Comprehensive Automotive Active Sound Design part 1: electric and combustion vehicles

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ABSTRACT

The optimization of vehicle sound does not only require the optimization of each component, but the optimization of the combination of the different sounds in order to achieve a homogenous and effective overall sound. Active Sound Design methods offer new possibilities to achieve this ambitious aim, and furthermore to align the overall sound to the Brand Identity. neosonic has developed the modular comprehensive Active Sound Design system elvis3 (ELaborate Vehicle Integrated Sound Signature System) which integrates all audio aspects of the vehicle into one comprehensive tool chain.

One component of the system, elvis3 e-motion, is the world's first system used in series in an electric vehicle to create interior vehicle sound (AMG SLS ED Coupe). With the innovative signature-based approach the AMG sound of the 21st century has been realized. A second component, elvis3 Cesar, implements sophisticated support for vehicles with combustion engines using refined signal processing. These two components will be explained in detail along with the flexible system concept. Advanced system modules and applications are part of the second presentation.

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1. INTRODUCTION

A lot of different components contribute to the overall vehicle sound. Major sources are the engine and road and wind contributions, supplemented by a variety of other components originating from the gearbox, the climate system, and all electric and mechanic components, plus the feedback and warning sounds. The typical way is to optimize each component separately during its development process, resulting in the fact that a systematic optimization and harmonization of the resulting overall vehicle sound is not possible. This approach results from the fact that the vehicle itself is only available at the very end of the development process, hindering a systematic optimization of the combination of the different sound components.

But, to optimize the overall vehicle sound, it is not sufficient to combine optimized components, it is necessary to optimize the interaction between the different sound components – a perfect orchestra does not require just the combination of perfect musicians, it requires their perfect alignment.

The availability of active methods offers new possibilities to realize the optimization and harmonization of the overall sound. neosonic has developed the modular approach elvis^3 ((*EL*aborate *V*ehicle *I*ntegrated *S*ound *S*ynthesis *S*ystem), which integrates all audio aspects of vehicles. The concept of the system and sample applications will be illustrated and extended in a separate paper (1).

2. CURRENT APPLICATIONS IN AUTOMOTIVE INDUSTRIES

Sound Design is applied in industry and especially the automotive sector since about two decades. It's traditional application is to optimize the sound emitted by the product by means of changing the mechanical excitation, modifying sound radiation and influencing the transfer paths. This means that the product itself is changed, which is a tedious, time consuming and costly task.

In contrast to that Active Sound Design allows to add sound to a product without changing the product itself. This shows a variety of advantages:

- sound generation is much more flexible since it is detached from the mechanical process of the product;

- the sound can be much better controlled and easily adapted to different conditions;
- the sound can be changed during the life period of the product;
- due to declining costs of electronics an active solution can save costs.
- the development process is optimized since the sound can be fixed at a late stage when all components are developed.

In most applications the aim of the Active Sound Design strategy is to either increase or create a feedback to the user of the product. An early application of this Active Sound Design approach is described in (2), where an acoustic feedback is created for a vacuum cleaner which eases the handling of the cleaner and realized a motivation for the user.

In automotive industries Active Sound Design methods have been the scope of research activities for the past two decades, but were mainly restricted to the case of supporting combustion engine sound. The methods had in principle been ready for market since more than 10 years, and case studies have proven their capability (e.g., 3,4). Besides cost aspects mainly uncertainty of car manufacturers concerning the acceptability of the methods by the customers hindered a series implementation. Manufacturers were afraid that customers would not accept artificially generated sounds which do not origin directly from the vehicle itself, and that they might feel cheated. Nevertheless, within the past years corresponding systems were implemented into vehicles and are now globally accepted.

Implementations of Active Sound Design to support combustion engine sound follow quite different approaches:

- integrated into the intake system:
  passive sound generation methods use the pulsations in the intake system and feed them with an actively controlled path (i.e., a tube with a flap) into the vehicle interior. Since this method uses excitation signals directly taken from the engine itself the resulting sound is natural, but it's Sound Design capabilities are limited since no new sound characters can be generated.
- integrated into the exhaust system:
  passive generation methods use actively controlled flaps in the exhaust to emit sporty sounds, active methods use loudspeakers to add generated sound components into the exhaust system. The exhaust primarily effects the exterior sound, so that the exterior sound can only be influenced with heavy effect on the exterior which might conflict with legal requirements as the exterior pass-by-noise regulations which will be tightened in the next years.
- structure borne excitation of the vehicle body structure:
  active engine mounts can be used to control the amount of engine vibration fed into the vehicle body structure, and structure borne exciters attached to the vehicle body feed controlled generated vibration in the structure which is then mainly emitted to the vehicle interior.
- sound synthesis using the interior audio system:
  synthetic sound components are generated and played back to the vehicle interior using the vehicles audio system. In principle this method offers the highest degree of Sound Design freedom since sounds can be generated and emitted in the complete audio frequency range and with the highest acoustic quality. Specific attention has to be paid that the resulting sound is not perceived as being artificial and is not localized from the loudspeakers, so that this method has the strongest requirements on the quality of the Sound Design itself.

The standard sound synthesis method to support combustion engine sound is the order based synthesis. Due to the period firing of the cylinders a combustion engine is mainly composed of a series of sine waves determined by the engine rpm and the firing order. Adding specific engine orders can significantly increase the perceived sportiness, and the amount of added sound can for example be controlled by the engine load and/or the pedal position. Following this approach the engine sounds sporty during acceleration, so that the driver gets the feedback in the driving condition where it is required.

Nevertheless these methods purely concentrate on influencing just one dimension of vehicle sound perception, powerfulness. Different investigations on dimensions of sound perception of driving sounds are available from literature, and mainly all come to the same conclusion that perception is driven by two dimensions, the first being "pleasantness", and the second being "powerfulness" or "sportiness". In (5) pleasantness explains 58% of the variance, powerfulness 23%, which points out that pleasantness is more important than powerfulness.

Figure 1 shows the results of customer investigations of driving quality in different driving conditions applying a factor analysis and depicting the main two dimensions. Each OEM may set a slightly different target sector, but they are all positioned in the upper right quarter. The graph shows that the order based approach can be used to move a vehicle into the target sector which shows a high pleasantness, but lacks of powerfulness (vehicle A). As a result the vehicle is comfortable e.g. during cruising, but gives clear sporty feedback during acceleration.

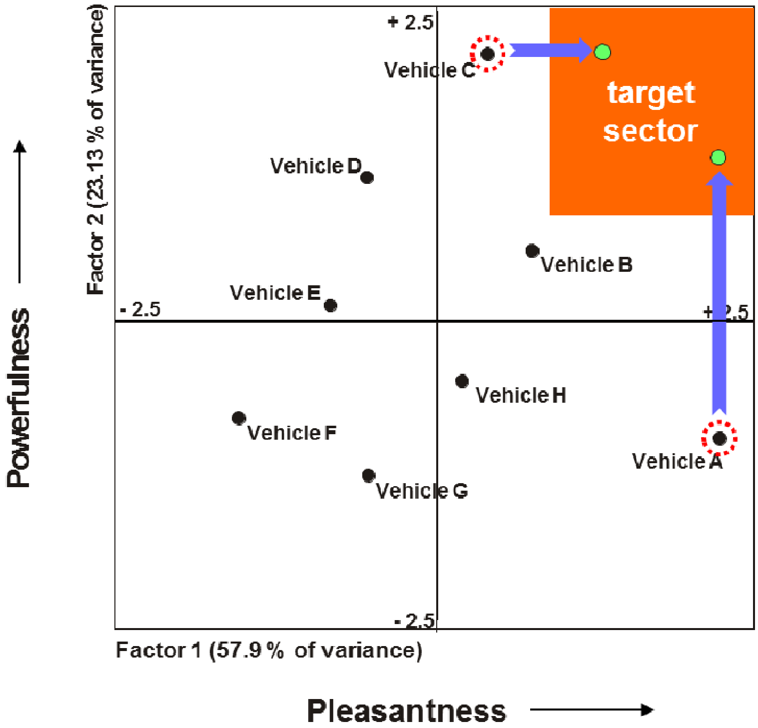

Figure 1 – main dimensions of the perception of vehicle driving sound (after 5).

A main drawback is that the first dimension has to be treated by conventional methods, which can be a tedious, time consuming and costly task. A vehicle which shows medium pleasantness, but high powerfulness (as vehicle C) can not be moved into the target sector. Different methods thus have to be applied here, and this was a major motivation for the development of the neosonic elvis[3] system. In contrast to optimizing each component separately in the traditional mechanical Sound Design approach, an implementation as a central system in vehicles which controls all sound and audio aspects Active Sound Design can optimize the resulting overall vehicle sound, and it can especially harmonize vehicle sound and even furthermore implement a Brand Sound into the vehicles.

3. CENTRALIZED COMPREHENSIVE ACTIVE SOUND DESIGN

A systematic approach to tackle all audio and sound aspects of vehicles requires different modules taking over different tasks:

- complete synthesis for electric and fuel cell vehicles
- support of engine noise for combustion vehicles
- specific combination of methods for hybrid vehicles
- consideration of operational sounds
- harmonization of the overall vehicle sound
- implementation of the Brand Identity.

These different modules will be discussed in the next paragraphs using the application example of the neosonic system elvis[3].

3.1 Electric and fuel cell vehicles

Electric and fuel cell vehicles more or less completely lack of sound feedback which is related to the dynamic driving performance. The motors itself, the gear system and the power converters mainly produce some tonal components which are not well related to the driving condition. Although they usually are of low level they can be quite annoying, and since the vehicles only have a single gear the frequency increase over speed is very slow and does not fit to the dynamic strong acceleration of the vehicle.

The absence of the engine sound can also result in a spectral gap between the low-frequency road noise and the high-frequency wind noise, and thus cause an inharmonic overall sound. Furthermore, the reduced masking leads to the fact that the different vehicle components are better audible, thus bearing the risk that Sound Quality is reduced although the overall level is low. The vehicles components thus even have to be better acoustically treated than for combustion vehicles, which is hard to achieve and costly. In addition, each damping material needed to achieve this further increases the vehicle weight and reduces the anyhow critical driving range. Finally, a Brand Identity can not be established with the pure electric vehicle sound since all electric vehicles basically sound very similar.

The question whether an electric vehicle should be equipped with a synthetic sound or not should in principle be easy to answer considering the above facts. The reason why OEMs hesitate to do so mainly is driven by the fact that the finding of the correct sound requires different procedures than those which have been used in the automotive sector for decades. It had always been the case that the vehicle sound was predetermined by the combustions engine, thus allowing only some minor modifications by the Sound Design. Now the situation is completely different, a complete new sound has to be developed, and no clear starting point or borderlines are given. It thus requires a complete new Sound Design strategy, which can also not be copied from other application fields like film or media Sound Design. The sound has to interact heavily, and it has to “work” even for daily presence of several hours.

For the exterior case car manufacturers will be forced by the laws in the US, japan and Europe to equip their vehicles with a sound generation device. The physical characteristics of the corresponding sound are yet well defined, but the character still remains quite unclear.

This class of vehicles thus requires a complete synthesis of the driving-related sound and represents the most complicated and challenging application of Active Sound Design. The sound to be generated has to represent the dynamic behavior of the vehicle, it has to merge with the vehicle in each driving condition, has to be perceived as being generated by the vehicle itself, has to fit into the sounds originating from the vehicle and has to harmonize the overall vehicle sound. The sound has to be attractive on one side, but also long-lasting and not turning to be annoying after a long period of usage.

In order to achieve this, comprehensive and sophisticated synthesis methods and elaborate Sound Design using dynamic vehicle parameters have to be applied.

The corresponding system elvis^3 e-motion was presented in detail in (7). It is the world’s first series system to generate interior sound for an electric vehicle, the AMG SLS Coupé ED. Since this vehicle is a super sports car, the demands to the sound are very high, and a variety of different driving conditions are acoustically represented in differentiated manner (detailed description in (8)).

The sound generation is based on the Sound Signature approach. A Sound Signature defines the basic character of the vehicle sound, and the dynamic vehicle parameters influence the sound so that it fits to the dynamic behavior of the vehicle. A sample spectrogram of an interior electric vehicle sound is depicted on Figure 2.

In principle each vehicle parameter can be associated to a specific sound event or sound feature. Base parameters are the engine load, the motor rpm (or speed) and the pedal position, but any other parameter can be used in addition – increasing the complexity usually results in a better acoustic representation of the vehicle status, and a more natural and emotional sounding.

3.2 Vehicles with combustion engine

The use of Active Sound Design to support the sound of combustion engines has yet been described on chapter 2. In contrast to electric and fuel cell vehicles there is no need to synthesize the complete engine sound, but to add specific components which support the perception of the basic sound of the engine.

Early implementations and experiments tried to completely change the character of the sound, for example to change an I4 engine to a V6 or V8 engine, or to reproduce specific well known sounds like the historic VW beetle sound. But, such heavy changes of the sound mostly result in artificial sounds which also usually do not fit to the vehicle itself.

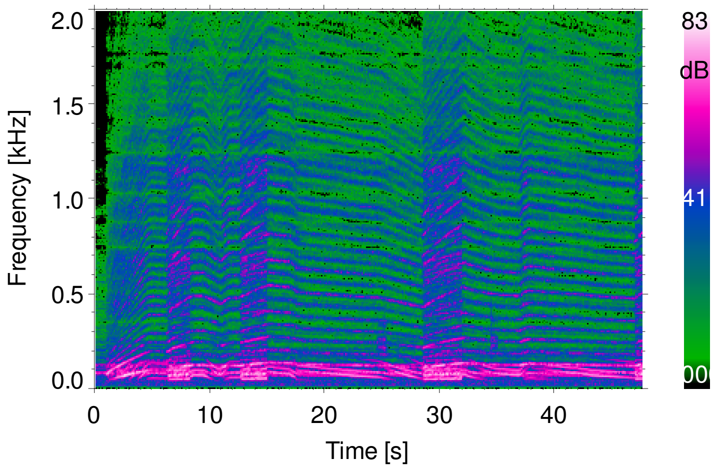

Figure 2 – sample sound of an electric vehicle interior sound synthesis

As described, current vehicle implementations use the engine order based approach to enhance the powerfulness. This type of implementation can be regarded as a starting point for Active Sound Design, but does not use the possibilities by far.

The main motivation for the order based approach is the reproduction of a part of the physics of the combustion engine process. This can be a tedious task, since the engine orders have to be controlled as a function of the vehicle parameters like rpm, load, and gear. The sine waves are originating from the periodic firing of the cylinders, which means that a huge number of orders is necessary to describe replicate the process. The adaptation of the vehicles to the sound thus can be time consuming, and there is no clear and stringent optimization strategy.

In addition, the order based approach is a kind of rigid and idealized implementation of the engine process. The sine waves are usually implemented with a strict relation to the engine rpm neglecting the micro structure operation of the engine. There is no real continuous power of the engine, but a periodic input of forces caused by the firing, and including variations from each firing to the next – the cylinder firings are never completely identical. The micro structure of the engine parameters thus is not smooth or constant, they show variations.

The approach proposed here is more centered towards the perception of the resulting sound and the creation of "natural" sounds. Perception can be much better and direct controlled if other sound manipulation strategies are used. These can be filtering, distortion or modulations which are applied after a basic order based signal generation. Furthermore, we consider the micro structure variations and apply that to the strict engine order based approach. The parameters of the synthesis are overlaid with controllable variations resulting in more natural sounds (6).

Figure 3 shows examples of the combustion sound enhancement using the elvis[3] Cesar tool for a traffic light start situation. The original engine sound (top left) shows a lack of specific engine orders during load, and the engine has no specific acoustic character and a lack of emotional appeal. The other graphs show three different styles of combustion engine support.

In order to influence the sound character also the sound-signature-based approach can be applied to combustion engine sound, especially if the intention is to optimize the main dimension of vehicle sound perception, pleasantness, or to realize harmonization of the overall vehicle sound and implement a Brand Sound.

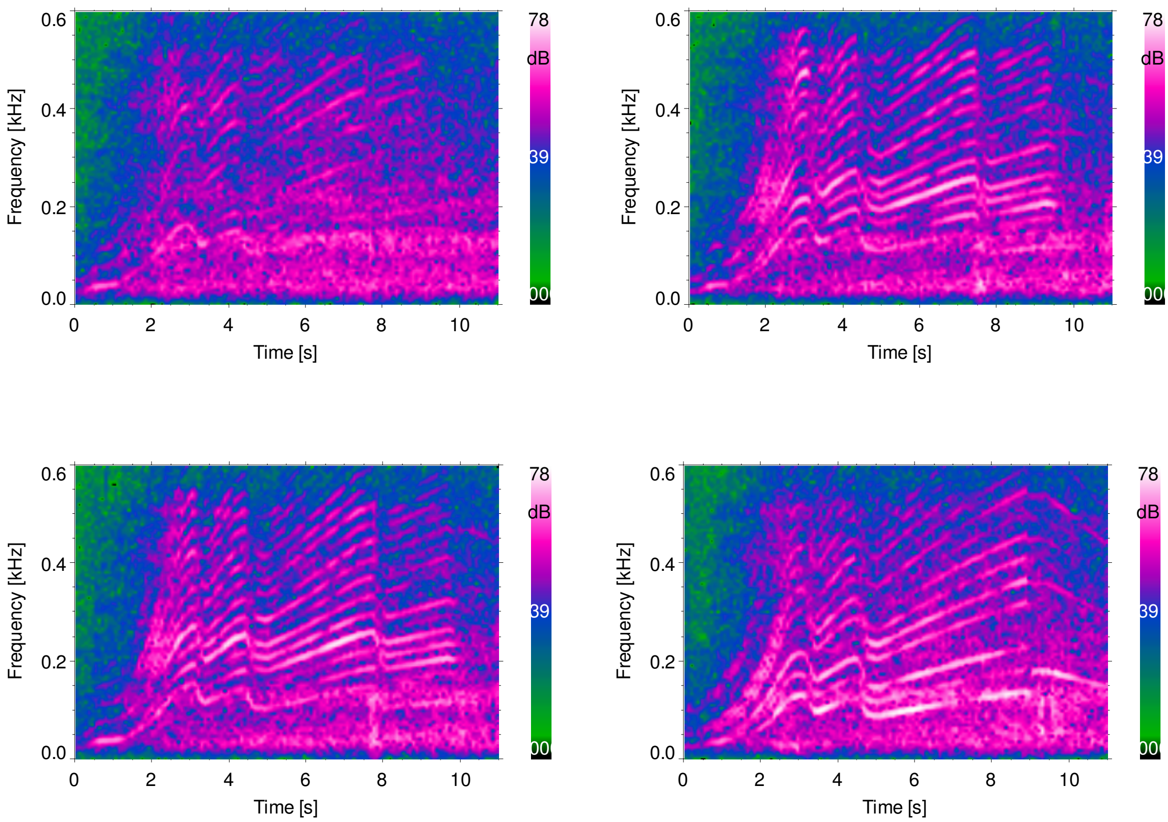

Figure 3 – sample spectrograms of combustion vehicle sounds in a traffic light start maneuver without (top left) and with three different styles of Active Sound Design of the elvis[3] Cesar tool.

4. SUMMARY

Active Sound Design allows a comprehensive forming of vehicle sounds. To do so, a centralized approach is proposed that tackles the different Sound Design tasks by a modular implementation. Further parts of that systematic approach are presented in (1).

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