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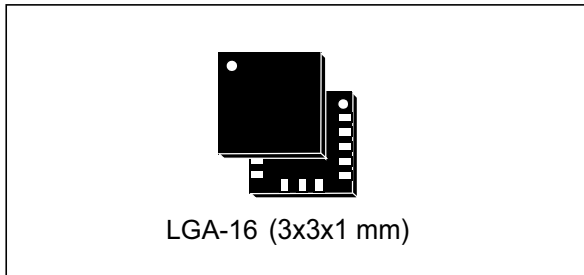
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MEMS digital output motion sensor: ultra-low-power high-performance three-axis "nano" accelerometer

Datasheet - production data



Features

- Wide supply voltage, 1.71 V to 3.6 V
- Independent IOs supply (1.8 V) and supply voltage compatible
- Ultra-low power consumption
- $\pm 2g/\pm 4g/\pm 6g/\pm 8g/\pm 16g$ dynamically selectable full scale
- I²C/SPI digital output interface
- 16-bit data output
- Programmable embedded state machines
- Embedded temperature sensor
- Embedded self-test
- Embedded FIFO
- 10000 g high shock survivability
- ECOPACK[®], RoHS and "Green" compliant

Applications

- Motion-controlled user interface
- Gaming and virtual reality
- Pedometers
- Intelligent power saving for handheld devices
- Display orientation
- Click/double-click recognition
- Impact recognition and logging
- Vibration monitoring and compensation

Description

The LIS3DSH is an ultra-low-power high-performance three-axis linear accelerometer belonging to the "nano" family with an embedded state machine that can be programmed to implement autonomous applications.

The LIS3DSH has dynamically selectable full scales of $\pm 2g/\pm 4g/\pm 6g/\pm 8g/\pm 16g$ and is capable of measuring accelerations with output data rates from 3.125 Hz to 1.6 kHz.

The self-test capability allows the user to check the functioning of the sensor in the final application.

The device can be configured to generate interrupt signals activated by user-defined motion patterns.

The LIS3DSH has an integrated first-in, first-out (FIFO) buffer allowing the user to store data in order to limit intervention by the host processor.

The LIS3DSH is available in a small thin 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

Order codes	Temperature range [°C]	Package	Packaging
LIS3DSHTR	-40 to +85	LGA-16	Tape and reel

Contents

1	Block diagram and pin description	10
1.1	Block diagram	10
1.2	Pin description	10
2	Mechanical and electrical specifications	12
2.1	Mechanical characteristics	12
2.2	Electrical characteristics	13
2.3	Communication interface characteristics	14
2.3.1	SPI - serial peripheral interface	14
2.3.2	I ² C - inter-IC control interface	15
2.4	Absolute maximum ratings	16
2.5	Terminology	17
2.5.1	Sensitivity	17
2.5.2	Zero-g level	17
2.6	Functionality	17
2.6.1	Self-test	17
2.7	Sensing element	17
2.8	IC interface	18
2.9	Factory calibration	18
3	Application hints	19
3.1	Soldering information	19
4	Digital main blocks	20
4.1	State machine	20
4.2	FIFO	21
4.2.1	Bypass mode	21
4.2.2	FIFO mode	21
4.2.3	Stream mode	21
4.2.4	Stream-to-FIFO mode	21
4.2.5	Retrieving data from FIFO	21
5	Digital interfaces	22

5.1	I ² C serial interface	22
5.1.1	I ² C operation	23
5.2	SPI bus interface	25
5.2.1	SPI read	26
5.2.2	SPI write	27
5.2.3	SPI read in 3-wire mode	28
6	Register mapping	29
7	Register description	32
7.1	INFO1 (0Dh)	32
7.2	INFO2 (0Eh)	32
7.3	WHO_AM_I (0Fh)	32
7.4	CTRL_REG3 (23h)	32
7.5	CTRL_REG4 (20h)	33
7.6	CTRL_REG5 (24h)	34
7.7	CTRL_REG6 (25h)	34
7.8	STATUS (27h)	35
7.9	OUT_T (0Ch)	36
7.10	OFF_X (10h)	36
7.11	OFF_Y (11h)	36
7.12	OFF_Z (12h)	36
7.13	CS_X (13h)	36
7.14	CS_Y (14h)	37
7.15	CS_Z (15h)	37
7.16	LC (16h - 17h)	37
7.17	STAT (18h)	37
7.18	VFC_1 (1Bh)	38
7.19	VFC_2 (1Ch)	38
7.20	VFC_3 (1Dh)	38
7.21	VFC_4 (1Eh)	38
7.22	THRS3 (1Fh)	39
7.23	OUT_X (28h - 29h)	39
7.24	OUT_Y (2Ah - 2Bh)	39

7.25	OUT_Z (2Ch - 2Dh)	39
7.26	FIFO_CTRL (2Eh)	40
7.27	FIFO_SRC (2Fh)	40
7.28	CTRL_REG1 (21h)	41
7.29	STx_1 (40h-4Fh)	41
7.30	TIM4_1 (50h)	41
7.31	TIM3_1 (51h)	42
7.32	TIM2_1 (52h - 53h)	42
7.33	TIM1_1 (54h - 55h)	42
7.34	THRS2_1 (56h)	42
7.35	THRS1_1 (57h)	42
7.36	MASK1_B (59h)	43
7.37	MASK1_A (5Ah)	43
7.38	SETT1 (5Bh)	44
7.39	PR1 (5Ch)	44
7.40	TC1 (5Dh-5E)	44
7.41	OUTS1 (5Fh)	45
7.42	PEAK1 (19h)	45
7.43	CTRL_REG2 (22h)	45
7.44	STx_1 (60h-6Fh)	46
7.45	TIM4_2 (70h)	46
7.46	TIM3_2 (71h)	46
7.47	TIM2_2 (72h - 73h)	46
7.48	TIM1_2 (74h - 75h)	46
7.49	THRS2_2 (76h)	47
7.50	THRS1_2 (77h)	47
7.51	MASK2_B (79h)	47
7.52	MASK2_A (7Ah)	48
7.53	SETT2 (7Bh)	48
7.54	PR2 (7Ch)	49
7.55	TC2 (7Dh-7E)	49
7.56	OUTS2 (7Fh)	49
7.57	PEAK2 (1Ah)	50

7.58	DES2 (78h)	50
8	Package information	51
8.1	LGA-16 package information	51
9	Revision history	52

List of tables

Table 1.	Device summary	1
Table 2.	Pin description	11
Table 3.	Mechanical characteristics	12
Table 4.	Electrical characteristics	13
Table 5.	SPI slave timing values	14
Table 6.	I ² C slave timing values	15
Table 7.	Absolute maximum ratings	16
Table 8.	Serial interface pin description	22
Table 9.	I ² C terminology	22
Table 10.	SAD+Read/Write patterns	23
Table 11.	Transfer when master is writing one byte to slave	23
Table 12.	Transfer when master is writing multiple bytes to slave	24
Table 13.	Transfer when master is receiving (reading) one byte of data from slave	24
Table 14.	Transfer when master is receiving (reading) multiple bytes of data from slave	24
Table 15.	Register address map	29
Table 16.	INFO1 register default values	32
Table 17.	INFO2 register default values	32
Table 18.	WHO_AM_I register default values	32
Table 19.	Control register 3	32
Table 20.	CTRL_REG3 register description	32
Table 21.	Control register 4	33
Table 22.	CTRL_REG4 register description	33
Table 23.	CTRL4 ODR configuration	33
Table 24.	Control register 5	34
Table 25.	Control register 5 description	34
Table 26.	Self-test mode selection	34
Table 27.	Control register 6	34
Table 28.	Control register 6 description	35
Table 29.	Status register	35
Table 30.	Status register description	35
Table 31.	OUT_T register	36
Table 32.	OUT_T register description	36
Table 33.	Offset X default values	36
Table 34.	Offset Y default values	36
Table 35.	Offset Z default values	36
Table 36.	Constant shift X-axis default values	36
Table 37.	Constant shift Y-axis default values	37
Table 38.	Constant shift Z-axis default values	37
Table 39.	LC_L default values	37
Table 40.	LC_H default values	37
Table 41.	STAT register	37
Table 42.	STAT register description	38
Table 43.	Vector filter coefficient register 1 default values	38
Table 44.	Vector filter coefficient register 2 default values	38
Table 45.	Vector filter coefficient register 3 default values	38
Table 46.	Vector filter coefficient register 4 default values	38
Table 47.	Threshold value register 3 default values	39
Table 48.	OUT_X_L register default values	39

Table 49.	OUT_X_H register default values	39
Table 50.	OUT_Y_L register default values	39
Table 51.	OUT_Y_H register default values	39
Table 52.	OUT_Z_L register default values	39
Table 53.	OUT_Z_H register default values	39
Table 54.	FIFO control register	40
Table 55.	FIFO control register description	40
Table 56.	FIFO mode selection	40
Table 57.	FIFO_SRC register	40
Table 58.	FIFO_SRC register description	41
Table 59.	SM1 control register	41
Table 60.	SM1 control register structure	41
Table 61.	Timer4 default values	41
Table 62.	Timer3 default values	42
Table 63.	TIM2_1_L default values	42
Table 64.	TIM2_1_H default values	42
Table 65.	TIM1_1_L default values	42
Table 66.	TIM1_1_H default values	42
Table 67.	THRS2_1 default values	42
Table 68.	THRS1_1 default values	42
Table 69.	MASK1_B axis and sign mask register	43
Table 70.	MASK1_B register structure	43
Table 71.	MASK1_A axis and sign mask register	43
Table 72.	MASK1_A register structure	43
Table 73.	SETT1 register structure	44
Table 74.	SETT1 register description	44
Table 75.	PR1 register	44
Table 76.	PR1 register description	44
Table 77.	TC1_L default values	44
Table 78.	TC1_H default values	44
Table 79.	OUTS1 register	45
Table 80.	OUTS1 register description	45
Table 81.	PEAK1 default values	45
Table 82.	SM2 control register	45
Table 83.	SM2 control register description	45
Table 84.	Timer4 default values	46
Table 85.	Timer3 default values	46
Table 86.	TIM2_2_L default values	46
Table 87.	TIM2_2_H default values	46
Table 88.	TIM1_2_L default values	46
Table 89.	TIM1_2_H default values	46
Table 90.	THRS2_2 default values	47
Table 91.	THRS1_2 default values	47
Table 92.	MASK2_B axis and sign mask register	47
Table 93.	MASK2_B register description	47
Table 94.	MASK2_A axis and sign mask register	48
Table 95.	MASK2_A register description	48
Table 96.	SETT2 register	48
Table 97.	SETT2 register description	48
Table 98.	PR2 register	49
Table 99.	PR2 register description	49
Table 100.	TC2_L default values	49

Table 101.	TC2_H default values	49
Table 102.	OUTS2 register	49
Table 103.	OUTS2 register description	49
Table 104.	PEAK2 default values	50
Table 105.	DES2 default values	50
Table 106.	Document revision history	52

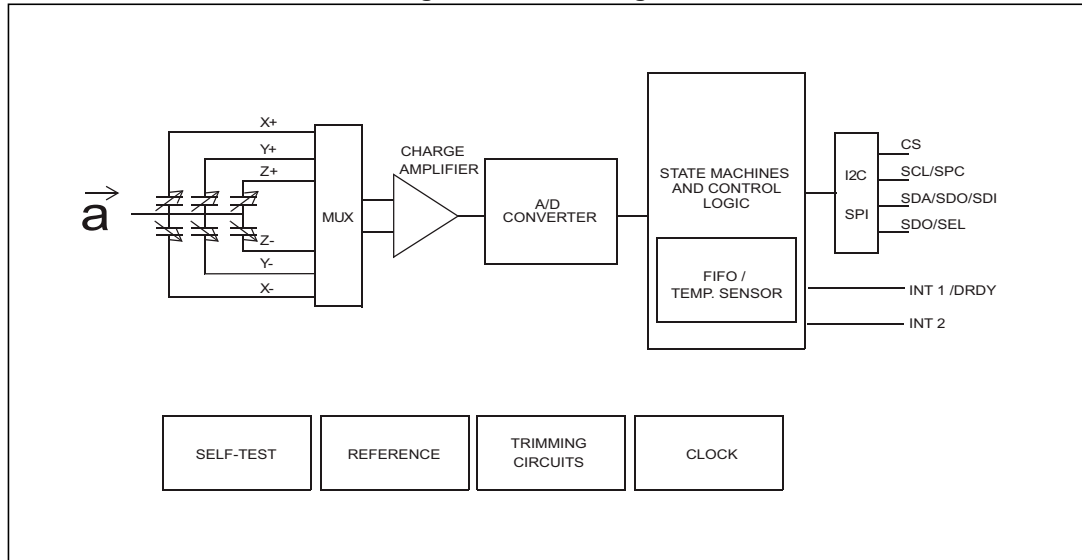
List of figures

Figure 1.	Block diagram	10
Figure 2.	Pin connections	10
Figure 3.	SPI slave timing diagram	14
Figure 4.	I2C slave timing diagram	15
Figure 5.	LIS3DSH electrical connections	19
Figure 6.	LIS3DSH state machines: sequence of state to execute an algorithm	20
Figure 7.	Read and write protocol	25
Figure 8.	SPI read protocol	26
Figure 9.	Multiple byte SPI read protocol (2-byte example).	26
Figure 10.	SPI write protocol	27
Figure 11.	Multiple byte SPI write protocol (2-byte example).	27
Figure 12.	SPI read protocol in 3-wire mode	28
Figure 13.	LGA-16: package outline and mechanical data	51

1 Block diagram and pin description

1.1 Block diagram

Figure 1. Block diagram



1.2 Pin description

Figure 2. Pin connections

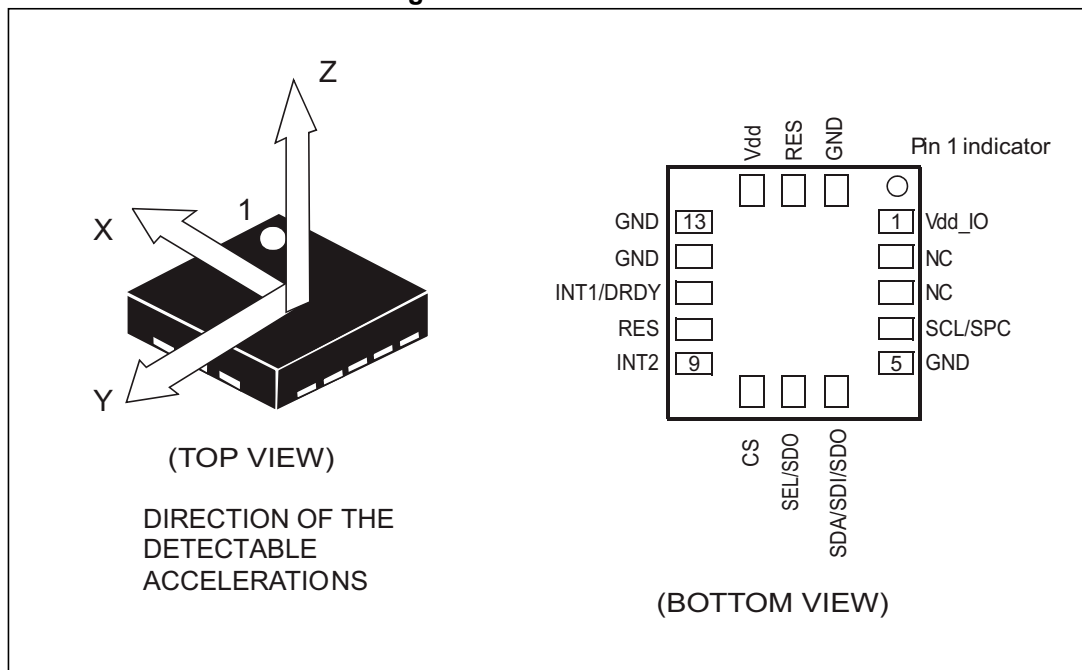


Table 2. Pin description

Pin#	Name	Function
1	Vdd_IO	Power supply for I/O pins
2	NC	Not connected
3	NC	Not connected
4	SCL SPC	I ² C serial clock (SCL) SPI serial port clock (SPC)
5	GND	0 V supply
6	SDA SDI SDO	I ² C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
7	SEL SDO	I ² C address selection SPI serial data output (SDO)
8	CS	SPI enable I ² C/SPI mode selection (1: SPI idle mode / I ² C communication enabled; 0: SPI communication mode / I ² C disabled)
9	INT 2	Interrupt 2
10	Reserved	Connect to GND
11	INT 1/DRDY	Interrupt 1/ DRDY
12	GND	0 V supply
13	GND	0 V supply
14	Vdd	Power supply
15	Reserved	Connect to Vdd, connect to GND, or leave unconnected
16	GND	0 V supply

2 Mechanical and electrical specifications

2.1 Mechanical characteristics

@ Vdd = 2.5 V, T = 25 °C unless otherwise noted^(a).

Table 3. Mechanical characteristics

Symbol	Parameter	Test conditions	Min.	Typ. ⁽¹⁾	Max.	Unit
FS	Measurement range ⁽²⁾	FS bit set to 000		±2.0		g
		FS bit set to 001		±4.0		
		FS bit set to 010		±6.0		
		FS bit set to 011		±8.0		
		FS bit set to 100		±16.0		
So	Sensitivity	FS bit set to 000		0.06		mg/digit
		FS bit set to 001		0.12		
		FS bit set to 010		0.18		
		FS bit set to 011		0.24		
		FS bit set to 100		0.73		
TCSO	Sensitivity change vs. temperature	FS bit set to 00		0.01		%/°C
TyOff	Typical zero-g level offset accuracy ⁽³⁾	FS bit set to 00		±40		mg
TCOff	Zero-g level change vs. temperature	Max. delta from 25 °C		±0.5		mg/°C
An	Acceleration noise density	FS bit set to 00, normal mode, ODR = 100 Hz		150		µg/sqrt(Hz)
ST	Self test positive difference ⁽⁴⁾	± 2 g range, X, Y-axis ST2,ST1 = [01] see Figure 23		140		mg
		± 2 g range, Z-axis ST2,ST1 = [01] see Figure 23		590		
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed.

2. Verified by wafer level test and measurement of initial offset and sensitivity.

3. Typical zero-g level offset value after MSL3 preconditioning.

4. Self-test output change" is defined as: $OUTPUT[mg]_{(CNTL5\ ST2,\ ST1\ bits=01)} - OUTPUT[mg]_{(CNTL5\ ST2,\ ST1\ bits=00)}$

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

2.2 Electrical characteristics

@ Vdd = 2.5 V, T = 25 °C unless otherwise noted^(b).

Table 4. Electrical characteristics ⁽¹⁾

Symbol	Parameter	Test conditions	Min.	Typ. ⁽²⁾	Max.	Unit
Vdd	Supply voltage		1.71	2.5	3.6	V
Vdd_IO	I/O pins supply voltage ⁽³⁾		1.71		Vdd+0.1	V
IddA	Current consumption in active mode	1.6 kHz ODR		225		μA
		3.125 Hz ODR		11		μA
IddPdn	Current consumption in power-down/standby mode			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		0.9*Vdd_IO			V
VOL	Low-level output voltage				0.1*Vdd_IO	V
Top	Operating temperature range		-40		+85	°C

1. The product is factory calibrated at 2.5 V. The operational power supply range is from 1.71 V to 3.6 V.
2. Typical specifications are not guaranteed.
3. It is possible to remove Vdd while maintaining Vdd_IO without blocking the communication busses, 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.

2.3 Communication interface characteristics

2.3.1 SPI - serial peripheral interface

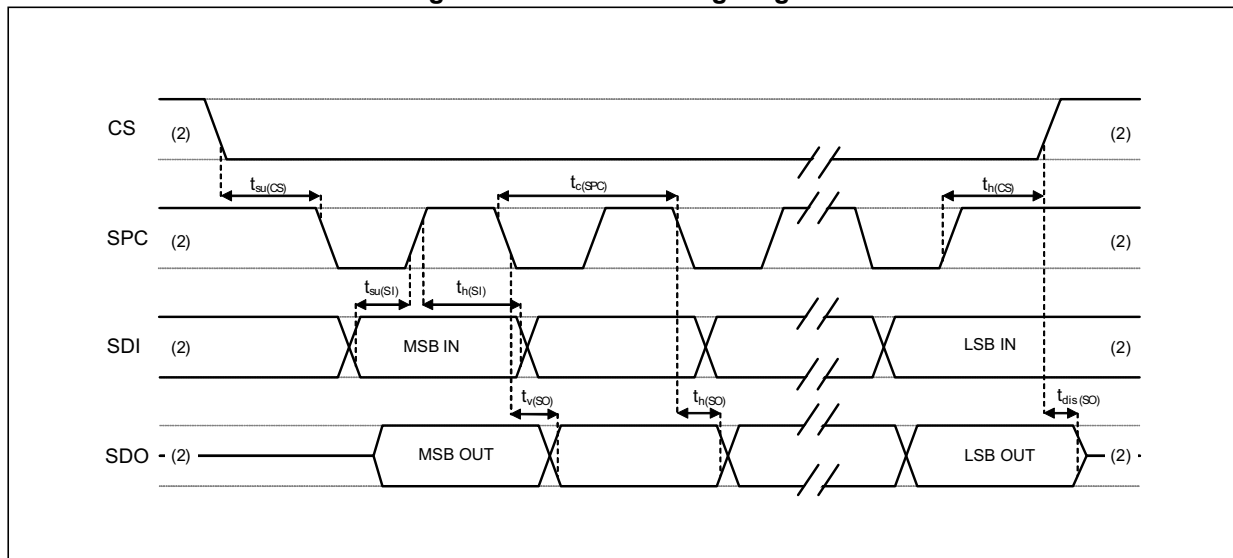
Subject to general operating conditions for Vdd and Top.

Table 5. 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	6		ns
$t_{h(CS)}$	CS hold time	8		
$t_{su(SI)}$	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	9		
$t_{dis(SO)}$	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



2. When no ongoing communication, data on SDO is driven by internal pull-up resistor.

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

2.3.2 I²C - inter-IC control interface

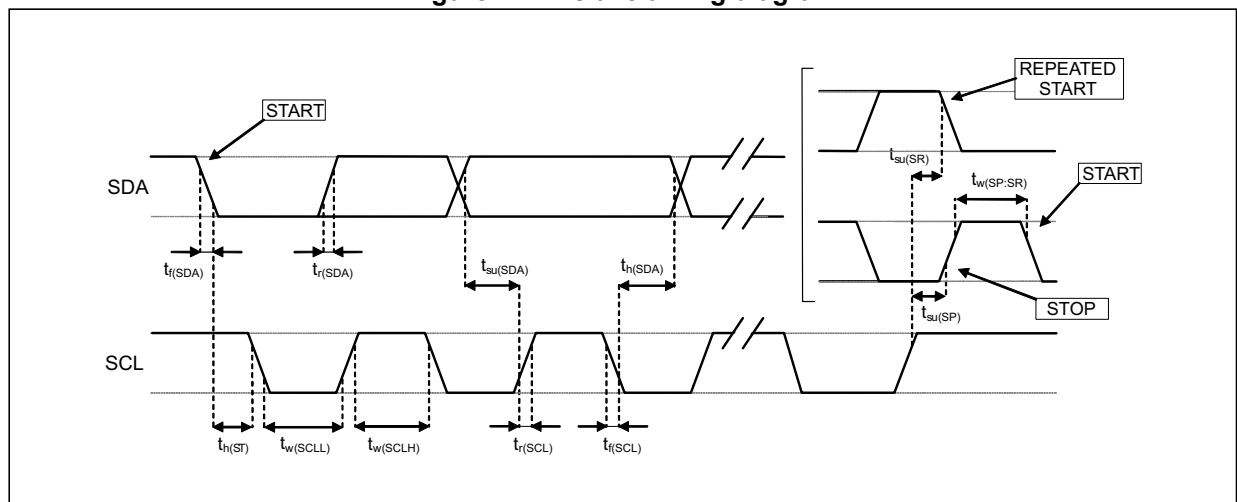
Subject to general operating conditions for Vdd and Top.

Table 6. I²C slave timing values

Symbol	Parameter	I ² C		I ² C fast		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	0.01	3.45	0.01	0.9	μs
t _{r(SDA)} t _{r(SCL)}	SDA and SCL rise time		1000	20 + 0.1C _b ⁽²⁾	300	ns
t _{f(SDA)} t _{f(SCL)}	SDA and SCL fall time		300	20 + 0.1C _b ⁽²⁾	300	
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 I²C protocol requirement, not tested in production.
2. C_b = total capacitance of one bus line, in pF.

Figure 4. I²C slave timing diagram



Note: Measurement points are done at 0.2·Vdd_{IO} and 0.8·Vdd_{IO}, for both ports.

2.4 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 7. Absolute maximum ratings

Symbol	Ratings	Maximum value	Unit
V _{dd}	Supply voltage	-0.3 to 4.8	V
V _{dd_IO}	I/O pins supply voltage	-0.3 to 4.8	V
V _{in}	Input voltage on any control pin (CS, SCL/SPC, SDA/SDI/SDO, SDO/SEL)	-0.3 to V _{dd_IO} +0.3	V
A _{POW}	Acceleration (any axis, powered, V _{dd} = 2.5 V)	3000 for 0.5 ms	<i>g</i>
		10000 for 0.1 ms	<i>g</i>
A _{UNP}	Acceleration (any axis, unpowered)	3000 for 0.5 ms	<i>g</i>
		10000 for 0.1 ms	<i>g</i>
T _{OP}	Operating temperature range	-40 to +85	°C
T _{STG}	Storage temperature range	-40 to +125	°C
ESD	Electrostatic discharge protection	2 (HBM)	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.

2.5 Terminology

2.5.1 Sensitivity

Sensitivity describes the gain of the sensor and can be determined, for example, 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 also time. The sensitivity tolerance describes the range of sensitivities of a large population of sensors.

2.5.2 Zero-g level

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 measures 0 g for the X-axis and 0 g for the Y-axis, whereas the Z-axis measures 1 g. The output is ideally 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 on a printed circuit board or exposing it to extensive mechanical stress. Offset changes little over temperature, see "Zero-g level change vs. temperature". The Zero-g level tolerance (TyOff) describes the standard deviation of the range of Zero-g levels of a population of sensors.

2.6 Functionality

2.6.1 Self-test

The self-test allows checking the sensor functionality without moving it. The self-test function is off when the self-test bit (ST) is programmed to '0'. When the self-test bit is programmed to '1', an actuation force is applied to the sensor, simulating a definite input acceleration. In this case the sensor outputs exhibit a change in their DC levels which are related to the selected full scale through the device sensitivity. When the self-test is activated, the device output level is given by the algebraic sum of the signals produced by the acceleration acting on the sensor and by the electrostatic test-force. If the output signals change within the amplitude specified in [Table 3](#), then the sensor is working properly and the parameters of the chip interface are within the defined specifications.

2.7 Sensing element

A proprietary process is used to create a surface micromachined accelerometer. The technology allows processing suspended silicon structures which are attached to the substrate in a few points called anchors and are free to move in the direction of the sensed acceleration. In order to be compatible with traditional packaging techniques, a cap is placed on top of the sensing element to avoid blocking the moving parts during the molding phase of the plastic encapsulation.

When an acceleration is applied to the sensor, the proof mass displaces from its nominal position, causing an imbalance in the capacitive half bridge. This imbalance is measured using charge integration in response to a voltage pulse applied to the capacitor.

At steady-state the nominal value of the capacitors are a few pF and when an acceleration is applied, the maximum variation of the capacitive load is in the fF range.

2.8 IC interface

The complete measurement chain is made up of a low-noise capacitive amplifier which converts the capacitive unbalancing of the MEMS sensor into an analog voltage that is available to the user through an analog-to-digital converter.

The acceleration data may be accessed through an I²C/SPI interface, therefore making the device particularly suitable for direct interfacing with a microcontroller.

The LIS3DSH features a Data-Ready signal (DRDY) which indicates when a new set of measured acceleration data is available, therefore simplifying data synchronization in the digital system that uses the device.

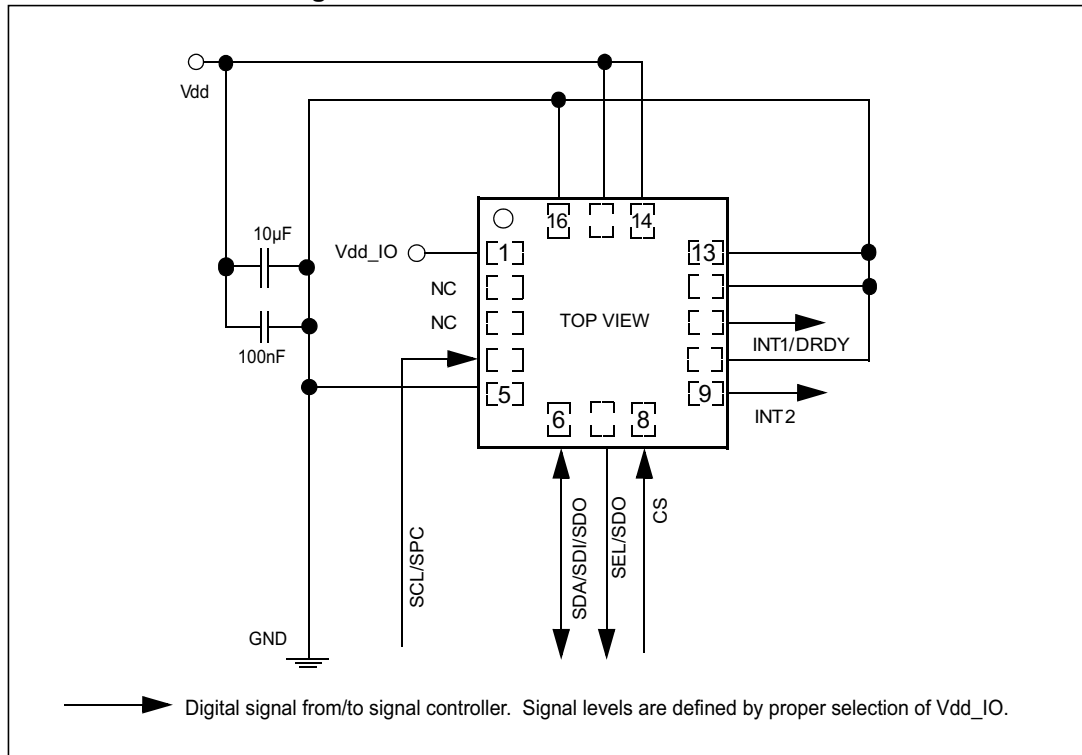
2.9 Factory calibration

The IC interface is factory calibrated for sensitivity (So) and Zero-g level (TyOff).

The trimming values are stored inside the device in nonvolatile memory. Any time the device is turned on, the trimming parameters are downloaded into the registers to be used during the active operation. This allows using the device without further calibration.

3 Application hints

Figure 5. LIS3DSH electrical connections



Note: Pin 15 can be connected to Vdd or GND or left unconnected.

The device core is supplied through the Vdd line while the I/O pins are supplied through the Vdd_IO line. Power supply decoupling capacitors (100 nF ceramic, 10 μ F) should be placed as near as possible to pin 14 of the device (common design practice).

All the voltage and ground supplies must be present at the same time to have proper behavior of the IC (refer to [Figure 5](#)). It is possible to remove Vdd while maintaining Vdd_IO without blocking the communication bus, in this condition the measurement chain is powered off.

The functionality of the device and the measured acceleration data are selectable and accessible through the I²C or SPI interfaces. When using the I²C, CS must be tied high.

3.1 Soldering information

The LGA package is compliant with the ECOPACK[®], RoHS and “Green” standard. It is qualified for soldering heat resistance according to JEDEC J-STD-020.

Leave “Pin 1 Indicator” unconnected during soldering.

Land pattern and soldering recommendations are available at www.st.com.

4 Digital main blocks

4.1 State machine

The LIS3DSH embeds two state machines able to run a user-defined program.

The program is made up of a set of instructions that define the transition to successive states. Conditional branches are possible.

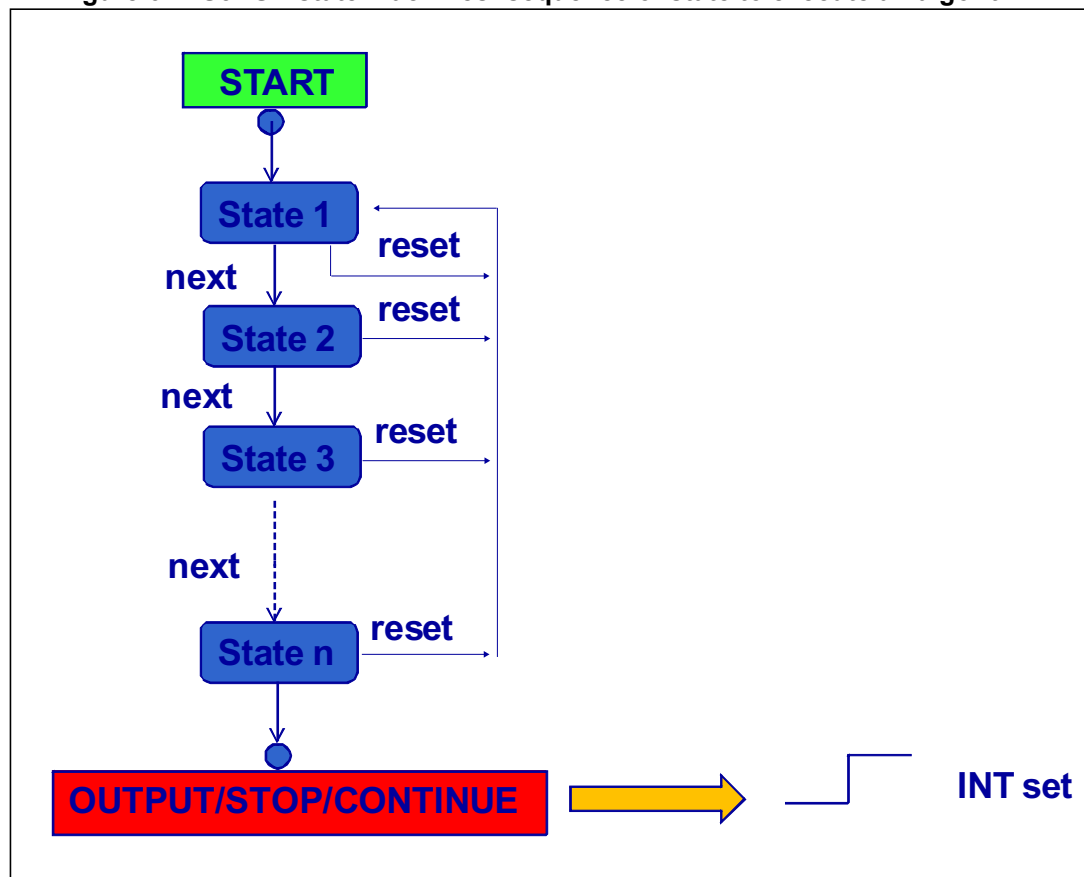
From each state (n) it is possible to have a transition to the next state (n+1) or to a reset state. The transition to the reset point happens when "RESET condition" is true; The transition to the next step happens when "NEXT condition" is true.

An interrupt is triggered when the output/stop/continue state is reached.

Each state machine allows implementing gesture recognition in a flexible way, free-fall, wake-up, 4D/6D orientation, pulse counter and step recognition, click/double-click, shake/double-shake, face-up/face-down, turn/double-turn:

- Code and parameters are loaded by the host into dedicated memory areas for the state program
- State program with timing based on ODR or decimated time
- Possibility of conditional branches

Figure 6. LIS3DSH state machines: sequence of state to execute an algorithm



4.2 FIFO

The LIS3DSH embeds an acceleration data FIFO for each of the 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 according to four different modes: Bypass mode, FIFO mode, Stream mode and Stream-to-FIFO mode. Each mode is selected by the FIFO_MODE bits. Programmable watermark level, FIFO_empty or FIFO_Full events can be enabled to generate dedicated interrupts on the INT1/2 pins.

4.2.1 Bypass mode

In Bypass mode, the FIFO is not operational and for this reason it remains empty. For each channel only the first address is used. The remaining FIFO slots are empty.

4.2.2 FIFO mode

In FIFO mode, data from the X, Y, and Z channels are stored in the FIFO. A watermark interrupt can be enabled in order to be raised when the FIFO is filled to the level specified by the internal register. The FIFO continues filling until it is full. When full, the FIFO stops collecting data from the input channels.

4.2.3 Stream mode

In Stream mode, data from the X, Y, and Z measurements are stored in the FIFO. A watermark interrupt can be enabled and set as in the FIFO mode. The FIFO continues filling until it's full. When full, the FIFO discards the older data as the new arrive.

4.2.4 Stream-to-FIFO mode

In Stream-to-FIFO mode, data from the X, Y, and Z measurements are stored in the FIFO. A watermark interrupt can be enabled in order to be raised when the FIFO is filled to the level specified by the internal register. The FIFO continues filling until it's full. When full, the FIFO discards the older data as the new arrive. Once a trigger event occurs, the FIFO starts operating in FIFO mode.

4.2.5 Retrieving data from FIFO

FIFO data is read from the OUT_X, OUT_Y and OUT_Z registers. When the FIFO is in Stream, Bypass or FIFO mode, a read operation to the OUT_X, OUT_Y or OUT_Z registers provides the data stored in the FIFO. Each time data is read from the FIFO, the oldest X, Y, and Z data are placed in the OUT_X, OUT_Y and OUT_Z registers and both single-read and read-burst operations can be used.

5 Digital interfaces

The registers embedded inside the LIS3DSH may be accessed through both the I²C and SPI serial interfaces. The latter may be SW configured to operate either in 3-wire or 4-wire interface mode.

The serial interfaces are mapped to the same pins. To select/exploit the I²C interface, the CS line must be tied high (i.e. connected to Vdd_IO).

Table 8. Serial interface pin description

Pin name	Pin description
CS	SPI enable I ² C/SPI mode selection (1: SPI idle mode / I ² C communication enabled; 0: SPI communication mode / I ² C disabled)
SCL SPC	I ² C serial clock (SCL) SPI serial port clock (SPC)
SDA SDI SDO	I ² C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
SEL SDO	I ² C address selection SPI serial data output (SDO)

5.1 I²C serial interface

The LIS3DSH I²C is a bus slave. The I²C is employed to write data into registers whose content can also be read back.

The relevant I²C terminology is given in the table below.

Table 9. I²C terminology

Term	Description
Transmitter	The device which sends data to the bus
Receiver	The device which receives data from the bus
Master	The device which initiates a transfer, generates clock signals and terminates a transfer
Slave	The device addressed by the master

There are two signals associated with the I²C bus: the serial clock line (SCL) and the serial data line (SDA). The latter is a bidirectional line used for sending and receiving the data to/from the interface. Both lines must be connected to Vdd_IO through an external pull-up resistor. When the bus is free, both lines are high.

The I²C interface is compliant with fast mode (400 kHz) I²C standards as well as with normal mode.

5.1.1 I²C operation

The transaction on the bus is started through a start (ST) signal. A start condition is defined as a HIGH to LOW transition on the data line while the SCL line is held HIGH. After this has been transmitted by the master, the bus is considered busy. The next byte of data transmitted after the start condition contains the address of the slave in the first 7 bits and the eighth bit tells whether the master is receiving data from the slave or transmitting data to the slave. When an address is sent, each device in the system compares the first seven bits after a start condition with its address. If they match, the device considers itself addressed by the master.

The slave address (SAD) associated to the LIS3DSH is 00111xxb where the xx bits are modified by the SEL/SDO pin in order to modify the device address. If the SEL pin is connected to the voltage supply, the address is 0011101b, otherwise the address is 0011110b if the SEL pin is connected to ground. This solution allows connecting and addressing two different accelerometers to the same I²C lines.

Data transfer with acknowledge is mandatory. The transmitter must release the SDA line during the acknowledge pulse. The receiver must then pull the data line LOW so that it remains stable low during the HIGH period of the acknowledge clock pulse. A receiver which has been addressed is obliged to generate an acknowledge after each byte of data received.

The I²C embedded inside the LIS3DSH behaves as a slave device and the following protocol must be adhered to. After the start condition (ST) a slave address is sent, once a slave acknowledge (SAK) has been returned, an 8-bit sub-address (SUB) is transmitted: the 7 LSb represents the actual register address while the ADD_INC bit (CTRL_REG6) defines the address increment.

The slave address is completed with a read/write bit. If the bit is '1' (Read), a repeated start (SR) condition must be issued after the two sub-address bytes; if the bit is '0' (Write), the master transmits to the slave with direction unchanged. [Table 10](#) explains how the SAD+Read/Write bit pattern is composed, listing all the possible configurations.

Table 10. SAD+Read/Write patterns

Command	SAD[6:2]	SAD[1] = $\overline{\text{SEL}}$	SAD[0] = SEL	R/W	SAD+R/W
Read	00111	1	0	1	00111101
Write	00111	1	0	0	00111100
Read	00111	0	1	1	00111011
Write	00111	0	1	0	00111010

Table 11. Transfer when master is writing one byte to slave

Master	ST	SAD + W		SUB		DATA		SP
Slave			SAK		SAK		SAK	

Table 12. Transfer when master is writing multiple bytes to slave

Master	ST	SAD + W		SUB		DATA		DATA		SP
Slave			SAK		SAK		SAK		SAK	

Table 13. Transfer when master is receiving (reading) one byte of data from slave

Master	ST	SAD + W		SUB		SR	SAD + R			NMAK	SP
Slave			SAK		SAK			SAK	DATA		

Table 14. Transfer when master is receiving (reading) multiple bytes of data from slave

Master	ST	SAD+W		SUB		SR	SAD+R			MAK		MAK		NMAK	SP
Slave			SAK		SAK			SAK	DATA		DATA		DATA		

Data are transmitted in byte format (DATA). Each data transfer contains 8 bits. The number of bytes transferred per transfer is unlimited. Data is transferred with the Most Significant bit (MSb) first. If a receiver can't receive another complete byte of data until it has performed some other function, it can hold the clock line, SCL LOW, to force the transmitter into a wait state. Data transfer only continues when the receiver is ready for another byte and releases the data line. If a slave receiver doesn't acknowledge the slave address (i.e. it is not able to receive because it is performing some real-time function) the data line must be left HIGH by the slave. The master can then abort the transfer. A LOW to HIGH transition on the SDA line while the SCL line is HIGH is defined as a STOP condition. Each data transfer must be terminated by the generation of a STOP (SP) condition.

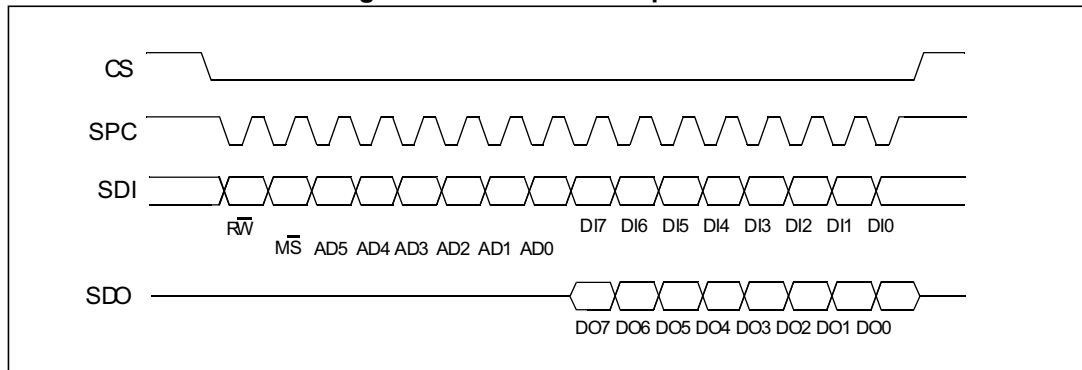
In the communication format presented, MAK is Master acknowledge and NMAK is No Master Acknowledge.

5.2 SPI bus interface

The LIS3DSH SPI is a bus slave. The SPI allows writing to and reading from the registers of the device.

The serial interface interacts with the outside world with 4 wires: CS, SPC, SDI and SDO.

Figure 7. Read and write protocol



CS is the serial port enable and it is controlled by the SPI master. It goes low at the start of the transmission and goes back high at the end. SPC is the serial port clock and it is controlled by the SPI master. It is stopped high when CS is high (no transmission). SDI and SDO are respectively the serial port data input and output. Those lines are driven at the falling edge of SPC and should be captured at the rising edge of SPC.

Both the read register and write register commands are completed in 16 clock pulses or in multiples of 8 in case of multiple read/write bytes. Bit duration is the time between two falling edges of SPC. The first bit (bit 0) starts at the first falling edge of SPC after the falling edge of CS while the last bit (bit 15, bit 23, ...) starts at the last falling edge of SPC just before the rising edge of CS.

bit 0: $R\bar{W}$ bit. When 0, the data DI(7:0) is written into the device. When 1, the data DO(7:0) from the device is read. In the latter case, the chip drives **SDO** at the start of bit 8.

bit 1-7: address AD(6:0). This is the address field of the indexed register.

bit 8-15: data DI(7:0) (write mode). This is the data that is written into the device (MSb first).

bit 8-15: data DO(7:0) (read mode). This is the data that is read from the device (MSb first).

In multiple read/write commands further blocks of 8 clock periods are added. When the ADD_INC [CTRL_REG6 \(25h\)](#) bit is '0', the address used to read/write data remains the same for every block. When the ADD_INC bit is '1', the address used to read/write data is increased at every block.

The function and the behavior of **SDI** and **SDO** remain unchanged.