Triaxial ±2g/±10g Accelerometer SMB360

KEY FEATURES

- Three-axis accelerometer
- Switchable g-range (2g/10g)
- Standard SMD package: MLF 6x6mm^2 footprint, 1.45mm height
- 4mg resolution at 50Hz bandwidth
- Ultra-low power ASIC: 600µA at V_{DD} 2.5V
- SPI interface
- Interrupt feature for mobile wake-up or zero-g detection (free fall)
- Full self-test capability
- 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 SMB360 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 SMB360 provides a digital 10bit output signal in SPI format. Via 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 is 500µg/√Hz leading to a sensitivity resolution of 4mg or an accuracy of 0.3° in an inclination sensing application, respectively. The current consumption is typically 600µA 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 MLF package with a footprint of 6x6mm^2 and a height of 1.45mm.

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1 Specification

If not stated otherwise, the given values are maximum values over lifetime and full performance temperature range (-15 – +55°C) and voltage range (2.4 – 2.6V) in the normal operation mode.

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}	full performance	2.4	2.5	2.6	V
		operational	2.3	2.5	3.0	
Supply Voltage Digital	V_{DDD}	only for SPI I/O; $V_{DDD} \leq V_{DDA}$	1.6	1.8	3.0	V
Supply Current in Normal Mode	I_{DD}	digital and analog		600		μA
Supply Current in Low-Power Mode	I_{DDlpm}	digital and analog		500		μA
Supply Current in Standby Mode	I_{DDsbm}	digital and analog		5		μA
Operating Temperature	T_A	full performance	-15		+55	°C
		operational	-40		+85	
OUTPUT SIGNAL						
Sensitivity	S_{2g}	g-range 2g		256		LSB/g
	S_{10g}	g-range 10g		51.2		LSB/g
Zero-g Offset	Off	T_A=25°C		±10		LSB
Zero-g Offset Temperature Drift	TCO	-15°C ≤ T_A ≤ +55°C		±5		LSB
Bandwidth	f_{-3dB}	1st order filter		50		Hz
Nonlinearity	NL	best fit straight line		±0.5		%FS
Self Test Response	TST	activated via SPI: 2g		210		LSB
		activated via SPI: 10g		42		
NOISE PERFORMANCE						
Spectral Density	n_{SD}	rms		0.5		mg/√Hz

MECHANICAL CHARACTERISTICS Cross Axis Sensitivity	$\overline{S}$	relative contribution between 3 axes			0.5	%

2 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 ≤ 50μs		10,000	g
	duration ≤ 1.0ms		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_{DDD}.

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. 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.

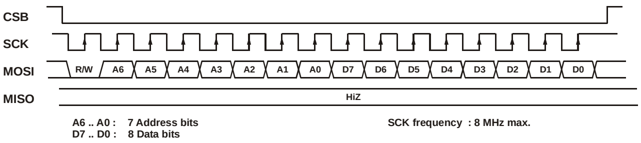
3.1 SPI Specification

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

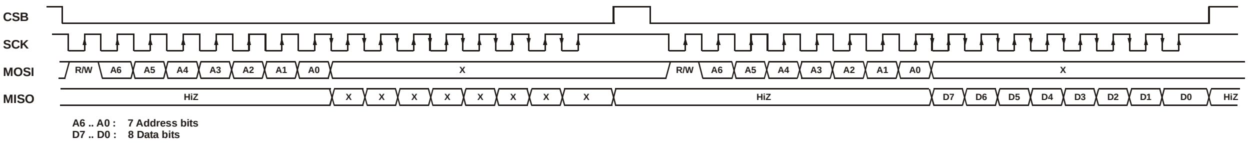
3.2 SPI Protocol

The used protocol corresponds to the standard SPI mode 3.

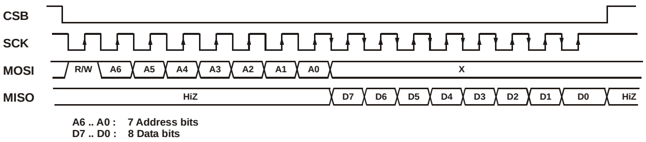
SPI Memory Write cycle description



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 fo 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.

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

- internal oscillator adjustment (ASIC)
- bandgap voltage reference (ASIC)
- gain or sensitivity, respectively
- 0g offset
- correction value of offset temperature drift
- chip alignment error/cross axis sensitivity
- 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 Mapping

The EEPROM contains all calibration/trimming parameters. All parameters are accessible through the SPI interface with a standard SPI protocol.

- ±2g / ±10g : Range selection (1=”±10g” full range, **0**=”±2g” full range [default value]) (1 bit)
- Operation mode + PROT : Selection of the operation mode (00=”normal mode” [default value], 01=”low power mode”, 10=”stand-by mode”, 11=”enable writing of trimming parameters” [protection mode activated]) (2 bits)
- Interrupt mode : Definition of the interrupt mode (**0** = “Global interrupt threshold (1x7bits) and global hysteresis value (1x7bits) common to the 3 channels [default value],
  1 = “Independent interrupt threshold (3x5bits) and independent hysteresis value (3x3bits) for X, Y and Z)
- th X : Interrupt threshold for X axis (5 bits)
- th Y : Interrupt threshold for Y axis (5 bits)
- th Z : Interrupt threshold for Z axis (5 bits)
- th : Global interrupt threshold common to X, Y and Z (7 bits)
- hy X : Hysteresis value for interrupt debouncing of the X axis (3 bits)
- hy Y : Hysteresis value for interrupt debouncing of the Y axis (3 bits)
- hy Z : Hysteresis value for interrupt debouncing of the Z axis (3 bits)
- hy : Hysteresis value for global interrupt debouncing (7 bits) The bits of each parameter are stored from the LSB to the MSB by increasing address.

The logic communicates with the EEPROM. A register working as buffer is used to for reading and writing a content from/to EEPROM. For all working modes, the global EEPROM content is stored in latches. They are refreshed after RESET and POR (Power-On Reset) signal. After writing a new value into a byte of the EEPROM, the corresponding latches are also updated.

After a memory-writing cycle via SPI, the next SPI command should not occur before a 20ms-delay. If an SPI command is sent before, it will be ignored.

The memory-reading cycle via SPI is separated into 2 sub-cycles, separated by 10µs due to the non-zero access time. The EEPROM content can also be read indirectly from the latches (images of the EEPROM). In this case, only one SPI cycle is required.

4.1.2 Register Arithmetic

The following arithmetics are used for memory registers.

Register	Format	Bit width
$A_{X\|Y\|Z}$	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	reset (any value read or written to these addresses causes reset of the device)								NA
30h - 3Fh	address space for testing registers								-
2Ch - 2Fh	unused addresses								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(6) hy_Z(1)	hy(5) hy_Z(0)	hy(4) th_Z(4)	hy(3) th_Z(3)	hy(2) th_Z(2)	hy(1) th_Z(1)	hy(0) th_Z(0)	00h
29h	hy_X(2)	th(6) hy_X(1)	th(5) hy_X(0)	th(4) th_X(4)	th(3) th_X(3)	th(2) th_X(2)	th(1) th_X(1)	th(0) th_X(0)	NA
28h									NA
27h	Self Test								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	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
0Ah	hy_Z(2)	hy(6) hy_Z(1)	hy(5) hy_Z(0)	hy(4) th_Z(4)	hy(3) th_Z(3)	hy(2) th_Z(2)	hy(1) th_Z(1)	hy(0) th_Z(0)	00h
09h	hy_X(2)	th(6) hy_X(1)	th(5) hy_X(0)	th(4) th_X(4)	th(3) th_X(3)	th(2) th_X(2)	th(1) th_X(1)	th(0) th_X(0)	NA
08h									00h
07h	Self Test								00h
06h	Int. mode	Operation mode + PROT							00h
05h	2g / 10g								00h
04h									00h
03h									00h
02h									00h
01h									00h
00h									00h

EEPROM Protected	EEPROM	Read-only	Image

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

5 Operation

5.1 General Description

The SMB360 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 mircromachined 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 MLF 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.

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 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 then 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 theses 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):

INT is activated when ABS(A_X) ≥ 16*TH_X

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) ≥ 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.

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 ±2g measurement range can be observed (±10g correspondingly):

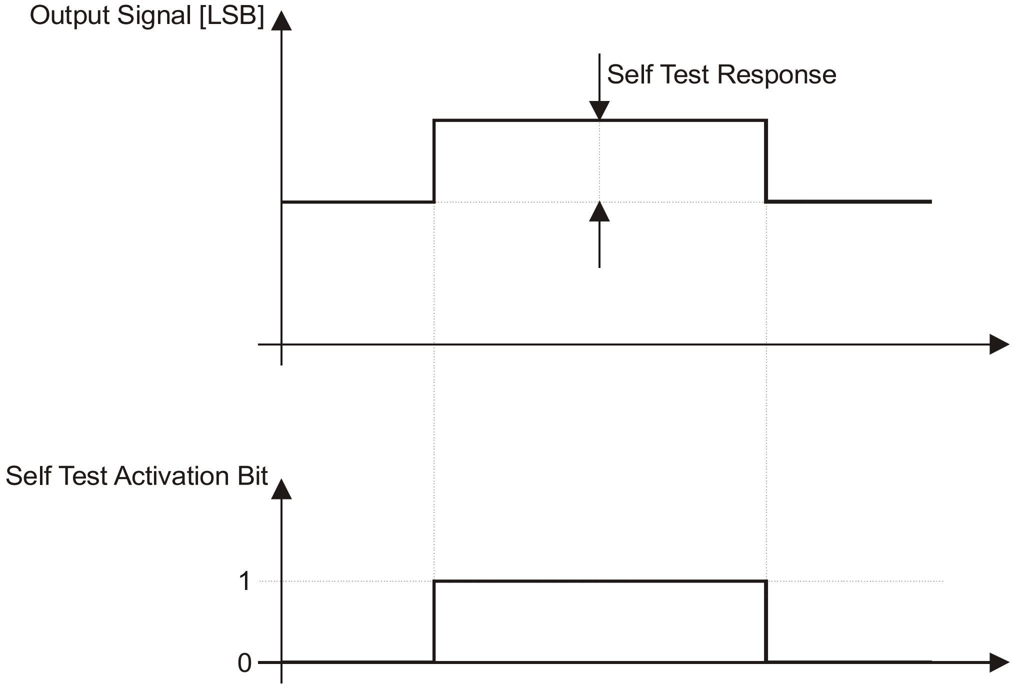
-2.000g : 10 0000 0000
-1.996g : 10 0000 0001
...
-0.004g : 11 1111 1111
0.000g : 00 0000 0000
+0.004g : 00 0000 0001
...
+1.992g : 01 1111 1110
+1.996g : 01 1111 1111

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.

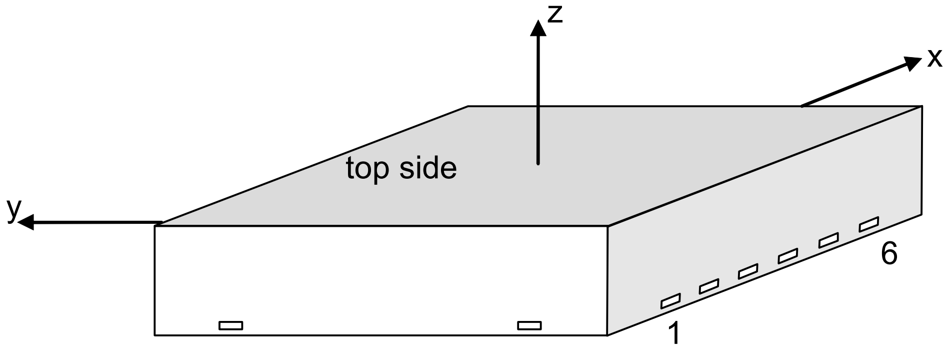
The self test is activated by setting the self test activation bit to 1. The test works in all measurement modes (2g, 10g, normal, low-power) and acts on all three channels simultaneously. The typical change in output will be 210LSB in the 2g-mode and 42LSB in the 10g-mode. The self test response remains 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.

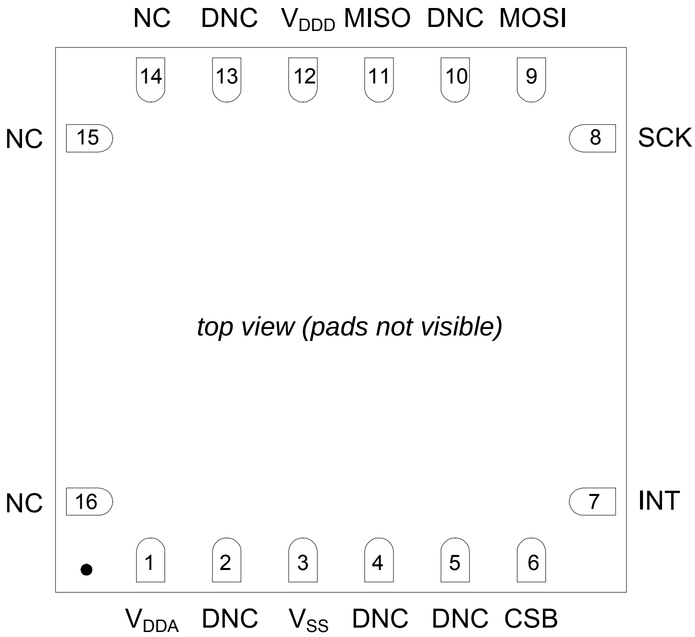


5.6 Polarity of the Acceleration Output

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.



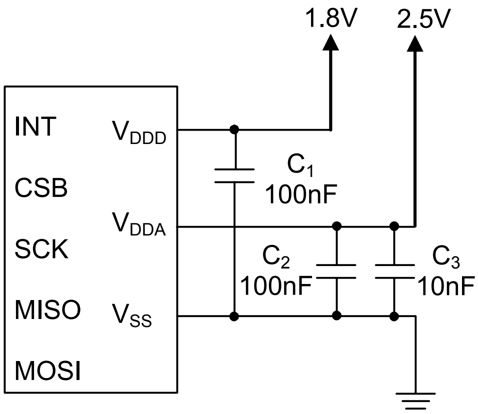
5.7 Pin Configuration



Pin No.	Name	Function
1	V_{DDA}	ASIC analog core supply
2	DNC	Do not connect (L/F suspended in package)
3	V_{SS}	ASIC ground
4	DNC	Pin only for factory use
5	DNC	Do not connect (L/F suspended in package)
6	CSB	SPI select (chip select bar)
7	INT	Interrupt output signal
8	SCK	SPI clock
9	MOSI	SPI output (master out slave in)
10	DNC	Do not connect (L/F suspended in package)
11	MISO	SPI input (master in slave out)
12	V_{DDD}	ASIC digital core supply
13	DNC	Do not connect (L/F suspended in package)
14	NC	Not connected inside package
15	NC	Not connected inside package
16	NC	Not connected inside package

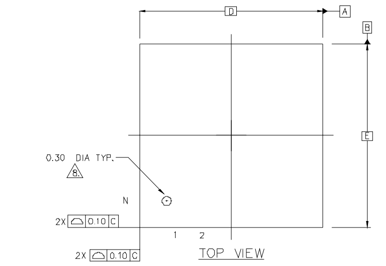
5.8 Connecting Diagram

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


1.8V
2.5V
INT
CSB
SCK
MISO
MOSI
V_DDD
V_DDA
V_SS
C1
100nF
C2
100nF
C3
10nF

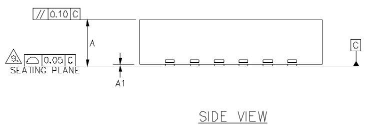
6 Package Outline Dimensions

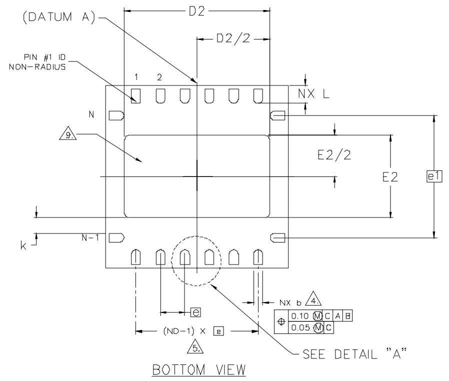
The sensor housing is a standard MLF package. It is compliant with JEDEC Standard MO-220. Its dimensions are the following:

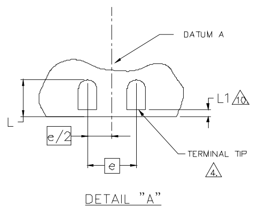


NOTES :

1. DIMENSIONING AND TOLERANCING CONFORM TO ASME Y14.5M. – 1994.
2. ALL DIMENSIONS ARE IN MILLIMETERS, θ IS IN DEGREES.
3. N IS THE TOTAL NUMBER OF TERMINALS.
4. DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.30mm FROM TERMINAL TIP. IF THE TERMINAL HAS THE OPTIONAL RADIUS ON THE OTHER END OF THE TERMINAL, THE DIMENSION b SHOULD NOT BE MEASURED IN THAT RADIUS AREA.
5. ND AND NE REFER TO THE NUMBER OF TERMINALS ON D AND E SIDE RESPECTIVELY.
6. MAX. PACKAGE WARPAGE IS 0.05 mm.
7. MAXIMUM ALLOWABLE BURRS IS 0.076 mm IN ALL DIRECTIONS.
8. PIN #1 ID ON TOP WILL BE LASER MARKED.
9. BILATERAL COPLANARITY ZONE APPLIES TO THE EXPOSED HEAT SINK SLUG AS WELL AS THE TERMINALS.
10. A MAXIMUM 0.15mm PULL BACK (L1) MAYBE PRESENT.







SYMBOL	MIN.	NOM.	MAX.	NOTE
e		0.80 BSC		
e1		4.00 BSC		
N		16		3
ND		6		5
NE		2		5
L	0.55	0.60	0.65	
b	0.25	0.30	0.35	4
D2	4.65	4.75	4.85	
E2	2.60	2.70	2.80	
D		6.00 BSC		
E		6.00 BSC		
A	1.40	1.45	1.50	
A1	0.00	0.02	0.05	
L1		0.15 MAX.		10
θ	0	——	12	2
K		0.20 MIN.		