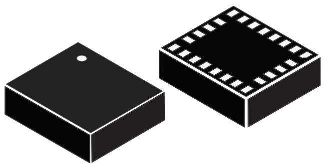
iNEMO inertial module: 3D accelerometer, 3D gyroscope, 3D magnetometer

Datasheet - production data



LGA-24L (3.5x3x1.0 mm)

Features

- 3 acceleration channels, 3 angular rate channels, 3 magnetic field channels
- ±2/±4/±8/±16 *g* linear acceleration full scale
- ±4/±8/±12/±16 gauss magnetic full scale
- ±245/±500/±2000 dps angular rate full scale
- 16-bit data output
- SPI / I²C serial interfaces
- Analog supply voltage 1.9 V to 3.6 V
- "Always-on" eco power mode down to 1.9 mA
- Programmable interrupt generators
- Embedded temperature sensor
- Embedded FIFO
- Position and motion detection functions
- Click/double-click recognition
- Intelligent power saving for handheld devices
- ECOPACK®, RoHS and "Green" compliant

Applications

- Indoor navigation
- Smart user interfaces
- Advanced gesture recognition
- Gaming and virtual reality input devices
- Display/map orientation and browsing

Description

The LSM9DS1 is a system-in-package featuring a 3D digital linear acceleration sensor, a 3D digital angular rate sensor, and a 3D digital magnetic sensor.

The LSM9DS1 has a linear acceleration full scale of ±2*g*/±4*g*/±8/±16 *g*, a magnetic field full scale of ±4/±8/±12/±16 gauss and an angular rate of ±245/±500/±2000 dps.

The LSM9DS1 includes an I²C serial bus interface supporting standard and fast mode (100 kHz and 400 kHz) and an SPI serial standard interface.

Magnetic, accelerometer and gyroscope sensing can be enabled or set in power-down mode separately for smart power management.

The LSM9DS1 is available in a plastic land grid array package (LGA) and it is guaranteed to operate over an extended temperature range from -40 °C to +85 °C.

Table 1. Device summary

Part number	Temperature range [°C]	Package	Packing
LSM9DS1	-40 to +85	LGA-24L	Tray
LSM9DS1TR	-40 to +85	LGA-24L	Tape and reel

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1 Pin description

Figure 1. Pin connections

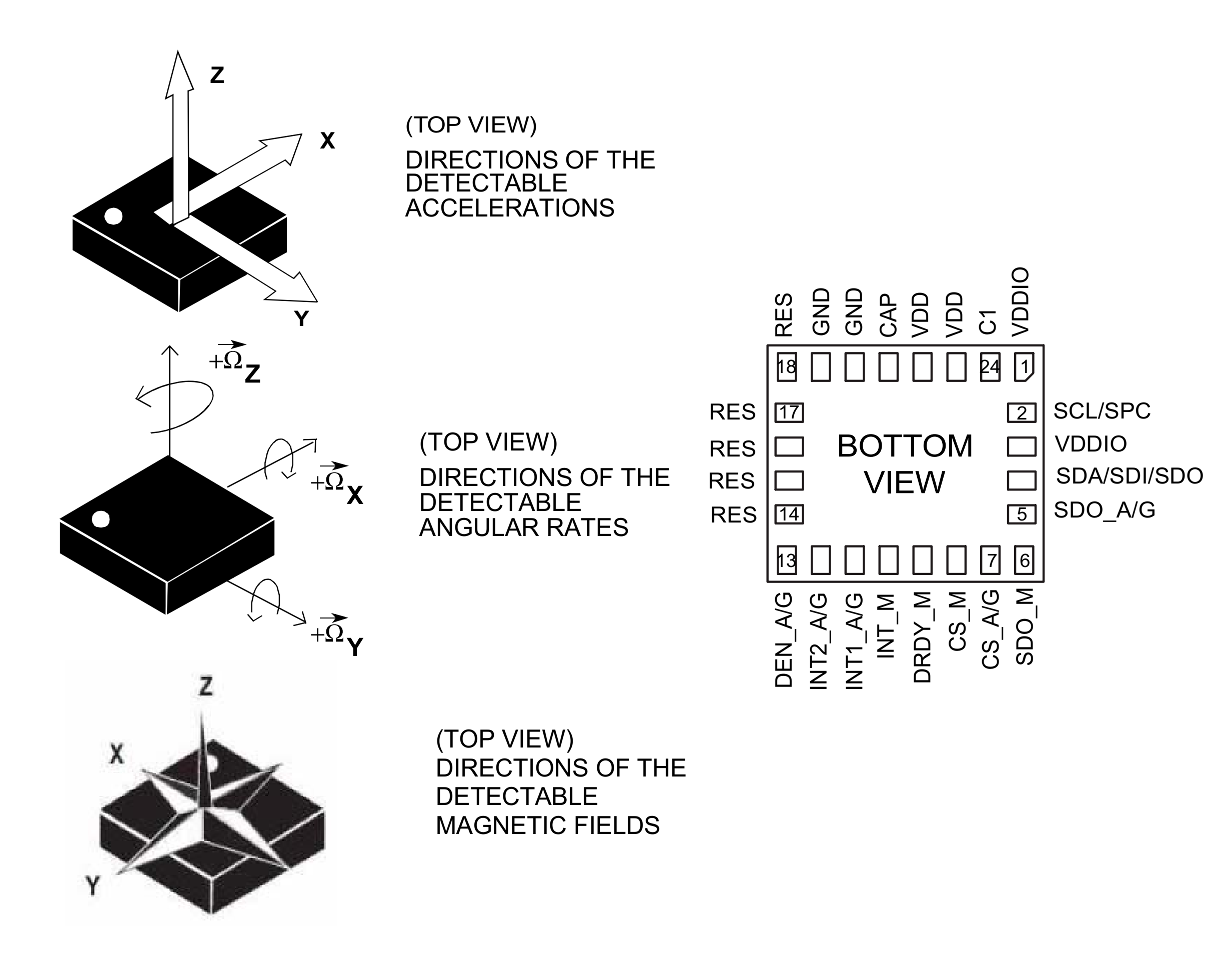


Table 2. Pin description

Pin #	Name	Function
1	VDDIO(1)	Power supply for I/O pins
2	SCL/SPC	I^2C serial clock (SCL) / SPI serial port clock (SPC)
3	VDDIO(2)	Power supply for I/O pins
4	SDA/SDI/SDO	I^2C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
5	SDO_A/G	SPI serial data output (SDO) for the accelerometer and gyroscope I^2C least significant bit of the device address (SA0) for the accelerometer and gyroscope
6	SDO_M	SPI serial data output (SDO) for the magnetometer I^2C least significant bit of the device address (SA0) for the magnetometer
7	CS_A/G	SPI enable I^2C/SPI mode selection for the accelerometer and gyroscope (1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled)
8	CS_M	SPI enable I^2C/SPI mode selection for the magnetometer (1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled)
9	DRDY_M	Magnetic sensor data ready
10	INT_M	Magnetic sensor interrupt
11	INT1_A/G	Accelerometer and gyroscope interrupt 1
12	INT2_A/G	Accelerometer and gyroscope interrupt 2
13	DEN_A/G	Accelerometer and gyroscope data enable
14	RES	Reserved. Connected to GND.
15	RES	Reserved. Connected to GND.
16	RES	Reserved. Connected to GND.
17	RES	Reserved. Connected to GND.
18	RES	Reserved. Connected to GND.
19	GND	0 V supply
20	GND	0 V supply
21	CAP	Connected to GND with ceramic capacitor(3)
22	VDD(4)	Power supply
23	VDD(5)	Power supply
24	C1	Capacitor connection (C1 = 100 nF)

1. Recommended 100 nF filter capacitor.
2. Recommended 100 nF filter capacitor.
3. 10 nF (±10%), 16 V. 1 nF minimum value has to be guaranteed under 11 V bias condition.
4. Recommended 100 nF plus 10 µF capacitors.
5. Recommended 100 nF plus 10 µF capacitors.

2 Module specifications

2.1 Sensor characteristics

@ Vdd = 2.2 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 measurement range			±4		gauss
				±8		
				±12		
				±16		
G_FS	Angular rate measurement range			±245		dps
				±500		
				±2000		
LA_So	Linear acceleration sensitivity	Linear acceleration FS = ±2 *g*		0.061		m*g*/LSB
		Linear acceleration FS = ±4 *g*		0.122		
		Linear acceleration FS = ±8 *g*		0.244		
		Linear acceleration FS = ±16 *g*		0.732		
M_GN	Magnetic sensitivity	Magnetic FS = ±4 gauss		0.14		mgauss/ LSB
		Magnetic FS = ±8 gauss		0.29		
		Magnetic FS = ±12 gauss		0.43		
		Magnetic FS = ±16 gauss		0.58		
G_So	Angular rate sensitivity	Angular rate FS = ±245 dps		8.75		mdps/ LSB
		Angular rate FS = ±500 dps		17.50		
		Angular rate FS = ±2000 dps		70		
LA_TyOff	Linear acceleration typical zero-*g* level offset accuracy(2)	FS = ±8 *g*		±90		m*g*
M_TyOff	Zero-gauss level (3)	FS = ±4 gauss		±1		gauss
G_TyOff	Angular rate typical zero-rate level (4)	FS = ±2000 dps		±30		dps
M_DF	Magnetic disturbance field	Zero-gauss offset starts to degrade			50	gauss
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed
2. Typical zero-*g* level offset value after soldering
3. Typical zero-gauss level value after test and trimming
4. Typical zero rate level offset value after MSL3 preconditioning

a. The product is factory calibrated at 2.2 V. The operational power supply range is from 1.9 V to 3.6 V.

2.2 Electrical characteristics

@ Vdd = 2.2 V, T = 25 °C unless otherwise noted[b]

Table 4. Electrical characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
Vdd	Supply voltage		1.9		3.6	V
Vdd_IO	Module power supply for I/O		1.71		Vdd+0.1	
Idd_XM	Current consumption of the accelerometer and magnetic sensor in normal mode [2]			600		µA
Idd_G	Gyroscope current consumption in normal mode[3]			4.0		mA
Top	Operating temperature range		-40		+85	°C
Trise	Time for power supply rising[4]		0.01		100	ms
Twait	Time delay between Vdd_IO and Vdd[4]		0		10	ms

1. Typical specifications are not guaranteed
2. Magnetic sensor in high-resolution mode (ODR = 20 Hz), accelerometer sensor in normal mode, gyroscope in power-down mode
3. Accelerometer and magnetic sensor in power-down mode
4. Please refer to *Section 2.2.1: Recommended power-up sequence* for more details.

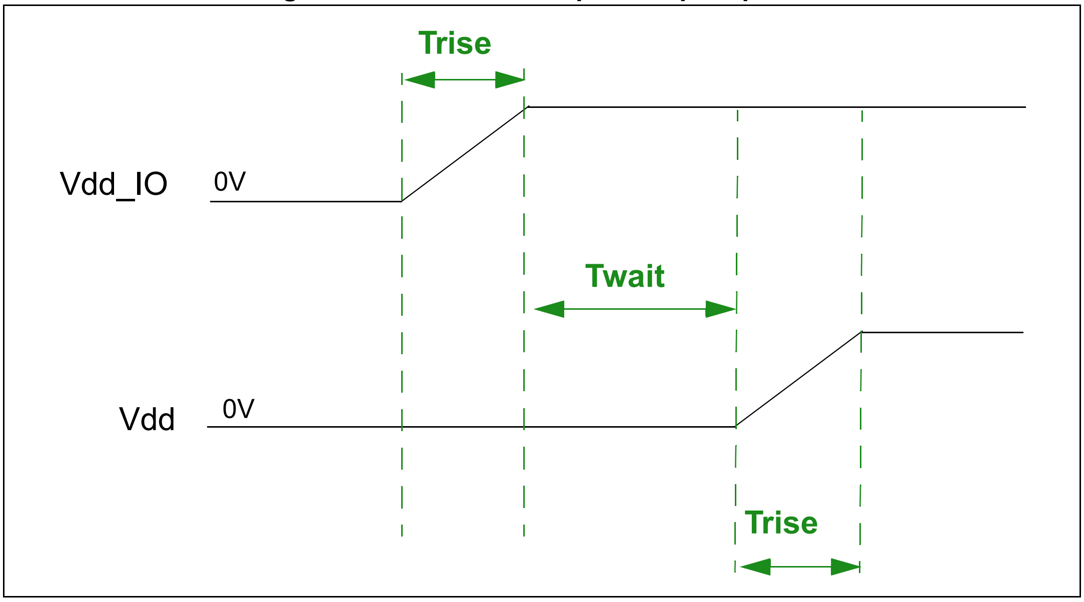
b. LSM9DS1 is factory calibrated at 2.2 V.

2.2.1 Recommended power-up sequence

For the power-up sequence please refer to the following figure, where:

- Trise is the time for the power supply to rise from 10% to 90% of its final value
- Twait is the delay between the end of the Vdd_IO ramp (90% of its final value) and the start of the Vdd ramp

Figure 2. Recommended power-up sequence



2.3 Temperature sensor characteristics

@ Vdd = 2.2 V, T = 25 °C unless otherwise noted [c]

Table 5. Temperature sensor characteristics

Symbol	Parameter	Test condition	Min.	Typ.[1]	Max.	Unit
TODR	Temperature refresh rate	Gyro OFF[2]		50		Hz
		Gyro ON		59.5		
TSen	Temperature sensitivity[3]			16		LSB/°C
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.
2. When the accelerometer ODR is set to 10 Hz and the gyroscope part is turned off, the TODR value is 10 Hz.
3. The output of the temperature sensor is 0 (typ.) at 25 °C

c. The product is factory calibrated at 2.2 V.

2.4 Communication interface characteristics

2.4.1 SPI - serial peripheral interface

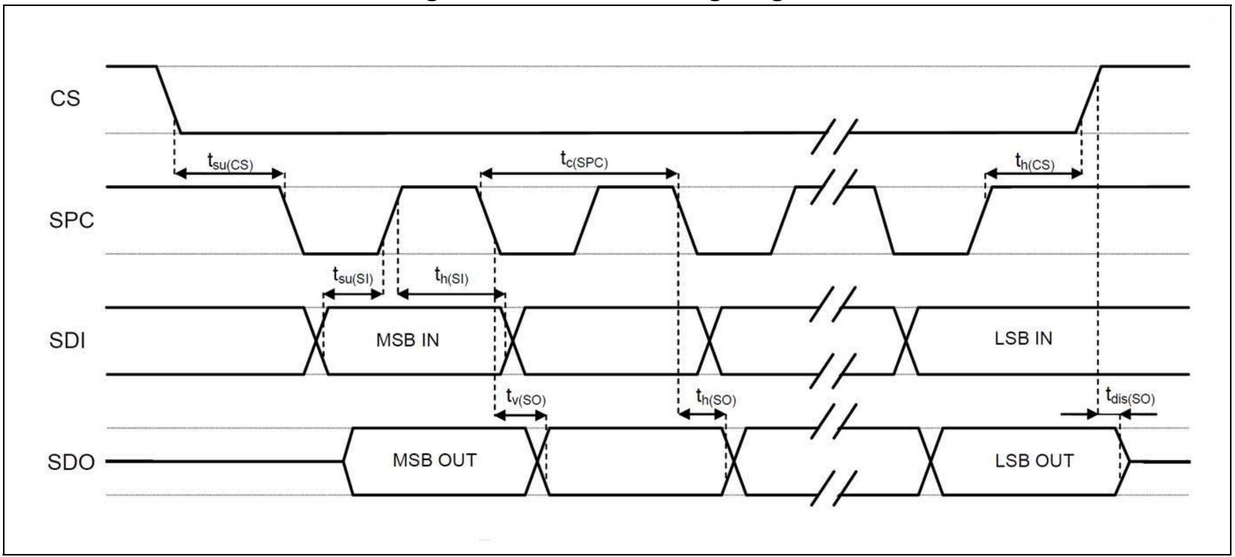
Subject to general operating conditions for Vdd and Top.

Table 6. SPI slave timing values

Symbol	Parameter	Value(1)		Unit
		Min	Max	
$t_{c(SPC)}$	SPI clock cycle	100		ns
$f_{c(SPC)}$	SPI clock frequency		10	MHz
$t_{su(CS)}$	CS setup time	5		ns
$t_{h(CS)}$	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	

1. Values are guaranteed at 10 MHz clock frequency for SPI with both 4 and 3 wires, based on characterization results, not tested in production

Figure 3. SPI slave timing diagram



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

2.4.2 I^2C - inter-IC control interface

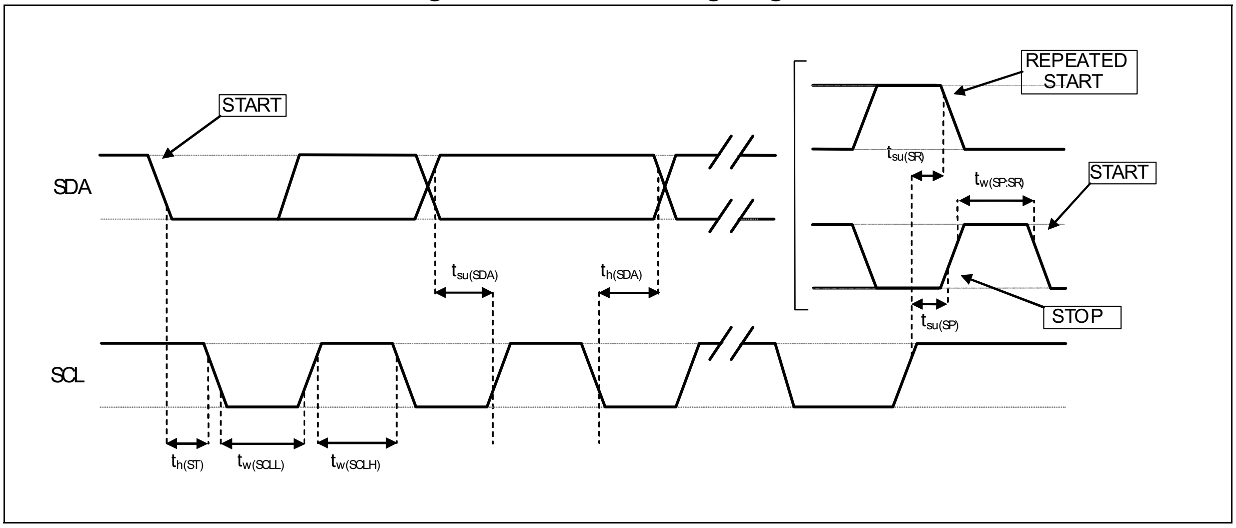
Subject to general operating conditions for Vdd and Top.

Table 7. I^2C slave timing values

Symbol	Parameter	I^2C Standard mode[(1)]		I^2C Fast mode [(1)]		Unit
		Min	Max	Min	Max	
$f_{(SCL)}$	SCL clock frequency	0	100	0	400	kHz
$t_{w(SCLL)}$	SCL clock low time	4.7		1.3		µs
$t_{w(SCLH)}$	SCL clock high time	4.0		0.6		
$t_{su(SDA)}$	SDA setup time	250		100		ns
$t_{h(SDA)}$	SDA data hold time	0	3.45	0	0.9	µs
$t_{h(ST)}$	START condition hold time	4		0.6		µs
$t_{su(SR)}$	Repeated START condition setup time	4.7		0.6		
$t_{su(SP)}$	STOP condition setup time	4		0.6		
$t_{w(SP:SR)}$	Bus free time between STOP and START condition	4.7		1.3		

1. Data based on standard I^2C 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 8. 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 (including CS_A/G, CS_M, SCL/SPC, SDA/SDI/SDO, SDO_A/G, SDO_M)	0.3 to Vdd_IO +0.3	V
A_{UNP}	Acceleration (any axis)	3,000 for 0.5 ms	g
		10,000 for 0.1 ms	g
M_{EF}	Maximum exposed field	1000	gauss
ESD	Electrostatic discharge protection (HBM)	2	kV
T_{STG}	Storage temperature range	-40 to +125	°C

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.

2.6 Terminology

2.6.1 Sensitivity

Linear acceleration sensitivity can be determined, for example, by applying 1 *g* acceleration to the device. Because the sensor can measure DC accelerations, this can be done easily by pointing the selected axis towards the ground, noting the output value, rotating the sensor 180 degrees (pointing towards 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 over time. The sensitivity tolerance describes the range of sensitivities of a large number of sensors.

An angular rate gyroscope is device that produces a positive-going digital output for counterclockwise rotation around the axis considered. Sensitivity describes the gain of the sensor and can be determined by applying a defined angular velocity to it. This value changes very little over temperature and time.

Magnetic sensor sensitivity describes the gain of the sensor and can be determined, for example, by applying a magnetic field of 1 *gauss* to it.

2.6.2 Zero-*g*, zero-rate and zero-*gauss* level

Linear acceleration zero-*g* level offset (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 both the X-axis and Y-axis, whereas the Z-axis will measure 1 *g*. Ideally, the output is 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 over temperature, see “Linear acceleration zero-*g* level change vs. temperature” in *Table 3*. The zero-*g* level tolerance (TyOff) describes the standard deviation of the range of zero-*g* levels of a group of sensors.

Zero-rate level describes the actual output signal if there is no angular rate present. The zero-rate level of precise MEMS sensors is, to some extent, a result of stress to the sensor and therefore the zero-rate level can slightly change after mounting the sensor onto a printed circuit board or after exposing it to extensive mechanical stress. This value changes very little over temperature and time.

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.

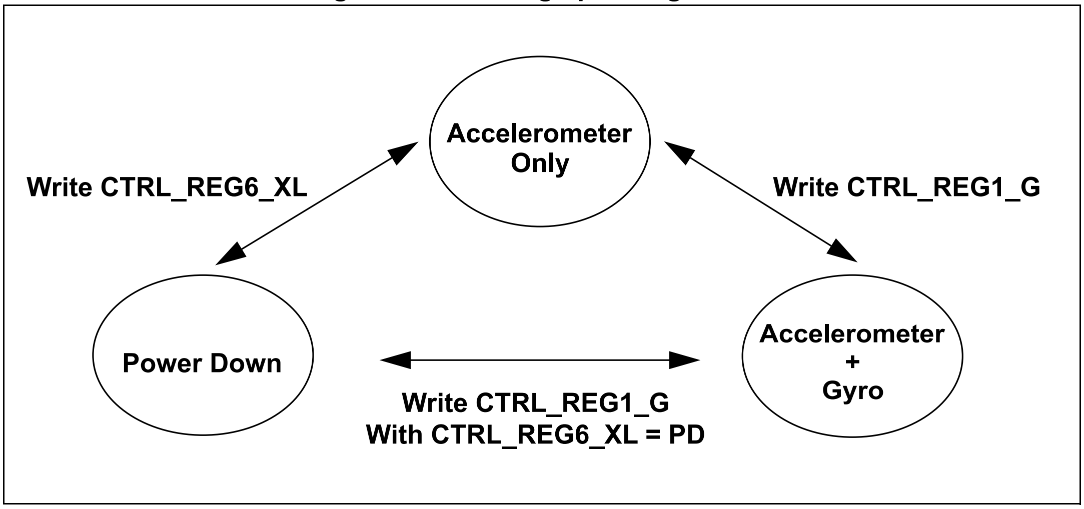
3 LSM9DS1 functionality

3.1 Operating modes

In the LSM9DS1 the accelerometer and gyroscope have two operating modes available: only accelerometer active and gyroscope in power down or both accelerometer and gyroscope sensors active at the same ODR. Switching from one mode to the other requires one write operation: writing to *CTRL_REG6_XL (20h)*, the accelerometer operates in normal mode and the gyroscope is powered down, writing to *CTRL_REG1_G (10h)* both accelerometer and gyroscope are activated at the same ODR.

Figure 5 depicts both modes of operation from power down.

Figure 5. Switching operating modes



The magnetic sensor has three operating modes available: power-down (default), continuous-conversion mode and single-conversion mode. Switching from power-down to the other modes requires one write operation to *CTRL_REG3_M (22h)*, setting values in the MD[1:0] bits. For the output of the magnetic data compensated by temperature, the TEMP_COMP bit in *CTRL_REG1_M (20h)* must be set to ‘1’.

3.2 Gyroscope power modes

In the LSM9DS1, the gyroscope can be configured in three different operating modes: power-down, low-power and normal mode.

Low-power mode is available for lower ODR (14.9, 59.5, 119 Hz) while for greater ODR (238, 476, 952 Hz) the device is automatically in normal mode. *Table* summarizes the ODR configuration (ODR_G[2:0] bits set in *CTRL_REG1_G (10h)*) and corresponding power modes.

To enable low-power mode, the LP_mode bit in *CTRL_REG3_G (12h)* has to be set to ‘1’.

Low-power mode allows reaching low power consumption while maintaining the device always on, refer to *Table 10*.

Table 9. Gyroscope operating modes

ODR_G [2:0]	ODR [Hz]	Power mode
000	Power down	Power-down
001	14.9	Low-power/Normal mode
010	59.5	Low-power/Normal mode
011	119	Low-power/Normal mode
100	238	Normal mode
101	476	Normal mode
110	952	Normal mode

Table 10. Operating mode current consumption

ODR [Hz]	Power mode	Current consumption(1) [mA]
14.9	Low-power	1.9
59.5	Low-power	2.4
119	Low-power	3.1
238	Normal mode	4.3
476	Normal mode	4.3
952	Normal mode	4.3

1. Typical values of gyroscope and accelerometer current consumption are based on characterization data.

Table 11. Accelerometer turn-on time

ODR [Hz]	BW = 400 Hz(1)	BW = 200 Hz(1)	BW = 100 Hz(1)	BW = 50 Hz(1)
14.9	0	0	0	0
59.5	0	0	0	0
119	1	1	1	2
238	1	1	2	4
476	1	2	4	7
952	2	4	7	14

1. The table contains the number of samples to be discarded after switching between power-down mode and normal mode.

Table 12. Gyroscope turn-on time

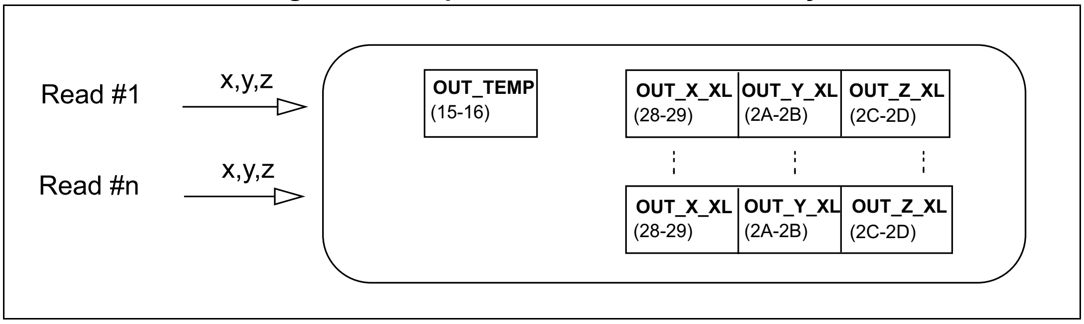
ODR [Hz]	LPF1 only[(1)]	LPF1 and LPF2[(1)]
14.9	2	LPF2 not available
59.5 or 119	3	13
238	4	14
476	5	15
952	8	18

1. The table contains the number of samples to be discarded after switching between low-power mode and normal mode.

3.3 Accelerometer and gyroscope multiple reads (burst)

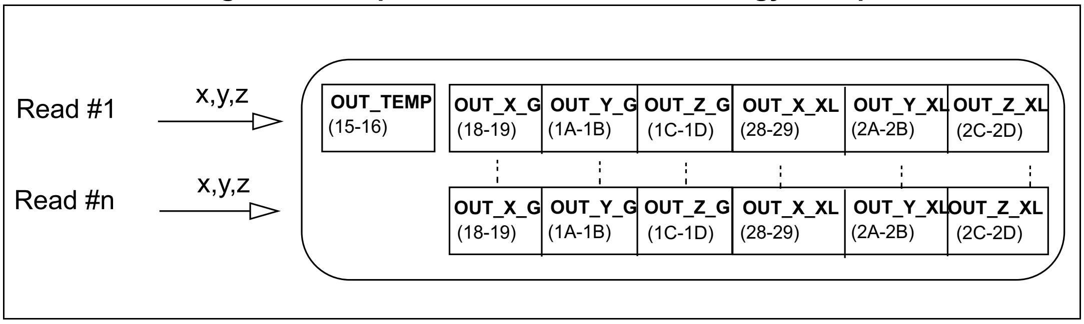
When only accelerometer is activated and the gyroscope is in power down, starting from *OUT_X_XL (28h - 29h)* multiple reads can be performed. Once *OUT_Z_XL (2Ch - 2Dh)* is read, the system automatically restarts from *OUT_X_XL (28h - 29h)* (see *Figure 6*).

Figure 6. Multiple reads: accelerometer only



When both accelerometer and gyroscope sensors are activated at the same ODR, starting from *OUT_X_G (18h - 19h)* multiple reads can be performed. Once *OUT_Z_XL (2Ch - 2Dh)* is read, the system automatically restarts from *OUT_X_G (18h - 19h)* (see *Figure 7*).

Figure 7. Multiple reads: accelerometer and gyroscope



3.4 Block diagram

Figure 8. Accelerometer and gyroscope digital block diagram

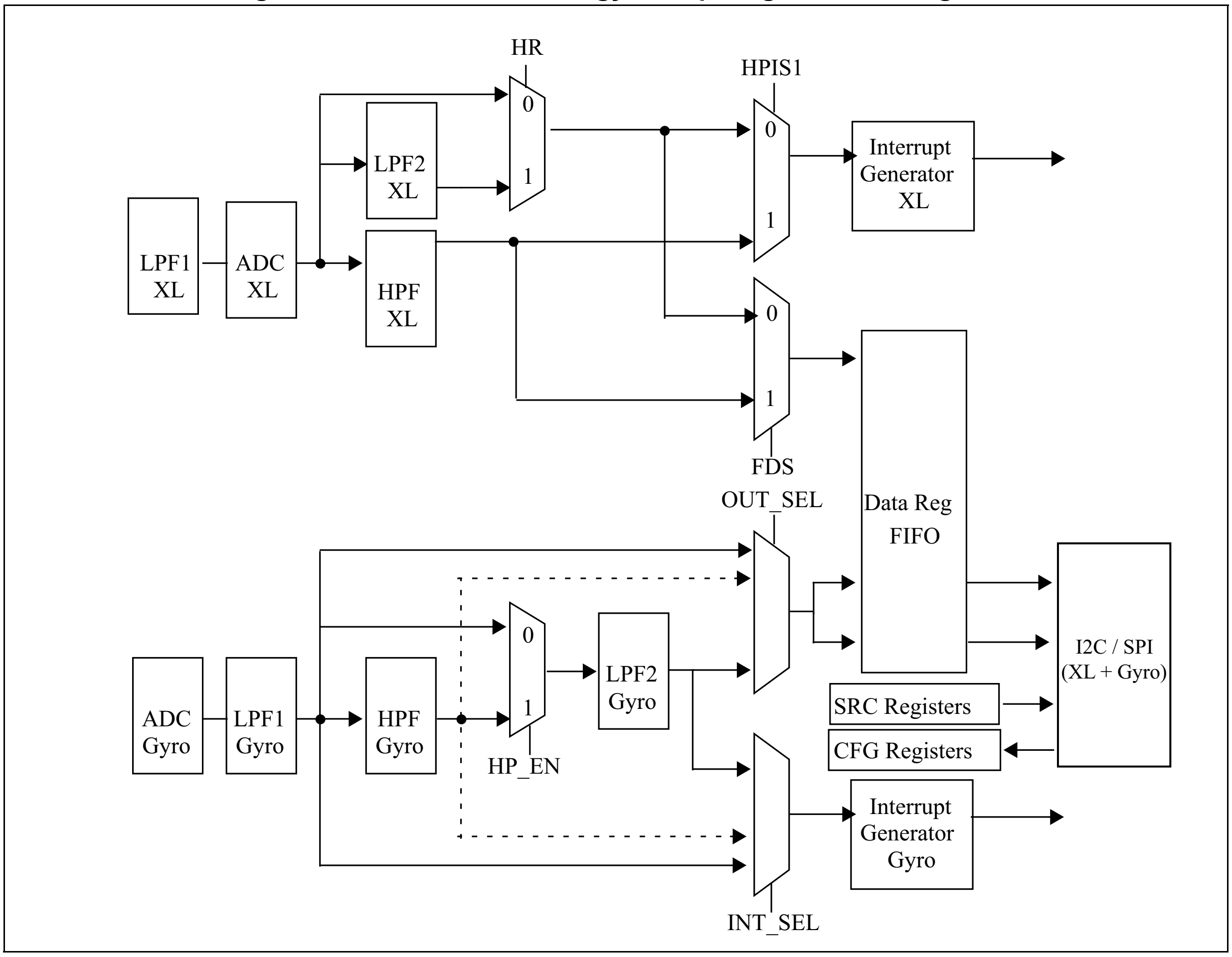
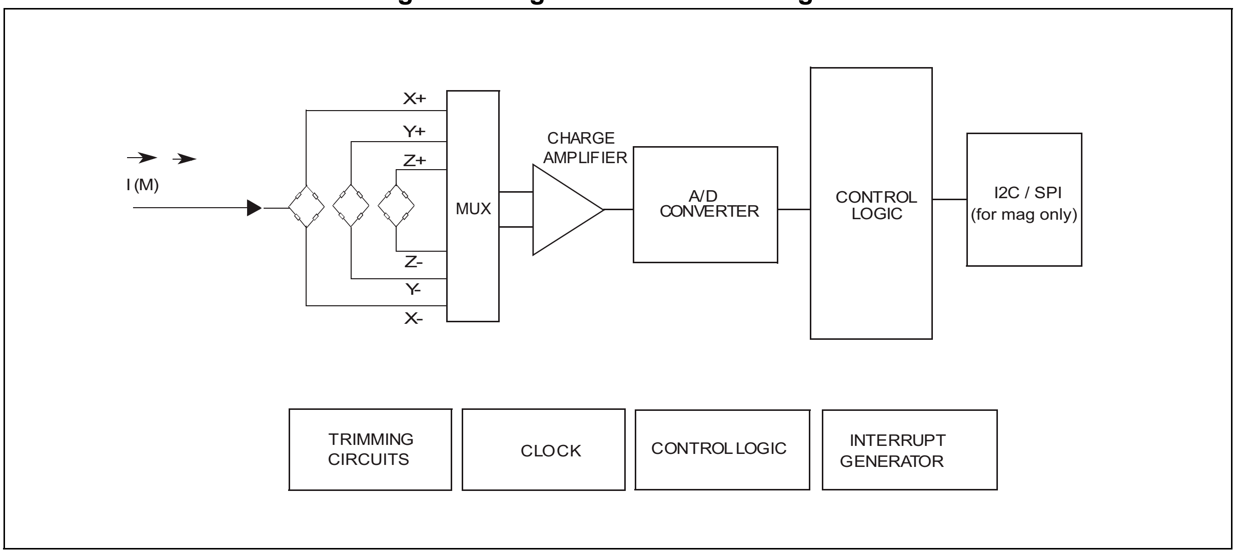


Figure 9. Magnetometer block diagram



3.5 Accelerometer and gyroscope FIFO

The LSM9DS1 embeds 32 slots of 16-bit data FIFO for each of the gyroscope's three output channels, yaw, pitch and roll, and 16-bit data FIFO for each of the accelerometer's three output channels, X, Y and Z. This allows consistent power saving for the system since the host processor does not need to continuously poll data from the sensor, but it can wake up only when needed and burst the significant data out from the FIFO. This buffer can work accordingly to five different modes: Bypass mode, FIFO-mode, Continuous mode, Continuous-to-FIFO mode and Bypass-to-Continuous. Each mode is selected by the FMODE [2:0] bits in the *FIFO_CTRL (2Eh)* register. Programmable FIFO threshold status, FIFO overrun events and the number of unread samples stored are available in the *FIFO_SRC (2Fh)* register and can be set to generate dedicated interrupts on the INT1_A/G pin in the *INT1_CTRL (0Ch)* register and on the INT2_A/G pin in the *INT2_CTRL (0Dh)* register.

FIFO_SRC (2Fh)(FTH) goes to '1' when the number of unread samples (*FIFO_SRC (2Fh)* (FSS5:0)) is greater than or equal to FTH [4:0] in *FIFO_CTRL (2Eh)*. If *FIFO_CTRL (2Eh)* (FTH[4:0]) is equal to 0, *FIFO_SRC (2Fh)*(FTH) goes to '0'.

FIFO_SRC (2Fh)(OVRN) is equal to '1' if a FIFO slot is overwritten.

FIFO_SRC (2Fh)(FSS [5:0]) contains stored data levels of unread samples. When FSS [5:0] is equal to '000000' FIFO is empty, when FSS [5:0] is equal to '100000' FIFO is full and the unread samples are 32.

The FIFO feature is enabled by writing '1' in *CTRL_REG9 (23h)* (FIFO_EN).

To guarantee the correct acquisition of data during the switching into and out of FIFO mode, the first sample acquired must be discarded.

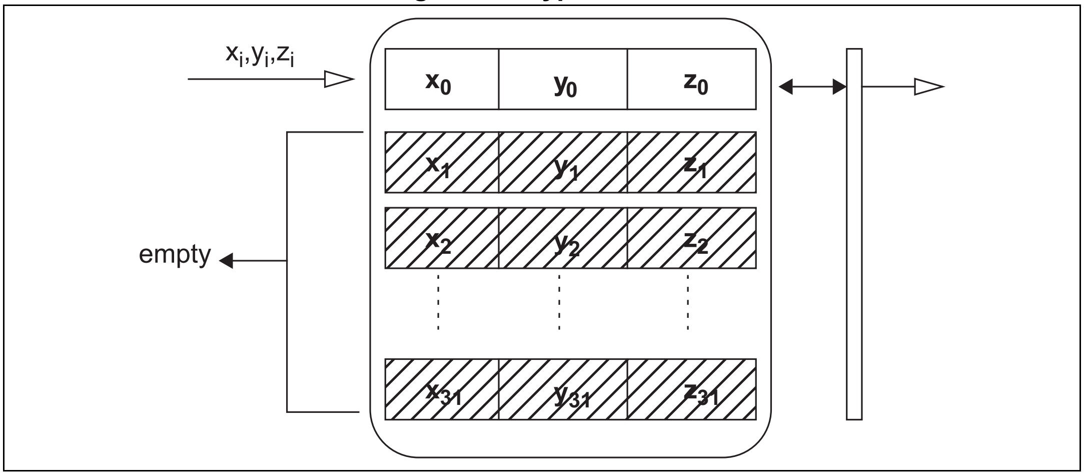
3.5.1 Bypass mode

In Bypass mode (*FIFO_CTRL (2Eh)*(FMODE [2:0]= 000), the FIFO is not operational and it remains empty.

Bypass mode is also used to reset the FIFO when in FIFO mode.

As described in *Figure 10*, for each channel only the first address is used. When new data is available the old data is overwritten.

Figure 10. Bypass mode



3.5.2 FIFO mode

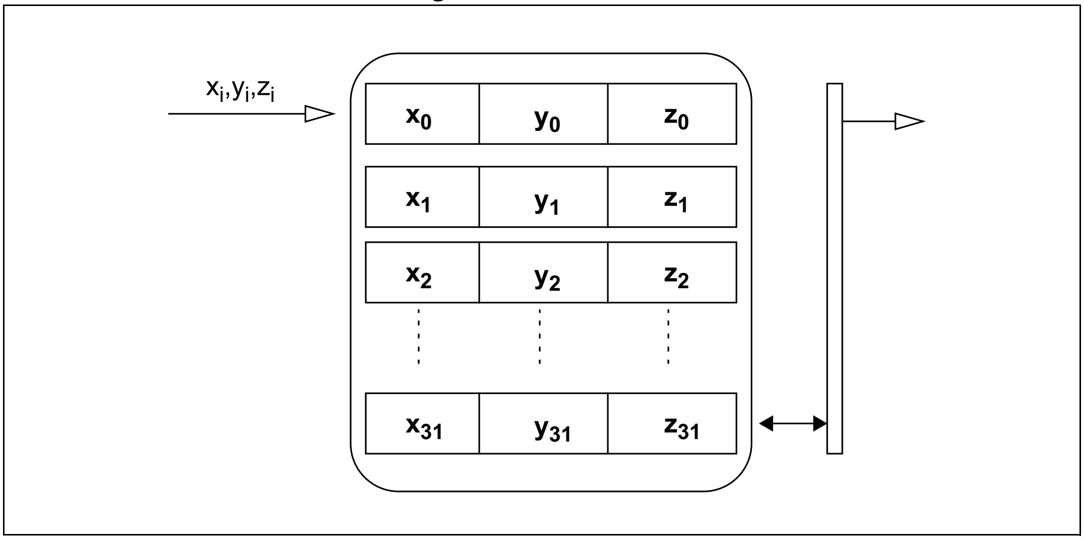
In FIFO mode (*FIFO_CTRL (2Eh)* (FMODE [2:0] = 001) data from the output channels are stored in the FIFO until it is overwritten.

To reset FIFO content, Bypass mode should be selected by writing *FIFO_CTRL (2Eh)* (FMODE [2:0]) to '000'. After this reset command, it is possible to restart FIFO mode by writing *FIFO_CTRL (2Eh)* (FMODE [2:0]) to '001'.

The FIFO buffer memorizes 32 levels of data but the depth of the FIFO can be resized by setting the STOP_ON_FTH bit in *CTRL_REG9 (23h)*. If the STOP_ON_FTH bit is set to '1', FIFO depth is limited to *FIFO_CTRL (2Eh)*(FTH [4:0]) + 1 data.

A FIFO threshold interrupt can be enabled (INT_OVR bit in *INT1_CTRL (0Ch)*) in order to be raised when the FIFO is filled to the level specified by the FTH[4:0] bits of *FIFO_CTRL (2Eh)*. When a FIFO threshold interrupt occurs, the first data has been overwritten and the FIFO stops collecting data from the input channels.

Figure 11. FIFO mode



3.5.3 Continuous mode

Continuous mode (*FIFO_CTRL (2Eh)*(FMODE[2:0] = 110) provides continuous FIFO update: as new data arrives the older is discarded.

A FIFO threshold flag *FIFO_SRC (2Fh)*(FTH) is asserted when the number of unread samples in FIFO is greater than or equal to *FIFO_CTRL (2Eh)*(FTH4:0).

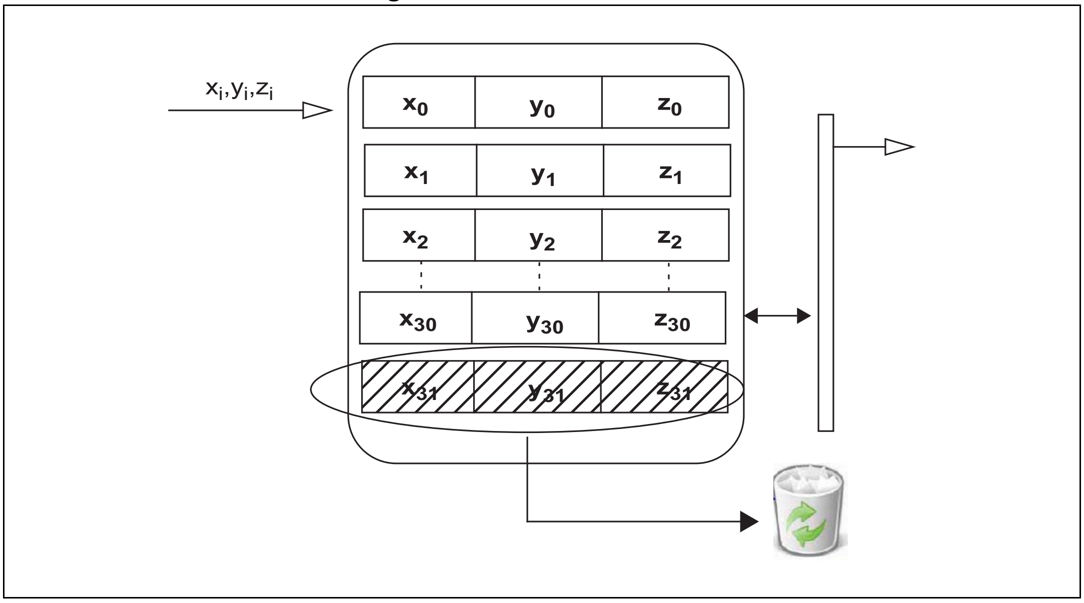
It is possible to route *FIFO_SRC (2Fh)*(FTH) to the INT1_A/G pin by writing in register *INT1_CTRL (0Ch)* (INT1_FTH) = '1', or to the INT2_A/G pin by writing in register *INT2_CTRL (0Dh)* (INT2_FTH) = '1'.

A full-flag interrupt can be enabled, (*INT1_CTRL (0Ch)* (INT_ FSS5)= '1') when the FIFO becomes saturated and in order to read the contents all at once.

If an overrun occurs, the oldest sample in FIFO is overwritten and the OVRN flag in *FIFO_SRC (2Fh)* is asserted.

In order to empty the FIFO before it is full it is also possible to pull from FIFO the number of unread samples available in *FIFO_SRC (2Fh)* (FSS[5:0]).

Figure 12. Continuous mode



3.5.4 Continuous-to-FIFO mode

In Continuous-to-FIFO mode (*FIFO_CTRL (2Eh)*(FMODE [2:0] = 011), FIFO behavior changes according to the *INT_GEN_SRC_XL (26h)*(IA_XL) bit. When the *INT_GEN_SRC_XL (26h)*(IA_XL) bit is equal to '1', FIFO operates in FIFO-mode, when the *INT_GEN_SRC_XL (26h)*(IA_XL) bit is equal to '0', FIFO operates in Continuous mode.

The interrupt generator should be set to the desired configuration by means of *INT_GEN_CFG_XL (06h)*, *INT_GEN_THS_X_XL (07h)*, *INT_GEN_THS_Y_XL (08h)* and *INT_GEN_THS_Z_XL (09h)*.

The *CTRL_REG4 (1Eh)*(LIR_XL) bit should be set to '1' in order to have latched interrupt.

Figure 13. Continuous-to-FIFO mode