Measuring AC Accelerations: To Calibrate or Not to Calibrate?

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For applications such as inclinometers, the dc response of an accelerometer is the signal of interest, as the application requires sensing small changes in the static accelerometer output. In most applications, such as platform stabilization, downhole directional drilling, crane stability systems, and in the construction industry for leveling in road graders and surveying equipment, the inclination change can be assumed to be quasistatic, as the time scales involved in change of inclination are typically much smaller than the bandwidth of the accelerometers. However, in applications such as vibration monitoring and structural health monitoring (SHM), the ac response of an accelerometer also becomes important, as the signals of interest may have a frequency spectrum with power spread over a wide range of frequencies.

Since vibration is periodic, spectral analysis offers a convenient way to characterize the vibration profile (the relationship between vibration, magnitude, and frequency). Every piece of moving equipment will have its own vibration profile, with spectral tones often representing the natural resonance frequencies of the equipment. Knowing the accelerometer's frequency response of sensitivity, for example, how the sensitivity varies as a function of frequency of applied input vibration, is necessary to scale the frequency content of the accelerometer output from a voltage PSD [V/√Hz] to acceleration PSD [*g*/√Hz]. The ADXL354 and ADXL355 are part of a new family of low noise, low power MEMS accelerometers, that enable low vibration level monitoring applications such as structural health monitoring. This article discusses the ac response of these accelerometers and factors that should be taken into account for deciding whether calibrating the accelerometer output is necessary in such applications.

Factors Contributing to AC Response

Both the ADXL354 and ADXL355 accelerometers use an analog low-pass, antialiasing filter to reduce out of band noise. The analog antialiasing filter is a sinc3 filter, and provides a fixed bandwidth (3 dB corner) of approximately 1.5 kHz. This limits the bandwidth in the ADXL354 and the ADXL355, and additionally, filters out aliasing noise from the internal, 20-bit, Σ-Δ analog-to-digital converter (ADC) in the ADXL355. The ADXL355 also incorporates an additional digital filter stage that consists of a low-pass decimation filter and a bypassable high-pass filter. A combination of all these filter stages defines the ac response of these devices. These filter stages effectively attenuate the sensitivity of the ADXL354 and the ADXL355 outside the 3 dB corner. The MEMS sensor used in the ADXL354 and ADXL355 has a resonance frequency of approximately 2.5 kHz on the X and Y-axis, and 2.1 kHz on the Z-axis, thereby causing a resonant enhancement of sensitivity around the sensor's resonance frequency.

Measurement of AC Sensitivity

A sinusoidal sweep vibration test is performed to evaluate the sensor's frequency response. The accelerometer is bolted to a fixture and mounted on an Unholtz-Dickie model 20 shaker system. A reference accelerometer (PCB 320B14) is used for calibration of the shaker excitation, along with an Endevco model 133 signal conditioner. For the ADXL354, a vibration research VR9500 is used as a vibration controller and data acquisition system. For the ADXL355, an NI PCI 7850R is used as the data acquisition system. The frequency of the sinusoidal vibration signal is swept from 30 Hz to 5 kHz. The mounting of the accelerometer is changed after performing measurements to align a different axis of sensitivity to the axis of vibration of the shaker system.

ADXL354

The parts were operated in a ±8 *g* range, with a 1 *g* peak excitation on the sinusoidal vibration, using the setup described in the previous section. The frequency response for the sensitivity (normalized to the dc sensitivity) of the ADXL354 is shown in Figure 1. As can be inferred from the plot, the combination of the resonance enhancement and the attenuation, due to the analog antialiasing filter, limits the flat band (±5% variation from dc) to roughly 1.3 kHz. The +3 dB frequency corner, for example, the frequency at which the sensitivity is twice the dc sensitivity, is roughly 2.1 kHz for the X and Y-axes. The quality factor of the Z-axis sensor is lower than the X and Y-axes sensors, and thus, the ac sensitivity does not equal twice the dc sensitivity at any frequency. The maximum sensitivity for the Z-axis sensor is at its resonance frequency.

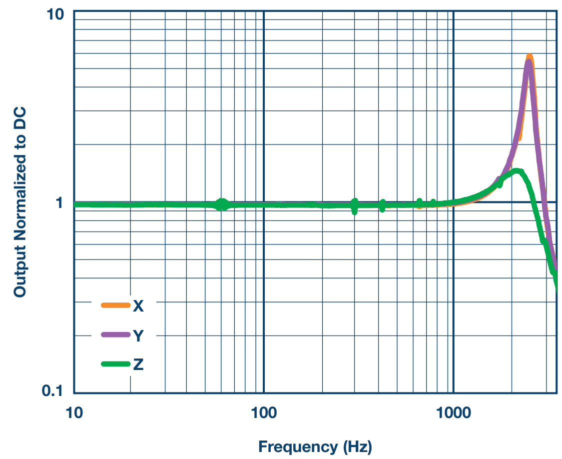

Figure 1. ADXL354 sensitivity vs. vibration frequency.

ADXL355

The parts were operated in ±8 *g* range with 5 *g* peak excitation on the sinusoidal vibration, using the setup described above. The frequency response for the sensitivity of the ADXL355 is shown in the Figure 2, for an ODR selection of 4 kHz. The plots show the sensitivity at all frequencies, normalized to the sensitivity at dc. Due to the additional digital filtering implemented in the ADXL355, the flat bandwidth is limited by the user programmed ODR (bandwidth = ODR/4). In the plots shown here, an ODR selection of 4 kHz results in a –3 dB corner of approximately 1 kHz. Vibrations at frequencies around the device resonance will encounter a resonant enhancement of sensitivity.

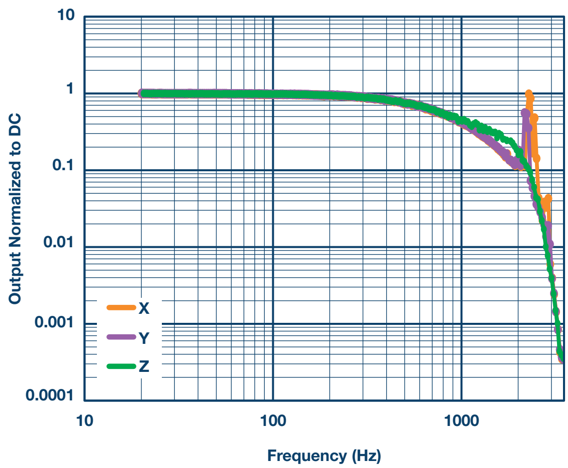

Figure 2. ADXL355 sensitivity vs. vibration frequency.

Calibration

The dc sensitivity of the ADXL354 and ADXL355 is guaranteed in a range of ±8% from nominal. Should the dc sensitivity not be calibrated, the maximum error in an acceleration measurement at dc is 8%. If higher accuracy is required, dc sensitivity calibration can be implemented by measuring at least two values per axis, by applying known input acceleration to the device. The simplest method to perform such a calibration is by orienting both directions (positive and negative), along each axis to the 1 *g* gravity field.[1]

AC sensitivity variation in ADXL354 essentially depends on the variation of the resonance frequency and the quality factor. The variation in these parameters is typically very small, governed by process variations. The frequency variation is typically less than 2% across multiple devices, and the Q variation is typically less than 10% across parts. Figure 3 shows a comparison of two ADXL354 parts (X-axis) with vastly different Q and resonance frequencies. The combination of the antialiasing filter, along with the resonance results in the normalized ac sensitivity at 2 kHz, equal to 1.63 and 1.74 for both devices, a difference of approximately 6%. Thus, if 100 m*g* of vibration is sensed by the accelerometer with higher Q at 2 kHz, the other accelerometer will report the same signal as 94 m*g*. In applications where absolute accuracy of the vibration content at a particular frequency is important, additional ac calibration with a precision shaker table is recommended.

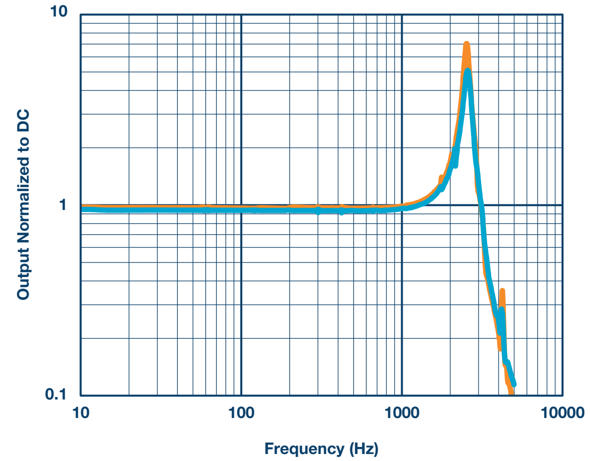

Figure 3. ADXL354 part-to-part sensitivity variation vs. vibration frequency.

In conclusion, the decision to calibrate or not to calibrate the accelerometer is dependent on the signal of interest. For vibration monitoring and structural health monitoring applications that require monitoring absolute magnitude of vibration harmonic frequencies, additional calibration is required. In applications that are intended to track relative shifts in natural oscillation, amplitude, and frequencies, the ADXL354 and ADXL355 accelerometers can be used with a baseline measurement, without additional calibration.

References

[1] Christopher J. Fisher. Application Note, AN-1057, *Using an Accelerometer for Inclination Sensing*. Analog Devices.

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