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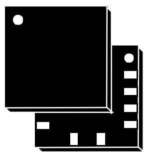
LSM303AGR

Ultra-compact high-performance eCompass module: ultra-low-power 3D accelerometer and 3D magnetometer

Datasheet - production data



LGA-12 (2.0x2.0x1.0 mm)

Features

- 3 magnetic field channels and 3 acceleration channels
- ±50 gauss magnetic dynamic range
- ±2/±4/±8/±16 *g* selectable acceleration full scales
- 16-bit data output
- SPI / I^2C serial interfaces
- Analog supply voltage 1.71 V to 3.6 V
- Selectable power mode/resolution for accelerometer and magnetometer
- Single measurement mode for magnetometer
- Programmable interrupt generators for free-fall, motion detection and magnetic field detection
- Embedded self-test
- Embedded temperature sensor
- Embedded FIFO
- ECOPACK®, RoHS and “Green” compliant

Applications

- Tilt-compensated compasses
- Map rotation
- Position detection
- Motion-activated functions
- Free-fall detection
- Click/double-click recognition
- Pedometers
- Intelligent power saving for handheld devices
- Display orientation
- Gaming and virtual reality input devices
- Impact recognition and logging
- Vibration monitoring and compensation

Description

The LSM303AGR is an ultra-low-power high-performance system-in-package featuring a 3D digital linear acceleration sensor and a 3D digital magnetic sensor.

The LSM303AGR has linear acceleration full scales of ±2*g*/±4*g*/±8*g*/±16*g* and a magnetic field dynamic range of ±50 gauss.

The LSM303AGR includes an I^2C serial bus interface that supports standard, fast mode, fast mode plus, and high-speed (100 kHz, 400 kHz, 1 MHz, and 3.4 MHz) and an SPI serial standard interface.

The system can be configured to generate an interrupt signal for free-fall, motion detection and magnetic field detection.

The magnetic and accelerometer blocks can be enabled or put into power-down mode separately.

The LSM303AGR is available in a plastic land grid array package (LGA) and is guaranteed to operate over an extended temperature range from -40 °C to +85 °C.

Table 1. Device summary

Part number	Temp. range [°C]	Package	Packaging
LSM303AGR	-40 to +85	LGA-12	Tray
LSM303AGRTR	-40 to +85	LGA-12	Tape and reel

Contents

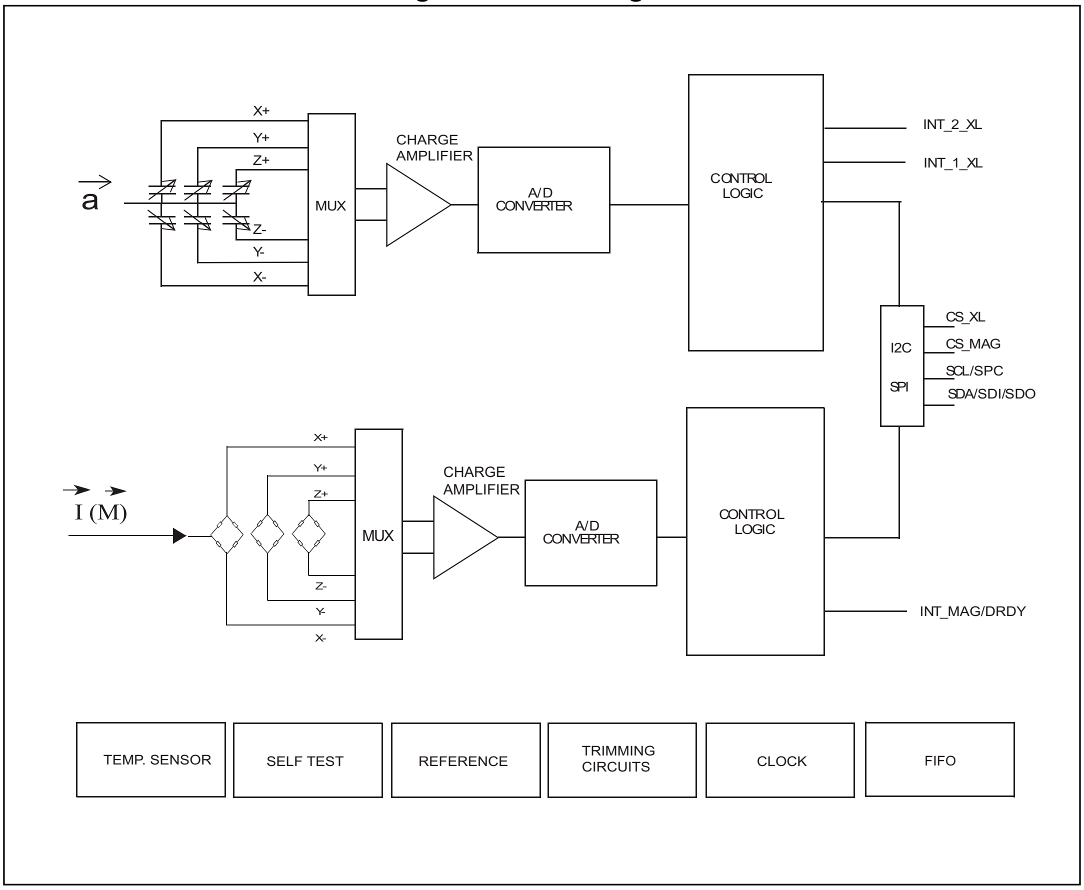
List of tables

List of figures

1 Block diagram and pin description

1.1 Block diagram

Figure 1. Block diagram



1.2 Pin description

Figure 2. Pin connections

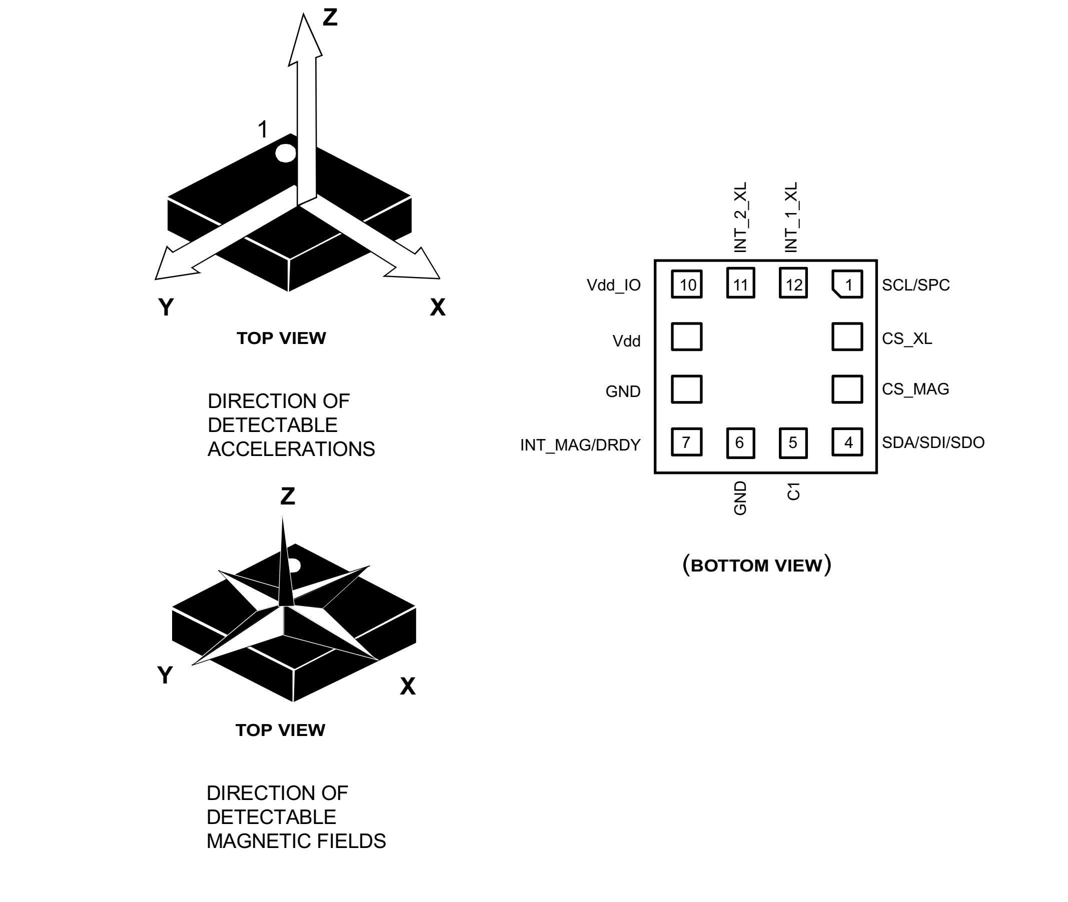


Table 2. Pin description

Pin#	Name	Function
1	SCL SPC	I^2C serial clock (SCL) SPI serial port clock (SPC)
2	CS_XL	Accelerometer: SPI enable I^2C/SPI mode selection 1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled
3	CS_MAG	Magnetometer: SPI enable I^2C/SPI mode selection 1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled
4	SDA SDI SDO	I^2C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
5	C1	Capacitor connection (C1 = 220 nF)
6	GND	Connected to GND
7	INT_MAG/DRDY	Magnetometer interrupt/data-ready signal
8	GND	0 V
9	Vdd	Power supply
10	Vdd_IO	Power supply for I/O pins
11	INT_2_XL	Accelerometer interrupt 2
12	INT_1_XL	Accelerometer interrupt 1

2 Module specifications

2.1 Sensor characteristics

@ Vdd = 2.5 V, T = 25 °C unless otherwise noted[a].

Table 3. Sensor characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
LA_FS	Linear acceleration measurement range			±2		*g*
				±4		
				±8		
				±16		
M_FS	Magnetic dynamic range			±49.152		gauss
LA_So	Linear acceleration sensitivity[2]	FS = ±2 *g* and in high-resolution mode	-7%	0.98	+7%	m*g*/LSB
		FS = ±4 *g* and in high-resolution mode	-7%	1.95	+7%	
		FS = ±8 *g* and in high-resolution mode	-7%	3.9	+7%	
		FS = ±16 *g* and in high-resolution mode	-7%	11.72	+7%	
		FS = ±2 *g* and in normal mode	-7%	3.9	+7%	
		FS = ±4 *g* and in normal mode	-7%	7.82	+7%	
		FS = ±8 *g* and in normal mode	-7%	15.63	+7%	
		FS = ±16 *g* and in normal mode	-7%	46.9	+7%	
		FS = ±2 *g* and in low-power mode	-7%	15.63	+7%	
		FS = ±4 *g* and in low-power mode	-7%	31.26	+7%	
		FS = ±8 *g* and in low-power mode	-7%	62.52	+7%	
		FS = ±16 *g* and in low-power mode	-7%	187.58	+7%	
M_So	Magnetic sensitivity[2]		-7%	1.5	+7%	mgauss/ LSB
LA_TCSo	Linear acceleration sensitivity change vs. temperature[3]			0.01		%/°C
M_TCSo	Magnetic sensitivity change vs. temperature[3]			±0.03		%/°C
LA_TyOff	Linear acceleration zero-*g* level offset accuracy[2]		-80	±40	+80	m*g*
M_TyOff	Magnetic sensor offset	With offset cancellation[4][5]	-60		+60	mgauss
LA_TCOff	Linear acceleration zero-*g* level change vs. temp.[3]	Max. delta from 25 °C		±0.5		m*g*/°C
M_TCOff	Magnetic sensor offset change vs. temp.[4]	With offset cancellation	-0.3		+0.3	mgauss/ °C

a. The product is factory calibrated at 2.5 V. The operational power supply range is from 1.71 V to 3.6 V.

Table 3. Sensor characteristics (continued)

Symbol	Parameter	Test conditions	Min.	Typ.(1)	Max.	Unit
LA_An	Linear acceleration RMS noise	ODR = 100 Hz, high-resolution mode, FS = ±2 *g*		3		m*g* (RMS)
M_R	Magnetic RMS noise(6)	High-performance mode		3		mgauss (RMS)
LA_ST	Linear acceleration self-test positive output change(7)(8)(9)	FS = ±2 *g*; normal mode	17		360	LSB
M_ST	Magnetic self-test(10)		15		500	mgauss
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.
2. Values after factory calibration test and trimming.
3. Measurements are performed in a uniform temperature setup and they are based on characterization data in a limited number of samples, not measured during final test for production.
4. Based on characterization data on a limited number of samples, not measured during final test for production.
5. Excluding drift due to magnetic shock.
6. With low-pass filter or offset cancellation enabled.
7. The sign of “Self-test output change” is defined by the ST bit in *CTRL_REG4_A (23h)*, for all axes.
8. “Self-test output change” is defined as the absolute value of:
   $OUTPUT[LSb]_{(Self\text{-}test\ enabled)} - OUTPUT[LSb]_{(Self\text{-}test\ disabled)}$. 1LSb = 3.9 m*g* in normal mode (10-bit) at FS=±2 *g*.
9. After enabling the ST bit, correct data is obtained after two samples (low-power mode / normal mode) or after eight samples (high-resolution mode).
10. Magnetic “self-test” is defined as: $OUTPUT[gauss]_{(Self\text{-}test\ enabled)} - OUTPUT[gauss]_{(Self\text{-}test\ disabled)}$.

2.2 Temperature sensor characteristics

@ Vdd = 2.5 V, T = 25 °C unless otherwise noted [b].

Table 4. Temperature sensor characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
TSDr	Temperature sensor output change vs. temp.			1		digit/°C[2]
TODR	Temperature refresh rate			ODR[3]		Hz
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.
2. 8-bit resolution.
3. Refer to *Table 35*.

2.3 Electrical characteristics

@ Vdd = 2.5 V, T = 25 °C unless otherwise noted.[b]

Table 5. Electrical characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
Vdd	Supply voltage		1.71		3.6	V
Vdd_IO	Module power supply for I/O[2]		1.71	1.8	Vdd+0.1	V
LA_Idd_NM	Accelerometer current consumption Magnetic sensor in power-down mode.	50 Hz ODR in normal mode		12.6		µA
		1 Hz ODR in normal mode		3.7		µA
		50 Hz ODR in low-power mode		7.7		µA
M_Idd_HR	Magnetic current consumption in high-resolution mode Accelerometer in power-down mode.	ODR = 20 Hz		200		µA
M_Idd_LP	Magnetic current consumption in low-power mode Accelerometer in power-down mode.	ODR = 20 Hz		50		µA
Idd_PD	Current consumption in power-down			2		µA
VIH	Digital high-level input voltage		0.8*Vdd_IO			V
VIL	Digital low-level input voltage				0.2*Vdd_IO	V
VOH	High-level output voltage	IOH = 4 mA	Vdd_IO - 0.2			V
VOL	Low-level output voltage	IOL = 4 mA			0.2	V
T_{OP}	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.
2. It is possible to remove Vdd maintaining Vdd_IO without blocking the communication bus, in this condition the measurement chain is powered off.

b. The product is factory calibrated at 2.5 V.The operational power supply range is from 1.71 V to 3.6 V.

2.4 Communication interface characteristics

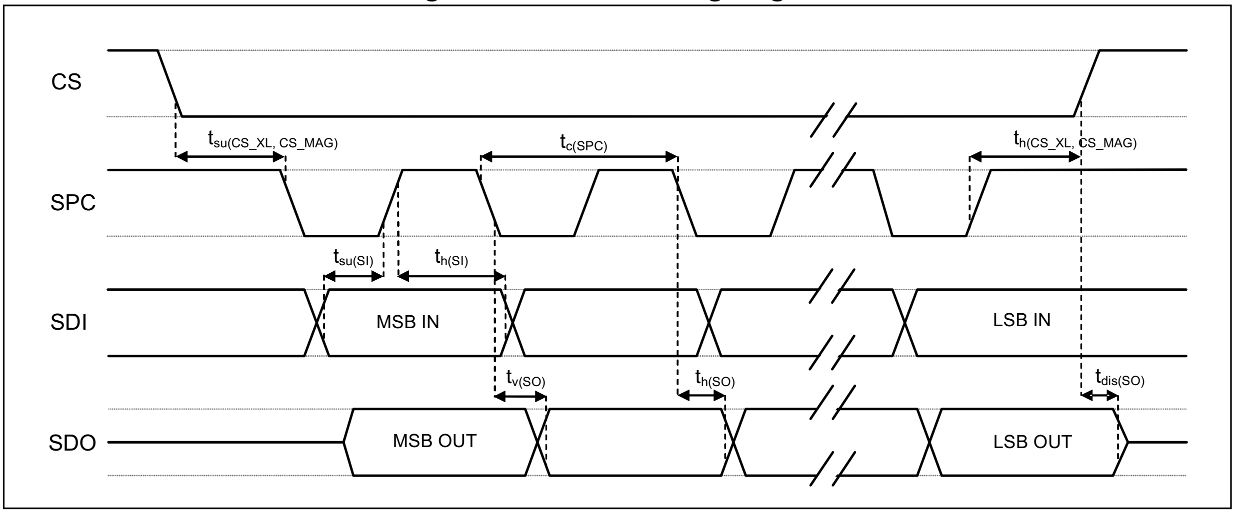
2.4.1 SPI - serial peripheral interface

Subject to general operating conditions for Vdd and Top.

Table 6. SPI slave timing values

Symbol	Parameter	Value [1] Min	Value [1] Max	Unit
$t_{c(SPC)}$	SPI clock cycle	100		ns
$f_{c(SPC)}$	SPI clock frequency		10	MHz
$t_{su(CS\_XL, CS\_MAG)}$	CS setup time	5		ns
$t_{h(CS\_XL, CS\_MAG)}$	CS hold time	20		
$t_{su(SI)}$	SDI input setup time	5		
$t_{h(SI)}$	SDI input hold time	15		
$t_{v(SO)}$	SDO valid output time		50	
$t_{h(SO)}$	SDO output hold time	5		
$t_{dis(SO)}$	SDO output disable time		50	

Figure 3. SPI slave timing diagram



Note: Values are guaranteed at 10 MHz clock frequency for SPI with 3 wires, based on characterization results, not tested in production.

Measurement points are done at 0.2·Vdd_IO and 0.8·Vdd_IO, for both input and output ports.

2.4.2 I²C - inter-IC control interface

Subject to general operating conditions for Vdd and Top.

Table 7. I²C slave timing values (standard and fast mode)

Symbol	Parameter	I²C standard mode [1]		I²C fast mode [1]		Unit
		Min	Max	Min	Max	
$f_{(SCL)}$	SCL clock frequency	0	100	0	400	kHz
$t_{w(SCLL)}$	Low period of the SCL clock	4.7		1.3		μs
$t_{w(SCLH)}$	High period of the SCL clock	4.0		0.6		μs
$t_{su(SDA)}$	Data setup time	250		100		ns
$t_{h(SDA)}$	Data hold time	0	3.45	0	0.9	μs
$t_{h(ST)}$	START condition hold time	4		0.6		μs
$t_{su(SR)}$	Setup time for a repeated START condition	4.7		0.6		μs
$t_{su(SP)}$	Setup time for STOP condition	4		0.6		μs
$t_{w(SP:SR)}$	Bus free time between STOP and START condition	4.7		1.3		μs

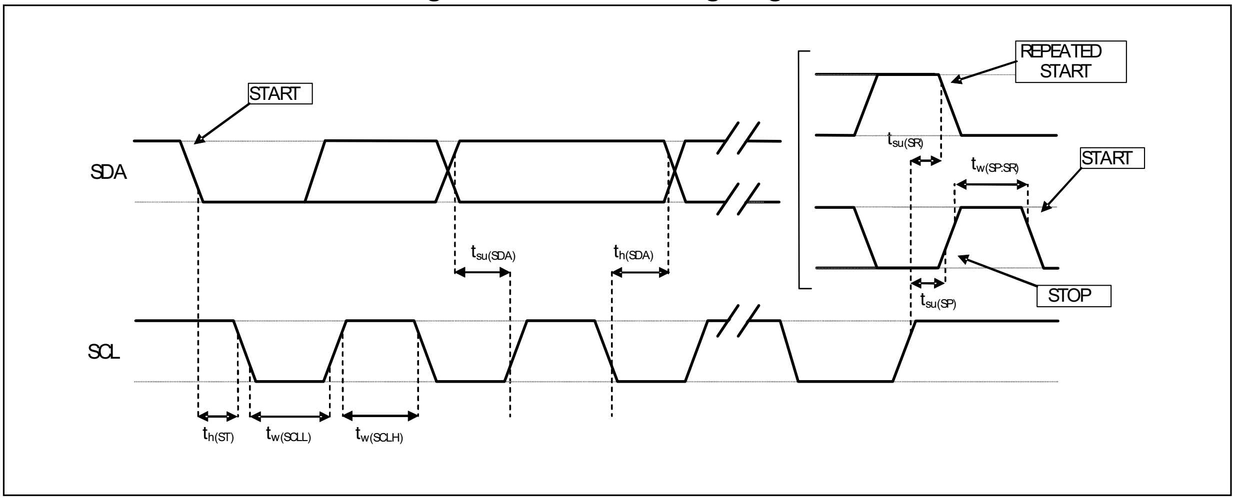
1. Data based on standard I²C protocol requirement, not tested in production.

Table 8. I²C slave timing values (fast mode plus and high speed)

Symbol	Parameter	I²C fast mode plus[1]		I²C high speed[1]		Unit
		Min	Max	Min	Max	
$f_{(SCL)}$	SCL clock frequency	0	1	0	3.4	MHz
$t_{w(SCLL)}$	Low period of the SCL clock	0.5		0.16		μs
$t_{w(SCLH)}$	High period of the SCL clock	0.26		0.06		μs
$t_{su(SDA)}$	Data setup time	50		10		ns
$t_{h(SDA)}$	Data hold time	0		0	0.07	μs
$t_{h(ST)}$	START condition hold time	0.26		0.16		μs
$t_{su(SR)}$	Setup time for a repeated START condition	0.26		0.16		μs
$t_{su(SP)}$	Setup time for STOP condition	0.26		0.16		μs
$t_{w(SP:SR)}$	Bus free time between STOP and START condition	0.5				μs

1. Data based on standard I²C protocol requirement, not tested in production.

Figure 4. I^2C slave timing diagram



Note: Measurement points are done at 0.2·Vdd_IO and 0.8·Vdd_IO, for both ports.

2.5 Absolute maximum ratings

Stresses above those listed as “absolute maximum ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device under these conditions is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

Table 9. Absolute maximum ratings

Symbol	Ratings	Maximum value	Unit
Vdd	Supply voltage	-0.3 to 4.8	V
Vdd_IO	I/O pins supply voltage	-0.3 to 4.8	V
Vin	Input voltage on any control pin (CS_XL, CS_MAG, SCL/SPC, SDA/SDI/SDO)	-0.3 to Vdd_IO +0.3	V
A_{POW}	Acceleration (any axis, powered, Vdd = 2.5 V)	3000 for 0.5 ms	*g*
		10000 for 0.2 ms	*g*
A_{UNP}	Acceleration (any axis, unpowered)	3000 for 0.5 ms	*g*
		10000 for 0.2 ms	*g*
M_{EF}	Maximum exposed field	10000	gauss
T_{OP}	Operating temperature range	-40 to +85	°C
T_{STG}	Storage temperature range	-40 to +125	°C
ESD	Electrostatic discharge protection (HBM)	2	kV

Note: Supply voltage on any pin should never exceed 4.8 V

This device is sensitive to mechanical shock, improper handling can cause permanent damage to the part.

This device is sensitive to electrostatic discharge (ESD), improper handling can cause permanent damage to the part.

3 Terminology

3.1 Sensitivity

3.1.1 Linear acceleration sensor sensitivity

Sensitivity describes the gain of the sensor and can be determined by applying 1 *g* acceleration to it. As the sensor can measure DC accelerations this can be done easily by pointing the axis of interest towards the center of the Earth, noting the output value, rotating the sensor by 180 degrees (pointing to the sky) and noting the output value again. By doing so, ±1 *g* acceleration is applied to the sensor. Subtracting the larger output value from the smaller one, and dividing the result by 2, leads to the actual sensitivity of the sensor. This value changes very little over temperature and time. The sensitivity tolerance describes the range of sensitivities of a large population of sensors.

3.1.2 Magnetic sensor sensitivity

Sensitivity describes the ratio of the output digital data expressed in LSB units and the applied magnetic field expressed in mG (milligauss). It can be measured, for example, by applying a known magnetic field along one axis and measuring the digital output of the device.

3.2 Zero-*g* level

The zero-*g* level offset (LA_TyOff) describes the deviation of an actual output signal from the ideal output signal if no acceleration is present. A sensor in a steady state on a horizontal surface will measure 0 *g* on the X-axis and 0 *g* on the Y-axis whereas the Z-axis will measure 1 *g*. The output is ideally in the middle of the dynamic range of the sensor (content of OUT registers 00h, data expressed as two’s complement number). A deviation from the ideal value in this case is called zero-*g* offset. Offset is to some extent a result of stress to MEMS sensor and therefore the offset can slightly change after mounting the sensor onto a printed circuit board or exposing it to extensive mechanical stress. Offset changes little with temperature, see *Table 3* “Zero-*g* level change vs. temperature” (LA_TCOff). The zero-*g* level tolerance (TyOff) describes the standard deviation of the range of zero-*g* levels of a population of sensors.

3.3 Zero-*gauss* level

Zero-*g*auss level offset (M_TyOff) describes the deviation of an actual output signal from the ideal output if no magnetic field is present.

3.4 Magnetic dynamic range

The magnetic dynamic range is defined as the magnetic field driven along one sensitive axis, giving the maximum digital output value.

4 Functionality

4.1 Magnetometer

4.1.1 Magnetometer power modes

The LSM303AGR magnetometer provides two different power modes: high-resolution and low-power modes.

The tables below summarize the magnetometer RMS noise values and current consumption in different product configurations.

When the low-pass filter is enabled, the bandwidth is reduced while noise performance is improved without any increase in power consumption.

Table 10. RMS noise of operating modes

CFG_REG_B_M[LPF] or CFG_REG_B_M[OFF_CANC]	(CFG_REG_A_M [LP = 0]) high-resolution mode		(CFG_REG_A_M [LP = 1]) low-power mode	
	BW [Hz]	Noise RMS [m*g*]	BW [Hz]	Noise RMS [m*g*]
0 (disable)	ODR/2	4.5	ODR/2	9
1 (enable)	ODR/4	3	ODR/4	6

Table 11. Current consumption of operating modes

ODR (Hz)	Current consumption (µA) (CFG_REG_A_M [LP] = 0) high-resolution CFG_REG_B_M [OFF_CANC] = 0	Current consumption (µA) (CFG_REG_A_M [LP] = 1) low-power CFG_REG_B_M [OFF_CANC] = 0	Current consumption (µA) (CFG_REG_A_M [LP] = 0) high-resolution CFG_REG_B_M [OFF_CANC] = 1	Current consumption (µA) (CFG_REG_A_M [LP] = 1) low-power CFG_REG_B_M [OFF_CANC] = 1
10	100	25	120	50
20	200	50	235	100
50	475	125	575	235
100	950	250	1130	460

The following table summarizes the turn-on time of the magnetometer in the two different power modes with the offset cancellation function enabled or disabled (see *Section 4.1.2: Magnetometer offset cancellation*).

Table 12. Operating mode and turn-on time

Operating mode	Turn-on time	
CFG_REG_A_M[LP]	CFG_REG_A_M[OFF_CANC = 0]	CFG_REG_A_M[OFF_CANC = 1]
0 (high-resolution)	9.4 ms	9.4 ms + 1/ODR
1 (low-power)	6.4 ms	6.4 ms + 1/ODR

The LSM303AGR offers single measurement mode in both high-resolution and low-power modes.

Single measurement mode is enabled by writing bits MD[1:0] to '01' in *CFG_REG_A_M (60h)*.

In single measurement mode, once the measurement has been performed, the DRDY pin is set to high, data is available in the output register and the LSM303AGR is automatically configured in idle mode by setting the MD[1] bit to '1'.

Single measurement is independent of the programmed ODR but depends on the frequency at which the MD[1:0] bits are written by the microcontroller/application processor.

Maximum ODR frequency achievable in single mode measurement is given in the following table.

Table 13. Maximum ODR in single measurement mode (HR and LP modes)

Maximum ODR	Power mode (CFG_REG_A_M[LP])
100 Hz	High resolution (LP = ‘0’)
150 Hz	Low power (LP = ‘1’)

In single measurement mode, for ODR < 10 Hz, current consumption can be calculated with the following formula:

(Current_consumption_10Hz - Current_consumption_in_power_down) / (10 Hz / ODR) + Current_consumption_in_power_down

Where Current_consumption_in_power_down and Current_consumption_10Hz can be found, respectively, in *Table 5* and *Table 11*.

4.1.2 Magnetometer offset cancellation

Offset cancellation is the result of performing a set and reset in the magnetic sensor.

The offset cancellation technique is defined as follows:

$$H_{out} = \frac{H_n + H_{n-1}}{2}$$

where H_n and H_{n-1} are two consecutive magnetic field measurements, one after a set pulse, the other after a reset pulse.

Considering a magnetic offset (H_{off}), the two magnetic field measurements are:

- Set: $H_n = H + H_{off}$
- Reset: $H_{n-1} = H – H_{off}$

The offset is cancelled according to the offset cancellation technique:

$$H_{out} = \frac{H_n + H_{n-1}}{2} = \frac{2H + H_{off} - H_{off}}{2} = H$$

In the LSM303AGR offset cancellation is enabled by setting bit OFF_CANC = 1 (and bit OFF_CANC_ONE_SHOT = 1 in single measurement mode) in *CFG_REG_B_M (61h)*.

Offset cancellation is automatically managed by the device in continuous mode.

Offset cancellation has to be managed by the user in single measurement mode averaging two consecutive measurements H_n and H_{n-1}.

If offset cancellation is disabled, a set of the magnetic sensor is performed anyway.

The set pulse frequency can be configured by setting the Set_FREQ bit in *CFG_REG_B_M (61h)*.

4.1.3 Magnetometer interrupt

In the LSM303AGR the magnetometer interrupt signal generation is based on the comparison between data and a programmable threshold.

To enable the interrupt function, in INT_CTRL_REG_M register (63h) the "IEN" bit must be set to '1'.

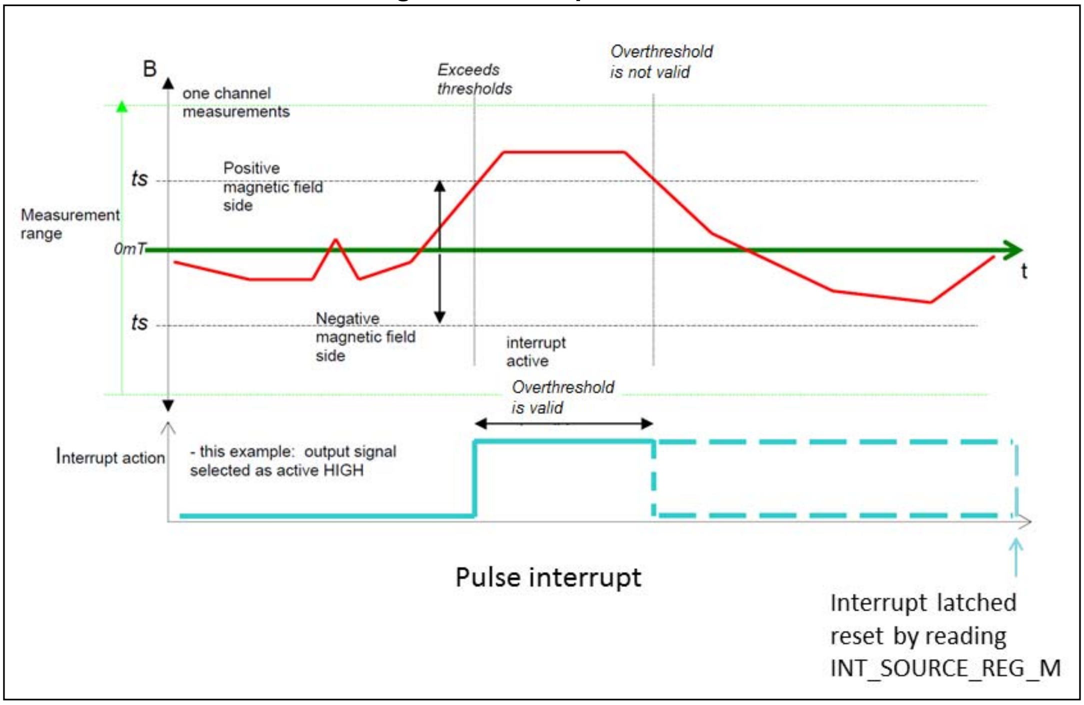
In the LSM303AGR the user can select the axis/axes in which the interrupt function can be enabled. In order to do this, the XIEN, YIEN, and ZIEN bits in *INT_CTRL_REG_M (63h)* need be set properly.

The threshold value can be programmed by setting the *INT_THS_L_REG_M (65h)* and *INT_THS_H_REG_M (66h)* registers.

The threshold is expressed in absolute value as a 15-bit unsigned number. The threshold has the same sensitivity as the magnetic data.

When magnetic data exceeds the positive or the negative threshold, the interrupt signal is generated and the information about the type of interrupt is stored in the *INT_SOURCE_REG_M (64h)* register. In particular, when magnetic data exceeds the positive threshold the P_TH_S_axis bit is set to '1', while if data exceeds the negative threshold the N_TH_S_axis bit is set to '1'. If magnetic data lay between the positive and the negative thresholds, no interrupt signal is released.

Figure 5. Interrupt function



Two different approaches for the interrupt function are available:

- Typical: comparison is between magnetic data read by the sensor and the programmable threshold;
- Advanced: comparison is made between magnetic data after hard-iron correction and the programmable threshold.

These approaches are configurable by setting the INT_on_DataOFF bit in *CFG_REG_B_M (61h)*.

If INT_on_DataOFF is set to '0' the typical approach is selected, otherwise if it is set to '1' the advanced approach is selected.

Two different interrupts are available:

- Pulsed interrupt signal: it goes high when the magnetic data exceed one of the two thresholds and goes low when the magnetic data are between the two thresholds. This kind of interrupt is selected by setting the IEL bit in *INT_CTRL_REG_M (63h)* to '0'.
- Latched interrupt signal: it goes high when the data exceed one of the two thresholds but is reset only once the source register is read and not when the magnetic data returns between the two thresholds. This kind of interrupt is selected by setting the IEL bit in *INT_CTRL_REG_M (63h)* to '1'.

The interrupt signal polarity can be set using the IEA bit in *INT_CTRL_REG_M (63h)*.

If IEA is set to '1' then the interrupt signal is active high, while if it is set to '0' the interrupt signal is active low.

In order to drive the interrupt signal from the DRDY pad, the INT_MAG_PIN bit in *CFG_REG_C_M (62h)* must be set to '1'.

4.1.4 Magnetometer hard-iron compensation

Hard-iron distortion occurs when a magnetic object is placed near the magnetometer and appears as a permanent bias in the sensor's outputs.

The hard-iron correction consists of compensating magnetic data from hard-iron distortion.

The operation is defined as follows:

$H_{out} = H_{read} - H_{HI}$

where:

- H_{read} is the generic uncompensated magnetic field data, as read by the sensor;
- H_{HI} is the hard-iron distortion field;
- H_{out} is the compensated magnetic data.

The computation of the hard-iron distortion field should be performed by an external processor. After the computation of the hard iron-distortion field has been performed, the measured magnetic data can be compensated.

The LSM303AGR offers the possibility of storing hard-iron data inside six dedicated registers from 45h to 4Ah.

Each register contains eight bits so that the hard-iron data can be expressed as a 16-bit two's complement number. The OFFSET_axis_REG_H registers contain the MSBs of the hard-iron data, while the OFFSET_axis_REG_L registers contain the LSBs.

Hard-iron data have the same format and weight of the magnetic output data. The hard-iron values stored in dedicated registers are automatically subtracted from the output data.

4.1.5 Magnetometer self-test

The self-test function is available for the magnetic sensor. When the magnetic self-test is enabled, a current is forced into a coil inside the device. This current will generate a magnetic field that will produce a variation of the magnetometer output signals. If the output signals change within the amplitude limits specified in *Table 3*, then the sensor is working properly and the parameters of the interface chip are within the defined specifications.

The self-test procedure is described in the following figure.