is that during the active measurement phase, the coil current is enabled. The recommended usage of advanced self test is the following:

1. Set sleep mode
2. Disable X, Y axis
3. Set Z repetitions to desired level
4. Enable positive advanced self test current
5. Set forced mode, readout Z and R channel after measurement is finished
6. Enable negative advanced self test current
7. Set forced mode, readout Z and R channel after measurement is finished
8. Disable advanced self test current (this must be done manually)
9. Calculate difference between the two compensated field values. This difference should be around 200 µT with some margins.
10. Perform a soft reset of manually restore desired settings

Please refer to the corresponding application note for the exact thresholds to evaluate advanced self-test.

Below table describes how the advanced self-test is controlled:

Table 12: Magnetometer advanced self-test control

(0x4C) Adv.ST <1:0>	**Configuration**
00b	Normal operation (no self-test), default
01b	*Reserved, do not use*
10b	Negative on-chip magnetic field generation
11b	Positive on-chip magnetic field generation

The BMC050 API/driver provided by Bosch Sensortec provides a comfortable way to perform both self-tests and to directly obtain the result without further calculations. It is recommended to use this as a reference.

4.6 Accelerometer offset compensation

Offsets in measured acceleration signals can have several causes but they are always unwanted and disturbing in many cases. Therefore, the BMC050 offers an advanced set of four digital offset compensation methods which are closely matched to each other. These are slow, fast, and manual compensation, and inline calibration.

The compensation is performed for unfiltered and filtered acceleration data independently. It is done by adding a compensation value to the acceleration data coming from the ADC. The result of this computation is saturated if necessary to prevent any overflow errors (the smallest or biggest possible value is set, depending on the sign). However, the public registers used to read and write compensation values have only a width of 8 bits.

An overview of the offset compensation principle is given in Figure 6:

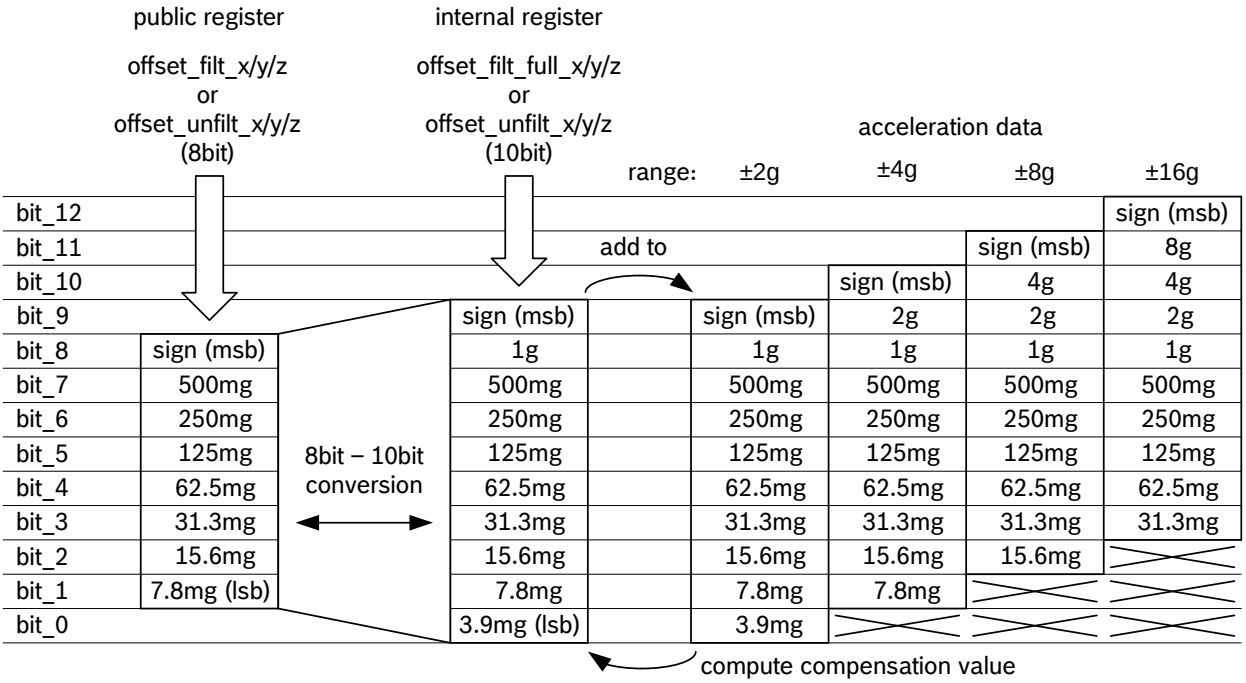


Figure 6: Principle of offset compensation

The meaning of both public and internal registers is the same for all acceleration measurement ranges. Therefore, with measurement ranges other than ±2g, one or more lower significant bits of the internal registers are lost when added to an acceleration value, or are set to zero when the internal compensation value is computed. If a compensation value is too small or too big to fit into the corresponding internal register, it is saturated to prevent an overflow error.

In a similar way the conversion of the internal register value to the public register value (10bit to 8bit) uses saturation.

Summarized, in dependence to the measurement range which has been set, the compensation value, which has been written into the public register will correct the data output according to Figure 6.

e.g. ±2g range:
public register = 00000001b → add to acceleration data = ±7.8mg = +2LSB
public register = 00000010b → add to acceleration data = +15.6mg = +4LSB
public register = 00000101b → add to acceleration data = +39.1mg = +10LSB

The public registers are image registers of EEPROM registers. With each image update (see chapter 4.7 for details) the contents of the non-volatile EEPROM registers are written to the public registers. At any time the public register can be over-written by the user. After changing the contents of the public registers by either an image update or manually, all 8bit values are widened to 10bit values and stored in the corresponding internal registers. In the opposite direction, if the value of an internal register changes due to the computation performed by a compensation algorithm, it is converted to an 8bit value and stored in the public register.
For slow and fast offset compensation, the compensation target can be chosen by setting the bits *(0x37) offset_target_x*, *(0x37) offset_target_y*, and *(0x37) offset_target_z* according to Table 13:

Table 13: Offset target settings

(0x37) offset_target_x/y/z	**Target value**
00b	0g
01b	+1g
10b	-1g
11b	0g

By writing "1" to the *(0x36) offset_reset* bit, all offset compensation registers are reset to zero.

4.6.1 **Slow compensation**

Slow compensation is a quasi-continuous process which regulates the acceleration value of each axis towards the target value by comparing the current value with the target and adding or subtracting a fixed value depending on the comparison.

The algorithm in detail: If an acceleration value is larger (smaller) than the target value *(0x37) offset_target_x/y/z* for a number of samples (given by the parameter Offset Period, see Table 14), the internal offset compensation value *(0x38, 0x39, 0x3A) offset_filt_x/y/z* or *(0x3B, 0x03C, 0x3D) offset_unfilt_x/y/z* is decremented (incremented) by 4 LSB.

The public registers *(0x38, 0x39, 0x3A) offset_filt_x/y/z* and *(0x3B, 0x03C, 0x3D) offset_unfilt_x/y/z* are not used for the computations but they are updated with the contents of the internal registers (using saturation if necessary) and can be read by the user.

The compensation period offset_period is set by the *(0x37) cut_off* bit as represented in Table 14:

Table 14: Compensation period settings

(0x37) cut_off	Offset Period
0b	8
1b	16

The slow compensation can be enabled (disabled) for each axis independently by setting the bits *(0x36) hp_x_en, hp_y_en, hp_z_en* to “1” (“0”), respectively.

Slow compensation should not be used in combination with low-power mode. In low-power mode the conditions (availability of necessary data) for proper function of slow compensation are not fulfilled.

4.6.2 **Fast compensation**

Fast compensation is a one-shot process by which the compensation value is set in such a way that when added to the raw acceleration, the resulting acceleration value of each axis equals the target value.

The algorithm in detail: An average of 16 consecutive acceleration values is computed and the difference between target value and computed value is written to *(0x38, 0x39, 0x3A) offset_filt_x/y/z* or *(0x3B, 0x3C, 0x3D) offset_unfilt_x/y/z* The public registers *(0x38, 0x39, 0x3A) offset_filt_x/y/z* and *(0x3B, 0x3C, 0x3D) offset_unfilt_x/y/z* are updated with the contents of the internal registers (using saturation if necessary) and can be read by the user.

Fast compensation is triggered for each axis individually by setting the *(0x36) cal_trigger* bits as shown in Table 15:

Table 15: Fast compensation axis selection

(0x36) cal_trigger	Selected Axis
00b	none
01b	x
10b	y
11b	z

The register *(0x36) cal_trigger* keeps its non-zero value while the fast compensation procedure is running. Slow compensation is blocked as long as fast compensation endures. Bit *(0x36) cal_rdy* is “0” when *(0x36) cal_trigger* is not “00”.

Fast compensation should not be used in combination with low-power mode. In low-power mode the conditions (availability of necessary data) for proper function of fast compensation are not fulfilled.

4.6.3 **Manual compensation**

As explained above, the contents of the public compensation registers *(0x38, 0x39, 0x3A) offset_filt_x/y/z* and *(0x3B, 0x3C, 0x3D) offset_unfilt_x/y/z* can be set manually via the digital interface. It is recommended to write into these registers immediately after a new data interrupt in order not to disturb running offset computations.

Writing to the offset compensation registers is not allowed if slow compensation is enabled or if the fast compensation procedure is running.

4.6.4 **Inline calibration**

For a given application, it is often desirable to calibrate the offset once and to store the compensation values permanently. This can be achieved by using one of the aforementioned offset compensation methods to determine the proper compensation values and then storing these values permanently in the non-volatile memory (EEPROM). See chapter 4.7 for details of the storing procedure.

Each time the device is reset, the compensation values are loaded from the non-volatile memory into the image registers and used for offset compensation until they are possibly overwritten using one of the other compensation methods.

4.7 Non-volatile memory

4.7.1 **Accelerometer non-volatile memory**

The memory of the accelerometer part of BMC050 consists of three different kinds of registers: hard-wired, volatile, and non-volatile. Non-volatile memory is implemented as EEPROM. Part of it can be both read and written by the user. Access to non-volatile memory is only possible through (volatile) image registers.

Altogether, there are eight registers (bytes) of EEPROM which are accessible by the customer. The address range of the image registers range from *0x38* to *0x3F*. While the addresses up to *0x3D* are used for offset compensation (see 4.6 Offset Compensation), addresses *0x3E* and *0x3F* are general purpose registers not linked to any sensor-specific functionality.

The content of the EEPROM is loaded to the image registers after a reset (either POR or softreset) or after a user request which is performed by writing “1” to bit *(0x33) nvm_load*. As long as the image update is not yet complete, bit *(0x33) nvm_load* is “1”, otherwise it is “0”.

The image registers can be read and written like any other register.

Writing to the EEPROM is a three-step procedure:

1. Write the new contents to the image registers.
2. Write “1” to bit *(0x33) nvm_prog_mode* in order to unlock the EEPROM.
3. Write “1” to bit *(0x33) nvm_prog_trig* and keep “1” in bit *(0x33) nvm_prog_mode* in order to trigger the write process.

Writing to the EEPROM always renews the entire EEPROM contents. It is possible to check the write status by reading bit *(0x33) nvm_rdy*. While *(0x33) nvm_rdy* = “0”, the write process is still enduring; if *(0x33) nvm_rdy* = “1”, then writing is completed. As long as the write process is ongoing, no power mode change and no image update is allowed. It is forbidden to write to the EEPROM while the image update is running, in low-power mode, and in suspend mode.

4.7.2 **Magnetometer non-volatile memory**

Some of the memory of the BMC050 magnetometer is non-volatile memory (NVM). This NVM is pre-programmed in Bosch Sensortec fabrication line and can not be modified afterwards. It contains trimming data which are required for sensor operation and sensor data compensation, thus it is read out by the BMC050 API/driver during initialization.

4.8 Accelerometer interrupt controller

Seven accelerometer based interrupt engines are integrated in the accelerometer part of BMC050. Each interrupt can be independently enabled and configured. If the condition of an enabled interrupt is fulfilled, the corresponding status bit is set to “1” and the selected interrupt pin is activated. There are two interrupt pins for the accelerometer part, INT1 and INT2; interrupts can be freely mapped to any of these pins. The pin state is a logic ´or´ combination of all mapped interrupts.

The interrupt status registers are updated together with writing new data into the acceleration data registers. If an interrupt is disabled, all active status bits and pins are immediately reset.
All time constants are based upon the typical frequency of the internal oscillator. This is reflected by the bandwidths (*bw*) as specified in Table 9.

4.8.1 **General features**

An interrupt is cleared depending on the selected interrupt mode, which is common to all interrupts. There are three different interrupt modes for the accelerometer part: non-latched, latched, and temporary. The mode is selected by the *(0x21) latch_int* bits according to Table 16.

Table 16: Accelerometer interrupt mode selection

(0x21) latch_int	**Interrupt mode**
0000b	non-latched
0001b	temporary, 250ms
0010b	temporary, 500ms
0011b	temporary, 1s
0100b	temporary, 2s
0101b	temporary, 4s
0110b	temporary, 8s
0111b	latched
1000b	non-latched
1001b	temporary, 500µs
1010b	temporary, 500µs
1011b	temporary, 1ms
1100b	temporary, 12.5ms
1101b	temporary, 25ms
1110b	temporary, 50ms
1111b	latched

An interrupt is generated if its activation condition is met. It can not be cleared as long as the activation condition is fulfilled. In the non-latched mode the interrupt status bit and the selected pin (the contribution to the ´or´ condition for INT1 and/or INT2) are cleared as soon as the activation condition is no more valid. Exceptions to this behaviour are the new data, orientation, and flat interrupts, which are automatically reset after a fixed time.

In the latched mode an asserted interrupt status and the selected pin are cleared by writing “1” to bit *(0x21) reset_int*. If the activation condition still holds when it is cleared, the interrupt status is asserted again with the next change of the acceleration registers.

In the temporary mode an asserted interrupt and selected pin are cleared after a defined period of time. The behaviour of the different interrupt modes is shown graphically in Figure 7:

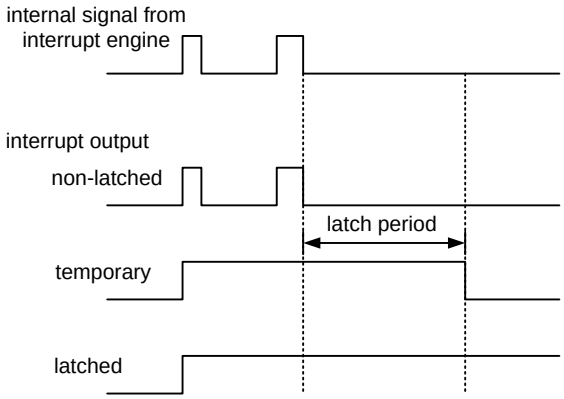


Figure 7: Interrupt modes

Several interrupt engines can use either unfiltered or filtered acceleration data as their input. For these interrupts, the source can be selected with the respective *(0x1E) int_src_...* bits, in details these are *(0x1E) int_src_data*, *(0x1E) int_src_tap*, *(0x1E) int_src_slope*, *(0x1E) int_src_high*, and *(0x1E) int_src_low*. Setting the respective bits to “0” (“1”) selects filtered (unfiltered) data as input. For the other interrupts, orientation recognition and flat detection, such a selection is not possible. They always use filtered input data.

It is strongly recommended to set interrupt parameters prior to enabling the interrupt. Changing parameters of an already enabled interrupt may cause unwanted interrupt generation and generation of a false interrupt history. A safe way to change parameters of an enabled interrupt is to keep the following sequence: disable the desired interrupt, change parameters, wait for at least 600 μs, enable the desired interrupt.

4.8.2 **Mapping (inttype to INT Pin#)**

The mapping of interrupts to the interrupt pins #05 or #06 is done by registers *(0x19)* to *(0x1B)*. Setting *(0x19) int1_*”inttyp” to “1” (“0”) maps (unmaps) “inttyp” to pin #5 (INT1), correspondingly setting *(0x1B) int2_*”inttyp” to “1” (“0”) maps (unmaps) “inttyp” to pin #6 (INT2).

Note: “inttyp” to be replaced with the precise notation, given in the memory map in chapter 5.

Example: For flat interrupt (int1_flat): Setting *(0x19) int1_flat* to “1” maps *int1_flat* to pin #5 (INT1).

4.8.3 **Electrical behavior (INT pin# to open-drive or push-pull)**

Both interrupt pins can be configured to show desired electrical behaviour. The ´active´ level of each pin is determined by the *(0x20) int1_lvl* and *(0x20) int2_lvl* bits.

If *(0x20) int1_lvl* = “1” (“0”) / *(0x20) int2_lvl* = “1” (“0”), then pin #05 (INT1) / pin #06 (INT2) is active “1” (“0”). In addition to that, also the electric type of the interrupt pins can be selected. By setting bits *(0x20) int1_od* / *(0x20) int2_od* to “0”, the interrupt pin output type becomes open-drive, by setting the configuration bits to “1”, the output type becomes push-pull.

Remark: The states of both INT pins are not defined during the first 2 ms after power-up.

4.8.4 **New data interrupt**

This interrupt serves for synchronous reading of acceleration data. It is generated after storing a new value of z-axis acceleration data in the data register. The interrupt is cleared automatically when the next cycle of data acquisition starts. The interrupt status is “0” for at least 50µs.

The interrupt mode of the new data interrupt is fixed to non-latched.

It is enabled (disabled) by writing “1” (“0”) to bit *(0x17) data_en*. The interrupt status is stored in bit *(0x0A) data_int*.

4.8.5 **Any-motion (slope) detection**

Any-motion detection uses the slope between successive acceleration signals to detect changes in motion. An interrupt is generated when the slope (absolute value of acceleration difference) exceeds a preset threshold. It is cleared as soon as the slope falls below the threshold. The principle is clarified in Figure 8.

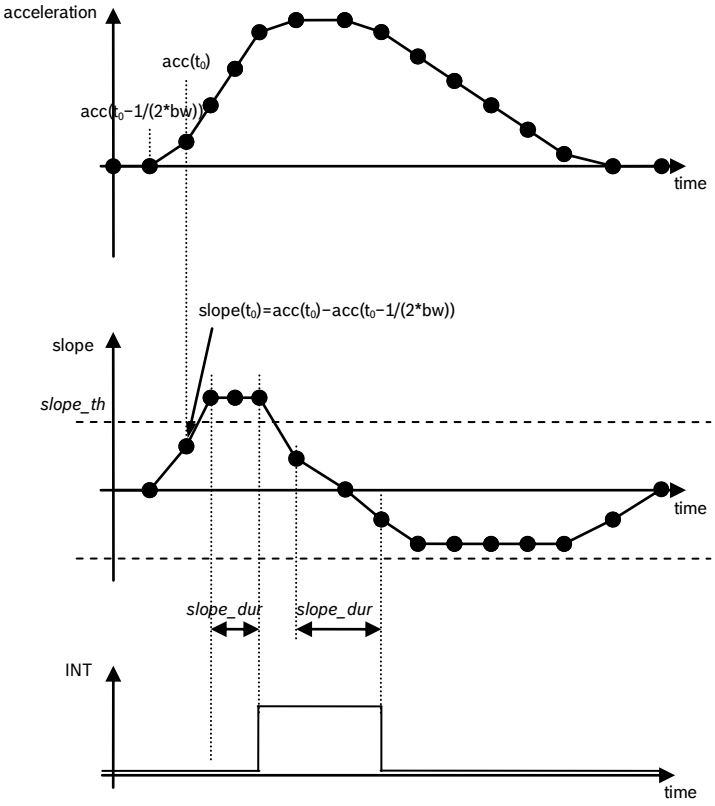


Figure 8: Principle of any-motion detection

The threshold is set with the value of register *(0x28) slope_th*. 1 LSB of *(0x28) slope_th* corresponds to 1 LSB of acceleration data. Therefore, an increment of *(0x28) slope_th* is 3.91 mg in 2g-range (7.81 mg in 4g-range, 15.6 mg in 8g-range and 31.3 mg in 16g-range). And the maximum value is 996 mg in 2g-range (1.99g in 4g-range, 3.98g in 8g-range and 7.97g in 16g-range).

The time difference between the successive acceleration signals depends on the selected bandwidth and equates to 1/(2*bandwidth) (Δt=1/(2*bw)). In order to suppress failure signals, the interrupt is only generated (cleared) if a certain number *N* of consecutive slope data points is larger (smaller) than the slope threshold given by *(0x28) slope_th*. This number is set by the *(0x27) slope_dur* bits. It is *N* = *(0x27) slope_dur* + 1 for *(0x27)*.

Example: *(0x27) slope_dur* = 00b, ..., 11b = 1decimal, ..., 4decimal

4.8.5.1 Enabling (disabling) for each axis

Any-motion detection can be enabled (disabled) for each axis separately by writing “1” (“0”) to bits *(0x16) slope_en_x*, *(0x16) slope_en_y*, *(0x16) slope_en_z*. The criteria for any-motion detection are fulfilled and the slope interrupt is generated if the slope of any of the enabled axes exceeds the threshold *(0x28) slope_th* for [*(0x27) slope_dur* +1] consecutive times. As soon as the slopes of all enabled axes fall or stay below this threshold for [*(0x27) slope_dur* +1] consecutive times the interrupt is cleared unless interrupt signal is latched.

4.8.5.2 Axis and sign information of any motion interrupt

The interrupt status is stored in bit *(0x09) slope_int*. The any-motion interrupt supplies additional information about the detected slope. The axis which triggered the interrupt is given by that one of bits *(0x0B) slope_first_x*, *(0x0B) slope_first_y*, *(0x0B) slope_first_z* that contains a “1”. The sign of the triggering slope is held in bit *(0x0B) slope_sign*. If *(0x0B) slope_sign* = “0” (“1”), the sign is positive (negative).

4.8.5.3 Serial interface and dedicated wake-up mode

When serial interface is active, any-motion detection logic is enabled if any of the axis specific *(0x16) slope_en_...* register bits are set. To disable the any-motion interrupt, clear all the axis specific *(0x16) slope_en_...* bits.

4.8.6 **Tap sensing**

Tap sensing has a functional similarity with a common laptop touch-pad or clicking keys of a computer mouse. A tap event is detected if a pre-defined slope of the acceleration of at least one axis is exceeded. Two different tap events are distinguished: A ‘single tap’ is a single event within a certain time, followed by a certain quiet time. A ‘double tap’ consists of a first such event followed by a second event within a defined time frame.

Only one of the tap interrupts can be enabled at the same time. Single tap interrupt is enabled (disabled) by writing “1” (“0”) to bit *(0x16) s_tap_en*. Double tap interrupt is enabled (disabled) by writing “1” (“0”) to bit *(0x16) d_tap_en*. If one tries to enable both interrupts by writing “1” to *(0x16) s_tap_en* and *(0x16) d_tap_en*, then only *(0x16) d_tap_en* keeps the value “1” and the double tap interrupt is enabled.
The status of the single tap interrupt is stored in bit *(0x09) s_tap_int*, the status of the double tap interrupt is stored in bit *(0x09) d_tap_int*.

The slope threshold for detecting a tap event is set by bits *(0x2B) tap_th*. The meaning of *(0x2B) tap_th* depends on the range setting. 1 LSB of *(0x2B) tap_th* corresponds to a slope of 62.5mg in 2g-range, 125mg in 4g-range, 250mg in 8g-range, and 500mg in 16g-range.

In Figure 9 the meaning of the different timing parameters is visualized:

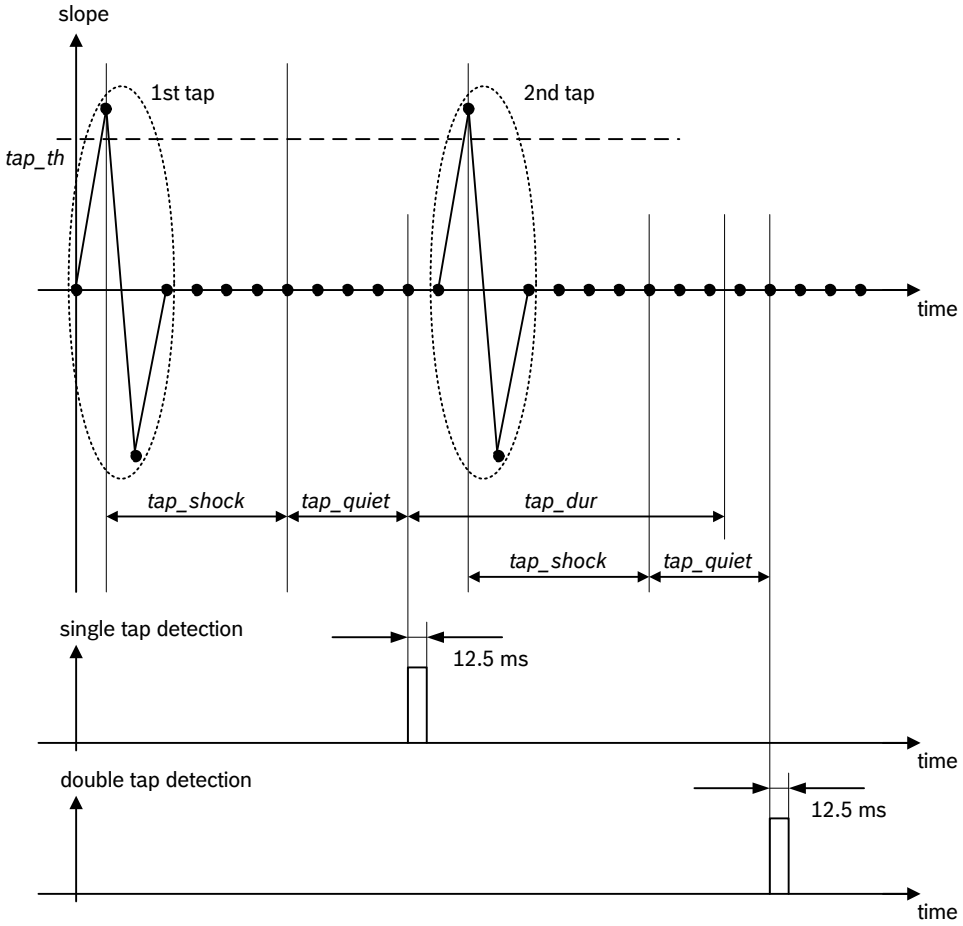


Figure 9: Timing of tap detection

The parameters *(0x2A) tap_shock* and *(0x2A) tap_quiet* apply to both single tap and double tap detection, while *(0x2A) tap_dur* applies to double tap detection only. Within the duration of *(0x2A) tap_shock* any slope exceeding *(0x2B) tap_th* after the first event is ignored. Contrary to this, within the duration of *(0x2A) tap_quiet* no slope exceeding *(0x2B) tap_th* must occur, otherwise the first event will be cancelled.

4.8.6.1 Single tap detection

A single tap is detected and the single tap interrupt is generated after the combined durations of *(0x2A) tap_shock* and *(0x2A) tap_quiet*, if the corresponding slope conditions are fulfilled. The interrupt is cleared after a delay of 12.5 ms.

4.8.6.2 Double tap detection

A double tap is detected and the double tap interrupt is generated if an event fulfilling the conditions for a single tap occurs within the set duration in *(0x2A) tap_dur* after the completion of the first tap event. The interrupt is cleared after a delay of 12.5 ms.

4.8.6.3 Selecting the timing of tap detection

For each of parameters *(0x2A) tap_shock* and *(0x2A) tap_quiet* two values are selectable. By writing "0" ("1") to bit *(0x2A) tap_shock* the duration of *(0x2A) tap_shock* is set to 50 ms (75 ms). By writing "0" ("1") to bit *(0x2A) tap_quiet* the duration of *(0x2A) tap_quiet* is set to 30 ms (20 ms).

The length of *(0x2A) tap_dur* can be selected by setting the *(0x2A) tap_dur* bits according to Table 17:

Table 17: Selection of *tap_dur*

(0x2A) tap_dur	**length of *tap_dur***
000b	50 ms
001b	100 ms
010b	150 ms
011b	200 ms
100b	250 ms
101b	375 ms
110b	500 ms
111b	700 ms

4.8.6.4 Axis and sign information of tap sensing

The sign of the slope of the first tap which triggered the interrupt is stored in bit *(0x0B) tap_sign* ("0" means positive sign, "1" means negative sign). The value of this bit persists after clearing the interrupt.

The axis which triggered the interrupt is indicated by bits *(0x0B) tap_first_x*, *(0x0B) tap_first_y*, and *(0x0B) tap_first_z*.
The bit corresponding to the triggering axis contains a "1" while the other bits hold a "0". These bits are cleared together with clearing the interrupt status.

4.8.6.5 Tap sensing in low power mode

In low-power mode, a limited number of samples is processed after wake-up to decide whether an interrupt condition is fulfilled. The number of samples is selected by bits *(0x2B) tap_samp* according to Table 18.

Table 18: Meaning of *(0x2B) tap_samp*

(0x2B) tap_samp	**Number of Samples**
00b	2
01b	4
10b	8
11b	16

4.8.7 **Orientation recognition**

The orientation recognition feature informs on an orientation change of the sensor with respect to the gravitational field vector ‘g’. The measured acceleration vector components with respect to the gravitational field are defined as shown in Figure 10.

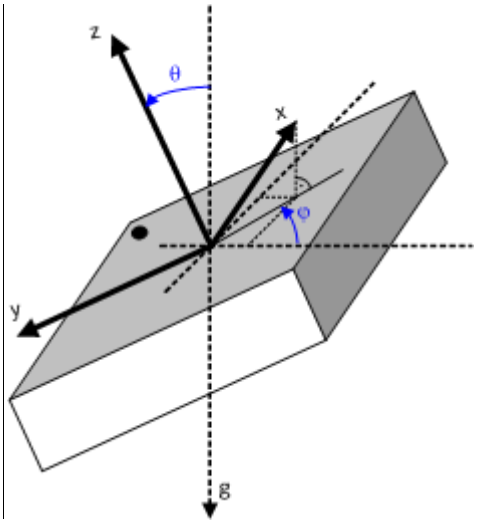


Figure 10: Definition of vector components

Therefore, the magnitudes of the acceleration vectors are calculated as follows:

$$acc\_x = 1g \cdot \sin\theta \cdot \cos\varphi$$
$$acc\_y = -1g \cdot \sin\theta \cdot \sin\varphi$$
$$acc\_z = 1g \cdot \cos\theta$$
$$\rightarrow acc\_y/acc\_x = -\tan\varphi$$

Depending on the magnitudes of the acceleration vectors the orientation of the device in the space is determined and stored in the three *(0x0C) orient* bits. These bits may not be reset in the sleep phase of low-power mode. There are three orientation calculation modes with different thresholds for switching between different orientations: symmetrical, high-asymmetrical, and low-asymmetrical. The mode is selected by setting the *(0x2C) orient_mode* bits as given in Table 19.

Table 19: Orientation mode settings

(0x2C) orient_mode	Orientation Mode
00b	symmetrical
01b	high-asymmetrical
10b	low-asymmetrical
11b	symmetrical

For each orientation mode the *(0x0C) orient* bits have a different meaning as shown in Table 20 to Table 22:

Table 20: Meaning of the *(0x0C) orient* bits in symmetrical mode

(0x0C) orient	Name	Angle	Condition
x00	portrait upright	315° < φ < 45°	|acc_y| < |acc_x| - 'hyst' and acc_x - 'hyst'' ≥ 0
x01	portrait upside down	135° < φ < 225°	|acc_y| < |acc_x| - 'hyst' and acc_x + 'hyst' < 0
x10	landscape left	45° < φ < 135°	|acc_y| ≥ |acc_x| + 'hyst' and acc_y < 0
x11	landscape right	225° < φ < 315°	|acc_y| ≥ |acc_x| + 'hyst' and acc_y ≥ 0

Table 21: Meaning of the *(0x0C) orient* bits in high-asymmetrical mode

(0x0C) orient	Name	Angle	Condition
x00	portrait upright	297° < φ < 63°	|acc_y| < 2·|acc_x| - 'hyst' and acc_x - 'hyst' ≥ 0
x01	portrait upside down	117° < φ < 243°	|acc_y| < 2·|acc_x| - 'hyst' and acc_x + 'hyst' < 0
x10	landscape left	63° < φ < 117°	|acc_y| ≥ 2·|acc_x| + 'hyst' and acc_y < 0
x11	landscape right	243° < φ < 297°	|acc_y| ≥ 2·|acc_x| + 'hyst' and acc_y ≥ 0

Table 22: Meaning of the *(0x0C) orient* bits in low-asymmetrical mode

(0x0C) orient	Name	Angle	Condition
x00	portrait upright	333° < φ < 27°	|acc_y| < 0.5·|acc_x| - 'hyst' and acc_x - 'hyst' ≥ 0
x01	portrait upside down	153° < φ < 207°	|acc_y| < 0.5·|acc_x| - 'hyst' and acc_x + 'hyst' < 0
x10	landscape left	27° < φ < 153°	|acc_y| ≥ 0.5·|acc_x| + 'hyst' and acc_y < 0
x11	landscape right	207° < φ < 333°	|acc_y| ≥ 0.5·|acc_x| + 'hyst' and acc_y ≥ 0

In the preceding tables, the parameter 'hyst' stands for a hysteresis, which can be selected by setting the *(0x0C) orient_hyst* bits. 1 LSB of *(0x0C) orient_hyst* always corresponds to 62.5 mg, in any g-range (i.e. increment is independent from g-range setting). It is important to note that by using a hysteresis ≠ 0 the actual switching angles become different from the angles given in the tables since there is an overlap between the different orientations.

The most significant bit of the *(0x0C) orient* bits (which is displayed as an "x" in the above given tables) contains information about the direction of the z-axis. It is set to "0" ("1") if acc_z ≥ 0 (acc_z < 0).

Figure 11 shows the typical switching conditions between the four different orientations for the symmetrical mode (i.e. without hysteresis):

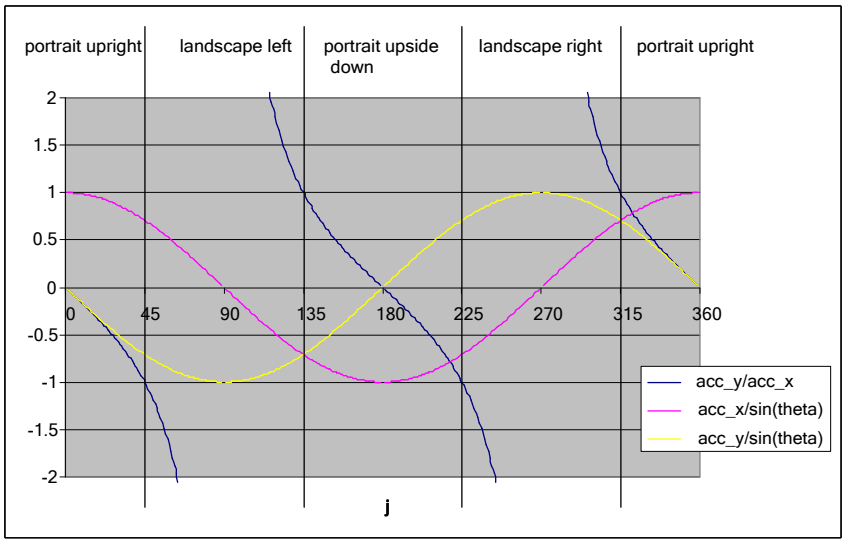


Figure 11: Typical orientation switching conditions w/o hysteresis

The orientation interrupt is enabled (disabled) by writing "1" ("0") to bit *(0x16) orient_en*. The interrupt is generated if the value of *(0x0C) orient* has changed. It is automatically cleared after one stable period of the *(0x0C) orient* value. The interrupt status is stored in the *(0x09) orient_int* bit.

If temporary or latched interrupt mode is used, after the generation of the interrupt the changed *(0x0C) orient* value is kept fixed as long as the interrupt persists (e. g. until the latch time expires or the interrupt is reset). After clearing the interrupt, the *(0x0C) orient* is only updated with the next following value change (i.e. with the next occurring interrupt). In order to ensure the continuous availability of up-to-date orientation data it is therefore optimal to use the non-latched interrupt. It is strongly advised against using latched interrupt mode or temporary interrupt mode with latch times above 50 ms for orient recognition.

4.8.7.1 Orientation blocking

The change of the *(0x0C) orient* value and – as a consequence – the generation of the interrupt can be blocked according to conditions selected by setting the value of the *(0x2C) orient_blocking* bits as described by Table 23.

Table 23: Blocking conditions for orientation recognition

(0x2C) orient_blocking	**Conditions**
00b	no blocking
01b	theta blocking
10b	theta blocking or acceleration slope in any axis > 0.2 g
11b	value of orient is not stable for at least 100 ms or theta blocking or acceleration slope in any axis > 0.4 g

The theta blocking is defined by the following inequality:

$$|\tan\theta| < \frac{\sqrt{blocking\_theta}}{8}.$$

The parameter *blocking_theta* of the above given equation stands for the contents of the *(0x2D) orient_theta* bits. Hereby it is possible to define a blocking angle between 0° and 44.8°. The internal blocking algorithm saturates the acceleration values before further processing. As a consequence, the blocking angles are strictly valid only for a device at rest; they can be different if the device is moved.

Example:
To get a maximum blocking angle of 19° the parameter *blocking_theta* is determined in the following way: (8 * tan(19°))² = 7.588, therefore, *blocking_value* = 8dec = 001000b has to be chosen.

In order to avoid unwanted generation of the orientation interrupt in a nearly flat position (z ~ 0, sign change due to small movements or noise), a hysteresis of 0.2 g is implemented for the z-axis, i. e. a after a sign change the interrupt is only generated after |z| > 0.2 g.

4.8.8 **Flat detection**

The flat detection feature gives information about the orientation of the devices´ z-axis relative to the g-vector, i. e. it recognizes whether the device is in a flat position or not.

The condition for the device to be in the flat position is

$$|\tan\theta| < \frac{\sqrt{parameter\_theta}}{8}.$$

Like *blocking_theta*, used with orientation recognition, the *parameter_theta* stands for a user-defined setting. In this case the content of the *(0x2E) flat_theta* bits. The possible flat angles also range from 0° to 44.8°. To ensure proper operation, *parameter_theta* has to be less than or equal to *blocking_theta*.

The flat interrupt is enabled (disabled) by writing “1” (“0”) to bit *(0x16) flat_en*. The flat interrupt is generated if the flat value has changed and the new value is stable for at least the time given by the *(0x2F) flat_hold_time* bits. The flat value is stored in the *(0x0C) flat* bit if the interrupt is enabled. This value is “1” if the device is in the flat position, it is “0” otherwise. The content of the *(0x0C) flat* bit is changed only if the interrupt is generated. The interrupt is automatically cleared after one sample period. Its status is stored in the *(0x09) flat_int* bit.

If temporary or latched interrupt mode is used, after the generation of the interrupt the changed *(0x0C) flat* value is kept fixed as long as the interrupt persists (e. g. until the latch time expires or the interrupt is reset). After clearing the interrupt, the *(0x0C) flat* value is only updated with the next following value change (i.e. with the next occurring interrupt).

The meaning of the *(0x2F) flat_hold_time* bits can be seen from Table 24.

Table 24: Meaning of flat_hold_time

(0x2F) flat_hold_time	**Time**
00b	0
01b	512 ms
10b	1024 ms
11b	2048 ms

4.8.9 **Low-g interrupt**

This interrupt is based on the comparison of acceleration data against a low-g threshold, which is most useful for free-fall detection.

The interrupt is enabled (disabled) by writing “1” (“0”) to the *(0x17) low_en* bit. There are two modes available, ‘single’ mode and ‘sum’ mode. In ‘single’ mode, the acceleration of each axis is compared with the threshold; in ‘sum’ mode, the sum of absolute values of all accelerations |acc_x| + |acc_y| + |acc_z| is compared with the threshold. The mode is selected by the contents of the *(0x24) low_mode* bit: “0” means ‘single’ mode, “1” means ‘sum’ mode.

The low-g threshold is set through the *(0x23) low_th* register. 1 LSB of *(0x23) low_th* always corresponds to an acceleration of 7.81 mg (i.e. increment is independent from g-range setting).

A hysteresis can be selected by setting the *(0x24) low_hy* bits. 1 LSB of *(0x24) low_hy* always corresponds to an acceleration difference of 125 mg in any g-range (as well, increment is independent from g-range setting).

The low-g interrupt is generated if the absolute values of the acceleration of all axes (´and´ relation, in case of single mode) or their sum (in case of sum mode) are lower than the threshold for at least the time defined by the *(0x22) low_dur* register. The interrupt is reset if the absolute value of the acceleration of at least one axis (´or´ relation, in case of single mode) or the sum of absolute values (in case of sum mode) is higher than the threshold plus the hysteresis for at least one data acquisition. In bit *(0x09) low_int* the interrupt status is stored.

The relation between the content of *(0x22) low_dur* and the actual delay of the interrupt generation is: delay [ms] = [*(0x22) low_dur* + 1] • 2 ms. Therefore, possible delay times range from 2 ms to 512 ms.

4.8.10 **High-g interrupt**

This interrupt is based on the comparison of acceleration data against a high-g threshold for the detection of shock or other high-acceleration events.

The high-g interrupt is enabled (disabled) per axis by writing “1” (“0”) to bits *(0x17) high_en_x*, *(0x17) high_en_y*, and *(0x17) high_en_z*, respectively. The high-g threshold is set through the *(0x26) high_th* register. The meaning of an LSB of *(0x26) high_th* depends on the selected g-range: it corresponds to 7.81 mg in 2g-range, 15.63 mg in 4g-range, 31.25 mg in 8g-range, and 62.5 mg in 16g-range (i.e. increment depends from g-range setting).

A hysteresis can be selected by setting the *(0x24) high_hy* bits. Analogously to *(0x26) high_th*, the meaning of an LSB of *(0x24) high_hy* is g-range dependent: it corresponds to an acceleration difference of 125 mg in 2g-range, 250 mg in 4g-range, 500 mg in 8g-range, and 1000mg in 16g-range (as well, increment depends from g-range setting).

The high-g interrupt is generated if the absolute value of the acceleration of at least one of the enabled axes (´or´ relation) is higher than the threshold for at least the time defined by the *(0x25) high_dur* register. The interrupt is reset if the absolute value of the acceleration of all enabled axes (´and´ relation) is lower than the threshold minus the hysteresis for at least the time defined by the *(0x25) high_dur* register. In bit *(0x09) high_int* the interrupt status is stored. The relation between the content of *(0x25) high_dur* and the actual delay of the interrupt generation is delay [ms] = [*(0x22) low_dur* + 1] • 2 ms. Therefore, possible delay times range from 2 ms to 512 ms.

4.8.10.1 Axis and sign information of high-g interrupt

The axis which triggered the interrupt is indicated by bits *(0x0C) high_first_x*, *(0x0C) high_first_y*, and *(0x0C) high_first_z*. The bit corresponding to the triggering axis contains a “1” while the other bits hold a “0”. These bits are cleared together with clearing the interrupt status. The sign of the triggering acceleration is stored in bit *(0x0C) high_sign*. If *(0x0C) high_sign* = “0” (“1”), the sign is positive (negative).

4.9 Magnetometer interrupt controller

Four magnetometer based interrupt engines are integrated in the magnetometer part of BMC050: Low-Threshold, High-Threshold, Overflow and Data Ready (DRDY). Each interrupt can be enabled independently.

When enabled, an interrupt sets the corresponding status bit in the interrupt status register (*0x4A*) when its condition is satisfied.
When the "Interrupt Pin Enable" bit (register *0x4E bit6*) is set, any occurring activated interrupts are flagged on the BMC050's INT3 output pin. By default, the interrupt pin is disabled (high-Z status).

Low-Threshold, High-Threshold and Overflow interrupts are mapped to the INT3 pin when enabled, Data Ready (DRDY) interrupt is mapped to the DRDY pin of BMC050 when enabled. For High- and Low-Threshold interrupts each axis X/Y/Z can be enabled separately for interrupt detection in the registers "High Int Z en", "High Int Y en", "High Int X en", "Low Int Z en", "Low Int Y En" and "Low Int X En" in register *0x4D bit5-bit0*. Overflow interrupt is shared for X, Y and Z axis.

When the "Data Ready Pin En" bit (register *0x4E bit7*) is set, the Data Ready (DRDY) interrupt event is flagged on the BMC050's DRDY output pin (by default the "Data Ready Pin En" bit is not set and DRDY pin is in high-Z state).
The interrupt status registers are updated together with writing new data into the magnetic field data registers. The status bits for Low-/High-Threshold interrupts are located in register *0x4A*, the Data Ready (DRDY) status flag is located at register *0x48 bit0*.

If an interrupt is disabled, all active status bits and pins are reset after the next measurement was performed.

4.9.1 **General features**

An interrupt is cleared depending on the selected interrupt mode, which is common to all interrupts. There are two different interrupt modes: non-latched and latched. All interrupts (except Data Ready) can be latched or non-latched. Data Ready (DRDY) is always cleared after readout of data registers ends.

A non-latched interrupt will be cleared on a new measurement when the interrupt condition is not valid anymore, whereas a latched interrupt will stay high until the interrupts status register (*0x4A*) is read out. After reading the interrupt status, both the interrupt status bits and the interrupt pin are reset. The mode is selected by the "Interrupt latch" bit (register *0x4A bit1*), where the default setting of "1" means latched. Figure 12 shows the difference between the modes for the example Low-Threshold interrupt.

INT3 and DRDY pin polarity can be changed by the "Interrupt polarity" bit (register *0x4E bit0*) and "DR polarity" (register *0x4E bit2*), from the default high active ("1") to low active ("0").

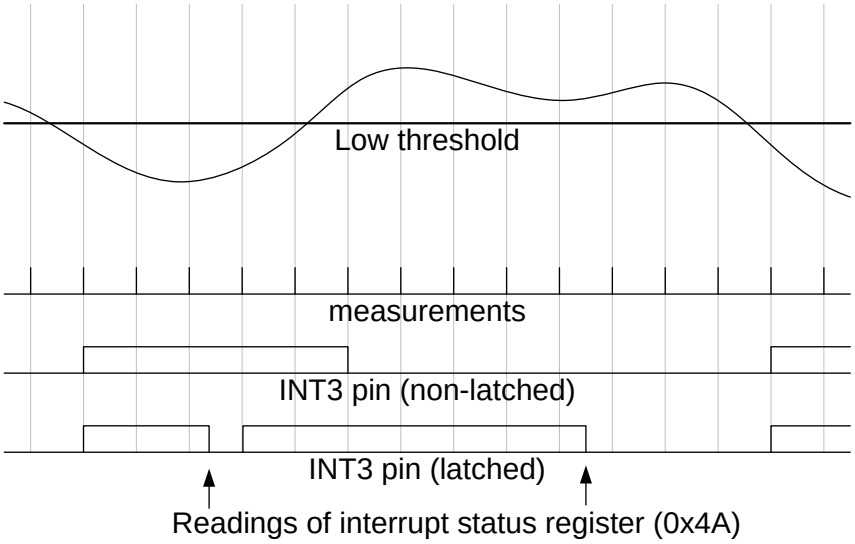


Figure 12: Interrupt latched and non-latched mode

4.9.2 **Electrical behavior of magnetic interrupt pins**

Both interrupt pins INT3 and DRDY are push/pull when the corresponding interrupt pin enable bit is set, and are floating (High-Z) when the corresponding interrupt pin enable bit is disabled (default).

4.9.3 **Data ready / DRDY interrupt**

This interrupt serves for synchronous reading of magnetometer data. It is generated after storing a new set of values (DATAX, DATAY, DATAZ, RHALL) in the data registers:

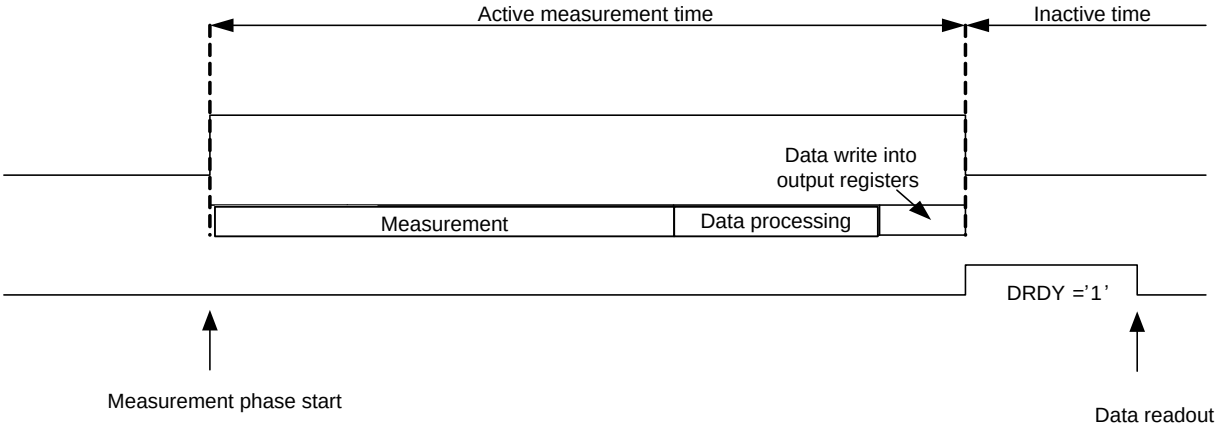


Figure 13: Data acquisition and DRDY operation (DRDY in “high active” polarity)

The interrupt mode of the Data Ready (DRDY) interrupt is fixed to non-latched.

It is enabled (disabled) by writing “1” (“0”) to “Data Ready pin En” in register *0x4E bit7*.

DRDY pin polarity can be changed by the “DR polarity” bit (register *0x4E bit2*), from the default high active (“1”) to low active (“0”).

4.9.4 **Low-threshold interrupt**

When the data registers’ (DATAX, DATAY and DATAZ) values drop below the threshold level defined by the “Low Threshold register (*0x4F*), the corresponding interrupt status bits for those axes are set (“Low Int X”, “Low Int Y” and “Low Int Z” in register *0x4A*). This is done for each axis independently. Please note that the X and Y axis value for overflow is -4096. However, no interrupt is generated on these values. See chapter 4.9.6 for more information on overflow.

Hereby, one bit in “Low Threshold” corresponds to roughly 6µT (not exactly, as the raw magnetic field values DATAX, DATAY and DATAZ are not temperature compensated).

The Low-threshold interrupt is issued on INT3 pin when one or more values of the data registers DATAX, DATAY and DATAZ drop below the threshold level defined by the “Low Threshold” register (*0x4F*), and when the axis where the threshold was exceeded is enabled for interrupt generation:

Result = (DATAX < “Low Threshold” x 16) AND “Low Int X en” is “0” OR
(DATAY < “Low Threshold” x 16) AND “Low Int Y en” is “0” OR
(DATAZ < “Low Threshold” x 16) AND “Low Int Z en” is “0”

Note: Threshold interrupt enable bits (“Low INT [XYZ] en”) are active low and “1” (disabled) by default.

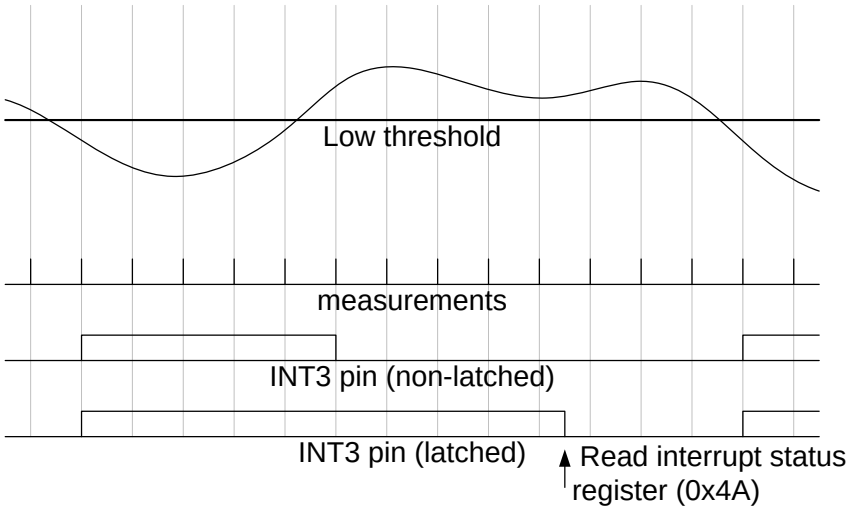


Figure 14: Low-threshold interrupt function

4.9.5 **High-threshold interrupt**

When the data registers' (DATAX, DATAY and DATAZ) values exceed the threshold level defined by the "High Threshold register (*0x50*), the corresponding interrupt status bits for those axes are set ("High Int X", "High Int Y" and "High Int Z" in register *0x4A*). This is done for each axis independently.
Hereby, one bit in "High Threshold" corresponds to roughly 6µT (not exactly, as the raw magnetic field values DATAX, DATAY and DATAZ are not temperature compensated).

The High-threshold interrupt is issued on INT3 pin when one or more values of the data registers DATAX, DATAY and DATAZ exceed the threshold level defined by the "High Threshold" register (*0x50*), and when the axis where the threshold was exceeded is enabled for interrupt generation:

Result = (DATAX > "High Threshold" x 16) AND "High Int X en" is "0" OR
(DATAY > "High Threshold" x 16) AND "High Int Y en" is "0" OR
(DATAZ > "High Threshold" x 16) AND "High Int Z en" is "0"

Note: Threshold interrupt enable bits ("High INT [XYZ] en") are active low and "1" (disabled) by default.

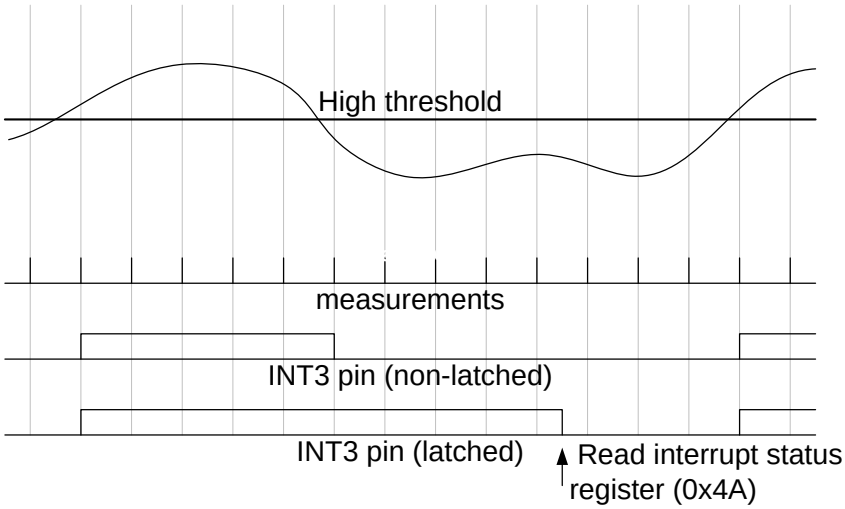


Figure 15: High-threshold interrupt function

4.9.6 **Overflow**

When a measurement axis had an overflow, the corresponding data register is saturated to the most negative value. For X and Y axis, the data register is set to the value -4096. For the Z axis, the data register is set to the value -16384.
The "Overflow" flag (register *0x4A bit6*) indicates that the measured magnetic field raw data of one or more axes exceeded maximum range of the device. The overflow condition can be flagged on the INT3 pin by setting the bit "overflow int enable" (register *0x4D bit6,* active high, default value "0"). The channel on which overflow occurred can be determined by assessing the DATAX/Y/Z registers.

5. Accelerometer register description

5.1 General remarks

The entire communication with the device is performed by reading from and writing to registers. Registers have a width of 8 bits; they are mapped to a common space of 64 addresses from *(0x00)* up to *(0x3F)*. Within the used range there are several registers which are either completely or partially marked as 'reserved'. Any reserved bit is ignored when it is written and no specific value is guaranteed when read. It is recommended not to use registers at all which are completely marked as 'reserved'. Further-more it is recommended to mask out (logical *and* with zero) reserved bits of registers which are partially marked as reserved.

Registers with addresses from *(0x00)* up to *(0x0E)* are read-only. Any attempt to write to these registers is ignored. There are bits within some registers that connected with an action to be done and, therefore, are intended for write-only access, e. g. *(0x21) reset_int* or the entire *(0x14) softreset* register. Such bits always give "0" when read.

5.2 Register map

Register Address	Default Value	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0x3F	0x00	reserved							
0x3E	0x00	reserved							
0x3D	0x00	offset_unfilt_z<7:0>							
0x3C	0x00	offset_unfilt_y<7:0>							
0x3B	0x00	offset_unfilt_x<7:0>							
0x3A	0x00	offset_filt_z<7:0>							
0x39	0x00	offset_filt_y<7:0>							
0x38	0x00	offset_filt_x<7:0>							
0x37	0x00	reserved	offset_target_z<1:0>		offset_target_y<1:0>		offset_target_x<1:0>		cut_off
0x36	0x00	offset_reset	cal_trigger<1:0>		cal_rdy	reserved	hp_z_en	hp_y_en	hp_x_en
0x35	0x00	reserved							
0x34	0x00	reserved					i2c_wdt_en	i2c_wdt_sel	spi3
0x33	0x04	reserved				nvm_load	nvm_rdy	nvm_prog_trig	nvm_prog_mode
0x32	0x70	reserved					self_test_sign	self_test_axis	
0x31	0x00	reserved							
0x30	0x00	reserved							
0x2F	0x10	reserved		flat_hold_time<1:0>		reserved			
0x2E	0x08	reserved		flat_theta<5:0>					
0x2D	0x08	reserved		orient_theta<5:0>					
0x2C	0x18	reserved	orient_hyst<2:0>			orient_blocking<1:0>		orient_mode<1:0>	
0x2B	0x0A	tap_samp<1:0>		reserved	tap_th<4:0>				
0x2A	0x04	tap_quiet	tap_shock	reserved			tap_dur<2:0>		
0x29	0x00	reserved							
0x28	0x14	slope_th<7:0>							
0x27	0x00	reserved						slope_dur<1:0>	
0x26	0xC0	high_th<7:0>							
0x25	0x0F	high_dur<7:0>							
0x24	0x81	high_hy<1:0>		reserved			low_mode	low_hy<1:0>	
0x23	0x30	low_th<7:0>							
0x22	0x09	low_dur<7:0>							
0x21	0x00	reset_int	reserved			latch_int<3:0>			
0x20	0x05	reserved				int2_od	int2_lvl	int1_od	int1_lvl
0x1F	0x00	reserved							
0x1E	0x00	reserved		int_src_data	int_src_tap	reserved	int_src_slope	int_src_high	int_src_low
0x1D	0x00	reserved							
0x1C	0x00	reserved							
0x1B	0x00	int2_flat	int2_orient	int2_s_tap	int2_d_tap	reserved	int2_slope	int2_high	int2_low
0x1A	0x00	int2_data	reserved						int1_data
0x19	0x00	int1_flat	int1_orient	int1_s_tap	int1_d_tap	reserved	int1_slope	int1_high	int1_low
0x18	0x00	reserved							
0x17	0x00	reserved			data_en	low_en	high_en_z	high_en_y	high_en_x
0x16	0x00	flat_en	orient_en	s_tap_en	d_tap_en	reserved	slope_en_z	slope_en_y	slope_en_x
0x15	0x00	reserved							
0x14	0x00	softreset							
0x13	0x00	data_high_bw	shadow_dis	reserved					
0x12	0x00	reserved							
0x11	0x00	suspend	lowpower_en	reserved	sleep_dur<3:0>				reserved
0x10	0x1F	reserved			bw<4:0>				
0x0F	0x03	reserved				range<3:0>			
0x0E	0x00	reserved							
0x0D	0x00	reserved							
0x0C	0x00	flat	orient[2:0]			high_sign	high_first_z	high_first_y	high_first_x
0x0B	0x00	tap_sign	tap_first_z	tap_first_y	tap_first_x	slope_sign	slope_first_z	slope_first_y	slope_first_x
0x0A	0x00	data_int	reserved						
0x09	0x00	flat_int	orient_int	s_tap_int	d_tap_int	reserved	slope_int	high_int	low_int
0x08	0x00	temp<7:0>							
0x07	0x00	acc_z_msb<9:2>							
0x06	0x00	acc_z_lsb<1:0>		0					new_data_z
0x05	0x00	acc_y_msb<9:2>							
0x04	0x00	acc_y_lsb<1:0>		0					new_data_y
0x03	0x00	acc_x_msb<9:2>							
0x02	0x00	acc_x_lsb<1:0>		0					new_data_x
0x01	0x21	reserved							
0x00	0x03	Chip ID							

	w/r
	write only
	read only
	reserved

5.3 Chip ID

Register *(0x00)* *Chip ID* contains the accelerometer chip identification number.

Table 25: Chip identification number, register (0x00)

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	0	0	0	0	0	1	1

Register *(0x01)* *is reserved*

5.4 Acceleration data

Register *(0x02)* contains the LSB part of x-axis acceleration data and the new data flag for the x-axis.

Table 26: LSB part of x-axis acceleration, register *(0x02)*

(0x02) **Bit**	**Name**	**Description**
Bit 7	*acc_x_lsb <1>*	Bit 1 of x-axis acceleration data
Bit 6	*acc_x_lsb <0>*	Bit 0 of x-axis acceleration data **= x LSB**
Bit 5	-	(fixed to 0)
Bit 4	-	(fixed to 0)
Bit 3	-	(fixed to 0)
Bit 2	-	(fixed to 0)
Bit 1	-	(fixed to 0)
Bit 0	*new_data_x*	New data flag of x-axis

Register *(0x03)* contains the MSB part of x-axis acceleration data.

Table 27: MSB part of x-axis acceleration, register *(0x03)*

(0x03) **Bit**	**Name**	**Description**
Bit 7	*acc_x_msb <9>*	Bit 9 of x-axis acceleration data **= x MSB**
Bit 6	*acc_x_msb <8>*	Bit 8 of x-axis acceleration data
Bit 5	*acc_x_msb <7>*	Bit 7 of x-axis acceleration data
Bit 4	*acc_x_msb <6>*	Bit 6 of x-axis acceleration data
Bit 3	*acc_x_msb <5>*	Bit 5 of x-axis acceleration data
Bit 2	*acc_x_msb <4>*	Bit 4 of x-axis acceleration data
Bit 1	*acc_x_msb <3>*	Bit 3 of x-axis acceleration data
Bit 0	*acc_x_msb <2>*	Bit 2 of x-axis acceleration data

Register *(0x04)* contains the LSB part of y-axis acceleration data and the new data flag for the y-axis.

Table 28: LSB part of y-axis acceleration, register *(0x04)*

(0x04) **Bit**	**Name**	**Description**
Bit 7	*acc_y_lsb <1>*	Bit 1 of y-axis acceleration data
Bit 6	*acc_y_lsb <0>*	Bit 0 of y-axis acceleration data **= y LSB**
Bit 5	-	(fixed to 0)
Bit 4	-	(fixed to 0)
Bit 3	-	(fixed to 0)
Bit 2	-	(fixed to 0)
Bit 1	-	(fixed to 0)
Bit 0	*new_data_y*	New data flag of y-axis

Register *(0x05)* contains the MSB part of acceleration data for the y-axis.

Table 29: MSB part of y-axis acceleration, register *(0x05)*

***(0x05)* Bit**	**Name**	**Description**
Bit 7	*acc_y_msb <9>*	Bit 9 of y-axis acceleration data **= y MSB**
Bit 6	*acc_y_msb <8>*	Bit 8 of y-axis acceleration data
Bit 5	*acc_y_msb <7>*	Bit 7 of y-axis acceleration data
Bit 4	*acc_y_msb <6>*	Bit 6 of y-axis acceleration data
Bit 3	*acc_y_msb <5>*	Bit 5 of y-axis acceleration data
Bit 2	*acc_y_msb <4>*	Bit 4 of y-axis acceleration data
Bit 1	*acc_y_msb <3>*	Bit 3 of y-axis acceleration data
Bit 0	*acc_y_msb <2>*	Bit 2 of y-axis acceleration data

Register *(0x06)* contains the LSB part of acceleration data and the new data flag for the z-axis.

Table 30: LSB part of y-axis acceleration, register *(0x06)*

***(0x06)* Bit**	**Name**	**Description**
Bit 7	*acc_z_lsb <1>*	Bit 1 of z-axis acceleration data
Bit 6	*acc_z_lsb <0>*	Bit 0 of z-axis acceleration data **= z LSB**
Bit 5	-	(fixed to 0)
Bit 4	-	(fixed to 0)
Bit 3	-	(fixed to 0)
Bit 2	-	(fixed to 0)
Bit 1	-	(fixed to 0)
Bit 0	*new_data_z*	New data flag of z-axis

Register *(0x07)* contains the MSB part of acceleration data for the z-axis.

Table 31: MSB part of z-axis acceleration, register *(0x07)*

***(0x07)* Bit**	**Name**	**Description**
Bit 7	*acc_z_msb <9>*	Bit 9 of z-axis acceleration data **= z MSB**
Bit 6	*acc_z_msb <8>*	Bit 8 of z-axis acceleration data
Bit 5	*acc_z_msb <7>*	Bit 7 of z-axis acceleration data
Bit 4	*acc_z_msb <6>*	Bit 6 of z-axis acceleration data
Bit 3	*acc_z_msb <5>*	Bit 5 of z-axis acceleration data
Bit 2	*acc_z_msb <4>*	Bit 4 of z-axis acceleration data
Bit 1	*acc_z_msb <3>*	Bit 3 of z-axis acceleration data
Bit 0	*acc_z_msb <2>*	Bit 2 of z-axis acceleration data

5.5 Temperature data

Register *(0x08) temp* contains temperature data in two's complement representation. Center temperature = 24 °C → i.e. *(0x08) temp* = 00000000b
1 LSB increment of temperature sensor is 0.5 °C (0.9 °F).

Table 32: Temperature data, register *(0x08)*

Bit 7	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
Temp <7>	*Temp <6>*	*Temp <5>*	*Temp <4>*	*Temp <3>*	*Temp <2>*	*Temp <1>*	*Temp <0>*

5.6 Status registers

Register *(0x09)* contains the states of several interrupts.

Table 33: Interrupt status, register *(0x09)*

***(0x09)* Bit**	**Name**	**Description**
Bit 7	*flat_int*	Flat interrupt status
Bit 6	*orient_int*	Orientation interrupt status
Bit 5	*s_tap_int*	Single tap interrupt status
Bit 4	*d_tap_int*	Double tap interrupt status
Bit 3	*- reserved -*	reserved
Bit 2	*slope_int*	Slope interrupt status
Bit 1	*high_int*	High-g interrupt status
Bit 0	*low_int*	Low-g interrupt status

Register *(0x0A)* contains the status of the new data interrupt.

Table 34: New data status, register *(0x0A)*

***(0x0A)* Bit**	**Name**	**Description**
Bit 7	*data_int*	New data interrupt status
Bit 6	*- reserved -*	reserved
Bit 5	*- reserved -*	reserved
Bit 4	*- reserved -*	reserved
Bit 3	*- reserved -*	reserved
Bit 2	*- reserved -*	reserved
Bit 1	*- reserved -*	reserved
Bit 0	*- reserved -*	reserved

Register *(0x0B)* contains the sign and triggering axis information for the tap and slope interrupts. Here tap interrupt comprises both single and double tap interrupt.

Table 35: Tap and slope interrupts status, register *(0x0B)*

***(0x0B)* Bit**	**Name**	**Description**
Bit 7	*tap_sign*	Sign of 1st tap that triggered the interrupt (“0”=positive, “1”=negative)
Bit 6	*tap_first_z*	“1” indicates that z-axis is triggering axis of tap interrupt
Bit 5	*tap_first_y*	“1” indicates that y-axis is triggering axis of tap interrupt
Bit 4	*tap_first_x*	“1” indicates that x-axis is triggering axis of tap interrupt
Bit 3	*slope_sign*	Sign of slope that triggered the interrupt (“0”=positive, “1”=negative)
Bit 2	*slope_first_z*	“1” indicates that z-axis is triggering axis of slope interrupt
Bit 1	*slope_first_y*	“1” indicates that y-axis is triggering axis of slope interrupt
Bit 0	*slope_first_x*	“1” indicates that x-axis is triggering axis of slope interrupt

Register *(0x0C)* contains the flat and orientation status, and the sign and triggering axis information for the high-g interrupt. Registers *(0x0D)* and *(0x0E)* are *reserved*.

Table 36: Flat and orientation Status, register *(0x0C)*

***(0x0C)* Bit**	**Name**	**Description**
Bit 7	*flat*	flat detection (“1” if flat condition is fulfilled, “0” otherwise)
Bit 6	*orient <2>*	orientation value of z-axis (“0“ if upward looking, “1“ if downward looking)
Bit 5	*orient <1>*	orientation value of x-y plane (“00”=portrait upright, “01”=portrait upside-down, “10”=landscape left, “11”=landscape right)
Bit 4	*orient <0>*	
Bit 3	*high_sign*	Sign of slope that triggered the interrupt (“0”=positive, “1”=negative)
Bit 2	*high_first_z*	“1” indicates that z-axis is triggering axis of high-g interrupt
Bit 1	*high_first_y*	“1” indicates that y-axis is triggering axis of high-g interrupt
Bit 0	*high_first_x*	“1” indicates that x-axis is triggering axis of high-g interrupt

Registers *(0x0D)* and ***(0x0E)*** are *reserved*.

5.7 g-range selection

Register *(0x0F)* contains the selection of the g-range. Proper settings for *(0x0F) range* are “0011b” (selects ±2g range), “0101b” (selects ±4g range), “1000b” (selects ±8g range), “1100b” (selects ±16g range). All other settings are irregular; if such a setting is used, ±2g range is selected. Default value of *(0x0F) range* (after reset) is “0011b”.

Table 37: g-range, register *(0x0F)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*reserved*	*reserved*	*range <3>*	*range <2>*	*range <1>*	*range <0>*

5.8 Bandwidths

Register *(0x10)* contains the selection of the bandwidth for filtered acceleration data. Settings for *(0x10) bw* are “00xxxb” (bandwidth = 7.81 Hz), “01000b” (bandwidth = 7.81 Hz), “01001b” (bandwidth = 15.63 Hz), “01010b” (bandwidth = 31.25 Hz), “01011b” (bandwidth = 62.5 Hz), “01100b” (bandwidth = 125 Hz), “01101b” (bandwidth = 250 Hz), “01110b” (bandwidth = 500 Hz), “01111b” (bandwidth = 1000 Hz), “1xxxxb” (bandwidth = 1000 Hz). Default value of *(0x10) bw* (after reset) is “11111b”. It is recommended to actively use the range from “01000b” to “01111b” only in order to be compatible with future products.

Table 38: Bandwidths, register *(0x10)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*reserved*	*bw <4>*	*bw <3>*	*bw <2>*	*bw <1>*	*bw <0>*

5.9 Power modes

Register *(0x11)* contains the configuration of the power modes. *(0x11) suspend* = “1” (“0”) sets (resets) suspend mode; default value of *(0x11) suspend* is “0”.
(0x11) lowpower_en = “1” (“0”) sets (resets) low-power mode, default value of *(0x11) lowpower_en* is “0”.

The settings for *(0x11) sleep_dur* are “0000b” to “0101b” (sleep phase duration = 0.5 ms), “0110b” (sleep phase duration = 1 ms), “0111b” (sleep phase duration = 2 ms), “1000b” (sleep phase duration = 4 ms), “1001b” (sleep phase duration = 6 ms), “1010b” (sleep phase duration = 10 ms), “1011b” (sleep phase duration = 25 ms), “1100b” (sleep phase duration = 50 ms), “1101b” (sleep phase duration = 100 ms), “1110b” (sleep phase duration = 500 ms), “1111b” (sleep phase duration = 1 s). Default value of *(0x11) sleep_dur* is “0000b”.

Table 39: Power modes, register *(0x11)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
suspend	*lowpower_en*	*reserved*	*sleep_dur<3>*	*sleep_dur<2>*	*sleep_dur<1>*	*sleep_dur<0>*	*reserved*

5.10 Special control settings

Register *(0x12)* is *reserved*.

Register *(0x13)* contains settings for the configuration of the acceleration data acquisition and the data output format.

(0x13) data_high_bw = “0” (“1”) selects filtered (unfiltered) acceleration data to be written into the data registers (0x02) to (0x07). Default value of *(0x13) data_high_bw* is “0”.
(0x13) shadow_dis = “0” (“1”) enables (disables) the shadowing procedure. Shadowing means that the MSB register is updated by reading the corresponding LSB register. Default value of *(0x13) shadow_dis* is “0”.

Table 40: Acceleration data acquisition & data output format, register *(0x13)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
data_high_bw	*shadow_dis*	*reserved*	*reserved*	*reserved*	*reserved*	*reserved*	*reserved*

Register *(0x14)* is the *softreset* register. A user-triggered reset (softreset) of the sensor is performed after writing “0xB6h” to the softreset register. After that reset all registers return to their default values. Reading *(0x14) softreset* returns 0x00.

Register *(0x15)* is *reserved*.

5.11 Interrupt settings

Registers *(0x16)* and *(0x17)* contain the enable bits for the interrupts. Default value of each enable bit is “0”.

Table 41: Interrupt setting, register *(0x16)*

***(0x16)* Bit**	**Name**	**Description**
Bit 7	*flat_en*	“1” (“0”) enables (disables) flat interrupt
Bit 6	*orient_en*	“1” (“0”) enables (disables) orientation interrupt
Bit 5	*s_tap_en*	“1” (“0”) enables (disables) single tap interrupt
Bit 4	*d_tap_en*	“1” (“0”) enables (disables) double tap interrupt
Bit 3	*- reserved -*	reserved
Bit 2	*slope_en_z*	“1” (“0”) enables (disables) slope interrupt for z-axis
Bit 1	*slope_en_y*	“1” (“0”) enables (disables) slope interrupt for y-axis
Bit 0	*slope_en_x*	“1” (“0”) enables (disables) slope interrupt for x-axis

Table 42: Interrupt setting, register *(0x17)*

***(0x17)* Bit**	**Name**	**Description**
Bit 7	*- reserved -*	reserved
Bit 6	*- reserved -*	reserved
Bit 5	*- reserved -*	reserved
Bit 4	*data_en*	“1” (“0”) enables (disables) new data interrupt
Bit 3	*low_en*	“1” (“0”) enables (disables) low-g interrupt
Bit 2	*high_en_z*	“1” (“0”) enables (disables) high-g interrupt for z-axis
Bit 1	*high_en_y*	“1” (“0”) enables (disables) high-g interrupt for y-axis
Bit 0	*high_en_x*	“1” (“0”) enables (disables) high-g interrupt for x-axis

Register *(0x18)* is *reserved*.

Registers *(0x19)* to *(0x1B)* contain the mapping of interrupts onto the interrupt pins. Default value of each mapping bit is “0”.

Table 43: Interrupt mapping, register *(0x19)*

***(0x19)* Bit**	**Name**	**Description**
Bit 7	*int1_flat*	“1” (“0”) maps (unmaps) flat interrupt to INT1 pin
Bit 6	*int1_orient*	“1” (“0”) maps (unmaps) orientation interrupt to INT1 pin
Bit 5	*int1_s_tap*	“1” (“0”) maps (unmaps) single tap interrupt to INT1 pin
Bit 4	*int1_d_tap*	“1” (“0”) maps (unmaps) double tap interrupt to INT1 pin
Bit 3	*- reserved -*	reserved
Bit 2	*int1_slope*	“1” (“0”) maps (unmaps) slope interrupt to INT1 pin
Bit 1	*int1_high*	“1” (“0) maps (unmaps) high-g interrupt to INT1 pin
Bit 0	*int1_low*	“1” (“0”) maps (unmaps) low-g interrupt to INT1 pin

Table 44: Interrupt mapping, register *(0x1A)*

***(0x1A)* Bit**	**Name**	**Description**
Bit 7	*int2_data*	“1” (“0”) maps (unmaps) new data interrupt to INT2 pin
Bit 6	*- reserved -*	reserved
Bit 5	*- reserved -*	reserved
Bit 4	*- reserved -*	reserved
Bit 3	*- reserved -*	reserved
Bit 2	*- reserved -*	reserved
Bit 1	*- reserved -*	reserved
Bit 0	*int1_data*	“1” (“0”) maps (unmaps) new data interrupt to INT1 pin

Table 45: Interrupt mapping, register *(0x1B)*

***(0x1B)* Bit**	**Name**	**Description**
Bit 7	*int2_flat*	“1” (“0”) maps (unmaps) flat interrupt to INT2 pin
Bit 6	*int2_orient*	“1” (“0”) maps (unmaps) orientation interrupt to INT2 pin
Bit 5	*int2_s_tap*	“1” (“0”) maps (unmaps) single tap interrupt to INT2 pin
Bit 4	*int2_d_tap*	“1” (“0”) maps (unmaps) double tap interrupt to INT2 pin
Bit 3	*- reserved -*	reserved
Bit 2	*int2_slope*	“1” (“0”) maps (unmaps) slope interrupt to INT2 pin
Bit 1	*int2_high*	“1” (“0”) maps (unmaps) high-g interrupt to INT2 pin
Bit 0	*int2_low*	“1” (“0”) maps (unmaps) low-g interrupt to INT2 pin

Registers *(0x1C)* and *(0x1D)* are *reserved*.

Register *(0x1E)* contains the data source definition for those interrupts with selectable data source. Default value of each data source selection bit is “0”.

Table 46: Interrupt data source definition, register *(0x1E)*

***(0x1E)* Bit**	**Name**	**Description**
Bit 7	*- reserved -*	reserved
Bit 6	*- reserved -*	reserved
Bit 5	*int_src_data*	“1” (“0”) selects unfiltered (filtered) data for the new data interrupt
Bit 4	*int_src_tap*	“1” (“0”) selects unfiltered (filtered) data for the single tap and double tap interrupts
Bit 3	*- reserved -*	reserved
Bit 2	*int_src_slope*	“1” (“0”) selects unfiltered (filtered) data for the slope interrupt
Bit 1	*int_src_high*	“1” (“0”) selects unfiltered (filtered) data for the high-g interrupt
Bit 0	*int_src_low*	“1” (“0”) selects unfiltered (filtered) data for the low-g interrupt

Register *(0x1F)* is *reserved*.

Register *(0x20)* contains the behavioural configuration (electrical behaviour) of the interrupt pins. Default value of *(0x20) int1_od* and *(0x20) int2_od* is "0". Default value of *(0x20) int1_lvl* and *(0x20) int2_lvl* is "1".

Table 47: Electrical behaviour of interrupt pin, register *(0x20)*

***(0x20)* Bit**	**Name**	**Description**
Bit 7	*- reserved -*	reserved
Bit 6	*- reserved -*	reserved
Bit 5	*- reserved -*	reserved
Bit 4	*- reserved -*	reserved
Bit 3	*int2_od*	"0" selects push-pull, "1" selects open drive for INT2 pin
Bit 2	*int2_lvl*	"0" ("1") selects active level "0" ("1") for INT2 pin
Bit 1	*int1_od*	"0" selects push-pull, "1" selects open drive for INT1
Bit 0	*int1_lvl*	"0" ("1") selects active level "0" ("1") for INT1 pin

Register *(0x21)* contains the interrupt reset bit and the interrupt mode selection. Writing "1" to *(0x21) reset_int* resets any latched interrupt.

The settings for *(0x21) latch_int* are "0000b" (non-latched), "0001b" (temporary, 250 ms), "0010b" (temporary, 500 ms), "0011b" (temporary, 1 s), "0100b" (temporary, 2 s), "0101b" (temporary, 4 s), "0110b" (temporary, 8 s), "0111b" (latched), "1000b" (non-latched), "1001b" (temporary, 500 µs), "1010b" (temporary, 500 µs), "1011b" (temporary, 1 ms), "1100b" (temporary, 12.5 ms), "1101b" (temporary, 25 ms), "1110b" (temporary, 50 ms), "1111b" (latched).
Default value of *(0x21) latch_int* is "0000b".

Table 48: Interrupt reset bit and interrupt mode selection, register *(0x21)*

Bit 7	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
reset_int	*reserved*	*reserved*	*reserved*	*latch_ int<3>*	*latch_ int<2>*	*latch_ int<1>*	*latch_ int<0>*

Register *(0x22)* contains the delay time definition for the low-g interrupt. The physical delay time can be computed from the content of *(0x22) low_dur* according to:
delay [ms] = [*(0x22) low_dur* + 1] • 2 ms.

Possible delay times range from 2 ms to 512 ms. Default value of *(0x22) low_dur* is 0x09, corresponding to a delay of 20 ms.

Table 49: Delay time definition for the low-g interrupt, register *(0x22)*

Bit 7	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
low_ dur<7>	*low_ dur<6>*	*low_ dur<5>*	*low_ dur<4>*	*low_ dur<3>*	*low_ dur<2>*	*low_ dur<1>*	*low_ dur<0>*

Register *(0x23)* contains the threshold definition for the low-g interrupt. An LSB of *(0x23) low_th* corresponds to an actual acceleration of 7.81 mg. Therefore, the threshold ranges from 0 g to 1.992 g. Default value of *(0x23) low_th* is 0x30, corresponding to an acceleration of 375 mg.

Table 50: Threshold definition for the low-g interrupt, register *(0x23)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
low_ th<7>	*low_ th<6>*	*low_ th<5>*	*low_ th<4>*	*low_ th<3>*	*low_ th<2>*	*low_ th<1>*	*low_ th<0>*

Register *(0x24)* contains the low-g interrupt mode selection, the low-g interrupt hysteresis setting, and the high-g interrupt hysteresis setting. Setting *(0x24) low_mode* to ”0” (“1”) selects ´single´ mode (´sum´ mode). Default value is “0” (´single´ mode).

(0x24) low_hy sets the hysteresis of the low-g interrupt. An LSB of *(0x24) low_hy* corresponds to an acceleration difference of 125 mg. Default value of *(0x24) low_hy* is “01b”.

(0x24) high_hy sets the hysteresis of the high-g interrupt. The meaning of an LSB of *(0x24) high_hy* depends on the selected g-range. It corresponds to an acceleration difference of 125 mg in 2g-range, 250 mg in 4g-range, 500 mg in 8g-range, and 1000mg in 16g-range.
Default value of *(0x24) high_hy* is “10b”.

Table 51: Threshold definition for the low-g interrupt, register *(0x24)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
high_ hy<1>	*high_ hy<0>*	*reserved*	*reserved*	*reserved*	*low_ mode*	*low_ hy<1>*	*low_ hy<0>*

Register *(0x25)* contains the delay time definition for the high-g interrupt. The physical delay time can be computed from the content of *(0x25) high_dur* according to
delay [ms] = [*(0x22) high_dur* + 1] • 2 ms. Possible delay times range from 2 ms to 512 ms.
Default value of *(0x25) high_dur* is 0x0F, corresponding to a delay of 32 ms.

Table 52: Delay time definition for the high-g interrupt, register *(0x25)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
high_ dur<7>	*high_ dur<6>*	*high_ dur<5>*	*high_ dur<4>*	*high_ dur<3>*	*high_ dur<2>*	*high_ dur<1>*	*high_ dur<0>*

Register *(0x26)* contains the threshold definition for the high-g interrupt. The meaning of an LSB of *(0x26) high_th* depends on the selected g-range. It corresponds to 7.81 mg in 2g-range, 15.63 mg in 4g-range, 31.25 mg in 8g-range, and 62.5 mg in 16g-range.
Default value of *(0x26) high_th* is 0xC0.

Table 53: Threshold definition for the high-g interrupt, register *(0x26)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
high_ th<7>	*high_ th<6>*	*high_ th<5>*	*high_ th<4>*	*high_ th<3>*	*high_ th<2>*	*high_ th<1>*	*high_ th<0>*

Register *(0x27)* contains the definition of the number of samples to be evaluated for the slope interrupt (any-motion detection). The number of samples is *N = (0x27) slope_dur* + 1.
Default value of *(0x27) slope_dur* is “00b”.

Table 54: Samples number definition for the slope interrupt, register *(0x27)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*reserved*	*reserved*	*reserved*	*reserved*	*slope_ dur<1>*	*slope_ dur<0>*

Register *(0x28)* contains the threshold definition for the slope interrupt. An LSB of *(0x28) slope_th* corresponds to an LSB of acceleration data. Its meaning therefore depends on the selected g-range. Default value of *(0x28) slope_th* is 0x14.

Table 55: Samples number definition for the slope interrupt, register *(0x28)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
slope_ th<7>	*slope_ th<6>*	*slope_ th<5>*	*slope_ th<4>*	*slope_ th<3>*	*slope_ th<2>*	*slope_ th<1>*	*slope_ th<0>*

Register *(0x29)* is *reserved*.

Register *(0x2A)* contains the timing definitions for the single tap and double tap interrupts.

(0x2A) tap_quiet = “0” (“1”) selects a quiet duration of 30 ms (20 ms). The default value of *(0x2A) tap_quiet* is “0”.

(0x2A) tap_shock = “0” (“1”) selects a shock duration of 50 ms (75 ms). The default value of *(0x2A) tap_shock* is “0”.

(0x2A) tap_dur selects the length of the time window for the second shock event (for double tap detection). The settings for *(0x2A) tap_dur* are “000b” (50 ms), “001b” (100 ms), “010b” (150 ms), “011b” (200 ms), “100b” (250 ms), “101b” (375 ms), “110b” (500 ms), “111b” (700 ms). The default value of *(0x2A) tap_dur* is “100b”.

Table 56: Tap Quiet duration and tap shock duration, register *(0x2A)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
tap_ quiet	*tap_ shock*	*reserved*	*reserved*	*reserved*	*tap_ dur<2>*	*tap_ dur<1>*	*tap_ dur<0>*

Register *(0x2B)* contains the definition of the number of samples to be processed after wake-up in low-power mode and the threshold definition for the single and double tap interrupts. *(0x2B) tap_samp* selects the number of samples that are processed after wake-up in the low-power mode. The settings for *(0x2B) tap_samp* are “00b” (2 samples), “01b” (4 samples), “10b” (8 samples), and “11b” (16 samples). Default value of *(0x2B) tap_samp* is “00b”.

The meaning of an LSB of *(0x2B) tap_th* depends on the selected g-range. It corresponds to an acceleration difference of 62.5mg in 2g-range, 125mg in 4g-range, 250mg in 8g-range, and 500mg in 16g-range. Default value of *(0x2B) tap_th* is 0x0A.

Table 57: Samples number after wake-up and threshold tap interrupt, register *(0x2B)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
tap_ samp<1>	*tap_ samp<0>*	*reserved*	*tap_ th<4>*	*tap_ th<3>*	*tap_ th<2>*	*tap_ th<1>*	*tap_ th<0>*

Register *(0x2C)* contains the definition of hysteresis, blocking, and mode for the orientation interrupt. *(0x2C) orient_hyst* sets the hysteresis of the orientation interrupt; 1 LSB always corresponds to 62.5 mg, in any g-range (i.e. increment is independent from g-range setting). Default value of *(0x2C) orient_hyst* is “001b”.

(0x2C) orient_blocking selects the kind of blocking that is used for the generation of the orientation interrupt. The settings for *(0x2C) orient_blocking* are “00b” (no blocking), “01b” (theta blocking), “10b” (theta blocking or slope in any axis > 0.2 g), and “11b” (*orient* value not stable for at least 100 ms or theta blocking or slope in any axis > 0.4 g). Default value of *(0x2C) orient_blocking* is “10b”.

(0x2C) orient_mode sets the thresholds for switching between the different orientations. The settings for *(0x2C) orient_mode* are “00b” (symmetrical), “01b” (high-asymmetrical), “10b” (low-asymmetrical), “11b” (symmetrical). Default value of *(0x2C) orient_mode* is “00b”.

Table 58: Hysteresis, Blocking for Orientation Interrupt, Register *(0x2C)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*orient_ hyst<2 >*	*orient_ hyst<1 >*	*orient_ hyst<0 >*	*orient_ blocking<1>*	*orient_ blocking<0>*	*orient_ mode<1 >*	*orient_ mode<0 >*

Register *(0x2D)* contains the definition of the theta blocking angle for the orientation interrupt. *(0x2D) orient_theta* defines a blocking angle between 0° and 44.8° as described in chapter 4.8.7.1. Default value of *(0x2D) orient_theta* is 0x08.

Table 59: Theta blocking angle, register *(0x2D)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*orient_ theta<5>*	*orient_ theta<4>*	*orient_ theta<3>*	*orient_ theta<2>*	*orient_ theta<1>*	*orient_ theta<0>*

Register *(0x2E)* contains the definition of the flat threshold angle for the flat interrupt. *(0x2E) flat_theta* defines a blocking angle between 0° and 44.8° as described in chapter 4.8.8. Default value of *(0x2E) flat_theta* is 0x08.

Table 60: Flat threshold angle, register *(0x2E)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*flat_ theta<5>*	*flat_ theta<4>*	*flat_ theta<3>*	*flat_ theta<2>*	*flat_ theta<1>*	*flat_ theta<0>*

Register *(0x2F)* contains the definition of the flat hold time. *(0x2F) flat_hold_time* defines the time a new flat value has to be at least stable for before the interrupt is generated. The settings for *(0x2F) flat_hold_time* are “00b” (0), “01b” (512 ms), “10b” (1024 ms), “11b” (2048 ms). Default value of *(0x2F) flat_hold_time* is “01b”.

Table 61: Flat threshold angle, register *(0x2F)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*flat_hold_time<1>*	*flat_hold_time<0>*	*reserved*	*reserved*	*reserved*	*reserved*

Register *(0x30) and (0x31)* are *reserved*.

5.12 Self-test

Register *(0x32)* contains the settings for the activation of the sensor self-test.

(0x32) self_test_sign sets the sign of the electrostatic excitation. The settings for *(0x32) self_test_sign* are “0” (positive sign) and “1” (negative sign). Default value of *(0x32) self_test_sign* is “0”.

(0x32) self_test_axis defines the axis which shall be excited. Only one axis can be excited at the same time. The settings for *(0x32) self_test_axis* are “00b” (no self-test), “01” (x-axis), “10” (y-axis), and “11” (z-axis). Default value of *(0x32) self_test_axis* is “00b”.

Table 62: Sensor self-test, register *(0x32)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*reserved*	*reserved*	*reserved*	*self_test_sign*	*self_test_axis<1>*	*self_test_axis<0>*

5.13 Non-volatile memory control (EEPROM control)

Register *(0x33)* contains the control settings for the non-volatile memory (EEPROM). *(0x33) nvm_load* is used to perform a user-defined image update. Writing "1" *(0x33) nvm_load* starts the update procedure. The value "1" is kept as long as the update procedure runs, afterwards it is reset to "0".

(0x33) nvm_rdy contains the status of writing the EEPROM. *(0x33) nvm_rdy* is "0" as long as writing the EEPROM endures, it is "1" if currently no write access is performed and, therefore, a new write access can be initiated.

Writing "1"to *(0x33) nvm_prog_trig* triggers writing the EEPROM. The EEPROM can only be written if it was unlocked before.

Writing "1"to *(0x33) nvm_prog_mode* unlocks the EEPROM.

Table 63: EEPROM control settings, register *(0x33)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*reserved*	*reserved*	*nvm_load*	*nvm_rdy*	*nvm_prog_trig*	*nvm_prog_mode*

5.14 Interface configuration

Register *(0x34)* contains the settings for the digital interfaces. Writing “1” to *(0x34) i2c_wdt_en* enables the watchdog at the SDI pin (= SDA for I²C) if I²C is selected. Default value of *(0x34) i2c_wdt_en* is “0”.

(0x34) i2c_wdt_sel selects the I²C data pad watchdog timer period. The settings for *(0x34) i2c_wdt_sel* are “0” (1 ms) and “1” (50 ms). Default value of *(0x34) i2c_wdt_sel* is “0”.

(0x34) spi3 selects the SPI mode. The settings for *(0x34) spi3* are “0” (4-wire SPI) and “1” (3-wire SPI). Default value of *(0x34) spi3* is “0”.

Table 64: EEPROM control settings, register *(0x34)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*reserved*	*reserved*	*reserved*	*reserved*	*i2c_wdt_en*	*i2c_wdt_sel*	*spi3*

Register *(0x35)* is *reserved*.

5.15 Offset compensation

Register *(0x36)* contains settings for the offset compensation in general, for fast offset compensation, and for slow offset compensation. Writing “1”to *(0x36) offset_reset* sets all offset compensation registers *(0x38 to 0x3D)* to zero.

Default value of *(0x36) offset_reset* is “0”.

(0x36) cal_trigger starts the fast compensation process for the specified axis. The settings for *(0x36) cal_trigger* are “00b” (no axis selected), “01b” (x-axis), “10b” (y-axis), “11b” (z-axis). A non-zero value is kept until the fast compensation procedure is finished. Default value of *(0x36) cal_trigger* is “00b”.

(0x36) cal_rdy indicates the state of the fast compensation. *(0x36) cal_rdy* is “0” when *(0x36) cal_trigger* has a nonzero value, otherwise *(0x36) cal_rdy* is “1”.

Writing “1” (“0”) to *(0x36) hp_z_en* enables (disables) slow offset compensation for the z-axis.
Writing “1” (“0”) to *(0x36) hp_y_en* enables (disables) slow offset compensation for the y-axis.
Writing “1” (“0”) to *(0x36) hp_x_en* enables (disables) slow offset compensation for the x-axis.
Default value for each of *(0x36) hp_x_en, (0x36) hp_y_en,* and *(0x36) hp_x_en* is “0”, respectively.

Table 65: Offset compensation, fast offset compensation, register *(0x36)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_reset	*cal_trigger<1>*	*cal_trigger<0>*	*cal_rdy*	*reserved*	*hp_z_en*	*hp_y_en*	*hp_x_en*

Register *(0x37)* contains settings for the offset compensation in general, and for slow offset compensation. *(0x37) offset_target_z* sets the target value for the offset compensation of the z-axis.

(0x37) offset_target_y sets the target value for the offset compensation of the y-axis.
(0x37) offset_target_x sets the target value for the offset compensation of the x-axis.
The settings for *(0x37) offset_target_x, (0x37) offset_target_y,* and *(0x37) offset_target_z* are “00b” (0 g), “01b” (+1 g), “10b” (-1 g), and “11b” (0 g). Default value of each of *(0x37) offset_target_x, (0x37) offset_target_y,* and *(0x37) offset_target_z* is “00b”, respectively.

(0x37) cut_off defines the number of samples for comparison by the slow offset compensation. The settings for *(0x37) cut_off* are “0” (8 samples) and “1” (16 samples). The default value of *(0x37) cut_off* is “0”.

Table 66: Offset compensation, slow offset compensation, register *(0x37)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
reserved	*offset_target_z<1>*	*offset_target_z<0>*	*offset_target_y<1>*	*offset_target_y<0>*	*offset_target_x<1>*	*offset_target_x<0>*	*cut_off*

Register *(0x38)* contains the compensation value for filtered data for the x-axis. The contents of each of the registers *(0x38)* to *(0x3D)* is added to the corresponding acceleration data; it can be set either automatically by one of the implemented compensation algorithms or manually. These

registers are image registers of registers in the EEPROM; the content of the EEPROM is copied to them after every reset.

Table 67: Filtered data compensation for the x-axis, register *(0x38)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_ filt_x<7>	*offset_ filt_x<6>*	*offset_ filt_x<5>*	*offset_ filt_x<4>*	*offset_ filt_x<3>*	*offset_ filt_x<2>*	*offset_ filt_x<1>*	*offset_ filt_x<0>*

Register *(0x39)* contains the compensation value for filtered data for the y-axis.

Table 68: Filtered data compensation for the y-axis, register *(0x39)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_ filt_y<7>	*offset_ filt_y<6>*	*offset_ filt_y<5>*	*offset_ filt_y<4>*	*offset_ filt_y<3>*	*offset_ filt_y<2>*	*offset_ filt_y<1>*	*offset_ filt_y<0>*

Register *(0x3A)* contains the compensation value for filtered data for the z-axis.

Table 69: Filtered data compensation for the z-axis, register *(0x3A)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_ filt_z<7>	*offset_ filt_z<6>*	*offset_ filt_z<5>*	*offset_ filt_z<4>*	*offset_ filt_z<3>*	*offset_ filt_z<2>*	*offset_ filt_z<1>*	*offset_ filt_z<0>*

Register *(0x3B)* contains the compensation value for unfiltered data for the x-axis.

Table 70: Unfiltered data compensation for the x-axis, register *(0x3B)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_ unfilt_x <7>	*offset_ unfilt_x <6>*	*offset_ unfilt_x <5>*	*offset_ unfilt_x <4>*	*offset_ unfilt_x <3>*	*offset_ unfilt_x <2>*	*offset_ unfilt_x <1>*	*offset_ unfilt_x <0>*

Register *(0x3C)* contains the compensation value for unfiltered data for the y-axis.

Table 71: Unfiltered data compensation for the x-axis, register *(0x3C)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_ unfilt_y <7>	*offset_ unfilt_y <6>*	*offset_ unfilt_y <5>*	*offset_ unfilt_y <4>*	*offset_ unfilt_y <3>*	*offset_ unfilt_y <2>*	*offset_ unfilt_y <1>*	*offset_ unfilt_y <0>*

Register *(0x3D)* contains the compensation value for unfiltered data for the z-axis.

Table 72: Unfiltered data compensation for the y-axis, register *(0x3D)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
offset_ unfilt_z <7>	*offset_ unfilt_z <6>*	*offset_ unfilt_z <5>*	*offset_ unfilt_z <4>*	*offset_ unfilt_z <3>*	*offset_ unfilt_z <2>*	*offset_ unfilt_z <1>*	*offset_ unfilt_z <0>*

Registers *(0x3E)* and *(0x3F)* are image registers of registers in the EEPROM. They are not linked to any sensor-specific functionality.

6. Magnetometer register description

6.1 General remarks

The entire communication with the device's magnetometer part is performed by reading from and writing to registers. Registers have a width of 8 bits; they are mapped to a common space of 50 addresses from *(0x40)* up to *(0x71)*. Within the used range there are several registers which are marked as 'reserved'. Any reserved bit is ignored when it is written and no specific value is guaranteed when read. Especially, in SPI mode the SDO pin may stay in high-Z state when reading some of these registers.

Registers with addresses from *(0x40)* up to *(0x4A)* are read-only. Any attempt to write to these registers is ignored.

6.2 Register map

Register Address	Default Value	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0x71	N/A	reserved							
0x70	N/A								
0x6F	N/A								
0x6E	N/A								
0x6D	N/A								
0x6C	N/A								
0x6B	N/A								
0x6A	N/A								
0x69	N/A								
0x68	N/A								
0x67	N/A								
0x66	N/A								
0x65	N/A								
0x64	N/A								
0x63	N/A								
0x62	N/A								
0x61	N/A								
0x60	N/A								
0x5F	N/A								
0x5E	N/A								
0x5D	N/A								
0x5C	N/A								
0x5B	N/A								
0x5A	N/A								
0x59	N/A								
0x58	N/A								
0x57	N/A								
0x56	N/A								
0x55	N/A								
0x54	N/A								
0x53	N/A								
0x52	0x00	REPZ Number Of Repetitions (valid for Z) [7:0]							
0x51	0x00	REPXY Number Of Repetitions (valid for XY) [7:0]							
0x50	0x00	High Threshold [7:0]							
0x4F	0x00	Low Threshold [7:0]							
0x4E	0x07	Data Ready Pin En	Interrupt Pin En	Channel Z	Channel Y	Channel X	DR Polarity	Interrupt Latch	Interrupt Polarity
0X4D	0x3F	Data Overrun En	Overflow Int En	High Int Z en	High Int Y en	High Int X en	Low Int Z en	Low Int Y en	Low Int X en
0x4C	0x06	Adv. ST [1:0]		Data Rate [2:0]			Opmode [1:0]		Self Test
0x4B	0x01	Soft Reset '1'	fixed '0'	fixed '0'	fixed '0'	fixed '0'	SPI3en	Soft Reset '1'	Power Control Bit
0x4A	0x00	Data Overrun	Overflow	High Int Z	High Int Y	High Int X	Low Int Z	Low Int Y	Low Int X
0x49	N/A	RHALL [13:6] MSB							
0x48	N/A	RHALL [5:0] LSB						fixed '0'	Data Ready Status
0x47	N/A	DATA Z [14:7] MSB							
0x46	N/A	DATA Z [6:0] LSB							Z-Self-Test
0x45	N/A	DATA Y [12:5] MSB							
0x44	N/A	DATA Y [4:0] LSB					fixed '0'	fixed '0'	Y-Self-Test
0x43	N/A	DATA X [12:5] MSB							
0x42	N/A	DATA X [4:0] LSB					fixed '0'	fixed '0'	X-Self-Test
0x41	N/A	reserved							
0x40	0x32	Chip ID = 0x32 (can only be read if power control bit ="1")							

	w/r
	w/r accessible in suspend mode
	read only
	reserved

6.3 Chip ID

Register *(0x40)* *Chip ID* contains the magnetometer chip identification number, which is 0x32. This number can only be read if the power control bit (register *0x4B bit0*) is enabled.

Table 73: Chip identification number, register *(0x40)*

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	0	1	1	0	0	1	0

Register *(0x01)* *is reserved*

6.4 Magnetic field data

Register *(0x42)* contains the LSB part of x-axis magnetic field data and the self-test result flag for the x-axis.

Table 74: LSB part of x-axis magnetic field, register *(0x42)*

(0x42) Bit	Name	Description
Bit 7	*DATAX_lsb <4>*	Bit 4 of x-axis magnetic field data
Bit 6	*DATAX_lsb <3>*	Bit 3 of x-axis magnetic field data
Bit 5	*DATAX_lsb <2>*	Bit 2 of x-axis magnetic field data
Bit 4	*DATAX_lsb <1>*	Bit 1 of x-axis magnetic field data
Bit 3	*DATAX_lsb <0>*	Bit 0 of x-axis magnetic field data **= x LSB**
Bit 2	-	(fixed to 0)
Bit 1	-	(fixed to 0)
Bit 0	*SelfTestX*	Self-test result flag for x-axis, default is “1”

Register *(0x43)* contains the MSB part of x-axis magnetic field data.

Table 75: MSB part of x-axis magnetic field, register *(0x43)*

(0x43) Bit	Name	Description
Bit 7	*DATAX_msb <12>*	Bit 12 of x-axis magnetic field data **= x MSB**
Bit 6	*DATAX_msb <11>*	Bit 11 of x-axis magnetic field data
Bit 5	*DATAX_msb <10>*	Bit 10 of x-axis magnetic field data
Bit 4	*DATAX_msb <9>*	Bit 9 of x-axis magnetic field data
Bit 3	*DATAX_msb <8>*	Bit 8 of x-axis magnetic field data
Bit 2	*DATAX_msb <7>*	Bit 7 of x-axis magnetic field data
Bit 1	*DATAX_msb <6>*	Bit 6 of x-axis magnetic field data
Bit 0	*DATAX_msb <5>*	Bit 5 of x-axis magnetic field data

Register *(0x44)* contains the LSB part of y-axis magnetic field data and the self-test result flag for the y-axis.

Table 76: LSB part of y-axis magnetic field, register *(0x44)*

***(0x44)* Bit**	**Name**	**Description**
Bit 7	*DATAY_lsb <4>*	Bit 4 of y-axis magnetic field data
Bit 6	*DATAY_lsb <3>*	Bit 3 of y-axis magnetic field data
Bit 5	*DATAY_lsb <2>*	Bit 2 of y-axis magnetic field data
Bit 4	*DATAY_lsb <1>*	Bit 1 of y-axis magnetic field data
Bit 3	*DATAY_lsb <0>*	Bit 0 of y-axis magnetic field data **= y LSB**
Bit 2	-	(fixed to 0)
Bit 1	-	(fixed to 0)
Bit 0	*SelfTestY*	Self-test result flag for y-axis, default is “1”

Register *(0x45)* contains the MSB part of y-axis magnetic field data.

Table 77: MSB part of y-axis magnetic field, register *(0x45)*

***(0x43)* Bit**	**Name**	**Description**
Bit 7	*DATAY_msb <12>*	Bit 12 of y-axis magnetic field data **= y MSB**
Bit 6	*DATAY_msb <11>*	Bit 11 of y-axis magnetic field data
Bit 5	*DATAY_msb <10>*	Bit 10 of y-axis magnetic field data
Bit 4	*DATAY_msb <9>*	Bit 9 of y-axis magnetic field data
Bit 3	*DATAY_msb <8>*	Bit 8 of y-axis magnetic field data
Bit 2	*DATAY_msb <7>*	Bit 7 of y-axis magnetic field data
Bit 1	*DATAY_msb <6>*	Bit 6 of y-axis magnetic field data
Bit 0	*DATAY_msb <5>*	Bit 5 of y-axis magnetic field data

Register *(0x46)* contains the LSB part of z-axis magnetic field data and the self-test result flag for the z-axis.

Table 78: LSB part of z-axis magnetic field, register *(0x44)*

***(0x44)* Bit**	**Name**	**Description**
Bit 7	*DATAZ_lsb <6>*	Bit 6 of z-axis magnetic field data
Bit 6	*DATAZ_lsb <5>*	Bit 5 of z-axis magnetic field data
Bit 5	*DATAZ_lsb <4>*	Bit 4 of z-axis magnetic field data
Bit 4	*DATAZ_lsb <3>*	Bit 3 of z-axis magnetic field data
Bit 3	*DATAZ_lsb <2>*	Bit 2 of z-axis magnetic field data
Bit 2	*DATAZ_lsb <1>*	Bit 1 of z-axis magnetic field data
Bit 1	*DATAZ_lsb <0>*	Bit 0 of z-axis magnetic field data **= z LSB**
Bit 0	*SelfTestZ*	Self-test result flag for z-axis, default is “1”

Register *(0x47)* contains the MSB part of z-axis magnetic field data.

Table 79: MSB part of z-axis magnetic field, register *(0x45)*

***(0x45)* Bit**	**Name**	**Description**
Bit 7	*DATAZ_lsb <14>*	Bit 14 of y-axis magnetic field data **= z MSB**
Bit 6	*DATAZ_lsb <13>*	Bit 13 of y-axis magnetic field data
Bit 5	*DATAZ_lsb <12>*	Bit 12 of y-axis magnetic field data
Bit 4	*DATAZ_lsb <11>*	Bit 11 of y-axis magnetic field data
Bit 3	*DATAZ_lsb <10>*	Bit 10 of y-axis magnetic field data
Bit 2	*DATAZ_lsb <9>*	Bit 9 of y-axis magnetic field data
Bit 1	*DATAZ_lsb <8>*	Bit 8 of y-axis magnetic field data
Bit 0	*DATAZ_lsb <7>*	Bit 7 of y-axis magnetic field data

Register *(0x48)* contains the LSB part of hall resistance and the Data Ready (DRDY) status bit.

Table 80: LSB part of hall resistance, register *(0x46)*

***(0x46)* Bit**	**Name**	**Description**
Bit 7	*RHALL_lsb <5>*	Bit 5 of hall resistance
Bit 6	*RHALL _lsb <4>*	Bit 4 of hall resistance
Bit 5	*RHALL _lsb <3>*	Bit 3 of hall resistance
Bit 4	*RHALL _lsb <2>*	Bit 2 of hall resistance
Bit 3	*RHALL _lsb <1>*	Bit 1 of hall resistance
Bit 2	*RHALL _lsb <0>*	Bit 0 of hall resistance **= RHALL LSB**
Bit 1	-	(fixed to 0)
Bit 0	*Data Ready Status*	Data ready (DRDY) status bit

Register *(0x49)* contains the MSB part of hall resistance.

Table 81: MSB part of hall resistance, register *(0x47)*

***(0x47)* Bit**	**Name**	**Description**
Bit 7	*RHALL_msb <13>*	Bit 13 of hall resistance **= RHALL MSB**
Bit 6	*RHALL_msb <12>*	Bit 12 of hall resistance
Bit 5	*RHALL_msb <11>*	Bit 11 of hall resistance
Bit 4	*RHALL_msb <10>*	Bit 10 of hall resistance
Bit 3	*RHALL_msb <9>*	Bit 9 of hall resistance
Bit 2	*RHALL_msb <8>*	Bit 8 of hall resistance
Bit 1	*RHALL_msb <7>*	Bit 7 of hall resistance
Bit 0	*RHALL_msb <6>*	Bit 6 of hall resistance

6.5 Interrupt status register

Register *(0x4A)* contains the states of all magnetometer interrupts.

Table 82: Interrupt status, register *(0x4A)*

***(0x4A)* Bit**	**Name**	**Description**
Bit 7	*Data overrun*	Data overrun status flag
Bit 6	*Overflow*	Overflow status flag
Bit 5	*High Int Z*	High-Threshold interrupt z-axis status flag
Bit 4	*High Int Y*	High-Threshold interrupt y-axis status flag
Bit 3	*High Int X*	High-Threshold interrupt x-axis status flag
Bit 2	*Low Int Z*	Low-Threshold interrupt z-axis status flag
Bit 1	*Low Int Y*	Low-Threshold interrupt y-axis status flag
Bit 0	*Low Int X*	Low-Threshold interrupt x-axis status flag

6.6 Power and operation modes, self-test and data output rate control registers

Register *(0x4B)* contains control bits for power control, soft reset and interface SPI mode selection. This special control register is also accessible in suspend mode.

Soft reset is executed when both bits (register *0x4B bit7* and *bit1*) are set “1”. Soft reset does not execute a full POR sequence, but all registers are reset except for the “trim” registers above register *0x54* and the power control register (*0x4B*). Soft reset always brings the device into sleep mode. When device is in the suspend mode, soft reset is ignored and the device remains in suspend mode. The two “Soft Reset” bits are reset to “0” automatically after soft reset was completed.
When SPI mode is selected, the “SPI3En” bit enables SPI 3-wire mode when set “1”. When “SPI3En” is set “0” (default), 4-wire SPI mode is selected.
Setting the “Power Control bit” to “1” brings the device up from Suspend mode to Sleep mode, when “Power Control bit” is set “0” the device returns to Suspend mode (see chapter 4.3.2 for details of magnetometer power modes).

Table 83: Power control, soft reset and SPI mode control register *(0x4B)*

***(0x4B)* Bit**	**Name**	**Description**
Bit 7	*Soft Reset ‘1’*	One of the soft reset trigger bits.
Bit 6	-	(fixed to 0)
Bit 5	-	(fixed to 0)
Bit 4	-	(fixed to 0)
Bit 3	-	(fixed to 0)
Bit 2	*SPI3en*	Enable bit for SPI3 mode
Bit 1	*Soft Reset ‘1’*	One of the soft reset trigger bits.
Bit 0	*Power Control bit*	When set to “0”, suspend mode is selected

Register *(0x4C)* contains control bits for operation mode, output data rate and self-test.

The two “Adv. ST” bits control the on-chip advanced self-test (see chapter 4.5.2 for details of the magnetometer advanced self-test).
The three “Data rate” bits control the magnetometer output data rate according to below Table 85.
The two “Opmode” bits control the operation mode according to below Table 86 (see chapter 4.3.2 for a detailed description of magnetometer power modes).

Table 84: Operation mode, output data rate and self-test control register *(0x4C)*

***(0x4C)* Bit**	**Name**	**Description**
Bit 7	*Adv. ST <1>*	Advanced self-test control bit 1
Bit 6	*Adv. ST <0>*	Advanced self-test control bit 0
Bit 5	*Data rate <2>*	Data rate control bit 2
Bit 4	*Data rate <1>*	Data rate control bit 1
Bit 3	*Data rate <0>*	Data rate control bit 0
Bit 2	*Opmode <1>*	Operation mode control bit 1
Bit 1	*Opmode <0>*	Operation mode control bit 0
Bit 0	*Self Test*	Normal self-test control bit

Three “Data rate” bits control the output data rate (ODR) of the BMC050 magnetometer part:

Table 85: Output data rate (ODR) setting *(0x4C)*

***(0x4C)* Data rate <2:0>**	**Magnetometer output data rate (ODR)**
000b	10 (default)
001b	2
010b	6
011b	8
100b	15
101b	20
110b	25
111b	30

Two “Data rate” bits control the operation mode of the BMC050 magnetometer part:

Table 86: Operation mode setting *(0x4C)*

***(0x4C)* Opmode <1:0>**	**Magnetometer operation mode[4]**
00b	Normal mode
01b	Forced mode
10b	*Reserved, do not use*
11b	Sleep Mode

[4] See chapter 4.3.2 for a detailed description of magnetometer power modes.

6.7 Interrupt and axis enable settings control registers

Register *(0x4D)* contains control bits for interrupt settings. (Also refer to chapter 4.9 for the details of magnetometer interrupt operation).

Table 87: Interrupt settings control register *(0x4D)*

***(0x4D)* Bit**	**Name**	**Description**
Bit 7	*Data Overrun En*	Enables data overrun indication in the "Data Overrun" flag (active high, default is "0" disabled)
Bit 6	*Overflow Int En*	Activates mapping of Overflow flag status to the INT3 pin (active high, default is "0" disabled)
Bit 5	*High Int Z En*	Enables the z-axis detection for High-Threshold interrupts (active low, default is "1" disabled)
Bit 4	*High Int Y En*	Enables the y-axis detection for High-Threshold interrupts (active low, default is "1" disabled)
Bit 3	*High Int X En*	Enables the x-axis detection for High-Threshold interrupts (active low, default is "1" disabled)
Bit 2	*Low Int Z En*	Enables the z-axis detection for Low-Threshold interrupts (active low, default is "1" disabled)
Bit 1	*Low Int Y En*	Enables the y-axis detection for Low-Threshold interrupts (active low, default is "1" disabled)
Bit 0	*Low Int X En*	Enables the x-axis detection for Low-Threshold interrupts (active low, default is "1" disabled)

Register *(0x4E)* contains control bits interrupt settings and axes enable bits. (Also refer to chapter 4.9 for the details of magnetometer interrupt operation). If a magnetic measurement channel is disabled, its last measured magnetic output values will remain in the data registers. If the Z channel is disabled, the resistance measurement will also be disabled and the resistance output value will be set to zero. If interrupts are set to trigger on an axis that has been disabled, these interrupts will still be asserted based on the last measured value.

Table 88: Interrupt settings and axes enable bits control register *(0x4E)*

***(0x4E)* Bit**	**Name**	**Description**
Bit 7	*Data Ready Pin En*	Enables data ready status mapping on DRDY pin (active high, default is “0” disabled)
Bit 6	*Interrupt Pin En*	Enables interrupt status mapping on INT3 pin (active high, default is “0” disabled)
Bit 5	*Channel Z*	Enable z-axis and resistance measurement (active low, default is “0” enabled)
Bit 4	*Channel Y*	Enable y-axis (active low, default is “0” enabled)
Bit 3	*Channel X*	Enable x-axis (active low, default is “0” enabled)
Bit 2	*DR Polarity*	Data ready (DRDY) pin polarity (“0” is active low, “1” is active high, default is “1” active high)
Bit 1	*Interrupt Latch*	Interrupt latching (“0” means non-latched - interrupt pin is on as long as the condition is fulfilled, “1” means latched - interrupt pin is on until interrupt status register *0x4A* is read, default is “”1” latched)
Bit 0	*Interrupt Polarity*	Interrupt pin INT3 polarity selection (“1” – is active high, “0” is active low, default is “1” active high)

Register *(0x4F)* contains the Low-Threshold interrupt threshold setting. (Also refer to chapter 4.9 for the details of magnetometer interrupt operation and the threshold setting).

Table 89: Low-threshold interrupt threshold setting control register *(0x4F)*

***(0x4F)* Bit**	**Name**	**Description**
Bit 7	*LowThreshold <7>*	Bit 7 of Low-Threshold interrupt threshold setting
Bit 6	*LowThreshold <6>*	Bit 6 of Low-Threshold interrupt threshold setting
Bit 5	*LowThreshold <5>*	Bit 5 of Low-Threshold interrupt threshold setting
Bit 4	*LowThreshold <4>*	Bit 4 of Low-Threshold interrupt threshold setting
Bit 3	*LowThreshold <3>*	Bit 3 of Low-Threshold interrupt threshold setting
Bit 2	*LowThreshold <2>*	Bit 2 of Low-Threshold interrupt threshold setting
Bit 1	*LowThreshold <1>*	Bit 1 of Low-Threshold interrupt threshold setting
Bit 0	*LowThreshold <0>*	Bit 0 of Low-Threshold interrupt threshold setting

Register *(0x50)* contains the High-Threshold interrupt threshold setting. (Also refer to chapter 4.9 for the details of magnetometer interrupt operation and the threshold setting).

Table 90: High-threshold interrupt threshold setting control register *(0x4F)*

***(0x50)* Bit**	**Name**	**Description**
Bit 7	*HighThreshold <7>*	Bit 7 of High-Threshold interrupt threshold setting
Bit 6	*HighThreshold <6>*	Bit 6 of High-Threshold interrupt threshold setting
Bit 5	*HighThreshold <5>*	Bit 5 of High-Threshold interrupt threshold setting
Bit 4	*HighThreshold <4>*	Bit 4 of High-Threshold interrupt threshold setting
Bit 3	*HighThreshold <3>*	Bit 3 of High-Threshold interrupt threshold setting
Bit 2	*HighThreshold <2>*	Bit 2 of High-Threshold interrupt threshold setting
Bit 1	*HighThreshold <1>*	Bit 1 of High-Threshold interrupt threshold setting
Bit 0	*HighThreshold <0>*	Bit 0 of High-Threshold interrupt threshold setting

6.8 Number of repetitions control registers

Register *(0x51)* contains the number of repetitions for x/y-axis. Table 92 below shows the number of repetitions resulting out of the register configuration. The performed number of repetitions nXY can be calculated from unsigned register value as nXY = 1+2xREPXY as shown below, where b7-b0 are the bits 7 to 0 of register *0x51*:

$$nXY = 1 + 2 \cdot (b7 \cdot 2^7 + b6 \cdot 2^6 + b5 \cdot 2^5 + b4 \cdot 2^4 + b3 \cdot 2^3 + b2 \cdot 2^2 + b1 \cdot 2^1 + b0 \cdot 2^0)$$
$$= 1 + 2 \cdot (REPXY)$$

Table 91: X/y-axis repetitions control register *(0x51)*

	Name	**Description**
Bit 7	*REPXY <7>*	Bit 7 of number of repetitions (valid for XY)
Bit 6	*REPXY <6>*	Bit 6 of number of repetitions (valid for XY)
Bit 5	*REPXY <5>*	Bit 5 of number of repetitions (valid for XY)
Bit 4	*REPXY <4>*	Bit 4 of number of repetitions (valid for XY)
Bit 3	*REPXY <3>*	Bit 3 of number of repetitions (valid for XY)
Bit 2	*REPXY <2>*	Bit 2 of number of repetitions (valid for XY)
Bit 1	*REPXY <1>*	Bit 1 of number of repetitions (valid for XY)
Bit 0	*REPXY <0>*	Bit 0 of number of repetitions (valid for XY)

Table 92: Numbers of repetition for x/y-axis depending on value of register *(0x51)*

***(0x51)* register value (binary)**	***(0x51)* register value (hex)**	**Number of repetitions for x- and y-axis each**
00000000b	0x00h	1
00000001b	0x01h	3
00000010b	0x02h	5
00000011b	0x03h	7
…		…
11111111b	0xFFh	511

Register *(0x52)* contains the number of repetitions for z-axis. Table 94 below shows the number of repetitions resulting out of the register configuration. The performed number of repetitions nZ can be calculated from unsigned register value as nZ = 1+REPZ as shown below, where b7-b0 are the bits 7 to 0 of register *0x52*:

$$nZ = 1 + 1 \cdot (b7 \cdot 2^7 + b6 \cdot 2^6 + b5 \cdot 2^5 + b4 \cdot 2^4 + b3 \cdot 2^3 + b2 \cdot 2^2 + b1 \cdot 2^1 + b0 \cdot 2^0)$$
$$= 1 + REPZ$$

Table 93: Z-axis repetitions control register *(0x52)*

***(0x52)* Bit**	**Name**	**Description**
Bit 7	*REPZ <7>*	Bit 7 of number of repetitions (valid for Z)
Bit 6	*REPZ <6>*	Bit 6 of number of repetitions (valid for Z)
Bit 5	*REPZ <5>*	Bit 5 of number of repetitions (valid for Z)
Bit 4	*REPZ <4>*	Bit 4 of number of repetitions (valid for Z)
Bit 3	*REPZ <3>*	Bit 3 of number of repetitions (valid for Z)
Bit 2	*REPZ <2>*	Bit 2 of number of repetitions (valid for Z)
Bit 1	*REPZ <1>*	Bit 1 of number of repetitions (valid for Z)
Bit 0	*REPZ <0>*	Bit 0 of number of repetitions (valid for Z)

Table 94: Numbers of repetition for z-axis depending on value of register *(0x52)*

***(0x52)* register value (binary)**	***(0x52)* register value (hex)**	**Number of repetitions for z-axis**
00000000b	0x00h	1
00000001b	0x01h	2
00000010b	0x02h	3
00000011b	0x03h	4
…		…
11111111b	0xFFh	256

7. Digital interfaces

The BMC050 supports two serial digital interface protocols for communication as a slave with a host device for each of the accelerometer and magnetometer part: SPI and I²C (accelerometer part and magnetometer part only operate either both in I²C mode or either both in SPI mode, mixed communication protocols are not possible because the interface pins are shared).

The active interface is selected by the state of the two “protocol select” pins, Pin#2 (PS1) and Pin#3 (PS2): “0” (“1”) selects SPI (I²C). For details see chapter 4.2.

By default, SPI operates in the standard 4-wire configuration. It can be re-configured by software to work in 3-wire mode instead of standard 4-wire mode for both the accelerometer part and magnetometer part.

Both interfaces share the same pins. The mapping for each interface is given in the following table:

Table 95: Mapping of the interface pins

Pin#	Name	use w/ SPI	use w/ I²C	Description
10	SDO	SDO	Accelerometer and magnetometer part I²C address selection	SPI: Data Output (4-wire mode) I²C: Used to set LSB of I²C address of accelerometer part and magnetometer part
11	SDx	SDI	SDA	SPI: Data Input (4-wire mode) Data Input / Output (3-wire mode) I²C: Serial Data
5	CSB1[5]	CSB1	Unused, do not connect	SPI: Chip Select 1 for accelerometer part (enable)
6	CSB2[5]	CSB2	Magnetometer part I²C address selection	SPI: Chip Select 2 for magnetometer part (enable) I²C: Used to set bit1 of I²C address of magnetometer part
15	SCx	SCK	SCL	SPI: Serial Clock I²C: Serial Clock

[5] note: CSB1 and CSB2 must be operated separately and cannot be tied together.

The following table shows the electrical specifications of the interface pins:

Table 96: Electrical specification of the interface pins

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Pull-up Resistance CSB1	$R_{up, CSB1}$	Internal Pull-up Resistance to VDDIO	70	120	190	kΩ
Pull-up Resistance CSB2	$R_{up, CSB2}$	Internal Pull-up Resistance to VDDIO; deactivated in I²C mode	80	100	120	kΩ
Input Capacitance	C_{in}				10	pF
I²C Bus Load Capacitance (max. drive capability)	C_{I2C_Load}				400	pF

7.1 Serial peripheral interface (SPI)

The timing specification for SPI of the BMC050 is given in the following table:

Table 97: SPI timing for BMC050 accelerometer and magnetometer part

Parameter	Symbol	Condition	Min	Max	Unit
Clock Frequency	f_{SPI}	Max. Load on SDI or SDO = 25pF		10	MHz
SCK Low Pulse	t_{SCKL}		20		ns
SCK High Pulse	t_{SCKH}		20		ns
SDI Setup Time	t_{SDI_setup}		20		ns
SDI Hold Time	t_{SDI_hold}		20		ns
SDO Output Delay	t_{SDO_OD}	Load = 25pF		30	ns
		Load = 250pF, V_{DDIO} = 2.4V		40	ns
CSB Setup Time	t_{CSB_setup}		20		ns
CSB Hold Time	t_{CSB_hold}		40		ns

The following figure shows the definition of the SPI timings given in Table 97:

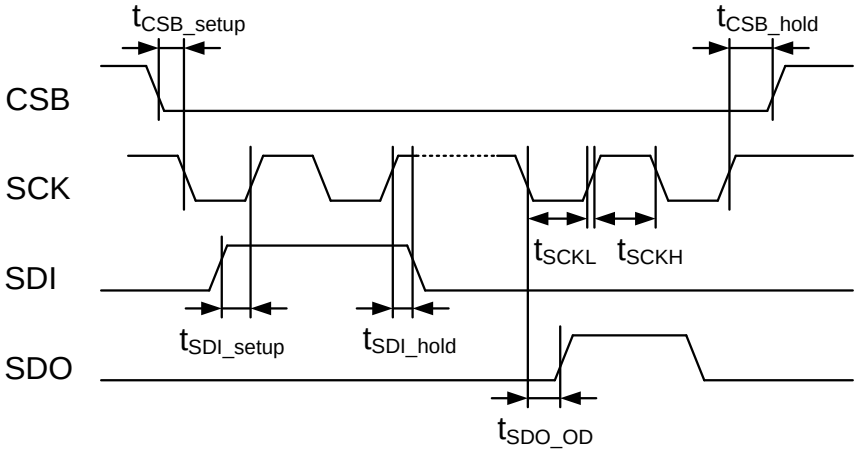


Figure 16: SPI timing diagram

The SPI interface of the BMC050 is compatible with two modes, “00” and “11”. The automatic selection between [CPOL = “0” and CPHA = “0”] and [CPOL = “1” and CPHA = “1”] is done based on the value of SCK after a falling edge of CSB.

Two configurations of the SPI interface are supported by the BMC050: 4-wire and 3-wire. The same protocol is used by both configurations. The device operates in 4-wire configuration by default. It can be switched to 3-wire configuration by writing “1” to *(0x34)* “spi3” for the accelerometer part and writing “1” to *(0x4B)* “SPI3en” for the magnetometer part (after power control bit was set). Pin SDI is used as the common data pin in 3-wire configuration.
For single byte read as well as write operations, 16-bit protocols are used. The BMC050 also supports multiple-byte read operations.

Note: CSB1 and CSB2 pin are separate chip select lines for accelerometer and magnetometer part, which *must* be operated separately. Tying them together is strictly forbidden, since this will make the accelerometer and magnetometer outputs compete against each other.

In SPI 4-wire configuration CSB1 or CSB2 (chip select low active), SCK (serial clock), SDI (serial data input), and SDO (serial data output) pins are used. The communication starts when the CSB is pulled low by the SPI master and stops when CSB is pulled high. SCK is also controlled by SPI master. SDI and SDO are driven at the falling edge of SCK and should be captured at the rising edge of SCK.

The basic write operation waveform for 4-wire configuration is depicted in Figure 17. During the entire write cycle SDO remains in high- impedance state.

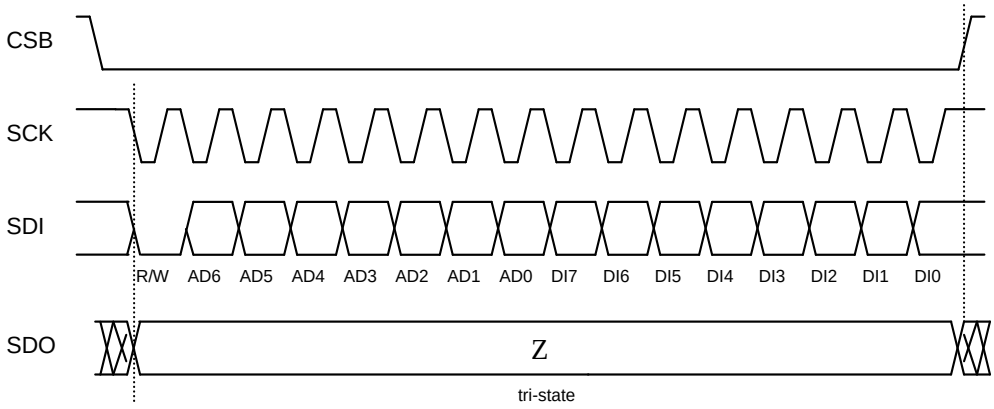


Figure 17: 4-wire basic SPI write sequence (mode “11”)

The basic read operation waveform for 4-wire configuration is depicted in Figure 18:

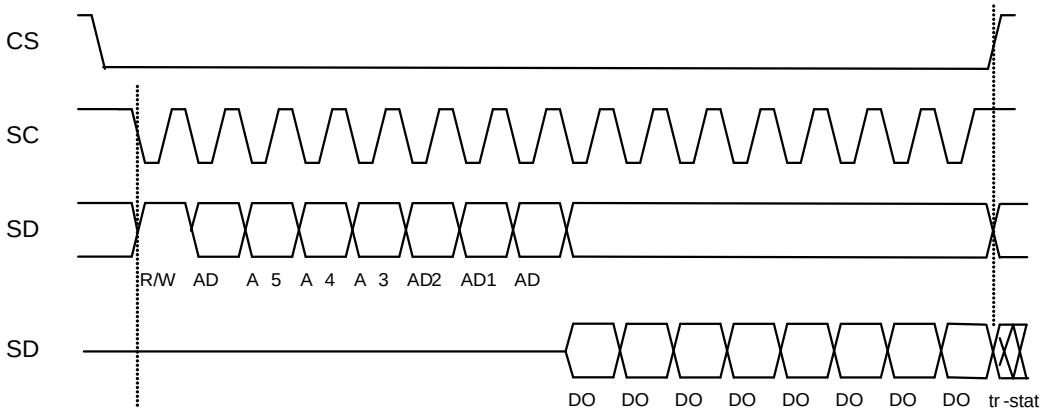


Figure 18: 4-wire basic SPI read sequence (mode “11”)

The data bits are used as follows:

Bit0: Read/Write bit. When 0, the data SDI is written into the chip. When 1, the data SDO from the chip is read.

Bit1-7: Address AD(6:0).

Bit8-15: when in write mode, these are the data SDI, which will be written into the address. When in read mode, these are the data SDO, which are read from the address.

Multiple read operations are possible by keeping CSB low and continuing the data transfer. Only the first register address has to be written. Addresses are automatically incremented after each read access as long as CSB stays active low.

The principle of multiple read is shown in Figure 19:

	Control byte		Data byte	Data byte	Data byte	
Start	RW	Register adress (02h)	Data register - adress 02h	Data register - adress 03h	Data register - adress 04h	Stop
CSB = 0	1	0 0 0 0 0 1 0	X X X X X X X X	X X X X X X X X	X X X X X X X X	CSB = 1

Figure 19: SPI multiple read

In SPI 3-wire configuration CSB1 or CSB2 (chip select low active), SCK (serial clock), and SDI (serial data input and output) pins are used. The communication starts when the CSB is pulled low by the SPI master and stops when CSB is pulled high. SCK is also controlled by SPI master. SDI is driven (when used as input of the device) at the falling edge of SCK and should be captured (when used as the output of the device) at the rising edge of SCK.

The protocol as such is the same in 3-wire configuration as it is in 4-wire configuration. The basic operation waveform (read or write access) for 3-wire configuration is depicted in Figure 20:

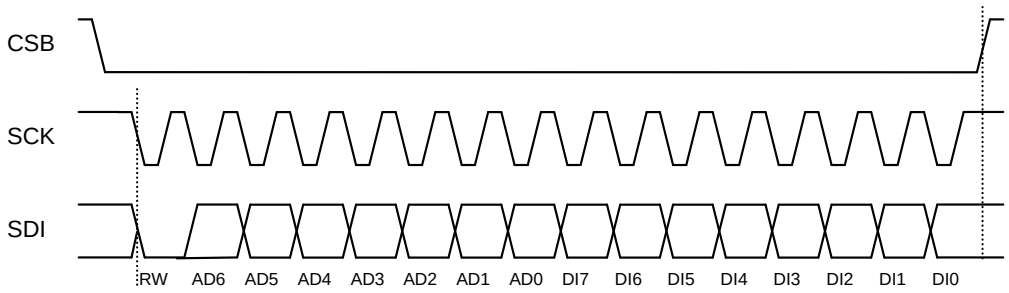


Figure 20: 3-wire basic SPI read or write sequence (mode “11”)

7.2 Inter-Integrated Circuit (I²C)

The I²C bus uses SCL (= SCx pin, serial clock) and SDA (= SDx pin, serial data input and output) signal lines. Both lines are connected to V_{DDIO} externally via pull-up resistors so that they are pulled high when the bus is free.

The I²C interface of the BMC050 is compatible with the I²C Specification UM10204 Rev. 03 (19 June 2007), available at http://www.nxp.com. The BMC050 supports I²C standard mode and fast mode, only 7-bit address mode is supported.

The default I²C address of the BMC050's accelerometer part is 0011000b (0x18). It is used if the SDO pin is pulled to "GND". The alternative address 0011001b (0x19) is selected by pulling the SDO pin to "VDDIO".

The default I²C address of the BMC050's magnetometer part is 0x10. The five MSB are hardwired to "00100". In order to prevent bus conflicts bit0 can be inverted by setting '1' to SDO, and the bit 1 can be inverted by setting '1' to the CSB line according to below Table:

Table 98: BMC050 I²C addresses

CSB2 pin	SDO pin	Accelerometer part I²C address	Magnetometer part I²C address
GND	GND	0x18	0x10
GND	VDDIO	0x19	0x11
VDDIO	GND	0x18	0x12
VDDIO	VDDIO	0x19	0x13

The timing specification for I²C of the BMC050 is given in Table 99:

Table 99: I²C timings.

Parameter	Symbol	Condition	Min	Max	Unit
Clock Frequency	f_{SCL}			400	kHz
SCL Low Period	t_{LOW}		[6]	[6]	µs
SCL High Period	t_{HIGH}		[6]	[6]	
SDA Setup Time	t_{SUDAT}		[6]	[6]	
SDA Hold Time	t_{HDDAT}		[6]	[6]	
Setup Time for a repeated Start Condition	t_{SUSTA}		[6]	[6]	
Hold Time for a Start Condition	t_{HDSTA}		[6]	[6]	
Setup Time for a Stop Condition	t_{SUSTO}		[6]	[6]	
Time before a new Transmission can start	t_{BUF}		[6]	[6]	

[6] fully compliant to the I²C specification"UM10204 I²C-bus specification Rev.03 – 19 June 2007"

Figure 21 shows the definition of the I²C timings given in Table 99:

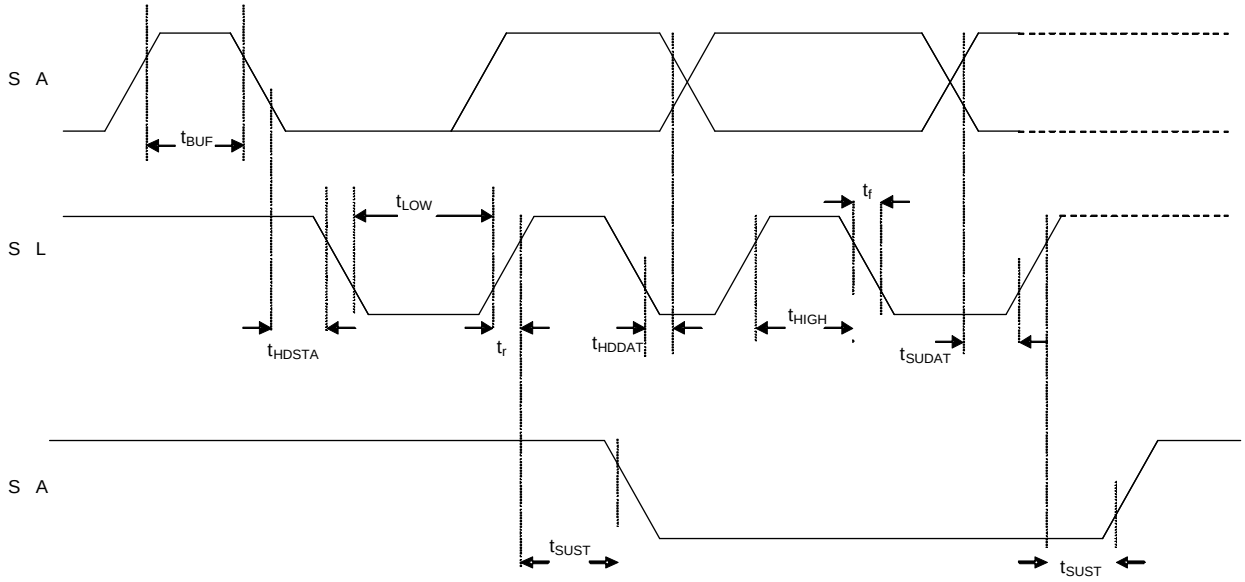


Figure 21: I²C timing diagram

The I²C protocol works as follows:

START: Data transmission on the bus begins with a high to low transition on the SDA line while SCL is held high (start condition (S) indicated by I²C bus master). Once the START signal is transferred by the master, the bus is considered busy.

STOP: Each data transfer should be terminated by a Stop signal (P) generated by master. The STOP condition is a low to HIGH transition on SDA line while SCL is held high.

ACK: Each byte of data transferred must be acknowledged. It is indicated by an acknowledge bit sent by the receiver. The transmitter must release the SDA line (no pull down) during the acknowledge pulse while the receiver must then pull the SDA line low so that it remains stable low during the high period of the acknowledge clock cycle.

In the following diagrams these abbreviations are used:

S	Start
P	Stop
ACKS	Acknowledge by slave
ACKM	Acknowledge by master
NACKM	Not acknowledge by master
RW	Read / Write

A START immediately followed by a STOP (without SCK toggling from logic “1” to logic “0”) is not supported. If such a combination occurs, the STOP is not recognized by the device.

I²C write access:
I²C write access can be used to write a data byte in one sequence.

The sequence begins with start condition generated by the master, followed by 7 bits slave address and a write bit (RW = 0). The slave sends an acknowledge bit (ACK = 0) and releases the bus. Then the master sends the one byte register address. The slave again acknowledges the transmission and waits for the 8 bits of data which shall be written to the specified register address. After the slave acknowledges the data byte, the master generates a stop signal and terminates the writing protocol.

Example of an I²C write access:

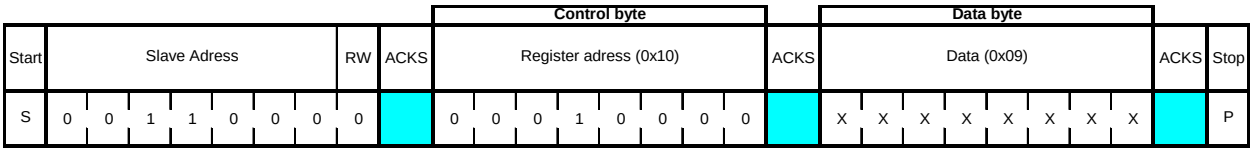


Figure 22: Example of an I²C write access

I²C read access:
I²C read access also can be used to read one or multiple data bytes in one sequence.

A read sequence consists of a one-byte I²C write phase followed by the I²C read phase. The two parts of the transmission must be separated by a repeated start condition (Sr). The I²C write phase addresses the slave and sends the register address to be read. After slave acknowledges the transmission, the master generates again a start condition and sends the slave address together with a read bit (RW = 1). Then the master releases the bus and waits for the data bytes to be read out from slave. After each data byte the master has to generate an acknowledge bit (ACK = 0) to enable further data transfer. A NACKM (ACK = 1) from the master stops the data being transferred from the slave. The slave releases the bus so that the master can generate a STOP condition and terminate the transmission.
The register address is automatically incremented and, therefore, more than one byte can be sequentially read out. Once a new data read transmission starts, the start address will be set to the register address specified in the latest I²C write command. By default the start address is set at 0x00. In this way repetitive multi-bytes reads from the same starting address are possible.

In order to prevent the I²C slave of the device to lock-up the I²C bus, a watchdog timer (WDT) is implemented in the accelerometer part of BMC050. The WDT observes internal I²C signals and resets the I²C interface if the bus is locked-up by the BMC050 accelerometer part. The activity and the timer period of the WDT can be configured through the bits *(0x34) i2c_wdt_en* and *(0x34) i2c_wdt_sel*.

Writing “1” (“0”) to *(0x34) i2c_wdt_en* activates (de-activates) the WDT. Writing “0” (“1”) to *(0x34) i2c_wdt_se* selects a timer period of 1 ms (50 ms).

Example of an I²C multiple read accesses:

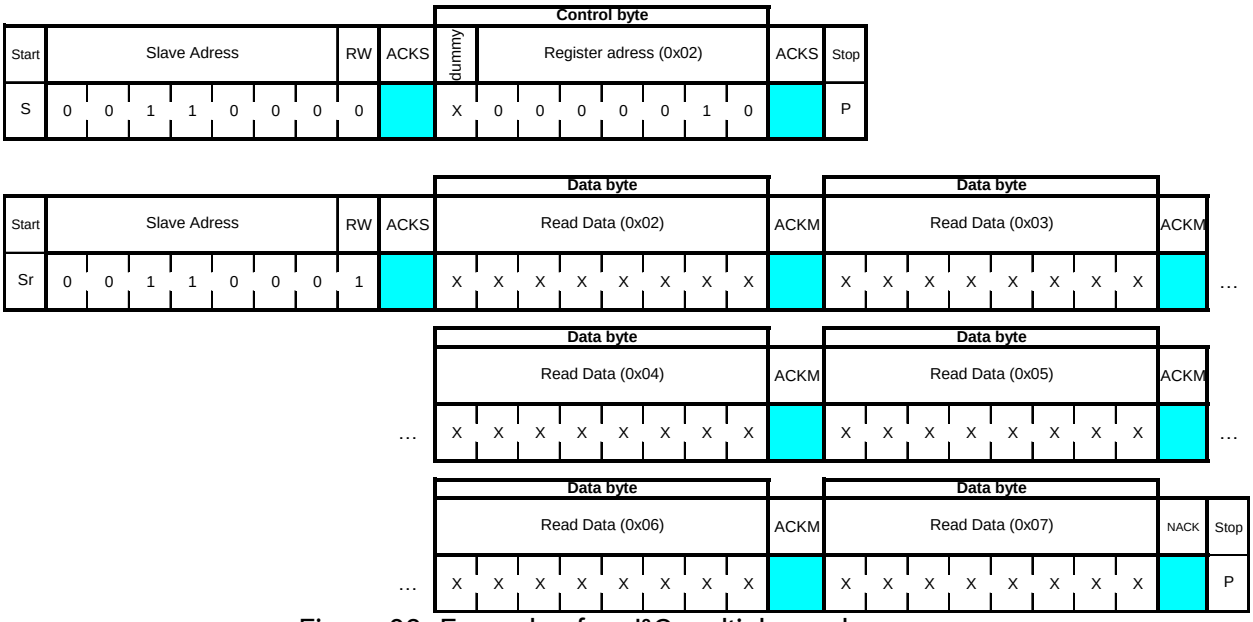


Figure 23: Example of an I²C multiple read access

8. Pin-out and connection diagram

8.1 Pin-out

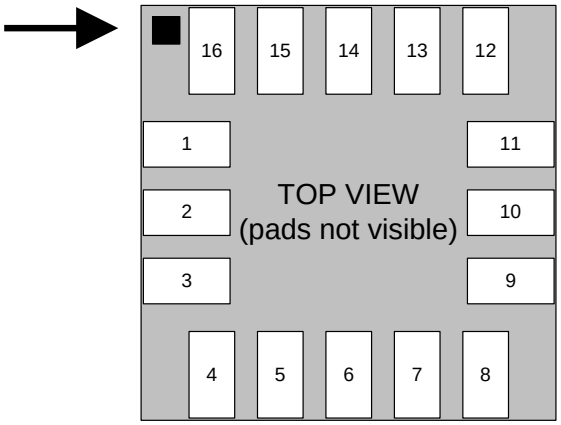


Figure 24: Pin-out top view

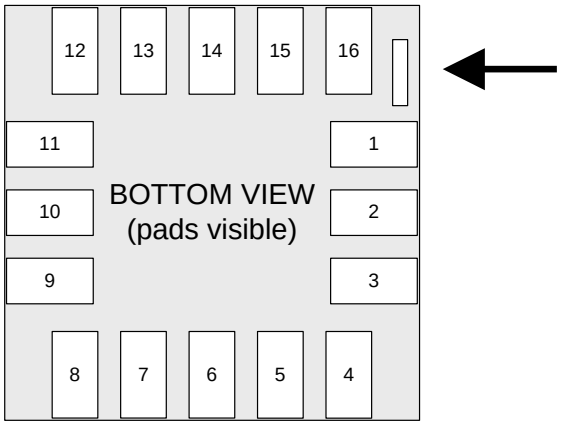


Figure 25: Pin-out bottom view

The arrows indicate the pin1 marking.

Table 100: Pin description

Pin	Name	I/O Type	Sensor	Description	Connect to		
					SPI 4W	SPI 3W	I²C
1	INT2	Out	Acc	Interrupt output #2	INT2 input or DNC if unused		
2	PS1	In	Acc	Protocol select #1	GND	GND	V_{DDIO}
3	PS2	In	Mag	Protocol select #2	GND	GND	V_{DDIO}
4	INT3	Out	Mag	Interrupt output #3	INT3 input or DNC if unused		
5	CSB1[7]	In	Acc	Chip Select #1	CSB1	CSB1	NC (float) or V_{DDIO}
6	CSB2[7]	In	Mag	Chip Select #2	CSB2	CSB2	GND for default address
7	GND	Supply	Mag+Acc	Ground	GND		
8	GND	Supply	Mag+Acc	Ground	GND		
9	DRDY	Out	Mag	Data ready	DRDY input or DNC if unused		
10	SDO	Out	Mag+Acc	SPI: Data out	SDO / MISO	DNC (float)	GND for default address
11	SDI	In/Out	Mag+Acc	SPI: Data in, I²C: Data	SDI / MOSI	SDA	SDA
12	GND	Supply	Mag+Acc	Ground	GND		
13	VDD	Supply	Mag+Acc	Supply voltage	V_{DD}		
14	VDDIO	Supply	Mag+Acc	I/O voltage	V_{DDIO}		
15	SCK	In	Mag+Acc	Serial clock	SCK	SCK	SCL
16	INT1	Out	Acc	Interrupt output #1	INT 1 input or DNC if unused		

[7] Note: CSB1 and CSB2 must be operated separately and cannot be tied together.

8.2 Connection diagram 4-wire SPI

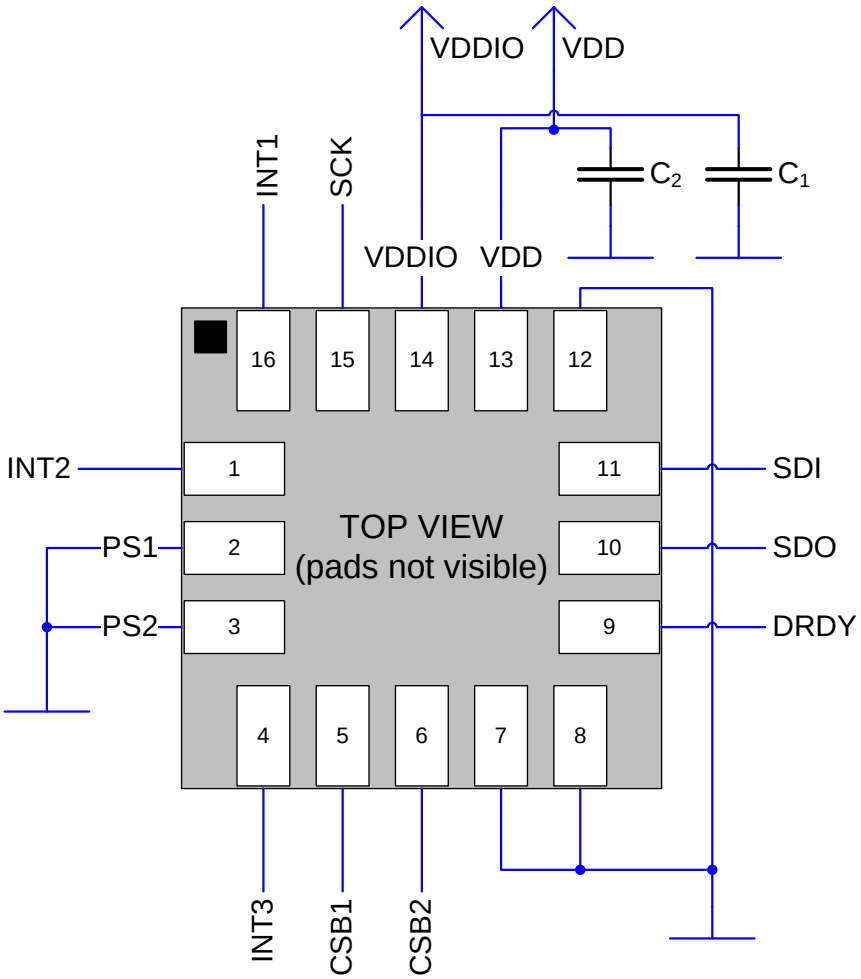


Figure 26: 4-wire SPI connection diagram

Note: the recommended value for C_1, C_2 is 100 nF. CSB1 and CSB2 must be operated separately.

8.3 Connection diagram 3-wire SPI

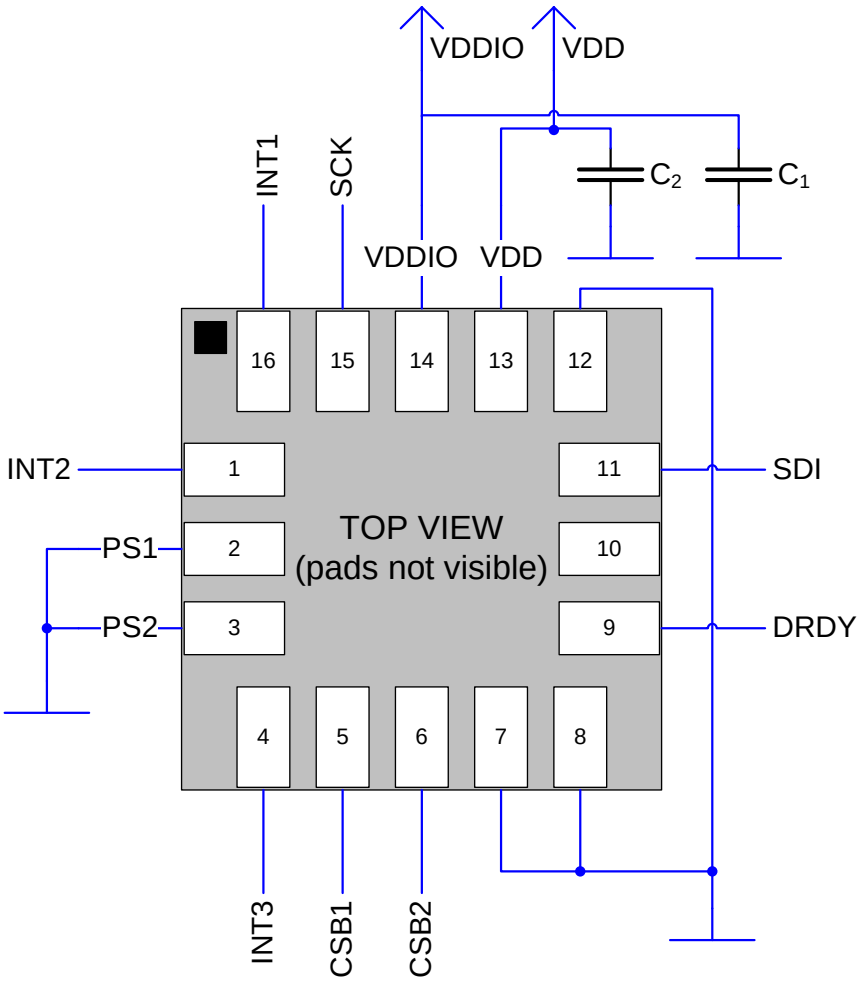


Figure 27: 3-wire SPI connection diagram

Note: the recommended value for C_1, C_2 is 100 nF. CSB1 and CSB2 must be operated separately.

8.4 Connection diagram I²C

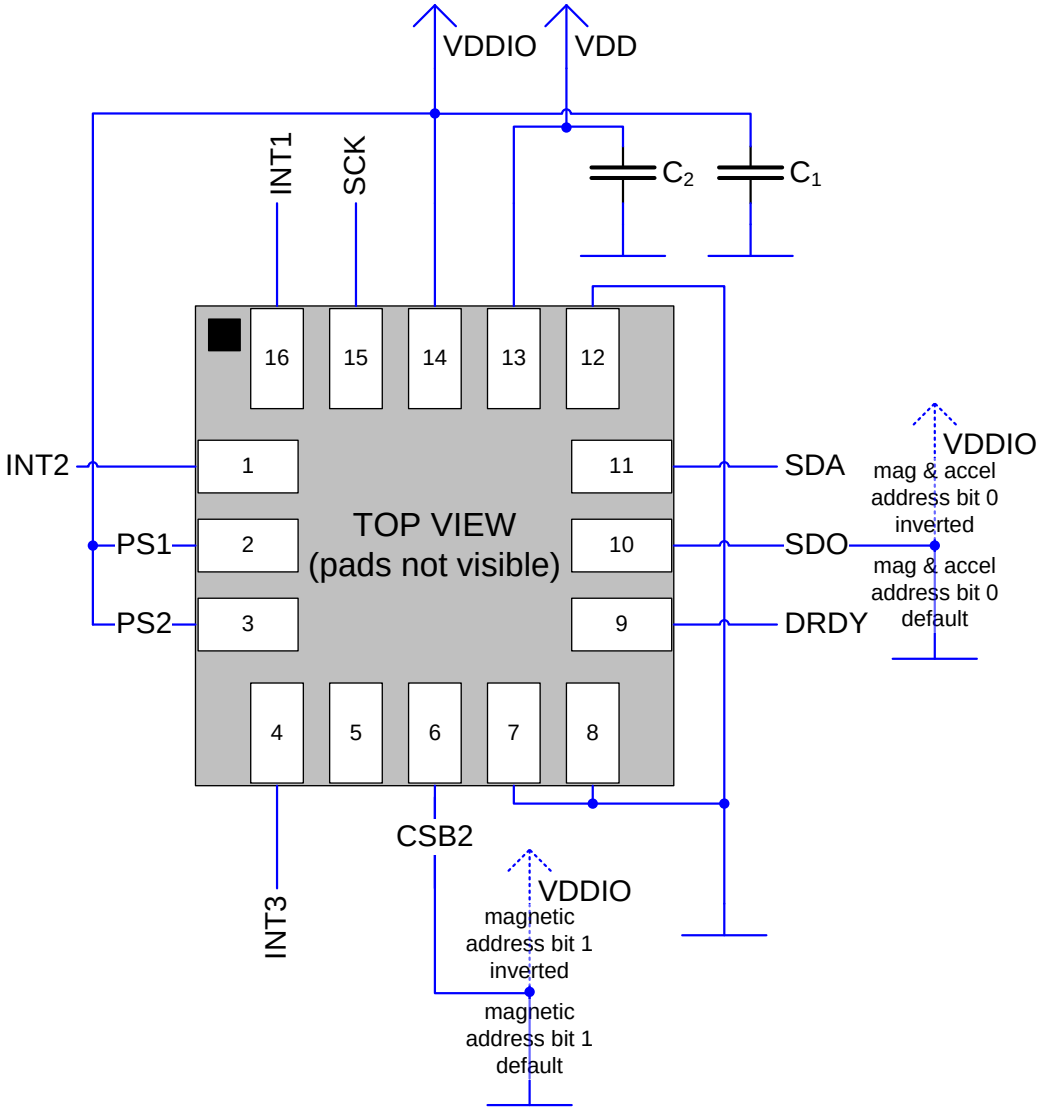


Figure 28: I²C connection diagram

Note: the recommended value for C_1, C_2 is 100 nF.

9. Package

9.1 Outline dimensions

The sensor housing is a standard LGA 3x3 16-lead package. Its dimensions are the following:

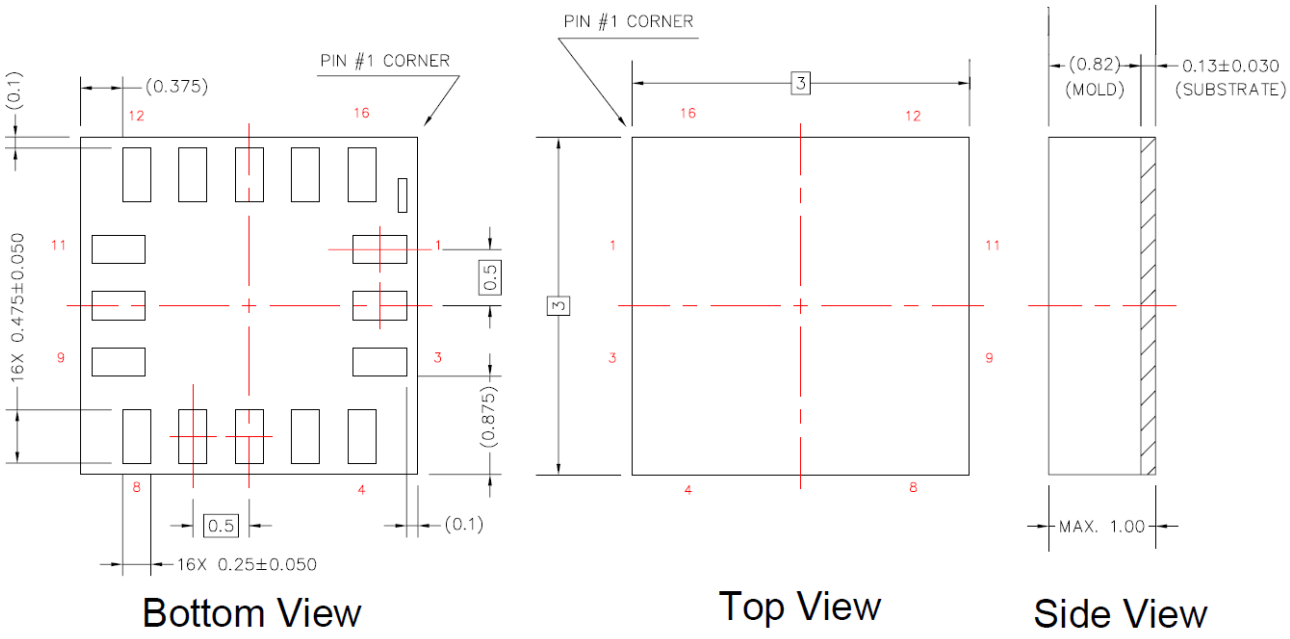


Figure 29: Package outline dimensions

9.2 Sensing axes orientation

The magnetic and acceleration sensing axes of the BMC050 are matching.
If the sensor is accelerated in the indicated directions, the corresponding channel will deliver a positive acceleration signal (dynamic acceleration). If the sensor is at rest and the force of gravity is acting along the indicated directions, the output of the corresponding channel will be negative (static acceleration). If a positive magnetic field is applied in the indicated directions, the corresponding channel will deliver a positive acceleration signal.

Example: If the sensor is at rest or at uniform motion in a gravitational and magnetic field according to the figure given below, the output signals are

- 0 g for the X acceleration channel, 0 µT for the X magnetic channel
- 0 g for the Y acceleration channel, 0 µT for the Y magnetic channel
- +1 g for the Z acceleration channel, -|B| for the Z magnetic channel

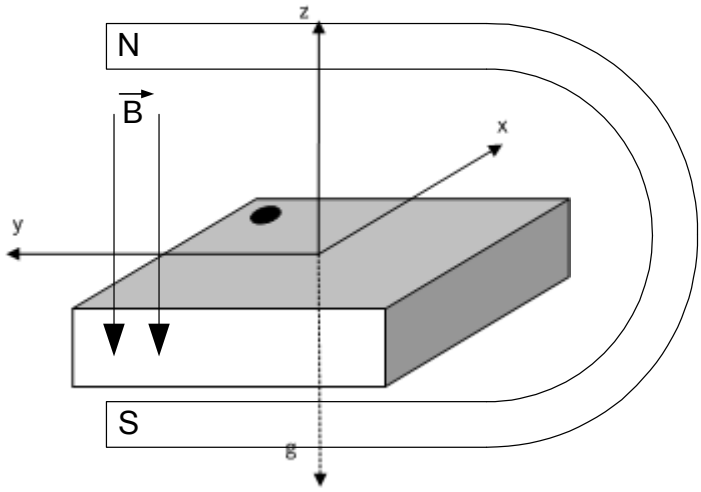
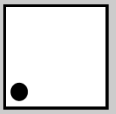
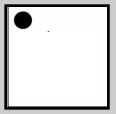
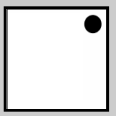
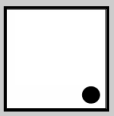


Figure 30: Orientation of sensing axes (acceleration and magnetic)

Please note that the planet's north pole is a magnetic south pole. This means that when the BMC050's X axis points towards the north pole, the measured field will be negative.
The following table lists all corresponding output signals on X, Y, and Z while the sensor is at rest or at uniform motion in a gravity field under assumption of a ±2g range setting and a top down gravity and magnetic vector as shown above.

Table 101: Output signals depending on sensor orientation

Sensor Orientation (gravity vector ↓ = acceleration vector ↑, magnetic vector ↓)						
Output Signal X	0g / 0LSB 0 µT	+1g / 256LSB -|B| µT	0g / 0LSB 0 µT	-1g / - 256LSB +|B| µT	0g / 0LSB 0 µT	0g / 0LSB 0 µT
Output Signal Y	-1g / - 256LSB +|B| µT	0g / 0LSB 0 µT	+1g / 256LSB -|B| µT	0g / 0LSB 0 µT	0g / 0LSB 0 µT	0g / 0LSB 0 µT
Output Signal Z	0g / 0LSB 0 µT	0g / 0LSB 0 µT	0g / 0LSB 0 µT	0g / 0LSB 0 µT	+1g / 256LSB -|B| µT	-1g / - 256LSB +|B| µT

9.3 Android axes orientation

The Android coordinate system is shown in Figure 31. The origin is in the lower-left corner with respect to the screen, with the X axis horizontal and pointing right, the Y axis vertical and pointing up and the Z axis pointing outside the front face of the screen. In this system, coordinates behind the screen have negative Z values.

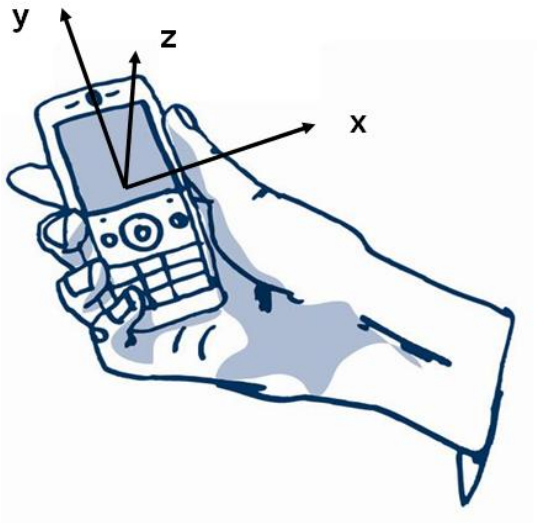


Figure 31: Android coordinate system

Attitude terms are defined in the following way (see Figure 32):

- Heading / Azimuth – angle between the magnetic north direction and the Y axis, around the Z axis (0° to 360°). 0° = North, 90° = East, 180° = South, 270° = West.
- Pitch – rotation around X axis (-180° to 180°), with positive values when the z-axis moves toward the y-axis.
- Roll – rotation around Y axis (-90° to 90°), with positive values when the x-axis moves toward the z-axis.

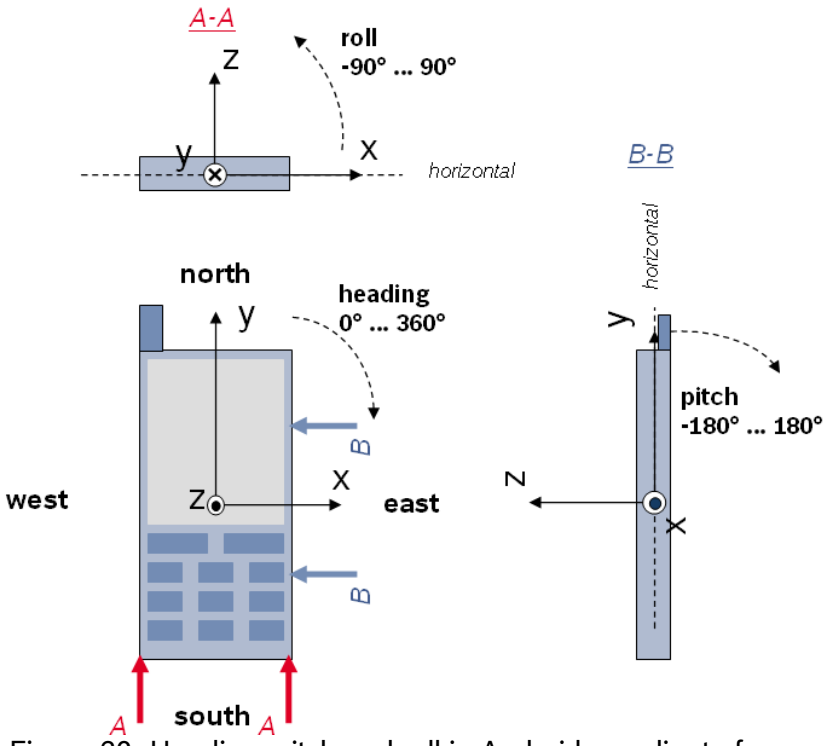


Figure 32: Heading, pitch and roll in Android coordinate frame

9.4 Landing pattern recommendation

For the design of the landing pattern, we recommend the following dimensioning:

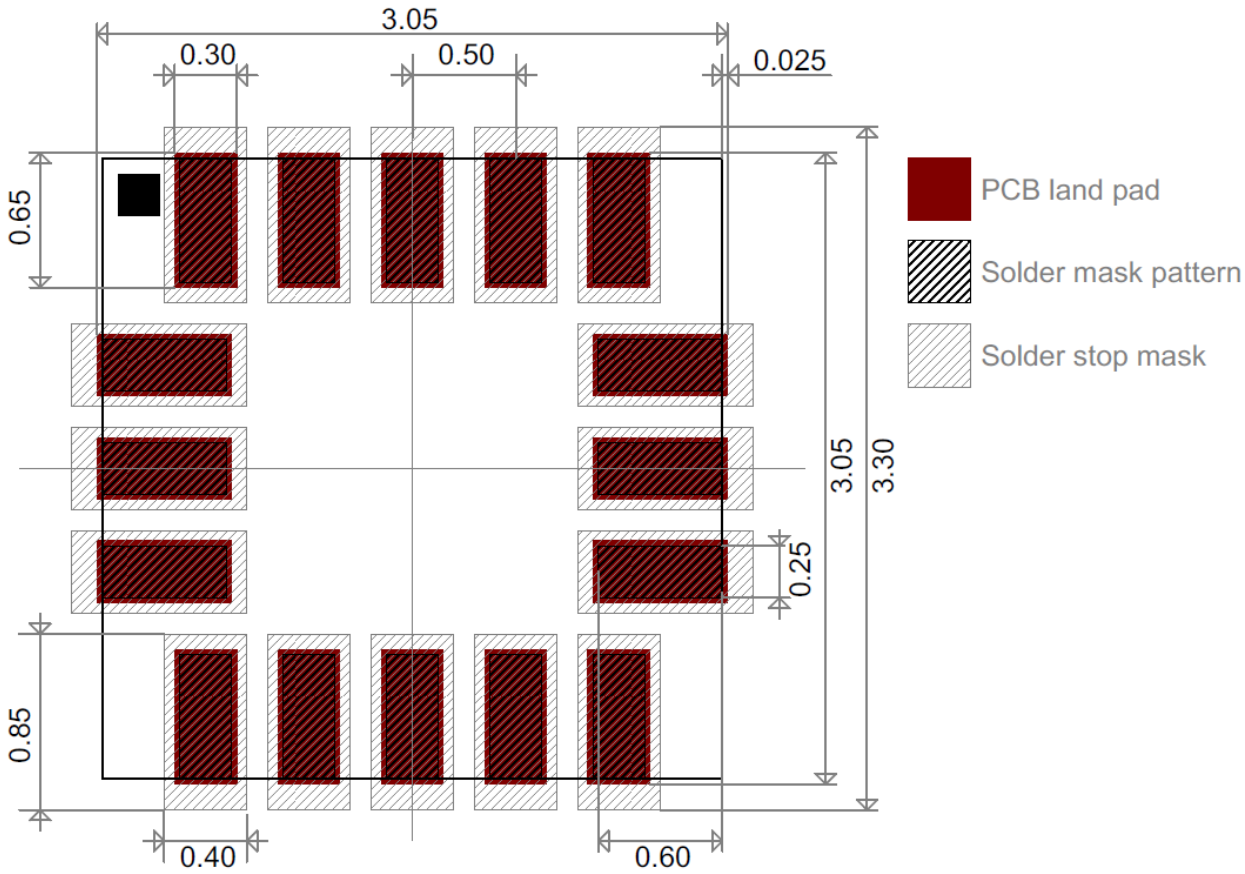
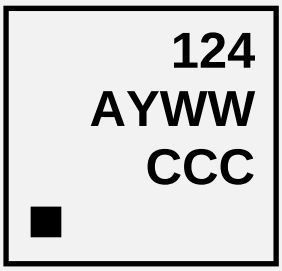


Figure 33: Landing patterns relative to the device pins, dimensions are in mm

9.5 Marking

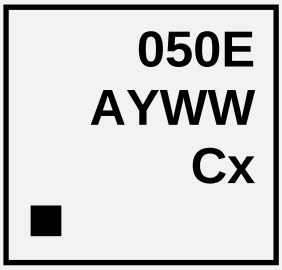
9.5.1 **Mass production devices**

Table 102: Marking of mass production samples

Labeling	Name	Symbol	Remark
	Product number	124	
	Sub-Con ID	A	Packaging sub-contractor identifier, coded alphanumerically
	Date code	YWW	Y: year, numerically coded: 9 = 2009, 0 = 2010, 1 = 2011, ... WW: Calendar week, numerical code
	Lot counter	CCC	Numerical counter
	Pin 1 identifier	■	

9.5.2 **Engineering samples**

Table 103: Marking of engineering samples

Labeling	Name	Symbol	Remark
	Product number	050E	BMC050 Engineering sample
	Sub-Con ID	A	Packaging sub-contractor identifier, coded alphanumerically
	Date code	YWW	Y: year, numerically coded: 9 = 2009, 0 = 2010, 1 = 2011, ... WW: Calendar week, numerical code
	Sample status	Cx	x = Numerical counter
	Pin 1 identifier	■	

9.6 Soldering guidelines

The moisture sensitivity level of the BMC050 sensors corresponds to JEDEC Level 1, see also:

- IPC/JEDEC J-STD-020C "Joint Industry Standard: Moisture/Reflow Sensitivity Classification for non-hermetic Solid State Surface Mount Devices"
- IPC/JEDEC J-STD-033A "Joint Industry Standard: Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices".

The sensor fulfils the lead-free soldering requirements of the above-mentioned IPC/JEDEC standard, i.e. reflow soldering with a peak temperature up to 260°C.

Profile Feature		Pb-Free Assembly
Average Ramp-Up Rate (Ts_{max} to Tp)		3° C/second max.
Preheat – Temperature Min (Ts_{min}) – Temperature Max (Ts_{max}) – Time (ts_{min} to ts_{max})		150 °C 200 °C 60-180 seconds
Time maintained above: – Temperature (T_L) – Time (t_L)		217 °C 60-150 seconds
Peak/Classification Temperature (Tp)		260 °C
Time within 5 °C of actual Peak Temperature (tp)		20-40 seconds
Ramp-Down Rate		6 °C/second max.
Time 25 °C to Peak Temperature		8 minutes max.

Note 1: All temperatures refer to topside of the package, measured on the package body surface.

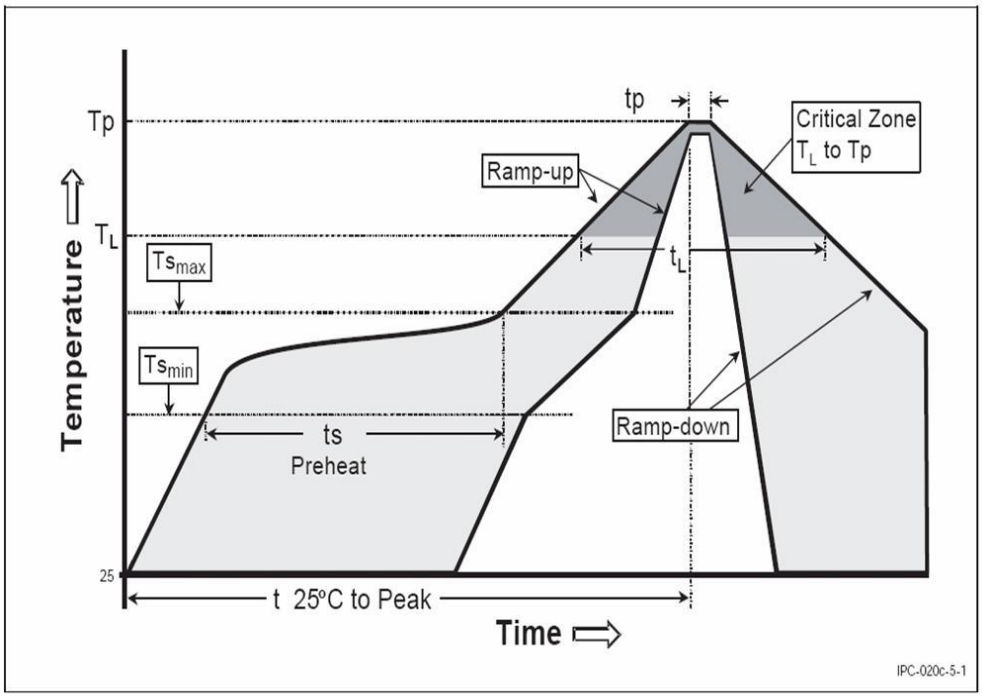


Figure 34: Soldering profile

9.7 Handling instructions

Micromechanical sensors are designed to sense acceleration with high accuracy even at low amplitudes and contain highly sensitive structures inside the sensor element. The MEMS sensor can tolerate mechanical shocks up to several thousand g. However, these limits might be exceeded in conditions with extreme shock loads such as e.g. hammer blow on or next to the sensor, dropping of the sensor onto hard surfaces etc.

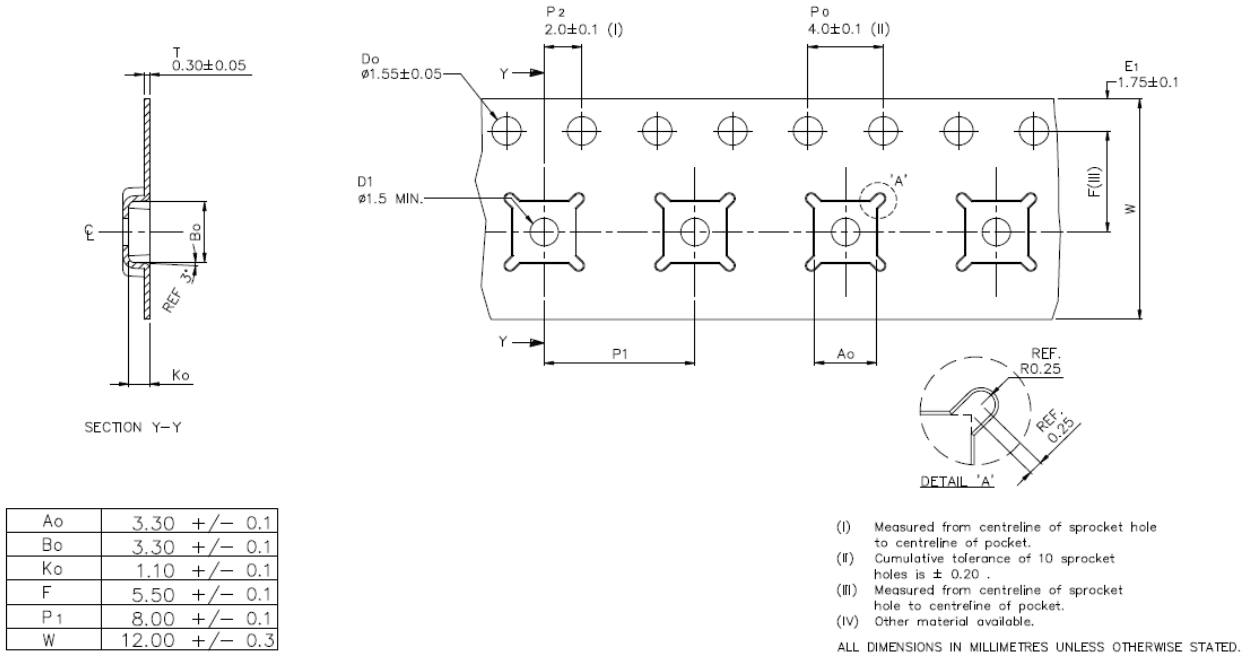
We recommend avoiding g-forces beyond the specified limits during transport, handling and mounting of the sensors in a defined and qualified installation process.

This device has built-in protections against high electrostatic discharges or electric fields (e.g. 2kV HBM); however, anti-static precautions should be taken as for any other CMOS component. Unless otherwise specified, proper operation can only occur when all terminal voltages are kept within the supply voltage range. Unused inputs must always be tied to a defined logic voltage level.

9.8 Tape and reel specification

9.8.1 **Tape and reel dimensions**

The following picture describes the dimensions of the tape used for shipping the BMC050 sensor device. The material of the tape is made of conductive polystyrene (IV).



Ao	3.30 +/– 0.1
Bo	3.30 +/– 0.1
Ko	1.10 +/– 0.1
F	5.50 +/– 0.1
P1	8.00 +/– 0.1
W	12.00 +/– 0.3

(I) Measured from centreline of sprocket hole to centreline of pocket.
(II) Cumulative tolerance of 10 sprocket holes is ± 0.20 .
(III) Measured from centreline of sprocket hole to centreline of pocket.
(IV) Other material available.

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED.

Figure 35: Tape and reel dimensions in mm

9.8.2 **Orientation within the reel**

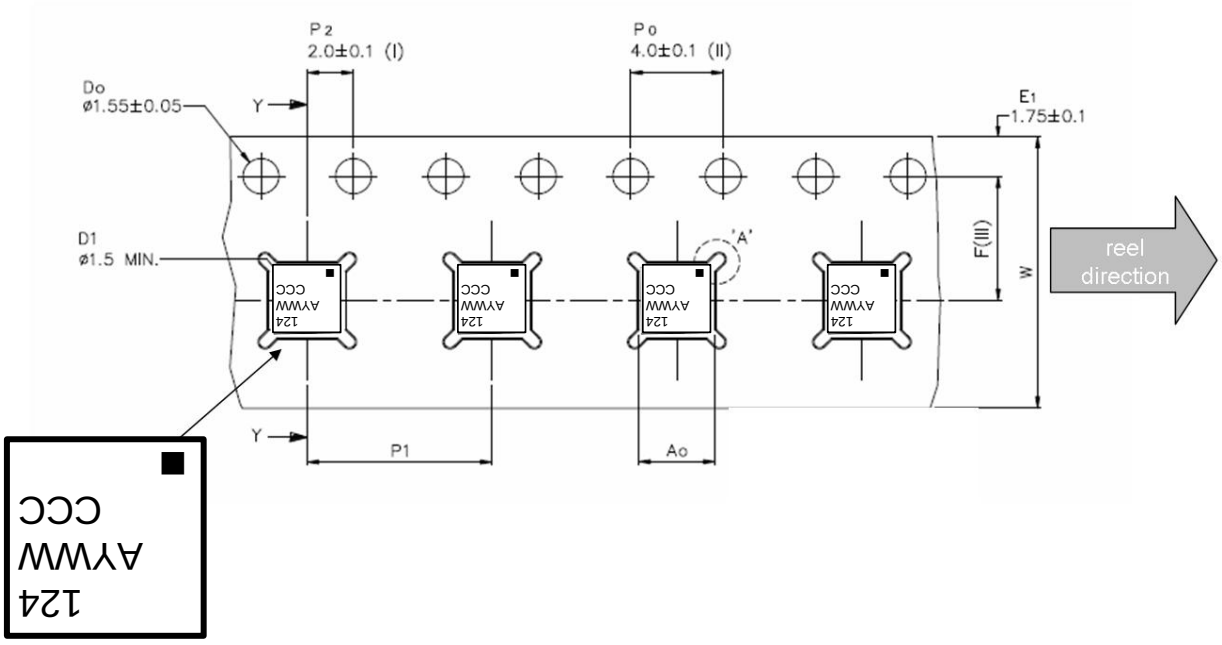


Figure 36: Orientation of the BMC050 devices relative to the tape

9.9 Environmental safety

The BMC050 sensor meets the requirements of the EC restriction of hazardous substances (RoHS) directive, see also:

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

9.9.1 **Halogen content**

Results of chemical analysis indicate that the BMC050 contains less than 900ppm (by weight) of Fluorine, Chlorine, Iodine and Bromine. Therefore the BMC050 can be regarded as halogen-free. For more details on the analysis results please contact your Bosch Sensortec representative.

9.9.2 **Internal package structure**

Within the scope of Bosch Sensortec's ambition to improve its products and secure the mass product supply, Bosch Sensortec qualifies additional sources (e.g. 2nd source) for the LGA package of the BMC050.

While Bosch Sensortec took care that all of the technical packages parameters are described above are 100% identical for all sources, there can be differences in the chemical content and the internal structural between the different package sources.

However, as secured by the extensive product qualification process of Bosch Sensortec, this has no impact to the usage or to the quality of the BMC050 product.

10. Legal disclaimer

10.1 Engineering samples

Engineering Samples are marked with an asterisk (*) or (e) or (E). Samples may vary from the valid technical specifications of the product series contained in this data sheet. They are therefore not intended or fit for resale to third parties or for use in end products. Their sole purpose is internal client testing. The testing of an engineering sample may in no way replace the testing of a product series. Bosch Sensortec assumes no liability for the use of engineering samples. The Purchaser shall indemnify Bosch Sensortec from all claims arising from the use of engineering samples.

10.2 Product use

Bosch Sensortec products are developed for the consumer goods industry. They may only be used within the parameters of this product data sheet. They are not fit for use in life-sustaining or security sensitive systems. Security sensitive systems are those for which a malfunction is expected to lead to bodily harm or significant property damage. In addition, they are not fit for use in products which interact with motor vehicle systems.

The resale and/or use of products are at the purchaser's own risk and his own responsibility. The examination of fitness for the intended use is the sole responsibility of the Purchaser.

The purchaser shall indemnify Bosch Sensortec from all third party claims arising from any product use not covered by the parameters of this product data sheet or not approved by Bosch Sensortec and reimburse Bosch Sensortec for all costs in connection with such claims.

The purchaser must monitor the market for the purchased products, particularly with regard to product safety, and inform Bosch Sensortec without delay of all security relevant incidents.

10.3 Application examples and hints

With respect to any examples or hints given herein, any typical values stated herein and/or any information regarding the application of the device, Bosch Sensortec hereby disclaims any and all warranties and liabilities of any kind, including without limitation warranties of non-infringement of intellectual property rights or copyrights of any third party. The information given in this document shall in no event be regarded as a guarantee of conditions or characteristics. They are provided for illustrative purposes only and no evaluation regarding infringement of intellectual property rights or copyrights or regarding functionality, performance or error has been made.

11. Document history and modification

Rev. No	Chapter	Description of modification/changes	Date
0.1		Document creation	2010-08-12
0.3		New revision	2011-03-07
0.4		New revision	2011-03-29
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0.6		New revision	2011-07-28
0.7		New revision	2011-10-13
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