An Axiometrix Solutions Brand

Automotive Audio Testing using AES TC-AA guidelines

GRAS Sound & Vibration
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TECH NOTE

Introduction

In this technote, we discuss the AES White Paper on In-car Acoustic Measurement, which proposes measurement procedures for evaluating the performance of a car audio system. We describe how to follow these recommendations using GRAS microphones and AP analyzers. We also explain the APx project files attached to this technote and developed to facilitate these measurements.

In-car acoustic field and microphone impact

The democratization of personal vehicles and technological advancements over the past few decades have introduced a feature that is now standard in cars: the audio system. Whether it is with a radio set, a CD player, or CarPlay, cars have become a space where you can not only drive but also listen to music, podcasts, or any other type of audio. However, the acoustics in a vehicle cannot be characterized by a traditional sound field, meaning a free field, a pressure field, or a diffuse field, as a car cabin is made of both reflective and absorptive materials. Therefore, the in-car acoustic measurements require extra attention, which is what we will explain in the technote by following the AES recommendations[1].

In this section, we begin by defining the three traditional sound fields and how the sound field inside a vehicle differs from them. Next, we discuss the impact of microphones on the sound field and how to pick the right one for in-vehicle measurements.

Free, pressure, and diffuse field

A free field is a region in space around a sound source where sound may propagate freely in all directions with no obstructions. If a loudspeaker and microphone are in a free field, the microphone will measure only the direct sound radiated from the loudspeaker, and the sound field can be approximated to simple plane waves radiated in a well-defined direction.

The pressure field is defined as the sound field on a surface or a small, closed chamber, where the phase and magnitude are the same throughout. This could be the inside of a wind tunnel, small cavities, boundary layers, or acoustic couplers.

A diffuse field, or random-incidence field, has sound arriving with equal probability, at any level and random phase, from all directions. It can be a room with many objects causing reflections in many directions (see standard IEC 61183 Random Incidence and diffuse field calibration of sound level meters).[2]

In-car acoustic field

The In-car acoustic field is a bit more complex than the three fields presented above. Indeed, as the car cabin has multiple sources due to the speakers being placed in several locations and is made of both absorbing and reflective materials, it cannot be characterized by a traditional sound field. It will tend to be between a free field and a diffuse field, as the figure below shows. The speakers' placement and the proportion of absorbing and reflective materials will also vary from car to car, making it even more difficult to characterize one sound field for in-cabin automobile acoustics.

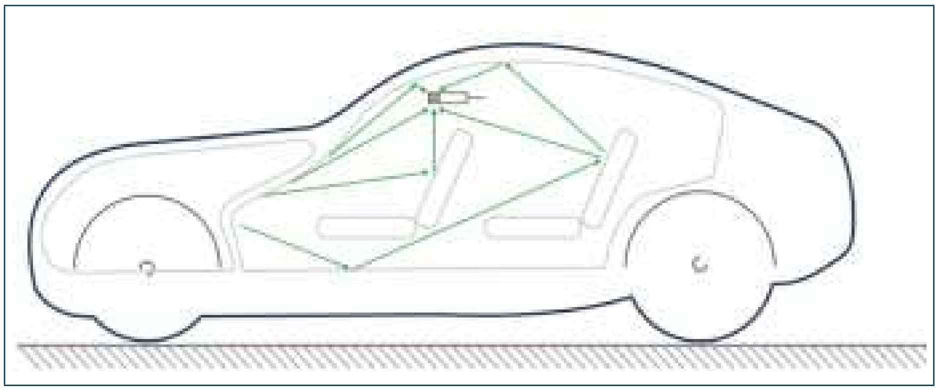


FIGURE 1.
The car cabin is a complex and non-ideal sound field made of a mix of highly reflecting materials like glass, and other absorbent materials like the ones used for the seats.

What is a measurement microphone?

In order to measure sound accurately in various acoustic fields, we use measurement microphones[3]. A measurement microphone is defined by the standard IEC 61094, which defines the characteristics of the microphone in terms of its dimension but also its basic specifications such as sensitivity, frequency response, linearity range, dynamic range limits, etc. Having microphones according to standards gives tolerances and calibration methods that allow us to trace the sensitivity and the frequency response. It then provides reliable and repeatable measurements, but also enables us to compare the measurements with each other. Different kinds of measurement microphones exist depending on the type of sound field (free field, pressure field, and random incidence field) and standards (laboratory or working standards), and have various established sizes (1", 1/2", and 1/4").

Microphone influence on the sound field

The microphone's size is a design parameter that has a huge impact on the measurements, as it interferes with the sound field. As the following formula shows, the frequency f and the wavelength λ are inversely proportional:

$$f = \frac{c}{\lambda}$$

Where c is the speed of sound in the media of interest.

This means that the higher the frequency, the lower the wavelength of the acoustic signal will be. When the wavelength and the size of the microphone become comparable, we can see the appearance of interference and diffusion. This is translated by a pressure build-up in front of the diaphragm resulting only from the interaction between the sound field and the microphone. Therefore, it is essential to choose your microphone according to the frequency range of interest.

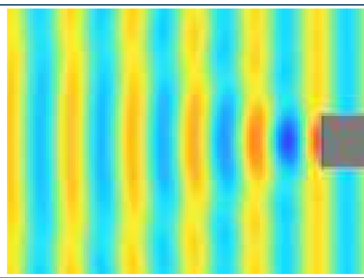


FIGURE 2.
Pressure build-up when the size of the microphone is of the same order as the wavelength.

Besides the frequency range, the size of the microphone will also affect the dynamic range we can measure. A common rule is that the bigger the diaphragm is, the lower the noise floor will be, meaning that it will be able to detect sound at a very low sound pressure level. On the other hand, smaller microphones show an ability to measure louder sounds and can cope with higher sound pressure levels. All in all, most measurement microphones have a dynamic range of around 120dB, as you can observe in the figure below.

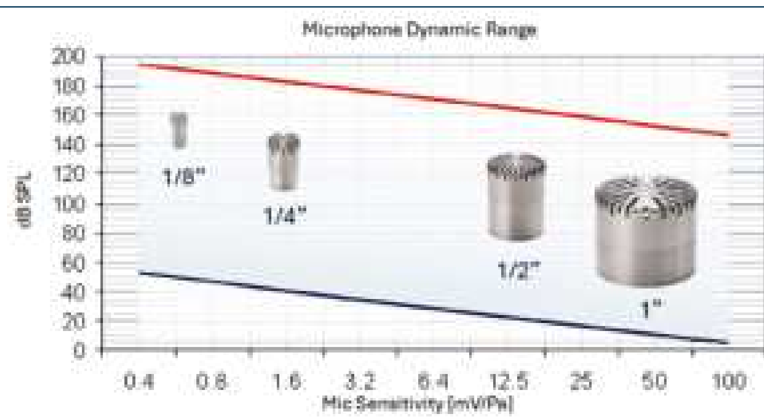


FIGURE 3.
Typical dynamic range difference for measurement microphones of different sizes.

Types of microphones for different sound fields

As explained earlier in this section, we can count three traditional sound fields: free field, pressure field, and random incidence (or diffuse) field. Measurement microphones are designed to have a flat frequency response in one of these three sound fields. So, for example, a free-field microphone will have a flat frequency response in a free-field environment when pointing at a 0-degree angle of incidence from a sound source. But if the same free-field microphone is put into a diffuse field, a pressure field, or a non-ideal sound field, its frequency response will deviate from the expected flat. Picking the right microphone type for your sound field of interest is therefore primordial.

As already mentioned, in some cases, the sound field cannot be defined as a free field, pressure field, or diffuse field. For these non-ideal fields, the concept of multifield microphones comes in handy. The idea behind it is to get a flat frequency response when the microphone is placed in a non-ideal sound field, but as non-ideal environments don't have a precise definition and vary considerably, multifield microphones aim to reduce the spread of frequency response in non-ideal sound fields.

To illustrate this idea, figure 4 compares the frequency response of three GRAS microphones: the 46BC[4], a 1/4" multifield microphone; the 46BL-1[5], a high-sensitivity 1/4" pressure microphone; and the GRAS 46BE[6], a typical 1/4" free-field microphone. For the three microphones, the free field response (navy blue), the random field response (green), and the pressure field response (light blue) are plotted. Even though the microphones are all 1/4" and have the same form factor, their response varies a lot, illustrating the importance of choosing the right microphone for your application.

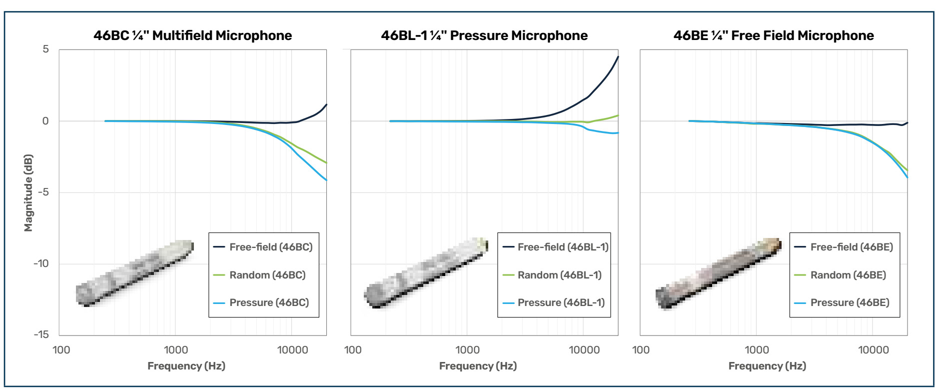


FIGURE 4.
Comparison of free-field, random, and pressure response for GRAS 46BC, 46BL-1, and 46BE.

In-vehicle Standards

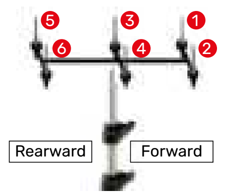
As the Technical Committee in Automotive Audio (TC-AA) noticed, “there is no consensus in the world of automotive audio on how essential attributes of the audio system in a car are measured.”[7] This lack of standards regarding audio system testing in cars makes it complicated to agree on what features are important to be tested or what method to use. Having a consensus would allow comparisons and repetitions, so a group from the TC-AA gathered in 2023 and agreed on some recommendations for measurement procedures by publishing a first version of a white paper on in-car acoustic measurements.

The white paper highlights certain processes, including clarifying which measurements should be conducted, specifying the test setup, determining the appropriate test signals to use, and outlining microphone placement.

The TC-AA recommends three measurements to determine the most important parameters of in-car acoustics: frequency response, max SPL (Sound Pressure Level), and impulsive distortion. Frequency response is important for quickly assessing the spectral balance of the audio sound system and is also a reference measurement in acoustics. Max SPL measurement is essential as it involves the entire audio system, from the loudspeakers to the power supply, and allows for easy comparison with other audio systems. Finally, impulsive distortion measurement, which includes squeak and rattle, rub and buzz, and extraneous noise, helps in identifying defects in the car that may be easily noticeable and negatively affect the quality of the sound.

In the measurement notes section of the white paper, we can read more about how the measurements mentioned in the previous paragraph should be conducted. First of all, the audio system settings of the car should be restored to their default settings or reset to their factory state. Regarding the microphones, it is advised to use six microphones as power averaging over multiple points represents the character of the sound field better than the uncertainty of doing single-point measurements. 1/4" high-sensitivity pressure microphones are recommended, as it is possible to measure high SPL, while their size does not affect measurements under 40 kHz. On top of that, the choice of high-sensitivity microphones offers the ability to measure lower SPL compared to regular microphones of the same size[8].

The spatial disposition of the microphones should respect an "H-shaped" array configuration, which is designed with specific dimensions, as shown in the figure below. These dimensions were carefully picked to represent the 5th, 50th, and 95th percentile locations in the range of head positions, allowing for the characterization of a large number of drivers.



Array Dimensions (cm)		
X	Z	Y
13.2	7.6	15
angle = 30º		

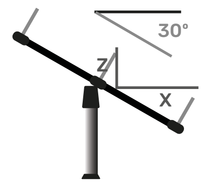


FIGURE 5.
Pictures of the microphone array and its dimensions, from the AES White Paper.

The measurements should be done with the microphone array positioned at the driver's seat, but additional tests can also be performed on other seats. If the head location information is available, position the microphone array's center at the median head location suitable for the given vehicle otherwise, the microphone array and stand can be placed according to the following figure 6.

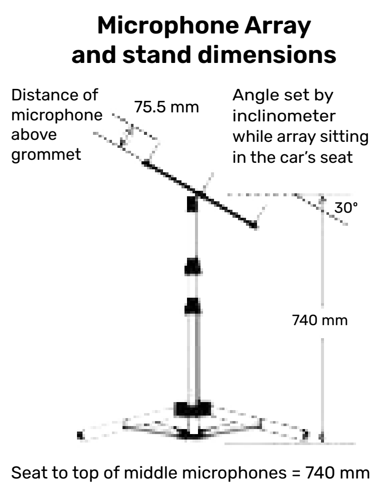


FIGURE 6.
Figure explaining how to place the microphone array, from AES White Paper.

Regarding the stimulus used for the in-car acoustics tests, they are provided through .wav files with the white paper. They consist of a pink noise signal from 20Hz to 20kHz at -12dBFS (for Frequency Response and max SPL) and a sinusoidal chirp with logarithm variation through time (for Impulsive Distortion). These signals can be played by the car audio system using various sources: a Bluetooth connection, CD, memory stick, auxiliary line-in, etc.

The frequency response and impulsive distortion can be measured at various listening levels. The reference level is set at 80 dBA, but some other measurements can then be performed by increasing or decreasing the listening level. It is preferable to start at 50 dBA and increase the level by 10 dBA steps until the maximum capacity of the audio system is reached.

The TC-AA specifies that the measurements should be done with an electroacoustic measurement and test system able to measure calibrated sound levels in dB SPL; A-, C-, and Z- weighted as described in IEC 61672. It also mentions that the acquisition devices have to be able to power average the independent signals from the 6 positions in order to measure a 30-second Leq.

It is important to remember that these recommendations are expected to evolve over time. They represent an initial step toward building consensus on how to measure the key attributes needed to compare in-cabin acoustics, with the goal of eventually establishing a standard. As the name suggests, these recommendations do not evaluate whether in-car acoustics are good or bad; rather, they aim to provide a common framework for measurement and comparison.

Finally, the use of a 6-microphone array is gaining popularity—not only for measurements aligned with AES recommendations, but also for general acoustic assessments within the vehicle cabin, including sound field characterization and audio system tuning.

Equipment for in-car testing

After having been through what a measurement microphone is, how to find the right one for a specific sound field, and what the AES white paper recommends for in-car acoustics, we are now going to explain how to follow the recommendations with GRAS and Audio Precision equipment.

The microphones

Regarding which GRAS microphone to select, two options are available. As recommended by the TC-AA, GRAS offers a high-sensitivity 1/4" pressure microphone referenced as the 46BL-1, which has the lowest noise floor in the market for 1/4" microphones. The second option would be the 46BC, which is the only multifield microphone on the market and answers the challenges of in-vehicle acoustics very well. Both microphones have a small footprint while having a high sensitivity comparable to 1/2" microphones: they are, therefore, perfect for in-cabin measurements.

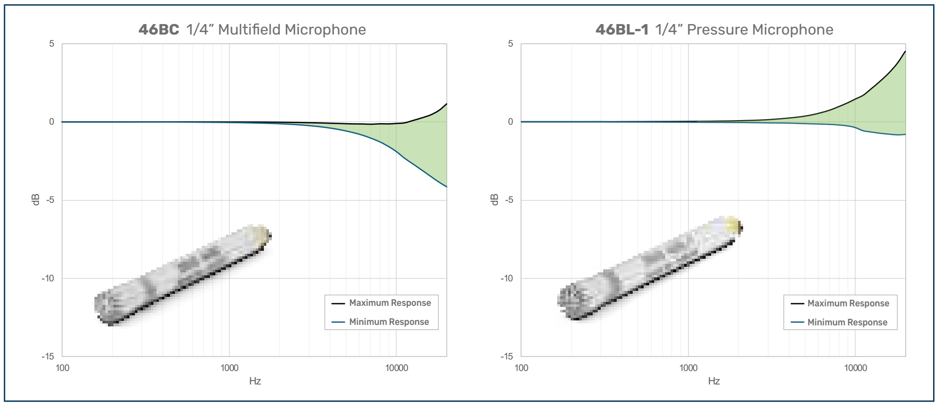


FIGURE 7.
Maximum and minimum responses of the GRAS 46BC and 46L-1 in a non-ideal sound field.

The graph above shows the frequency response spread of the 46BC and 46BL-1 when placed in a non-ideal sound field. Their versatility makes them ideal candidates for in-car acoustic measurement as the measurements are prone to fewer errors.

The GRAS PR0004 AutoArray

As explained in the previous section, the six microphones must be placed according to a specific position. To support this requirement, GRAS has released the PR0004 AutoArray AES Configuration[9], which features a 6-microphone array designed according to the dimensions specified in the AES white paper. The array comes with a seat mount and an adjustable-angle adapter, enabling easy and precise mounting. With components such as a pole, ball joint, ball level attachment, and a magnetic surface for an inclinometer, the PR0004 allows for accurate placement in terms of position, height, and pitch angle. All six microphone signals are channelled through a 7-pin LEMO connector, which is then split into six BNC connectors, simplifying the setup and reducing cable clutter.

FIGURE 8.
The PR0004 AutoArray AES configuration.

GRAS also offers the PR0003 AutoArray Cross Configuration, which is an array with a slightly different shape tailored to the proven test methodology for audio system design and tuning popularized and used by companies such as Harman.

The power modules and the analyzer

When it comes to the choice of the analyzer, various setups are suggested: with over 6-channel analyzers, with 2-channel analyzers, or with ASIO devices and AP FlexKey. In the first scenario, we suggest using an APx585 or 586[10], featuring eight analog input channels that enable simultaneous signal acquisition from the six microphones. As the APx585 and 586 do not have a built-in microphone power supply, two GRAS 12BB 4ch CCP power modules[11] should be used to drive the microphones. This setup is highly recommended as it makes measurement easier, faster, and less prone to errors, thanks to the simultaneous acquisition.

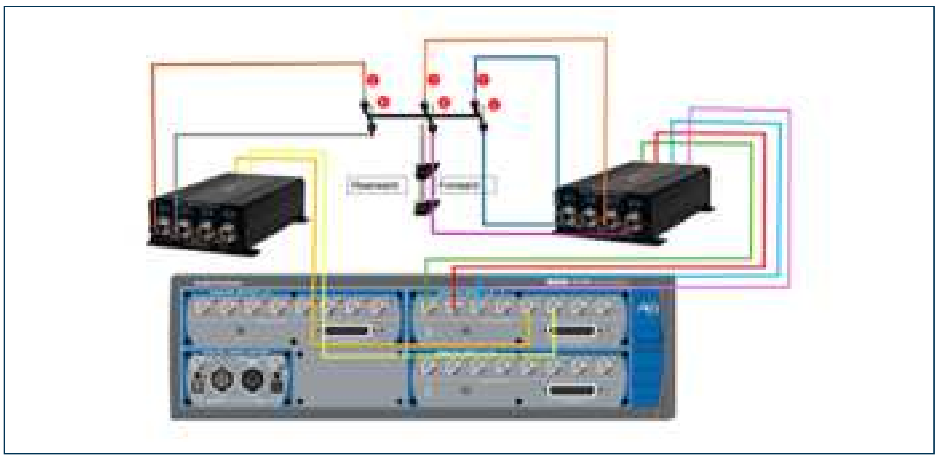


FIGURE 9.
Setup with APx58x.

For setups with 2-channel analyzers, we advise using a switcher like the AP SWR 2755B-U[12]. The six microphones can then be connected to the switcher, and the two output channels of the switcher will go to the analyzer's input channels. It is also possible to do the measurement without a switcher by plugging/unplugging the microphones manually, but doing the measurements this way increases the risk of error and incorrectly connected microphones.

If the analyzer is an APx515, APx516, APx52x, or APx555[13], a 2ch CCP power module such as the GRAS 12BE should be used between the analyzer and the switcher to power the microphones.

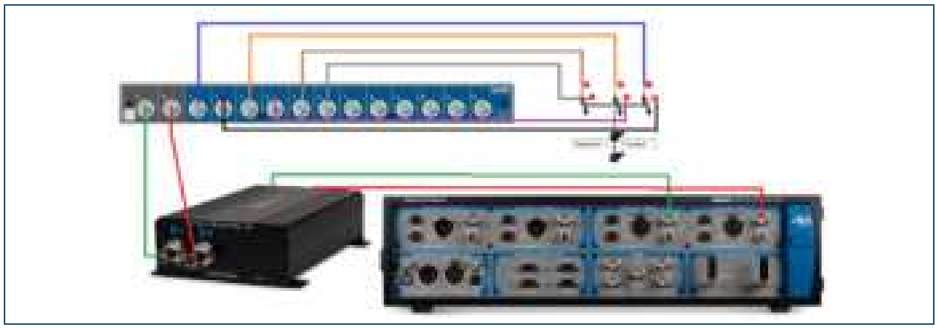


FIGURE 10.
Setup with APx555.

If the analyzer is an APx517[14], as it has a built-in CCP supply to drive the microphones, a power module is not needed between the switcher and the analyzer, as shown in the figure below:

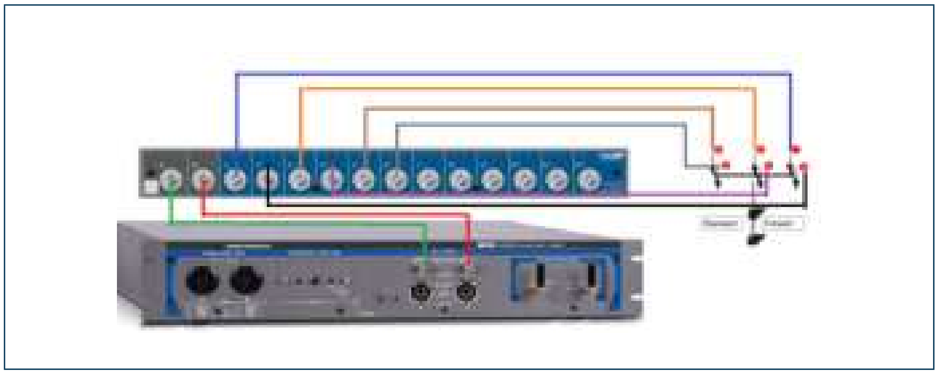


FIGURE 11.
Setup with APx517.

Alternatively, it is also possible to use APx500 Flex Key[15] with supported ASIO devices with or without the need for a CCP Power Module to drive the microphones.

FIGURE 12.
APx Flex and ASIO Devices.

It should be noted that the setups presented above are only recommendations: using other GRAS or AP equipment is, of course, possible as long as it follows the AES recommendations.

APx Project File

This application note comes with four project files corresponding to the four setups described in the previous part. It is important to remember that these project files aren't turnkey solutions: they are meant to be modified and adapted to your setup, equipment, and results that you believe are the most relevant. It is possible to modify the project files by clicking on 'Unlock' and entering the password 123.

Project File Structure

The project files are intended to be used in sequence mode. They include various sequences depending on the setup.

The project files are designed for open-loop measurements. The operator can connect a device to the vehicle via Bluetooth, CarPlay, Android Auto, or AUX input to play the test signals provided by AES. On-screen prompts guide the operator through the sequence, indicating which signal to play at each step.

The project files made for two-channel analyzers have two sequences: AES In-Car Acoustic Measurements and AES In-Car Acoustic Measurements with Switcher. As their names suggest, the first project file is used when the connections are made manually, while the second file works with a switcher.

The project file meant to be used with APx585 or 586 has three sequences: Mic Calibration (TEDS), Mic Calibration (External Calibrator), and AES In-car Acoustic Measurements.

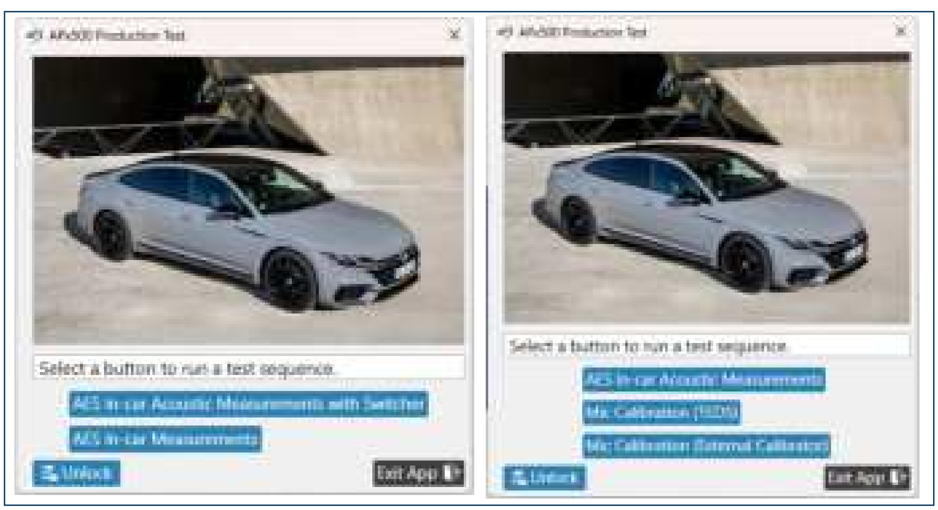


FIGURE 13.
Prompt for 2-channel analyzers (left) and for APx58x (right).

Mic Calibration (TEDS) Sequence

TEDS (Transducer Electronic Data Sheet) is a method, defined by IEEE 1451, of storing the microphone's sensitivity information on a chip inside the preamplifier.[16]

When using the Mic Calibration (TEDS) sequence, the TEDS calibration data will be read from the six microphones, and the microphones' sensitivity will be set in the Signal Path Setup.

Mic Calibration (External Calibration) Sequence

For the Mic Calibration (External Calibration) sequence, a prompt will ask the operator to calibrate each microphone with a sound calibrator, such as the 42AG[17], adjusted to 114dB at 250Hz to set the sensitivity in the Signal Path Setup.

FIGURE 14.
Prompt when using external calibration.

The Mic Calibration sequences are not included in the project files for two-channel analyzers. This is because, in this setup, only two microphones can operate simultaneously, so three pairs of microphones have to be used for each measurement. As microphones need to be calibrated before each measurement, Reading TEDS is the only suitable option, as performing external calibrations in this setup would take too much time. You will find the automatic TEDS calibration steps in the Sequence Steps of each measurement.

AES In-Car Acoustic Measurements Sequence

The AES In-car Acoustic Measurements sequence uses several signal paths. As explained in the previous section, the AES recommendation includes three tests:

- Frequency response
- Impulsive Distortion
- Max SPL

The white paper states that the Frequency response and Impulsive distortion have to be measured at 80 dBA, and some additional measurements at lower or higher sound pressure levels are possible. In the sequence, the operator can do the measurements from 50 dBA to 100 dBA by checking/unchecking the levels of interest once the project file is unlocked.

When starting the sequence, a prompt requests the operator to enter the vehicle's model. Once it's done, a new window opens and indicates to place the microphone array according to the AES recommendation. When the user is ready with the setup, the measurements can start.

The first measurement in this sequence is an APx Noise (RMS) measurement which has been renamed "Noise (RMS) 80 dBA". It starts with a prompt asking the operator to play the signal "PinkNoise 20-20000Hz CF15dB Fs 48000Hz 120s" and adjust the sound level of the car audio system to the desired level, so 80 dBA here. They can see the live A-weighted level from 20 Hz to 20 kHz. Once the level of the audio system in the car corresponds to the expected one, the bar will turn blue, and the operator can continue with the next measurement.

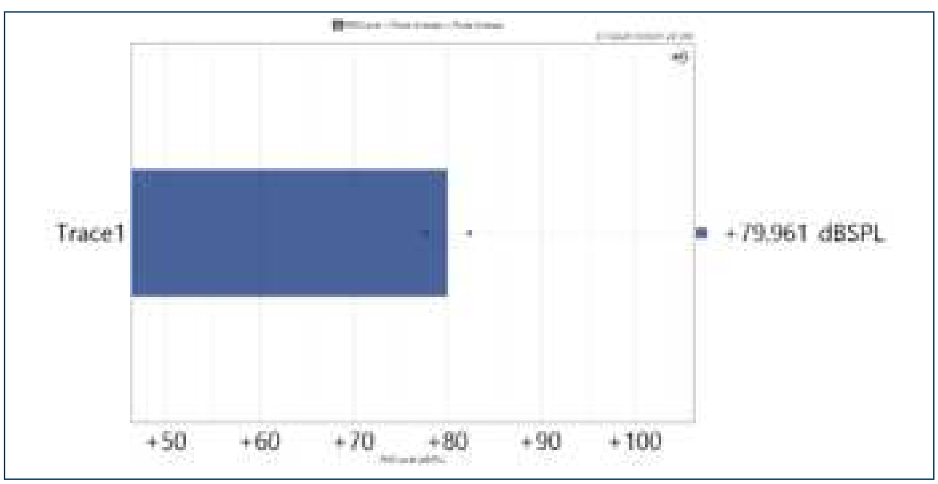


FIGURE 15.
Noise (RMS) 80 dBA result.

The second measurement is an APx Noise Recorder (RMS) measurement, which has been renamed “LEQA 80 dBA”. It measures the RMS noise level and computes the power average on a 30-second sweep time. For this measurement, the analyzer applies an A-weighting and uses a 20 Hz Butterworth high-pass filter and a 20 kHz Butterworth low-pass filter .

The third measurement is an APx Signal Analyzer Measurement, which has been renamed “Response 80 dBA”. It shows the Frequency response power averaged over 30 seconds. When starting this measurement, the pink noise signal should still be playing. The analyzer then measures the frequency response with an FFT length of 48000 and an AP-Equiripple window before power averaging over a 30-second acquisition.

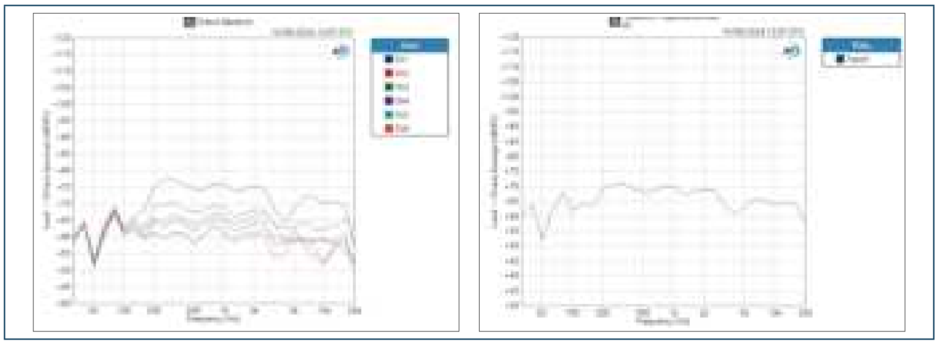


FIGURE 16.
Octave spectrum for the six microphones (left) and power averaged (right).

The fourth measurement is an APx Acoustic Response, which has been renamed “Impulsive Distortion 80 dBA”. The test signal is a sinusoidal chirp varying logarithmically with time, with a sweep time of 5 seconds, from 17,8 Hz to 1413 Hz in order to have 19 third octaves with center frequencies from 20 to 1250 Hz. With this Application Note comes a file called “OLC48k.wav”, which is the file given in the AES white paper, plus a 4 kHz pilot tone added at the beginning that triggers the measurement in APx500. Various results are shown, including the impulsive distortion HOHD (High Order Harmonic Distortion), the impulsive distortion peak ratio, the THD+N level and ratio, and the Rub and Buzz Crest Factor. The Impulsive Distortion Peak Ratio aligns with the AES recommendation, as it isolates high-order harmonics and spurious noise using a high-pass filter that tracks the fundamental frequency. In the APx500 software, this result can only be displayed as a ratio. Therefore, we also include the ID HOHD metric, which is expressed in dB SPL and can be directly compared to the measured RMS level[18], as in the white paper.

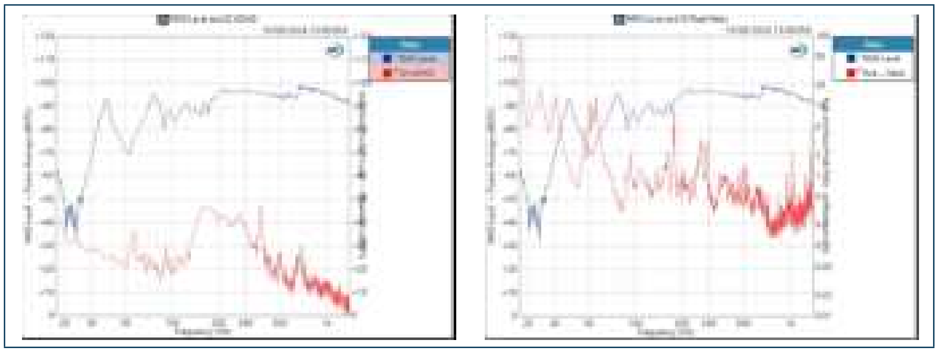


FIGURE 17.
The ID HOHD (left) and ID Peak ratio (right) plotted against the RMS Level.

It has been mentioned before that the project file was designed so that other measurements between 50 dBA and 100 dBA could be done. For each level, the measurements are the same as the ones just described for 80 dBA, meaning a Noise, LEQA, Response, and Impulsive distortion measurement.

The two last measurements of the sequences focus on the maximum sound pressure level. First, there is an APx Noise Recorder (RMS) measurement in the sequence, which has been renamed “MAX SPL”. A prompt indicates the user to increase the audio system level to its maximum. Once it’s done, the prompt asks the operator to start playing the test signal. The analyzer applies a Butterworth high pass and low pass filter respectively at 20 and 20 kHz and a C weight on the recorded signal before power averaging on the 30-second recording in order to get a single value for the max SPL.

The final measurement is an APx Signal Analyzer measurement, which has been renamed “MAX SPL Spectrum”. This measurement uses the same parameters as “Response 80 dBA” with the only exception that the infotainment system level is set to its maximum. The frequency response is once again power-averaged over 30 seconds before being shown.

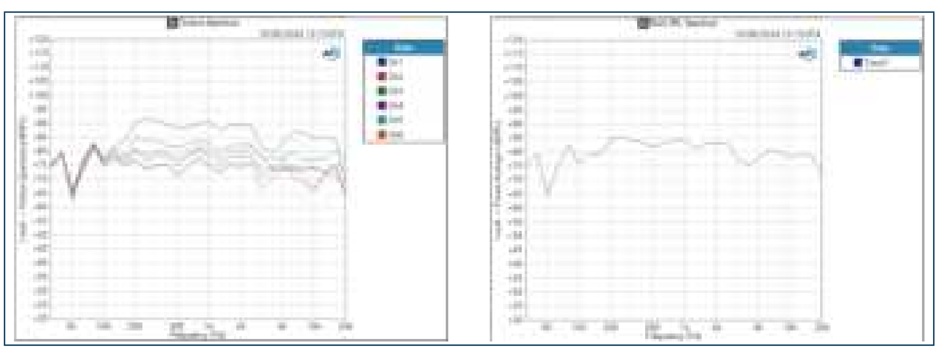


FIGURE 18.
Octave spectrum for the six microphones (left) and power averaged (right) at max SPL.

In these project files, the report checkbox at the bottom of the navigator is checked. As such, when the sequence is complete, a detailed report will be displayed. This report can be saved in one of the several formats supported (PDF, Text File, Excel Workbook, HTML, etc).

FIGURE 19.
Example of the first page of a Sequence Report.

As explained earlier in this section, the Sequence has been designed to be used in open-loop. However, the user can easily modify the project file to enable closed-loop measurements. For example, if the analyzer is equipped with a Bluetooth module, it can be connected directly to the vehicle's audio system via Bluetooth. Alternatively, a balanced cable connection can also be used to create a closed-loop setup.

Note for two-channel analyzers

If the operator is using a two-channel analyzer (APx52x, APx555, APx515, APx516), they can do the measurement with or without a switcher.
Both sequences are identical to the one presented earlier, with the sole exception that some sequence steps or prompts have been added.

Without a switcher, the operator has to change the connections manually, therefore, prompts have been included to guide them for every measurement.

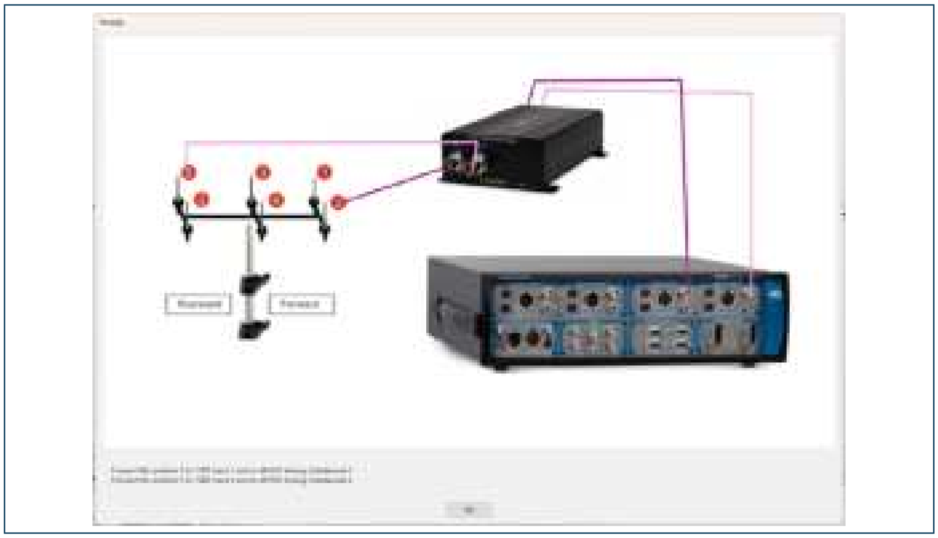


FIGURE 20.
Example of a prompt indicating the connections to be done.

With a switcher, the operator avoids manual connection changes, as the six microphones are connected to the switcher that will automatically assign the right channels to the analyzer. To do so, a "Set Switcher Configuration" step is introduced.

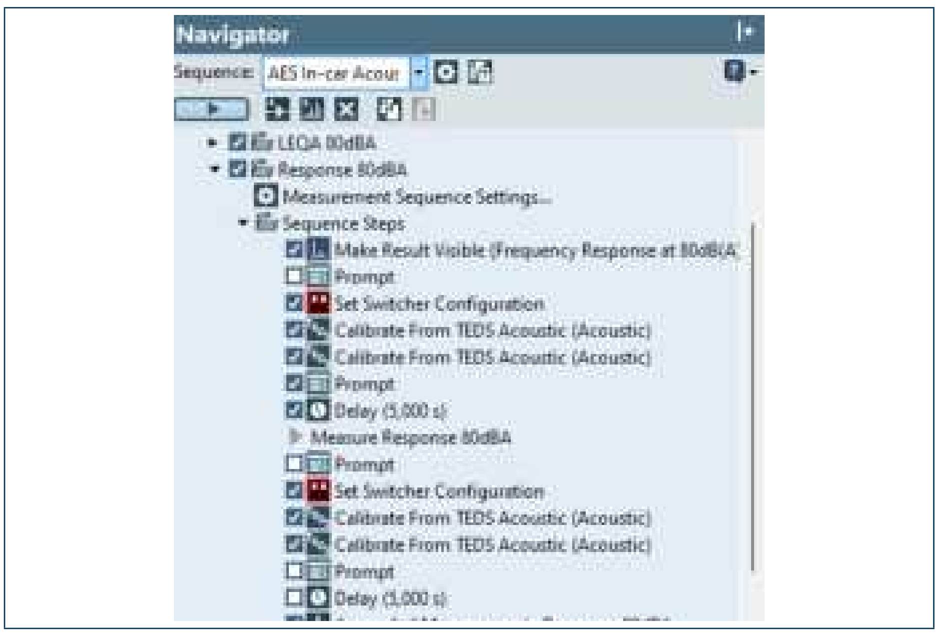


FIGURE 21.
The sequence steps when using a switcher.

Note for ASIO devices

An example of a project file made for an RME interface is provided and can give a solid base for building a project file when using an ASIO device with an AP Flex Key. As mentioned in the introduction of this section, the project file can be unlocked with the password "123" and modified to fit your setup.

Conclusion

The AES white paper on in-car acoustic measurement is the first step to creating a consensus on car audio system measurement. The TC-AA group recommends three measurements (Frequency response, Impulsive Distortion, and Max SPL) that need to be done with a specific microphone disposition and specified test signals.

This technote introduces four setups featuring different analyzers, including 2-channel analyzers, multi-channel analyzers, and ASIO devices equipped with the APx Flex Key, all in accordance with AES recommendations. The 46BL-1 and 46BC microphones were picked as they were the most suitable candidates for this application. Each setup includes an attached APx project file, which is explained in detail within this technote.

It is important to remember that the setups and project files are suggestions and can be adapted. We recommend using a multichannel measurement solution as this not only makes the process quicker but also makes it less prone to errors. However, two-channel project files are also offered to support customers who may already have APx analyzers.

Finally, AES is providing recommendations that may change as more car manufacturers adopt them, and the organization is working toward establishing these recommendations as an AES standard.

Together, the GRAS PR0004 AutoArray, GRAS 1/4" high-sensitivity microphones, and APx audio analyzers and software from Audio Precision form a comprehensive and reliable solution for the accurate testing and characterization of automotive audio systems—delivering consistency, precision, and repeatability across every stage of the development process.

References

1 AES Technical Comittee Automative Audio

2 How to Match a Measurement Microphone to a Sound Field

3 GRAS Microphone Guide

4 GRAS 46BC - Product Information

5 GRAS 46BL-1 - Product Information

6 GRAS 46BE - Product Information

7 AES White Paper In-Car Acoustics Measurements

8 Dynamic Range of a microphone - GRAS Article

9 PR0004 AutoArray AES Configuration - Product Information

10 APx58x Analyzers - Product Information

11 GRAS 12BA, BB, BE - Product Information

12 SWR 2755B Switcher - Product Information

13 AP Analyzers - Product Information

14 APx517 Analyzers - Product Information

15 APx500 Flex - Product Information

16 What is TEDS - GRAS Blog

17 GRAS 42AG - Product Information

18 AP Application Note Loudspeaker Rub and Buzz Measurements