ANALOG DEVICES

TECHNICAL NOTE

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USING THE ADXL202 ACCELEROMETER AS A MULTIFUNCTION SENSOR (TILT, VIBRATION AND SHOCK) IN CAR ALARMS

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By using an intelligent algorithm, the ADXL202 (±2 g dual axis accelerometer) can serve as a low cost, multifunction sensor for vehicle security systems, capable of acting simultaneously as a shock/vibration detector as well as a tilt sensor (to detect towing or jacking up of the car). The accelerometer's output is passed through two parallel filters. A bandpass filter to extract shock/vibration information, and a low pass filter to extract tilt information. This application note describes the basics of such an implementation.

INTRODUCTION

The ADXL202 is a low cost, low power, complete dual axis accelerometer with a measurement range of ±2 *g*. The ADXL202 outputs analog and digital signals proportional to acceleration in each of the sensitive axes (see Figure 1).

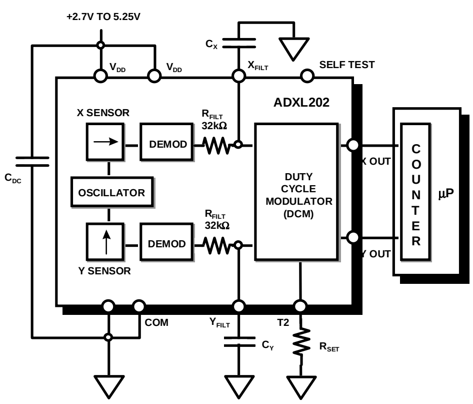

Figure 1. ADXL202 Block Diagram

Currently automotive security systems use shock/vibration sensors to detect collision or forced intrusion into the car. Typically, these sensors are based on magneto-inductive sensing. Sensors of this type generally have adequate sensitivity, but fall short in other areas. Often a fair amount of signal conditioning and trimming is required between the shock sensor and microcontroller due to variations in magnetic material and Hall effect sensor sensitivity and their frequency response is fairly unpredictable due to inconsistency in mounting. In addition such sensors have no response to gravity-induced acceleration, so they are incapable of sensing inclination (a static acceleration). Tilt sensing is the most direct way of detecting if a vehicle is being jacked up, about to be towed, or being loaded onto a flatbed truck. Some of the most common methods of car theft today.

The ADXL202 is a true accelerometer, easily capable of shock/vibration sensing with virtually no external signal conditioning circuitry. Since the ADXL202 is also sensitive to static (gravitational) acceleration, tilt sensing is also possible. Tilt sensing requires a very low noise floor which usually necessitates restricting the bandwidth of the accelerometer, while shock/vibration sensing requires wide bandwidth. These conflicting requirements may be met using clever design techniques.

PRINCIPLE OF OPERATION

The ADXL202 is set up to acquire acceleration from 0 to 200 Hz (the maximum frequency of interest). Figure 2 shows a block diagram of the system. The accelerometer's output is fed into two filters; a low pass filter with a corner frequency at 12.5 Hz used to lower the noise floor sufficiently for accurate tilt sensing, and a band pass filter to minimize the noise in the shock/vibration pass band of interest. The low pass filtered (tilt) output then goes to a differentiator (described in the Tilt Sensing section) where the determination is made as to whether the accelerometer actually sensed tilt or some other event such as noise or temperature drift. Then an auto-zero block performs further signal processing to reject temperature drift. The band pass filtered output goes to an integrator (described in the

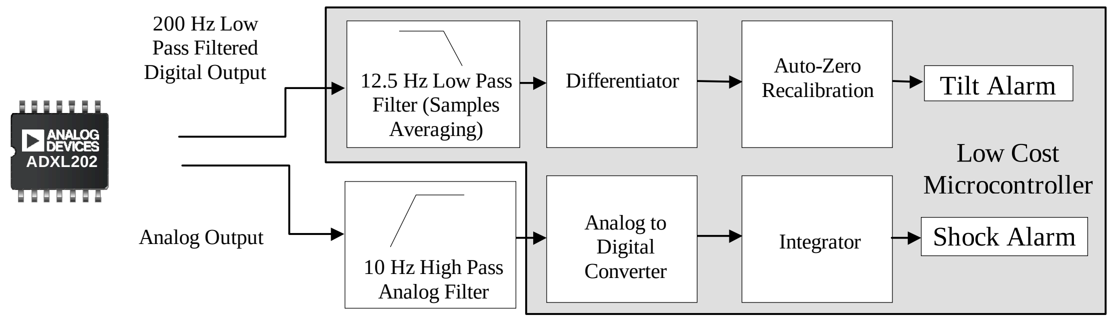

Figure 2. Shock and Tilt Sensing Using the ADXL202

Shock Sensing section) that measures vibrational energy over a small period of time (40 ms). A decision as to whether or not to set off the alarm may then be made by the microcontroller. Most of these tasks are most easily implemented in the digital domain and require very little computational power.

Since the two measurements (shock/vibration and tilt) are basically exclusive and only share a common sensor, their respective signal processing tasks will be described separately.

TILT SENSING

FUNDAMENTALS

The alarm system must detect a change in tilt slow enough to be the result of the vehicle being towed or jacked up, but must be immune to temperature changes and movement due to passing vehicles or wind. Note that the ADXL202 is most sensitive to tilt when its sensitive axes are perpendicular to the force of gravity, i.e., parallel to the earth's surface. Figure 3 shows that the change in projection of a 1 *g* gravity-induced acceleration vector on the axis of sensitivity of the accelerometer will be more significant if the axis is tilted 10 degrees from the horizontal than if it is tilted by the same amount from the vertical.

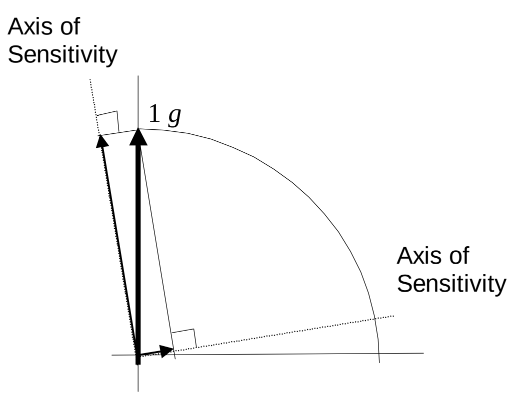

Figure 3. Tilt Sensitivity

However, the car may not always be level when the alarm is activated, and while the zero *g* offset can be recalibrated for any initial inclination, effectively the farther from the horizontal the axes of sensitivity are, the less sensitive the system will be to tilt (see ADXL202 datasheet, page 9). In most cases, this should not be of great concern, since the sensitivity only declines by about 2.5 m*g* per degree of tilt when inclination goes from zero (horizontal) to thirty degrees of tilt. Nevertheless, installation guidelines should recommend that the tilt sensing module containing the accelerometer be mounted such that the axes of sensitivity be as level as possible.

IMPLEMENTATION

In general we are interested in knowing if the inclination of the car has changed more than ±5 degrees from it's inclination when initially parked. When the car is turned off, a measurement of the car's inclination is made. If the car's inclination is changed by more than ±5 degrees, an alarm is triggered. Alternatively, the rate of change of tilt may be evaluated and if its absolute value is above 0.2 degrees per second for several seconds the alarm may be triggered.

Each technique has certain advantages. The former algorithm is better at false alarm rejection due to jostling of the car, while the rate of change algorithm may be set up to react more quickly. Algorithms using a combination of both techniques may be used as well. It is left to the reader to decide which technique is best for their application. While all of the concepts presented here are valid for both algorithms, for consistency this application note will describe the former (absolute inclination) algorithm.

For the purpose of the following discussion, we will assume a less than perfect tilt sensitivity for the accelerometer of 15 m*g* per degree of tilt, or 75 m*g* for 5 degrees. The ADXL202 will be set up to have a bandwidth of 200 Hz so that vibration may be detected. A 200 Hz bandwidth will result in a noise floor of:

$$\text{Noise} = 500\ \mu g/\sqrt{\text{Hz}} \times (\sqrt{200 \times 1.5})\ \text{rms}$$
$$\text{Noise} = 8.5\ \text{m}g\ \text{rms}$$

or 34 m*g* peak-to-peak of noise (using a peak-to-peak to rms ratio of 4:1), well within our 75 m*g* requirement. For reliability purposes, we would like to have a noise floor about 10 times lower than this, or around 8 m*g*. Since towing a car takes at least a few seconds, we are free to narrow the bandwidth to lower the noise floor. An analog or digital low pass filter may be used, but since low pass filtering in the digital domain is very simple, it is the preferred method. By taking the average of 16 samples we reduce the effective bandwidth to 12.5 Hz (200 Hz/16 samples). The resulting noise performance is approximately 8.7 m*g* peak-to-peak, close enough to our target.

Lowering the noise floor even further, by taking up to 128 samples for example, would result in about 3 m*g* peak-to-peak of noise, which would allow us to easily detect the 15 m*g* of static acceleration resulting from a change in tilt of less than a degree.

The typical zero *g* drift due to temperature for the ADXL202 is 2 m*g*/°C. Since our trigger point for a tilt alarm could be as low as 15 m*g*, it is conceivable that temperature drift alone would cause a false alarm (a car parked overnight could easily experience more than 7.5 °C in ambient temperature change). Therefore we will include a differentiator to reject temperature drift.

In the event of the car being jacked up or lifted for towing, we would expect the rate of change in tilt to be faster than five degrees or 75 m*g* per minute (or 1.25 m*g* per second). Each time the acceleration is measured it is compared to the previous reading. If the change is less than 1.25 m*g* per second we know that the change in accelerometer output is due to temperature drift. We can now add an auto-zero block that adjusts our "zero *g*" reference (that is the static acceleration sensed when the car was initially parked) to compensate for zero *g* drift due to temperature.

SHOCK SENSING

Generally for automotive shock/vibration sensing we are interested in signals between 10 and 200 Hz. Since the response of the ADXL202 extends from DC to 5 kHz, a band pass filter will have to be added to remove out of band signals. This band pass filter is most easily implemented in the analog domain (Figure 4 shows a simple 10 Hz high pass filter). When coupled with the 200 Hz low pass filter (from Xfilt and Yfilt on the ADXL202), a 10 to 200 Hz bandpass filter is realized.

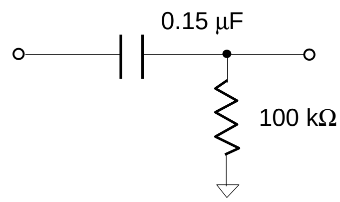

Figure 4. 10 Hz High Pass Filter

While analog bandpass filtering is very simple and requires no software overhead from the microcontroller, it does necessitate having an analog to digital converter. Today, even low cost microcontrollers can commonly be found, integrating an A to D converter on board. Bandpass filtering in the digital domain may be more effective, but may require a more powerful processor than one normally finds in automobile security systems. There are several methods for implementing band pass filters in the digital domain. Specific recommendations will not be given here since processor selection will influence what method will be most efficient.

Whether a digital or analog bandpass filter is used, the Nyquist criteria for signal sampling must be satisfied. That is that we must sample at at least twice the maximum frequency of interest. Sampling at 400 Hz (for our 200 Hz pass band) gives us one sample every 2.5 ms. Our very simple software integrator will take the sum of the absolute value of 16 samples and evaluate if there is sufficient energy in that 40 ms period of time to warrant setting off the alarm (i.e. is the sum of 16 samples greater than some set point). It is assumed that no events will be missed in 40 ms.

DESIGN TRADE-OFFS

The ADXL202 has digital (Pulse Width Modulated) as well as analog (312 mV/*g*) outputs. In theory, either output may be used. Using the PWM interface for tilt sensing is recommended for two reasons:

1. We are interested in very small acceleration signals (on the order of 3 m*g*). This would correspond to approximately .94 mV. Probably not resolvable by the on board A to D converter of any microcontroller likely to be used in this application. The resolution of the pulse width modulator of the ADXL202 is around 14 bits. Sufficient for resolution of 3 m*g* acceleration signals.

2. All signal processing will be done in the digital domain.

An analog interface for the shock/vibration sensor is recommended since, as previously mentioned, bandpass filtering in the digital domain may be beyond the capability of many microcontrollers.

In addition using the PWM interface to acquire 200 Hz bandwidth requires that the PWM frequency be at least 4 Khz. 10 bit resolution implies that the microcontroller have a timer resolution of approximately 250 ns. Once again, probably beyond the capability of most microcontrollers.