Accelerometer

What is an Accelerometer?

An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration. These sensors are used in a variety of ways from space stations to handheld devices, and there's a good chance you already own a device with an accelerometer in it. For example, almost all smartphones today house an accelerometer. They help the phone know whether it undergoes acceleration in any direction, and it’s the reason why your phone’s display switches on when you flip it. In an industry setting, accelerometers help engineers understand a machine's stability and enable them to monitor for any unwanted forces/vibrations.

How does an accelerometer work?

An accelerometer works using an electromechanical sensor that is designed to measure either static or dynamic acceleration. Static acceleration is the constant force acting on a body, like gravity or friction. These forces are predictable and uniform to a large extend. For example, the acceleration due to gravity is constant at 9.8m/s, and the gravitation force is almost the same at every point on earth.

Dynamic acceleration forces are non-uniform, and the best example is vibration or shock. A car crash is an excellent example of dynamic acceleration. Here, the acceleration change is sudden when compared to its previous state. The theory behind accelerometers is that they can detect acceleration and convert it into measurable quantities like electrical signals.

Accelerometers Types:

There are two types of piezoelectric accelerometers (vibration sensors). The first type is a "high impedance" charge output accelerometer. In this type of accelerometer the piezoelectric crystal produces an electrical charge which is connected directly to the measurement instruments. The charge output requires special accommodations and instrumentation most commonly found in research facilities. This type of accelerometer is also used in high temperature applications (>120C) where low impedance models can not be used.

The second type of accelerometer is a low impedance output accelerometer. A low impedance accelerometer has a charge accelerometer as its front end but has a tiny built-in micro-circuit and FET transistor that converts that charge into a low impedance voltage that can easily interface with standard instrumentation. This type of accelerometer is commonly used in industry. An accelerometer power supply like the ACC-PS1, provides the proper power to the microcircuit 18 to 24 V @ 2 mA constant current and removes the DC bias level, they typically produces a zero based output signal up to +/- 5V depending upon the mV/g rating of the accelerometer. All OMEGA(R) accelerometers are this low impedance type.

Key Applications of Accelerometers:

Accelerometers find many applications in industries. As already discussed, you can find them in the most complex machines to your handheld devices. Let’s look at some of the real-world applications of accelerometers. Digital Devices: Accelerometers in smartphones and digital cameras are responsible for rotating the display based on the orientation you hold it.

Vehicles: The invention of airbags have saved millions of lives over the years. Accelerometers are used to trigger the airbags as the sensor would send a signal when it experiences a sudden shock. Drones: Accelerometers help drones to stabilize their orientation mid flight. Rotating Machinery: Accelerometers used in rotating machines detect undulating vibrations. Industrial Platforms: To measure platform stability or tilt. Vibration Monitoring: Machines that move generate vibrations, and these vibrations can be harmful to the machines if left to amplify without supervision. Accelerometers are useful in monitoring vibrations and are increasingly used in industrial plants, turbines, etc.

Vibration Sensor Vs. Accelerometer:

The device that you see as a vibration sensor is nothing but an accelerometer. Since accelerometers are extremely good at measuring the velocity change, this trait is best used to measure vibrations as the velocity is always constantly changing.

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Acceleration:

Acceleration is the rate of change of velocity (the derivative of velocity) with respect to time. It is a vector which
has magnitude and direction relative to the axis of sensitivity or other reference frame. The units are length/time2. Gravity ìgî is
an acceleration.

Bandwidth:

This is the frequency range that the sensor operates in. Freescale accelerometers have a frequency range from DC
to the mechanical resonant frequency (-3dB) defined by the sensor. This frequency range can be limited by adding an external
filter on the output of the X, Y and Z axes. Some of the accelerometers already have this filter internally built in, and others have
only an internal resistor which requires the consumer to choose the bandwidth desired by choosing the capacitor value.

Cross-axis Sensitivity:

The output that is subjected on the sensing axis from accelerations on a perpendicular axis, expressed
as a percentage of the sensitivity. Each axis has two cross axis sensitivities:
X: SXY, SXZ
Y: SYZ, SYX
Z: SXY, SZX
The first subscript is the sense axis and the second subscript is the off-axis direction.

$$Sxcross = (Sxy / Sx) * 100$$
$$Sxcross = (Sxz / Sx) * 100$$

ESD Tolerance:

The device will remain within the specification after an electrostatic shock that is less than the specified ESD
Tolerance given for the accelerometer. The human body model is used where an ESD pulse is the equivalent of that produced
by a person electrically charged.

G-level:

This refers to the acceleration value. +1 g is the acceleration measurement for gravity which is equal to 9.81m/s2

g-Select:

A feature on the accelerometer device that allows for the selection between more than one sensitivity. Depending on
the logic of this input the internal gain is changed allowing the accelerometer to function with a higher or lower acceleration range.

Noise:

Noise determines the minimum resolution of the sensor. The noise floor can be lowered by lowering the bandwidth.

Noise Density:

The power spectral density is measured in $g / \sqrt{Hz}$.
When this value is multiplied by the square root of the measurement bandwidth, this result is the RMS acceleration noise of the
sensor at nominal VDD and temperature. Accelerations below this value will not be resolvable.

Non-linearity:

The transfer function of the sensor (input/output relationship) is not perfectly linear. The non-linearity is the maximum deviation of output voltage from a best fit straight line, which is divided by the sensitivity of the device. This is expressed as a percentage of Full-Scale Output in g's. The method for calculating the non-linearity is shown below.

$$\text{Non linearity} = \text{MaximumDeviation}\ (g) / \text{FullScaleOutput}\ (g) * 100\%$$

Offset:

Offset refers to the DC output level of the accelerometer when no motion or gravity is acting on it, often called the 0g-offset.

Offset Calibration:

This is a technique used to set the 0g-offset to store the known offset voltage value when there is no motion or gravity acting on the accelerometer. This voltage value is subtracted off when taking acceleration measurements for accuracy. The offset value can vary device-to-device due to trim errors, mechanical stress and temperature changes.

Offset vs. Temperature:

The maximum change in the nominal zero-g output over the full operating temperature range.

Operating Temperature:

This is the temperature range that the device will meet the performance specifications.

Power Consumption:

This is specified device-to-device, but can be minimized by using power cycling techniques.

Ratiometricity:

This means the output offset voltage and sensitivity will scale linearly with applied supply voltage. As the supply voltage increases, the sensitivity and offset increases, and as the supply voltage decreases, the sensitivity and offset decreases.

Ratiometric Error:

Ideally, the sensor is ratiometric which means that the output scales by the same ratio that the VDD changes. Ratiometric error is defined as the difference between the ratio that 0g offset or sensitivity changed and the ratio that VDD changed, expressed as a percentage.

Offset Ratiometric Error Calculation

Error @ 1.03VDD = (Offset @ 1.03V DD / Offset @ 1.0V DD - 1.03) * 100%

Sensitivity Ratiometric Error Calculation

Error @ 0.93VDD = (Sensitivity @ 0.93VDD/Sensitivity @ 1.0VDD - 0.93) * 100%

Resolution:

The smallest detectable increment in acceleration. It is necessary to know what the smallest change is that needs to be detected. The accelerometer bandwidth will determine the measurement resolution, but filtering can be used to lower the noise floor and improve resolution further. The resolution can be improved by decreasing the bandwidth of the output low-pass filter. The trade-off with better resolution is a longer enable time. The resolution is calculated by the following equation:

$$R = N \times \sqrt{BW_{LPF}} \times 1.6$$

where N is the power spectral density noise in g / √Hz. The power spectral density noise value is characteristic of the accelerometer.

N = 350 g / √Hz for X, Y and Z; characteristic of the MMA73x0L.

NOTE: If the resolution of the A/D converter is less than the resolution calculated for the accelerometer, then the system will be limited by the A/D converter. Otherwise the limitation is due to the noise and filter using the equations above.

Self-Test:

This is a feature that provides verification of the mechanical and electrical integrity of the accelerometer. This feature is critical in applications such as hard disk drive protection where system integrity must be ensured over the life of the product. If holding the accelerometer upside down, then the Z-axis output is -1g. When the self-test function is activated, an electrostatic force is applied to each axis to cause it to deflect +1g and the final output should return to 0g in the Z-axis.

Sensitivity:

The output voltage change per unit of input acceleration at nominal VDD and temperature, measured in mV/g (Voltage Output per g).