In-Car Acoustic Measurements (AES) AN86

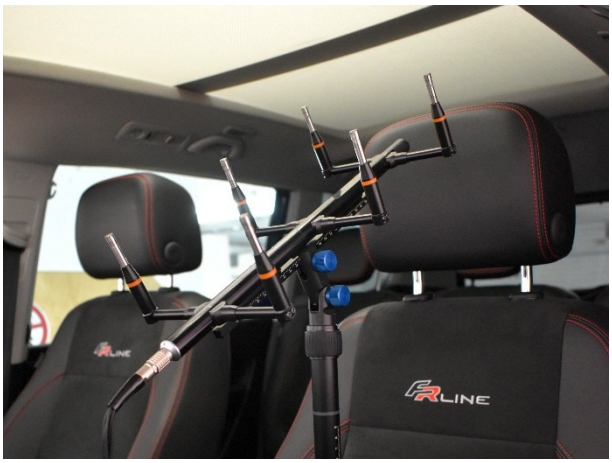
Application Note for the KLIPPEL ANALYZER SYSTEM (Document Revision 1.0)

FEATURES

- Frequency response, Max-SPL, Rub&Buzz
- Analyzing aggregated channels of a microphone array
- Open-Loop and Closed-Loop measurements (Bluetooth®, Line, USB)

BENEFITS

- Standardized procedure for industry-wide comparability
- Fast and repeatable measurements
- Flexible Open-Loop setups



DESCRIPTION

The setup of acoustic measurements in cars is not consistently standardized across the industry. This makes it difficult to acquire comparable data. This application note describes the process of In-Car acoustic measurements using a microphone array to measure frequency response, maximum sound pressure level (Max-SPL), and impulsive distortion (Rub&Buzz). Following the white paper “In-car Acoustic Measurements v1.0” by the AES – Technical Committee on Automotive Audio (TC-AA), this enables the comparison and repetition of measurements across different cars, manufacturers, and interiors. Different approaches for conducting measurements in Closed-Loop and Open-Loop configurations are discussed in detail.

CONTENT

1 Overview

1.1 Principle

Following the white paper, the acoustic performance of the car audio system is evaluated using the Klippel Analyzer System. To ensure reproducible measurements, it is essential to set up a microphone array in accordance with the provided guidelines.

A key step in the measurement process is the selection of the appropriate synchronization method. Two configurations are supported:

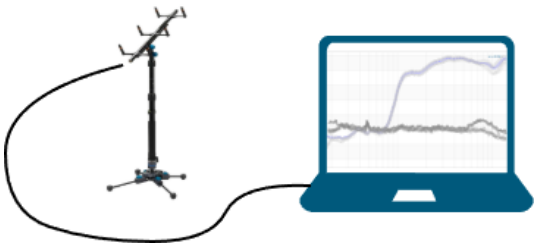
- Closed-Loop synchronization
- Open-Loop synchronization

The choice between these configurations depends on the following considerations:

- How are the excitation signals delivered to the car audio system?
- How are the microphone array signals transferred back to dB-Lab for analysis?

In a Closed-Loop configuration, dB-Lab is directly connected to both the car playback system (for example, via Bluetooth® or a wired connection) and the microphone array. This configuration provides a simple and efficient measurement workflow. Stimulus generation, playback, recording, and analysis are handled within a single synchronized signal chain. A Closed-loop configuration is recommended for its ease of use and speed.

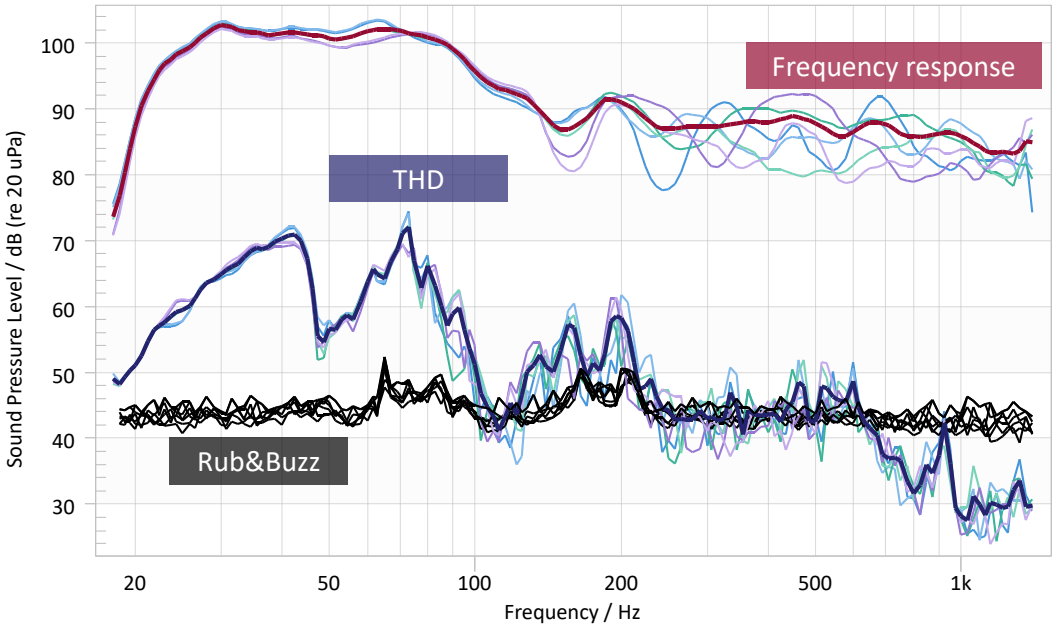
In an Open-Loop configuration, dB-Lab is not directly connected to the car's playback system, nor is the microphone array directly connected to dB-Lab. Hence, the signal chain must be split into parts. In this case, the excitation signal is exported from dB-Lab and played back using an external playback device, while the microphone signals are recorded independently. The recorded data is subsequently imported into dB-Lab for post-processing and analysis. The Open-Loop approach allows the playback and recording stages to be separated in time or performed by different operators. This can be advantageous in complex test setups or when a Closed-loop configuration is not possible.

Closed-Loop	Open-Loop
Playback	
Direct connection between dB-Lab and the car audio system 	**Export** Stimuli are exported from dB-Lab  Playback is realized by a car audio system or external device connected to it (More Information can be found in AN76 QC Testing of Wireless Audio Devices)
Capture	
Direct connection between the microphone array and dB-Lab 	**Import** Record signals from microphone array onto external device  Files are exported as one multichannel WAV-File and imported into dB-Lab

1.2 Results

The following data are obtained during the basic measurement procedure:

- Frequency response
- Impulsive distortion (Rub&Buzz)
- Total harmonic distortion (THD)
- Sound pressure level in dB(A)
- Maximum sound pressure level in dB(C) with suitable C-weighting for high-level measurements



2 Requirements

The descriptions of the sections “Requirements” and “Measurement” refer solely to measurements taken using a 3rd party audio interface. Configurations using the KA3 are also possible, but have certain limitations. These include, for example, the number of microphones, although a multiplexer could serve as a workaround in this case. If you are setting up a custom configuration and have any queries, please contact Klippel support team (support@klippel.de).

2.1 Hardware

Microphone array	A microphone array should be used for the In-car measurements. The six-microphone array G.R.A.S PR0004 AutoArray is specifically designed to meet the requirements defined in the AES white paper. Note: The Klippel software framework is limited to a maximum of 15 microphone array channels 
Microphones	High sensitivity ¼ inch microphones should be used for the measurements. The following microphones are characterized by very low noise floor and high accuracy: • GRAS 46BL-1 • GRAS 46BC 
Audio interface	An audio interface with phantom power is required for connection with microphones. For the G.R.A.S microphones, an audio interface with an IEPE supply should be used.

Bluetooth transmitter (optional)	A Bluetooth capable device or Bluetooth transmitter is required for playback in order to establish a connection with the car's multimedia system. Suitable options can be found under A6 Accessories for the Klippel Analyzer System.
Open Loop	
Recording device (optional)	Open-Loop (Import) measurements require an external device to handle recording. Depending on the device, an ASIO-capable digital audio workstation (DAW), such as Reaper, may be used for recording.
Export Device	Exporting stimuli and/or .wav-files onto an external memory device (e.g., USB)

2.2 Software

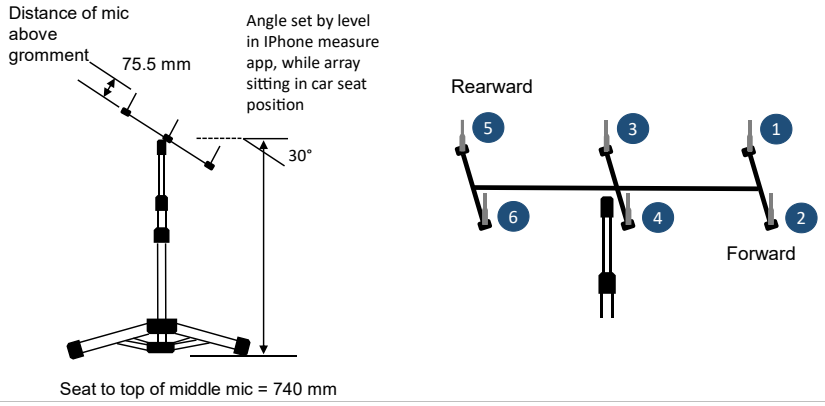
Klippel QC framework	• QC software (Stand-alone) - QC Version 7.9 or higher for plain acoustic tests using 3rd party sound cards • QC SPL – Sound Pressure Task – measurement of impulsive distortion and Rub&Buzz • QC SAN – Spectrum Analysis Task – measurement of frequency response and Max-SPL • QC SYN – External Synchronization Task – used for device synchronization in Open-Loop configuration (optional)
Open Loop	
DAW (optional)	Digital Audio Workstation (DAW) is used for recording signals with an Open-Loop setup and exporting a multichannel .wav-files.
SoX - Sound Exchange (optional)	Converting multiple .wav-files into one multichannel .wav-file. Useful when there is no direct way of exporting the recorded signals as a multichannel .wav-file.

2.3 Device under Test

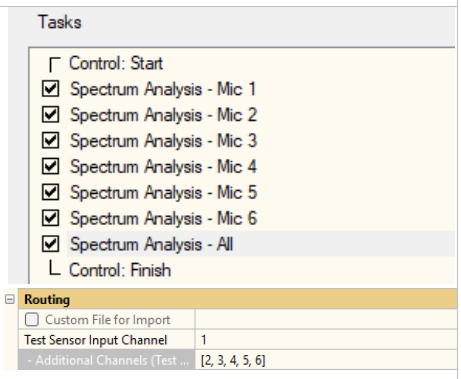
Automotive unit	Any car equipped with an audio system and an external audio input can be used for the measurement. As described below, there are several methods of stimulus playback. Playback-chain stability is of high priority. Also, testing different methods (if there is more than one) can be beneficial to optimize accuracy and noise floor. Some cars and audio systems exhibit certain behaviors that can negatively influence the measurement if not accounted for:
	• Audio system configuration/setup limitations:
	  ○ coarse stepped volume control
	  ○ automatic standby/sleep mode/eco mode
	• Microphone array placement:
	  ○ height, headrest, seat position settings
	  ○ cable management
	• Sources of parasitic vibration (Rub&Buzz) that are not part of the audio system (for example door compartments)
	In addition, the following limitations regarding the measurement should be noted:
	• The car is not moving
	• The engine is shut off
	• Doors and windows are closed

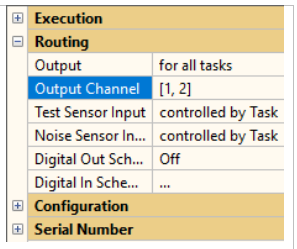
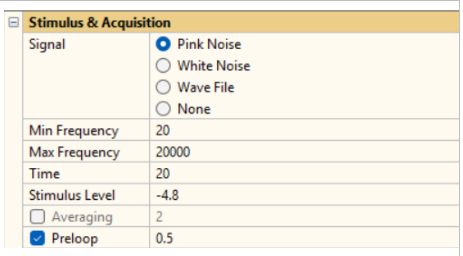
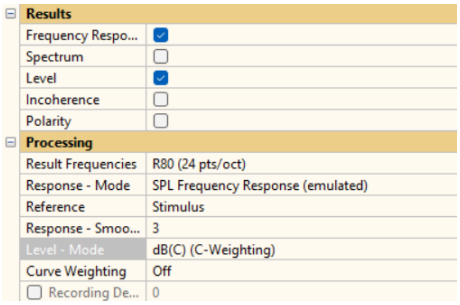
3 Measurement

3.1 Hardware preparation

Microphone array construction	Place the microphone array in the car. The AES white paper defines the proper order and placement of the (typically) 6 microphones. The numbering convention scheme is shown in the picture (right). Forward refers to the steering wheel. Rearward refers to the head-rest. Follow the white paper instructions to document the mic array positioning: • Eye/Ear ellipse: Placement at the median head location • Centered on a seat with feet pushed to the point between seat and back • For consistency, a spirit level can help to center the array in the plumb in relation to the seat • Microphones 3 and 4 at 740 mm above the seat and at an angle of 30° • Array is facing to the steering wheel / driver's line of sight 
Hardware setup	The rest of the hardware setup is described in the section of the selected signal routing (Closed-Loop or Open-Loop).

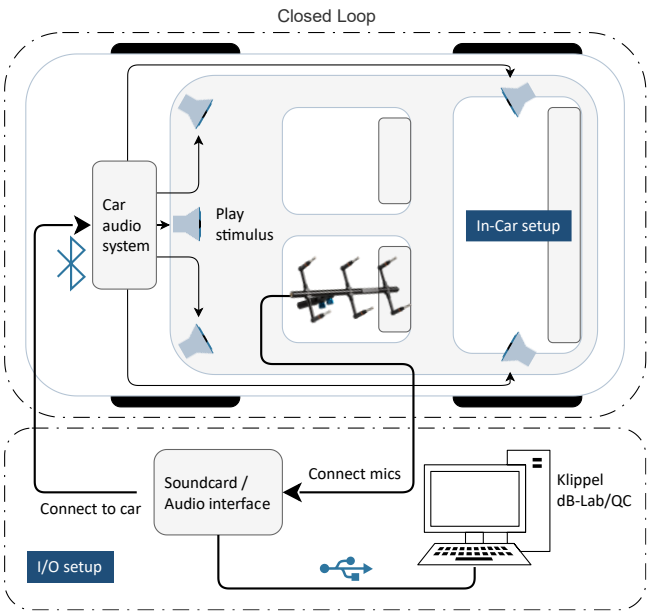
3.2 Software preparation

Car audio system	Set to default / factory settings / reset or document the setup
Microphone calibration	Calibration is needed for every microphone. A detailed explanation of the calibration process can be found in TN17 Setting up Dante & Powersoft Mezzo for QC Stand-Alone (section 5). It is recommended to calibrate the microphones with the assigned signal chain: • Mic 1 is calibrated in array position 1 connected to sound card input 1 • etc.
Measurement sequence	A measurement sequence is set up according to the desired measurement parameters and the number of microphones. For more information, see the user manual on how to Create a Test. It is recommended to use one task for each microphone to display individual mic channels. Additionally, one task is configured to aggregate the measurements from all array microphones. The aggregated curve is the main result representing the spatial average. 

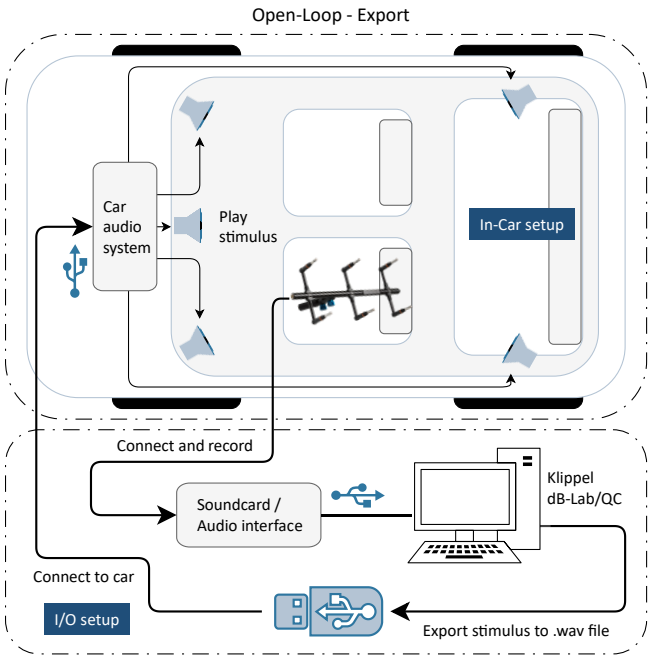
Signal routing	The channel assignment can be set both globally for the complete test sequence or individually for each task. A detailed explanation can be found in AN79b Efficient, Mobile Quality Assurance of PA Speakers (section 5.5). Standard car audio systems are stereo which implies a 2-input-channel setup. Therefore, it is important to specify the soundcard output channels 1 (left) and 2 (right). 
Stimulus	• Pink noise stimulus for frequency response and Max-SPL • Sinusoidal logarithmic chirp for THD and Rub&Buzz  The Spectrum Analysis Task (SAN) task is used for the measurements of the frequency response and Max-SPL using a pink noise stimulus. Once integrated into the measurement sequence, the stimulus should be adjusted in accordance with the recommendations in the white paper. Note: The Klippel software is limited to a maximum stimulus length of 20 seconds The result parameters 'Frequency Response' and 'Level', must be enabled as results. The appropriate weighting should be set for the level calculation. While the A-weighting is used for level adjustments, the C-weighting is needed for the Max-SPL measurement.  The Sound Pressure Level (SPL) task is used to measure THD and Rub&Buzz using the sinusoidal chirp. The stimulus should be adjusted in accordance with the recommendations in the white paper. At least "Rub&Buzz" must be enabled as results. Additional settings can be configured as desired, the results "Frequency Response" and "THD" are optional.
Volume adjustment	After successful input device calibration in dB-Lab, it is possible to manually adjust the desired output level with stepped playback. Therefore, the aggregated task should be used for the measurements ranging from 50 dB(A) to Max-SPL with 10 dB(A) increments. For Open-Loop setups where dB-Lab is not directly connected to the input device, it is possible to use a sound level meter, although it does not provide spatial averaging.
Software setup	The rest of the software setup is described in the section on the selected signal routing (Closed-Loop or Open-Loop). A preconfigured test sequence is provided for this application note (see Additional Data).

3.3 Closed-Loop

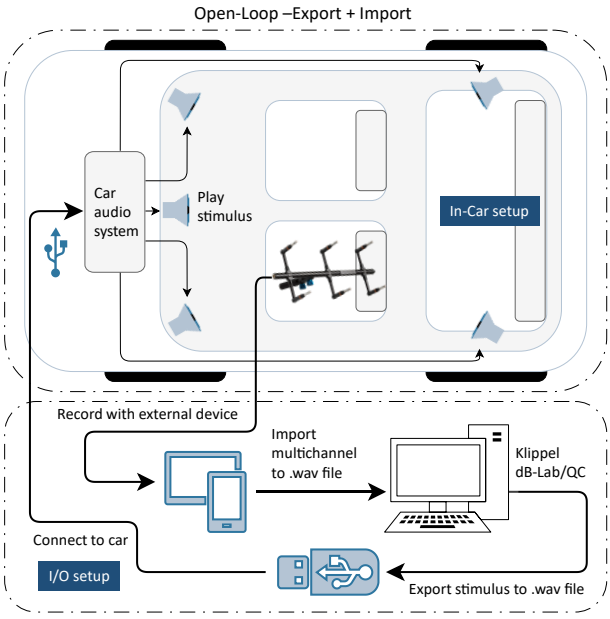
Hardware setup	• Connect a multichannel audio interface (ASIO preferred) to the PC • Connect the car audio system to the output of the audio interface • Connect the microphone array to the input of the audio interface
Software setup	• Assign the audio interface as input/output for dB-Lab in the Configure Hardware settings • Perform sensor calibration or load existing calibration files for all microphones • Adjust the playback level as described above
Measurement	The following diagram can be used as a guide for assembly. Once it is complete, the measurement can be performed.



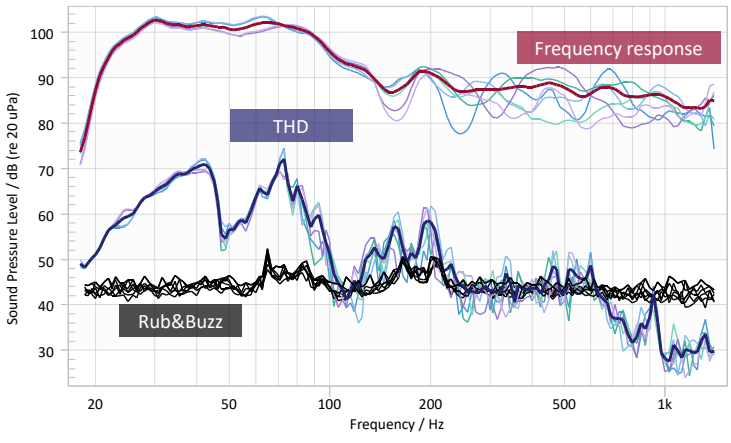
3.4 Open-Loop – Export: Playback via USB Stick, Recording via Soundcard

Hardware setup	• Connect a multichannel audio interface (ASIO preferred) to the PC • Connect external device (USB drive or similar) to the car audio system • Connect the microphone array to the input of the audio interface
Software setup	• Select SYN: Open Loop – Capture + Wave Export in “Control: Start” of measurement sequence and follow guide for Capture + Wave Export • Save .wav-file on external device • Assign audio interface as input for dB-Lab in the Configure Hardware settings • Perform sensor calibration or load existing calibration files for all microphones • Adjust the playback level as described
Measurement	The following diagram can be used as a guide for assembly. Once it is complete, the measurement can be performed. Make sure the Klippel QC operation starts before the stimulus playback is triggered. 

3.5 Open-Loop – Export + Import: Playback via USB Stick, Recording of .wav-files

Hardware setup	• Connect external device (USB drive or similar) to the car audio system • Connect the microphone array to the input of the external recording device (e.g. laptop with DAW or digital recorder)
Software setup	• Select SYN: Open Loop – Capture + Wave Export in "Control: Start" of measurement sequence and follow guide for Capture + Wave Export • Save .wav-file on external device • Set up the external recording device • Adjust the playback level as described • Export the recorded tracks as a multichannel .wav-file, or convert multiple files into a multichannel file using SoX (Sound eXchange) or another suitable method • Select SYN: Open Loop – Wave Import + Playback in "Control: Start" of measurement sequence and follow the guide for Wave Import + Playback
Measurement	The following diagram can be used as a guide for assembly. Once it is complete, the measurement can be performed. Make sure the recording starts before the playback of the stimulus is triggered. 

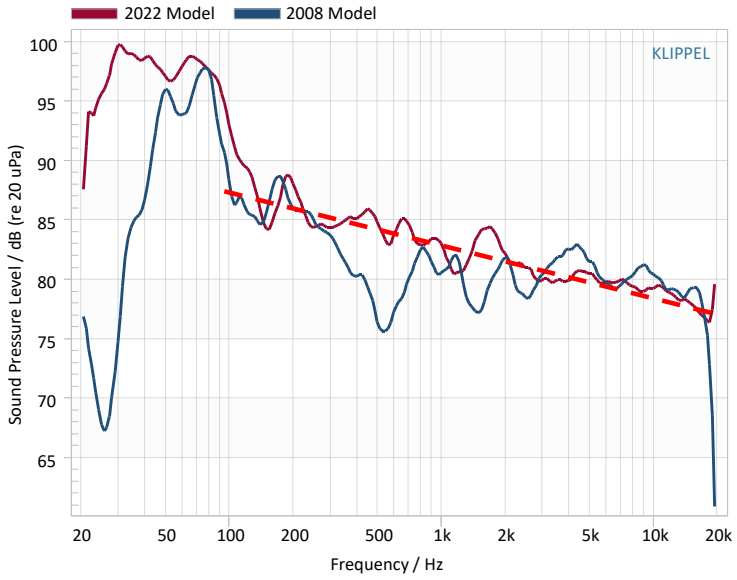
3.6 Results

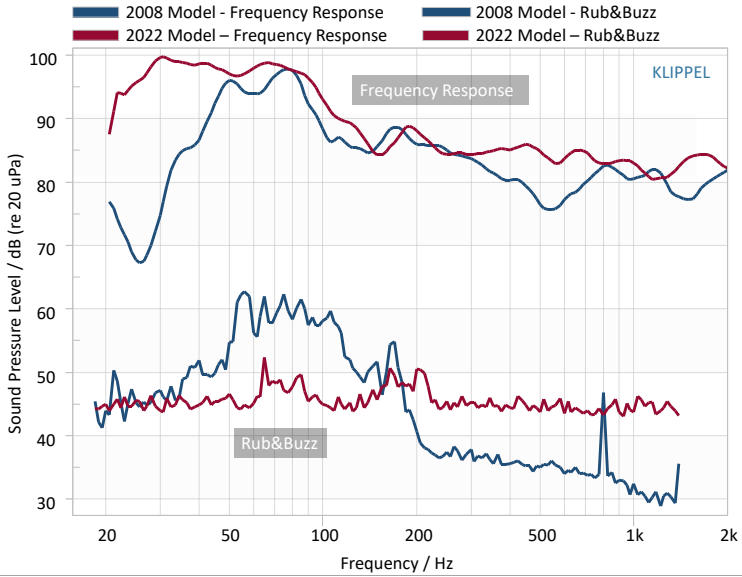
Frequency response	

	In the “Frequency Response” window, all individual microphone channels and the aggregated channel are displayed. These curves represent the frequency responses and their average in the vehicle at the ear ellipse, corresponding to a typical head position. If the frequency response is measured at different levels, the dependency of the playback volume (for example loudness control) becomes visible.
Rub&Buzz	Rub&Buzz reflects higher-order harmonic distortion with an impulsive nature caused by most defects of the transducer and other irregularities in the playback chain. The result curves for all channels are plotted in the “Frequency Response” window.
Total harmonic distortion (THD)	Harmonic distortion components found in the output spectrum indicate nonlinearities inherent in the device under test. Total Harmonic Distortion (THD) is displayed in the “Frequency Response” window. Note: THD is an optional measure.
Max-SPL	Setting the gain control to its maximum value, Max-SPL is measured. The Max-SPL is based on the SAN operation of the aggregated channels and is displayed in dB(C) in the “Summary” window.

Name	Value	Unit	Description
Level	93.5	dB (C)	total input level (C-Weighting)

4 Example

Device under Test	The following section presents measurement results of two different vehicles at a playback level of 80 dB(A): • 2022 model (red) • 2008 model (blue) The discussion focuses solely on the results of the aggregated microphone channel measurement. Although the two measurements show slight differences in noise floor level, the results clearly demonstrate inherent differences in the audio reproduction quality of the two sound systems. The curves are displayed using 1/3-octave smoothing.
Frequency Response	

	Notable differences can be observed in the smoothness of the frequency response and the low-frequency extension. The 2022 vehicle exhibits a relatively controlled response with approximately ±3 dB deviation and a −1.5 dB/octave tilt above 100 Hz, indicating a well-balanced tuning. In contrast, the 2008 vehicle shows significantly larger irregularities, with dips of up to 8 dB and greater overall variation. This results in a noticeable deficiency in the mid-frequency range between 300 Hz and 800 Hz, creating an audible gap in the response. Below 150 Hz, both vehicles show an elevated low-frequency response of approximately 8–12 dB, which is typical for In-car playback conditions.
Rub&Buzz	The older vehicle also produces a higher level of Rub&Buzz in the bass region, clearly visible between 40 Hz and 200 Hz. Differences of up to 13 dB compared to the 2022 vehicle can be observed. In addition, a distinct parasitic Rub&Buzz spike at 800 Hz is present in the older vehicle, further indicating lower mechanical and acoustic quality. 
Max-SPL	For this example, the car audio systems were not operated at their maximum output levels to avoid potential damage. Both vehicles were set to an equivalent sound pressure level of 83 dB(A) during the Max-SPL measurement. Under these controlled conditions, the newer vehicle demonstrates approximately 3 dB higher C-weighted output capability than the older vehicle, while also exhibiting fewer indications of impulsive distortion. **Name** **Value** **Unit** **Description** 2008 Model Level 90.7 dB (C) total input level (C-Weighting) **Name** **Value** **Unit** **Description** 2022 Model Level 93.5 dB (C) total input level (C-Weighting)

5 More Information

5.1 Application Notes	QC Testing of Wireless Audio Devices, Application Note 76 Accessories for the Klippel Analyzer System, Application Note 6
5.2 Modules	QC Software Sound Pressure (SPL) Spectrum Analysis (SAN) External Synchronization (SYN)
5.3 Manuals	User Manual QC – Quality Control
5.4 Other	AES [TC-AA] In-Car Acoustic Measurements White Paper is available in Additonal Data Audio Converting Software - SoX - Sound Exchange

Find explanations for symbols at:
http://www.klippel.de/know-how/literature.html
Last updated: May 27, 2026