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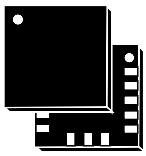
LSM6DS33

iNEMO inertial module: always-on 3D accelerometer and 3D gyroscope

Datasheet - production data



LGA-16L (3 x 3 x 0.86 mm) typ.

Features

- Power consumption: 0.9 mA in combo normal mode and 1.25 mA in combo high-performance mode up to 1.6 kHz.
- “Always-on” experience with low power consumption for both accelerometer and gyroscope
- Smart FIFO up to 8 kbyte based on features set
- Compliant with Android K and L
- ±2/±4/±8/±16 *g* full scale
- ±125/±245/±500/±1000/±2000 dps full scale
- Analog supply voltage: 1.71 V to 3.6 V
- Independent IOs supply (1.62 V)
- Compact footprint, 3 mm x 3 mm x 0.86 mm
- SPI/I^{2}C serial interface with main processor data synchronization feature
- Embedded temperature sensor
- ECOPACK®, RoHS and “Green” compliant

Applications

- Pedometer, step detector and step counter
- Significant motion and tilt functions
- Indoor navigation
- Tap and double-tap detection
- IoT and connected devices
- Intelligent power saving for handheld devices
- Vibration monitoring and compensation
- Free-fall detection
- 6D orientation detection

Description

The LSM6DS33 is a system-in-package featuring a 3D digital accelerometer and a 3D digital gyroscope performing at 1.25 mA (up to 1.6 kHz ODR) in high-performance mode and enabling always-on low-power features for an optimal motion experience for the consumer.

The LSM6DS33 supports main OS requirements, offering real, virtual and batch sensors with 8 kbyte for dynamic data batching.

ST’s family of MEMS sensor modules leverages the robust and mature manufacturing processes already used for the production of micromachined accelerometers and gyroscopes.

The various sensing elements are manufactured using specialized micromachining processes, while the IC interfaces are developed using CMOS technology that allows the design of a dedicated circuit which is trimmed to better match the characteristics of the sensing element.

The LSM6DS33 has a full-scale acceleration range of ±2/±4/±8/±16 *g* and an angular rate range of ±125/±245/±500/±1000/±2000 dps.

High robustness to mechanical shock makes the LSM6DS33 the preferred choice of system designers for the creation and manufacturing of reliable products.

The LSM6DS33 is available in a plastic land grid array (LGA) package.

Table 1. Device summary

Part number	Temp. range [°C]	Package	Packing
LSM6DS33	-40 to +85	LGA-16L (3 x 3 x 0.86 mm)	Tray
LSM6DS33TR	-40 to +85		Tape & Reel

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1 Overview

The LSM6DS33 is a system-in-package featuring a high-performance 3-axis digital accelerometer and 3-axis digital gyroscope.

The integrated power-efficient modes are able to reduce the power consumption down to 1.25 mA in high-performance mode, combining always-on low-power features with superior sensing precision for an optimal motion experience for the consumer thanks to ultra-low noise performance for both the gyroscope and accelerometer.

The LSM6DS33 delivers best-in-class motion sensing that can detect orientation and gestures in order to empower application developers and consumers with features and capabilities that are more sophisticated than simply orienting their devices to portrait and landscape mode.

The event-detection interrupts enable efficient and reliable motion tracking and contextual awareness, implementing hardware recognition of free-fall events, 6D orientation, tap and double-tap sensing, activity or inactivity, and wakeup events.

The LSM6DS33 supports main OS requirements, offering real, virtual and batch mode sensors. In addition, the LSM6DS33 can efficiently run the sensor-related features specified in Android, saving power and enabling faster reaction time. In particular, the LSM6DS33 has been designed to implement hardware features such as significant motion, tilt, pedometer functions, and timestamping.

Up to 8 kbyte of FIFO with dynamic allocation of significant data (i.e. sensors, temperature, step counter and timestamp) allows overall power saving of the system.

Like the entire portfolio of MEMS sensor modules, the LSM6DS33 leverages the robust and mature in-house manufacturing processes already used for the production of micromachined accelerometers and gyroscopes. The various sensing elements are manufactured using specialized micromachining processes, while the IC interfaces are developed using CMOS technology that allows the design of a dedicated circuit which is trimmed to better match the characteristics of the sensing element.

The LSM6DS33 is available in a small plastic land grid array (LGA) package of 3 x 3 x 0.86 mm to address ultra-compact solutions.

2 Embedded low-power features

The LSM6DS33 has been designed to be fully compliant with Android, featuring the following on-chip functions:

- 8 kbyte data buffering
  - 100% efficiency with flexible configurations and partitioning
  - possibility to store timestamp
- Event-detection interrupts (fully configurable):
  - free-fall
  - wakeup
  - 6D orientation
  - tap and double-tap sensing
  - activity / inactivity recognition
- Specific IP blocks with negligible power consumption and high-performance:
  - pedometer functions: step detector and step counters
  - tilt (Android compliant, refer to *Section 2.1: Tilt detection* for additional info
  - significant motion (Android compliant)

2.1 Tilt detection

The tilt function helps to detect activity change and has been implemented in hardware using only the accelerometer to achieve both the targets of ultra-low power consumption and robustness during the short duration of dynamic accelerations.

It is based on a trigger of an event each time the device's tilt changes by an angle greater than 35 degrees from the start position.

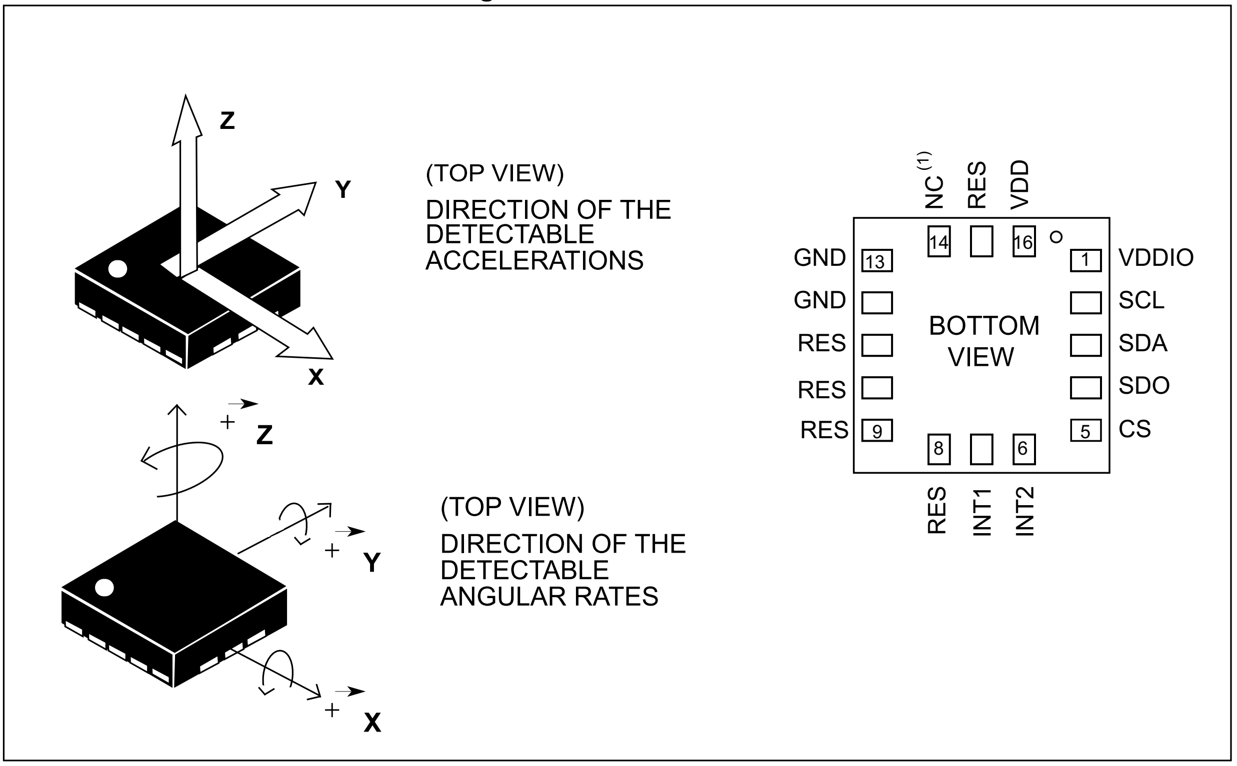
The tilt function can be used with different scenarios, for example:

a) Trigger when phone is in a front pants pocket and the user goes from sitting to standing or standing to sitting;

b) Doesn’t trigger when phone is in a front pants pocket and the user is walking, running or going upstairs.

3 Pin description

Figure 1. Pin connections



1. Leave pin electrically unconnected and soldered to PCB.

In the LSM6DS33 an I^2C slave interface or SPI (3- and 4-wire) serial interface is available.

Table 2. Pin description

Pin#	Name	Function
1	VDDIO(1)	Power supply for I/O pins
2	SCL	I^2C serial clock (SCL) SPI serial port clock (SPC)
3	SDA	I^2C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
4	SDO/SA0	SPI 4-wire interface serial data output (SDO) I^2C least significant bit of the device address (SA0)
5	CS	I^2C/SPI mode selection (1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled)
6	INT2	Programmable interrupt 2 (INT2) / Data enabled (DEN)
7	INT1	Programmable interrupt 1
8	RES	Reserved, connect to GND
9	RES	Reserved, connect to GND
10	RES	Reserved, connect to GND
11	RES	Reserved, connect to GND
12	GND	0 V supply
13	GND	0 V supply
14	NC(2)	Leave unconnected
15	RES	Reserved, connect to GND
16	VDD(3)	Power supply

1. Recommended 100 nF filter capacitor.
2. Leave pin electrically unconnected and soldered to PCB.
3. Recommended 100 nF capacitor.

4 Module specifications

4.1 Mechanical characteristics

@ Vdd = 1.8 V, T = 25 °C unless otherwise noted.

Table 3. Mechanical characteristics

Symbol	Parameter	Test conditions	Min.	Typ.(1)	Max.	Unit
LA_FS	Linear acceleration measurement range			±2		*g*
				±4		
				±8		
				±16		
G_FS	Angular rate measurement range			±125		dps
				±245		
				±500		
				±1000		
				±2000		
LA_So	Linear acceleration sensitivity	FS = ±2		0.061		mg/LSB
		FS = ±4		0.122		
		FS = ±8		0.244		
		FS = ±16		0.488		
G_So	Angular rate sensitivity	FS = ±125		4.375		mdps/LSB
		FS = ±245		8.75		
		FS = ±500		17.50		
		FS = ±1000		35		
		FS = ±2000		70		
G_So%	Sensitivity tolerance(2)	at component level		±1.5		%
LA_SoDr	Linear acceleration sensitivity change vs. temperature(3)	from -40° to +85° delta from T=25°		±1		%
G_SoDr	Angular rate sensitivity change vs. temperature(3)	from -40° to +85° delta from T=25°		±1.5		%
LA_TyOff	Linear acceleration typical zero-*g* level offset accuracy(4)			±40		m*g*
G_TyOff	Angular rate typical zero-rate level(4)			±10		dps
LA_OffDr	Linear acceleration zero-*g* level change vs. temperature(3)			±0.5		m*g*/ °C
G_OffDr	Angular rate typical zero-rate level change vs. temperature(3)			±0.05		dps/°C
Rn	Rate noise density			7		mdps/√Hz
An	Acceleration noise density	FS= ±2 *g* ODR = 104 Hz		90		µ*g*/√Hz

Table 3. Mechanical characteristics (continued)

Symbol	Parameter	Test conditions	Min.	Typ.(1)	Max.	Unit
LA_ODR	Linear acceleration output data rate			12.5 26 52 104 208 416 833 1666 3332 6664		Hz
G_ODR	Angular rate output data rate			12.5 26 52 104 208 416 833 1666		Hz
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.
2. Sensitivity values after factory calibration test and trimming.
3. Measurements are performed in a uniform temperature setup.
4. Values after soldering.

4.2 Electrical characteristics

@ Vdd = 1.8 V, T = 25 °C unless otherwise noted.

Table 4. Electrical characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
Vdd	Supply voltage		1.71	1.8	3.6	V
Vdd_IO	Power supply for I/O		1.62		Vdd+0.1	V
IddHP	Gyroscope and accelerometer in high-performance mode	up to ODR = 1.6 kHz		1.25		mA
IddNM	Gyroscope and accelerometer in normal mode	ODR = 208 Hz		0.9		mA
IddLP	Gyroscope and accelerometer in low-power mode	ODR = 12.5 Hz		0.42		mA
LA_IddHP	Accelerometer current consumption in high-performance mode	up to ODR = 1.6 kHz		240		µA
LA_IddNM	Accelerometer current consumption in normal mode	ODR = 104 Hz		70		µA
LA_IddLM	Accelerometer current consumption in low-power mode	ODR = 12.5 Hz		24		µA
IddPD	Gyroscope and accelerometer in power down			6		µA
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.

For details related to the LSM6DS33 operating modes, refer to *5.2: Gyroscope power modes* and *5.3: Accelerometer power modes*.

4.3 Temperature sensor characteristics

@ Vdd = 1.8 V, T = 25 °C unless otherwise noted.

Table 5. Temperature sensor characteristics

Symbol	Parameter	Test condition	Min.	Typ.[1]	Max.	Unit
TODR	Temperature refresh rate			52		Hz
Toff	Temperature offset[2]		-15		+15	°C
TSen	Temperature sensitivity			16		LSB/°C
TST	Temperature stabilization time[3]				500	µs
T_ADC_res	Temperature ADC resolution			12		bit
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.
2. The output of the temperature sensor is 0 LSB (typ.) at 25 °C.
3. Time from power ON bit to valid data based on characterization data.

4.4 Communication interface characteristics

4.4.1 SPI - serial peripheral interface

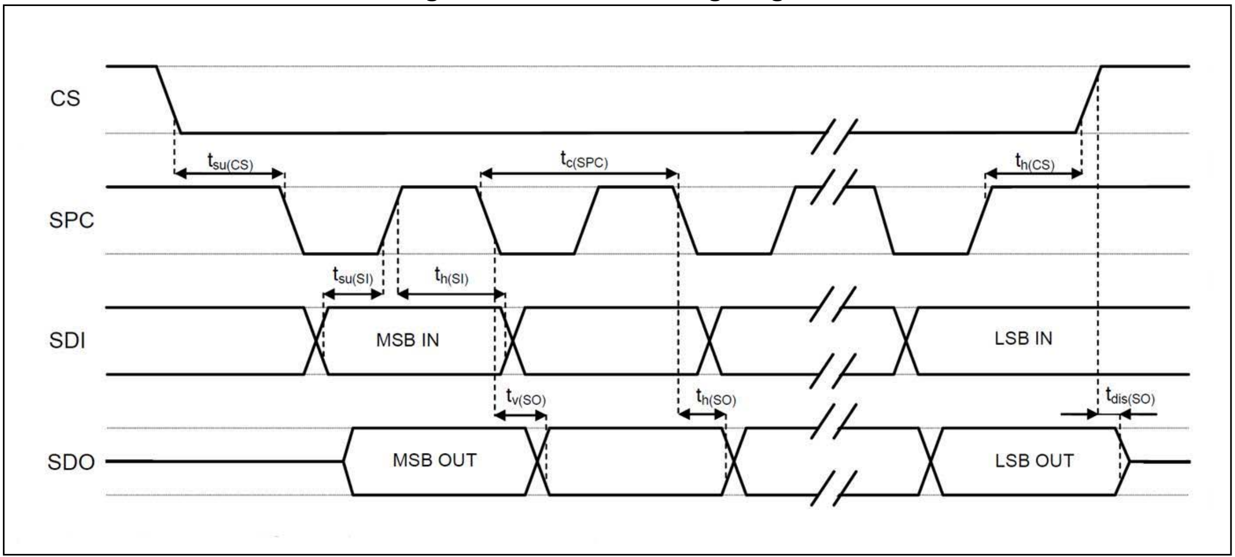
Subject to general operating conditions for Vdd and Top.

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
$t_{su(CS)}$	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 2. 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.

4.4.2 I²C - inter-IC control interface

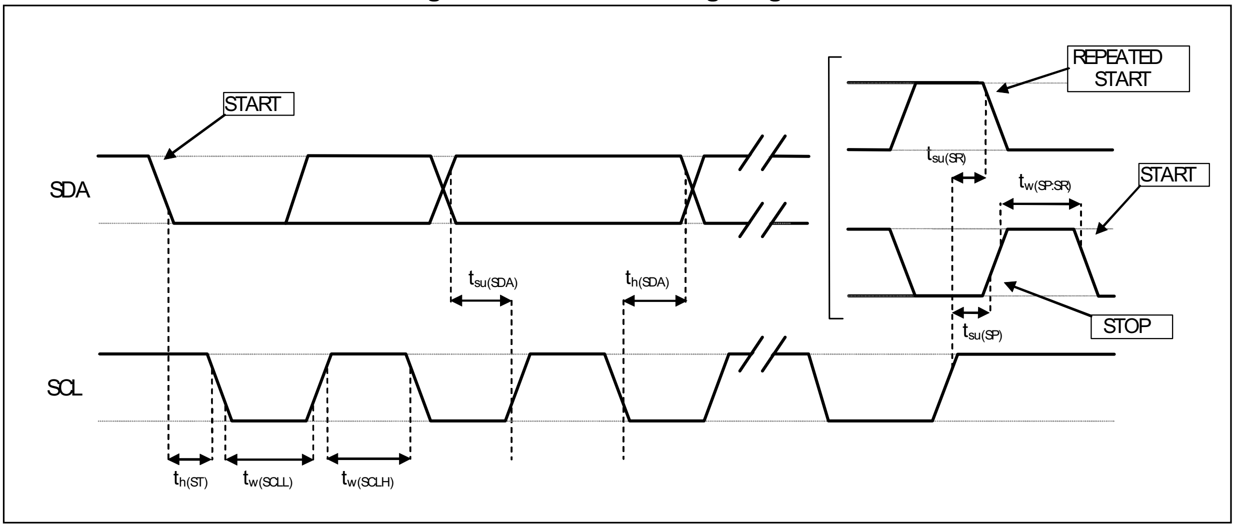
Subject to general operating conditions for Vdd and Top.

Table 7. I²C slave timing values

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
$t_{w(SCLL)}$	SCL clock low time	4.7		1.3		µs
$t_{w(SCLH)}$	SCL clock high time	4.0		0.6		µs
$t_{su(SDA)}$	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		µs
$t_{su(SP)}$	STOP condition setup time	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.

Figure 3. I²C slave timing diagram



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

4.5 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
T_{STG}	Storage temperature range	-40 to +125	°C
Sg	Acceleration *g* for 0.2 ms	10,000	*g*
ESD	Electrostatic discharge protection (HBM)	2	kV
Vin	Input voltage on any control pin (including CS, SCL/SPC, SDA/SDI/SDO, SDO/SA0)	0.3 to Vdd_IO +0.3	V

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.

4.6 Terminology

4.6.1 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.

4.6.2 Zero-*g* and zero-rate 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 2’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.

5 Functionality

5.1 Operating modes

The LSM6DS33 has three operating modes available:

- only accelerometer active and gyroscope in power-down
- only gyroscope active and accelerometer in power-down
- both accelerometer and gyroscope sensors active with independent ODR

The accelerometer is activated from power down by writing ODR_XL[3:0] in *CTRL1_XL (10h)* while the gyroscope is activated from power-down by writing ODR_G[3:0] in *CTRL2_G (11h)*. For combo mode the ODRs are totally independent.

5.2 Gyroscope power modes

In the LSM6DS33, the gyroscope can be configured in four different operating modes: power-down, low-power, normal mode and high-performance mode. The operating mode selected depends on the value of the G_HM_MODE bit in *CTRL7_G (16h)*. If G_HM_MODE is set to '0', high-performance mode is valid for all ODRs (from 12.5 Hz up to 1.6 kHz).

To enable the low-power and normal mode, the G_HM_MODE bit has to be set to '1'. Low-power mode is available for lower ODR (12.5, 26, 52 Hz) while normal mode is available for ODRs equal to 104 and 208 Hz.

5.3 Accelerometer power modes

In the LSM6DS33, the accelerometer can be configured in four different operating modes: power-down, low-power, normal mode and high-performance mode. The operating mode selected depends on the value of the XL_HM_MODE bit in *CTRL6_C (15h)*. If XL_HM_MODE is set to '0', high-performance mode is valid for all ODRs (from 12.5 Hz up to 6.66 kHz).

To enable the low-power and normal mode, the XL_HM_MODE bit has to be set to '1'. Low-power mode is available for lower ODRs (12.5, 26, 52 Hz) while normal mode is available for ODRs equal to 104 and 208 Hz.

5.4 FIFO

The presence of a FIFO allows consistent power saving for the system since the host processor does not need continuously poll data from the sensor, but it can wake up only when needed and burst the significant data out from the FIFO.

LSM6DS33 embeds 8 kbytes data FIFO to store the following data:

- gyroscope
- accelerometer
- step counter and timestamp
- temperature

Writing data in the FIFO can be configured to be triggered by the:

- accelerometer/gyroscope data-ready signal; in which case the ODR must be lower than or equal to both the accelerometer and gyroscope ODRs;

- step detection signal.

In addition, each data can be stored at a decimated data rate compared to FIFO ODR and it is configurable by the user, setting the registers *FIFO_CTRL3 (08h)* and *FIFO_CTRL4 (09h)*. The available decimation factors are 2, 3, 4, 8, 16, 32.

Programmable FIFO threshold can be set in *FIFO_CTRL1 (06h)* and *FIFO_CTRL2 (07h)* using the FTH [11:0] bits.

To monitor the FIFO status, dedicated registers (*FIFO_STATUS1 (3Ah)*, *FIFO_STATUS2 (3Bh)*, *FIFO_STATUS3 (3Ch)*, *FIFO_STATUS4 (3Dh)*) can be read to detect FIFO overrun events, FIFO full status, FIFO empty status, FIFO threshold status and the number of unread samples stored in the FIFO. To generate dedicated interrupts on the INT1 and INT2 pads of these status events, the configuration can be set in *INT1_CTRL (0Dh)* and *INT2_CTRL (0Eh)*.

FIFO buffer can be configured according to five different modes:

– Bypass mode
– FIFO mode
– Continuous mode
– Continuous-to-FIFO mode
– Bypass-to-continuous mode

Each mode is selected by the FIFO_MODE_[2:0] in *FIFO_CTRL5 (0Ah)* register. To guarantee the correct acquisition of data during the switching into and out of FIFO mode, the first sample acquired must be discarded.

5.4.1 Bypass mode

In Bypass mode (*FIFO_CTRL5 (0Ah)* (FIFO_MODE_[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.

5.4.2 FIFO mode

In FIFO mode (*FIFO_CTRL5 (0Ah)* (FIFO_MODE_[2:0] = 001) data from the output channels are stored in the FIFO until it is full.

To reset FIFO content, Bypass mode should be selected by writing *FIFO_CTRL5 (0Ah)* (FIFO_MODE_[2:0]) to '000' After this reset command, it is possible to restart FIFO mode by writing *FIFO_CTRL5 (0Ah)* (FIFO_MODE_[2:0]) to '001'.

FIFO buffer memorizes up to 4096 samples of 16 bits each but the depth of the FIFO can be resized by setting the FTH [11:0] bits in *FIFO_CTRL1 (06h)* and *FIFO_CTRL2 (07h)*. If the STOP_ON_FTH bit in *CTRL4_C (13h)* is set to '1', FIFO depth is limited up to FTH [11:0] bits in *FIFO_CTRL1 (06h)* and *FIFO_CTRL2 (07h)*.

5.4.3 Continuous mode

Continuous mode (*FIFO_CTRL5 (0Ah)* (FIFO_MODE_[2:0] = 110) provides a continuous FIFO update: as new data arrives, the older data is discarded.

A FIFO threshold flag *FIFO_STATUS2 (3Bh)*(FTH) is asserted when the number of unread samples in FIFO is greater than or equal to *FIFO_CTRL1 (06h)* and *FIFO_CTRL2 (07h)*(FTH [11:0]).

It is possible to route *FIFO_STATUS2 (3Bh)* (FTH) to the INT1 pin by writing in register *INT1_CTRL (0Dh)* (INT1_FTH) = '1' or to the INT2 pin by writing in register *INT2_CTRL (0Eh)* (INT2_FTH) = '1'.

A full-flag interrupt can be enabled, *INT1_CTRL (0Dh)* (INT_ FULL_FLAG) = '1', in order to indicate FIFO saturation and eventually read its content all at once.

If an overrun occurs, at least one of the oldest samples in FIFO has been overwritten and the OVER_RUN flag in *FIFO_STATUS2 (3Bh)* 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_STATUS1 (3Ah)* and *FIFO_STATUS2 (3Bh)* (DIFF_FIFO[11:0]).

5.4.4 Continuous-to-FIFO mode

In Continuous-to-FIFO mode (*FIFO_CTRL5 (0Ah)* (FIFO_MODE_[2:0] = 011), FIFO behavior changes according to the trigger event detected in one of the following interrupt registers *FUNC_SRC (53h)*, *TAP_SRC (1Ch)*, *WAKE_UP_SRC (1Bh)* and *D6D_SRC (1Dh)*.

When the selected trigger bit is equal to '1', FIFO operates in FIFO mode.

When the selected trigger bit is equal to '0', FIFO operates in Continuous mode.

5.4.5 Bypass-to-Continuous mode

In Bypass-to-Continuous mode (*FIFO_CTRL5 (0Ah)* (FIFO_MODE_[2:0] = '100'), data measurement storage inside FIFO operates in Continuous mode when selected triggers in one of the following interrupt registers *FUNC_SRC (53h)*, *TAP_SRC (1Ch)*, *WAKE_UP_SRC (1Bh)* and *D6D_SRC (1Dh)* are equal to '1', otherwise FIFO content is reset (Bypass mode).

5.4.6 FIFO reading procedure

The data stored in FIFO are accessible from dedicated registers (*FIFO_DATA_OUT_L (3Eh)* and *FIFO_DATA_OUT_H (3Fh)*) and each FIFO sample is composed of 16 bits.

All FIFO status registers (*FIFO_STATUS1 (3Ah)*, *FIFO_STATUS2 (3Bh)*, *FIFO_STATUS3 (3Ch)*, *FIFO_STATUS4 (3Dh)*) can be read at the start of a reading operation, minimizing the intervention of the application processor.

Saving data in the FIFO buffer is organized in four FIFO data sets consisting of 6 bytes each:

The 1st FIFO data set is reserved for gyroscope data;

The 2nd FIFO data set is reserved for accelerometer data;