



# Low Cost $\pm 1.5g$ Single/Dual Axis Accelerometer

## PRELIMINARY TECHNICAL DATA

ADXL103/203

### FEATURES

Single/Dual Axis Accelerometer on a Single IC Chip

5mm x 5mm x 2mm LCC Package

1mg Resolution at 60Hz

Low power:  $< 700\mu A$  at  $V_{DD}=5V$

High zero g bias stability and sensitivity accuracy

X and Y axes aligned to within  $0.1^\circ$  (typical)

BW Adjustment with a Single Capacitor

Single Supply Operation

3500g Shock Survival

### APPLICATIONS

Vehicle Dynamic Control

Alarms and motion detectors

High accuracy, 2 Axis tilt sensing with faster response than electrolytic, mercury or thermal sensors

Navigation

Platform stabilization

Electronic chassis control

### GENERAL DESCRIPTION

The ADXL103/203 are high precision, low power, complete single and dual axis accelerometers with signal conditioned voltage outputs, all on a single monolithic IC. The ADXL103/203 will measure acceleration with a full-scale range of  $\pm 1.7g$  (typical). The ADXL103/203 can measure both dynamic acceleration (e.g. vibration) and static acceleration (e.g. gravity).

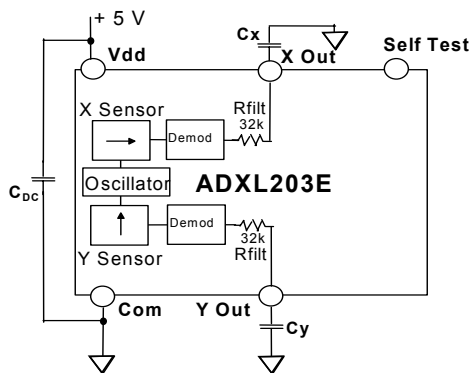
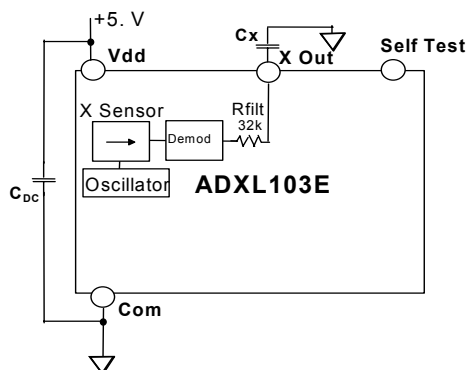


The outputs are analog voltages proportional to acceleration (1V/g). Innovative design techniques are used to ensure high zero g bias accuracy ( $\pm 25mg$  typical), and stability (typically better than  $0.1mg/^\circ C$ ), as well as tight sensitivity accuracy ( $\pm 6\%$ ), and stability (typically better than 50PPM/ $^\circ C$ ).

The typical noise floor is  $150\mu g/\sqrt{Hz}$  allowing signals below 1mg ( $0.06^\circ$  of inclination) to be resolved in tilt sensing applications using narrow bandwidths ( $< 10Hz$ ).

The user selects the bandwidth of the accelerometer using capacitors  $C_x$  and  $C_y$  at the  $X_{OUT}$  and  $Y_{OUT}$  pins. Bandwidths of 1Hz to 2KHz may be selected to suit the application.

The ADXL103/203 are available in 5mm x 5mm x 2mm 8 pad hermetic LCC package.



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One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.

Tel: 781.329.4700

[www.analog.com](http://www.analog.com)

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# PRELIMINARY TECHNICAL DATA

# ADXL103/203

## ABSOLUTE MAXIMUM RATINGS\*

Acceleration (Any Axis, Unpowered for 0.5ms)	3500g
Acceleration (Any Axis, Powered for 0.5ms)	3500g
Drop test (concrete)	1.2m
+Vs	-0.3V to +6.0V
Output Short Circuit Duration, (any pin to common)	Indefinite
Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C

\*Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only; the functional operation of the device at these or any other conditions above those indicate in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## CAUTION

ESD (electrostatic discharge) sensitive device.

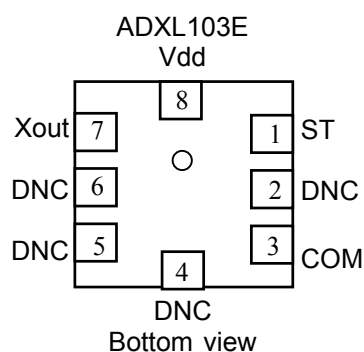
Shocks of greater than 3,500g exceed the absolute maximum rating of the device. Care should be exercised in handling to avoid damage.

## Package Characteristics

Package	ThetaJA	ThetaJC	Device Weight
8 pin LCC	tbd C/W	tbd C/W	<1.0 grams

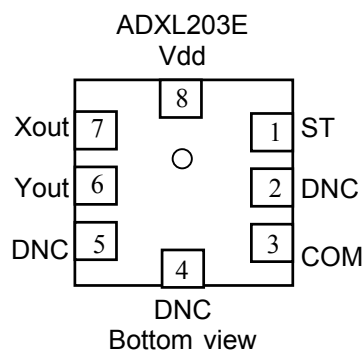
## Ordering Guide

Model	# Axes	Specified Voltage	Temperature Range
ADXL103BE-Reel	1	+5V	-40°C to +125°C
ADXL203BE-Reel	2	+5V	-40°C to +125°C



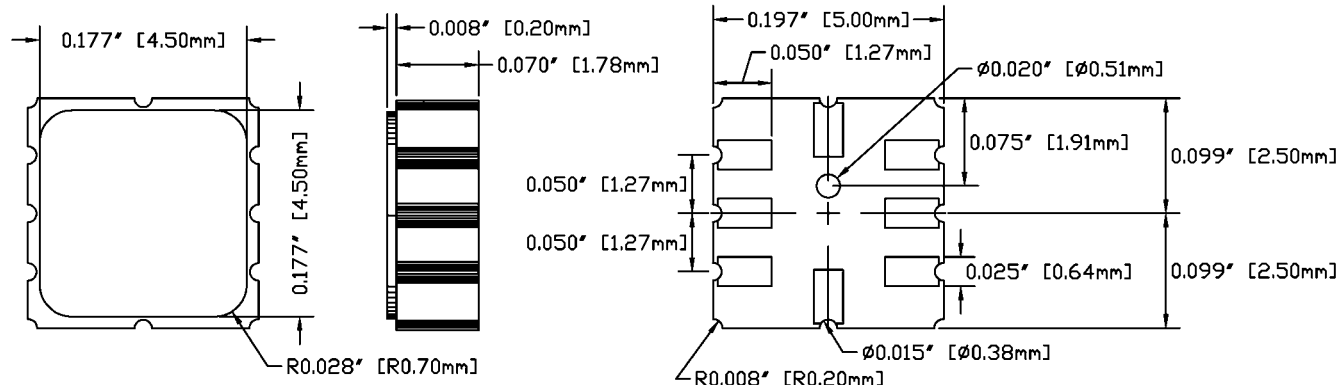
## ADXL103 PIN DESCRIPTION

Pin	Name	Description
1	ST	Self Test
2	DNC	Do not connect
3	COM	Common
4	DNC	Do not connect
5	DNC	Do not connect
6	DNC	Do not connect
7	X <sub>OUT</sub>	X channel output
8	Vdd	+5V



## ADXL203 PIN DESCRIPTION

Pin	Name	Description
1	ST	Self Test
2	DNC	Do not connect
3	COM	Common
4	DNC	Do not connect
5	DNC	Do not connect
6	Y <sub>OUT</sub>	Y channel output
7	X <sub>OUT</sub>	X channel output
8	Vdd	+5V



## ADXL103/203-SPECIFICATIONS

(TA = -40 to +125°C, Vs=+5V ±5%, Cx = Cy = 0.1µF, Acceleration = 0g, unless otherwise noted)

Parameter	Conditions	ADXL103/203BE			Units
		Min	Typ	Max	
<b>SENSOR</b>	Each axis				
Full Scale Range <sup>1</sup>		±1.5	±1.7		g
Nonlinearity <sup>2</sup>			±0.5	±2.5	%
Package Alignment Error			±1		degree
Alignment Error (ADXL203)	X sensor to Y sensor		0.1		degrees
Cross Axis Sensitivity			±2	±5	%
<b>SENSITIVITY (ratiometric)<sup>3</sup></b>	Each axis				
Sensitivity	Vs=+5.0V	940	1000	1060	mV/g
Sensitivity Drift Over Temperature	Vs=+5.0V		±0.3		%
<b>ZERO g BIAS LEVEL (ratiometric)</b>	Each axis				
Initial Zero g Output Deviation From Ideal	@25°C, Vs=+5.0V		±25		mg
Zero g Drift Over Temperature			±0.1		mg/°C
Zero g Voltage	Vs=+5.0V	2.40	2.5	2.60	V
<b>NOISE PERFORMANCE</b>					
Output Noise	<4KHz, Vs=+5.0V, @25°C			6	mV RMS
Noise Density	@ 25°C		150		ug/Root Hz RMS
<b>FREQUENCY RESPONSE<sup>4</sup></b>					
Sensor Resonant Frequency	@25°C, Vs=+5.0V		5.5		kHz
Cx, Cy Range <sup>5</sup>		0.002		4.7	µF
Rfilt Tolerance	32k Ohm Nominal	22	32	42	kΩ
<b>SELF TEST<sup>6</sup></b>	Vs=+5.0V				
Logic Input Low				1	V
Logic Input High		4			V
Output Change (at Xout and Yout)	Self Test Input "Low to High"	500	800	1500	mV
Input resistance to Ground		30	50		kΩ
<b>Output Amplifier</b>					
Output Swing Low	No Load		0.5		V
Output Swing High	No Load		4.5		V
<b>POWER SUPPLY</b>					
Functional Voltage Range		3.00		6.00	V
Supply Current			0.7	1.1	mA
Turn on time <sup>7</sup>	Cx, Cy = 0.01µF		10		mS

## Notes

<sup>1</sup> Guaranteed by measurement of initial offset and sensitivity<sup>2</sup> % of input (i.e. 5mg at 1g input typically)<sup>3</sup> Sensitivity is ratiometric to Vs. For Vs=4.75 to 5.25V sensitivity is 184 to 216mV/V/g<sup>4</sup> Actual frequency response controlled by user supplied external capacitor (Cx, Cy)<sup>5</sup> Bandwidth =  $1/(2\pi \cdot 32k\Omega \cdot C)$ . For Cx, Cy=0.002µF, bandwidth=2000Hz. For Cx, Cy=4.7µF, bandwidth=1Hz. Minimum/maximum values are not tested.<sup>6</sup> Self test response changes cubically with Vs.<sup>7</sup> Larger values of Cx, Cy will increase turn on time. Please see application section on power cycling.

Typical specifications are not guaranteed

## THEORY OF OPERATION

The ADXL103/203 are complete, acceleration measurement systems on a single monolithic IC. The ADXL103 is a single axis accelerometer, while the ADXL203 is a dual axis accelerometer. They contain a polysilicon surface-micromachined sensor and signal conditioning circuitry to implement an open loop acceleration measurement architecture. The output signals are analog voltage proportional to acceleration. The ADXL103/203 is capable of measuring both positive and negative accelerations to at least  $\pm 1.5g$ . The accelerometer can measure static acceleration forces such as gravity, allowing it to be used as a tilt sensor.

The sensor is a surface micromachined polysilicon structure built on top of the silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and central plates attached to the moving mass. The fixed plates are driven by  $180^\circ$  out of phase square waves. Acceleration will deflect the beam and unbalance the differential capacitor, resulting in an output square wave whose amplitude is proportional to acceleration. Phase sensitive demodulation techniques are then used to rectify the signal and determine the direction of the acceleration.

The output of the demodulator is amplified and brought off-chip through a  $32k\Omega$  resistor. At this point the user can set the signal bandwidth of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing.

## Performance

Rather than using additional temperature compensation circuitry, innovative design techniques have been used to ensure high performance is built in. As a result there is essentially no quantization errors or non-monotonic behavior, and temperature hysteresis is very low (typically less than  $10mg$  over the  $-40$  to  $+125^\circ C$  temperature range).

Figure 1 shows the zero g output performance of eight parts (X and Y axis) over a  $-40^\circ$  to  $+125^\circ C$  temperature range.

Figure 2 demonstrates the typical sensitivity shift over temperature for supply voltages of 2.5V to 6V. Sensitivity stability is optimized for  $V_{DD}=5V$ , but is still very good over the specified range.

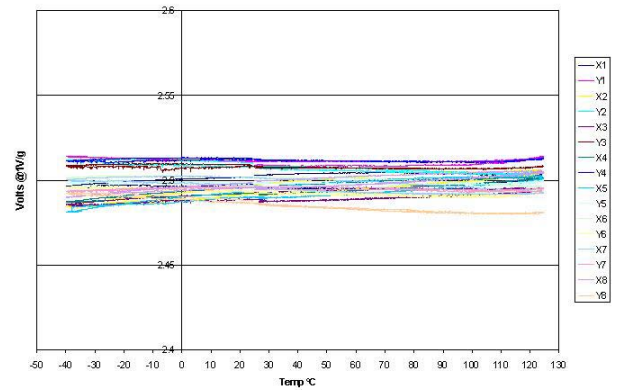


Figure 1. Zero g Output Drift Over Temperature

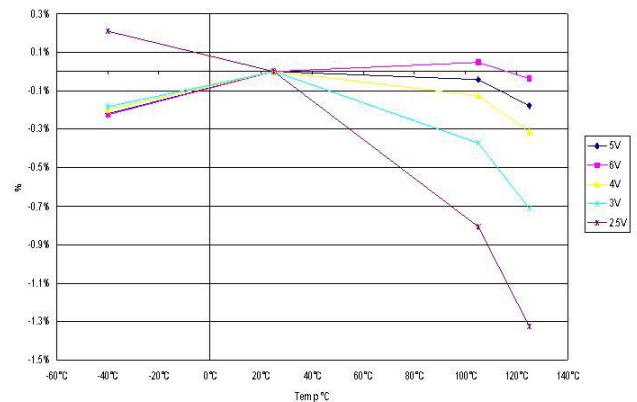


Figure 2. Sensitivity Shift Over Temperature

## APPLICATIONS

### POWER SUPPLY DECOUPLING

For most applications a single  $0.1 \mu F$  capacitor,  $C_{DC}$ , will adequately decouple the accelerometer from noise on the power supply. However, in some cases, particularly where noise is present at the  $140kHz$  internal clock frequency (or any harmonic thereof), noise on the supply may cause interference on the ADXL103/203 output. If additional decoupling is needed, a  $100\Omega$  (or smaller) resistor or ferrite bead, may be inserted in the supply line of the ADXL103/203. Additionally, a larger bulk bypass capacitor (in the  $1\mu F$  to  $4.7\mu F$  range) may be added in parallel to  $C_{DC}$ .

### Setting the Bandwidth Using $C_X$ and $C_Y$

The ADXL103/203 has provisions for band-limiting the  $X_{OUT}$  and  $Y_{OUT}$  pins. Capacitors must be added at these pins to implement low-pass filtering for anti-aliasing and noise reduction. The equation for the 3 dB bandwidth is:

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$$F_{-3db} = 1/(2\pi(32k\Omega) * C_{(x,y)})$$

or, more simply,

$$F_{-3db} = 5uF/C_{(x,y)}$$

The tolerance of the internal resistor ( $R_{FLT}$ ) can vary typically as much as  $\pm 15\%$  of its nominal value of 32 k $\Omega$ ; so the bandwidth will vary accordingly. A minimum capacitance of 1000 pF for  $C(X, Y)$  is required in all cases.

**Table I. Filter Capacitor Selection, CX and CY**

Capacitor	Bandwidth
10 Hz	0.47 $\mu$ F
50 Hz	0.10 $\mu$ F
100 Hz	0.05 $\mu$ F
200 Hz	0.027 $\mu$ F
500 Hz	0.01 $\mu$ F
5 kHz	0.001 $\mu$ F

## SELF TEST

The ST pin controls the self-test feature. When this pin is set to  $V_{DD}$ , an electrostatic force is exerted on the beam of the accelerometer. The resulting movement of the beam allows the user to test if the accelerometer is functional. The typical change in output will be 800mg (corresponding to 800mV). This pin may be left open circuit or connected to common in normal use.

## DESIGN TRADE-OFFS FOR SELECTING FILTER CHARACTERISTICS: THE NOISE/BW TRADE-OFF

The accelerometer bandwidth selected will ultimately determine the measurement resolution (smallest detectable acceleration). Filtering can be used to lower the noise floor, which improves the resolution of the accelerometer. Resolution is dependent on the analog filter bandwidth at  $X_{OUT}$  and  $Y_{OUT}$ .

The output of the ADXL103/203 has a typical bandwidth of 2kHz. The user must filter the signal at this point to limit aliasing errors. The analog bandwidth must be no more than half the A/D sampling frequency to minimize aliasing. The analog bandwidth may be further decreased to reduce noise and improve resolution.

The ADXL103/203 noise has the characteristics of white Gaussian noise that contributes equally at all frequencies and is described in terms of  $\mu$ g per root Hz; i.e., the noise is proportional to the square root of

# ADXL103/203

the bandwidth of the accelerometer. It is recommended that the user limit bandwidth to the lowest frequency needed by the application, to maximize the resolution and dynamic range of the accelerometer.

With the single pole roll-off characteristic, the typical noise of the ADXL103/203 is determined by the following equation:

$$\text{RMS Noise} = (150\mu\text{g}/\sqrt{\text{Hz}}) * (\sqrt{\text{BW}} * 1.6)$$

For example, at 100 Hz the noise will be:

$$\text{Noise} = (150\mu\text{g}/\sqrt{\text{Hz}}) * (\sqrt{100} * 1.6) = 1.9\text{mg RMS}$$

Often the peak value of the noise is desired. Peak-to-peak noise can only be estimated by statistical methods. Table II is useful for estimating the probabilities of exceeding various peak values, given the RMS value.

The peak-to-peak noise value will give the best estimate of the uncertainty in a single measurement. Table III gives typical noise output of the ADXL103/203 for various  $C_X$  and  $C_Y$  values.

**Table II. Estimation of Peak-to-Peak Noise**

Peak-to-Peak Value	% of Time that Noise Will Exceed Nominal Peak-to-Peak Value
2 x RMS	32%
4 x RMS	4.6%
6 x RMS	0.27%
8 x RMS	0.006%

**Table III. Filter Capacitor Selection (CX, CY)**

Bandwidth	Cx, Cy	RMS Noise	Peak-to-Peak Noise Estimate
10Hz	0.47uF	0.6mg	3.6mg
50Hz	0.1uF	1.3mg	8mg
100Hz	0.047uF	1.9mg	11.4mg
500Hz	0.01uF	4.2mg	25mg

**Using the ADXL103/203 With Operating Voltages Other Than 5V**

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The ADXL103/203 is tested and specified at Vdd=5V, however it can be powered with Vdd as low as 3V or as high as 5.25V. Some performance parameters will change as the supply voltage is varied.

The ADXL103/203 output is ratiometric, so the output sensitivity (or scale factor) will vary proportionally to supply voltage. At Vdd=3V the output sensitivity is typically 560mV/g.

The zero g bias output is also ratiometric, so the zero g output is nominally equal to Vdd/2 at all supply voltages.

The output noise is not ratiometric, but absolute in volts. Therefore the noise density increases as the supply voltage decreases. This is because the scale factor (mV/g) decreases while the noise voltage remains constant.

Self-test response in g is roughly proportional to the square of the supply voltage. At Vdd=3V the self-test response will be approximately equivalent to 300mg (typical).

Supply current decreases as the supply voltage decreases. Typical current consumption at Vdd=3V is 500uA.

## USING THE ADXL203 AS A DUAL-AXIS TILT SENSOR

One of the most popular applications of the ADXL203 is tilt measurement. An accelerometer uses the force of gravity as an input vector to determine orientation of an object in space.

An accelerometer is most sensitive to tilt when its sensitive axis is perpendicular to the force of gravity, i.e. parallel to the earth's surface. At this orientation its sensitivity to changes in tilt is highest. When the accelerometer is oriented on axis to gravity, i.e., near its +1 g or -1 g reading, the change in output acceleration per degree of tilt is negligible. When the accelerometer is perpendicular to gravity, its output will change nearly 17.5 mg per degree of tilt, but at 45° degrees it is changing only at 12.2 mg per degree, and resolution declines.

## A DUAL AXIS TILT SENSOR: CONVERTING ACCELERATION TO TILT

When the accelerometer is oriented so both its X and Y axes are parallel to the earth's surface it can be used as a two axis tilt sensor with a roll and a pitch axis. Once

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the output signal from the accelerometer has been converted to an acceleration that varies between -1 g and +1 g, the output tilt in degrees is calculated as follows:

$$\text{Pitch} = \text{ASIN} (A_x/1 \text{ g})$$

$$\text{Roll} = \text{ASIN} (A_y/1 \text{ g})$$

Be sure to account for overranges. It is possible for the accelerometers to output a signal greater than ±1 g due to vibration, shock or other accelerations.