

ADXL76, ADXL269, **ADXL276**

FEATURES

Complete Acceleration Measurement System on a Single Monolithic IC

2-Pole Filter On-Chip

No External Components Required for Direct Interface to ADC or μ Controller

Complete Mechanical and Electrical Self-Test on Digital Command

Sensitivity and Offset Are Ratiometric to Supply 5 V Supply Voltage with Operation Down to 4 V

Sensitive Axes in the Plane of the Chip

Linearity (0.2% of Full-Scale)

DC Response

Low Noise ($1.0 \text{ mg}/\sqrt{\text{Hz}}$)

Low-Power Consumption (1.8 mA per Axis)

$\pm 35 \text{ g}$, $\pm 50 \text{ g}$ Ranges Available (for $\pm 125 \text{ g}$ or $\pm 50 \text{ g}$ Contact Factory)

Surface Mount Package Available

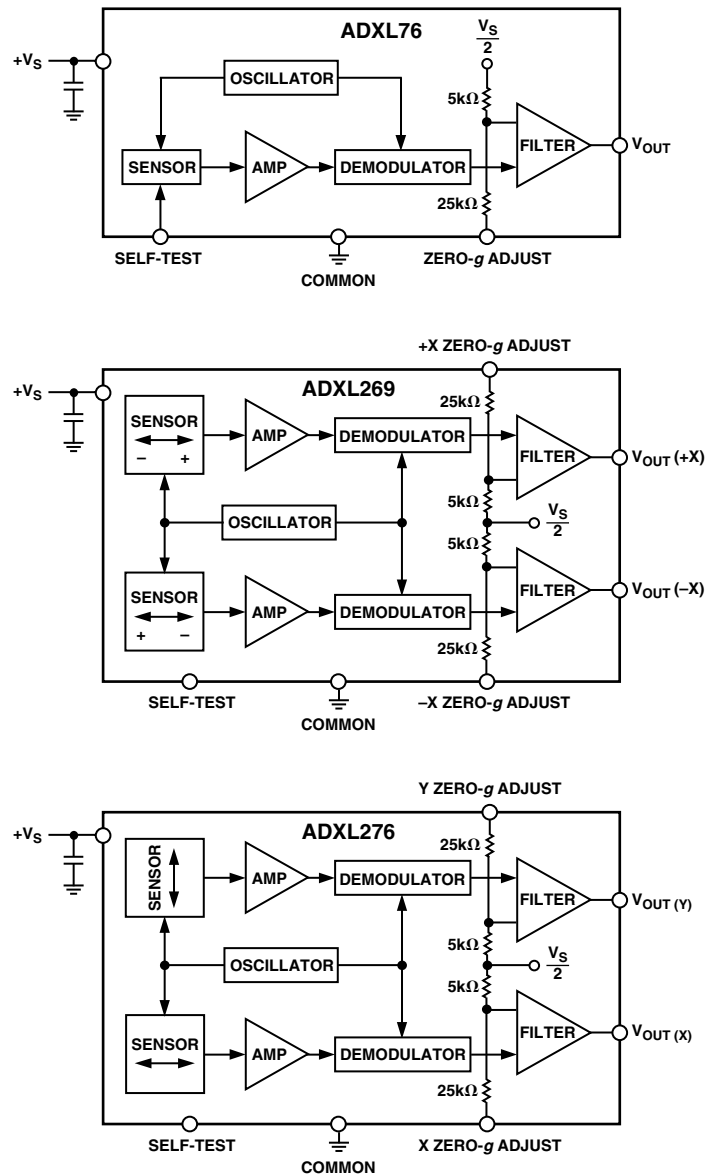
GENERAL DESCRIPTION

The ADXL76, ADXL276, and ADXL269 family of products are the third generation surface micromachined *i*MEMS accelerometers from Analog Devices with enhanced performance and lower cost. Designed for use in front and side impact airbag applications, these products also provide complete cost-effective solutions useful for a wide variety of other applications.

The ADXL276 is a monolithic two-axis (XY) version of the ADXL76 with the sensor axes orthogonal (90°) to each other and in the plane of the chip. It can be used for sensing crashes in the front or side of the vehicle and can be used to determine the angle of impact. The ADXL269 is a monolithic two-axis (+X/-X) version of the ADXL76 with the sensor axes arranged in anti-parallel orientation (180°) to provide redundancy and elimination of the need for an external mechanical safing/arming sensor.

The ADXL76, ADXL269, and ADXL276 are temperature stable and accurate over the automotive temperature range, with a self-test feature that fully exercises all the mechanical and electrical elements of the sensor with a digital signal applied to a single pin.

FUNCTIONAL BLOCK DIAGRAMS



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ADXL76, ADXL269, ADXL276—SPECIFICATIONS

(@ $T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$, $V_S = 5\text{ V} \pm 5\%$, Acceleration = 0 g; unless otherwise noted)

Parameter	Conditions	ADXLxxQx 18 ¹			ADXLxxQx 38 ¹			ADXLxxQx 55 ¹			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
SENSOR											
Guaranteed Full-Scale Range	ADXL76 Only, Offset Adjusted ² ADXL76 Only, Offset Adjusted	±115 ±105			±50 ±45			±35 ±30			g g g g
Nonlinearity					0.2						%
Package Alignment Error ³					±1						Degrees
Sensor-to-Sensor Alignment Error	ADXL276, ADXL269				0.1						Degrees
Transverse Sensitivity ⁴					±2						%
SENSITIVITY											
Sensitivity		18			38			55			mV/g
Sensitivity Tolerance ^{5,6}	Ratiometric				-8			+8			%
Temperature Drift	From 25°C to T_{MIN} to T_{MAX}				±0.5						%
ZERO-g OFFSET LEVEL											
Output Zero-g Voltage ^{6,7}	Offset from $V_S/2$	-198			-418			-605			mV
Temperature Drift	From 25°C to T_{MIN} to T_{MAX}	3.6			7.6			11			mV
ZERO-g ADJUSTMENT											
Voltage Gain	$\Delta V_{\text{OUT}}/\Delta V_{\text{ADJ PIN}}$				0.45			0.5			V/V
Input Resistance					20			30			kΩ
Input Resistor Network Ratio %:1								±0.1			%
NOISE PERFORMANCE											
Noise Density	10 Hz to Nominal Bandwidth	4			1			1			$\text{mg}/\sqrt{\text{Hz}}$
Clock Noise	See Figure 18	12			5			3			mV p-p
FREQUENCY RESPONSE											
-3 dB Frequency ⁸	Bandwidth Options: See Ordering Guide				-10			+10			%
Bandwidth Temperature Drift					20						Hz
Sensor Resonant Frequency	Q = 5				24						kHz
SELF-TEST⁹											
Output Change	@ 5 V	135			285			413			mV
Logic "1" Voltage		180			380			550			V
Logic "0" Voltage		270			570			825			V
Input Resistance	To GND				30			50			kΩ
OUTPUT AMPLIFIER											
Output Voltage Swing	$I_{\text{OUT}} = +100\ \mu\text{A}$ $I_{\text{OUT}} = -100\ \mu\text{A}$				$V_S - 0.25$			0.25			V
Capacitive Load Drive					1000						pF
POWER SUPPLY (V_S)											
Operating Voltage Range					4.75			5.25			V
Functional Voltage Range					4.0			6.0			V
Quiescent Supply Current	ADXL76, ADXL276, ADXL269				18			3			mA
					3.5			5			mA
TEMPERATURE RANGE¹⁰											
					-40			+85			°C

NOTES

¹For example: ADXLxxQx38 describes devices with a nominal sensitivity of 38 mV/g. See Ordering Guide for full part number.

²Trimmed at the factory to user specifications. May require 0-g adjust circuitry. Reference section on Zero-g Adjustment and Dynamic Range.

³Alignment error is specified as the angle between the true axis of sensitivity and the edge of the package.

⁴Transverse sensitivity is measured with an applied acceleration that is 90 degrees from the indicated axis of sensitivity.

⁵Ratiometric: $V_{\text{OUT}}(\text{accel}, V_S) = [V_S/2 \pm (a V_S/5\text{ V})] + [(\text{accel})(b V_S + c V_S^2)(1 \pm 0.08)]$ where a = offset range in volts. For a 38 mV/g sensor: $b = 5.725 \times 10^{-3}\text{ 1/g}$, $c = 0.375 \times 10^{-3}\text{ 1/g/V}$. (For a 55 mV/g sensor: $b = 8.284 \times 10^{-3}\text{ 1/g}$, $c = 0.542 \times 10^{-3}\text{ 1/g/V}$. See Figures 5 and 13. Spec includes temperature drift, life drift, and nonlinearity. Test conditions: 100 Hz, ±50 g for the 38 mV/g and 18 mV/g sensor; 100 Hz ± 35 g for the 55 mV/g sensor.

⁶Error included in full-scale range specification.

⁷Proportional to $V_S/2$. See Figures 6 and 19.

⁸Includes Temperature Drift.

⁹ST pin from Logic "0" to "1." For the ADXL76: $V_{\text{OUT}} \text{ change} = (V_{\text{OUT}} \text{ change @ } 5\text{ V}) \times (V_S/5\text{ V})$. For the ADXL269 and the ADXL276: $V_{\text{OUT}} \text{ change} = (V_{\text{OUT}} \text{ change @ } 5\text{ V}) \times (V_S/5\text{ V})^3$.

¹⁰A higher temperature range available.

Specifications subject to change without notice.

ADXL76, ADXL269, ADXL276

ABSOLUTE MAXIMUM RATINGS*

Acceleration (Any Axis, Unpowered for 0.5 ms) 2000 *g*
 Supply Voltage V_S -0.3 V to +7.0 V
 Output Short Circuit Duration (V_{OUT} to Ground) Indefinite
 Storage Temperature -65°C to +150°C
 Lead Temperature Range (Soldering, 10 sec) 245°C
 Drop Test 1.2 m

*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 indicated 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. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADXL76, ADXL269, ADXL276 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high-energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



ORDERING GUIDE

Standard Devices	Part Number	Sensitivity [mV/g]	Bandwidth (-3 dB) [Hz]	Package Description*	Package Option
ADXL76Q38	AD22215	38	400	Ceramic Dual-In-Line	Q-8
ADXL76QC38	AD22227	38	400	Surface Mount Ceramic	QC-14
ADXL76QC38-1	AD22229	38	1000	Surface Mount Ceramic	QC-14
ADXL76Q55	AD22224	55	400	Ceramic Dual-In-Line	Q-8
ADXL76QC55	AD22226	55	400	Surface Mount Ceramic	QC-14
ADXL276QC38	AD22235	38	400	Surface Mount Ceramic	QC-14
ADXL276QC38	AD22239	38	400X; 1000Y	Surface Mount Ceramic	QC-14
ADXL276QC55	AD22237	55	400	Surface Mount Ceramic	QC-14

Standard Devices	Part Number	Sensitivity [mV/g]	Bandwidth (-3 dB) [Hz]	Package Description*	Package Option
ADXL76QC18		18	400	Surface Mount Ceramic	QC-14
ADXL76Q38-1	AD22228	38	1000	Ceramic Dual-In-Line	Q-8
ADXL269QC38		38	400	Surface Mount Ceramic	QC-14
ADXL269QC55	AD22269	55	400	Surface Mount Ceramic	QC-14
ADXL276QC38-1	AD22236	38	1000	Surface Mount Ceramic	QC-14
ADXL276QC	AD22204	38X; 70Y	400	Surface Mount Ceramic	QC-14
ADXL276QC55-1	AD22238	55	1000	Surface Mount Ceramic	QC-14

*Contact factory for availability.

NOTE: Surface mount packages are shipped taped and reeled with a full reel quantity of 750 pieces. Dual-in-line packages are shipped in tubes (45 pieces per tube), 1080 pieces per box. Samples for preproduction development can be shipped in less than full box or full reel quantities.

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PIN FUNCTION DESCRIPTIONS

8-Lead Cerdip

Pin No.	ADXL76	Description
1	NC	Do Not Connect
2	NC	Do Not Connect
3	TP	Do Not Connect
4	COM	Common
5	Zero-g Adj	Zero-g Offset Input (Optional)
6	Self-Test	Self-Test Input
7	V _{OUT}	Voltage Output
8	V _S	Power Supply

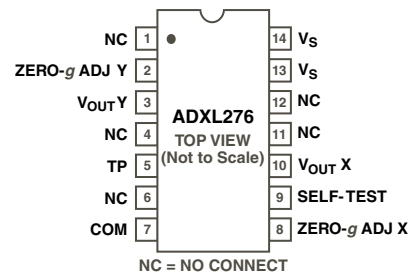
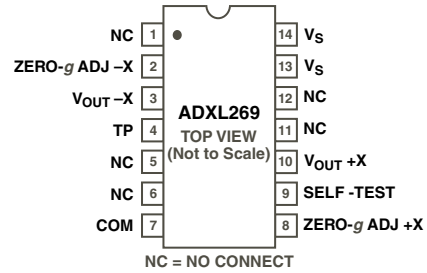
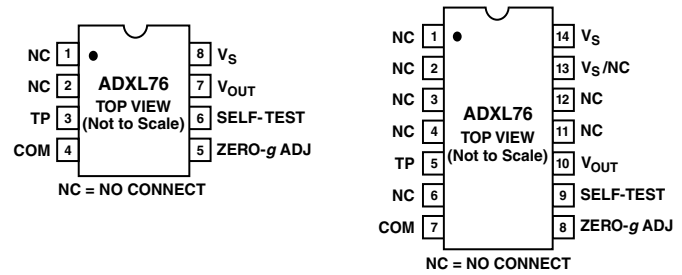
14-Lead Cerpak

Pin No.	ADXL76	Description
1	NC	Do Not Connect
2	NC	Do Not Connect
3	NC	Do Not Connect
4	NC	Do Not Connect
5	TP	Do Not Connect
6	NC	Do Not Connect
7	COM	Common Ground
8	Zero-g Adj	Optional Offset Adjust Input for X Axis
9	Self-Test	Self-Test Input Pin
10	V _{OUT}	Voltage Output of X Axis
11	NC	Do Not Connect
12	NC	Do Not Connect
13	NC/V _S *	Do Not Connect/Power Supply Pin
14	V _S	Power Supply Pin

*For new designs only: Pin 13 should be connected to Power Supply.
ADXL76QC18: Pin 13 must be connected to V_S.

Pin No.	ADXL276	ADXL269	Description
1	NC	NC	Do Not Connect
2	Zero-g Adj Y	Zero-g Adj (-X)	Optional Offset Adjust Input for Y or -X Axis
3	V _{OUT} Y	V _{OUT} (-X)	Voltage Output of Y or -X Axis
4	NC	TP	Do Not Connect
5	TP	NC	Do Not Connect
6	NC	NC	Do Not Connect
7	COM	COM	Common Ground
8	Zero-g Adj X	Zero-g Adj (+X)	Optional Offset Adjust Input for X or +X Axis
9	Self-Test	Self-Test	Self-Test Input Pin
10	V _{OUT} X	V _{OUT} (+X)	Voltage Output of X Axis
11	NC	NC	Do Not Connect
12	NC	NC	Do Not Connect
13	V _S	V _S	Power Supply Pin, Connect Also to Pin 14
14	V _S	V _S	Power Supply Pin, Connect Also to Pin 13

PIN CONFIGURATIONS



THEORY OF OPERATION

The ADXL76, ADXL269, and ADXL276 are fabricated using a proprietary *i*MEMS surface micromachining process that has been in high-volume production since 1993. The fabrication technique uses standard integrated circuit manufacturing methods enabling all the signal processing circuitry to be combined on the same chip with the sensor. The higher levels of integration and economies of volume production that exist for other ICs exist for ADI's surface micromachined process as well. This can be seen by comparing prior generation ADXL50 and ADXL75 to this third generation ADXL76 product family.

The ADXL76 family requires no external components, other than a standard power supply bypass capacitor. A 2-pole switched-capacitor Bessel filter is included on the chip.

The surface micromachined sensor element is made by depositing polysilicon on a sacrificial oxide layer that is then etched away leaving the suspended sensor element. Figure 1 is a simplified view of the ADXL76 sensor structures. In the ADXL276 there are two sensing elements orthogonal to each other and in the ADXL269 there two sensing elements of opposite polarity.

Each sensor has 42 unit sensing cells to sense acceleration. This differential capacitor sensor is composed of fixed plates and movable plates attached to the beam that moves in response to acceleration. Movement of the beam changes the differential capacitance which is measured with the on-chip circuitry.

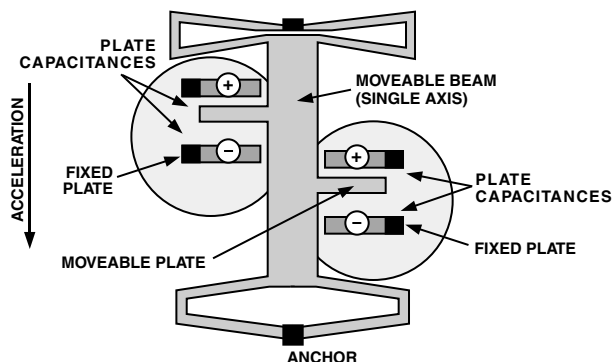


Figure 1. Simplified View of Sensor Under Acceleration

The fixed plates are driven by complementary 100 kHz clocks. When no acceleration is applied the signal output is zero. When the beam is deflected due to an acceleration the resulting signal is proportional to the acceleration (Figure 2). After amplification the signal is synchronously demodulated. This removes the oscillator frequency from the signal and provides a dc output signal. In the final stage of the accelerometer IC the dc signal is further amplified and filtered (Figure 3).

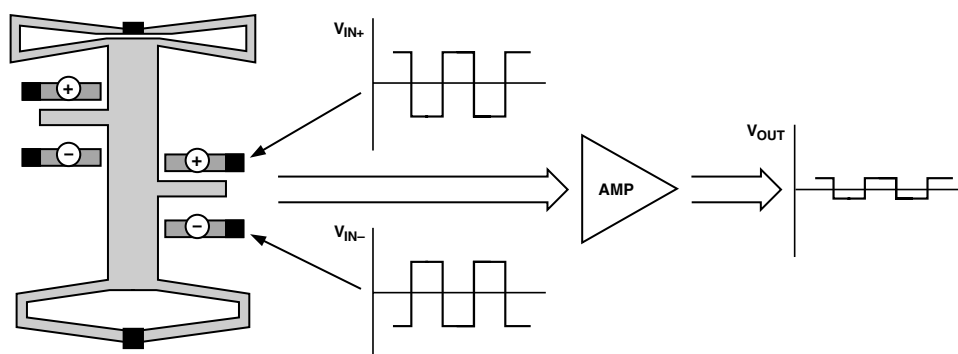


Figure 2. Drive signals to the differential capacitors are 180 degrees out of phase. When the differential capacitors are unequal, there is a signal out of the sensor which is proportional to the force on the beam. This modulated output from the beam is then demodulated to create a dc output (not shown).

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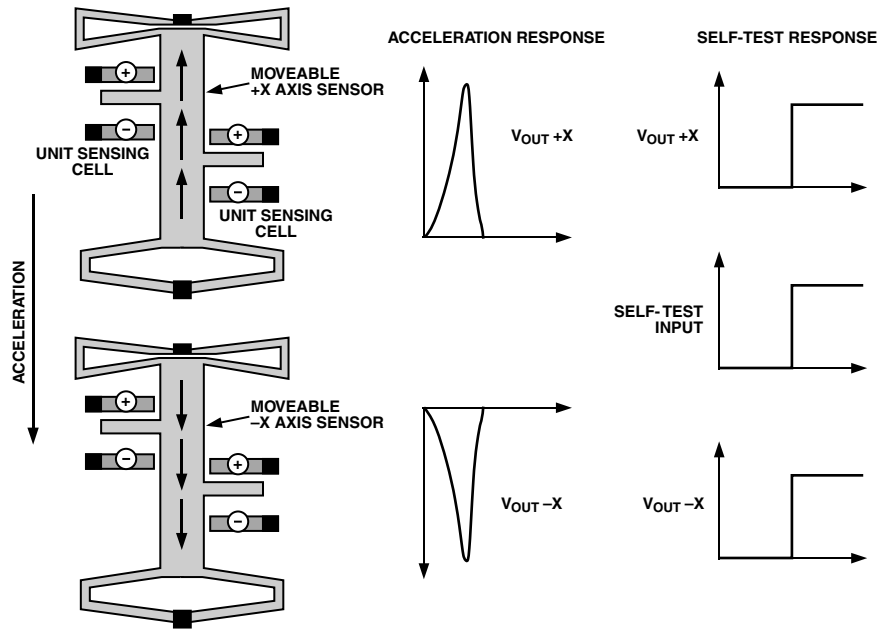


Figure 3. Simplified Top-Down View of +X and -X Sensors Under Acceleration in the ADXL269

Self-Test Feature

Each sensor element has 12 unit forcing cells for electrostatically moving the beam during a self-test (see Figure 1). Self-test is activated by the user with a dc logic high signal on the self-test input pin. During a logic high, an electrostatic force acts on the beam, equivalent to approximately 10 *g*s of acceleration input, and thus creates a proportional voltage change to appear on the output pin. When activated, the self-test feature exercises the entire mechanical structure and electrical circuitry.

As previously mentioned, the capacitive sensor is internally controlled with a series of clocked events. These events are not synchronized with the self-test input. When the self-test is applied during certain internal clock states, this will cause an initial transient at the output of less than 10% of the self-test output voltage. The shape of the initial transient will not affect the overall settling time or self-test response amplitude (see Figure 4).

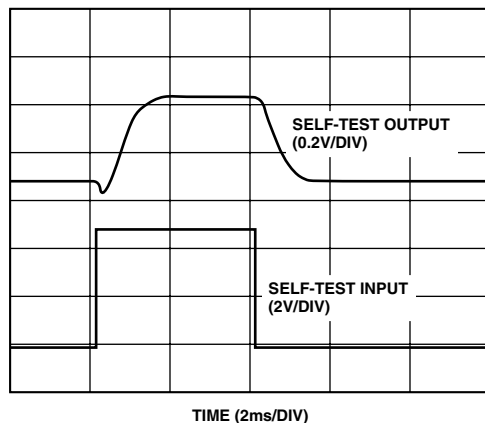


Figure 4. Typical Self-Test Response

The self-test function is designed to be a dc test. Applying a repetitive signal to the self-test pin is not recommended.

Sensors with different bandwidths will have different output signal rise times during self-test actuation. A 400 Hz sensor can be differentiated from a 1000 Hz sensor by monitoring the output. This simple method could be used to verify the chosen bandwidth option during an electrical in-circuit test.

ADXL269 Features and Benefits

The ADXL269 is specially designed for redundant sensor operation to protect against general system level faults. In the ADXL269 the sensing fingers are opposite in polarity for the two sensing elements. The output of each sensor, because of the orientation of the two sensors, provides the same voltage with different polarities resulting in symmetrical output signals (Figure 3). All the circuitry is comparable for each sensing channel (see the sensor diagram on the first page). The ADXL269 self-test has its own unique feature. When self-test is activated via the self-test pin the beams move in opposing directions. As a result of this movement, the sensor outputs will have identical polarity (i.e., both channels give a positive output, Figure 3), an improbable situation in a real world acceleration event. All the circuitry needed to drive the sensor and convert the capacitance change to voltage is incorporated on the chip requiring no external components, except for standard power supply decoupling.

More Notes On the XL76, XL269, and XL276

Both sensitivity and the zero-*g* value are essentially ratiometric to the supply voltage, so that a ratiometric ADC and the accelerometer scale factors track each other if the supply voltage changes.

The output voltage (V_{OUT}) is a function of both the acceleration input and the power supply voltage (V_S) as follows:

$$V_{OUT}(accel, V_S) = V_S [2 - [(accel)(b V_S + c V_S^2)]]$$

The coefficients *b* and *c* are dependent on the sensitivity of the accelerometer used. (See the Specifications page, Note 4 for the coefficient values and offset range values.) Typically, the differences between a true ratiometric response and the actual output are small (see Figures 5 and 6).

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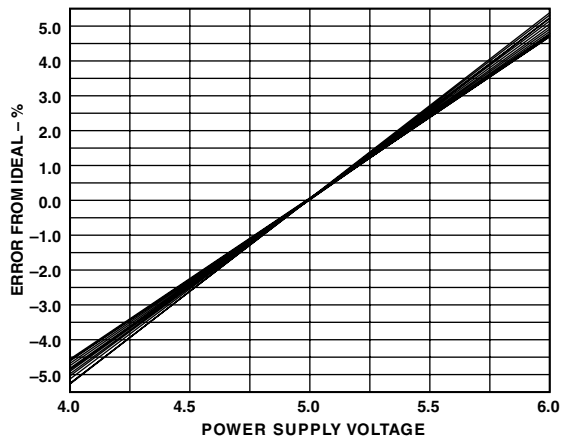


Figure 5. Typical Sensitivity Error from Ideal Ratiometric Response for a Number of Units

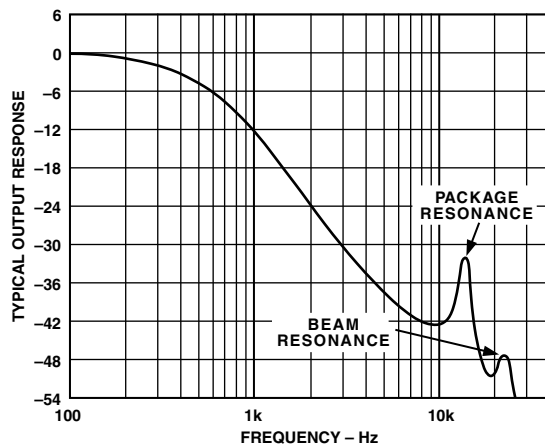


Figure 7. Typical Output Response of an ADXL76Qxx vs. Frequency on a PC Board

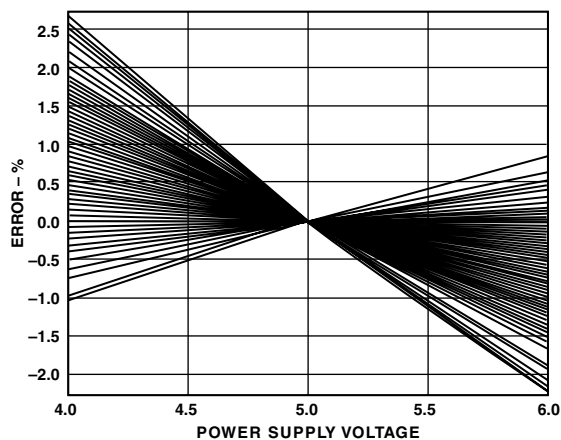


Figure 6. Offset Error of Zero-g Level from Ideal Ratiometric Response as a Percent of Full-Scale for a Number of Units

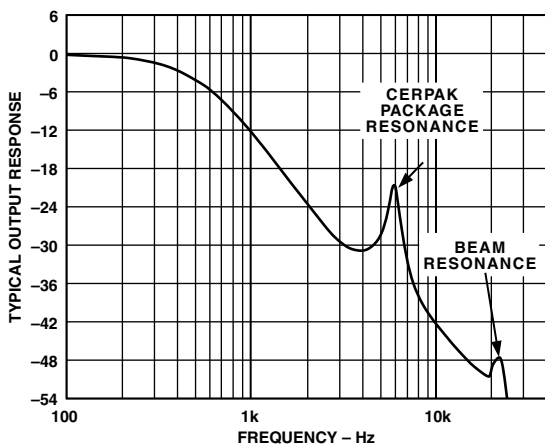


Figure 8. Typical Output Response of an ADXL76QCxx vs. Frequency on a PC Board

The final output stage of the accelerometer is a 2-pole Bessel switched-capacitor filter. Bessel filters, also called linear phase filters, have a step response with minimal overshoot and a maximally flat group delay. The -3 dB frequency of the poles is preset at the factory to either 400 Hz or 1 kHz. (See Figures 7, 8, and 9.) These filters are also completely self-contained and buffered, requiring no external components.

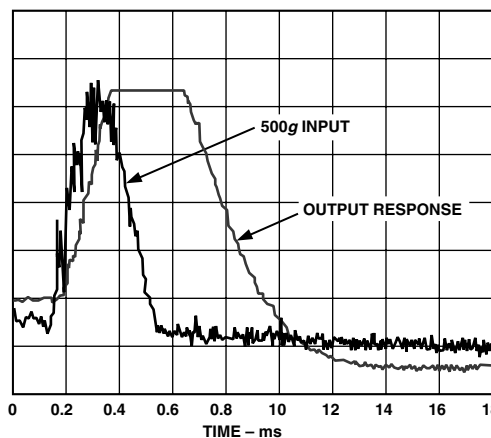


Figure 9. Typical 500 g Recovery at the Output

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Power-On Settling

The rising edges during power-on settling will have different shapes depending on the charge state of internal capacitors in the filter. Therefore, both the power supply voltage and the charge state of the filter/sensor will affect the shape of the output rising edge. Again, the final settling time is independent of the initial edge shape (see Figure 10).

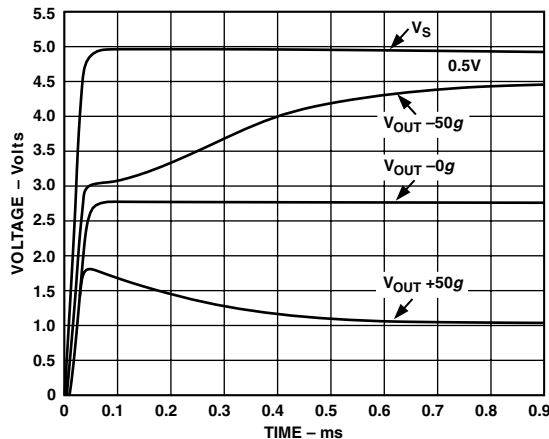


Figure 10. Typical power-on settling with full-scale Input. Time constant of internal filter dominates the response when a signal is present.

Zero-g Adjustment and Dynamic Range

In some cases the user may want to fine-adjust the zero-g output level (sometimes referred to as offset level) to obtain maximum dynamic range or achieve an asymmetrical output signal. The user may adjust the zero-g voltage level of the accelerometer by supplying a voltage to the zero-g adjustment pin. Any voltage difference between the zero-g adjustment pin and $V_S/2$ is reduced by a factor of six by the internal resistor divider. This value is then scaled up by a factor of three in the output stage for a total gain of 0.5 for the zero-g adjustment. (Note: The ratio of the resistors in the divider is consistent from part-to-part; however, the absolute values can have a tolerance as listed in the specifications.) The zero-g adjustment voltage can be setup by a variety of methods including a PWM signal or a simple three-state digital signal.

Table I. Achievable Zero-g Output Error

No Compensation	$\pm 11 g$
Three-State Compensation	
1 Bit I/O	$\pm 5 g^1$
2 Bit I/O	$\pm 2.2 g^1$
PWM Compensation	$\pm 0 g^1$
DAC	$\pm 0 g^2$

NOTES

¹Based on an external resistor tolerance of 5%, $V_S = 5 V$, 38 mV/g version.

²Achievable to zero-g output error within the resolution of the PWM or digital-to-analog converter (DAC).

Three-State Adjustment

An effective and easy method that provides increased dynamic range and coarse offset adjustment is to apply a voltage to the zero-g adjust pin from a microcontroller's three-state I/O pin (Figure 11). Using one three-state I/O pin creates three different levels of adjustment. For example, to adjust the zero-g level up by

$V_{ADJ} = 280 mV$, set the three-state I/O pin to a logic high (5 V) and use a resistor (R_{ADJ}) value of 104 k Ω . To adjust down by 280 mV set the logic level low. To calculate the value of R_{ADJ} , decide on the desired V_{ADJ} and apply the following equation:

$$R_{ADJ} = \frac{3 \times R_{5k\Omega} \times V_S}{2 \times V_{ADJ}} - R_{5k\Omega} - R_{25k\Omega}$$

This can be further simplified to:

$$R_{ADJ} = \frac{7.5 \times V_S}{V_{ADJ}} - 30 k\Omega$$

Note: $R_{5k\Omega}$ and $R_{25k\Omega}$ can vary—see Specification.

V_S is the supply voltage and $R_{5k\Omega}$ and $R_{25k\Omega}$ are the sensor's internal resistors (nominally 5 k Ω and 25 k Ω).

Table II. Adjustment Ranges Using One Bit

Zero-g Error Reading (mV)	I/O Setting	Nominal Adjust Amount (mV)
-140 to -420	H	280
-140 to +140	TS	0
140 to 420	L	-280

Figure 11 shows the zero-g adjust pin connected to one and two three-state I/O pins on the microcontroller. The resistor values shown do not include the on-resistance of the driving gates. The capacitor helps to filter noise on the power supply line and noise coming through the gate.

To adjust the output, the microcontroller reads the amplifier output and sets the I/O pins to the proper level, as described in Table II. A voltage is applied by the microcontroller depending on the states of the I/O pin, thus creating three different adjust levels. Table III describes the adjustment ranges when two bit adjustment is used. Two bits of adjustment results in nine different adjust levels. The zero-g error reading described in Tables II and III refers to the ADXL output error from $V_S/2$ before adjustment.

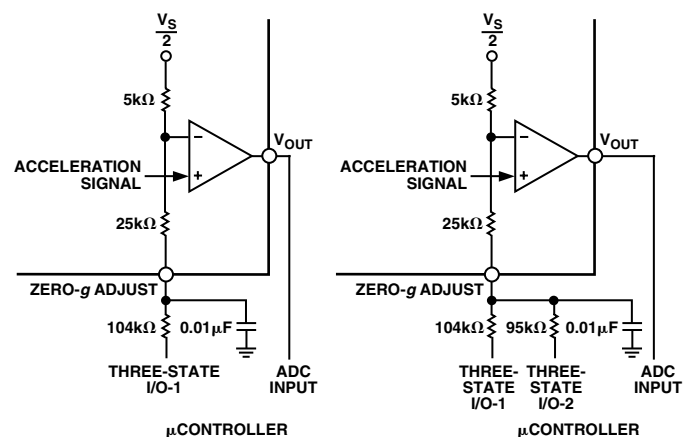


Figure 11. Optional Zero-g Adjust using three-state signals. On the left is a one-bit configuration and on the right is a two-bit configuration. A filter capacitor, shown here, may be required depending on the amount of noise on the microcontroller I/O pins.

Table III. Adjustment Ranges Using Two Bits

Zero-g Error Reading (mV)	I/O-1 Setting	I/O-2 Setting	Remaining Offset (mV)	Nominal Adjust Amount (mV)
-420 to -358	H	H	-5 to +57	415
-357 to -246	H	TS	-57 to +54	300
-246 to -152	TS	H	-55 to +39	191
-152 to -56	H	L	-39 to +57	113
-56 to +56	TS	TS	-56 to +56	0
56 to 152	L	H	-57 to +39	-113
152 to 246	TS	L	-39 to +55	-191
246 to 357	L	TS	-54 to +57	-300
357 to 420	L	L	-57 to +5	-415

Variations in the values for the zero-g adjust pin input impedance, the zero-g adjust gain, resistance of the driving gate, and external resistor will affect the adjustment value. The nominal adjust column in Tables II and III refers to the adjustment value when all of the above parameters are at their nominal values. Therefore, determining the microcontroller output settings that produce the lowest zero-g error may require an iterative process.

Using the Sensor Without Zero-g Output Adjustment

To determine the dynamic range without adjustment it is important to determine the maximum output voltage swing; this is the upper voltage limit ($V_S - 0.25\text{ V}$) minus the lower voltage limit (0.25 V). If a 5 V power supply is used, the maximum output swing would be $2.5\text{ V} \pm 2.25\text{ V}$. Therefore, without adjustment, the maximum offset and sensitivity tolerance leads to a maximum voltage output of:

$$(V_S/2 - 0.25\text{ V}) - \text{Zero-g Output (max)} \times \text{Sensitivity (max)} \\ = 2.25\text{ V} - 418\text{ mV} \times 1.08 = 1.799\text{ V}$$

this corresponds to a measurable acceleration maximum of:

$$\frac{1.799\text{ V}}{38\text{ mV/g} \times 1.08} = 43.8\text{ g}$$

In this example with maximum tolerances, the positive swing is limited to 43.8 g. The offset was assumed to be positive in this case so the measurable acceleration in the negative direction would be larger:

$$(V_S/2 - 0.25\text{ V}) + \text{Offset (max)} \times \text{Sensitivity (max)} \\ = 2.25\text{ V} + 418\text{ mV} \times 1.08 = 2.701\text{ V}$$

this corresponds to a measurable acceleration maximum of:

$$\frac{2.701\text{ V}}{38\text{ mV/g} \times 1.08} = -65.8\text{ g}$$

So in this particular example of a 38 mV/g accelerometer using the maximum offset and sensitivity specification, the measurable acceleration range without offset adjustment would be worst-case $+43.8\text{ g}/-65.8\text{ g}$ for an individual part. Since the sensitivity tolerance can be up to +8% or -8% the worst dynamic range for a population of accelerometers would have to be $\pm 43.8\text{ g}$. Test procedures ensure that the maximum offset does not coincide with the maximum sensitivity in a single part, which allows a minimum specification that is slightly higher than calculated above.

PWM Adjustment

In order to maximize the dynamic range it is important to minimize the zero-g offset error. A pulsewidth modulated signal (PWM)

from a microcontroller's counter/timer port can be used. PWM signals have an average dc level that can be used to apply a precise dc voltage to the zero-g offset adjust pin.

When zero-g adjustment is done by a PWM signal, as shown in Figure 12, the resolution of zero-g adjustment is determined by the number of bits in the counter. For example, a 60 kΩ resistor with an 8-bit counter provides an adjust resolution of 3.26 mV and a $\pm 418\text{ mV}$ adjustment range.

To understand how the PWM adjustment works, consider the case at the extreme of the adjustment range when the output from the microcontroller is always low or always high. The adjustment is then very similar to the three-state method. When the pulses are high for the same amount of time as they are low, the average dc level is $V_S/2$ and there is no adjustment. Everywhere between these levels the dc voltage applied is proportional to the difference between the time high and the time low. The adjustment resolution is limited by the number of bits in the PWM counter.

Noise energy at the internal clock frequency on the zero-g adjust pin will cause output errors (Figure 13). Therefore, high-frequency switching noise must be sufficiently filtered with a resistor and capacitor as shown in Figure 12.

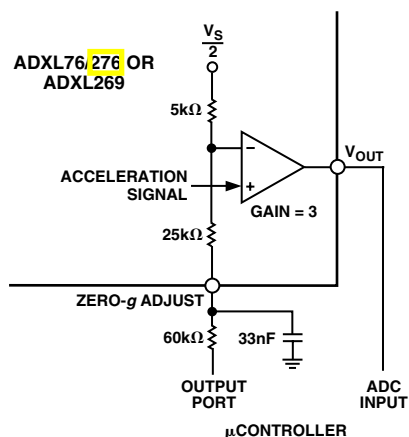


Figure 12. Optional Zero-g Adjust Using PWM

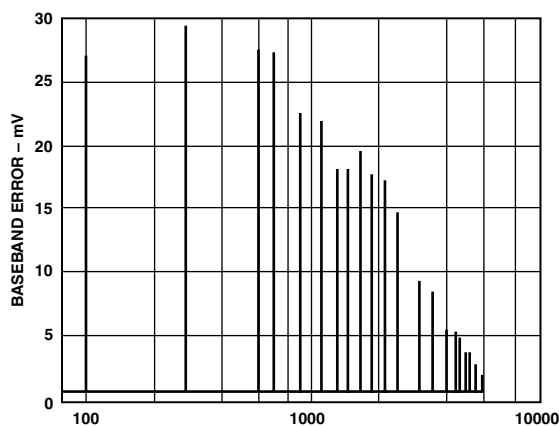


Figure 13. Supply voltage line interference at odd harmonic frequencies to the sensor oscillator frequency may also create output errors. This figure shows a typical noise amplitude appearing on the output signal if a 1 mV rms signal with these odd harmonics is present on the supply voltage. This noise is a baseband error and can be at any frequency in the baseband or at dc.

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The corner frequency (–3 dB point) of the filter in Figure 12 is 80 Hz and therefore sufficient in applications with 8-bit PWM and PWM frequencies of 12 kHz or more. At a corner frequency of 80 Hz the ripple on the ADXL output is below one LSB (@ 8-bit resolution, referred to V_{OUT}) for PWM frequencies of 12 kHz or higher.

The microcontroller output port frequency should be chosen to avoid harmonics with the accelerometer’s demodulator frequency. For maximum filtering, the effective RC time constant must be as large as possible. Using a larger capacitor will allow the reduction of the PWM frequency

The PWM adjustment method can provide continuous offset compensation. This method is well suited to eliminate temperature drifts since the temperature change in many real-world systems is only a few degrees per minute.

Asymmetrical Ranges

Zero- g offset level shifts can be used to create asymmetric measurement ranges. This can be achieved by connecting the zero- g adjust pin to V_S or to GND via an appropriate resistor. The asymmetry should not exceed $\pm 25\%$. Contact the factory for ranges beyond this amount. Note that the sensors are tested at $\pm 50 g$ or $\pm 35 g$, according to the sensor’s nominal sensitivity.

Low- g Applications

To use the ADXL76/ADXL276/ADXL269 in low- g applications, it is possible to add an output amplifier with filtering, as shown in Figure 14. Gain is set by $R1/R2$, and a single-pole low-pass filter is formed by $C1$ and $R1$.

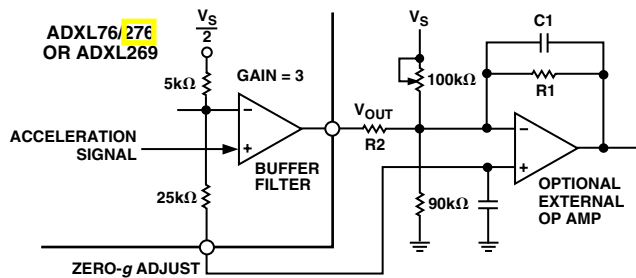


Figure 14. Optional Output Amplifier and Filter

To illustrate this Table IV lists different sensitivities based on a 55 mV/g sensor and different $R2$ values.

Table IV. Optional Gain Adjust Resistor Values for 55 mV/g-Versions

Desired Sensitivity	Gain	Full-Scale Range	R1 Value	R2 Value
100 mV/g	1.79	$\pm 20 g$	1 M Ω	560 k Ω
200 mV/g	3.64	$\pm 10 g$	1 M Ω	275 k Ω
400 mV/g	7.30	$\pm 5 g$	1 M Ω	137 k Ω

The bandwidth of the circuitry is determined by $C1$ and $R1$.

$$F_{(-3 \text{ dB})} = 1 / (2 \times 1/2 \times R1 \times C1)$$

Table V. Optional Bandwidth Adjust Component Values

Bandwidth	C1 Value	R1 Value
100 Hz	0.0015 μF	1 M Ω
30 Hz	0.0047 μF	1 M Ω
10 Hz	0.015 μF	1 M Ω
3 Hz	0.047 μF	1 M Ω

Any zero- g deviation from $V_S/2$ will be amplified along with the signal. It is important to adjust the zero- g level at V_{OUT} to $V_S/2$ to ensure the largest possible output voltage swing. The adjustment can be done at the zero- g adjust pin of the accelerometer, as previously described, or it can be done at the input of the external summing amplifier as shown in Figure 14.

The voltage of the zero- g adjust pin is at $V_S/2$ and can be used as a reference for the bias level of the external amplifier. If this is done then the zero- g adjust pin can no longer be used for adjustment of the zero- g level. A 100 nF capacitor at the positive input of the amplifier connected to ground helps against high frequency noise pickup.

$$G_{V_{OUT}} = \frac{R1}{R2}$$

Connection Diagram and Layout Guidelines

The basic connection diagram to a microcontroller is shown in Figure 15. The microcontroller ADC reference, V_{RH} , and the accelerometer supply voltage should be connected at exactly the same voltage. Since the accelerometer is ratiometric, the use of a ratiometric ADC will reduce system errors due to supply voltage changes.

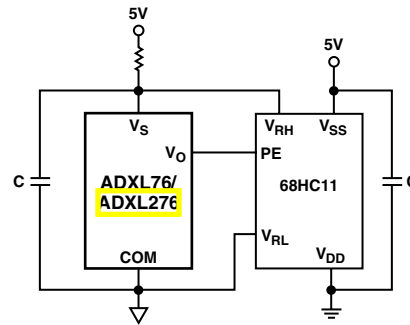


Figure 15. Basic Connection to a Microcontroller with ADC

Also, the ground for the accelerometer should be directly connected to V_{RL} of the microcontroller. Note that the analog and digital grounds are separated. It is important to keep analog and digital grounds separate to avoid ground loops. To minimize pickup and noise in the design of the PC Board, standard analog design techniques are recommended (e.g., ground planes, avoiding long routes to external components, avoiding placement near “noise generators” like crystals, switching transistors/logic ICs, and microcontrollers). Consider using the microcontroller manufacturer’s recommended signal isolation components.

The ADXL76, ADXL269, and ADXL276 use synchronous demodulation architecture, commonly used in accelerometers and other sensors. Noise on the supply that is synchronous with or near the clock frequency (approximately 100 kHz) or its odd harmonics will exhibit baseband errors at the output. These error signals are the beat frequency signals between the clock and the supply noise (see Figures 13 and 16).

Such noise can be generated by digital oscillations (power supply, microcontrollers, crystal, etc.) elsewhere in the system and must be attenuated by proper bypassing as shown in Figure 15. By inserting a small resistance in series with the accelerometer and ADC reference supply, a filter is created with the bypass capacitor. For example if $R = 3 \Omega$ and $C = 2.2 \mu\text{F}$, a 24 kHz filter is created which is usually adequate to attenuate noise on the supply from other digital circuits with proper ground and supply layout. Other values for the resistors and capacitors are possible. In this example, however, the voltage drop over the resistor is smaller than half of an LSB for an 8-bit 5 V input ADC. Thus the positive reference of the ADC V_{RH} is very close to 5 V and the span of the other ADC channels of the microcontroller are not significantly limited by the voltage drop over the resistor.

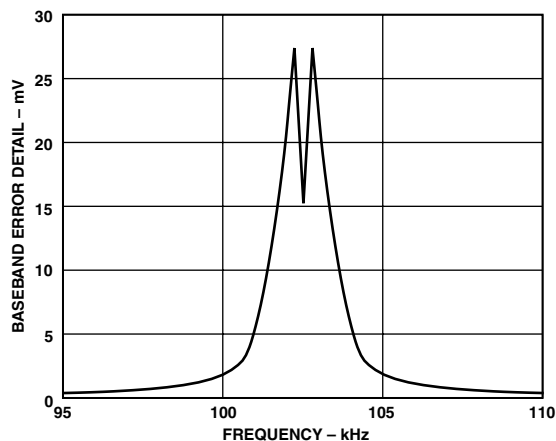


Figure 16. If high frequencies are present on the voltage supply line, output errors may result. This figure shows a typical noise amplitude appearing on the output signal if a 1 mV rms signal similar in frequency to the sensor's internal oscillator frequency is present on the supply voltage. In this case, the internal oscillator frequency was approximately 102.5 kHz. Using appropriate supply voltage filtering methods, this type of interference can be avoided.

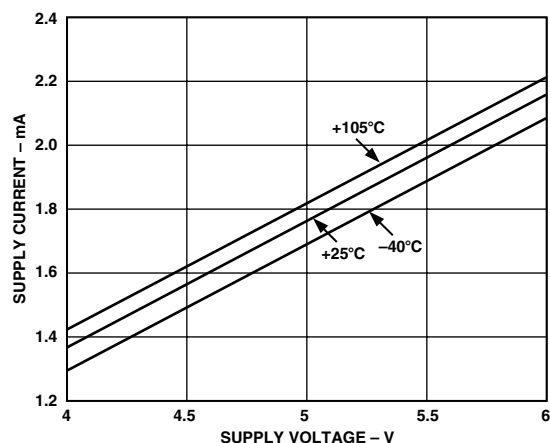


Figure 17. Typical Accelerometer Supply Current vs. Supply Voltage

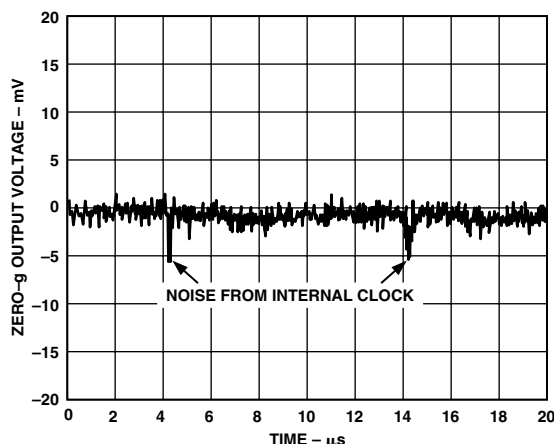


Figure 18. Typical Output Noise Voltage for ADXL76Q38 with Spikes Generated by Internal Clock. Measurement Bandwidth > 100 MHz.

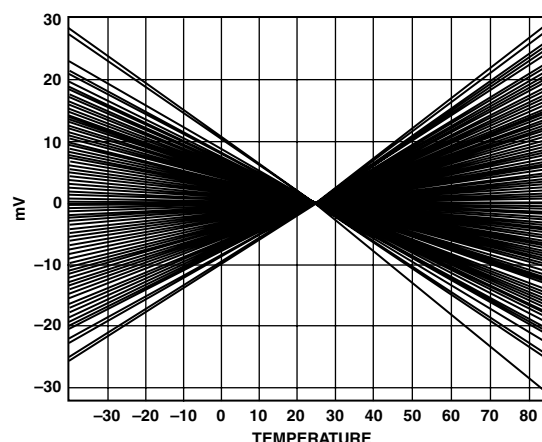


Figure 19. Zero-g Drift from -40°C to $+25^{\circ}\text{C}$ and from $+25^{\circ}\text{C}$ to $+85^{\circ}\text{C}$ for a Number of Units for ADXL76Q38

ADXL76, ADXL269, ADXL276

ORIENTATION OF SENSITIVE AXES

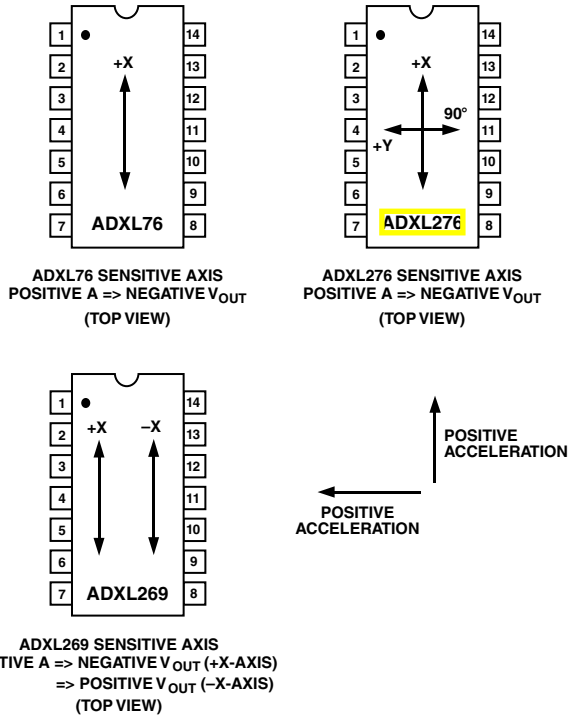
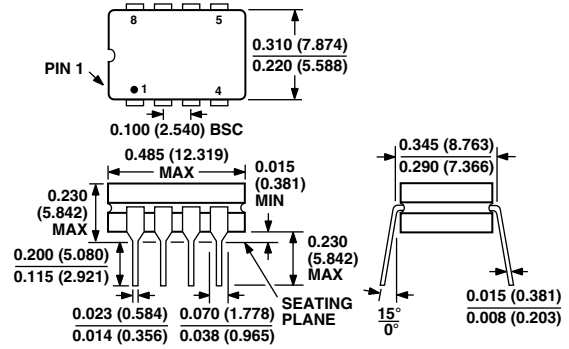


Figure 20. Sensitive Axes

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

Ceramic Dual-In-Line (QC-8)



Surface Mount Ceramic (QC-14)

