 BOSCH	Preliminary Datasheet SMB365 Three-axis accelerometer	Bosch Sensortec
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Triaxial $\pm 2g/\pm 10g$ Accelerometer SMB365

KEY FEATURES

- Three-axis accelerometer
- Switchable g-range (2g/10g)
- Standard SMD package: QFN 4.0x4.0 mm² footprint, 1.2mm height
- 4mg resolution at 50Hz bandwidth
- Ultra-low power ASIC: 600 μ A at V_{DD} 2.5V
- SPI interface
- Interrupt feature for mobile wake-up or zero-g detection (free fall)
- Full self-test capability
- RoHS lead-free compliant
- Based on automotive-proven Bosch Silicon Surface Micromachining Process

TYPICAL APPLICATIONS

Tilt, motion and vibration sensing in

- Cell phones
- Handhelds
- Computer peripherals
- Man-machine interfaces
- Virtual reality
- Games

GENERAL DESCRIPTION

The SMB365 is a triaxial low-g acceleration sensor for consumer market applications. It allows measurements of static as well as dynamic accelerations. Due to its three perpendicular axes it gives the absolute orientation in a gravity field. As all other Bosch inertial sensors, it is a two-chip arrangement. An application-specific IC evaluates the output of a three-channel micromechanical acceleration-sensing element that works according to the differential capacitance principle. The underlying micromachining process has proven its capability in more than 100 million Bosch accelerometers and gyroscopes so far.

The SMB365 provides a digital 10bit output signal via an SPI interface. With an appropriate SPI command the full measurement range can be chosen to 2g or 10g. A first-order filter with a pole-frequency of 50Hz is included to provide preconditioning of the measured acceleration signal. Typical noise level and quantization lead to a sensitivity resolution of 4mg or an accuracy of 0.3° in an inclination sensing application, respectively. The current consumption is typically 600 μ A at a supply voltage of 2.5V. Furthermore, the sensor can be switched into a low-power mode where it informs the host system about an acceleration change via an interrupt pin. This feature can be used to wake-up the host system from a sleep mode.

The sensor also features full self-test capability. It is activated via SPI command which results in a physical deflection of the seismic mass in the sensing element due to an electrostatic force. Thus, it provides full testing of the complete signal evaluation path including the micromachined sensor structure and the evaluation ASIC.


The sensor is available in a standard SMD QFN package with a footprint of 4x4mm² and a height of 1.2mm.

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1 Specification

Parameter	Symbol	Condition	Min	Typ	Max	Units
OPERATING RANGE						
Acceleration Range	g_{FS2g}	switchable via SPI command		2		g
	g_{FS10g}			10		g
Supply Voltage Analog	V_{DDA}		2.3	2.5	3.6	V
Supply Voltage Digital	V_{DDD}	only for SPI I/O; $V_{DDD} \leq V_{DDA}$	1.6	1.8	3.6	V
Supply Current in Normal Mode	I_{DD}	digital and analog		600		μ A
Supply Current in Low-Power Mode	I_{DDlpm}	digital and analog		500		μ A
Supply Current in Standby Mode	I_{DDsbm}	digital and analog		5		μ A
Operating Temperature	T_A		-40		+85	$^{\circ}$ C
OUTPUT SIGNAL						
Sensitivity	S_{2g}	g-range 2g	240	256	272	LSB/g
	S_{10g}	g-range 10g	47	51	55	LSB/g
Zero-g Offset ²	Off	$T_A=25^{\circ}$ C, $V_{DDD}=2.5$ V		± 10		LSB
Zero-g Offset Temperature Drift	TCO	-15° C $\leq T_A \leq +55^{\circ}$ C		± 0.5		LSB/K
Ratiometricity Error ³	δ_{rat_off}	Offset drift vs. V_{DDA}		± 30		LSB/V
Bandwidth	f_{-3dB}	1 st order filter	25	50	75	Hz
Nonlinearity	NL	best fit straight line		± 0.5		%FS
Self Test Response	TST	activated via SPI	2g xy		300	LSB
			2g z		150	
			10g xy		60	
			10g z		30	
Output Noise	n_{rms}	rms		1		LSB

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MECHANICAL CHARACTERISTICS					
Cross Axis Sensitivity	\bar{S}	relative contribution between 3 axes		0.2	%
Alignment Error	δ_a	relative to package outline		± 0.5	°

2 Absolute Maximum Ratings

Parameter	Condition	Min	Max	Units
Supply Voltage	V_{DDD} and V_{DDA}	-0.3	3.6	V
Storage Temperature range		-50	+150	°C
Mechanical Shock	duration $\leq 50\mu\text{s}$		10,000	g
	duration $\leq 1.0\text{ms}$		2,000	g
	free fall onto hard surfaces		1.5	m
ESD	HBM, at any pin		2	kV
	CDM		500	V

3 SPI Interface

- 16-bit SPI protocol (mode 3)
- Clock frequency up to 8MHz
- 1 read/write bit (R/W=0 for writing, R/W=1 for reading)
- 7 address bits
- 8 data bits
- The most significant bit (MSB) is transferred first during address and data phases.
- The data acquisition by the sensor occurs at the rising edge of SCK.
- The output data provided by the sensor is synchronized with the falling edges of SCK.
- The CSB input has a 120kΩ pull-up resistor to V_{DD}.

The SPI is used for regular reading of the acceleration signal coded on 10 bits. Periodically, an update of the digitalized temperature is also available (see the timing diagrams for a detailed description). For a complete readout of the acceleration, two successive read cycles are required because a maximum of 8 bits is readable within a cycle. A 10-bit coded signal is split into 7 MSB and 3 LSB.

The SPI interface is also used for the EEPROM programming/reading. Due to finite access time, the read cycle of an EEPROM byte needs two SPI cycles, in order to keep the standard protocol.

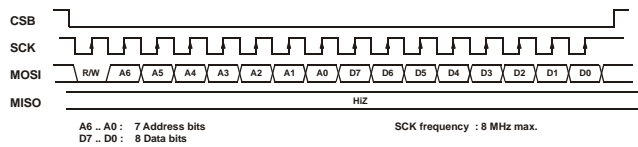
3.1 SPI Specification

Parameter	Symbol	Condition	Min	Typ	Max	Units
Clock input frequency	f _{SPI}		0.5		8	MHz
Capacitive load (MISO)	C _{SPI}	V _{DD} minimum			25	pF
Input-low level	V _{IL_SPI}				0.3* V _{DD}	V
Input-high level	V _{IH_SPI}		0.7*V _{DD}			V
Hysteresis of the inputs	V _{HYST_SPI}		0.1* V _{DD}			V
CSB pull-up resistor	R _{CSB}		70	120	190	kΩ

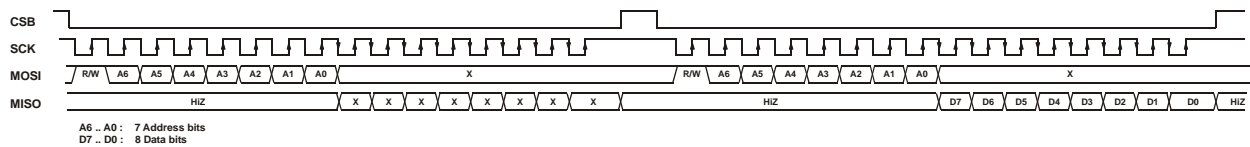
3.2 SPI Protocol

The used protocol corresponds to the standard SPI mode 3.

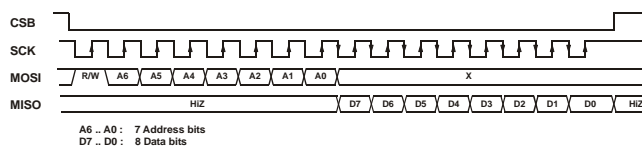
SPI Memory Write cycle description



SPI Memory Read cycle description (divided in two SPI cycles due to EEPROM read access time)



SPI Acceleration/Temperature Read cycle description

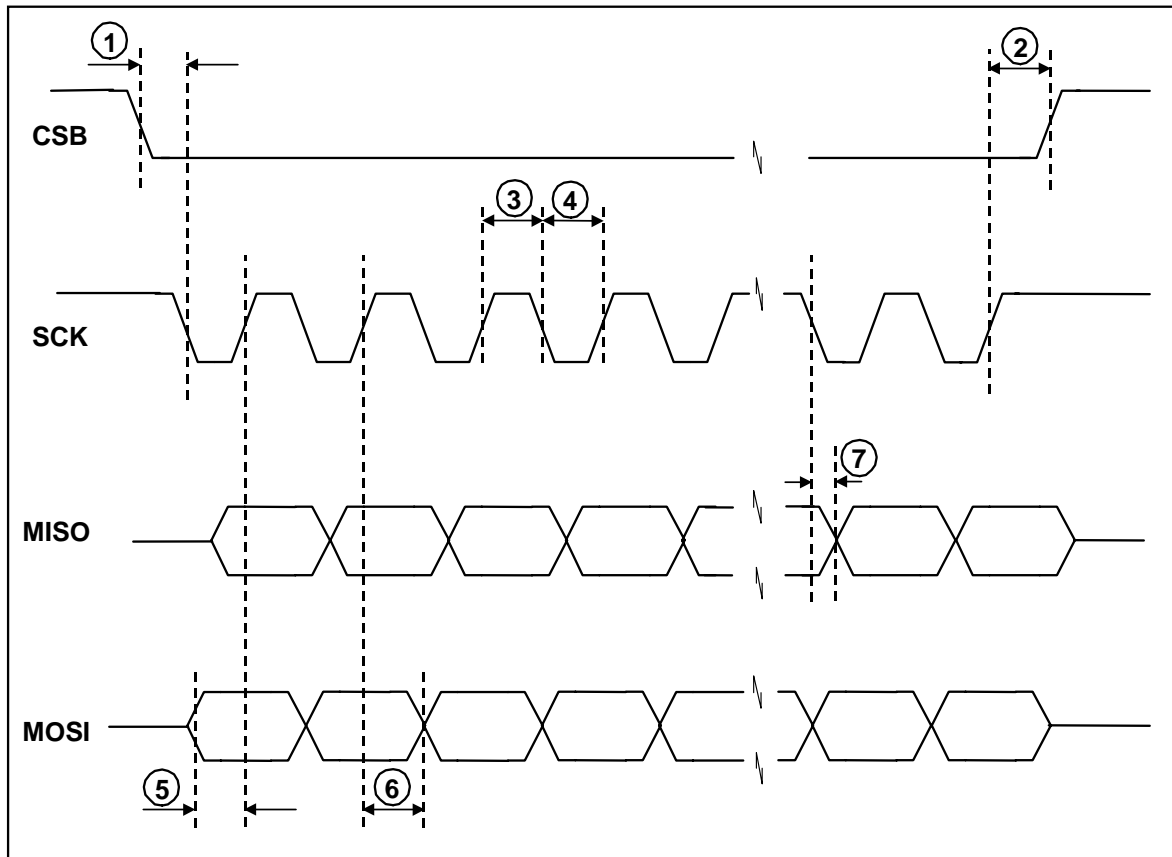


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Due to the standard 16-bit protocol, the digital codes for the acceleration values must be read by two successive SPI cycles. The user has to read the 7 MSB first and then the 3 LSB. It is also possible to read only the 7 MSB.

The 3 LSB are protected in such a way that during the read-out of the 7 MSB the LSB are not changed or updated. The update of the LSB does not take place before the MSB are read again. Therefore it cannot happen that a mixed acceleration value is read.

3.3 SPI Timing



#	Parameter	Symbol	Min	Units
1	CSB setup time	$t_{\text{setup_csb}}$	16	ns
2	CSB hold time	$t_{\text{hold_csb}}$	16	
3	SCK high period	$t_{\text{high_sck}}$	25	
4	SCK low period	$t_{\text{low_sck}}$	25	
5	MOSI setup time	$t_{\text{setup_mosi}}$	10	
6	MOSI hold time	$t_{\text{hold_mosi}}$	10	
7	MISO delay time	$t_{\text{valid_miso}}$	22	

4 Memory

4.1 EEPROM

An EEPROM is used to store the non-volatile data, calibration parameters and the current working modes. These are in detail

- g-range (2g or 10g)
- operation mode (full performance, low-power, standby)
- interrupt mode (global or independent)
- interrupt acceleration threshold and hysteresis level
- self test.

4.1.1 Register Arithmetic

The following arithmetics are used for memory registers.

Register	Format	Bit width
A _{X Y Z} (acceleration values)	2's complement	10
THRESHOLD (TH or TH_X Y Z)	unsigned positive	either 5 or 7
HYSTERESIS (HY or HY_X Y Z)	unsigned positive	either 3 or 7

4.2 Global Memory Mapping

The global memory mapping comprises EEPROM and latches.

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Reset	
40h - 7Fh									NA	
30h - 3Fh									-	
2Ch - 2Fh									NA	
2Bh	hy_Y(2)	hy_Y(1)	hy_Y(0)	th_Y(4)	th_Y(3)	th_Y(2)	th_Y(1)	th_Y(0)	00h	
2Ah	hy_Z(2)	hy_Z(1)	hy_Z(0)	th_Z(4)	th_Z(3)	th_Z(2)	th_Z(1)	th_Z(0)	00h	
29h	hy_X(2)	th(6) hy_X(1)	th(5) hy_X(0)	th(4)	th(3)	th(2)	th(1)	th(0)	NA	
28h	Oscillator trimming			Bandgap trimming					NA	
27h	Self Test	Sensor ID							NA	
26h	Int. mode	Operation mode + PROT							NA	
25h	2g / 10g								NA	
24h									NA	
23h									NA	
22h									NA	
21h									NA	
20h									NA	
1Fh	unused bits					A_Y (LSB)				00h
1Eh	A_Y (Current value of Z axis Acceleration) (MSB)								00h	
1Dh	unused bits					A_Z (LSB)				00h
1Ch	A_Z (Current value of Y axis Acceleration) (MSB)								00h	
1Bh	unused bits					A_X (LSB)				00h
1Ah	A_X (Current value of X axis Acceleration) (MSB)								00h	
10h-19h	unused addresses								NA	
0Fh									00h	
0Eh									00h	
0Dh									00h	
0Ch	reserved adress								NA	
0Bh									00h	
0Ah									00h	
09h									NA	
08h									00h	
07h									00h	
06h									00h	
05h									00h	
04h									00h	
03h									00h	
02h									00h	
01h									00h	
00h									00h	

EEPROM Protected	EEPROM	Read-only	Image
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The image registers are read-only. All EEPROM registers are duplicated into the corresponding image registers.

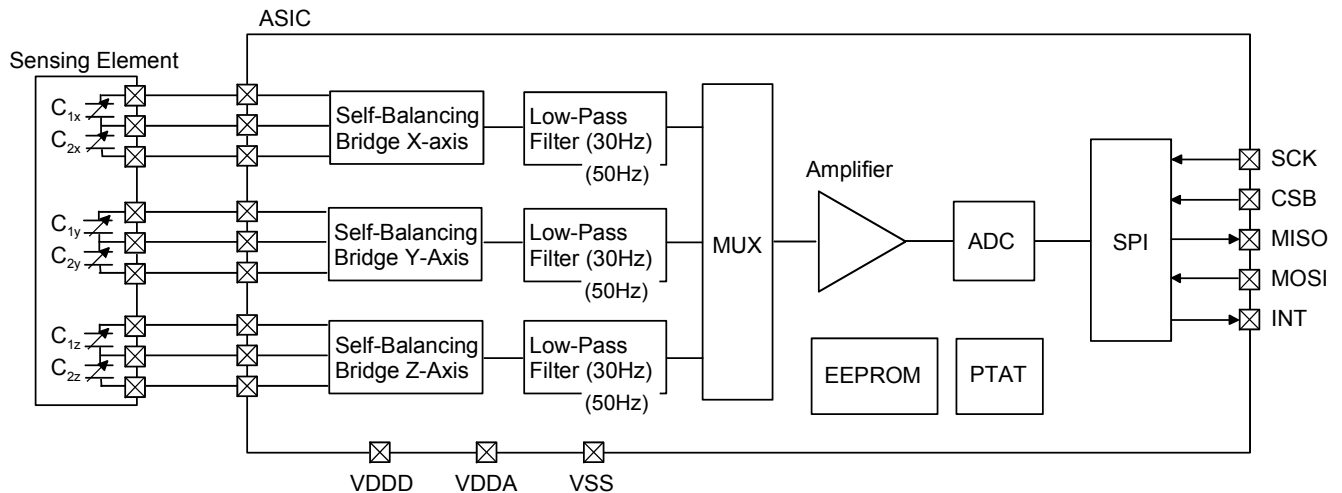
5 Operation

5.1 General Description

The SMB365 is a triaxial low-g acceleration sensor. It allows measurements of static as well as dynamic accelerations in all three dimensions. Due to its three perpendicular axes it gives the absolute orientation in a gravity field. The sensor is set up as a two-chip arrangement in a standard mold package. An application-specific IC evaluates the output of a three-channel micromechanical acceleration-sensing element that works according to the differential capacitance principle.

The ASIC is produced in a standard CMOS process. The production of the sensing element is based on standard semiconductor process steps followed by special steps providing the functional structure. These steps start with the deposition of a thick epitaxial layer on a sacrificial oxide. The large thickness allows the design of working capacitances of up to 1pF. This in turn enables the hybrid two-chip assembly. The poly layer is patterned by deep reactive ion etching in an inductive coupled plasma (DRIE-ICP, the so-called Bosch process). A large aspect ratio and a very high anisotropy is achieved by periodic passivation of the side walls in between the etch intervals. Afterwards the sacrificial layer is removed. Eventually the sensing element is hermetically sealed by a bulk micromachined cap to prevent damages of the structure by dicing, packaging and operation of the device. The encapsulation is performed in a cleanroom environment to reduce the risk of particle contamination to a minimum. Finally, the sensor is packaged in a standard surface mountable micro leadframe QFN housing. Here the ASIC is stacked onto the sensing element.

In the ASIC, three different so called self-balancing bridges convert the change of capacitances into voltages. These signals are preconditioned by first order 50Hz filters and then multiplexed, amplified and



converted into a digital output signal.

5.2 Operation Modes and Sensitivity Resolution

The sensor can be operated in three different modes:

- normal mode
- low-power mode
- standby mode.

The different modes are chosen via the SPI interface (see EEPROM mapping). In normal mode the sensor reaches its full performance. In the low-power (interrupt) mode the sensor is fully functional but

the performance is reduced. If the sensor is switched to standby, the ASIC enters a sleep mode. Only a part of the logic and the SPI block are active. All analog blocks including EEPROM are deactivated. The sensitivity resolution varies as follows:

Operation Mode	Sensitivity Resolution	Units
Normal	10	bit
Low-power (Interrupt)	7	
Standby	-	

10bit roughly corresponds to 4mg, 7bit to 30mg resolution.

Due to non-perfect decoupling, any SPI activity will perturb the A/D conversions. The best case is the absence of SPI activity during A/D conversion which is not possible all the time because of synchronization issues.

The A/D conversion for the acceleration signals about X-, Y-, Z-axis are performed sequentially. Therefore it is very unlikely that the A/D conversion of a given axis will be systematically perturbed by SPI activity because the duration of a SPI cycle is very short compared to an A/D conversion. Of course, this is only valid if there are not too many other peripherals on this SPI bus.

5.3 Interrupt Feature (Low Power Mode)

The sensor (slave) can inform the host system (master) about an acceleration change even if SPI communication is not taking place. This feature can be used as a “wake-up” for instance. It is working in both g-range modes (2g and 10g), but only in low-power mode. No interrupt is generated in normal mode and/or during SPI traffic.

In case of a certain acceleration change the sensor will send an interrupt signal (INT, active high) via the interrupt pin and will keep it up as long as the acceleration is larger than a certain hysteresis level.


Via SPI command it can be chosen between a global and a channel independent interrupt mode. In the global mode the same values for interrupt threshold and hysteresis level are valid for all three channels (both with 7 bit resolution, i.e. 16mg resolution in 2g-mode). In the independent mode these values can be chosen individually for each channel (interrupt 5 bit, hysteresis 3 bit resolution, i.e. 63mg/250mg resolution in 2g-mode).

The interrupt is activated when the acceleration signal (absolute value) in at least one of the channels exceeds its individual interrupt threshold (TH_X, TH_Y and TH_Z respectively) or the global interrupt threshold (TH) depending on the chosen interrupt mode. It is deactivated as soon as all channels fall (or still are) below their respective levels threshold levels minus their respective hysteresis values (individual: HY_X, HY_Y, HY_Z; global: HY).

As mentioned in the register arithmetic, all threshold and hysteresis values (TH_X, TH_Y, TH_Z, TH, HY_X, HY_Y, HY_Z and HY) are unsigned. The acceleration codes for the 3 channels A_X, A_Y and A_Z have a 2’s complement format and a coding on 10 bits. The MSB of the acceleration code gives the sign of the acceleration and the 9 LSB contain the information of the absolute acceleration value.

- Example of an interrupt generated by the X channel for the interrupt mode 1 (individual):

$$\text{INT is activated when } \text{ABS}(A_X) \geq 16 * \text{TH_X}$$

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INT is deactivated when $ABS(A_X) < 16*TH_X - 64*HY_X$
and no interrupt activation by the other channels

- Example of an interrupt generated by the X channel for the interrupt mode 0 (global):

INT is activated when $ABS(A_X) \geq 4*TH$

INT is deactivated when $ABS(A_X) < 4*TH - 4*HY$
and no interrupt activation by the other channels

Notice that $TH_X(4..2)$ is always larger than HY_X , i.e. $TH_X > 4*HY_X$. This is also valid for all other channels and the global values, where we have $TH > HY$ (both are coded on 7 bits). If the user does not respect this rule (for all channels) or as soon as one of the interrupt thresholds is set to 0, the interrupt is deactivated. The EEPROM registers dedicated to interrupt thresholds and hysteresis levels accept all code combinations which is required for storing the chip alignment error/cross axis sensitivity data.

If the user modifies any threshold and/or hysteresis value, the interrupt output is not updated immediately but only after a refresh of the acceleration codes.

Application Hints

Wake-Up:

A normal lifting of the sensor (like taking an object from a table) easily leads to acceleration gradients of $25g/s=100mg/4ms$ and to an amplitude of 500mg.

Zero-g/Free Fall Detection:

The interrupt can also be used for zero-g or free-fall detection. To this end 2g- and global interrupt mode have to be chosen and the output signal has to be interpreted as active low.

In case of a free fall all axes will experience zero-g. Therefore the interrupt threshold should be chosen close to 0 with the minimum hysteresis. The exact values depend on the application but a minimum value of ~100mg is required taking into account the 0g-offset tolerance and temperature drift:

In this case the interrupt will be at high level if the sensor is in normal use. Only in case of a free fall all 3 axes will experience accelerations smaller than 100mg and the output will switch to low level.

5.4 Acceleration Data Format

The description of the digital signal is "2's complement". From negative to positive accelerations, the following sequence for the $\pm 2g$ measurement range can be observed ($\pm 10g$ correspondingly):

```

-2.000g : 10 0000 0000
-1.996g : 10 0000 0001
...
-0.004g : 11 1111 1111
0.000g  : 00 0000 0000
+0.004g  : 00 0000 0001
...
+1.992g  : 01 1111 1110
+1.996g  : 01 1111 1111

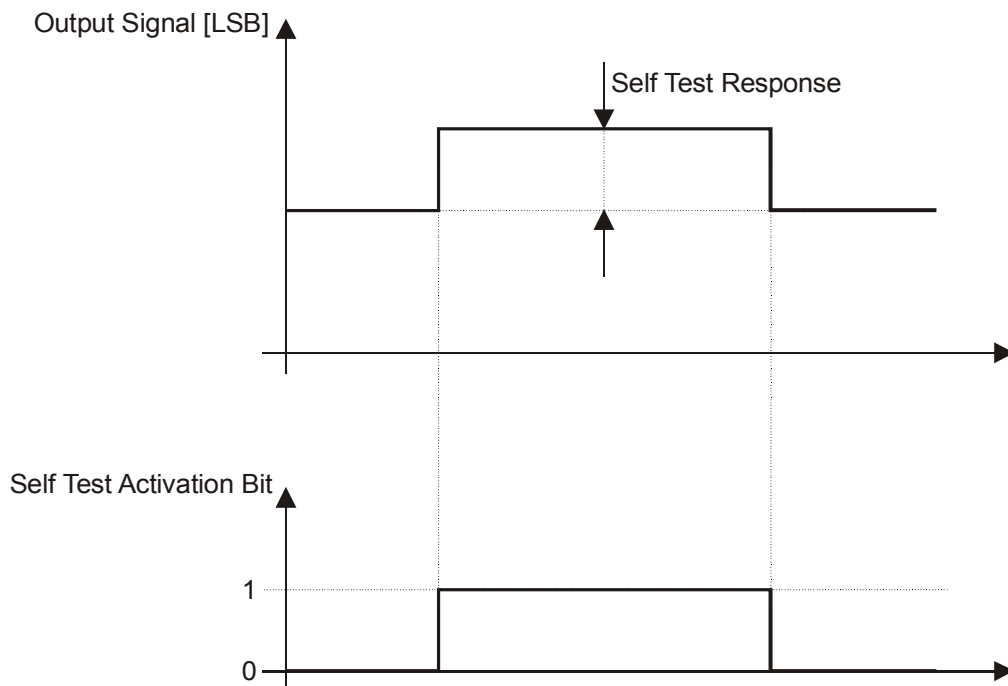
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5.5 Self Test

The sensor features an on-chip self-test which can be activated by changing the corresponding self test bit in the corresponding via SPI. The self test is realized by a physical deflection of the seismic mass due to an electrostatic force. Thus, it provides full testing of the complete signal evaluation path including the micromachined sensor structure and the evaluation ASIC.

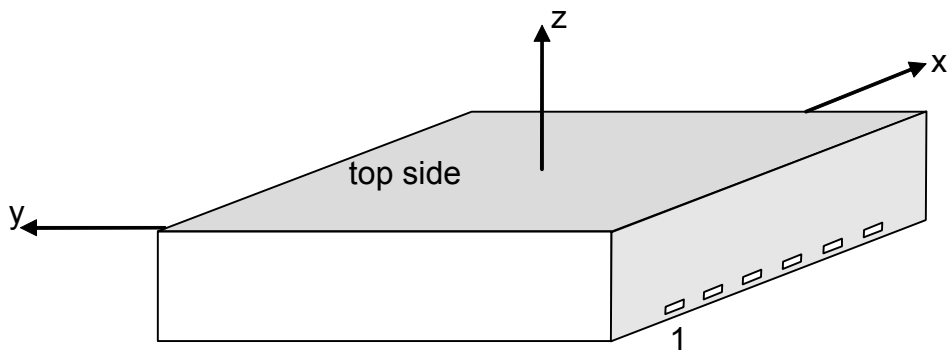
The self test is activated by setting the self test activation bit to 1. The test works in all measurement modes (2g, 10g, normal, low-power) and acts on all three channels simultaneously. The typical change in output will be 300LSB in the 2g-mode and 60LSB in the 10g-mode. The self test response remains as a static offset on the output as long as the self test register is not set back to 0.

While the self test is activated, any acceleration or gravitational force applied to the sensor will be observed in the output signal as a superposition of both acceleration and self test signal.

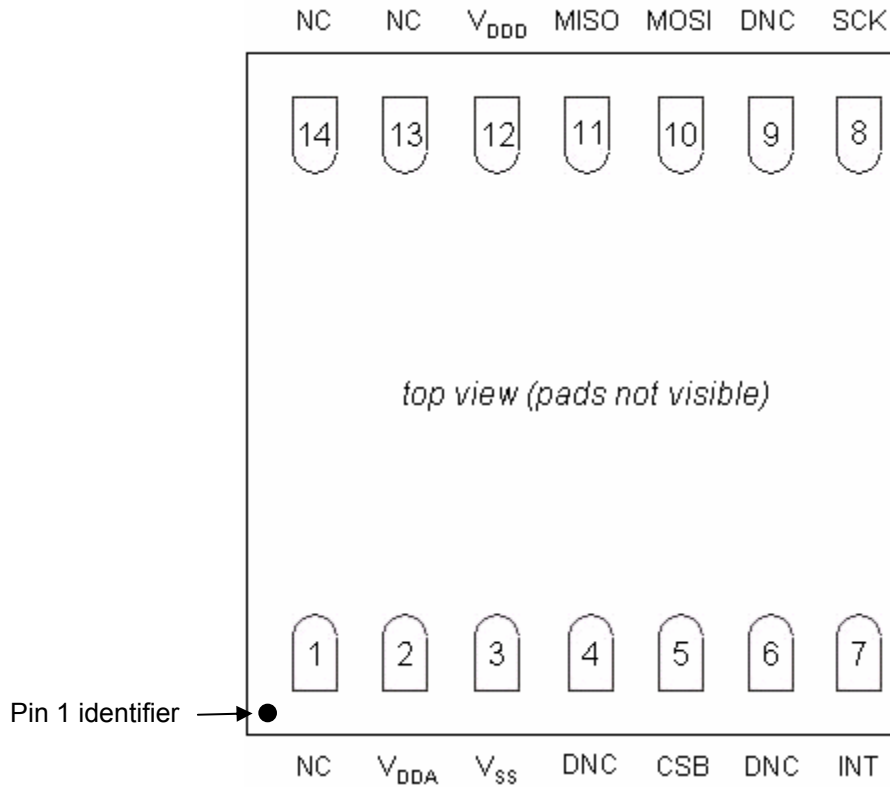


5.6 Polarity of the Acceleration Output

If the sensor is accelerated in the indicated directions, the corresponding channel will deliver a positive acceleration signal (dynamic acceleration). If the sensor is at rest and the force of gravity is working along the indicated directions, the output of the corresponding channel will be negative.



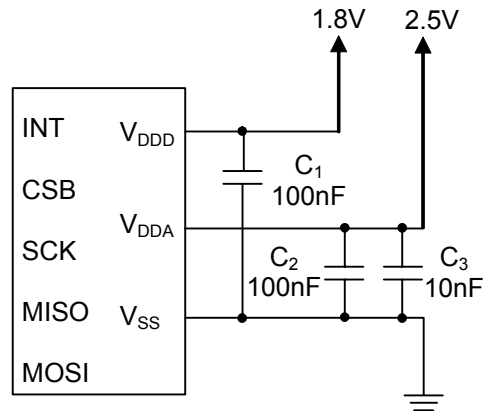
5.7 Pin Configuration



Pin No.	Name	Function
1	NC	not connected
2	V _{DDA}	ASIC analog core supply
3	V _{SS}	ASIC ground
4	DNC	do not connect
5	CSB	SPI select (chip select bar)
6	DNC	do not connect
7	INT	Interrupt output signal
8	SCK	SPI clock
9	DNC	do not connect
10	MOSI	SPI output (master out slave in)
11	MISO	SPI input (master in slave out)
12	V _{DDD}	ASIC digital core supply
13	NC	not connected
14	NC	not connected

5.8 Connecting Diagram

The following external components are recommended to decouple the power source.



5.9 Handling Instruction

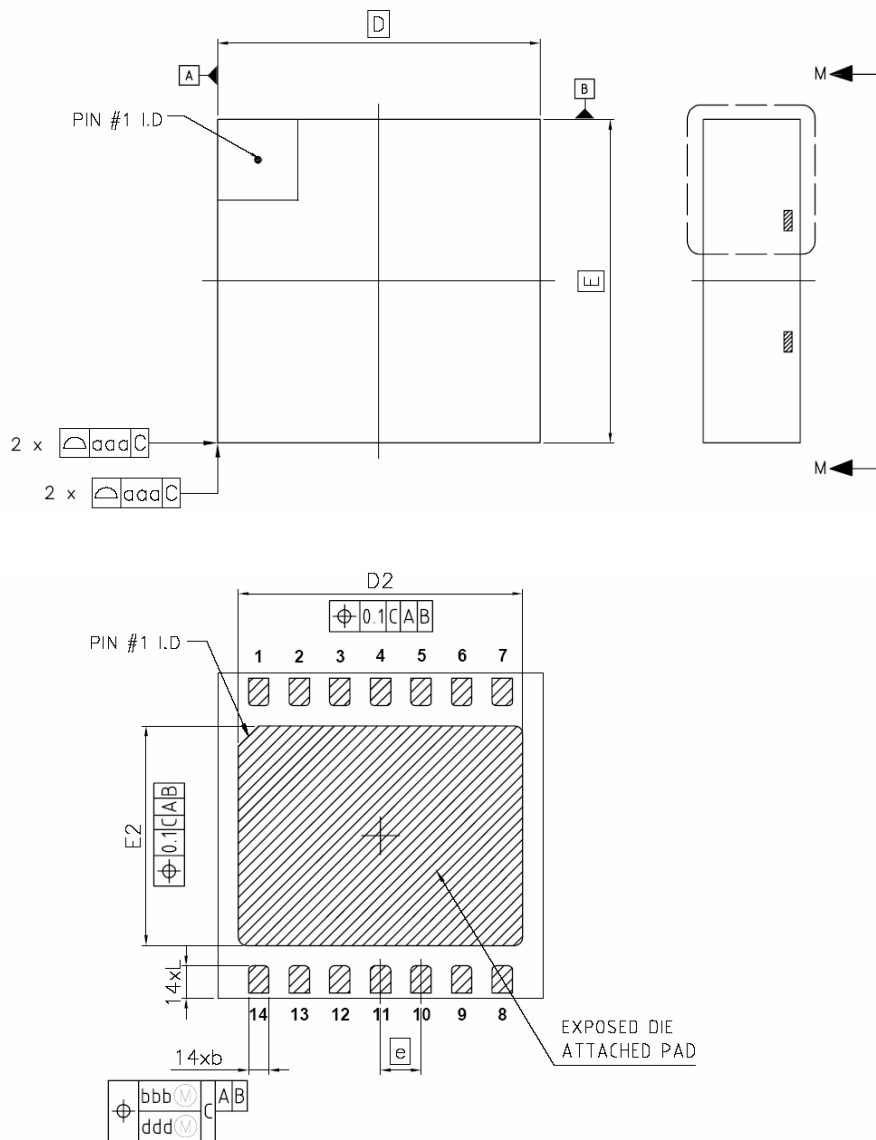
Micromechanical sensors are designed to sense acceleration with high accuracy even at low amplitudes and contain highly sensitive structures inside the sensor element. The micromachined sensors can tolerate mechanical shocks up to several thousand g's. However, these limits might be exceeded in conditions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

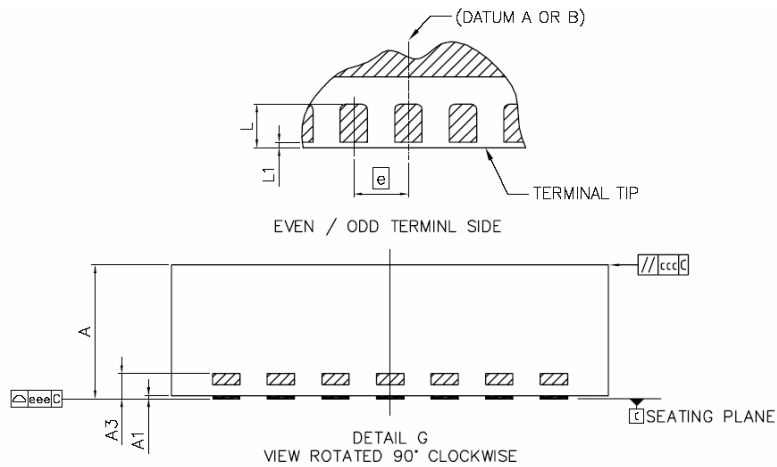
We recommend to avoid g-forces beyond the specified limits (see section 2) during transport, handling and mounting of the sensors in a defined and qualified installation process.

6 Package

6.1 Outline Dimensions

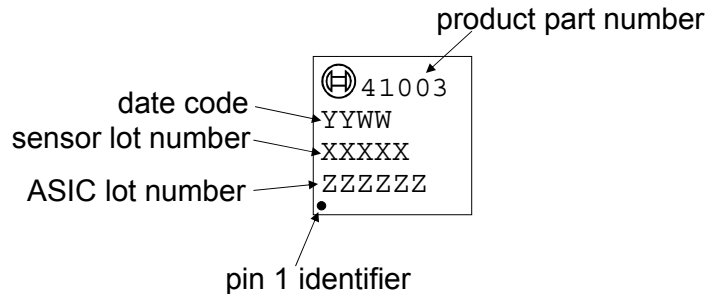
The sensor housing is a standard QFN package. It is compliant with JEDEC Standard MO-220. Its dimensions are the following:





DIM	MIN	NOM	MAX	NOTES
A	1.15	1.20	1.25	1.0 DIMENSIONING & TOLERANCEING CONFIRM TO ASME Y14.5M-1994. 2.0 ALL DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES. 3.0 DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25mm AND 0.30mm FROM TERMINAL TIP. DIMENSION L1 REPRESENTS TERMINAL FULL BACK FROM PACKAGE EDGE UP TO 0.1mm IS ACCEPTABLE. 4.0 COPLANARITY APPLIES TO THE EXPOSED HEAT SLUG AS WELL AS THE TERMINAL. 5.0 RADIUS ON TERMINAL IS OPTIONAL.
A1	0.00		0.05	
A3		0.203 REF		
b	0.20	0.25	0.30	
D		4.00 BSC		
E		4.00 BSC		
D2	3.40	3.50	3.60	
E2	2.60	2.70	2.80	
e		0.50 BSC		
L	0.35	0.40	0.45	
L1			0.10	
aaa		0.10		
bbb		0.10		
ccc		0.10		
ddd		0.05		
eee		0.08		

6.2 Marking



Engineering Samples are marked with the following symbol: *

6.3 Moisture Sensitivity Level and Soldering

The moisture sensitivity level of the SMB365 sensors corresponds to JEDEC Level 3, see also

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

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

6.4 RoHS Compliancy

The SMB365 sensor meets the requirements of the EC restriction of hazardous substances (RoHS) directive, see also

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

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7 Disclaimer

7.1 Engineering Samples

Engineering samples (marked with *) may not fulfill the complete technical data within this specification. As well, Engineering samples (marked with *) are not determined for use in safety relevant automotive applications, life support appliances reselling or passing to final consumers. The customer indemnifies Bosch Sensortec for product liability claims or waives of recourse to Bosch Sensortec, if third parties advance due to or in connection with a failure, a defect in function or misuse of the customer samples supplied by Bosch Sensortec.

7.2 Limiting values

Limiting values given are in accordance with the Absolute Maximum Ratings (Chapter 2). Stress above one or more of the limiting values may cause permanent damage to the device. Operation of the device at these or at any other conditions above is not implied. Exposure to limiting values for extended periods may also affect device reliability.

7.3 Life support- and automotive applications

The SMB365 is not designed for use in life support- or safety relevant automotive appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Again, the customer of Bosch Sensortec using or selling the SMB365 for use in such applications do so at one's own risk and agree again to fully indemnify Bosch Sensortec for any damages resulting from such improper use or sale.

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Document History and Modification

Rev. No	Chapter	Description of Modification/Changes	Name	Date
0.0				02-Feb-06
1.1	6.1 5.7	<ul style="list-style-type: none"> - New outline dimensions - New pin configuration 		27-Apr-06
1.11	7 5.7	Review <ul style="list-style-type: none"> - Disclaimer - Pin1 identifier 		27-May-06
1.2	1 4.2 5.7	Test signal z Memory Mapping Pin allocation		30-May-06

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 Version_1.2_062006