Deceleration-X Systems
Simon Fraser University
Burnaby, BC
V5A 1S6

March 15, 1999

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

RE: ENSC 370 Project Design Specifications

Dear Dr. Rawicz:

We have enclosed a copy of our design specifications for ENSC 370. Our design specifications outlines the details of our automobile deceleration indicator. The goal of the project is to provide drivers with a concrete means to determine the rate of deceleration of surrounding cars which ultimately translates to fewer motor vehicle accidents.

Our design specifications detail the specific implementation of each component of our project including the reasoning behind each engineering choice. The components of our system are: the sensor unit, the display unit, and the data logging unit.

Our group consists of four engineering students with experience and expertise in the hardware design. If you have questions or concerns regarding the functional specifications, please do not hesitate to contact me by phone at 461-6981 or by email at scwong@sfu.ca.

Sincerely,

Steven Wong
President, Deceleration-X Systems

Enclosure: Design Specifications for the Automobile Deceleration Indication System.

Deceleration-X Systems

Automobile Deceleration Indication System

Design Specifications

Submitted by: Deceleration-X Systems:
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Date: March 15, 1999

Executive Summary

Our Automobile Deceleration Indication System is intended to provide a means for drivers to judge the rate of deceleration of surrounding cars. The deceleration is measured using an accelerometer and the rate of deceleration is displayed at the rear of vehicles on an array of lights, much like a brake light on a car. When a vehicle decelerates at a slow rate, only a few lights will be illuminated. When the vehicle decelerates rapidly, all the lights will be illuminated.

However, the deceleration of a vehicle will be distorted by gravity if the vehicle is travelling up or down a hill. Therefore, we will use an accelerometer that measures the rate of acceleration (or deceleration) on two axes. Using this device, we can compensate for the effect of gravity along the horizontal axis when the vehicle moving in a direction that is not perpendicular to the force of gravity. The display unit will consist of a horizontal strip of lights. The center of the strip will light up on low deceleration and the light will illuminate outwards as the rate of deceleration increases. Our project also includes a data logger to record the deceleration of a vehicle the in the event of an accident. Insurance companies or accident investigators can then use the data from the data logger to.

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1 Introduction

Successfully piloting of a motor vehicle requires not only interaction between the driver and the motor vehicle, but also interaction between the driver and others sharing the roadway. Frequently, driving interaction breakdowns occur as a result of the limited means of communication and feedback between drivers. Communication between drivers is currently limited to simple visual signals such as car lights and simple auditory signals such as car horns, while most feedback available to a driver comes through the perceived motion of other cars. This document provides the design specifications of a system intended to improve the means of communication and feedback for drivers, thereby reducing the likelihood of motor vehicle collisions.

The intent of our design specifications is to provide a detailed description of the planned method of implementation of the project. This document specifies the means of measuring the rate of deceleration of a vehicle and the method of indicating this measurement to other drivers. Specifications for the data logger will also be included.

2 Signal Acquisition

The deceleration sensor unit will use a dual axis accelerometer for detecting vehicle deceleration. The accelerometer will be mounted inside the sensor unit to provide sensitivity as depicted in Figure 1. The labeling of the axes reflects the names of the axes of sensitivity adopted by the accelerometer manufacturers. The directions of the vectors representing the axes in Figure 1 indicate the directions of positive acceleration as sensed by the accelerometer.

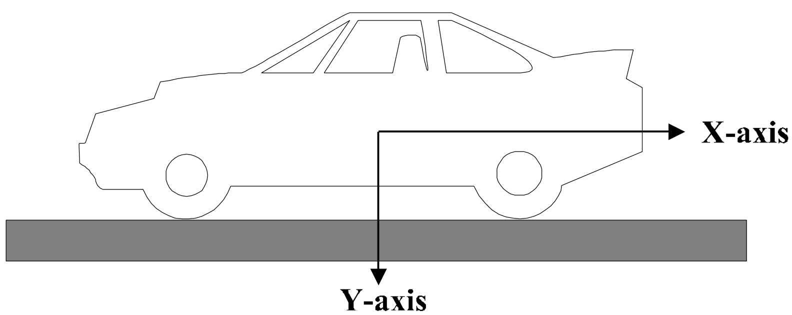

Figure 1: Accelerometer Axis Orientation

The x-axis of sensitivity will serve as the primary axis used to determine vehicle deceleration, while the y-axis of sensitivity will serve as the secondary axis used to determine vehicle orientation for the purpose of grade compensation.

2.1 Accelerometer Selection

An Analog Devices ADXL250AJQ dual axis accelerometer will be used in the sensor unit. The ADXL250 was chosen because the ADXL250AJQ offers two orthogonal axes of sensitivity in a low noise, low power, industrial grade hermetic surface mount package. The ADXL250 provides a stable output voltage in response to constant acceleration, which is crucial for ensuring the ADI system operates accurately during constant vehicle deceleration. The ADXL250 offers a typical SNR of 80 dB, allowing detection of accelerations below 10 mg, while providing a ±50 g full-scale range.

Furthermore, the ADXL250 is a ratiometric device with the output scale factor and zero acceleration level ratiometric to the power supply. When used to drive other ratiometric devices such as ratiometric A/D converters powered from a common supply voltage, output level error due to supply voltage drift will be compensated for as a result of the ratiometric output characteristics. The ratiometric output characteristics will significantly reduce the sensor unit's sensitivity to variations in the supply voltage, improving system behavior under the varying power conditions present in an automobile's electrical system.

The industrial AJQ package is certified to operate over a temperature range from -40°C to +85°C. Packages specifically intended for military and automotive use are additionally available upon request from Analog Devices, and would be incorporated into a production model. For further details, please refer to the ADXL150/ADXL250 data sheet extracts in Appendix A.

2.2 Sensor Enclosure

The sensor and signal conditioning units will be enclosed in a durable metal box providing physical protection for internal components and isolation from electromagnetic interference. The enclosure will provide means for securely fastening the sensor unit to the vehicle's chassis. The sensor will be mounted using a small piece of foam rubber or similar material to isolate the sensor from vehicle vibration, improving device performance.

3 Theory of Grade Compensation

Similar to other accelerometers, the design of the ADXL250 makes the device sensitive to the force of gravity. The accelerometer output signal e(t) due to the force of gravity is proportional to the component of the gravitational force projecting onto the axis of sensitivity, and may be determined according to Equation 1.

$$e(t) = Kg\cos q(t)$$ **Equation 1**

Here K denotes the accelerometer gain in volts/m/s^2, g denotes the acceleration due to gravity which is nominally 9.8 m/s^2, and θ denotes the angle separating the axis of sensitivity and the gravitational acceleration vector **g** as depicted in Figure 2.

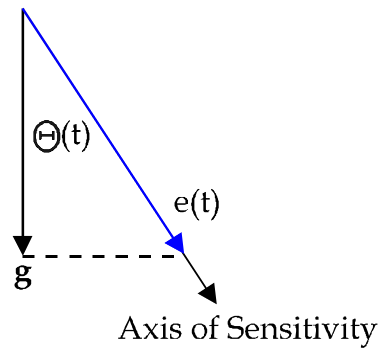

Figure 2: Gravity Induced Accelerometer Signal

Some non-zero component of gravity will project onto the x-axis of sensitivity whenever the vehicle travels on an incline, as depicted in Figure 3.

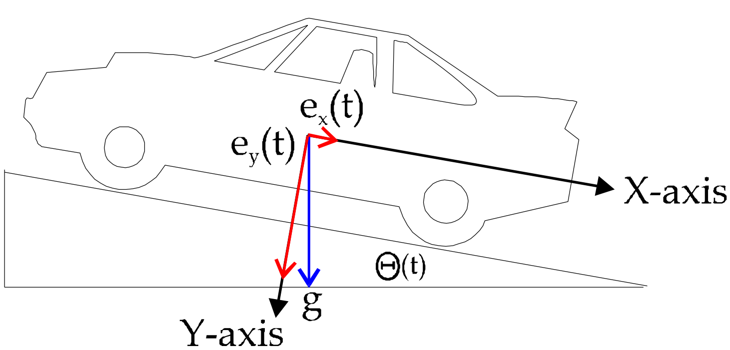

Figure 3: Error Signal due to Road Grade

Because the vehicle's deceleration is determined from the signal generated by the accelerometer's x-axis of sensitivity, any signal component resulting from some component of gravity projecting onto the x-axis will constitute an error signal. The x-axis signal component $e_x(t)$ resulting from gravity projecting onto the x-axis of sensitivity when the vehicle travels on an incline of θ degrees may be determined according to Equation 2.

$$e_x(t) = Kg\sin q(t) \qquad \textbf{Equation 2}$$

As the acceleration due to gravity g is of the order of the maximum deceleration capable by vehicles during emergency braking, it is necessary to compensate for the error signal $e_x(t)$ in order to preserve the accuracy in the determination of the vehicle's deceleration when the vehicle travels on roads with a grade of more than a few degrees.

Compensation may be realized using changes in the y-axis signal $e_y(t)$ to detect and measure grade changes. Clearly the value of $e_y(t)$ will decrease when the vehicle travels along steeper grades, with the value of $e_y(t)$ when the vehicle travels along on an incline of θ degrees determined according to Equation 3.

$$e_y(t) = Kg\cos q(t) \qquad \textbf{Equation 3}$$

The magnitude of the x-axis error signal $|e_x(t)|$ may be determine from the y-axis signal $e_y(t)$ according to Equation 4.

$$|e_x(t)| = Kg\sin\left(\arccos\left(\frac{e_y(t)}{Kg}\right)\right) \qquad \textbf{Equation 4}$$

The sign of $e_x(t)$ cannot be determined from the y-axis signal $e_y(t)$ because $e_y(t)$ is the same regardless of whether the vehicle travels up or down and incline, while $e_x(t)$ is positive when the vehicle travels up an incline and negative when the vehicle travels down an incline. However, the sign of $e_x(t)$ often may be inferred from the change in the x-axis signal occurring when the vehicle moves from traveling on the level to on a grade. If an increase in the x-axis signal is occurs with a reduction in the y-axis signal then the vehicle is most likely traveling up an incline and $e_x(t)$ may be assumed positive; conversely, if a reduction in the x-axis signal is occurs with a reduction in the y-axis signal then the vehicle is most likely traveling down an incline and $e_x(t)$ may be assumed negative.

Obviously the reasoning presented above may fail if the driver brakes or accelerates rapidly as the vehicle moves away from the level. It may be possible to improve the likelihood of correctly inferring whether the vehicle is traveling up or down an incline by only analyzing the change in the x-axis signal when the y-axis signal first moves away from is maximum output level. The reasoning behind this is that the driver is much less likely to brake or accelerate exactly at the start of the grade change thus reducing driver interference in the inference.

Once a sign has been determined for the x-axis error signal $e_x(t)$, the error may be compensated for by subtracting the error signal from the x-axis signal.

4 Signal Conditioning

Signal conditioning stage is a combination of two stages: a low-pass filter stage and a post-filter amplification stage. A function block diagram for the signal conditioning stage is depicted below in Figure 4.

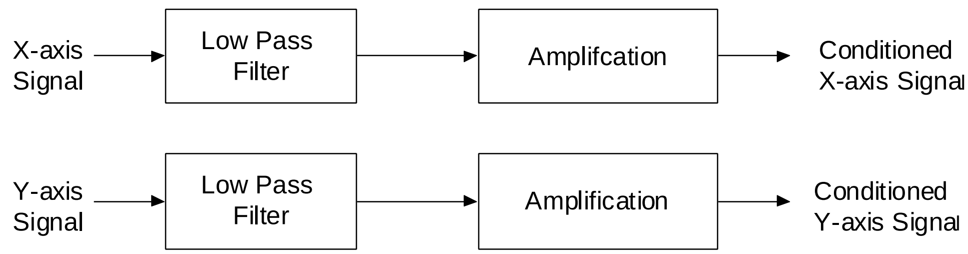

Figure 4: Signal Conditioning Function Block Diagram

The x-axis and y-axis signals will be conditioned differently to ensure each condition signal is suitable for the further processing required of it.

4.1 Filtering Stage

The accelerometer output signals will be filtered to increase the SNR and ensure the signal frequency spectrums are limited to avoid aliasing at later processing stages. Increasing the SNR will significantly improve device resolution, allowing smaller decelerations to be detected more accurately. Aliasing is primarily a concern at the data logger, which will operate at the lowest sampling rate. The data logger is anticipated to sample the deceleration signal at a sampling rate exceeding 40 Hz, requiring the deceleration signal frequency spectrum to be restricted primarily to frequencies below 20 Hz. A second order two-pole active low pass filter similar to that recommended by Analog Devices and depicted below in Figure 5 will be used.

The filter for the x-axis signal will be designed to achieve a 20 Hz bandwidth. Typical ADXL250 rms noise levels with a 20 Hz bandwidth is specified at less than 0.02 m/s^2, which will allow more than sufficient resolution. Should the two-pole filter provide insufficient signal attenuation beyond the 20 Hz bandwidth to avoid aliasing at the data logger, one or two additional poles may be added to the filter by concatenating additional filter circuitry at the output of the two-pole filter.

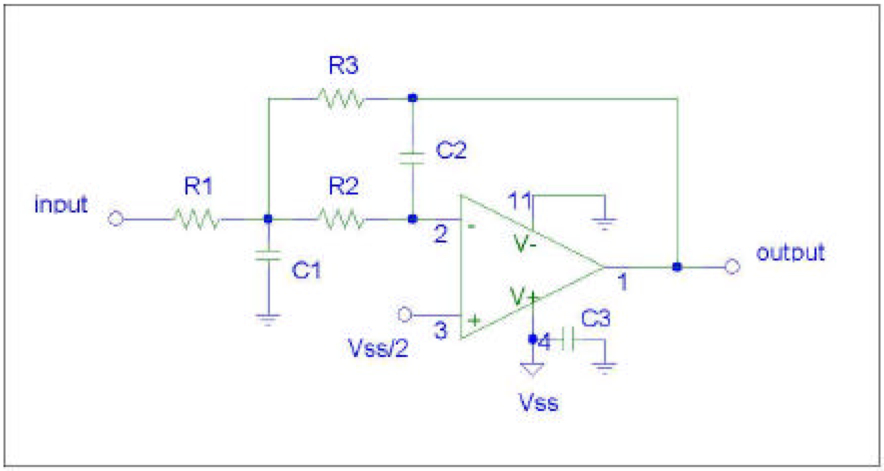

Figure 5: Two-Pole Active Low Pass Filter

Because the resolution of the y-axis acceleration must be significantly greater than the x-axis signal, the filter for the y-axis signal will be designed to achieve a 10 Hz bandwidth. Typical ADXL250 rms noise levels with a 10 Hz bandwidth is rated at less than 0.015 m/s^2, which should provide adequate resolution for resolving angles of inclination as low as 3°. When oriented along a 3° angle of inclination, the gravity error signal present in the x-axis signal is roughly 0.5 m/s^2. Thus, the ADI system will be limited in its maximum deceleration resolution to approximately 0.5 m/s^2. If necessary, a three or four-pole filter may be used instead to provide steeper roll-off beyond the 10 Hz stop band in order to achieve maximum signal resolution.

4.2 Amplification Stage

The filtered signals must be amplified prior to A/D conversion to improve device resolution. The ADXL250 provides a typical sensitivity of 38 ± 0.5 mV/g with a full-scale range of ±50 g. Since vehicle deceleration never exceeds ±1.5g except during collisions, it is desirable to map the ±50 g full-scale range onto a smaller amplified full-scale range to provide better resolution at the A/D converters. An amplification stage similar to that depicted below will be used. Note that the ADXL250 provides a nominal zero-acceleration output voltage of ½ V_{ss}.

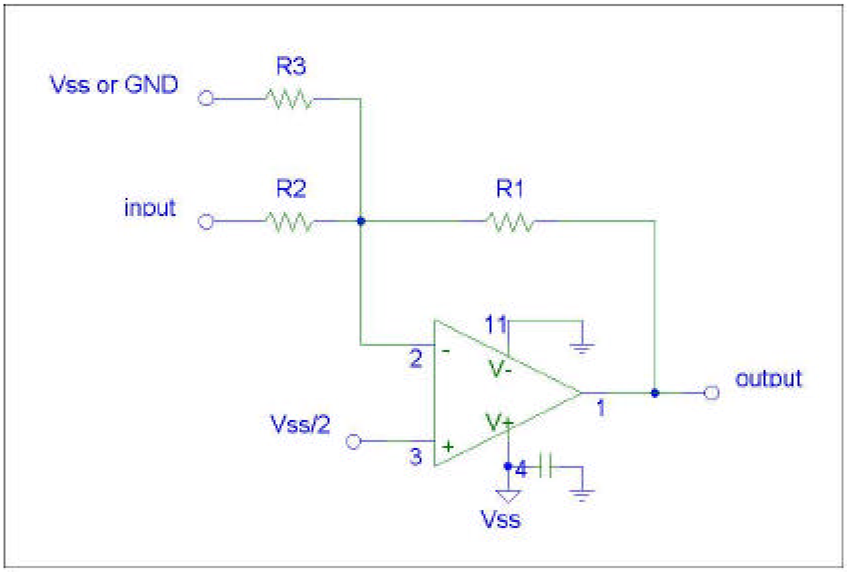

Figure 6: Amplifier Circuitry

The gain for the amplifier may be readily determined according to Equation 5.

$$Gain = -\frac{R_1}{R_2} \quad \textbf{Equation 5}$$

The value of resistor R_3 allows the zero-acceleration point to be adjusted upwards or downwards to exactly ½ V_{ss} should the zero-acceleration signal level from the ADXL250 deviate from the specified ½ V_{ss}. It is necessary to adjust the zero-acceleration signal level to exactly ½ V_{ss} to ensure only the acceleration signal is amplified and not the difference between the zero-acceleration signal level and the ½ V_{ss} reference level.

The op amps maximum output swing under normal operation should be restricted to ±2 volts to ensure the op amp operates within the linear region of operation. Gravity may result in an additional error signal appearing in the x-axis signal with a maximum magnitude of approximately 0.5 g under normal operating conditions. Since most vehicles cannot decelerate beyond approximately 1.2 g, a somewhat conservative ±2 g full-scale range is acceptable. The maximum safe gain required to achieve the desired full-scale range may be calculated according to as

$$Gain = \frac{2\text{ Volts}}{38\text{ mV / g} \times \text{Max Deceleration in g}} = \frac{2}{0.038 \times 2} \approx 26 \quad \textbf{Equation 6}$$

The ratio of R_1 and R_2 may be selected to provide the required gain of 26 according to Equation 5. The nominal values for R_1 and R_2 should be of the order of 100 kΩ to prevent the amplification stage from overloading the filter stage.

The greater resolution required for the y-axis signal requires the y-axis signal to be further amplified. It is desirable to provide sufficient gain so to ensure the maximum resolution available at the A/D converter slightly exceeds the resolution available from the filtered signal. Anticipating an 8-bit A/D converter providing 256 levels of quantization and requiring a resolution of 0.015 m/s^2, the maximum full-scale range for the amplified y-axis signal may be determined to be ½(0.015 x 256) = ±1.92 m/s^2. Such a full-scale range would provide accurate resolution of angles of inclination up to approximately 30°, which is sufficient for normal operating conditions. The gain required to achieve such a full-scale range may be calculated as

$$Gain = \frac{2\ \text{Volts}}{38\ \text{mV / g} \times \text{Max Deceleration in g}} = \frac{2}{0.038 \times 0.0195} \approx 270 \qquad \textbf{Equation 7}$$

4.3 Signal Conditioning Component Selection

High quality precision components must be used in constructing the signal conditioning stage since it is required that both signal conditioning paths similarly modify the input signals. The op amps used in constructing the filter and amplification stages need not provide a high slew rate since the ADXL250 has a nominal 3dB bandwidth of 1 kHz. Instead, op amps with stable temperature characteristics, large gain, and high common-mode rejection ratio will be preferred. As with all components selected for constructing the ADI system, it is important that the components provide minimal temperature drift because the ADI system will operate under automotive conditions.

5 Grade Compensation Stage

The non-linear relationship between the change in the y-axis signal and error in the x-axis signal resulting from the vehicle traveling on an incline prevents grade compensation from being readily performed in the Analog domain. Instead, a microcontroller or similar device will be required to perform grade compensation in the Digital domain. The functional block diagram for the grade compensation stage is depicted below in Figure 7.

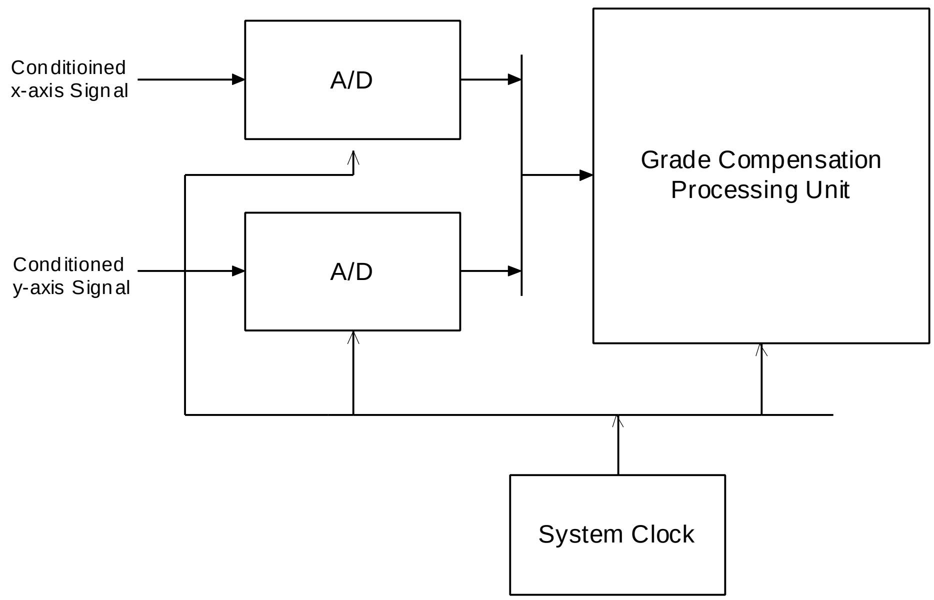

Figure 7: Grade Compensation Functional Block Diagram

5.1 Analog to Digital Conversion

The Analog-to-Digital conversion stage will use 8-bit ratiometric A/D converters operating from a 5 V supply shared with the ADXL250 accelerometer unit. The A/D converter sampling the x-axis signal will provide 256 quantization levels over the ±2.5g rail-to-rail acceleration range, providing a deceleration resolution of approximately 0.0195 g's or 0.2 m/s^2. The A/D converter samplings the y-axis signal will provide 256 quantization levels over the ±1.96 m/s^2 rail-to-rail acceleration range, providing a resolution of approximately 0.015 m/s^2 along the y-axis.

5.2 Grade Compensation Processing

The grade compensation unit must continuously sample the outputs from the A/D converters in order to detect changes in vehicle orientation and compensate for error in the deceleration signal.

A high level algorithmic outline of the grade compensation processing may be found in the following section. The function Error(y[n]) which takes as its argument a y-axis signal sample returns the magnitude of the error in the x-axis signal as determined from the argument value. The method by which the error magnitude is determined is most efficiently implemented by table lookup, with the y-axis sample value used to index a table of error magnitudes. The Error function will return

$$Error(y[n]) = C\sin\left(\arccos\left(\frac{y_0 - y[n]}{y_0}\right)\right)$$

where y_0 is the sampled 1g y-axis signal value and C is a constant selected to properly map the error onto the x-axis scale. Note that the error function returns zero when y[n] = 0.

5.3 Grade Compensation Algorithm

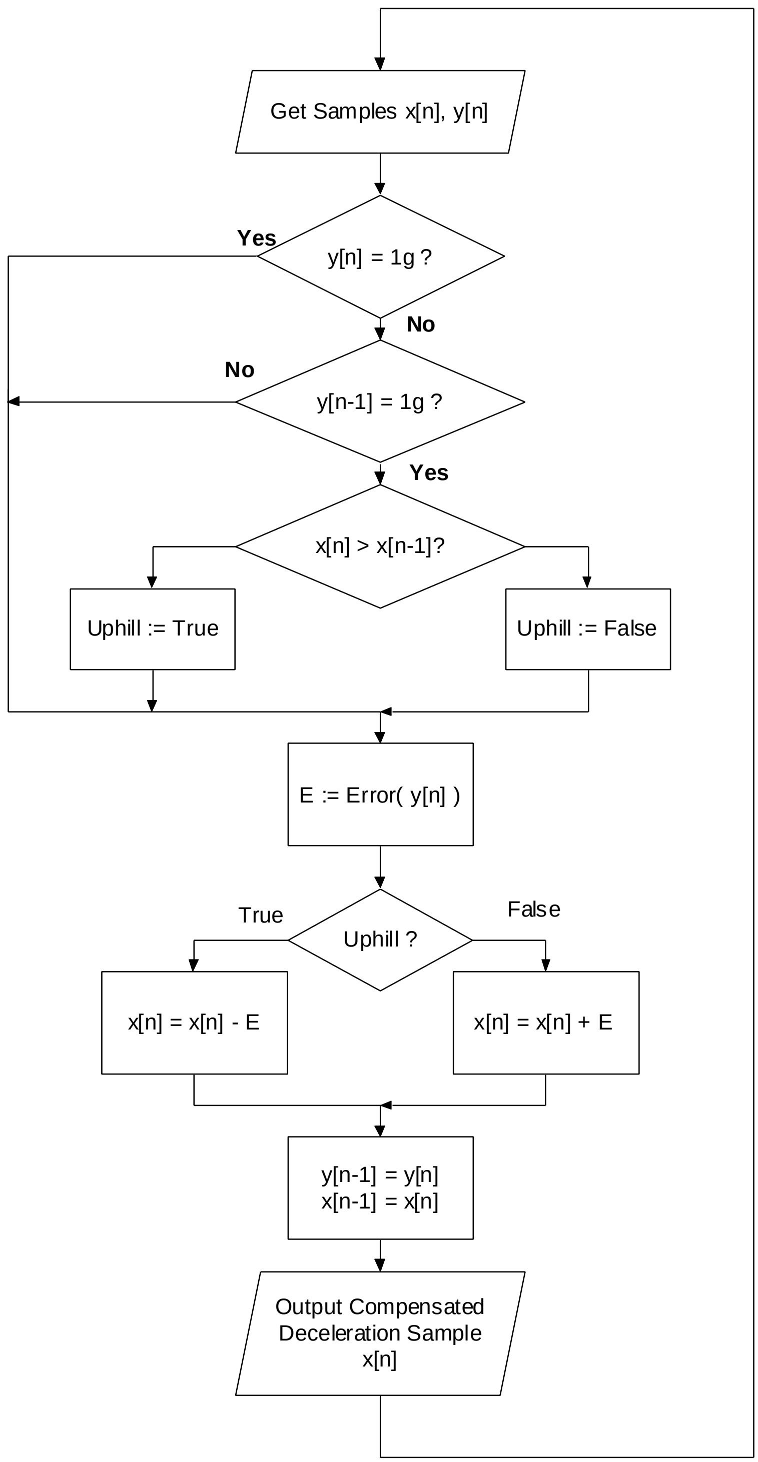

Figure 8: Grade Compensation Algorithm

6 Signal Analysis

Once the microcontroller has compensated for any grade, the signal is then analyzed to determine what output should be displayed. The compensated digitized deceleration level is compared to a sequence of increasing predetermined, digitized reference decelerations. Once a reference deceleration that the compensated deceleration does not exceed is determined, the corresponding encoded light level is outputted. Figure 9 indicates the algorithm used by the microcontroller to accomplish this.

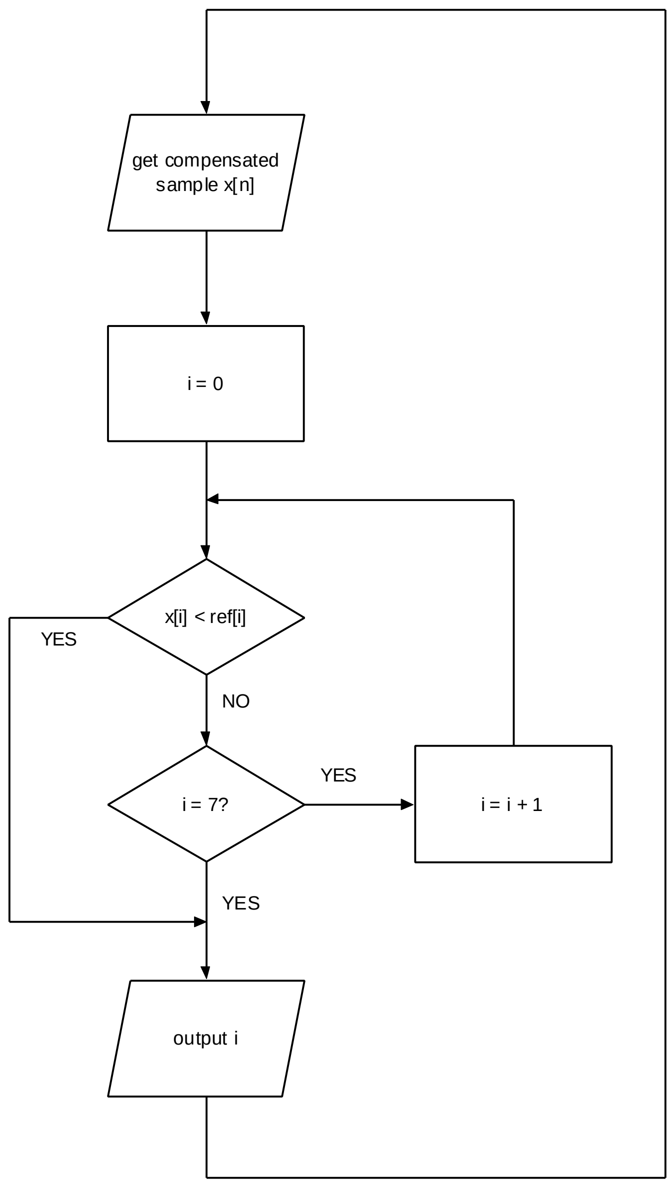

Figure 9: Algorithm for Determining Output Level

The threshold reference voltage selected for the first illumination level will be sufficiently large to prevent the lowest level from being erroneously activated as a result of noise or gravity errors below the minimum compensation level. The remaining reference voltages will be selected to provide a linear relationship between the vehicle deceleration and output illumination level.

The output of the signal analysis stage is a 3-bit binary encoded deceleration level, with the value 000_b representing no deceleration and 111_b representing full-scale deceleration. A digital signal is used for transmission from the Signal Analysis Stage to the Output Stage in order to minimize information loss due to signal degradation resulting from interference from other electrical systems in the vehicle.

7 Output Generation

7.1 Signal Decoding

The output generation stage will accept a 3-bit digital input corresponding to seven different levels of output to be displayed. The 3 bits will be analyzed by some digital logic circuitry to generate 7 binary signals, each used to control a switch which turns a light on or off. A symbolic depiction of this system is shown in Figure 10.

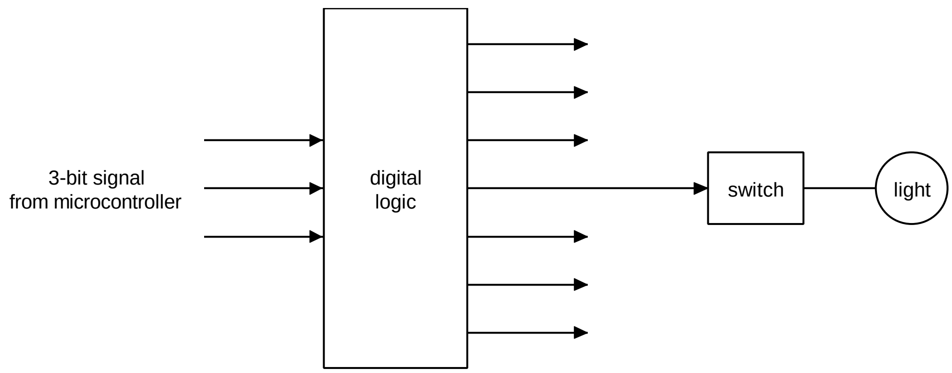

Figure 10: Output Signal Decoder

A switch is used here because the light display is likely to have high current requirements. The digital logic circuitry is not capable of delivering sufficient currents to drive the light sources; therefore, a switch is used to connect or disconnect the light display from a power source. The light will be composed of

7.2 Physical Output

Encased in a durable and lightweight plastic enclosure, the light system will be constructed as shown in Figure 11.

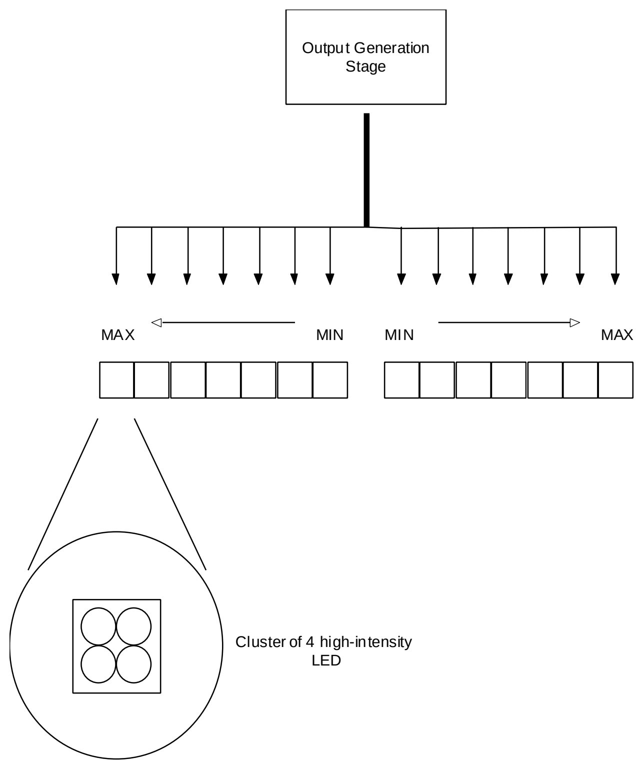

Figure 11: Light Display System

Coloured pieces of transparent plastic will cover the individual LED clusters. Amber coloured plastic will be used to cover the LED clusters illuminated during lower deceleration levels to indicate caution to rearward drivers, while red coloured plastic will be used to cover the LED clusters illuminated during greater decelerations.

8 System Power

The signal acquisition, conditioning, analysis, and data logging units of the ADI system will require 5V supply voltages. These voltages will be obtained through the vehicle's electrical system. The vehicle's electrical system provides approximately a 12 V supply voltage, so we will use 5V voltage regulators and voltage-divider networks to obtain a steady 5V signal. The voltage regulators should provide adequate protection against power fluctuations to ensure proper system operation.

Power for the display unit of the system will be provided by the part of the electrical system normally used to power the brake light mounted on a rear spoiler. Since the display unit has similar power requirements to a brake light, the electrical system should provide enough power to meet the varying demands of the display unit.

9 System Testing

9.1 Signal Acquisition Stage Testing

A signal is sensed by the sensor circuitry containing an accelerometer. The sensor circuitry will produce two signals, a horizontal and vertical component. To provide the necessary signals (g forces), sudden pushes and blows will be applied to the sensor in along with tilting the accelerometer to simulate hills and bumps. If functioning properly, corresponding analog signals from the sensor will be amplified and hooked up to an oscilloscope to display the amplified signal.

9.2 Signal Conditioning Stage Testing

A signal from the sensor will be fed into the conditioning stage. An oscilloscope will monitor the input and output signals to determine the difference between the unconditioned input signals and conditioned output signals. Normal installed system operating conditions will be simulated by tilting the sensor unit to simulate grade changes and using a shake or vibration table to simulate high frequency vehicle vibration and noise.

9.3 Signal Processing Stage Testing

The amplified signals from the sensor will be converted to digital format using an AD converter. The signals will then be fed into a microcontroller for further processing. The microcontroller will use these two signals to determine the actual horizontal acceleration by compensating for the error due to gravity on inclined surfaces. The actual horizontal acceleration may be stored to memory or outputted to an external device for data logging. The microcontroller will then output digital signals encoding the number of lights to be illuminated. Should the signal processing stage be competed prior to the signal acquisition and conditioning stages a function generator or RC network will be used to simulate input.

When applicable, the program written for the microcontroller will be tested by using a debugger and simulator.

9.4 Output Stage Testing

The microprocessor shall provide a digital signal to indicate the number of lights to be illuminated. The digital signal must be decoded and converted back to an analog signal to drive the output stage. The output stage will be tested using power supplies and simple circuitry to provide a suitable digital input signal. When functioning properly, the output stage will be further be tested by connecting the microcontroller and sensor and simulating normal operating conditions.

9.5 System Integration Testing

After each major stage is verified as operating correctly, system integration will be tested by connecting various subsystems and then testing the proper operation of the assembled subsystems. When the system is verified as operating within function specification, we shall commence system wide testing by mounting the assembled ADI system on a vehicle and observing operation under various driving conditions including:

- Decelerations due to gradual braking and stopping at stop signs or streetlights.
- Decelerations due to heavy breaking in simulated emergency situations.
- Vehicle operation and deceleration on various road grades.

10 Conclusion

We have presented the design specifications for the Automobile Deceleration Indication system through this document. The ADI system will be designed to meet the functional specifications presented in the Automobile Deceleration Indication System Functional Specifications. We plan to develop a prototype for the ADI system that adheres to the design specifications for the ADI system to prove the concept of our design and demonstrate the potential for the ADI system.

There is no question that safety was and continues to be a serious concern among all drivers. Even the most experienced and skilled drivers can find themselves in a potentially dangerous situation that results from actions of other drivers. We are confident that this system will not only be beneficial all drivers, but it can be seamlessly implemented on all vehicles while maintaining its economic viability. It is our mission to develop the ADI system into a revolutionary device responsible for the prevention of thousands of injuries, and perhaps even fatalities, that occur on the treacherous roads of today.

11 References

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Adel S. Sedra, Kenneth C. Smith. *Microelectronic Circuits*, 4th ed. Oxford University Press, London: 1997.

Thomas L. Floyd, David Buchla. *Basic Operational Amplifiers and Linear Integrated Circuits*, 2nd ed. Prentice Hall, New York: 1997.

Analog Devices Inc., *ADXL150/ADXL250 Accelerometers*, 1998.

Microchip Technologies Inc., *18-pin Flash/EEPROM 8-Bit Microcontrollers - PIC16F8X*, 1998.

Appendix A – ADXL150/ADXL250 DATASHEET

See attachment.

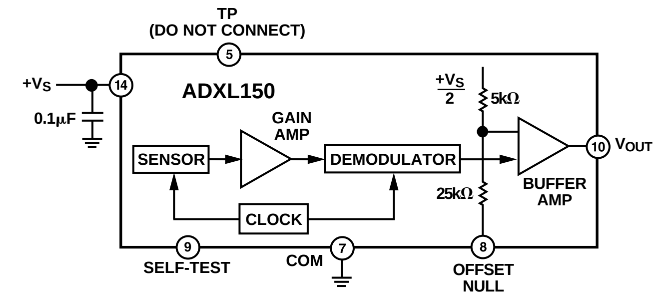
ANALOG DEVICES

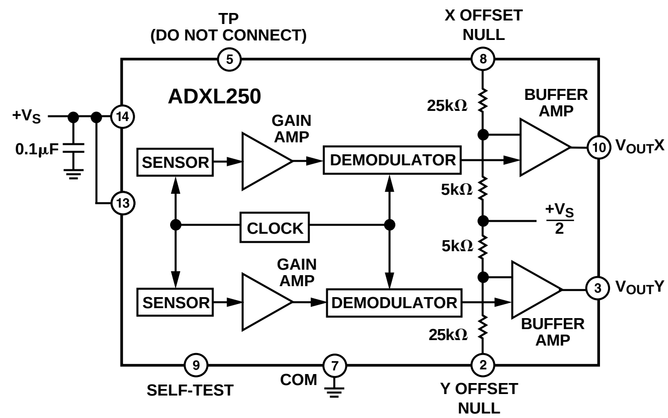
±5 *g* to ±50 *g*, Low Noise, Low Power, Single/Dual Axis *i*MEMS® Accelerometers

ADXL150/ADXL250

FEATURES
- **Complete Acceleration Measurement System on a Single Monolithic IC**
- **80 dB Dynamic Range**
- **Pin Programmable ±50 *g* or ±25 *g* Full Scale**
- **Low Noise: 1 m*g*/√Hz Typical**
- **Low Power: <2 mA per Axis**
- **Supply Voltages as Low as 4 V**
- **2-Pole Filter On-Chip**
- **Ratiometric Operation**
- **Complete Mechanical & Electrical Self-Test**
- **Dual & Single Axis Versions Available**
- **Surface Mount Package**

FUNCTIONAL BLOCK DIAGRAMS





GENERAL DESCRIPTION

The ADXL150 and ADXL250 are third generation ±50 *g* surface micromachined accelerometers. These improved replacements for the ADXL50 offer lower noise, wider dynamic range, reduced power consumption and improved zero *g* bias drift.

The ADXL150 is a single axis product; the ADXL250 is a fully integrated dual axis accelerometer with signal conditioning on a single monolithic IC, the first of its kind available on the commercial market. The two sensitive axes of the ADXL250 are orthogonal (90°) to each other. Both devices have their sensitive axes in the same plane as the silicon chip.

The ADXL150/ADXL250 offer lower noise and improved signal-to-noise ratio over the ADXL50. Typical S/N is 80 dB, allowing resolution of signals as low as 10 m*g*, yet still providing a ±50 *g* full-scale range. Device scale factor can be increased from 38 mV/*g* to 76 mV/*g* by connecting a jumper between V_{OUT} and the offset null pin. Zero *g* drift has been reduced to 0.4 *g* over the industrial temperature range, a 10× improvement over the ADXL50. Power consumption is a modest 1.8 mA per axis. The scale factor and zero *g* output level are both ratiometric to the power supply, eliminating the need for a voltage reference when driving ratiometric A/D converters such as those found in most microprocessors. A power supply bypass capacitor is the only external component needed for normal operation.

The ADXL150/ADXL250 are available in a hermetic 14-lead surface mount cerpac package specified over the 0°C to +70°C commercial and –40°C to +85°C industrial temperature ranges. Contact factory for availability of devices specified over automotive and military temperature ranges.

*i*MEMS is a registered trademark of Analog Devices, Inc.

REV. 0

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ADXL150/ADXL250–SPECIFICATIONS

(T_A = +25°C for J Grade, T_A = –40°C to +85°C for A Grade, V_S = +5.00 V, Acceleration = Zero *g*, unless otherwise noted)

Parameter	Conditions	ADXL150JQC/AQC Min	Typ	Max	ADXL250JQC/AQC Min	Typ	Max	Units
SENSOR								
Guaranteed Full-Scale Range		±40	±50		±40	±50		*g*
Nonlinearity			0.2			0.2		% of FS
Package Alignment Error[1]			±1			±1		Degrees
Sensor-to-Sensor Alignment Error						±0.1		Degrees
Transverse Sensitivity[2]			±2			±2		%
SENSITIVITY								
Sensitivity (Ratiometric)[3]	Y Channel				33.0	38.0	43.0	mV/*g*
	X Channel	33.0	38.0	43.0	33.0	38.0	43.0	mV/*g*
Sensitivity Drift Due to Temperature	Delta from 25°C to T_{MIN} or T_{MAX}		±0.5			±0.5		%
ZERO *g* BIAS LEVEL								
Output Bias Voltage[4]		$V_S/2 - 0.35$	$V_S/2$	$V_S/2 + 0.35$	$V_S/2 - 0.35$	$V_S/2$	$V_S/2 + 0.35$	V
Zero *g* Drift Due to Temperature	Delta from 25°C to T_{MIN} or T_{MAX}		0.2			0.3		*g*
ZERO-*g* OFFSET ADJUSTMENT								
Voltage Gain	Delta V_{OUT}/Delta $V_{OS\ PIN}$	0.45	0.50	0.55	0.45	0.50	0.55	V/V
Input Impedance		20	30		20	30		kΩ
NOISE PERFORMANCE								
Noise Density[5]			1	2.5		1	2.5	m*g*/√Hz
Clock Noise			5			5		mV p-p
FREQUENCY RESPONSE								
–3 dB Bandwidth		900	1000		900	1000		Hz
Bandwidth Temperature Drift	T_{MIN} to T_{MAX}		50			50		Hz
Sensor Resonant Frequency	Q = 5		24			24		kHz
SELF-TEST								
Output Change[6]	ST Pin from Logic “0” to “1”	0.25	0.40	0.60	0.25	0.40	0.60	V
Logic “1” Voltage		$V_S - 1$			$V_S - 1$			V
Logic “0” Voltage				1.0			1.0	V
Input Resistance	To Common	30	50		30	50		kΩ
OUTPUT AMPLIFIER								
Output Voltage Swing	I_{OUT} = ±100 µA	0.25		$V_S - 0.25$	0.25		$V_S - 0.25$	V
Capacitive Load Drive		1000			1000			pF
POWER SUPPLY (V_S)[7]								
Functional Voltage Range		4.0		6.0	4.0		6.0	V
Quiescent Supply Current	ADXL150		1.8	3.0				mA
	ADXL250 (Total 2 Channels)					3.5	5.0	mA
TEMPERATURE RANGE								
Operating Range J		0		+70	0		+70	°C
Specified Performance A		–40		+85	–40		+85	°C

NOTES

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

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

[3]Ratiometric: $V_{OUT} = V_S/2 + (\text{Sensitivity} \times V_S/5\text{ V} \times a)$ where a = applied acceleration in *g*s, and V_S = supply voltage. See Figure 21. Output scale factor can be doubled by connecting V_{OUT} to the offset null pin.

[4]Ratiometric, proportional to $V_S/2$. See Figure 21.

[5]See Figure 11 and Device Bandwidth vs. Resolution section.

[6]Self-test output varies with supply voltage.

[7]When using ADXL250, both Pins 13 and 14 must be connected to the supply for the device to function.

Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*

Acceleration (Any Axis, Unpowered for 0.5 ms) . . . . . . 2000 *g*
Acceleration (Any Axis, Powered for 0.5 ms) . . . . 500 *g*
$+V_S$ . . . . –0.3 V to +7.0 V
Output Short Circuit Duration
(V_{OUT}, V_{REF} Terminals 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 indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Drops onto hard surfaces can cause shocks of greater than 2000 *g* and exceed the absolute maximum rating of the device. Care should be exercised in handling to avoid damage.

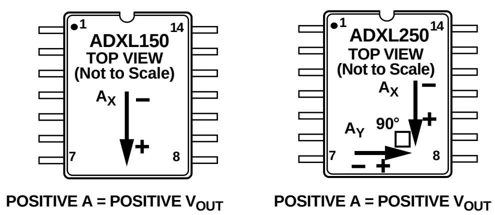


Figure 1. ADXL150 and ADXL250 Sensitive Axis Orientation

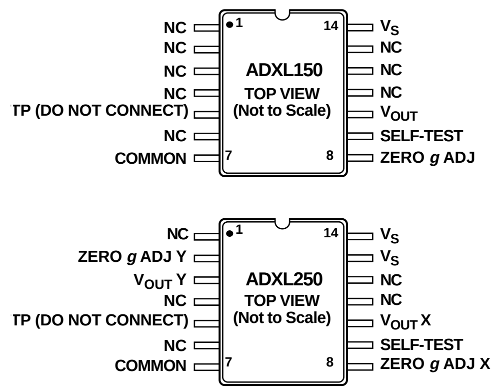
Package Characteristics

Package	θ_{JA}	θ_{JC}	Device Weight
14-Lead Cerpac	110°C/W	30°C/W	5 Grams

ORDERING GUIDE

Model	Temperature Range
ADXL150JQC	0°C to +70°C
ADXL150AQC	–40°C to +85°C
ADXL250JQC	0°C to +70°C
ADXL250AQC	–40°C to +85°C

PIN CONNECTIONS



NC = NO CONNECT

NOTE: WHEN USING ADXL250, BOTH PINS 13 AND 14 NEED TO BE CONNECTED TO SUPPLY FOR DEVICE TO FUNCTION

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 ADXL150/ADXL250 feature 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.

Typical Characteristics (@+5 V dc, +25°C with a 38 mV/*g* Scale Factor unless otherwise noted)

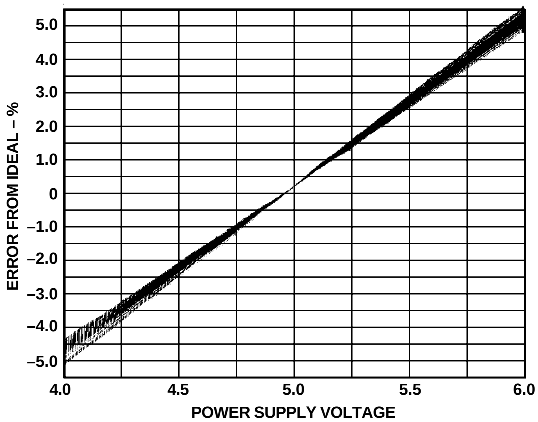


Figure 3. Typical Sensitivity Error from Ideal Ratiometric Response for a Number of Units

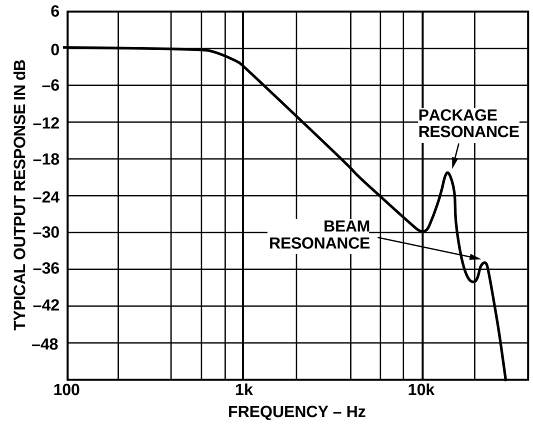


Figure 6. Typical Output Response vs. Frequency of ADXL150/ADXL250 on a PC Board that Has Been Conformally Coated

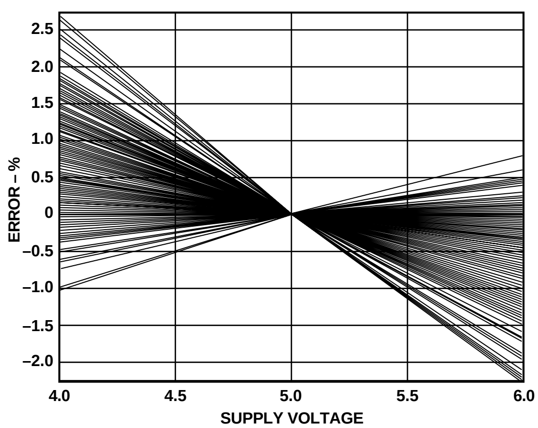


Figure 4. Offset Error of Zero g Level from Ideal $V_S/2$ Response as a Percent of Full-Scale for a Number of Units

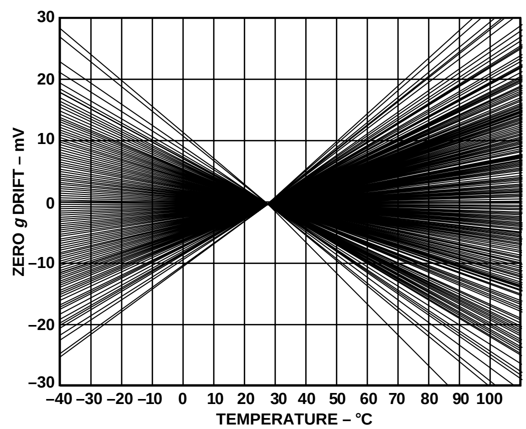


Figure 7. Typical Zero g Drift for a Number of Units

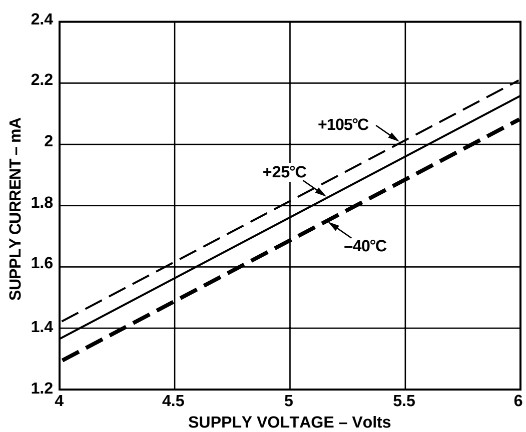


Figure 5. Typical Supply Current vs. Supply Voltage

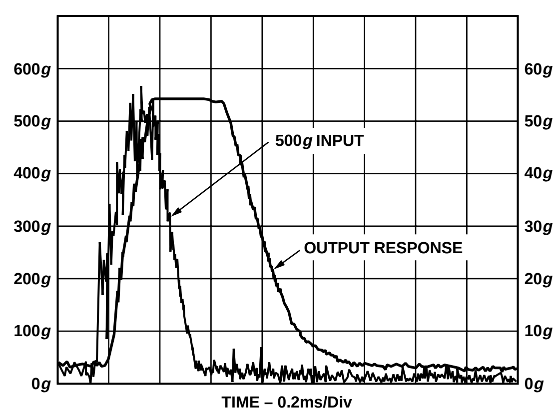


Figure 8. Typical 500 g Step Recovery at the Output

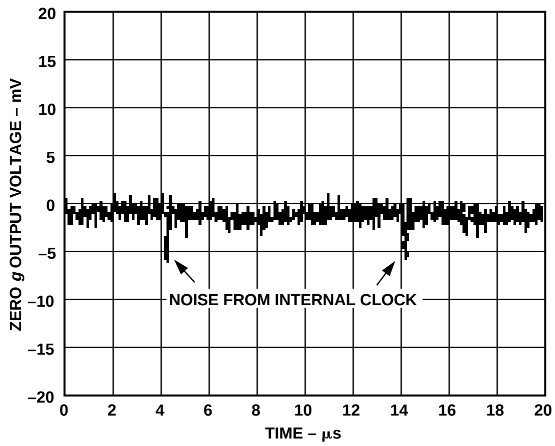


Figure 9. Typical Output Noise Voltage with Spikes Generated by Internal Clock

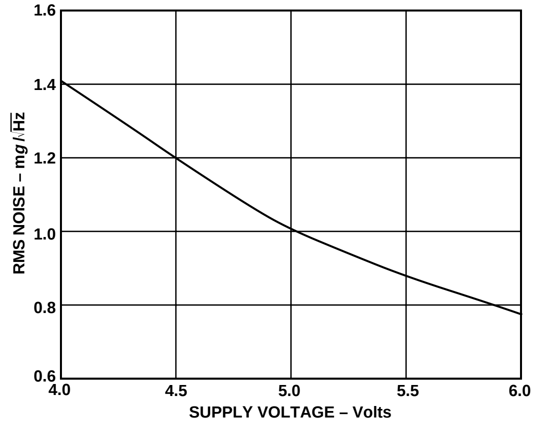


Figure 12. Noise vs. Supply Voltage

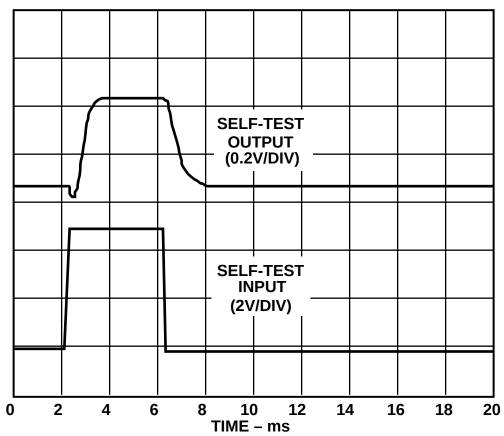


Figure 10. Typical Self-Test Response

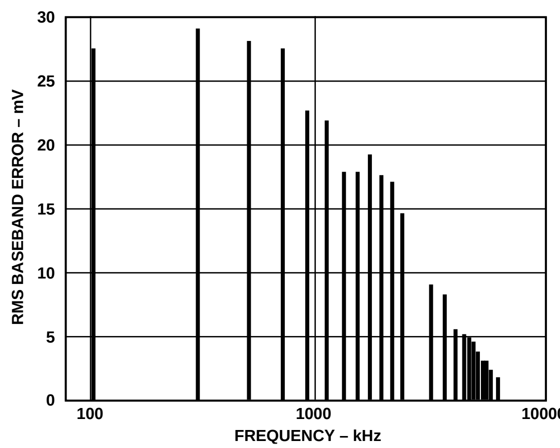


Figure 13. Baseband Error Graph

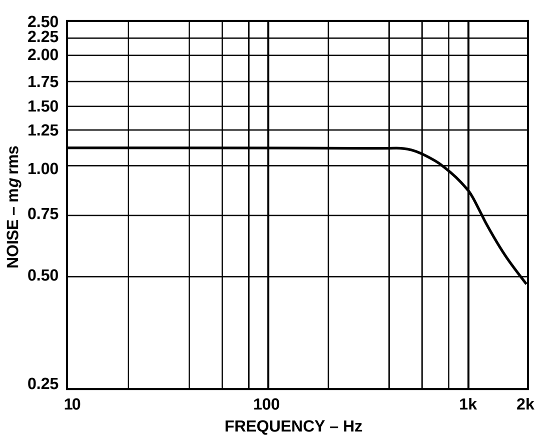


Figure 11. Noise Spectral Density

Figure 13 shows the mV rms error in the output signal if there is a noise on the power supply pin of 1 mV rms at the internal clock frequency or its odd harmonics. This is a baseband noise and can be at any frequency in the 1 kHz passband or at dc.

Appendix B – OUTPUT STAGE DECODER LOGIC

The following schematic depicts the Output Stage logic for decoding the light illumination levels provided by the Signal Analysis Stage.

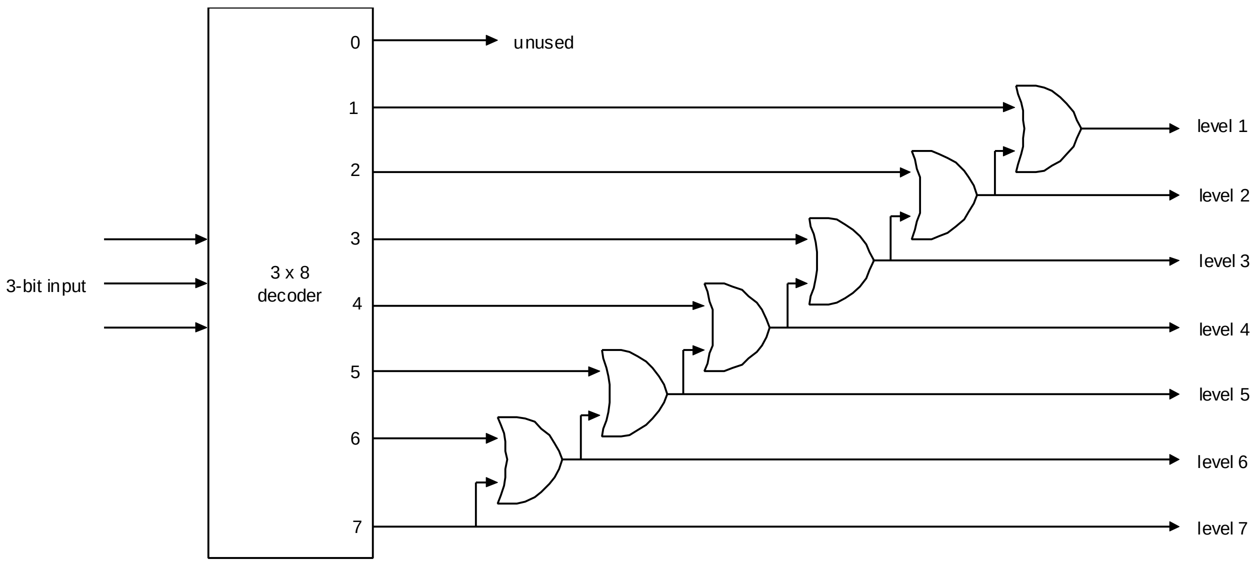


Figure 12: Light Illumination Level Decoder Logic