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# Identification of Low-Frequency/Low SNR Automobile Noise Sources

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## Abstract

This paper presents experimental investigations of determining and analyzing low-frequency, low-SNR (Signal to Noise Ratio) noise sources of an automobile by using a new technology known as Sound Viewer. Such a task is typically very difficult to do especially at low or even negative SNR. The underlying principles behind the Sound Viewer technology consists of a passive SODAR (Sonic Detection And Ranging) and HELS (Helmholtz Equation Least Squares) method. The former enables one to determine the precise locations of multiple sound sources in 3D space simultaneously over the entire frequency range consistent with a measurement microphone in non-ideal environment, where there are random background noise and unknown interfering signals. The latter enables one to reconstruct all acoustic quantities such as the acoustic pressure, acoustic intensity, time-averaged acoustic power, radiation patterns, etc. By combining a passive SODAR and modified HELS methods, engineers will be able to visualize all acoustic quantities. In particular, Sound Viewer enables engineers to extract target information with a negative SNR, for example, SNR < - 30 dB, and identify the precise locations of very low frequency (< 200 Hz) airborne and structure-borne sound sources with very high spatial resolution. Test results of Sound Viewer to analyze the engine sparkplug and muffler noise of an automobile sedan are presented.

## Introduction

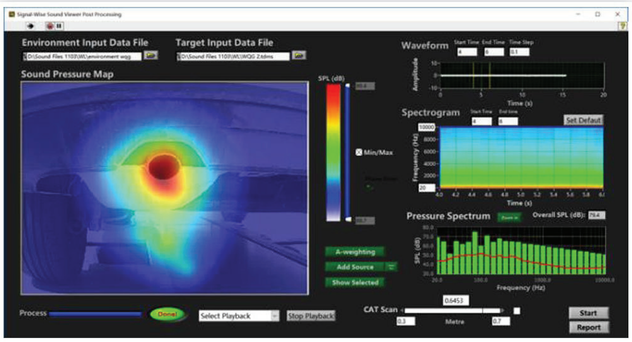
Diagnosing and analyzing low-frequency airborne and structure-borne sound has always been one of the major challenges in the automobile industry. Traditionally, measurements of structural vibrations and acoustic radiation must be measured simultaneously by using accelerometers, microphones, intensity probes, etc. at judiciously selected locations on and around a target vehicle. The amount of time and effort spent on these measurements can be excessive. Yet, the results are oftentimes inconclusive. This is because the spatial resolution of sound source localization at very low frequencies is typically very poor. Moreover, the background noise as well as interfering signals may be relatively high even inside a semi-anechoic chamber. These interfering signals, for example, generated by accessory parts or components of a test vehicle are always present and may be stronger than the target signals. This makes it extremely difficult to identify the target noise source. Meanwhile, the vibration signals measured by accelerometers do not necessarily equate the structure-borne sound radiation. This is because although sound is generated by structural vibrations, not all structural vibrations can produce sound.

In fact, most components of structural vibrations do not emit sound because their spatial wavelengths are too short to support effective sound radiation. These high-order structural waves are known as the near-field effects that stay close to the source surface and maintain structural vibrations. If our goal is to reduce sound radiation, then all we need to do is to focus on the components of structural vibrations that can actually produce sound radiation [1].

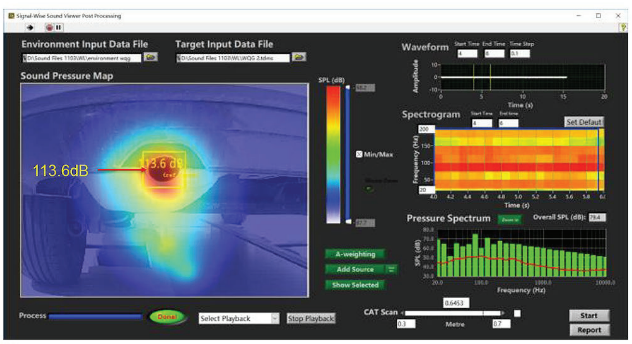
It is emphasized that the traditional NAH (Nearfield Acoustical Holography) based technologies [2 - 6], especially the one utilizing the Fourier transform will not be suited for this task. This is because the Fourier transform based NAH is valid for source-free space and for geometry that has a constant level of coordinate, for example, a planar surface with a constant height, a sphere of a constant radius, or a cylinder of very long length with a constant radius. In practice, the test site is never source free, namely, there are always sound sources including reflecting surfaces between the hologram surface and target source surface. Moreover, the structures are always of arbitrary shape that cannot be described by a constant coordinate.

Although the BEM (Boundary Element Method) based NAH [7 - 10] is suitable for an arbitrarily shaped surface, it is valid in source-free space. Accordingly, only the vibrating surface need be discretized. In practice, none of the test environment is source free because there are always boundary surfaces or other structures involved. Under such a condition, and all boundary surfaces and structural surfaces including

**FIGURE 6** The reconstructed acoustic pressure distribution over a vertical plane at the exhaust pipe exit. (6a): The acoustic pressure distribution over the entire frequency range of interest 20 - 10,000 Hz (Top). Note high amplitudes of the acoustic pressures at very low frequencies in the spectrogram (Middle right of Figure 6a). (6b): The acoustic pressure distribution on the same vertical plane focusing on the "hot frequency" range of 20 - 200 Hz. Both the location and the overall level of SPL values remained the same, which indicated that the muffler noise was primarily concentrated at 20 - 200 Hz frequency range.




(6a)




(6b)

pressure distribution over the same vertical plane (see Figure 6b).

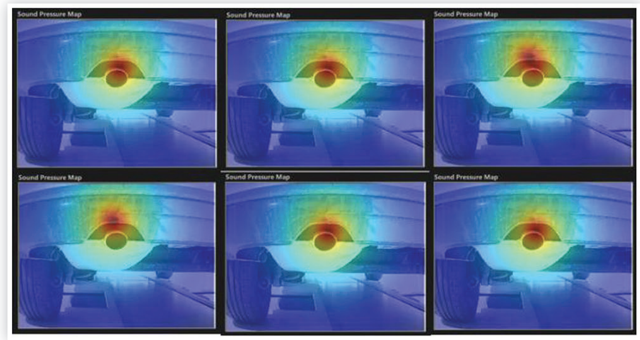
Note that the location and SPL value remained essentially the same, which means that the muffler noise was primarily concentrated at the very low frequency range of 20 - 200 Hz.

Also notice the spatial resolution in source localization using Sound Viewer software at this very low frequency range. Results show that Sound Viewer can locate sound sources in the entire frequency range with equal spatial resolution. In other words, the spatial resolution in source localization is frequency independent.

To obtain a quantitative measure of the source strength, we calculated the time-averaged acoustic power over the area of the muffler exhaust pipe exit at 113.6 dB (see Figure 6b).

Figure 7 displays the TSFVA relationship of the muffler noise at 20 - 200 Hz frequency range. Results indicated that the muffler noise was emitted from the top edge of the muffler exhaust pipe exit. This could be caused by the fact that there was a semi-circular cover above the muffler exhaust pipe exit. Because the clearance between the pipe exit and the cover was

**FIGURE 7** The TSFVA relationship of the muffler noise at 20 - 200 Hz frequency range. Results shows that the muffler noise was emitted from the top edge of the muffler exhaust pipe exit.




quite small, sound reflection from this cover may have contributed toward forming this "hot spot". Otherwise, the sound pressure distribution at the exhaust pipe exit would have been axisymmetric.

With the insight gained from this study, engineers can devise a more effective noise mitigation strategy either through active control [21] or through improved designs of exhaust valves [22, 23, 24].

## Conclusions

This paper demonstrates the application of using new technologies to diagnose and analyze low-frequency, low-SNR noise sources that are facing the practicing engineers. Specific examples include the engine compartment noise versus engine sparkplug noise, which has a SNR less than - 30 dB, muffler noise at 20 - 200 Hz frequency range, and the TSFVA relationship of a target sound source.

These results show that by using these technologies, it is possible for engineers to address a wide variety of airborne and structure-borne noise issues with relatively easiness. The setup, measurements, and post processing of reconstruction using Sound Viewer are relatively straightforward and fast. Basically, one only needs to ensure that the microphone array of Sound Viewer is mounted within the effective working range, which is three times the length of the microphone array, and facing the target area of interest. These requirements will lead to satisfactory source localization and reconstruction results for the frequency range and dynamic ranges that are consistent with the measurement microphone. Also, the spatial resolution of the source localization by using Sound Viewer is independent of the frequency.

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