ANALOG DEVICES ADVISORY TO ICS ALERT-17-073-01

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Executive Summary

MEMS inertial sensors perform displacement measurement through miniaturized sensing elements fabricated by specialized IC processes. In particular, MEMS accelerometers constitute one category of inertial sensors that measure acceleration attributable to external forces. These external forces may include intermittent forces such as those attributable to tilt, shock and vibration of the sensor, as well as more constant forces, such as the pull of gravity. In addition, it is well known that high sound pressure level (SPL) acoustic waves, especially in close proximity to an accelerometer carrier board, can generate undesired vibrations that are then sensed by an accelerometer, and which can impact or impair the overall performance of a system. When using Analog Devices' MEMS accelerometer products, undesired SPL effects can be mitigated by system-level vibration and frequency management through the use of proper board mounting and housing configurations, material dampening, sound source vibration isolation, and low-pass and antialiasing filtering.

Technical Response

The board vibration generated by acoustic waves has the same influence on an accelerometer as would mechanical vibration generated by physically shaking the accelerometer at a certain frequency. This vibration can be mostly mitigated through system device board mounting optimizations. In the academic studies reported by Trippel et al., high SPL sound around 110 dB (110 dB represents the typical human hearing pain threshold, 120 dB is generated by a thunderclap or chainsaw) exerted in close proximity to a device evaluation board can produce significant board vibrations and accelerations. This could be due to the nonoptimal size and mounting point of the evaluation board used in the studies. The research group has also performed similar sound tests on commercially available handheld devices and produced an undesired system response due to the application of significant out-of-band vibration stimulus. This could also be due to the nonideal board mounting or housing configuration of the devices.

MEMS accelerometers are designed to accurately measure accelerations within their designed response range, as stated in their associated data sheets. When operated beyond their designated range, accelerometers may still measure accelerations, but at a much reduced level of accuracy. Even further out-of-band rejection should be managed at a system application level and is dependent on system housing and board design, as well as data processing at the system level. Analog Devices often provides guidance on the correct board mounting configuration through data sheets, application notes[1–6], and direct consultations. Analog Devices has also implemented advanced design features of low-pass and antialiasing filtering, sampling, digital filtering, and application-specific processing to reduce the effects of out-of-band vibrations[1–6]. Our work to date suggests that reliable operation is not only possible, but should be expected when all of these factors are managed appropriately. This advisory addresses and references the particular Analog Devices products identified in the ICS Alert 17-073-01 (the ICS report), but may also apply to other Analog Devices MEMS accelerometer products, including accelerometers inside inertial measurement units (IMUs).

Theory and Method of Mitigation

Figure 1 shows a general accelerometer board mounting configuration under acoustic waves generated from a loud speaker. The printed circuit board (PCB) is fixed to the host device base with four mounting points. In this configuration, the board will deflect due to sound pressure. Based on plate bending theory, the maximum deflection is approximately proportional to the fourth order of the distance between the mounting points (D_m). Since D_m is typically in the range of a few tens of millimeters, whereas the accelerometer dimension is typically less than 4 mm, the board deflection is orders of magnitude larger than the accelerometer package deflection under a given pressure. Therefore, the sound pressure induced board deflection or vibration is dominant in affecting the accelerometer output.

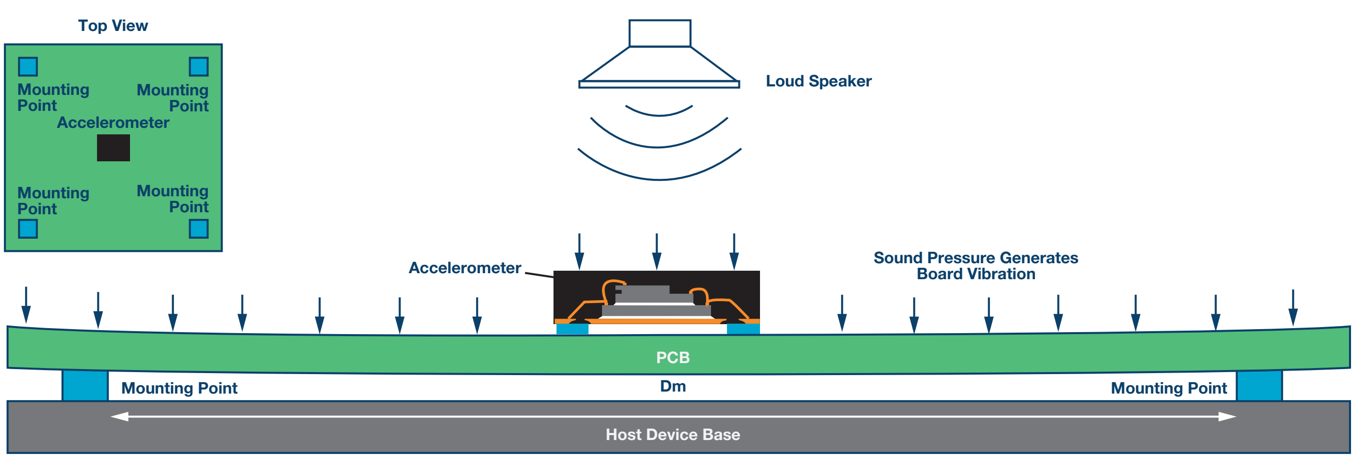

Figure 1. MEMS accelerometer board and mounting with acoustic vibration from off-board speaker.

The following derivations based on a single periodic sound frequency can be used to relate the board deflection to acceleration level.

The board harmonic deflection can be defined as:

$$deflection = d_{bd} \times \sin(\omega \times t) \quad (1)$$

where d_{bd} is the amplitude of the board deflection under the sound pressure and ω is the frequency of the sound.

The acceleration produced by the harmonic deflection is:

$$acceleration = d_{bd} \times \omega^2 \times \sin(\omega \times t) \quad (2)$$

In the case where the sound frequency matches the board resonant frequency, the deflection will be amplified by the qualify factor (Q_{bd}) of the board and Equation 2 will be modified as:

$$acceleration \text{ at } board\ resonance = Q_{bd} \times d_{bd} \times \omega^2 \times \sin(\omega \times t) \quad (3)$$

By inspecting Equation 3, one can find the following methods to mitigate the board acceleration effect. These methods have been either implemented in Analog Devices' accelerometer products or advised to the customers for system design considerations, whichever is applicable.

- **Method 1**: Reduce the board deflection d_{bd} by increasing the board resonant frequency through reducing the mounting distance, D_m, increasing the board thickness and stiffness, adding dampening materials, and optimizing the location of the accelerometer on board relative to the mounting point, etc. Analog Devices has advised the optimal mechanical mounting configurations in product data sheets[2 – 6] and has directly worked with customers to mitigate any vibration issues based on their specific housing and board configurations.
- **Method 2**: Reduce the board Q_{bd} amplification effect by increasing the board resonant frequency to be above the sound frequency or adding dampening materials. This method is used in concert with Method 1. The board Q_{bd} could be much higher than the accelerometer's intrinsic qualify factor and could significantly increase the resulting board acceleration.
- **Method 3**: Reduce the wide band frequency (ω) effect by implementing low-pass and antialiasing filtering to prevent out-of-band signal to alias back into the baseband. Analog Devices has already implemented these design features in the products[2 – 6] and effectively reduced the out-of-band vibration effect. If the acceleration is too large and beyond the sensor's designed full-scale range due to large board resonance from high SPL sound, the sensor will produce overrange output and trigger system-level detection and protection.
- **Method 4**: When the sound or board vibration frequency is coincident with the accelerometer's resonant frequency, the board acceleration sensed by the accelerometer will be amplified by the accelerometer's own qualify factor. Analog Devices clearly states each accelerometer's resonant frequencies in the associated data sheets and advises its customers to design their board resonant frequencies to be greater than the employed sensor's resonance frequencies[1 – 6] to ensure reliable performance.

In some system applications where the speaker and the accelerometer are co-located on the same board, both acoustic and mechanical vibrations from the speaker can affect the accelerometer. Additional methods may be implemented to mitigate the additional speaker mechanical vibration that can couple and propagate directly through the board. Figure 2 conceptually illustrates the additional methods of vibration mitigation, including the methods of creating a speaker vibration isolation region.

- **Additional Method 1**: Mount the accelerometer as far away as possible from the speaker.
- **Additional Method 2**: Mount the speaker as close as possible to a fixed outer mounting point. The mounting point will provide a path for the mechanical vibration energy to dissipate to the host device base and thus reduce the vibration that can propagate through the board.
- **Additional Method 3**: If possible, create through-PCB isolation trenches to physically isolate the speaker from the rest of the board. The isolation trenches will effectively filter out speaker vibrations.
- **Additional Method 4**: Create inner mounting points as close as possible to the accelerometer to stiffen the board locally under the accelerometer and suppress the local board vibration.
- **Additional Method 5**: If possible, create through-PCB isolation trenches to physically isolate the accelerometer from the rest of the board. The isolation trenches are preferably placed outside of the inner mounting points in order to further filter out the vibration without affecting the accelerometer local board rigidity and high resonant frequency.

In summary, acoustic and mechanical vibrations from either off-board or on-board speaker configurations can be mitigated by the abovementioned nine general methods, and the accelerometer and overall system performance can be ensured.

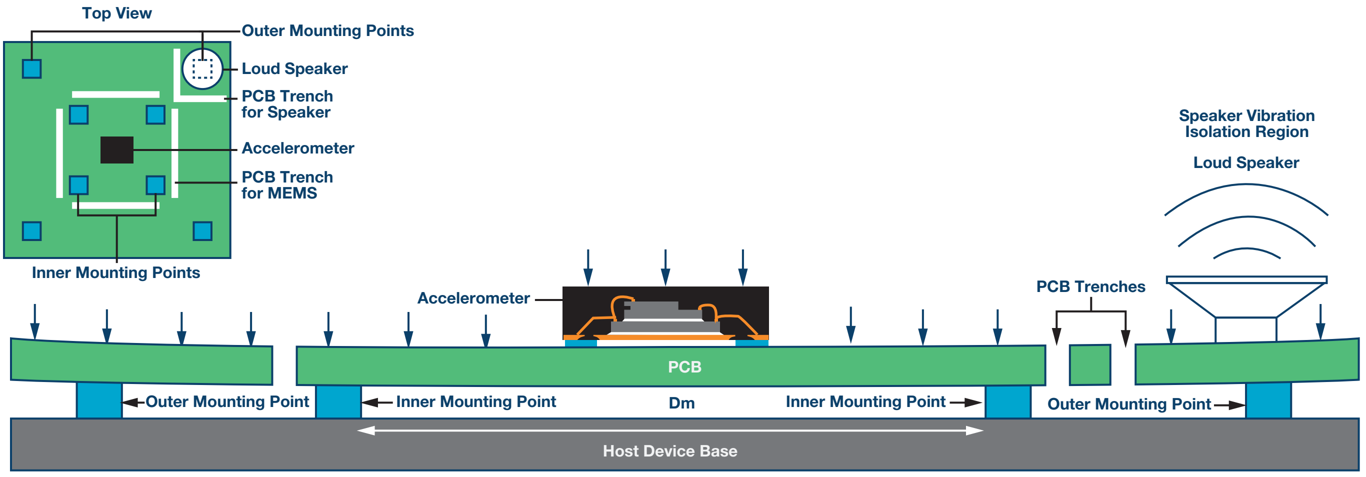

Figure 2. MEMS accelerometer board and mounting with acoustic and mechanical vibration from on-board speaker.

Related Resources to Mitigate Unwanted Vibrations

[1] Long Pham and Anthony DeSimone. "Vibration Rectification in MEMS Accelerometers." Analog Devices, Inc., 2017.

[2] ADXL312 Data Sheet, Mechanical Considerations for Mounting. Analog Devices, Inc., pp. 25, 2015.

[3] ADXL345 Data Sheet, Mechanical Considerations for Mounting. Analog Devices, Inc., pp. 28, 2015.

[4] ADXL346 Data Sheet, Mechanical Considerations for Mounting. Analog Devices, Inc., pp. 29, 2015.

[5] ADXL350 Data Sheet, Mechanical Considerations for Mounting. Analog Devices, Inc., pp. 28, 2012.

[6] ADXL362 Data Sheet, Mechanical Considerations for Mounting. Analog Devices, Inc., pp. 41, 2016.

How to Get Support in Using Analog Devices' MEMS Products

Analog Devices wants to ensure our customers are successful in development of their applications using the products mentioned. For support and guidance on avoiding the issues described above, please contact:

- Your field sales and application engineers
- Your local franchise distributors (*analog.com/sales*)
- ADI technical support (*form.analog.com/form_pages/support/integrated/techsupport.aspx*)

Analog Devices is committed to ensuring the security of our product offerings. To report potential security issues on Analog Devices' products, please contact *securityalert@analog.com* or your local technical support resource.

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