ANALOG DEVICES

3-Axis ±200 g Analog MEMS Accelerometer

Preliminary Technical Data

ADXL377

FEATURES

3-axis sensing
±200 g measurement range
Analog output for full impact event visibility
Low power: 300 µA (typical)
Selectable bandwidth
   Up to 1600Hz bandwidth (XY)
   Up to 1200Hz bandwidth (Z)
Single-supply operation: 1.8 V to 3.6 V
10,000 g shock survival
Small, low profile package
   3 mm × 3 mm × 1.45 mm LFCSP

APPLICATIONS

High Impact Detection for:
   Concussive Forces
   Possible Head Trauma
   Industrial Machinery
   Industrial Tools
   Warranty Protection
   Impact Black Boxes

GENERAL DESCRIPTION

The ADXL377 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±200 g. The ADXL377 is designed to measure dynamic acceleration resulting from high impact events without sensor saturation. The analog output of the ADXL377 provides for full visibility of an impact event so potentially critical data is not lost.

The user selects the bandwidth of the accelerometer using the C_X, C_Y, and C_Z capacitors at the X_{OUT}, Y_{OUT}, and Z_{OUT} pins. Bandwidths can be selected to suit the application, with a range of 0.5 Hz to 1600 Hz for X and Y axes and a range of 0.5 Hz to 1200 Hz for the Z axis. This wide bandwidth allows the ADXL377 to detect shock and impact events on industrial applications that have a higher frequency component.

The ADXL377 is available in a small, low profile, 3 mm × 3 mm × 1.45 mm, 16-lead, lead frame chip scale package (LFCSP_LQ).
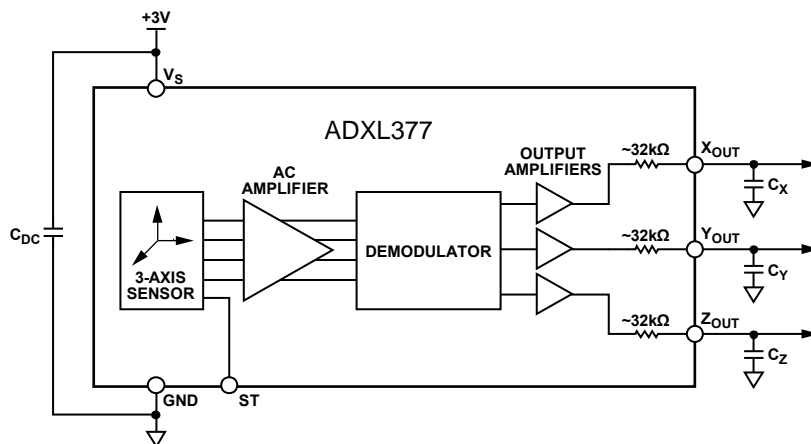
FUNCTIONAL BLOCK DIAGRAM

Figure 1.

TABLE OF CONTENTS

SPECIFICATIONS

$T_A = 25°C$, $V_S = 3$ V, $C_X = C_Y = C_Z = 0.1$ μF, acceleration = 0 g, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

Table 1.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range			±200		g
Nonlinearity	% of full scale		±0.3		%
Package Alignment Error			±1		Degrees
Interaxis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity[1]			±1		%
SENSITIVITY (RATIOMETRIC)[2]	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	$V_S = 3$ V	5.8	6.5	7.2	mV/g
Sensitivity Change Due to Temperature[3]	$V_S = 3$ V		±0.01		%/°C
0 g BIAS LEVEL (RATIOMETRIC)					
0 g Voltage at X_{OUT}, Y_{OUT}, Z_{OUT}	$V_S = 3$ V, 25°C	1.4	1.5	1.6	V
0 g Offset vs. Temperature X_{OUT}, Y_{OUT}			±11		mg/°C
0 g Offset vs. Temperature Z_{OUT}			±15		mg/°C
NOISE PERFORMANCE					
Noise Density X_{OUT}, Y_{OUT}			2.4		mg/√Hz rms
Noise Density Z_{OUT}			3.6		mg/√Hz rms
FREQUENCY RESPONSE[4]					
Bandwidth X_{OUT}, Y_{OUT}[5]	1 nF external filter		1600		Hz
Bandwidth Z_{OUT}[5]	1 nF external filter		1200		Hz
R_{FILT} Tolerance			32 ± 15%		kΩ
Sensor Resonant Frequency			16.5		kHz
SELF TEST[6]					
Logic Input Low			0.6		V
Logic Input High			2.4		V
ST Actuation Current			60		μA
Output Change at X_{OUT}	Self test 0 to 1		- 6.5		mV
Output Change at Y_{OUT}	Self test 0 to 1		6.5		mV
Output Change at Z_{OUT}	Self test 0 to 1		11.5		mV
OUTPUT AMPLIFIER					
Output Swing Low	No load		0.1		V
Output Swing High	No load		2.8		V
POWER SUPPLY					
Operating Voltage Range[7]		1.8	3.0	3.6	V
Supply Current	$V_S = 3$ V		300		μA
Turn-On Time[8]	1nF external filter		1		ms
TEMPERATURE					
Operating Temperature Range		−40		+85	°C

[1] Defined as coupling between any two axes.
[2] Sensitivity is essentially ratiometric to V_S.
[3] Defined as the output change from ambient-to-maximum temperature or ambient-to-minimum temperature.
[4] Actual frequency response controlled by user-supplied external filter capacitors (C_X, C_Y, C_Z).
[5] Bandwidth with external capacitors = $1/(2 \times \pi \times 32$ kΩ $\times C)$. For C_X, $C_Y = 0.003$ μF, bandwidth = 1.6 kHz. For $C_Z = 0.01$ μF, bandwidth = 500 Hz. For C_X, C_Y, $C_Z = 10$ μF, bandwidth = 0.5 Hz.
[6] Self test response changes cubically with V_S.
[7] Tested at 3.0 V and guaranteed by design only (not tested) to work over the full range from 1.8 V to 3.6 V.
[8] Turn-on time is dependent on C_X, C_Y, C_Z and is approximately $160 \times (C_X$ or C_Y or $C_Z) + 1$, where C_X, C_Y, and C_Z are in μF and the resulting turn-on time is in ms.

ABSOLUTE MAXIMUM RATINGS

Table 2.

| Parameter	Rating
Acceleration (Any Axis, Unpowered)	10,000 g
Acceleration (Any Axis, Powered)	10,000 g
V_S	−0.3 V to +3.6 V
All Other Pins	(GND − 0.3 V) to (V_S + 0.3 V)
Output Short-Circuit Duration (Any Pin to Common)	Indefinite
Temperature Range (Powered)	−55°C to +125°C
Temperature Range (Storage)	−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; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS
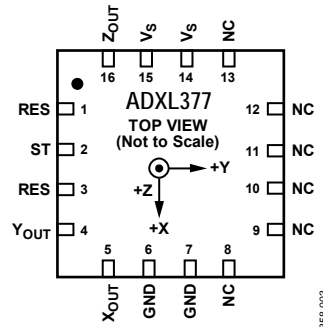
NOTES
1. NC = NO CONNECT.
2. EXPOSED PAD IS NOT INTERNALLY
   CONNECTED BUT SHOULD BE SOLDERED
   FOR MECHANICAL INTEGRITY.

Figure 2. Pin Configuration

Table 3. Pin Function Descriptions

Pin No.	Mnemonic	Description
1, 3	RES	Reserved. This pin must be connected to GND or left open.
2	ST	Self Test.
4	Y_{OUT}	Y Channel Output.
5	X_{OUT}	X Channel Output.
6, 7	GND	Must be connected to ground.
8 to 13	NC	Not internally connected.
14	V_S	Supply Voltage (3.0 V typical).
15	V_S	Supply Voltage (3.0 V typical).
16	Z_{OUT}	Z Channel Output.
	EPAD	Exposed Pad. Not internally connected but should be soldered for mechanical integrity.

TYPICAL PERFORMANCE CHARACTERISTICS
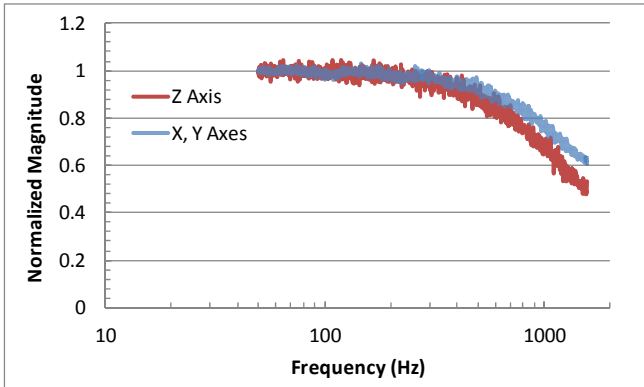
THEORY OF OPERATION

The ADXL377 is a complete 3-axis acceleration measurement system. The ADXL377 has a measurement range of ±200 g minimum. It contains a polysilicon surface micromachined sensor and signal conditioning circuitry to implement an open-loop acceleration measurement architecture. The output signals are analog voltages that are proportional to acceleration. The accelerometer can measure the static acceleration of gravity in tilt-sensing applications as well as dynamic acceleration resulting from motion, shock, or vibration. The accelerometer is designed to measure dynamic acceleration resulting from high impact events without output saturation.

The sensor is a polysilicon surface micromachined structure built on top of a 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 plates attached to the moving mass. The fixed plates are driven by 180° out-of-phase square waves. Acceleration deflects the moving mass and unbalances the differential capacitor resulting in a sensor output whose amplitude is proportional to acceleration. Phase-sensitive demodulation techniques are then used to determine the magnitude and direction of the acceleration.

The demodulator output is amplified and brought off chip through a 32 kΩ resistor. The user then sets the signal bandwidth (BW) of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing.

MECHANICAL SENSOR

The ADXL377 uses a single structure for sensing the X, Y, and Z axes. As a result, the three axes sense directions are highly orthogonal with little cross-axis sensitivity. Mechanical misalignment of the sensor die to the package is the chief source of cross-axis sensitivity. Mechanical misalignment can be calibrated out at the system level.

PERFORMANCE

Rather than using additional temperature compensation circuitry, innovative design techniques ensure that high performance is built into the ADXL377. As a result, there is neither quantization error nor nonmonotonic behavior, and temperature hysteresis is very low (typically less than 30 mg over the −25°C to +85°C temperature range).

APPLICATIONS INFORMATION

POWER SUPPLY DECOUPLING

For most applications, a single 0.1 μF capacitor, C_{DC}, placed close to the ADXL377 supply pins adequately decouples the accelerometer from noise on the power supply. However, in applications where noise is present at the 50 kHz internal clock frequency (or any harmonic thereof), additional care in power supply bypassing is required because this noise can cause errors in acceleration measurement. If additional decoupling is needed, a 100 Ω (or smaller) resistor or ferrite bead can be inserted in the supply line. Additionally, a larger bulk bypass capacitor (1 μF or greater) can be added in parallel to C_{DC}. Ensure that the connection from the ADXL377 ground to the power supply ground is low impedance because noise transmitted through ground has a similar effect as noise transmitted through V_S.

SETTING THE BANDWIDTH USING C_X, C_Y, AND C_Z

The ADXL377 has provisions for band limiting the X_{OUT}, Y_{OUT}, and Z_{OUT} pins. Capacitors must be added at these pins to implement low-pass filtering for antialiasing and noise reduction. The equation for the 3 dB bandwidth is

$$f_{-3\,dB} = 1/(2\pi(32\text{ k}\Omega) \times C_{(X, Y, Z)})$$

or more simply

$$f_{-3\,dB} = 5\text{ μF}/C_{(X, Y, Z)}$$

The tolerance of the internal resistor (R_{FILT}) typically varies as much as ±15% of its nominal value (32 kΩ), and the bandwidth varies accordingly. A minimum capacitance of 1000 pF for C_X, C_Y, and C_Z is recommended in all cases.

Table 4. Filter Capacitor Selection, C_X, C_Y, and C_Z

Bandwidth (Hz)	Capacitor (μF)
50	0.10
100	0.05
200	0.025
500	0.01
1000	0.005
1600	0.003

SELF TEST

The ST pin controls the self test feature. When this pin is set to V_S, an electrostatic force is exerted on the accelerometer beam. The resulting movement of the beam allows the user to test if the accelerometer is functional. The typical change in output is −1.08 *g* (corresponding to −6.5 mV) in the X-axis, +1.08 *g* (or +6.5 mV) on the Y-axis, and +1.83 *g* (or +11.5 mV) on the Z-axis. This ST pin can be left open circuit or connected to common (GND) in normal use.

Never expose the ST pin to voltages greater than V_S + 0.3 V. If this cannot be guaranteed due to the system design (for instance, if there are multiple supply voltages), then a low V_F clamping diode between ST and V_S is recommended.

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

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

The output of the ADXL377 has a typical bandwidth of greater than 500 Hz. The user must filter the signal at this point to limit aliasing errors. The analog bandwidth must be no more than half the analog-to-digital sampling frequency to minimize aliasing. The analog bandwidth can be decreased further to reduce noise and improve resolution.

The ADXL377 noise has the characteristics of white Gaussian noise, which contributes equally at all frequencies and is described in terms of μ*g*/√Hz (the noise is proportional to the square root of the accelerometer bandwidth). The user should 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 ADXL377 is determined by

$$rms\ Noise = Noise\ Density \times (\sqrt{BW \times 1.6})$$

It is often useful to know the peak value of the noise. Peak-to-peak noise can only be estimated by statistical methods. Table 5 is useful for estimating the probabilities of exceeding various peak values, given the rms value.

Table 5. Estimation of Peak-to-Peak Noise

Peak-to-Peak Value	Percent of Time that Noise Exceeds Nominal Peak-to-Peak Value
2 × rms	32
4 × rms	4.6
6 × rms	0.27
8 × rms	0.006

AXES OF ACCELERATION SENSITIVITY

The axes of sensitivity for the accelerometer are shown in Figure 3, and Figure 4 shows the output response when the accelerometer is oriented parallel to each of these axes.
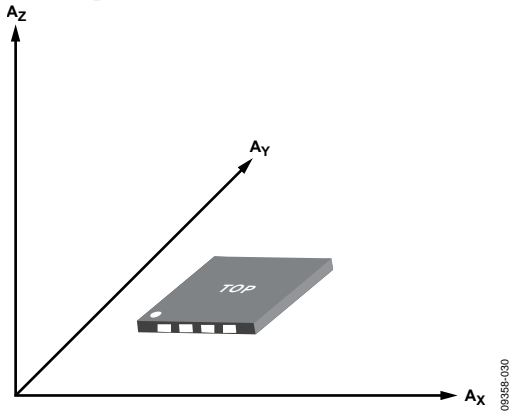

Figure 3. Axes of Acceleration Sensitivity, Corresponding Output Voltage Increases When Accelerated Along the Sensitive Axis
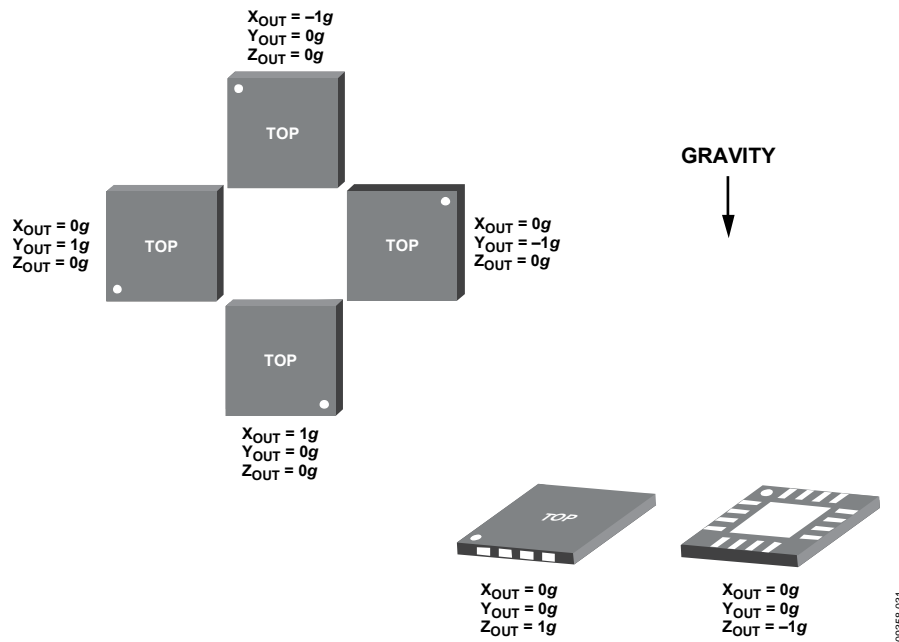

$X_{OUT} = -1g$
$Y_{OUT} = 0g$
$Z_{OUT} = 0g$

GRAVITY

$X_{OUT} = 0g$
$Y_{OUT} = 1g$
$Z_{OUT} = 0g$

$X_{OUT} = 0g$
$Y_{OUT} = -1g$
$Z_{OUT} = 0g$

$X_{OUT} = 1g$
$Y_{OUT} = 0g$
$Z_{OUT} = 0g$

$X_{OUT} = 0g$
$Y_{OUT} = 0g$
$Z_{OUT} = 1g$

$X_{OUT} = 0g$
$Y_{OUT} = 0g$
$Z_{OUT} = -1g$

Figure 4. Output Response vs. Orientation to Gravity

LAYOUT AND DESIGN RECOMMENDATIONS

The recommended soldering profile is shown in Figure 5 followed by a description of the profile features in Table 6. The recommended PCB layout or solder land drawing is shown in Figure 6.
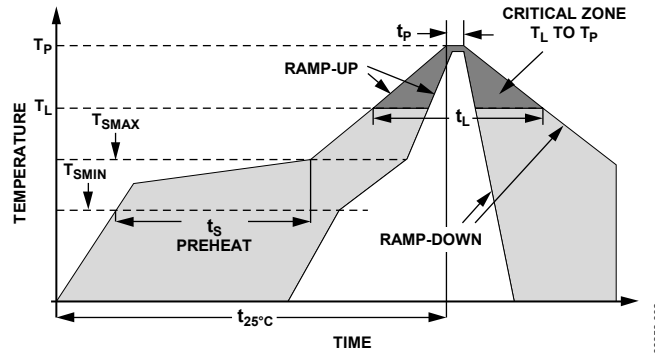

Figure 5. Recommended Soldering Profile

Table 6. Recommended Soldering Profile

Profile Feature	Sn63/Pb37	Pb-Free
Average Ramp Rate (T_L to T_P)	3°C/sec maximum	3°C/sec maximum
Preheat		
Minimum Temperature (T_{SMIN})	100°C	150°C
Maximum Temperature (T_{SMAX})	150°C	200°C
Time (T_{SMIN} to T_{SMAX}), t_S	60 sec to 120 sec	60 sec to 180 sec
T_{SMAX} to T_L		
Ramp-Up Rate	3°C/sec maximum	3°C/sec maximum
Time Maintained Above Liquidous (T_L)		
Liquidous Temperature (T_L)	183°C	217°C
Time (t_L)	60 sec to 150 sec	60 sec to 150 sec
Peak Temperature (T_P)	240°C + 0°C/−5°C	260°C + 0°C/−5°C
Time within 5°C of Actual Peak Temperature (t_P)	10 sec to 30 sec	20 sec to 40 sec
Ramp-Down Rate	6°C/sec maximum	6°C/sec maximum
Time 25°C to Peak Temperature ($t_{25°C}$)	6 minutes maximum	8 minutes maximum

DIMENSIONS SHOWN IN MILLIMETERS
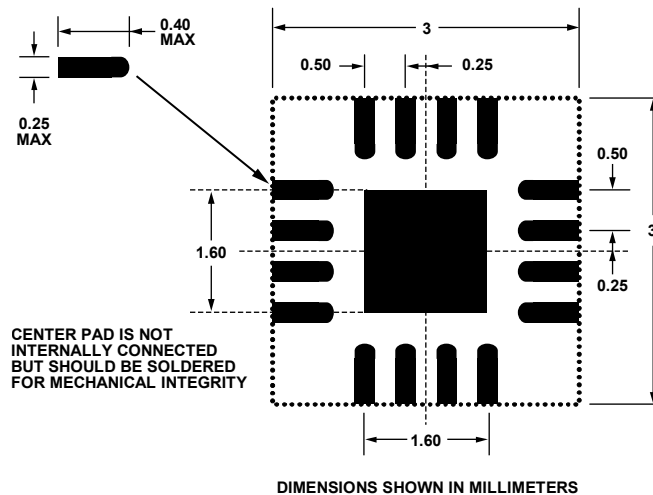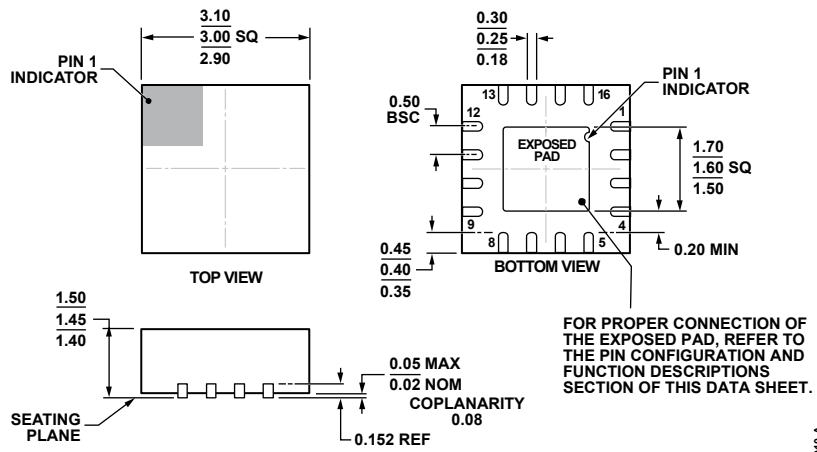
Figure 6. Recommended PCB Layout

OUTLINE DIMENSIONS

Figure 7. 16-Lead Lead Frame Chip Scale Package [LFCSP_LQ]
3 mm × 3 mm Body, Thick Quad
(CP-16-28)
Dimensions shown in millimeters

NOTES

NOTES

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