

Acoustic Vehicle Alerting Systems (AVAS) - Regulations, Realization and Sound Design Challenges

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ABSTRACT

Vehicles powered by electric machines offer the advantage to be more silent than vehicles equipped with an internal combustion engine. On the one hand, the reduced noise levels enable an improvement of the inner-city noise pollution. On the other hand, quiet vehicles entail risks not to be acoustically detected by surrounding pedestrians and cyclists in the lower speed range. The emitted noise can easily be masked by the urban background noise. Therefore, the UNECE has founded an informal working group which is currently developing guidelines in terms of an exterior noise required for detecting Quiet Road Transport Vehicles (QRTV). With the introduction of an Acoustic Vehicle Alerting System (AVAS), not only the exterior noise but also the perceived interior noise for an enhanced driving experience can be considered. Nevertheless, car manufactures have a big interest in maintaining their perceived brand identity. For the solution of this task, a synthetic sound generation system has been developed. Besides the realization of executable software for real-time capable vehicle communication and sound calculation, an implementation on an in-vehicle control unit has been engineered. Special attention has been paid to the aspect "ease of use". Important control parameters of the sound design can be modified with a graphical user interface directly in a road test from both in- and outside the test vehicle. The methodology of the AVAS, different sound design approaches for various demonstrator vehicles and key results regarding the audibility and sound quality are object of this paper.

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INTRODUCTION

Conventional vehicles with internal combustion engines (ICE) mostly produce order based noise caused by the gas exchange and the combustion process itself. To meet required target values in a type approval test, the noise level has to be reduced with passive measures in terms of silencers in the exhaust and intake system. In contrary to this, electric machines do not produce a high noise level when they are developed and constructed correctly. Compared to internal combustion engines, the dominant orders and therefore the frequency content of electric machines' noise emissions are 4 to 10 times higher and passive measures are unnecessary due to low sound pressure levels. The increasing number of electric and hybrid vehicles on public roads is on the one hand a success to reduce noise emissions and to improve the inner-city noise and air pollution. First estimations show, that a fully electrified fleet will reduce the average urban noise level by 3 to 4 dB and at the same time the annoyance effects will be reduced by more than 30 % [1]. On the other hand, the perception is impaired because the low noise emitted by electric vehicles cannot be separated clearly from the urban background noise in certain

situations. This causes problems in the acoustic perceptibility, especially in the lower speed range up to about 30 km/h. Above this speed, the audibility of electric vehicles increases by the means of tire-road and wind noise.

In past research studies conducted by the Institute for Automotive Engineering (ika), RWTH Aachen University, the audibility of electric and hybrid vehicles has been analyzed in different inner-city surrounding conditions [2]. For this purpose, urban background noises with various traffic scenarios have been combined with the exterior noise of electric, hybrid and conventional vehicles in different driving situations. The reaction time has been determined with a study in the ika psychoacoustics laboratory to identify the distance, in which approaching electric driven vehicles can be perceived compared to conventional vehicles. While the conventional vehicle is noticed in a sufficient distance for a pedestrian to react, the electric vehicles are noticed in most cases too late. Especially at speeds below 20 km/h, the distance in which the test persons notice the noise of the electric vehicle for the first time varies from 2 to 6 m

after the vehicle has already passed the virtual position of the pedestrian. For this reason, pedestrians with a limited range of vision (e.g. blind people) are compromised in their everyday life. First impulses for synthetic driving sounds have been given in this context by the National Federation of the Blind (NFB) to prescribe the implementation of synthetic driving sounds [3]. This measure is not only increasing the safety of pedestrians with limited field of view, but also the safety of inattentive or distracted outside traffic participants. After all, the human ear covers 360° of the environment, whereas the eye can only detect a limited angle without movement of the head or eyeballs visually (see Figure 1 and Figure 2).

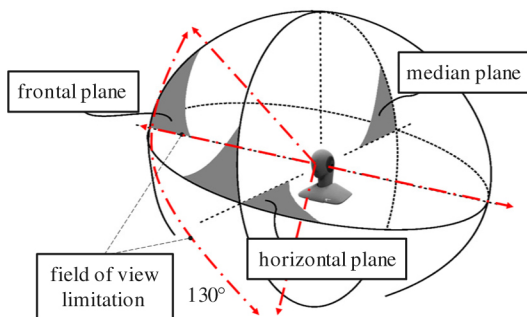


Figure 1. Comparison of hearing area and field of view [4]

The geometry of the human upper-body, the head and the position of the ears cause reflections, frequency shifts and time delay between the left and right ear. The human brain is able to process this information for a three dimensional localization of sound sources in the frontal, horizontal and median plane.

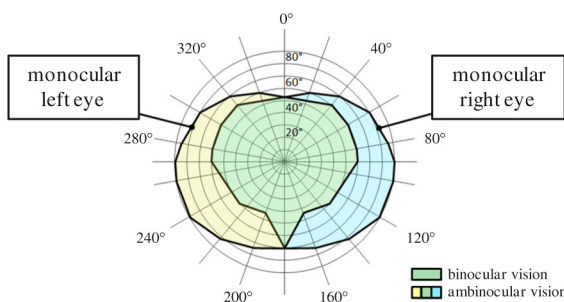


Figure 2. Monocular and binocular vision [5]

Compared to this, the human eye is able to detect visual events only in an angle of 130° in the median plane and 180° in the horizontal plane. Boundaries for the field of view are the eyebrows, cheeks and nose. They create an asymmetric field of view, which can be seen in detail for the left and right eye in Figure 2. Furthermore it has to be taken into account that in this limited range of vision only in a cone of about 4° opening angle sharp vision is possible.

Synthetic driving sounds can therefore not only be used to increase the safety for visually impaired pedestrians but also for children, cyclists, runners, the elderly or in general inattentive persons who partly rely on auditory cues. Regulations and guidelines are being developed in the United States, Japan and the European Union to define the requirements of such Acoustic Vehicle Alerting Systems (AVAS).

In addition to the safety aspect, vehicle manufacturers may be interested in an appealing exterior and interior driving sound, as well. The noise of electric machines is not strongly differentiated from each other and as a consequence the perceived brand identity in terms of NVH feedback is reduced. An electric sports car or an electric vehicle from the premium segment can hardly be separated from an electric compact car by the emitted exterior noise. This effect can also be noticed in the analysis of the interior noise of currently available electric vehicles (Figure 3).

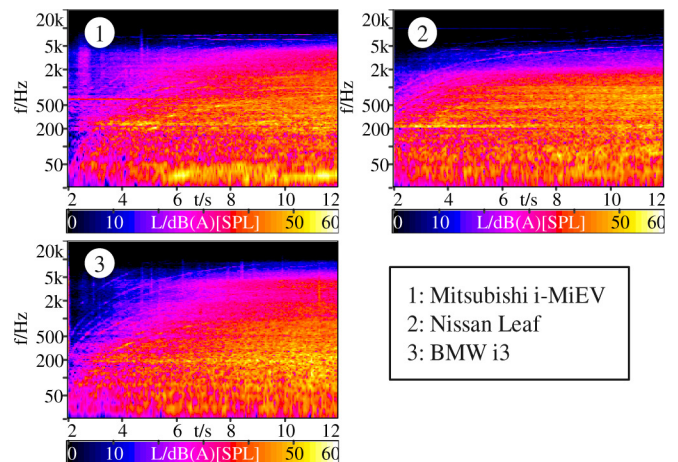


Figure 3. Interior noise spectrum of full electric vehicles at full load acceleration maneuvers

The comparison shows the spectrum analysis of the Mitsubishi i-MiEV, the Nissan Leaf and the BMW i3, which have been measured in a various number of test series during the continuous benchmarking conducted by the fka Forschungsgesellschaft Kraftfahrwesen mbH Aachen. For the analysis of the interior noise, full load acceleration maneuvers starting from standstill have been chosen. With increasing vehicle speed, only very little order based noise in form of parabolic lines in the frequency spectrum is transferred to the vehicle interior by the drivetrain. The most dominant effect is a broadband noise excitation caused by tire-road and wind noise that increases in amplitude and upper cut-off frequency with increasing vehicle speed. Comparing the interior noise of those three vehicles may lead to assumptions regarding the noise insulation quality, but overall they are very much alike and have only little divergence.

Furthermore, electric machines offer good dynamic behavior regarding the availability of maximum torque at zero rpm. Starting from a standing position, the electric vehicle accelerates faster than most comparable motorized, conventional vehicles with ICE. Driving the same electric vehicle with and without activated synthetic driving sound, the driving experience is often described as more sportive or inspiring, as previous studies at the ika have demonstrated. For the mentioned reasons, the acoustic feedback of the driving condition can be regarded as an additional benefit from an AVAS.

REGULATIONS FOR AVAS

With the introduction of synthetic sound generation systems, it is possible to realize a large variety of sound design characteristics easily. For a better harmonization of the synthetic vehicle sounds, the informal working group “Quiet Road Transport Vehicle” (QRTV / IWG) has been initiated by the UNECE to develop guidelines for the design of AVAS. The goal of the QRTV / IWG is to derive draft recommendations for regulations regarding the vehicle speed range in which the AVAS should be activated and which sound characteristics should be implemented in such a system. The current ideas for a new regulation concerning synthetic sound systems is described in [6], [7], [8], [9] and summed up in the following paragraphs.

Electric vehicles or more specific vehicles which are able to move exclusively by means of electric machines (e.g. hybrid or fuel cell vehicles) should inform the pedestrian and road users about the proximity of a hazard using AVAS. The emitted sound should easily indicate the vehicle driving condition and provide further information regarding the approach, presence and departure of the vehicle. Therefore, the frequency of the synthetic driving sound should increase and decrease as a function of the vehicle speed (frequency shift), in order to resemble the basic characteristic of speed-dependent noise.

The overall sound pressure level (SPL) of an activated AVAS should not exceed the SPL of a comparable, conventional vehicle in a constant speed test. At the same time, the sound should not be too quiet to avoid risks in high ambient noise environments. Measured in a distance of 2 m between the longitudinal center line of the vehicle and the microphone positions on the left and right side of the test track according to ISO 10844, a minimum overall SPL of 50 dB(A) for 10 km/h and 56 dB(A) for 20 km/h for pass-by tests with constant speed have been defined. In this test conditions, the vehicle equipped with an AVAS shall not emit an overall SPL of more than 75 dB(A) [9].

The frequency range of the AVAS should be in-between 140 Hz and 5.6 kHz. At least two third octave bands within this range should be included in the final sound concept. Content in the mid-frequency area (500 Hz to 2 kHz) and high-frequency area (2 kHz to 5 kHz) support audibility and directional cues. Low frequencies (below 500 Hz) support earlier detection but can be masked more easily in an urban environment. Thus it is requested that at least one frequency of the AVAS shall be below or within the 1.6 kHz third octave band.

A stationary sound for standing vehicles is optional and offers advantages signaling that the vehicle is ready for movement. E.g. blind people and pedestrians with low vision could decide better whether to cross a street, or not.

The speed range for operation is the range from 0 km/h up to and including 20 km/h. If desired, the AVAS can be automatically deactivated above this speed automatically by the car manufacturer or manually by the vehicle owner.

Alteration and permanent deactivation of an AVAS is prohibited except for repair or maintenance by a designated authority. The implementation of a pause function for temporary deactivation is

optional. When deactivated, it is within the driver's responsibility to ensure the lack of necessity of an active system due to missing pedestrians in the surrounding area.

Regarding the aspect of sound quality, various challenges have to be accomplished regarding the character of the synthetic driving sound, which are summarized in Figure 4 according to the requirements described in [10].

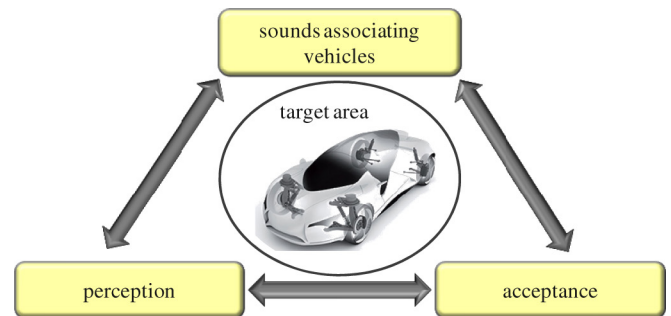


Figure 4. Target area for sound design

The target area for the design of a synthetic driving sound lies inbetween the partially contrary aspects of sounds associating vehicles, sounds creating a good perception and sounds creating a high acceptance. Creating a sound concept based on characteristics of an ICE leads to best results regarding the vehicle association. However, the new design freedom in the sound design process is not used in full extent in this way. Alarming sounds generate through their temporal structure and frequency range a very good perception. Natural and clear sounds induce a high level of acceptance by their pleasant sound character. Nevertheless, these sounds do not correspond to vehicle characteristics and they need to be adopted. This is why the target area is located in the intersection of these three categories.

Typical base elements and characteristics from conventional drivetrains have to be considered in an AVAS to achieve the association to well-known vehicle sounds. It is recommended to build the sound concept on order-based sound components to shift the frequency of the drive sound depending on the current vehicle or engine speed. An aspect which is not demanded by the regulations but leads to improved driving emotions lies in the additional inclusion of the engine load as a sound control parameter. For instance, this parameter can be used to couple volume or sound composition changes to the torque of the electric machines. The delay between the current driving condition (vehicle speed / acceleration) and the reaction of the synthetic sound generation system has to be kept as low as possible. In this way, a load differentiation can be obtained directly from the emitted sound and the authenticity of the synthetic sound can be increased.

SOUND DESIGN AND IMPLEMENTATION

In the development process of an AVAS, appealing sounds have to be designed and brought onto an in-vehicle application. Thus, a suitable soft- and hardware solution has to be found in terms of an ECU (electronic control unit) with sufficient resources and interfaces (e.g. CAN-bus and audio-out).