Improved Measurement Procedures for Engine Noise Reduction with Advanced Microphones

By Per Rasmussen

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The investigations presented in this paper have been done in collaboration with Volvo Cars

GRAS Sound & vibration

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The acoustic environment inside the car is a primary comfort parameter. With the change from internal combustion engines (ICE) to battery electrical vehicles (BEV) or hybrid electrical vehicles (HEV), a renewed focus on old and new noise sources in the engine bay and the transmission paths to the cabin is required.

A way to study this is by using a reverse transmission technique, placing a sound source in the receiver position in the cabin and measure the resulting sound pressure levels in the engine bay. Assuming reciprocity, the attenuation of transmission from sound sources in the engine bay to the cabin can be estimated. These measurements are cumbersome as they involve the placement of 20 or more microphones in the engine bay. This has traditionally been performed using off-the-shelf free-field measurement microphones.

To optimize this procedure a new pressure-field microphone, the GRAS 147AX, has been tested by Volvo Cars. The result has been a dramatic reduction in setup time; also, a new mounting method has increased accuracy and repeatability and made it possible to maintain the same baseline throughout a complete project cycle. In addition to this, hot engine and track testing is now possible using the same measurement setup.

Introduction

The acoustic environment inside a car is one of the primary comfort parameters. It is made up of a number of contributions from drive-train, auxiliary equipment, wind noise, and tire noise, and all are influenced by the transfer from the source to the receiver. With the change from internal combustion engines (ICE) to electrical (BEV) or electrically assisted (HEV) propulsion systems, a new set of noise sources are introduced in the engine bay, and this requires a renewed focus on the transmission paths to the receivers inside the cabin. In the present study of engine noise reduction (ENR), performed jointly by GRAS Sound & Vibration and Volvo Cars, the focus has been on the transfer of acoustical energy from the engine bay to the driver's position inside the car cabin (Figure 1).

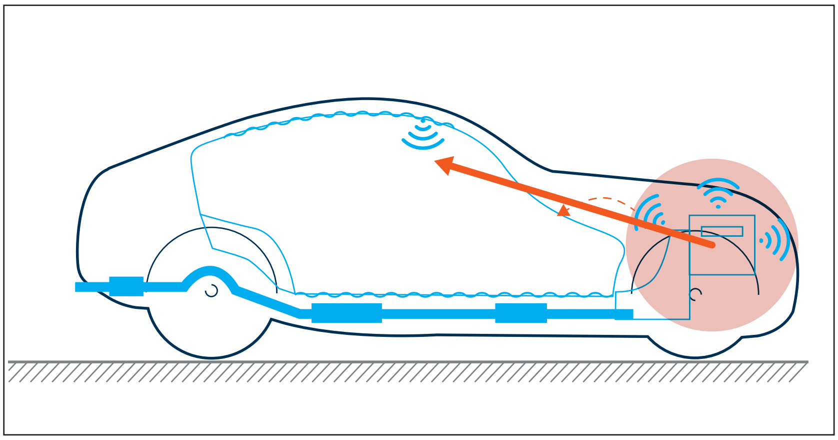

Figure 1
Acoustical transfer from engine bay

Typically, these mechanisms are studied using a reverse transmission technique (Figure 2). A well-defined sound source is mounted in the receiver position inside the car and the resulting sound pressure levels in the engine bay are measured. Assuming reciprocity, these measurements can be used to evaluate the attenuation of the transmission from sound sources in the engine bay to the receiver inside the car.

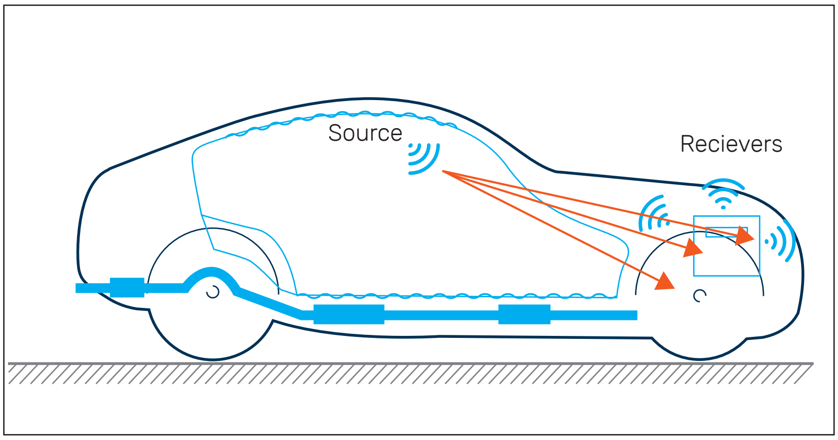

Figure 2
Reverse test for engine bay transmission

These measurements are cumbersome and time-consuming as they involve the placement of up to 20 microphones or more inside the engine bay. Also, the repeatability that can be obtained with these measurements is insufficient and makes it difficult to quantify the effects of different sound optimization packages and damping material configurations. As the transmission of sound to the engine bay is distributed on a number of different paths with almost equal contributions, any reduction of individual transmission paths may not result in a substantial reduction of the overall transmission. However, it is necessary to be able to investigate these changes individually to achieve a substantial overall reduction.

A typical test scenario would be to measure the noise transmission in a base configuration with up to 24 microphones mounted in different positions in the engine bay and then remove all the microphones and make design changes to the sound insulation configuration. After the design changes, the microphones are mounted again and the resulting changes in noise transmission are measured. However, if the base repeatability of the measurements is 2-3 dB and the effect of the design changes is of the same magnitude, it is not possible to conclude if the difference reflects the design changes or is caused by measurement uncertainty.

Analysis of the legacy method

To improve the repeatability and decrease the setup time, the legacy method was carefully studied in an initial project carried out on a Volvo XC90 passenger car. The test was performed with a high-frequency omnidirectional sound source (Figure 3). The sound source nozzle was positioned in the driver's head position.

Figure 3
High-frequency omnidirectional sound source

Microphones were mounted at 24 specified positions in the engine bay, some of which are shown in Figure 4, and the transmission of sound was measured and calculated as the average of all the microphone positions. The microphones were then removed, and the mounting and measurement procedure was repeated two more times.

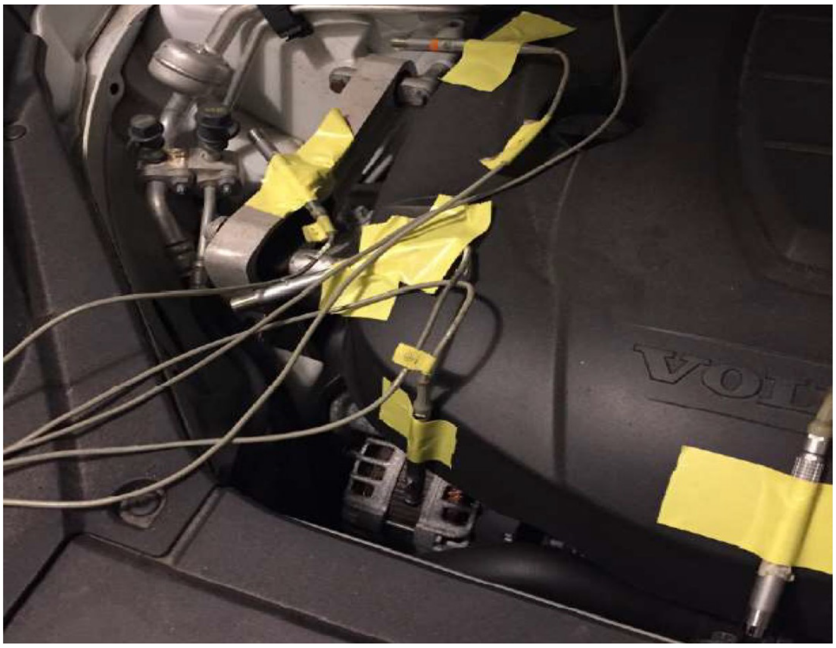

Figure 4
Microphones mounted in the engine bay

The sound transmission attenuation was calculated as the difference between the level measured with a reference microphone inside the cabin and the average of the levels measured in the engine bay.

As an example of the spread resulting from repeated mounting and dismounting, the results of three repetitions of the same measurements with three microphones in the front lower engine position are shown in Figure 5. It can be seen that in the frequency range up to around 1.6 kHz the results for the three otherwise identical tests may differ in the range of 2-3 dB, and for higher frequencies more than 5 db.

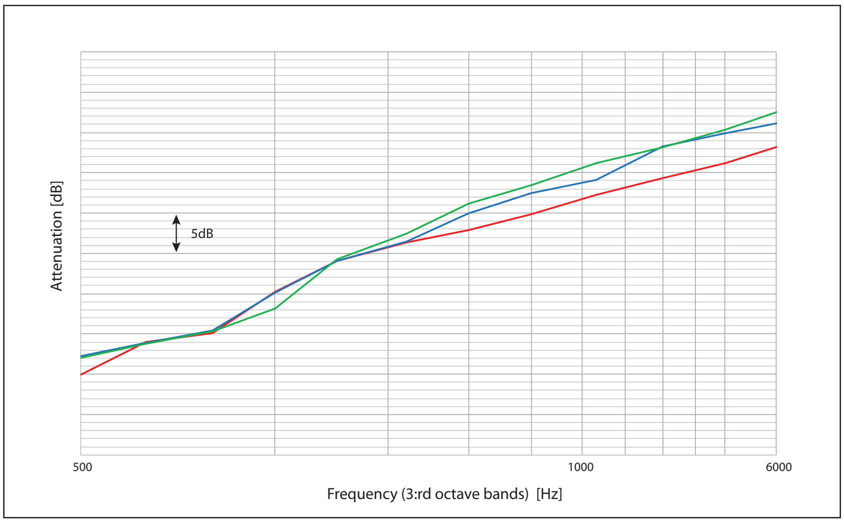

Figure 5
Three typical sound transmission measurements

These results led to a detailed study of the local sound field around the individual microphone positions and the overall variability of the sound field in the engine bay. One example of this was performed with an assembly of four microphones mounted side-by-side with 15 mm separation in one of the microphone positions (Figure 6), thus measuring the same sound field at slightly different positions.

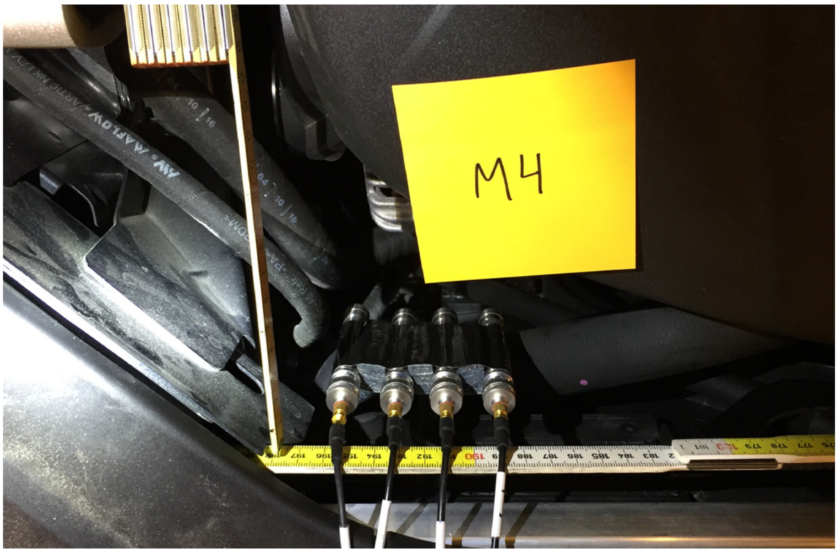

Figure 6
Four microphones mounted in the same measurement point at slightly different positions.

Figure 7 shows an example of the sound pressure levels in the engine bay as generated by the sound source in the cabin and measured by the four closely spaced microphones. It can be seen that even simultaneous measurements at closely spaced positions can differ by up to 3 dB in the critical frequency range from 500Hz to 5 kHz. Similarly, it was found that the sound pressure levels in different areas of the engine bay would vary by 10 dB or more over the entire frequency range of interest.

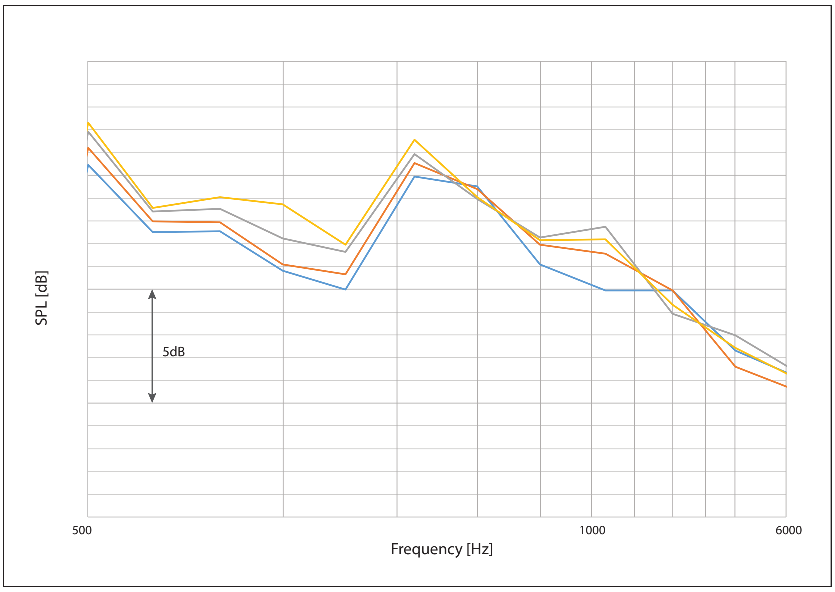

Figure 7
Sound pressure levels measured at four close positions

One of many conclusions from the initial method investigation was that the precise transducer mounting position and orientation was extremely critical in order to obtain repeatability. Also, differences in operator interpretation of the positioning instructions could generate differences in the results.

The new method and its implementation

As the investigation of the legacy method has shown, the imprecise location of the transducers was one of the primary limiting factors for obtaining repeatable measurement results. This method was based on the use of traditional measurement microphones: Cylindrical devices optimized for free-field conditions far away from sound sources and obstacles, with essentially no reflections and one dominating sound source. This is very different from the typical layout of a modern engine bay where almost all available space is filled and it is difficult to find relevant places to mount the microphones. The microphones are often mounted using ad-hoc mounting devices or taped to available structures. This introduces variations in the exact transducer positions from test to test and from one operator to the next. This also makes it difficult to make comparisons across different vehicle versions, models, and platforms as the layout in the engine bay will change. Instead of using the traditional free-field microphone, (GRAS 46AE, Figure 8a), a new pressure type microphone, (GRAS 147AX, Figure 8b), intended for mounting on structures was introduced.

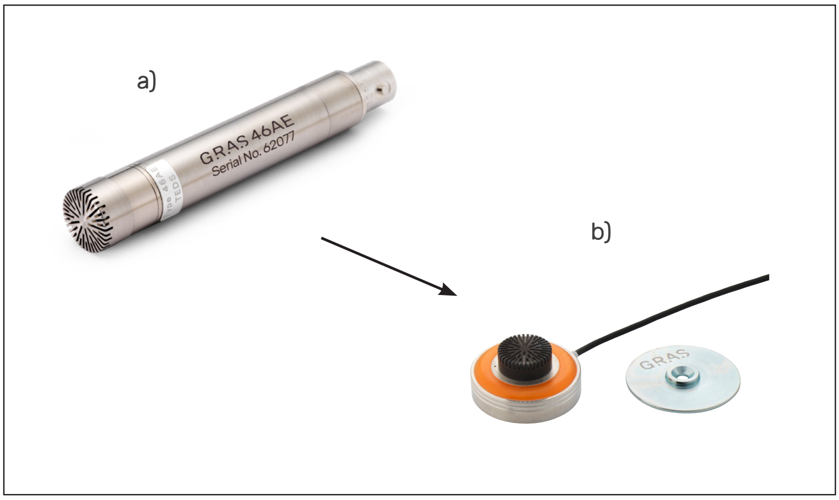

Figure 8
Traditional free-field microphone (a) and new pressure microphone (b)

The new transducer (GRAS 147AX) has been designed specifically with the rough automotive NVH testing environment in mind. As part of the design verification, the microphone has been subjected to comprehensive HALT (Highly Accelerated Life Time) testing, including tumble tests simulating vibrations, suddenly changing g-forces, and accidentally dropping the microphone. The microphone and its cable are designed to work within a temperature range from -40 and up to 125 deg C. Additionally, it has been made water and dustproof (IP67) so that the microphone may be used in harsh environments.

One of the major complications with multi-channel measurements is channel identification and calibration. To facilitate this, the microphone is equipped with a LED which makes it easy to verify that the microphone is properly connected and ready to use. Additionally, it is equipped with TEDS (Transducer Electronic Data Sheet) which can be activated by reversing the supply voltage. In this state, the transducer will transmit the full calibration data to the attached signal analyzer for channel identification. Reading the TEDS will also turn on the LED and this will allow the position of the specific transducer to be verified.

The microphone comes with a mounting disc (Figure 9), which can easily be mounted on well-defined and representative positions with, for example, double-sided self-adhesive tape, and the microphone element attaches magnetically to this mounting base. This means that the microphone can be mounted and removed within seconds even in hard to reach positions.

Figure 9
Mounting disc for magnetic attachment of microphone

For the test described here, the points were selected to represent typical structural elements independent of vehicle and engine configuration, so that results could be compared across vehicle platforms and type. Furthermore, the mounting discs would stay on for the duration of the project. The microphones can be removed and used for other tests while the vehicle is moved for modification or other tests. When the vehicle is returned, the tests can be performed with exactly the same microphone positions and with minimum setup time. The mounting positions are shown in Figure 10.

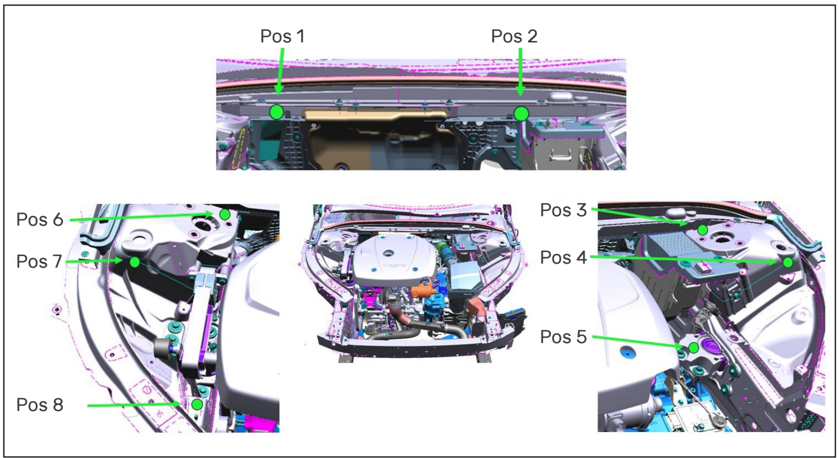

Figure 10
Measurement positions at well-defined structural points

Results with the new method

The new method produced test results that are comparable to the results obtained with the legacy method, so to a large degree the knowledge base from previous tests was maintained. However, the new method has reduced the setup time for each test considerably, and it has been possible to reduce the number of channels necessary for the test from 24 channels to a substantially lower number of channels and at the same time improve the repeatability of the test.

To test the repeatability the same measurement has been performed three times using both the old and the new method. Between each test all the microphones were removed and mounted again for the next test. Using the old method, the three tests showed a variation of 1 dB or more at frequencies above 2.5 kHz, as shown in Figure 11.

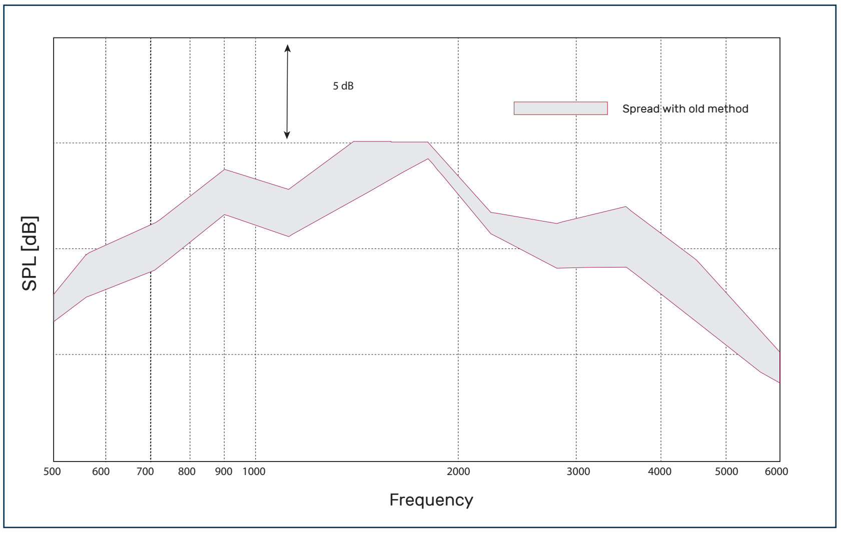

Figure 11
Variations with old method

The new method shows variation within 0.2 dB in the same frequency range, even with only 13 microphones as opposed to the 24 microphones for the old method, as shown in Figure 12.

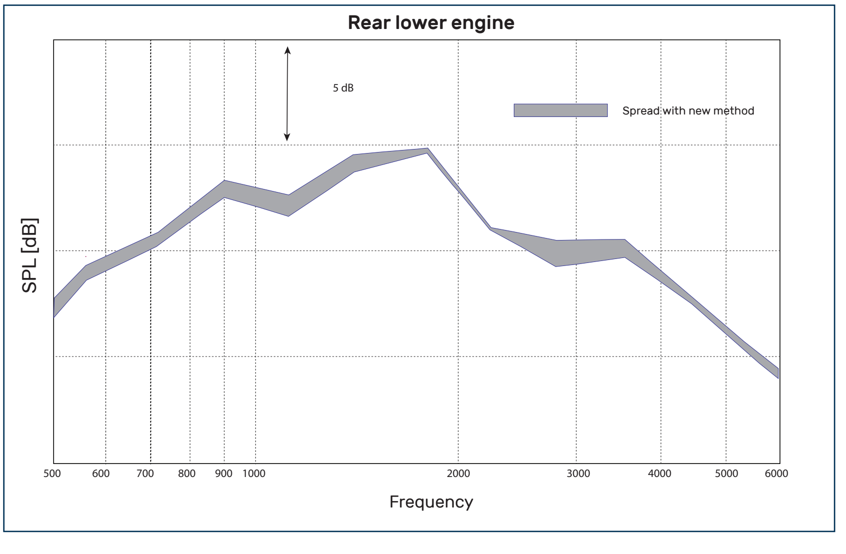

Figure 12
Variations with new method

The overall repeatability in the frequency range from 500 Hz to 6 kHz was improved from 0.75 dB to 0.3 dB. This enables precise and reliable evaluation of small, but important changes in sound attenuation performance during the progress of the project.

Looking at only a subset of the measurement points, the increase in repeatability is even greater. Figure 13 shows the repeatability with the old and new tests for three points near the rear part of the engine. It can be seen that for the old test method the results may vary 2-3 dB in almost the whole frequency range while the new method is within 1 dB. For the overall frequency range from 500 Hz to 6 kHz, the repeatability has been improved from 1.85 dB to 0.69 dB.

These improvements enable the new method to be used for better evaluation of sound transmission in particular areas of the engine bay instead of just the overall effects.

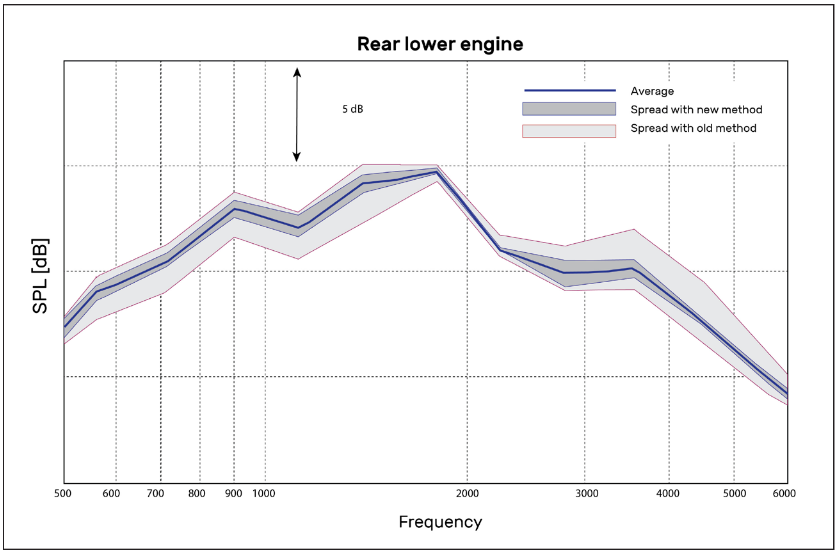

Figure 13
Repeatability for three points near rear engine, with old and new method

Conclusion

The new method for microphone mounting using GRAS 147AX pressure microphones has increased the repeatability of the measurements of sound transmission. This enables precise and reliable evaluation of different sound package optimization strategies and evaluation of different material selections.

The reduced setup time and reduced channel count makes it possible to test more options and configurations within the available time. Also, evaluating sound transmission for particular areas of the engine bay instead of just the overall effects is now possible with greater precision.

Thanks to the special characteristics such as extended temperature range, IP67 water and dust protection, size and mounting method, the GRAS 147AX can potentially be used for on-road, hot engine, brake and exhaust noise testing.

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