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Principles of Active Sound Design for electric vehicles

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ABSTRACT

Electric vehicles represent new challenges to vehicle acoustics. The exterior pedestrian warning is missing and the interior sound massively changed. Active Sound Design allows to implement exterior warning, to re-establish feedback to the driver, to realize emotional binding, to mask interior sound problems and to implement a stringent Brand Sound Strategy. Main requirements are that the resulting sounds are authentic (they have to be interpreted as coming from the vehicle in each driving condition), long-term applicable (they have to stay interesting for a long period of time) and clearly abstracted from known combustion engine sounds. The resulting Sound Design has to offer complex structures which go far beyond the simple coupling of the synthesis to the vehicle speed as required for exterior sound generation – a variety of different sounds and sound components have to be created and linked to the dynamic vehicle behavior. The principles of the resulting Sound Design approach will be discussed, and a sophisticated tool for Sound development and vehicle integration (the world's first system for interior electric vehicle sound generation as a series part of a vehicle) presented.

Keywords: Active Sound Design I-INCE Classification of Subjects Number(s): 38.2

1. INTRODUCTION

Electric vehicles have a significantly different interior and exterior sound than combustion driven vehicles. Active sound generation can be used to mask specific Sound Quality issues as high frequency converter tonals or component noises, to re-establish the required feedback to operate the vehicle, to create an emotional binding to the driver, and to allow for a stringent implementation of a Brand Sound. Main requirements to the sounds to be generated are authenticity (sounds have to be interpreted as originating from the vehicle) and long-term applicability (sounds are present for long durations), while they have to be clearly abstracted from the sounds known from combustion engines.

Sound Design for electric vehicles is a complex task since experience is missing regarding both, the generation of the sounds, and the customer acceptance of the sounds. The design approach has to use complex structures, going far beyond a simple coupling of the pitch to the vehicle speed as required by legislative rules for exterior sound generation. The design tools have to be very flexible allowing to generate a variety of different sounds, and at the same time a fast and efficient vehicle tuning.

2. ACTIVE SOUND DESIGN OF INTERIOR VEHICLE SOUND

Sound generation for electric vehicles is a controversly discussed topic. It represents the first complex application in automotive industries in which sounds have to be completely generated from scratch, and not only modified or slightly extended as in the case of Active Sound Design for combustion engine support.

2.1 Why interior sound generation is needed

From the physical point of view, electric vehicles show a lower overall sound pressure level in the vehicle interior than combustion driven vehicles. This reduction in sound pressure level usually results in an increased perception of comfort, thus supporting the most important dimension of vehicle Sound Quality perception.

Opposite to this positive effect, several facts result in reduced Sound Quality of electric vehicle interior sounds. First, masking is reduced, so that component sounds become audible which are masked in combustion driven vehicles. Since lightweight materials have to be used to reduce the

overall vehicle weight, the component sounds might even be worse than in combustion driven vehicles.

Furthermore, the electric drive train usually generates high frequency tonal components, yielding to uncomfortable and annoying perception. Since the combustion engine sound component is missing, the overall spectral balance is broken, and a spectral gap is introduced between the low frequency tire noise and the high frequency wind noise. These issues can only hardly be solved by tedious, cost and weight increasing countermeasures.

Other issues are related to the driver – the electric engine does not give enough feedback about the current status of operation to the driver, the sound does not address his emotion, and a transportation of Brand attributes is hindered.

All above listed issues can be tackled by a proper generation of interior sounds for electric vehicles. The necessity to perform this sound generation is supported by legislation, which prescribes the generation of sound for the exterior. Exterior sound generation thus becomes mandatory, resulting in the fact that Sound Design has to be performed and can no longer be avoided. Furthermore, portions of the exterior sounds usually are also audible in the vehicle interior and can result in undesired sound perception, which can be compensated by an aligned interior sound generation.

Nevertheless, Sound Design for electric vehicles is a complex task, especially since experience in the field of sound generation is missing and the customer acceptance is not well understood yet. Furthermore, comprehensive tools have to be developed, allowing a flexible generation of a variety of different sound characters and an easy and time-efficient vehicle adaptation.

2.2 Sound Design and Sound Quality

For electric vehicles, the sounds are not directly evoked by the operation of the vehicle, and a generic freedom on design applies – in general, all types of sounds might be synthesized. But, the resulting sounds have to fulfill generic principles of Sound Quality – they have to fulfill their respective tasks. The applied Sound Design has to be aligned to psychoacoustics, Sound Quality, Sound Scapes and of course the dynamic operation of the vehicle.

In order to achieve this, a systematic approach is required, allowing a flexible and rule based generation and adaptation of sounds. This so-called Sound-Signature approach is presented in the following chapters.

3. THE SOUND SIGNATURE CONCEPT

The sound signature defines a base overall Gestalt of the sound – it defines the sound character of the vehicle. The driving sound is created by a link to the dynamic vehicle parameters. The Sound Signature Concept has been proposed in (1) and has been further developed. The scheme is depicted in fig. 1.

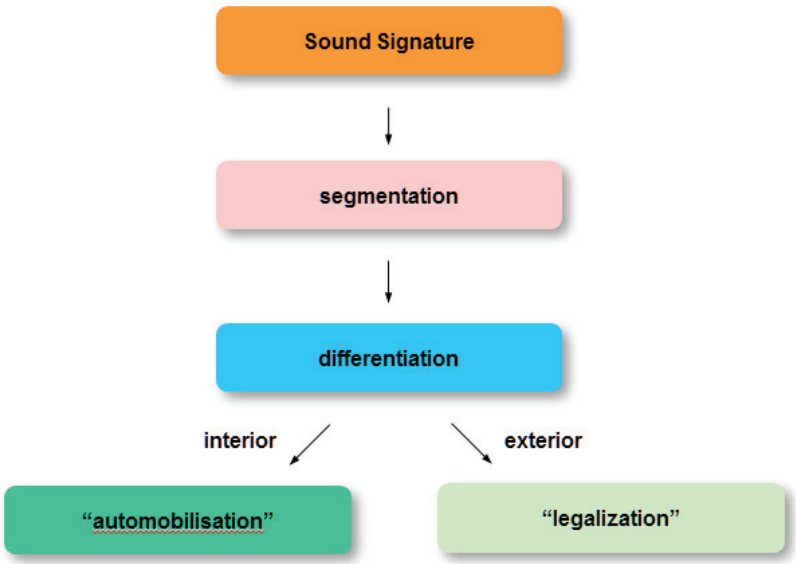

Figure 1 – The Sound Signature Concept

3.1 Sound Signatures

The Sound Signatures determine the typical overall sound character. They are thus ideally suited to implement a Brand Sound. The overall Brand Sound character therefore is defined by the Brand Sound Signature. The Sound Signature contains the base information for the synthesis of the dynamic driving sound. Depending on the type of synthesis method, it can be implemented in form of a sound sample, a set of sound samples, or a definition of acoustical parameters.

A Sound Signature can contain several sub-signatures as shown in fig. 2. They are mainly intended to make the resulting sound more dynamic and diversified.

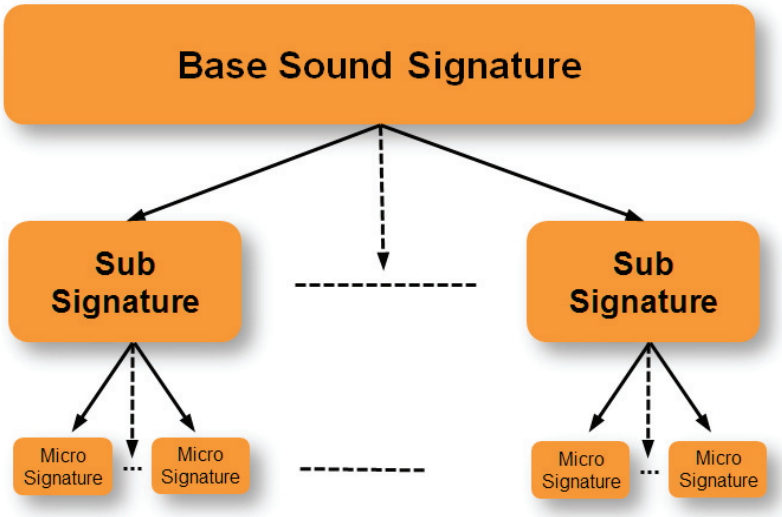

Figure 2 – Sound Signature Composition as hierarchical layering: Base Sound Signature, Sub Signatures and Micro Signatures

Engine sounds of combustion driven vehicles sound dynamic, interesting and diversified because different sound attributes show up in different driving conditions. The Sound Signature approach uses Sub Signatures to transfer this to electric vehicle sounds. The respective sub-signatures can for example be assigned to different vehicle parameters (e.g., load, recuperation etc) or to specific driving manoeuvers (usually represented by combinations of vehicle parameters). Again depending on the type of synthesis, Sub Signatures can be implemented by sound samples or complex manipulations of the Base Sound Signature.

In order to transform a usually strict synthetic sound into a vivid and emotional sound the micro structures of the sound play an important role. Combustion engines show micro variations of the physical excitations caused by the mechanical processes, resulting in corresponding changes of the micro sound structure. Electric drivetrains behave much more uniform, so that the micro variations have to be implemented into the synthesis process. The Micro Signatures are responsible for this task.

3.2 Segmentation

The base sound character for a vehicle model is defined as a derivative of the Brand Sound Signature. The typical character of the Brand thus is maintained, but allowing an adaptation of the sound to different vehicle types.

The Sound Signature approach consisting of the Base Sound Signature, the Sub Signatures and the Micro Signatures allows an efficient and effective segmentation for different vehicle types. By means of modifying and adapting the respective signatures, or different weighting of Sub and Micro Signatures quite different sounds can be implemented, which still follow the same Brand Identity.

3.3 Differentiation interior – „automobilization“

A synthesized sound will only be perceived as a vehicle sound if it is interpreted as originating from the vehicle in each operation condition. To achieve this, dynamic sounds have to be created from the Sound Signatures, following and supporting the dynamic vehicle behavior.

The most basic relation for dynamic conditions for vehicles with combustion engine is the pitch change with rpm – the higher the rpm, the higher the pitch. In fig. 3 the revolution speeds are

schematically drawn for a typical driving condition (traffic light start) for a combustion vehicle (left) and an electric vehicle (right).

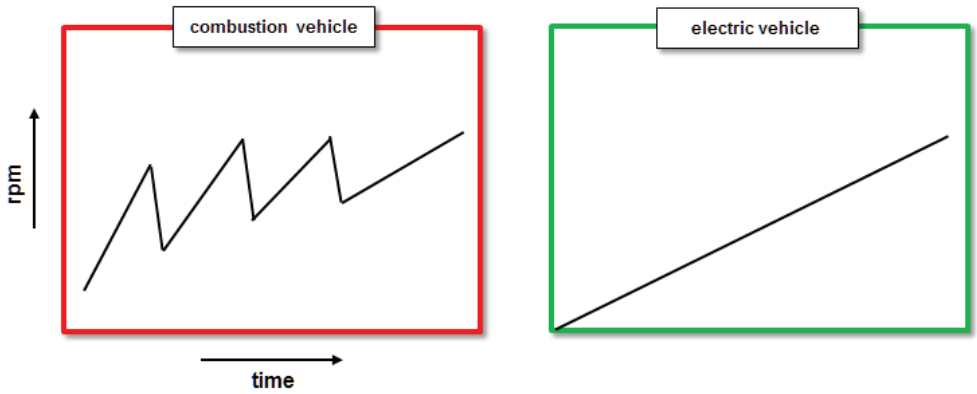

Figure 3 – Schematic representation of the rpm for a traffic light start maneuver. Left: combustion engine; right: electric engine

The comparison shows that the distribution of the rpm is much more dynamic and diversified for the combustion engine than for the electric engine – the combustion engine has much higher gradients and variations caused by the gearbox, which is missing for the electric drivetrain. As a consequence, also the sound of the combustion engine is much more dynamic and diversified, while the sound of the electric motor is much more static and monotonous.

The Sound Design thus has to incorporate additional means to make the sound of electric vehicles more lively and attractive – a pure transfer of the relations of combustion engine sounds to the engine parameters would result in boring and unacceptable sounds.

In order to achieve this, as many dynamic vehicle parameters as possible have to be incorporated into the sound generation. The proposed approach of the Sub and Micro Signatures allow the generation of such diversified sounds, and the application of specific sound synthesis algorithms support this.

3.4 Differentiation exterior – legalization

Legislation in different countries prescribes that electric vehicles have to or will have to be equipped with an exterior sound generation device. But, the sounds emitted to the exterior will eat least partly also be audible in the vehicle interior, which might result in strange interior sound perception.

A way to overcome this problem is to perform an aligned and harmonized exterior and interior sound generation. The Sound Signature approach allows to dedicate a Sub Signature to the exterior case. In doing so, it is guaranteed that sound properties interior and exterior fit to each other, and it allows an alignment to the legislative requirements which only concern the exterior sound.

4. TOOLING AND VEHICLE INTEGRATION

The topics discussed above show, that the generation of sounds for electric vehicles is a complex task, and that special attention has to be laid on the adaptation of the sounds to the dynamic vehicle parameters and the generation of variable and non-monotonic sounds.

In order to perform these tasks, the designer and developer requires powerful, flexible and efficient tools for sound generation and sound adaptation, which support the complete chain from the laboratory development to the in-vehicle tuning and target vehicle series solution.

A corresponding toolchain is represented by the neosonic system elvis[3]. The system can be used in different application scenarios like in laboratory conditions for basic investigations and sound character developments, directly in-vehicle for dynamic adaptation and tuning, and as series solution on own or third party hardware.

The system consists of a generic software framework that implements all interface points, the global data handling and vehicle connection, and a comprehensive set of modules for the different Active Sound Design tasks (see (2) and (3)).

A schematic overview of the system is given in fig. 4.

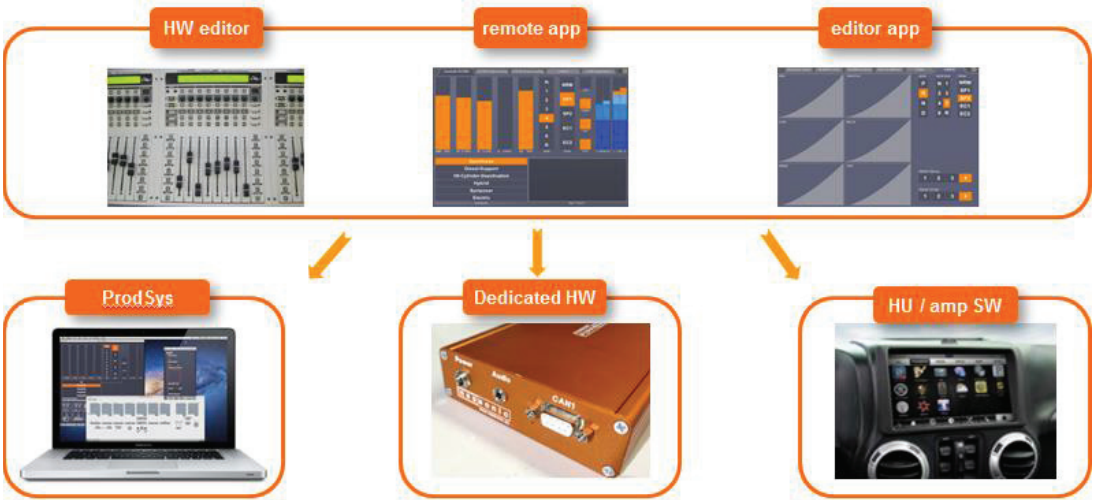

Figure 4 – elvis[3] system toolchain for laboratory, in-vehicle and series applications

The elvis[3] production system is a laptop implementation which mainly is intended for laboratory applications, but can also directly be used in-vehicle. It allows the highest flexibility with regard to the possibility to extend and adapt sound generation and manipulation algorithms. The system includes simulation capabilities for efficient laboratory developments, but can also be integrated into third party sound simulators.

A series-equivalent approach is to directly use the dedicated compact hardware unit in both, laboratory and in-vehicle conditions. It offers identical features as the production system, but can remain in the vehicle after tuning as an autarkic sound generation device, so that it is well suited for long-term evaluations. An integration into third party sound simulators is also possible, so that the time required for tuning in prototypes can be reduced to a minimum.

For series implementations the modules are also available as software libraries for third party hardware like vehicle head units or external DSP amplifiers.

Common for all systems is an identical and flexible direct-to-unit editor. All functions and parameters of the different elvis[3] modules can be changed in real time during driving, thus reducing the required vehicle tuning time to a minimum.

5. SUMMARY

The generation of sounds for electric vehicles still is a rather new topic in the automotive sector. It requires new expertise on one hand, but also flexible, sophisticated and efficient tools on the other hand. The Sound Signature approach including corresponding Sub and Micro Signatures enables the creation of versatile, diversified and dynamic sounds, nevertheless allowing to establish a stringent Brand Identity and the fulfillment of legal requirements for the exterior case.

The system elvis[3] represents the corresponding comprehensive toolchain, offering an identical platform from the laboratory development to the series vehicle implementation. Benefitting from the modular architecture, the system does not only allow generation of exterior and interior sounds for electric vehicles, but also the acoustical support of combustion engines, the increase of Sound Quality of components, and the implementation of a stringent vehicle fleet Brand Sound including all different basic drive arrangements. The application of the system from development to series implementation is exemplified in (4).

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