Fulfilment of legislative requirements in the electric vehicle exterior Sound Design Process

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Abstract

Electric vehicles emit less exterior sound than combustion vehicles, resulting in a higher risk for pedestrians to be involved in accidents. In order to overcome this, the generation of exterior sound for electric vehicles is or will be mandatory. But, the corresponding laws in the different continents are not identical, leading to the fact that different requirements have to be fulfilled in different markets.

On the other hand, the generation of exterior sound offers the possibility to implement a Brand Sound to the OEMs. But, the generated sound has to be compliant to legislative requirements, and has to be aligned to the interior sound. In general, portions of the generated exterior sound will also be audible in the interior, and this sound should not reduce the interior Sound Quality. In addition, the generation of sophisticated and interesting exterior sounds requires rather complex sound generation schemes, which are hard to match with the respective legislative requirements – these requirements restrict the design freedom, and cause a tedious, ineffective and long-lasting iterative Sound Design process.

In order to minimize the trade-off between the fulfilment of legislative requirements and the Sound Design target the agreement to legislation has to be incorporated into the Sound Design process. A corresponding process is implemented in the neosonic exterior Sound Design approach. The characteristics of the used acoustic transfer path are incorporated into the design tool, and the agreement to the legal requirements is automatically evaluated from the start if the basic Sound Design. Furthermore, additional semi-automatic sound generation layers can be used to make a Sound Design compliant to legislation. The implementation in the neosonic direct-to-unit editor is presented.

1 Introduction

The process of exterior sound generation for electric vehicles has to implement the Sound Quality and Sound Design claims of the car manufacturer, but has to fulfil the legal requirements at the same time. The legal requirements restrict the possibilities to implement OEM-specific target sounds, and – depending on the applied sound generation method – might not show a direct link to the sound generation parameters that have to be adapted to achieve a fulfilment. A satisfaction of both, Sound Design aims and legal requirements thus is hard to be achieved.

2 Legal Requirements

In most countries the legal requirements are not yet officially finalized, but detailed drafts are available and negotiations are in the final stage. The actual status of the requirements for the US is summarized in [1], for the EU in [2].

2.1 Main metrics and driving conditions

Table 1 gives an overview on the main proposed metrics to be investigated in the US and Europe.

Metrics	US	EU
Minimal overall level	-	✓
Maximal overall level	-	Forward
minimal Third Octave Bands levels	✓	✓
minimal Pitch Shift per km/h	✓	✓
Tonal required above 400 Hz	✓	-
Tonal required 6dB above vehicle level	✓	-

Table 1: Overview on main metrics used as legal requirements

The metric parameters (e.g., used third octave bands) are different for the US and Europe.

The evaluated vehicle driving conditions are summarized in Table 2.

Conditions	US	EU
Idle	✓	-
10 km/h	✓	✓
20 km/h	✓	✓
30 km/h	✓	-
Reverse	✓	✓

Table 2: Driving conditions to evaluate legal requirements

2.1.1 Minimum overall level

The EU prescribes the minimum overall levels listed in Table 3. The US does not impose a minimum overall level, but the required minimum third octave band levels result in the effective minimal levels listed below.

	US*	EU
Idle	49	
10 km/h	55	50
20 km/h	62	56
30 km/h	66	
Reverse	52	47

Table 3: Minimum overall level requirements. The US proposition does not explicitly require minimum levels, the overall levels result from the required minimum third octave band levels corresponding to Figure 1

2.1.2 Maximum overall level

For any forward driving condition a maximum overall level of 75 dB(A) is defined for the EU. There is no limitation given for the US.

2.1.3 Minimum third overall band levels

The required minimal sound pressure levels for the different driving conditions and the US and EU propositions are depicted in Figure 1.

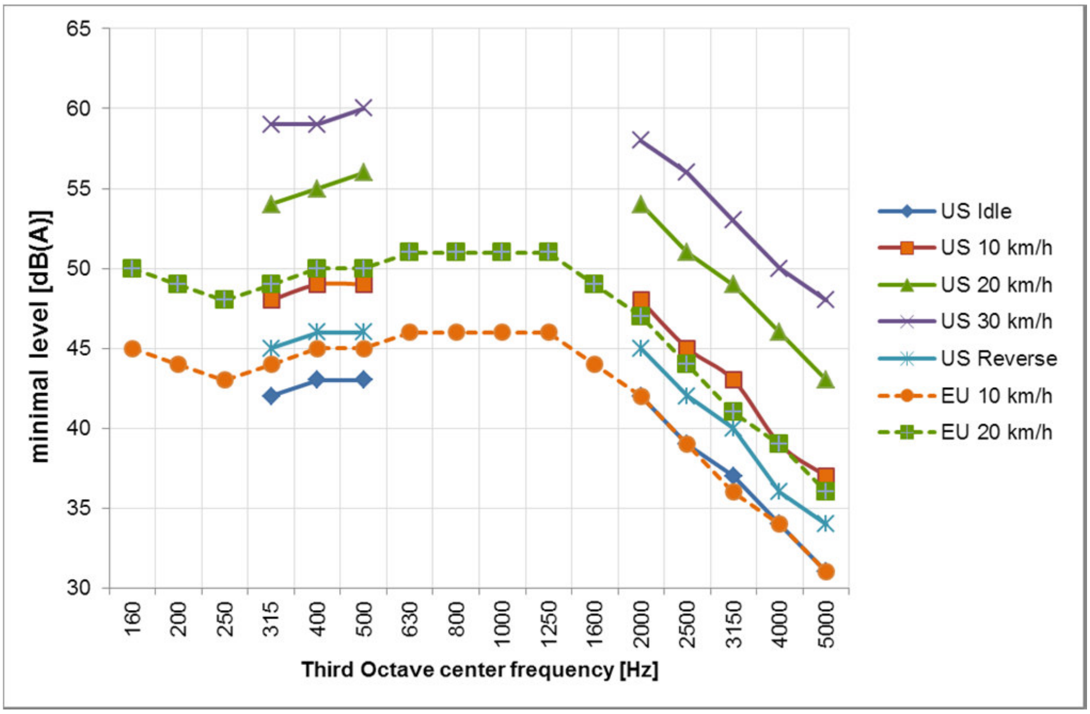

Figure 1: required minimum sound pressure levels for the different driving conditions. For the US regulations all 8 band levels have to be met, for the EU only 2 of 16 bands have to be met, one being below 1600 Hz

Although the EU proposal lists minimal levels for all third octave bands ranging from 160 to 5000 Hz, only two of them have to be met, with one being below 1600 Hz.

The US proposal concentrates on the frequency bands between 315 to 500 and 2000 to 5000 Hz, but for all bands this level has to be met. The respective required levels are 4-6 dB higher for the US than for the EU.

2.1.4 Tonals below 400 Hz

The US proposition prescribes one tonal component to be present below 400 Hz.

2.1.5 Pitch shift

Both propositions require that the pitch of a tonal is linked to the vehicle speed. Minimum pitch shifts of 0.8%/km/h and 1%/km/h are prescribed for the EU and the US.

2.1.6 Tonal above vehicle level

The US proposition requires that one tone should be 6 dB(A) higher than the sound emitted by the vehicle in that third octave band.

3 Standard Vehicle Exterior Sound Design Process

The generic process to Design exterior electric vehicle sound is composed of a series of subsequent and iterative steps as shown in Figure 2.

The base Sound Design usually is performed in laboratory conditions independent on the target vehicle and iteratively evaluated until an internal target is matched. In the next steps the sound is applied to the target vehicle and iteratively tuned to the dynamic behaviour of the vehicle. A vehicle level evaluation is used to decide if an internal target is achieved. Once this process is finished, the vehicle is forwarded to the evaluation of the legal requirements. If this evaluation shows any mismatch, either the vehicle adaptation or tuning has to be refined, or even the Base Sound Design has to be revised and the legal evaluation repeated.

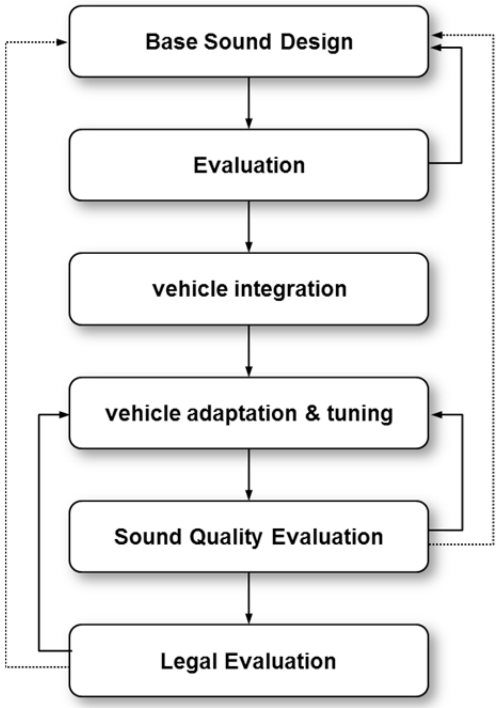

Figure 2: Standard iterative process to design an EV/HEV exterior sound

This process is tedious, time consuming and costly, since usually the link between the results of the evaluation of legal conformance and the Sound Design and Sound Generation process are decoupled. Depending on the applied Sound Design and Sound Generation approach and the type of mismatch towards legal requirements the necessary steps to achieve a fulfilment of the legal requirements might be unclear.

4 neosonic integrated AVAS design approach

The neosonic exterior sound design process as shown in Figure 3 combines the consideration of vehicle target sounds and fulfilment of legal requirements into a unique design step. From the beginning of the Sound Design process the vehicle influence can be considered and the fulfilment of legal requirements predicted. Direct actions to overcome the mismatch can be initiated or can even partly automatically be performed.

In order to fasten the process Sound Design can be performed on two different hardware platforms with identical sound generation:

- a PC based Sound Generation (neosonic ProdSys system)
- Sound Generation directly on the AVAS device

The process of sound generation is identical on both systems, so that the Sound Signatures and parameters can directly be transferred from one to the other. Both systems can be used in laboratory and in vehicle conditions.

The PC-based version allows a faster definition of the Base Sound Signature, since all sounds and parameters can be exchanged during running sound synthesis.

In case of sound generation on the AVAS device all parameters can be changed by the tool in real-time, too, but they have to be transmitted to the device via the available control channel, e.g., CAN. An exchange of sound samples would thus require too much time for a process where the main sound character should be investigated.

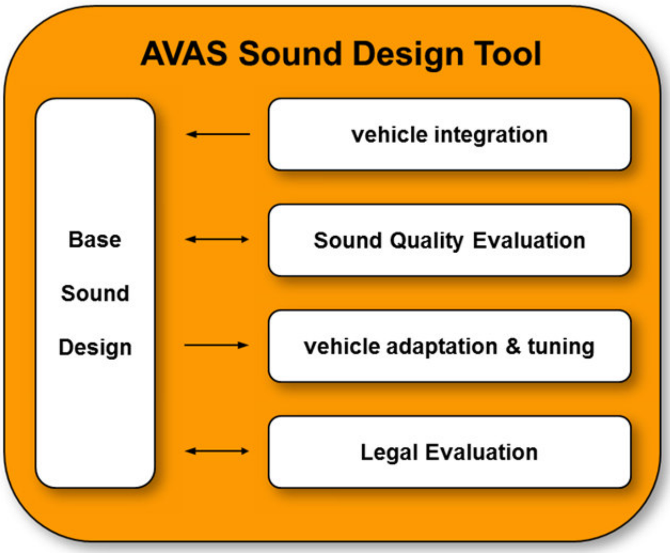

Figure 3: neosonic exterior vehicle Sound Design approach implemented in the AVAS Sound Design Tool

The different components of this combined approach as described in the next paragraphs.

4.1 Base Sound Design – Sound Signature approach

neosonic has developed the Sound Signature approach for the definition of electric vehicle interior and exterior sounds ([3], [4]). Figure 4 gives an overview on the concept.

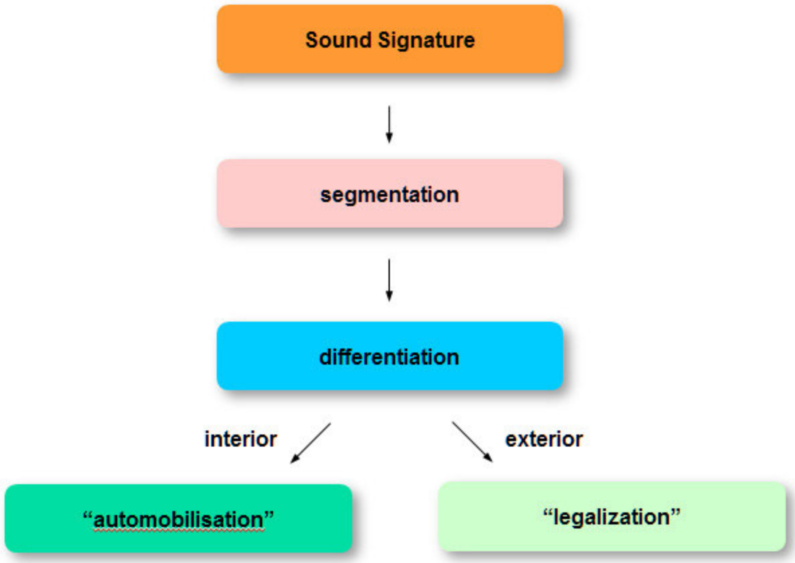

Figure 4: neosonic Sound Signature concept to define an electric vehicle sound

The Sound Signature describes the base character of the sound to be generated, typically in form of a Brand Sound Signature defining the acoustics character of a brand. The Vehicle Sound Signature is determined by segmenting the Brand Sound Signature to the target vehicle. In a differentiation process the sounds for the interior (“automobilization”) and exterior (“legalization”) are generated using the vehicle’s dynamic parameters as control values.

The process of legalization is described in chapter 4.4.

4.2 Vehicle integration

The vehicle integration for a specific target vehicle consists of two different steps: first, the segmentation of the Brand Sound Signature to the target vehicle Signature as described in the segmentation process above (and more detailed in [2]), and second, the consideration of the physical influences of the target vehicle implementation.

The second step has to consider the following physical influences:

1. The transfer function of the used exterior AVAS device HA.
2. The influence of vehicle installation of the used AVAS device HV.

This separation into two different transfer functions allows to consider the generic influence of the AVAS device itself into the design process of the sound signature, and to compensate for the vehicle specific influence in a separate, automated second step.

The AVAS transfer function (AVAS system transfer function H_A or AVAS-in-vehicle transfer function H_{AV} as measured below) are part of the Sound Design project definition and are stored with the Sound Signature parameters.

4.2.1 Transfer function of the AVAS device

AVAS devices have to be of small size, low weight and low cost. As a result, the used loudspeakers have to be rather small, and their frequency response typically is limited to the range prescribed in the legal requirements (160 to 5000 Hz).

Compared to loudspeakers or headphones that are usually applied in the laboratory Sound Design process, the acoustic response thus is significantly restricted. It is thus crucial for the success of the Sound Design that the acoustic properties of the AVAS device are considered.

In case that the ProdSys system is used the AVAS transfer function is reproduced in the synthesis in form of a corresponding filter. If the AVAS device itself is used it is automatically included in the playback.

4.2.2 Influence of the vehicle installation of the AVAS device

The installation of the AVAS device into the target vehicle introduces a second, vehicle specific transfer function H_V. Depending on the installation there can be a significant impact on both, the overall level and the frequency characteristics of the emitted sound (e.g., installation behind the bumper, in the front grill, in the engine compartment etc.). This transfer function has to be measured with the AVAS system installed in the vehicle at the target position.

The transfer function of the installed AVAS device (AVAS-in-vehicle transfer function H_{AV}) can directly be measured with the AVAS Sound Design Tool for supported AVAS devices, e.g., [5]. In doing so, the complete transfer function from electrical output level of the AVAS system to the acoustic receiver point can be measured.

To do so, a specific measurement signal is loaded for playback into the AVAS device through the AVAS Sound Design Tool. A measurement microphone connected to the AVAS Sound Design Tool PC is used to record the sound emitted by the AVAS device, and the corresponding transfer function H_{AV} is calculated. Since only the vehicle installation influence H_V is of interest the generic transfer function H_A of the AVAS system is subtracted from the measured overall AVAS-in-vehicle transfer function to determine H_V.

$$H_V = H_{AV} - H_A \tag{1}$$

The transfer functions are stored in a library in conjunction with the vehicle specific sound signature settings.

The Sound Design and tuning tool automatically compensates the effect of the vehicle transfer function H_V. Coefficients of internal filters of the AVAS device are determined that approximate the inverse transfer function $H^{1}{}_{V}$. These filter settings are not part of the Base Sound Signature, but are stored in the vehicle specific parameters since they implement the vehicle adaptation.

Following this approach, the effort required for sound adaptation to different vehicles is dramatically reduced. If a target sound is defined for vehicle of type A, it can easily be transferred to vehicle of type B by simply exchanging the corresponding vehicle transfer function H_V.

4.3 Vehicle adaptation and tuning

As stated before, the Sound Design and tuning tools allows to set all sound generation and adaptation parameters in real-time. An intuitive graphic user interface is used to control and set all parameters. Most control parameters can easily be set as curves of the corresponding vehicle dynamic control parameter (e.g., speed, load, pedal etc.).

4.4 Legal Evaluation

Within the legal evaluation the sounds generated by the AVAS system are assessed to check for the fulfilment of the corresponding legal requirements. Since the generated sound has to be evaluated, the legal evaluation is only available on the ProdSys system.

CAN data can either be simulated to match with the given driving conditions (speed, estimated load and pedal position), or measured sequences of corresponding drives can be used. The exterior sound is simulated by applying the measured AVAS-in-vehicle transfer function H_{AV}.

The resulting sounds are analysed to evaluate the accordance to the applicable legal requirements listed in chapter 2.1

The feedback to the user is given in different ways:

- overview on fulfilled requirements and mismatches according to tables 1 and 2 (accordance matrix)
- in case of mismatch, quantification of the degree of mismatch
- depending on the type of mismatch, proposals of automatic actions to resolve the issue.

The accordance matrix gives the user a direct overview of the fulfilment of the legal requirements. A sample overview is given in Table 4.

Metrics	US					EU		
	Idle	10 km/h	20 km/h	30 km/h	Reverse	10 km/h	20 km/h	Reverse
Minimal overall level	-					✓	✓	✓
Maximal overall level	-					✓	✓	
minimal Third Octave Bands levels	✓	×	×	×	✓	✓	✓	✓
minimal Pitch Shift per kph	-	✓	✓	✓		✓		
Tonal required above 400 Hz	✓	✓	✓	✓	✓			
Tonal required 6dB above vehicle level	✓	✓	✓	✓	✓			

Table 4: Sample legal evaluation result overview. Metrics are fulfilled besides the minimum third octave bands for the US regulations and speeds 10 to 30 km/h.

In this example all requirements for the EU are fulfilled, but for the US the minimum third-octave level requirement for the 10 to 30 km/h are not met.

In the quantification section the accordance can be depicted in form of graphs. Figure 5 shows an example for the fulfilment of minimum and maximum overall levels for the EU (left) and the US (right) for the example from Table 4. Besides the levels of the AVAS system at the relevant speeds the applicable limits are shown (none for the US).

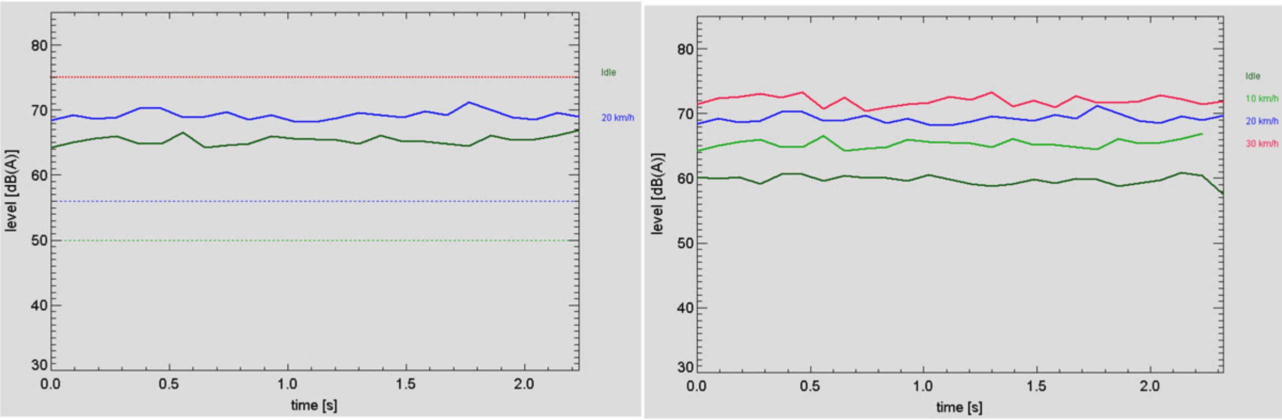

Figure 5: Assessment of correspondence of minimum and maximum level to legal requirements online during Sound Design at the relevant vehicle speeds (only forward depicted).
Left: EU (all requirements fulfilled), right: US (no limits)

The evaluation results of the accordance to the minimum third octave levels are shown in Figure 6. Curves are shown for the relevant conditions, the AVAS signal as straight lines, the requirements as dashed lines.

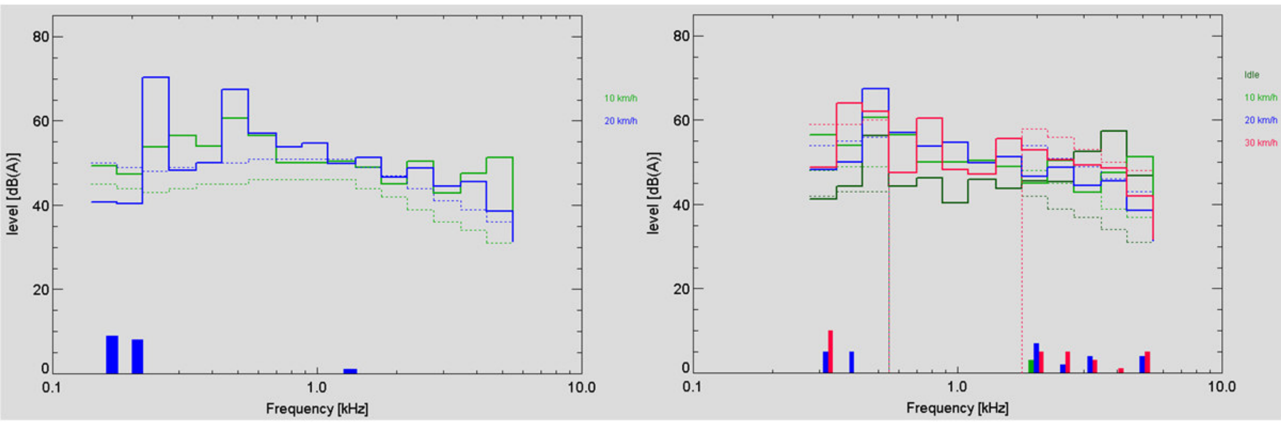

Figure 6: Assessment of the correspondence of minimum third octave levels to legal requirements online during Sound Design (only forward depicted). Left: EU, right: US. Bars at the button show the mismatches for the corresponding third octaves

The bars on the button indicate that the corresponding third octave band minimum level shows a mismatch of the height of the bar.

The evaluation for the EU shows that the requirements are fulfilled. Limits are reached for all bands for 10 km/h, and for 13 of 16 bands at 20 km/h. For the US requirements are not fulfilled for 10, 20 and 30 km/h. At 10 km/h it is violated in 1 band, and at 20 and 30 km/h in 6 bands. According to the bars the band levels mismatch the limits by 1 to 10 dB.

Depending on the cross-relation of mismatches semi-automatic optimizations can be initiated:

- if only minimum overall levels are not fulfilled the corresponding required amplifications are listed.
- if only maximum levels are not fulfilled the corresponding required attenuation is listed. The effect on the third octave levels and the tonal above vehicle level are crosschecked.
- if the third octave bands limits are not fulfilled the respective third octave bands are marked. The user then has several options:
    - in case of small deviations: the complete signal can be amplified to match the third octave(s) that fail the requirements
    - in case of systematic deviations in consistent frequency ranges: filter parameters are preset to solve the mismatches
    - in case of strong deviations in single third octaves: an automatically shaped noise can be generated to fill up the gap

In the example shown in Table 4 and Figures 5 to 6 the overall amplification approach could be used if only the US requirements should be fulfilled since there are no applicable maximal levels defined. According to the bars in Figure 6 (right side) the signals have to be amplified by 4, 7 and 10 dB at 10, 20 and 30 km/h, respectively.

If both, the EU and the US regulations should be fulfilled at the same time the overall amplification approach is not applicable. The amplification of the 20 km/h condition by 7 dB would violate the corresponding EU maximum level requirement. In order to fulfil the US requirements, filters in the low (300-400Hz) and high (2000-5000 Hz) frequency regions can be preset to realize a fulfilment of the US and the EU requirements.

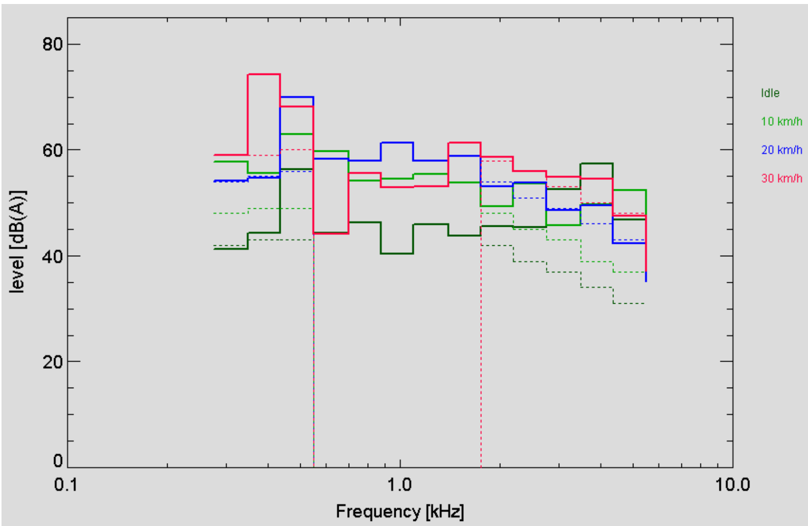

Figure 7: Filter setting in the Design process resulting in the fulfillment of both, EU and US regulations of example from Figure 6.

The pitch shift (2.1.5) is a direct parameter of the synthesis so that no signal-level-check has to be performed. If requirement 2.1.6 (tonal above vehicle level) should be checked, corresponding recordings of the vehicle for the different driving conditions have to be loaded.

5 Summary

The proposed process integrates the evaluation of the fulfilment of the legal requirements directly into the Base Sound Design process. At each phase in this process the conformity to the legal requirements is checked, and actions to fulfil the requirements are proposed. The required time and effort for Sound Design and adaptation process thus is significantly reduced.

References

[1] NHTSA Docket Number NHTSA-2011-0100, “Minimum sound requirements for hybrid and electic vehicles. Draft environmental assessment, U.S. Department of Transportation, National Highway Traffic Safety Administration Washington, DC, January 2013

[2] United Nations, Economic Commission for Europe, Inland Transportation Committee, Proposal for a new Regulation concerning the approval of quiet road transport vehicles (QRTV), ECE/TRANS/WP.29/2016/26, 22. Dec. 2015

[3] Bodden, M.; Belschner, T.: Sound Design for Silent Vehicles: Security - Identity - Emotion. Audio Branding Congress Proceedings 2010, 69-85

[4] Bodden, M. and Belschner, T.: Principles of Active Sound Design for electric vehicles, Proc. of the Internoise 2016, 1693-1697.

[5] MHE press release, http://www.mandohella.com/eng/support/notice_view.asp?intSeq=1953