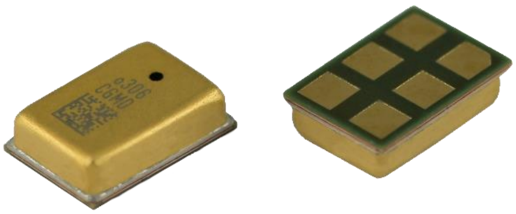
V2S Vibration Sensor:
Audio pickup through sound-induced vibration. Automotive application overview, integration, and signal processing guidelines.



Isaiah Farrell, Applications Engineer

Nikolay Skovorodnikov, Senior Manager, Applications Engineering

Abstract

The V2S vibration sensor is a compact, low-noise device that offers a full audible bandwidth frequency range. This document covers application category for the V2S sensor: sound-induced vibration pickup. This method gives maximum environmental robustness without open acoustic port for automotive and other applications. This document provides main design principles for using the V2S sensor, integration guidelines as well as signal post-processing ideas.

Syntiant Corp.
7555 Irvine Center Drive, Suite 200
Irvine, CA 92618

Phone: +1 949-774-4887
info@syntiant.com
www.syntiant.com

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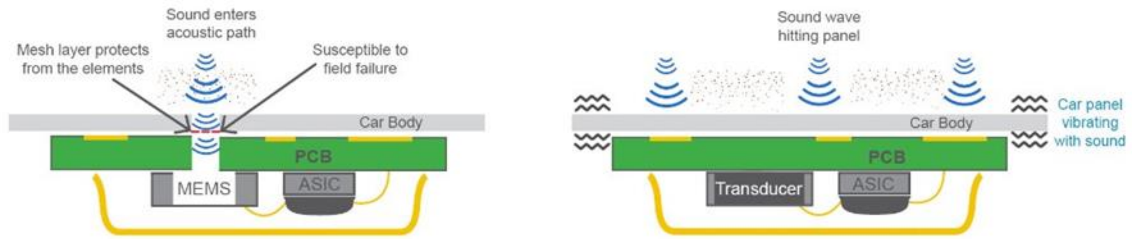
Applications of V2S for Sound-Induced Vibration

V2S vibration sensor is a wide-bandwidth, 1-axis accelerometer designed for audio applications. It's small size and low noise make it an ideal candidate for various audio applications, while delivering considerable value compared to traditional MEMS microphones. This document describes using V2S sensor in systems with high robustness against environmental contamination.

As an environmentally sealed device, V2S has distinct advantages over conventional MEMS microphones in outdoor settings, or any device that requires a high degree of robustness to environmental conditions. Replacing a microphone with V2S relies on the vibration of an object from impact of the falling sound wave. Instead of directly sensing acoustic pressure, V2S will sense the mechanical vibration of the device it is mounted to. This concept treats a panel-like form factor as a diaphragm for acoustic transduction. Considering this focus on devices with a panel construction, there are three primary application areas that are primed for integration with a focus on sound-induced vibration: wearable devices; external sound detection in automobiles; and outdoor panel devices.



Automotive applications

Automotive audio sensors must adhere to the vehicle's constraints for environmental robustness. This has been a problem for exterior microphones since they require a hole in the exterior to acoustically couple the MEMS microphone to outside sound. Since V2S may be internally mounted without any break in the sealed exterior, it fills this role well. There are two main application areas in external automotive audio sensing: voice command detection and emergency vehicle (siren) detection.

Emergency vehicle detection is a required feature for self-driving functionality. This feature detects a siren sound and responds by stopping the car and moving to the shoulder, if applicable. The mounting of multiple sensors on a vehicle can inform event direction in addition to simple siren detection.

Directional tracking utilizes amplitude differences between V2S sensors mounted to independent and sufficiently decoupled panels on the vehicle. The independent panels act similarly to microphone diaphragms; by using the amplitude differences between multiple sensors it is possible to directionally localize a sound source. This method of directional tracking by amplitude level is required as opposed to an acoustic phase-based approach typically seen in conventional MEMS mic applications with omnidirectional sensors and free-filed wave propagation assumption. Instead, sound is coming from the direction with maximum corresponding vibration amplitude around the perimeter of the car. The general approach for directional tracking relies on 4 sensors, mounted in the front, rear, left side and right side of the vehicle's exterior. Assuming L-R symmetry, the sensitivity discrepancy between the front and back panels on which the V2S sensors are mounted is required. When a siren event is detected, differences in L-R axis amplitude determine absolute value of the angle from which the siren is located, as well as which side the siren is detected. The amplitude difference between the normalized output of the front and rear sensors determines if the siren is in front or behind the vehicle. Together, these factors determine the angle of the siren’s location relative to the midpoint between the left and right sensors.

Siren event detection may be implemented using conventional DSP methods to deal with differences among emergency vehicle sounds across manufacturers and localities, or AI machine learning algorithms may be implemented to characterize several different siren types and detect events.

Wearable and Outdoor Applications

Wearable devices with a flat face also provide a viable platform for V2S integration. Typically, these devices benefit from being completely sealed for waterproof functionality. By eliminating the need for a microphone, the device achieves a significantly higher degree of environmental robustness over typical methods for sealing microphones against water. With a pickup surface, V2S will maintain voice functionality in the device, allowing for full frequency range pickup for human speech up to 10kHz. An example of device in this category is a smart watch geared towards outdoor use.

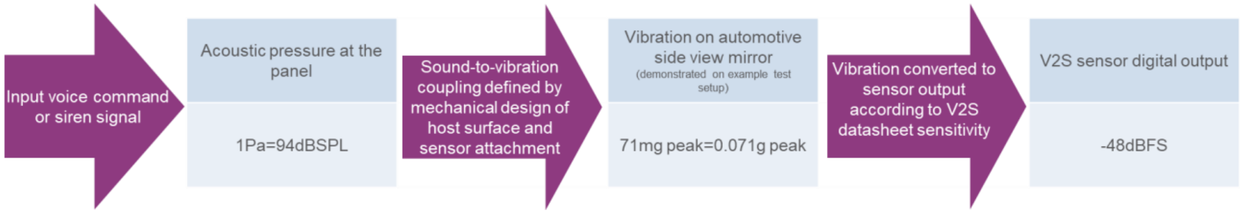
Any outdoor panels, such as outdoor televisions or glass doors or windows, benefit from integration of V2S over microphones for the same reasons as wearables. Devices regularly kept outdoors must be upheld to a high standard of environmental robustness. Achieving this is best accomplished with a fully sealed design. Any panel may serve as a vibrating mass for V2S functionality if it is composed of a sufficiently resonant material.

Comparison to MEMS Mic

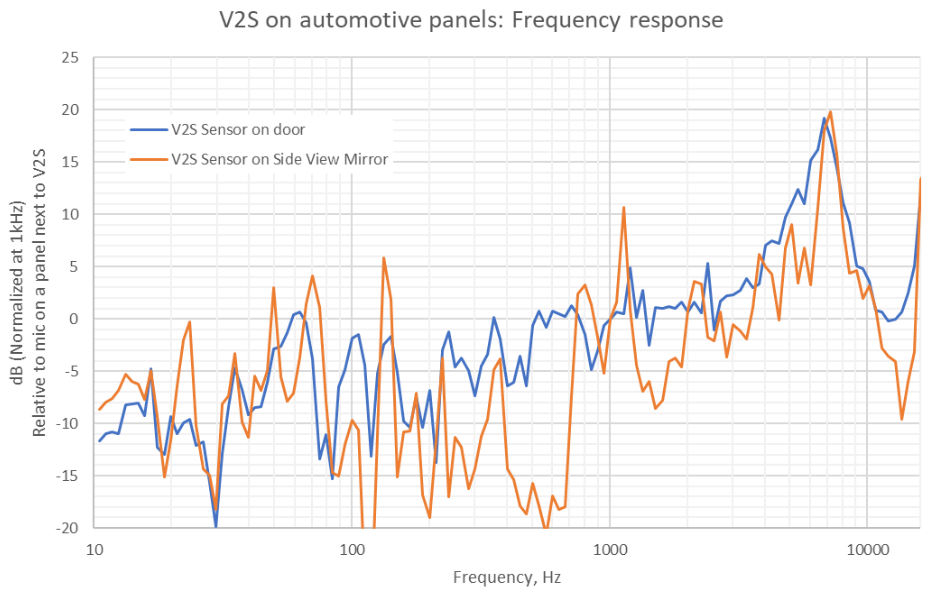
In applications requiring environmental robustness there are various options for sound pickup in the device. The most common solution is to implement a mesh over the port hole of a MEMS mic to protect from particles and moisture. While this approach can provide environmental protection, it requires additional components and assembly processes that increase costs. The mesh barrier also deteriorates acoustic performance, effectively lowering signal-to-noise ratio. Alternatively, one can mount the microphone inside of the device (or vehicle) without a direct acoustic path, relying on acoustic leakage between device panels to pick up sound. Amount of acoustic leakage is usually limited and the resulting sound quality is insufficient.

Using V2S vibration sensor instead of a MEMS microphone brings several advantages. V2S senses physical vibration of the device induced by impinging sound waves. Since there is no need for an acoustic port, V2S sensor offers a sound pickup solution with ultimate environmental robustness. Additionally, the lack of acoustic port offers more flexibility for V2S sensor placement. The sensor can be directly mounted on the main PCB inside the product, alongside other components and does not need an auxiliary flex PCB, commonly used for microphones to bring them against the surface of the device. These factors lower device BOM cost and simplify development.

The functionality of V2S fundamentally differs from a typical MEMS microphone. This factor is important to consider while designing systems integrating the sensor. In accelerometers, sensitivity is measured with 1g input vibration, where g = 9.81m/s^2. Sensitivity of a vibration sensor cannot be directly compared to sensitivity of a MEMS microphone which is defined at 1Pa input acoustic pressure. Amount of vibration created in the panel of a device under impact of the sound wave depends on various design aspects such as surface area, weight and boundary conditions. The diagram below provides an example of values across acoustical, vibrational and sensor output digital domains.



System-level frequency response will also be defined by properties of the host panel with the sensor response as an additional contour applied at output. Example below shows typical curves measured in demonstration setups. Multiple small resonances come from details of the host surface and sensor placement. Larger resonance around 8kHz comes from V2S sensor itself.



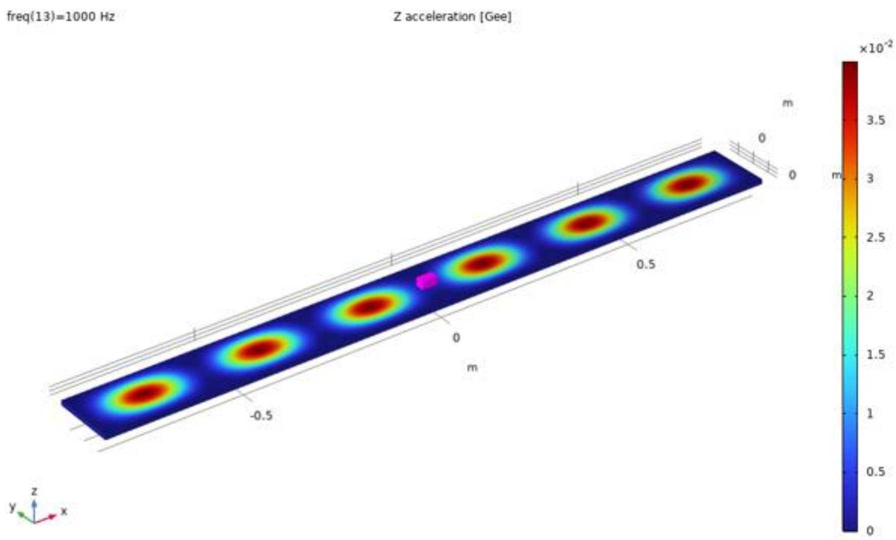
Example signal frequency response of V2S sensor on automotive panels

Integration Considerations

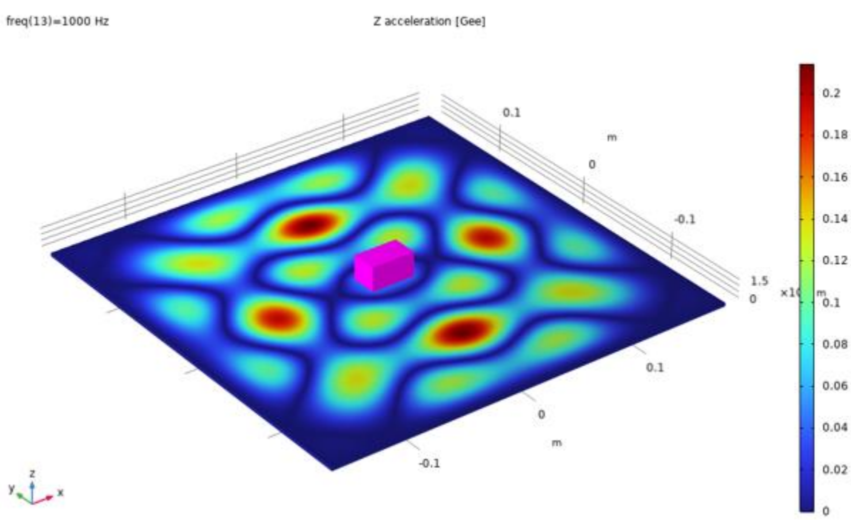
Typical design goal for sensor integration is to maximize the captured vibration signal while selecting a convenient mounting location that minimizes the cost and effort of wiring and connections. General guidelines are given in this chapter for maximizing vibration signal.

Panel area, thickness, and stiffness contribute significantly to the frequency response and output magnitude of a panel mounted V2S sensor. A larger panel area is related to a higher overall signal output. Typically, a doubling of the characteristic length of a panel will result in a 6-12dB boost in panel deflections and sensor pickup. Thinner panels generally have higher output than a thicker panel. This case does not hold in all implementations since any change to the panel thickness (higher or lower) will influence mode shapes and the location of modal nulls. This could result in a situation where a lower panel thickness results in a lower sensor output. Finally, panel stiffness, represented by the Young's modulus of the material, shows proportional relationship to the panel mode shape amplitude. For example, a more flexible acrylic will typically have a higher output than glass. The exception to this is where pretension dominates and YM has little effect.

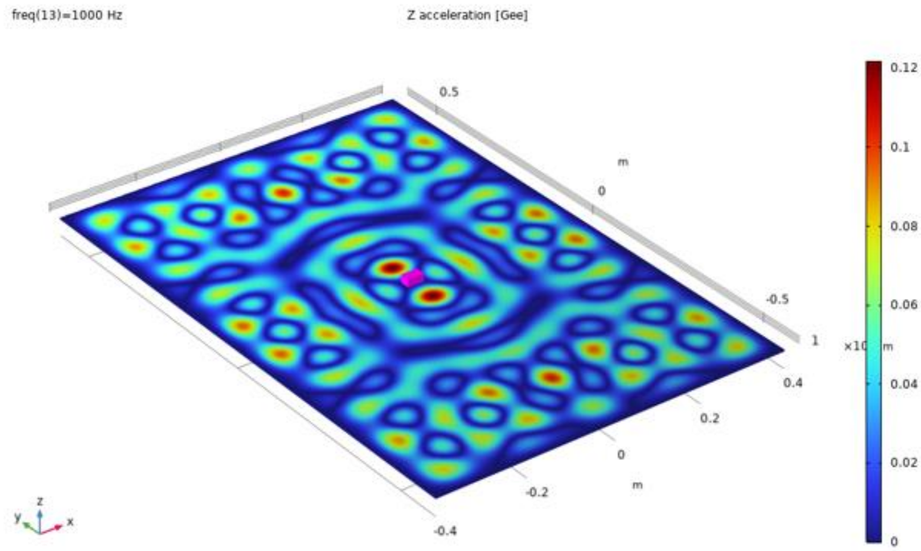
In automotive applications, these mechanical considerations carry over into mechanical characteristics of the module housing the V2S sensor. The mass of the sensor module is typically the most consequential parameter. A low module mass allows for greater vibration at its mounting point. Conversely, a high mass may introduce a vibrational node at its mounting location. This is not a fixed rule, however. Since any plate-mounted masses are highly interactive with the mode shapes of the plate, any changes in mass may shift modes and create unwanted nulls at the pickup point. Nulls at low mass are related to plate geometry and any fixed points. Simulation plots below illustrate differing vibrational behaviors caused by panel size and thickness with a panel mounted V2S module.



Panel Vibration at 1Khz, 1700mmx160mmx12mm, 1 Pa input, 20g Vibration sensor module



Panel Vibration at 1Khz, 346mmx346mmx2.8mm, 1 Pa input, 20g Vibration sensor module



Panel Vibration at 1Khz, 800mmx1200mmx4mm, 1 Pa input, 20g Vibration sensor module

Boundary conditions are also critical for vibration analysis. All real panels have points that are fixed to other parts of a structure. These anchor points create vibrational nodes and largely contribute to mode shapes in the panel. It is not recommended to place anchor points near the sensor to maximize output response. The method of fixture around a panel edge also matters. Foam or other compliant sealant will cause some degree of damping, especially if the panel on which the sensor is mounted is not the surface directly exposed to the sound waves. In the case of the mounting panel being a secondary panel coupled to the sound contact panel, it is recommended that contacts be made with hard materials to facilitate the vibration transfer.

Panel direction relative to sound also influences overall system pickup. Generally, a panel parallel to sound waves will have significantly lower deflections compared to a plate that is orthogonal to the waves. One could argue that v2s on a flat panel of a car has a natural built-in directional sensitivity.

Signal Post Processing

If V2S signal is used for siren detection of the emergency vehicles, then there is no reason to optimize it for human listening. One can detect the peak of fundamental siren frequency in the raw data using classical DSP (digital signal processing) techniques or by training AI model accordingly.

If V2S is used for voice command input (ex. *“hey vehicle, open the trunk”*), the goal is to have correct output of the classifier. Again, there is no reason to optimize the signal for comfortable

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info@syntiant.com
www.syntiant.com

human listening. It is recommended to train the model using raw V2S data. Exercise caution when using models pre-trained on microphone data for classifying V2S data.

Finally, V2S mounted on a panel can be used for communication. If a human is listening to the recorded data, the goal is to make it sound as close as possible to a high-quality microphone recording. V2S sensor resonance is inside human audible range and high frequencies are overrepresented in V2S data. It is recommended to apply equalization and attenuate high frequencies accordingly for more natural sound. Other resonances coming from properties of the host panel can be addressed similarly. Depending on the amount of vibration signal captured, V2S recording might sound noisier than a typical MEMS microphone. Noise suppression algorithm can be used for mitigation. Since sensor noise is very predictable and consistent, noise suppression can be very effective on V2S recordings.

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