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| GM WORLDWIDE ENGINEERING STANDARDS | Test Procedure | GMW14155 |

# Subsystem or Component Sound Master Laboratory Recording and Evaluation Procedure, Customer Actuated Sound

## 1 Introduction

**Note:** Nothing in this standard supercedes applicable laws and regulations.

**Note:** In the event of conflict between the English and domestic language, the English language shall take precedence.

**1.1 Purpose.** To provide a common procedure for recording in a laboratory the sounds of subsystems or components (that can be directly actuated by the customer, Customer Actuated Sounds (CAS)) for analysis for sound quality evaluation using measuring microphone.

**1.2 Applicability.** Any subsystem or component that is installed on vehicles and can be directly actuated by the customer.

**1.3 Remarks.** The sounds of subsystems must be recorded to apply the objective methods for Sound Quality Metric evaluation. Many subsystems have multiple modes of operation. Each mode of operation must be recorded independently for evaluation and comparison. This procedure is intended to describe the operating conditions of the subsystems, the recording methods to be used, and the various analysis methods that may be applied to the recordings for the objective Sound Quality Metric evaluations. Not all the analysis methods described in this procedure need to be applied to the sounds of every subsystem. The requirements or test procedures for the specific subsystems or components will identify which methods are to be used.

## 2 References

**Note:** Only the latest approved standards are applicable unless otherwise specified.

**2.1 External Standards/Specifications.**

DIN 45631 ISO 532

**Note:** ISO 532 Method for Calculating Loudness Level (Method B). (Caution: The most recent version of this standard is from 1975. It describes a process for manually plotting data on special graphs to determine a loudness value. This process was invented by E. Zwicker. Current commercially available sound quality systems reference this standard but use a computer algorithm (published by Zwicker) that is not documented in the standard. Some systems also use more advanced (and, as of yet, not standardized) processes documented by Zwicker and others. The results of analyzing the same recorded data with different systems using the more advanced versions of Zwicker's method may not always agree due to the lack of standardization.)

**Note:** DIN 45631 is comparable to ISO 532.

**2.2 GM Standards/Specifications.**

GMW14172

**2.3 Additional References.**

- Hardware and software operation manuals of analyzer/sound quality system and supporting equipment
- HEAD Acoustics ArtemiS Suite, available at www.head-acoustics.de/eng/nvh_artemis_suite.htm
- Percentile Frequency Method and Zwicker Loudness, R.J. Fridrich, Proceedings of the 2002 International Congress on Noise Control Engineering, August 2002
- Pitch Intervals: Linking Sound Quality Engineering and Musical Acoustics, R. J. Fridrich, Proceedings of the 2003 SAE Noise and Vibration Conference, May 2003
- Psychoacoustics, Facts and Models, Zwicker, E. and Fastl, H. Springer-Verlag, 1990



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## 3 Resources

**3.1 Facilities.** An Anechoic room or Hemi-anechoic room test area free from interfering noises. Unless otherwise specified, the maximum Zwicker specific loudness of the background noise is not to exceed 0.2 sones/Bark from 0 Bark to 5 Bark, and 0.1 sones/Bark at any frequency greater than 5 bark, and the overall Zwicker loudness is not to exceed 1.2 $sone_{GF}$. Background noise is considered to include room or test cell ambient noise and room support equipment noise.

**3.1.1 Calibration.** The test facilities and equipment shall be in good working order and shall have a valid calibration label.

**3.1.2 Alternatives.** Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

**3.2 Equipment.**

**3.2.1 Hardware.**

**3.2.1.1** Free field measurement microphone (12.7 mm diameter).

**3.2.1.2** Microphone Preamplifier and connecting cables.

**3.2.1.3** Microphone Power Supply (if the function is not already provided by the Digital Sound Recording System).

**3.2.1.4** Microphone Stands (floor stand and seat stand or equivalent method for supporting the microphone).

**3.2.1.5** Sound Level Calibrator.

**3.2.1.6** Digital Sound Recording System (DAT) using a sample rate of 48 kHz. If the recording system includes a user-selectable high pass filter, set it to 22.4 Hz.

**3.2.1.7** Door Velocity Meter (as needed for closure systems).

**3.2.1.8** Digital Voltmeter (as needed for electrically powered systems).

**3.2.1.9** DC Power Supply (as needed for electrically powered systems).

**3.2.1.10** PC Computer system (capable of running the sound quality analysis software).

**3.2.1.11** Small accelerometers (weight less than 0.006 kg).

**3.2.2 Software.**

**3.2.2.1** Sound Recorder data acquisition program by HEAD Acoustics or an equivalent sound recording program.

**3.2.2.2** ArtemiS sound quality analysis program by HEAD Acoustics or an equivalent analysis program.

**3.3 Test Vehicle/Test Piece.** A vehicle having the subsystem under test correctly installed.

**3.4 Test Time.**

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| Calendar time: | 1 to 2 days |
| Test time: | 8 to 16 hours |
| Coordination time: | 4 to 8 hours |

**3.5 Test Required Information.** Not applicable.

**3.6 Personnel/Skills.** One (1) technician or engineer with training in performing sound analysis, and with an understanding of the Zwicker Loudness Method and sound quality methods such as the Percentile Frequency method and the Relative Pitch evaluation method.

## 4 Procedure

**4.1 Preparation.**

**4.1.1 Subsystem or Component Setup.** Given in the test procedure for the specific subsystem or component.

**4.1.2 Measurement Microphone Setup.** Given in the test procedure for the specific subsystem or component.

**4.1.3 Position of Velocity Meter (as needed).** Given in the test procedure for the specific subsystem or component.

**4.1.4 Accelerometers.** Given in the test procedure for the specific subsystem or component.



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**4.2 Conditions.**

**4.2.1 Environmental Conditions.** Not applicable.

**4.2.2 Test Conditions.** Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

**4.3 Instructions.**

**4.3.1** Check equipment for valid calibration date. Replace out-of-date equipment. Perform equipment calibration verification. Reference GMW14172.

**4.3.2** Perform the following tasks to record the sound of the subsystem under test while it is being operated according to the test procedure for the specific subsystem or component.

**4.3.2.1** Record the sound of the subsystem in its mode of operation over its complete range. Record 2 s or more of quiet before and after operating the subsystem to ensure that extraneous sound (announcements, movement, etc.) do not occur during subsystem actuation. For power-operated systems controlled using switches, wait at least 2 s before releasing the switch to allow the switch noise to be distinguishable from the operating sound of the system.

**4.3.2.2** Repeat the preceding data acquisition sequence as needed for all other operating modes of the subsystem.

**4.3.3 Sound Analysis.**

**4.3.3.1 Loudness Setup.**

**4.3.3.1.1** Follow the appropriate sections described in the following, to analyze the recorded sounds of the subsystem. When using any of the analyses based on Zwicker Loudness, the analysis parameters are to be set as follows:

**4.3.3.1.2 Calculation Method.** Choose a method that employs Digital ⅓ Octave Filters and the Zwicker Loudness calculation algorithm (labeled Filter/ISO 532, Method B or DIN 45631, in ArtemiS).

The Filter-based method is more accurate in the lower frequencies due to the problem with the Time/Frequency trade-off that one must make with Fast Fourier Transfer (FFT) based analysis.

**4.3.3.1.3 Soundfield.** Choose Free Field for all evaluations including the background noise in the facility.

**4.3.3.1.4 Scale.** Choose the sones scale.

**4.3.3.1.5 Frequency Scaling.** If it is selectable, choose the method that displays the frequency data in the Bark scale with a minimum resolution ⅛ Bark. (The resolution in ArtemiS is fixed at $^{1}/_{10}$ Bark.)

**4.3.3.1.6 Filter Order.** If the system allows a choice, as in the case of ArtemiS, choose the 6$^{th}$ order filter method.

**4.3.3.1.7** Sound files intended for analysis using Zwicker Loudness must allow a minimum of 0.2 s of quiet before the sound of the event being analyzed. If the sound event is an impulse, the length of the sound file must be at least 1.0 s. The 0.2 s of quiet before the event will allow the Zwicker Loudness analysis to stabilize at the background noise level to ensure that the beginning of the sound event is properly analyzed. When the desired sound event has been selected using the mark editor in ArtemiS, save the selected sound event as a separate file before performing the analysis.

**4.3.3.2 Steady State Loudness.**

**4.3.3.2.1** Recall the files containing the subsystem sound of the individual subsystem operations.

**4.3.3.2.2** Display the Zwicker Loudness time history (Figure 1). Store the Zwicker Loudness time history data in a (preferably) MS Excel spreadsheet if the analysis program cannot determine the average Loudness in the method described as follows.

**4.3.3.2.3** Identify on the Zwicker Loudness time history the beginning and end of the time interval containing the steady-state sound of the individual subsystem operation. Be sure to exclude any impulsive sounds that may have occurred at the start and stop of the subsystem operation.

**4.3.3.2.4** Determine the average loudness that occurred during the steady-state sound by calculating the arithmetic average of the Zwicker Loudness time history data. If the analyzer or sound quality software cannot determine the arithmetic average, export the loudness time history to MS Excel and perform the statistical calculations described in the following.



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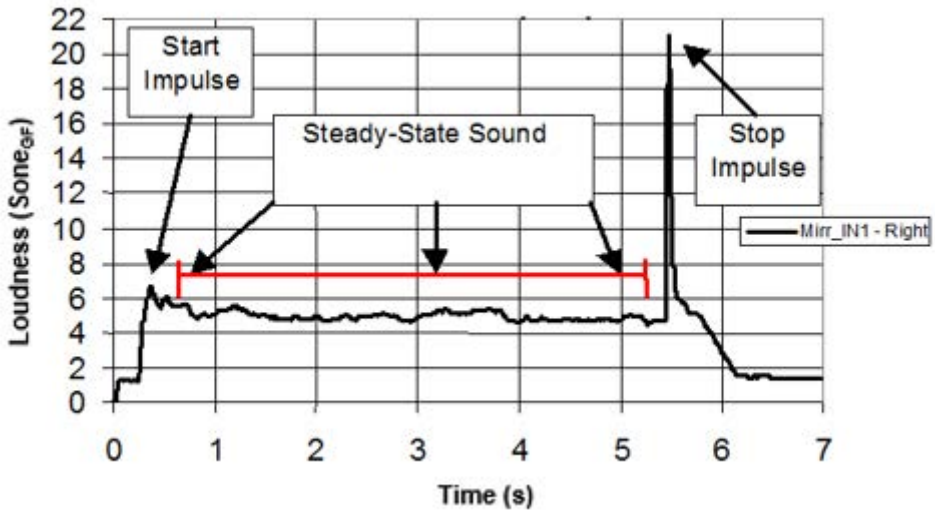
**Note:** DO NOT determine an average spectrum and then from the average spectrum determine a Zwicker Loudness value. The result obtained from an average spectrum (i.e., energy averaging) often is not the same as the result from averaging arithmetically the individual loudness values of the time history.

**Figure 1: Example of Loudness Time History with Start Impulse, Stop Impulse and Steady State Travel Identified**




**4.3.3.2.5** Determine the slope and intercept of the Zwicker Loudness time history of the steady-state sound using MS Excel functions.

**4.3.3.2.6** Repeat the preceding analysis from the beginning of 4.3.3.1 for all the subsystem data files as needed to obtain the number of statistical samples required by the requirement.

**4.3.3.3 Impulsive Loudness.**

**4.3.3.3.1** Recall the files containing the subsystem sound of the individual subsystem operations.

**4.3.3.3.2 Impulsive Overall Loudness.**

**4.3.3.3.2.1** Display the Zwicker Loudness time history. Export the Zwicker Loudness time history data to MS Excel and save the file on the PC.

**4.3.3.3.2.2** If the sound from the subsystem contains impulsive start and stop sounds with a steady-state portion in between, identify on the Zwicker Loudness time history the beginning and end of the time intervals containing the start sound and the stop sound.

**4.3.3.3.2.3** Exclude from any calculations, the steady-state sound that occurred during the subsystem operation (Figure 1).

**4.3.3.3.2.4 Maximum Loudness Determination.** Determine the maximum loudness of each impulse that occurred during the subsystem mode of operation. If the maximum loudness is not easily obtained using the analyzer or sound quality software, use the data exported to MS Excel to determine the maximum loudness that occurred during the impulsive sound for each mode of operation. Record the values in a table of results (e.g., for a power window system, the values of maximum loudness of start and stop impulses are determined individually for both the up and down modes).

**4.3.3.4 Steady-State Frequency Content (Specific Loudness).**

**4.3.3.4.1** The purpose of the Zwicker Specific Loudness Spectrum Analysis (specific loudness) is to provide a spectral (frequency specific) view of the loudness of the event that is being evaluated.

**4.3.3.4.2** Recall the files containing the subsystem sound of the individual subsystem operations.



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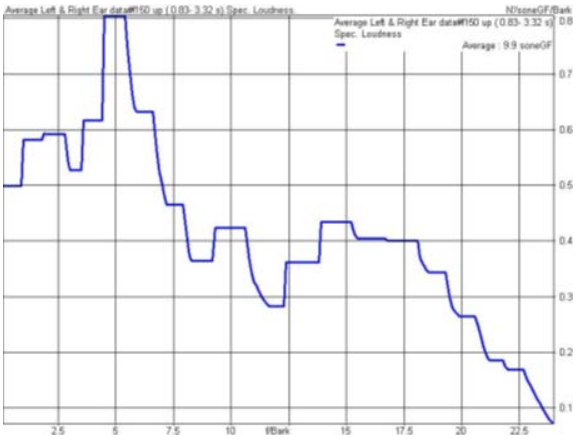
**4.3.3.4.3** Identify the beginning and end of the time interval containing the steady-state sound of the individual subsystem operation. Be sure to exclude any impulsive sounds that may have occurred at the start and stop of the subsystem operation (Figure 1).

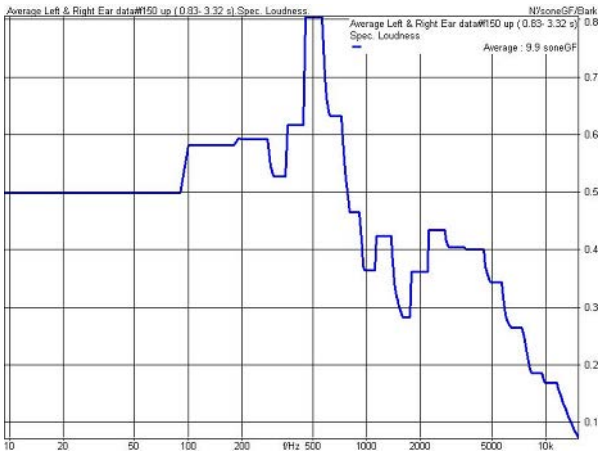
**4.3.3.4.4** Determine the Zwicker Loudness spectrum (specific loudness) the steady-state sound. See Figure 2 for an example of the Zwicker Specific Loudness spectrum (averaged over time interval of the steady-state sound).

**Figure 2: Example of Zwicker Specific Loudness Spectrum (Frequency Axis Scaled in Bark)**




**4.3.3.4.5** In Figure 3 the same analysis is presented but instead frequency in Hertz (Hz) was selected as the x-axis. **Caution:** The main premise of Zwicker's method is that the area under the curve of a Specific Loudness Pattern as presented in Figure 2 is proportional to the overall loudness. This premise holds true as long as the Specific Loudness data are graphed linearly in critical bands (Bark) as in Figure 2. The premise is not true when the data are graphed logarithmically in frequency (Hz) as in Figure 3. Therefore, Figure 3 should be used only as a means of referencing a feature in the data to frequency (Hz). Figure 3 must not be used to judge the relative contribution of the data to the overall loudness.

**Figure 3: Example Zwicker Specific Loudness Spectrum (Caution: Frequency Axis Scaled in Hz)**




**4.3.3.4.6** Repeat the preceding analysis from the beginning of 4.3.3.4 for all the subsystem data files as needed to obtain the number of statistical samples required by the requirement.



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**4.3.3.5 Steady-State Relative Pitch.**

**4.3.3.5.1** This analysis is necessary when the pitch of the sound is changing as a function of time. The intent of the analysis is to extract information on the variation in time of a single tonal component that can be viewed in a color spectrogram (see Figure 4). Two (2) possible methods for generating a color spectrogram are Power Spectral Density (PSD) vs. Time and the Hearing Model (a HEAD Acoustics proprietary method developed by Dr. Sottek). An alternative to this data acquisition method, that may be possible for in-laboratory evaluations of subsystem and components, is to measure the change in motor speed (rpm) as a function of time. If this alternative is used, the instrumentation and procedure for measuring motor speed of the subsystem must be documented as part of the subsystem evaluation report.

**4.3.3.5.2** Suggested starting parameters (in ArtemiS) for generating the color spectrogram using the PSD vs. Time (FFT vs. Time) analysis are 4096 points, Hanning window, and 50% overlap to yield a frequency resolution of about 11 Hz per FFT line. For finer frequency resolution (at the expense of time resolution), increase the number of points (e.g., 8192 points yields a frequency resolution approximate 5.4 Hz but at half the time resolution). For finer time resolution, increase the overlap to 70%. An option when using ArtemiS is to use the Hearing Model - Spectrum vs. Time analysis to generate the color spectrogram.

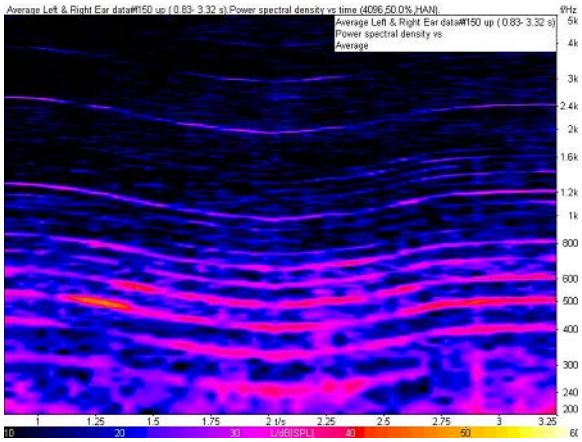
**4.3.3.5.3** Users of this analysis method should listen to the sound while viewing the color spectrogram to decide if the selected analysis parameters are adequate for resolving the audible tones both in frequency and in time.

**4.3.3.5.4** An example of a PSD vs. Time analysis is given in Figure 4 (spectrogram). The Hearing Model also can generate a spectrogram that looks similar to Figure 4.

**Note:** The curvature of the horizontal lines (tonal components) in the spectrogram. This results from the fact that this electric motor driven system slowed down in the middle of its travel. The horizontal axis is the time domain (time change is represented left to right), the vertical axis is the frequency domain (low frequencies lower on the axis and high frequencies higher on the axis), and color represents the level according to the scale provided.

**4.3.3.5.5** Adjust the color scale of the spectrogram to highlight the tones in the sound.

**Figure 4: Example of PSD vs. Time Analysis (Color Spectrogram)**




**4.3.3.5.6** Identify a dominant tone that exists for the entire duration of the event.

**Note:** Selecting a tone from the higher frequency region will produce better resolution in the Relative Pitch evaluation than selecting a tone at low frequencies.

**4.3.3.5.7** Adjust the vertical frequency scale on the color spectrogram to narrow the displayed frequency range of the selected tone.

**4.3.3.5.8** The frequency and time coordinates of the tonal component can be obtained by using a cursor on the color spectrogram to pick frequency and time coordinates that correspond with significant changes in frequency. If there are regions without significant changes in frequency, pick frequency and time coordinates at approximately the same sampling interval as used for regions with significant changes in frequency.



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