Electric vehicle sound design - Just wishful thinking?
Sounddesign von Elektrofahrzeugen - Ein Wunschgedanke?

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Abstract

The electrification of vehicle propulsion has caused a radical change also in the world of acoustics. Comments from the media range from „silently hums the future“ to „electric car roars with V8 sound“. Decades of experience in designing brand-specific vehicle sound, based on noise and vibration generated by combustion engines, cannot be simply transferred to the upcoming purely electric power trains. Although electric vehicles are almost always considerably quieter, the interior noise is marked by high-frequent noise components which can be subjectively perceived as annoying and unpleasant. Moreover, disturbing noise is no longer masked by combustion engine noise. Fundamental questions regarding the sound design of electric vehicles have yet to be answered: it remains unclear what exactly the interior noise of an electric vehicle should sound like. Also questions regarding the ways to achieve a particular interior sound are still open, such as whether to use artificially generated noise for sound design. There is also an intense debate on whether electric vehicles should emit additional noise to avoid the endangerment of pedestrians which could work against the hoped-for noise reduction. This paper is intended as a contribution to the current discussion on what the target noise of electric vehicles could sound like and what possibilities there are for acoustic engineers to design the sound of electric cars.

Zusammenfassung

Motivation / Introduction

Even though the E-motor is the standard drive of passenger cars on our satellite in the outer space (Lunar Roving Vehicle, Apollo 15, 1971, Figure 1), this is not the case in the nearby mass market. But since some years the electrification of vehicle propulsion has gained speed and causes radical changes also in the world of vehicle acoustics. The comments from the German media are quiet different and reach from „silently hums the future“ to „electric car roars with V8 sound“.

As a contribution to the discussion of these questions this paper starts with an analysis of electric vehicle interior noise using the example of the FEV build electric vehicle “Liiondrive”. Further on the different interior noise shares of the electric vehicle are considered in detail and compared with the corresponding vehicle sound generated by internal combustion engines. Thereby it focuses on the comparison of two vehicles with identical body but different drive trains, thus allowing to see the effect of the drive train change alone.

Also included is the subjective evaluation of electric vehicle noise samples with admixed virtual noise shares, which may be used to mask disturbing noise shares or to give a more dynamic impression. Finally some criteria for possible target sounds of electric vehicles are considered.

Beside vehicle interior noise also the influence of electrification on the vehicle exterior noise is widely discussed. On one hand the electrification is seen as a chance to reach a significant reduction of the environmental noise pollution. On the other hand there is the risk that quiet vehicles might not be noticed by pedestrians. Therefore the effect of possibly reduced exterior noise emission of electric vehicles on pedestrian safety has to be considered.

Most of the NVH topics discussed here do not concern only pure electric driven vehicles but also hybrid vehicles, which have the ability of pure electric drive. During the development of a hybrid vehicle additionally the features of the combustion engine noise and especially the start and stop of the combustion engine have to be considered, which is described in [1].

Surely this paper will not give final answers on all the new questions in conjunction with the acoustic effect of the electrification. It is intended as a contribution to the current discussion on what the target noise of electric vehicles could sound like and what possibilities there are for acoustic engineers to design the sound of electric cars.

Figure 1: Electric all wheel driven passenger car: Lunar Roving Vehicle, Apollo 15, 1971.


In general it is expected that electric vehicles are considerably quieter, because the combustion engine as main excitation source beside road and wind induced noise is eliminated. But it has to be considered that not only the noise level is important but also the noise character. The interior noise of an electric vehicle usually contains significant high-frequency noise shares, which can be subjectively perceived as annoying and unpleasant. Moreover, disturbing noise shares caused by other components are no longer masked by combustion engine noise.

Fundamental questions regarding the interior sound design of electric vehicles have yet to be answered: it remains unclear what exactly the interior noise of an electric vehicle should sound like. Also questions regarding the ways to achieve a particular interior sound are still open, such as whether to use artificially generated noise for sound design.
**Interior noise shares of the electric vehicle**

Here the electric vehicle interior noise is investigated using the example of the FEV-Liiondrive (Figure 2). It is a fully electric prototype vehicle with an optional range extender, which is not considered here. During the electrification of the drivetrain the series type transmission was kept for simplicity reasons and blocked in 2\textsuperscript{nd} gear.

<table>
<thead>
<tr>
<th>Base vehicle: Fiat 500</th>
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<tbody>
<tr>
<td><strong>Electrification</strong></td>
</tr>
<tr>
<td>Fully electric vehicle (FEV)</td>
</tr>
<tr>
<td>High Voltage Li-Ion-Battery</td>
</tr>
<tr>
<td>Inverter</td>
</tr>
<tr>
<td>Permanent excited synchronous motor</td>
</tr>
<tr>
<td>Optional range extender module (20 kW)</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
</tr>
<tr>
<td>Capacity: 12 kWh</td>
</tr>
<tr>
<td><strong>Performance</strong> (continuous/peak)</td>
</tr>
<tr>
<td>Power: 45/75 kW</td>
</tr>
<tr>
<td>Torque: 150/240 Nm</td>
</tr>
<tr>
<td>Top speed: 120 km/h</td>
</tr>
<tr>
<td>0-60 km/h: 6s</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
</tr>
<tr>
<td>Series type</td>
</tr>
<tr>
<td>2nd gear blocked</td>
</tr>
</tbody>
</table>

![Diagram of FEV LiIONDRIVE: Fully Electric Vehicle](image)

**Figure 2: FEV LIIONDRIVE: Fully Electric Vehicle**

FEV LIIONDRIVE Elektrofahrzeug

For the target oriented sound design of the vehicle interior noise a basic understanding of its noise composition is necessary. Figure 3 shows the Campbell diagram of Liiondrive interior noise at full load. The interior noise consists of a set of vehicle speed proportional orders reaching from 20 Hz up to above 10 kHz. As mentioned already above the Liiondrive makes use of the series type transmission, blocked in the 2\textsuperscript{nd} gear. Therefore vehicle speed and E-motor speed have a fixed relation.

With known number of teeth of 2\textsuperscript{nd} gear and final drive toothing and with known inner design of the E-motor the different orders can be assigned to their excitation process. The frequencies below are specified for a vehicle speed of 85 km/h:
<table>
<thead>
<tr>
<th>Excitation process</th>
<th>Order number (rel. source)</th>
<th>Frequency at 85 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel orders,</td>
<td>3rd, 8th, 16th and others,</td>
<td>20 Hz – 300 Hz</td>
</tr>
<tr>
<td>E-motor orders,</td>
<td>1st – 5th,</td>
<td>100 Hz – 500 Hz</td>
</tr>
<tr>
<td>Final drive toothing orders,</td>
<td>1st, 1.5th, 2nd,</td>
<td>700 Hz – 1500 Hz</td>
</tr>
<tr>
<td>2nd gear toothing orders,</td>
<td>1st, 2nd,</td>
<td>2000 Hz – 4000 Hz</td>
</tr>
<tr>
<td>E-motor pole orders</td>
<td>3rd, 4th, 6th and others,</td>
<td>5000 Hz – 11000 Hz</td>
</tr>
</tbody>
</table>

The low frequency range below 500 Hz is dominated by wheel and E-motor orders, the medium frequency range from 500 Hz to 4 kHz mainly consists of transmission noise from 2nd gear and final drive toothing and the high frequency range above 5 kHz shows some non level relevant, but significant pole orders from the E-motor. The medium frequency range is important for the subjective impression – as further discussed below – and excited by the non E-drive specific transmission. Due to the missing masking of the combustion engine, the transmission noise becomes more prominent, but also at the series vehicle with combustion engine it is obvious, that the transmission is not one of the quietest. For simplicity reasons the series transmission was decided in the Liiondrive prototype vehicle project starting 2008. The evolution of the “Liiondrive” called “LiionA” will feature a smaller, single stage transmission especially fitted to this application in 2010. The high frequency E-motor pole orders can hardly be seen in this scaling of the Campbell diagram and they do not contribute significantly to the overall level. But as described below, that does not mean that it is also unimportant for the subjective impression.

Here a rough overview of the interior noise shares is achieved by the knowledge of the frequencies and orders of the different excitation processes. A more detailed analysis of the interior noise can be done by the vehicle interior noise simulation (VINS), which delivers the strengths and weaknesses of the individual excitations and transfer paths. It separates e.g. airborne and structure borne share of the interior noise and assigns the corresponding noise shares to the individual powertrain mounts. The VINS method is frequently applied to combustion engine driven vehicles since many years [3], [4], but can also be applied to E-vehicles, as it is described in [1].
Comparison of internal combustion engine and electric motor vehicle sound

Beside the acoustic effect of replacing the IC engine with the E-motor also other sources may cause disturbing noise shares. Typical candidates are e.g. auxiliaries like oil pump or water pump, HVAC-system, battery fan and ambient noise like raindrops on the vehicle body. The effects of these components depend on the particular selected concept of the electric vehicle and are here not considered in detail. For the NVH target setting of these possibly noise emitting components it has to be kept in mind, that there is no combustion noise, which could mask the disturbing noise shares.

This paper focuses on the powertrain induced vehicle interior noise. This depends strongly on both: the excitation from the powertrain and the transfer behavior of the vehicle body. To see the effect of the powertrain electrification alone it is helpful to compare the acoustic features of two vehicles with the same vehicle body.

In the following most presented figures are based on a comparison of a series type Fiat 500 - driven by a 1.2l, 4 cylinder gasoline engine - with the FEV-Liiondrive driven by an electric motor. Most of the here shown measurements of the gasoline vehicle are also performed in the 2nd gear and are done with the same tire set. That means that wind, road and transmission noise for both vehicles is based on the same hardware and that the differences in interior or exterior noise are caused mainly by the airborne and structure borne noise from the propelling motor.

Full load condition

Several differences of the emitted noise from ICE engine and E-motor have already been discussed in [2]. In Figure 4 these differences are visualized by a Campbell diagram showing the engine compartment noise of the Liiondrive and the Fiat 500 series vehicle. The latter consists of the well known fan of half engine orders, caused by the two crankshaft revolution periodicity of the four-stroke combustion process. It shows clearly the lower engine orders but also high levels in the range from 1 to 5 kHz, influenced by resonances and a huge set of engine orders. In contrast the Liiondrive engine compartment noise is much quieter, shows nearly no low frequency orders and
the high frequency range has no broad band character like the ICE-engine noise but consists of a set of clearly separated orders up to 10 kHz.

Figure 4: Engine compartment noise of Fiat 500 compared with Liiondrive, full load, 2nd gear

Motorraumgeräusch des Fiat 500, verglichen mit Liiondrive, Vollast, 2. Gang

The simultaneous measured interior noise is shown in Figure 5 in the left and middle Campbell diagrams with different scaling compared to Figure 4. Relative to the engine compartment noise the centre of the frequency spectra is shifted towards lower frequencies, thus reflecting the low-pass transmission character of the vehicle body. At low and medium frequencies also additional road noise shares are visible. The drive train induced interior noise of the electric vehicle is much quieter than the one of the ICE driven vehicle, which results at full load, dependent on speed, in up to 12 dB lower interior noise levels. The right hand side Campbell diagram additionally shows the rolling noise measured at neutral gear. It indicates that a significant share of the interior noise of the electric driven Liiondrive (middle diagram) is induced by rolling noise.

An octave analysis of these three interior noise variants yields that in several octave bands the Liiondrive interior noise at full load is only slightly above the rolling noise and that it is in every octave band below the interior noise of the series vehicle. Therefore the possibility of masking other disturbing noise components is reduced for the electric vehicle.

In the high frequency range of the Liiondrive interior noise several orders are visible, which do not result in a high octave level compared the combustion engine driven vehicle, but are subjectively striking and unpleasant. The noise composition of the Liiondrive can summarized be as follows. The Liiondrive interior noise is quieter compared to the series vehicle offers less masking possibilities due to the missing broad
band combustion engine noise exhibits several significant high frequency, subjectively unpleasant tonal engine orders.

Even though the interior noise of the combustion engine vehicle possesses a strong 2\textsuperscript{nd} engine order at full load and coasting condition due to its 4-cylinder engine, the load dependency of its interior noise is significantly stronger than the one of the electric vehicle. That means that the electric vehicle may be perceived as less dynamic, which does especially not fit to the well-known, quick and strong torque build-up of the E-motor. It has to be considered for electric vehicles how the desired degree of dynamic impression can be conveyed to the driver. One possibility considered below is the admix of load dependent noise shares, as it is already done for several series vehicles with combustion engine.

**Figure 5:** Interior noise of Fiat 500 compared with Liiondrive at full load, 2\textsuperscript{nd} gear and rolling noise

**Innengeräusch des Fiat 500 verglichen mit Liiondrive bei Volllast im 2. Gang und Rollgeräusch**

**Sound character**

Beside pleasantness also the dynamic impression of the interior noise is an important feature, which is often used to design a brand or market segment specific interior sound. This dynamic impression is strongly influenced by the changes of the interior noise level coupled to the load request via gas pedal position by of the driver [3]. This load dependency of the interior noise is shown in Figure 6 by the comparison of the corresponding Campbell diagrams at full load and coast down of the electric driven Liiondrive and the combustion engine driven series Fiat 500.
Constant vehicle speed

At constant vehicle speed the drivetrain induced interior noise share is usually lower than at full load condition. Rolling noise and, at higher speeds, also wind noise come to the fore. The interior noise level at different, but in each case constant speeds is shown in Figure 7 for the electric vehicle Liiondrive and its series type counterpart with IC-engine. Further on it is compared with rolling noise of the same vehicle. The constant speed level of Liiondrive and series Fiat 500 is very similar and is only 1 or 2 dB(A) above the rolling noise. But the interior noise of a luxury class vehicle, plotted for comparison, is significantly below the Fiat 500 noise level. That shows that the level of the noise is less influenced by the type of propulsion than by the vehicle class. At higher vehicle classes road and wind noise are usually on a significantly lower noise level.

Surely the level is one of the main noise characteristics, but the frequency distribution is also very important. In Figure 8 the frequency distribution of Liiondrive and series Fiat 500 is compared with the Fiat 500 rolling noise for low (30 km/h) and medium (70 km/h) vehicle speed. At low vehicle speed all three spectra are very similar. Around 70 Hz the series Fiat 500 spectrum possesses a small peak due to its 2nd engine order and at high frequencies the level is a little higher, probably due to the mechanical noise of the combustion engine, but both is subjectively not very conspicuous.

At medium vehicle speed the three spectra are also rather similar, beside some high frequency resonances of the Liiondrive. These are caused by E-motor pole orders, as already described above (Figure 3): At speeds above 55 km/h the power electronics switches into an acoustically less favorable mode for the benefit of power and efficiency. These high frequency noise shares are also subjectively clearly noticeable and become annoying if one concentrates on them. For series
type applications this should be avoided by another mode of the power electronics. Another probability would be an appropriate sound package, because these high frequencies are surely transmitted via the airborne noise path.

**Subjective evaluation and target sound**

Usually the final goal of acoustic vehicle development work is to reach a pleasant and – depending on the vehicle class – more or less dynamic interior noise. For reaching this goal objective noise analysis is an important method, but what finally counts is the subjective impression of the customer. Therefore objective analysis has always to be verified and accompanied by subjective evaluation. This is especially important if new noise characteristics and compositions are considered, as it is the case for E-vehicles.

Figure 7: Interior noise level at constant speed.

Innengeräuschpegel bei konstanter Geschwindigkeit.
Figure 8: Spectra of interior noise at constant speeds of 30 km/h and 70 km/h.

Beside an assessment regarding pleasantness and dynamic impression the evaluators were also asked, which sounds they prefer. This is a global evaluation of the sound, summarizing somehow the pleasantness and dynamic rating. There might be e.g. the case that a certain sound is much more dynamic than another, but such a dynamic character is not wanted by the listener. This is then reflected in the preference rating.

All sounds were evaluated while keeping in mind, that the acoustic of electric vehicles is investigated. That means that sounds, which might be expected for ICE-driven vehicles, are rated with low preference, because the listener senses them as unfitting for electric vehicles.

Here the subjective evaluation is done on one hand on the road, which represents realistic conditions, and on the other hand in the audio lab, which allows a detailed analysis of specific and also virtual noise shares in the time, frequency and order domain by listening to filtered sounds. The evaluation in the audio lab also allows to rate the sounds independent from other factors like brand and vehicle image and engine performance.

A further option for analysis in the audio lab is to perform an anonymized listening test with a group of participants. This avoids the prejudice due to knowledge about the sound source and puts the evaluation on a better statistical base. Here the subjective sound evaluation should answer several questions:

What is the pleasantness evaluation of the E-vehicle (Liiondrive) relative to its series counterpart with combustion engine?

Which noise shares of the E-vehicle should be reduced to improve pleasantness?

Can the unpleasant high frequency noise shares be masked by admix of low or high frequency noise shares?

Can the admix of noise shares improve the dynamic impression?

The admix of virtual sounds was done with a Matlab tool, which allows to generate an arbitrary
set of engine orders fitting to the engine speed course of the base sound.

Figure 9 shows Campbell diagrams of some of the evaluated interior sounds. They correspond to a “saw tooth” driving condition, including two load changes, which was used for the evaluation regarding “dynamic” and “preference”. Earlier investigations have shown, that the acoustic behavior at load changes is very important for the dynamic impression. For the evaluation of the pleasantness impression the same virtual sound modifications as already used for the dynamic evaluation are applied, but the driving condition is different. Instead of a “saw tooth” condition a full load condition is selected, because this allows including a wider speed range with speeds above 60 km/h, where the high frequency noise shares from the E-motor pole orders become prominent at the Liiondrive.

Beside the Liiondrive original interior noise (Figure 9a), further “cleaned” variants are included, at which the noise shares of the E-Motor, the transmission and the power electronics are reduced (Figure 9b). The reduction of the high frequency shares, caused by the power electronics, significantly improves the pleasantness and preference rating. The reduction of the medium frequency shares from transmission and final drive teeth orders improves pleasantness as well, but less significant. The latter has also a negative effect on the dynamic impression, because the frequency rise and fall of these orders gives the driver feedback to load changes and speed increase. A combination of high and mid frequency noise reduction improves the pleasantness rating even more. The reduction of the low frequency first E-motor order had no significant effect on all three criteria.

Several sound variants with admixed low, mid and high frequency orders are included. On one hand their potential of masking unpleasant noise shares is evaluated. In all cases the admix of additional noise shares worsens the pleasantness and preference rating, especially the admix of high frequency noise shares and the admix of booming and rumbling noise shares similar to some 4-cylinder engine sounds. Beside the here considered variants a huge amount of other virtual sounds is thinkable. But nevertheless this result indicates, that not the masking of unpleasant noise shares but their reduction should be the goal of the acoustic development work. Especially the reduction of noise shares above 1 kHz is perceived as positive by nearly all evaluators.
On the other hand such samples with admixed sounds are included to evaluate their potential to improve the dynamic impression. Depending on the foreseen market segment, a more dynamic sound might fit to the vehicle, while accepting a slight loss in pleasantness. Especially the admix of low and mid frequency orders are assumed to have a positive effect on the dynamic impression. Therefore the order composition of the different virtual sounds, admixed with this goal, is based on the order content of an I4- and an I6-cylinder engine (Figure 9c). The addition of these orders only has a positive effect on the dynamic impression, if the admix is load dependent. That means these shares are only added for the full load phase of the saw tooth driving condition and not for the coast down phase (Figure 9d). As expected the admix of the 6-cylinder engine orders is preferred compared to the 4-cylinder engine orders and the admixed sound should not be too loud. Even more complex admixes are thinkable, e.g. the change of order composition during speed increase, simulating a gear shift (Figure 9e).

Also two original sounds from vehicles with combustion engines are included in the listening test: A sound sample from the series Fiat 500 (Figure 9f) and a series middle class vehicle with I6 engine. Regarding pleasantness both sounds are rated similar to the Liiondrive original sound, even though they do not possess the subjectively significant high frequency orders. Probably their
low pleasantness rating is due to their higher noise level at full load. Even though the dynamic rating of the ICE-vehicle sounds is better than the rating of the original or cleaned Liiondrive sounds, these sounds are not preferred for an electric vehicle. Probably the listener/driver prefers a sound fitting to the technology installed in the vehicle and does not want to listen to combustion engines while driving an electric vehicle.

**Exterior noise of electric vehicles**

The in principle positive effect of possibly reduced vehicle exterior noise of electric driven vehicles is also discussed in the context of pedestrian safety. The missing noise radiation of the combustion engine might cause that the vehicle is noticed with delay by a nearby pedestrian.

For a better substantiated assessment of this risk, the exterior noise of vehicles with combustion engine is compared with the exterior noise of vehicles with pure electric drive for different driving conditions. This is shown in Figure 10 for the example of the Liiondrive. The exterior noise level of the electric vehicle at pass by noise position is compared with the exterior noise of the conventional vehicle at different, but constant speeds. Plotted here is the maximum level, which is usually achieved, when the vehicle is closest to the microphone position. For the conventional vehicle the gear fitting to the selected speed is chosen. As already mentioned the Liiondrive makes also use of the serial transmission, but it is blocked in the 2nd gear.

![Figure 10: Exterior noise level at pass by noise position at constant speed.](image)

Außengeräuschpegel an der Vorbeifahrposition bei konstanter Geschwindigkeit.
For comparison also the pure rolling noise of a Fiat 500 with engine switched off and gear neutral is plotted. In difference to what might be expected at first, the exterior noise levels of the Liiondrive and the conventional Fiat 500 are only 0-3 dB(A) above the pure rolling noise. At vehicle speeds below 40 km/h the Liiondrive and the conventional Fiat 500 show nearly the same exterior noise level. At higher speeds above 40 km/h the conventional Fiat 500 is even quieter, probably because it is operated in a higher gear and therefore with lower engine speed.

The frequency content of the vehicles exterior noise is compared in Figure 11. Third band octave spectra of the exterior noise at pass by noise position are shown at a constant vehicle speed of 30 km/h. The course of the spectra from Liiondrive, the conventional Fiat 500 and the rolling noise is similar, but the conventional Fiat 500 shows higher levels on one hand at the ignition order around 60 Hz and at frequencies above 1 kHz.

From subjective impression the Fiat 500 series vehicle is easier noticed at pass by up to speeds of about 30 km/h, on one hand because of the higher noise levels in the high frequency range (Figure 11), but also because the characteristic periodic combustion engine sound is more significant than the Liiondrive noise shares. That means that concerning safety aspects the exterior vehicle noise should not only be evaluated by measured noise levels or spectra, but also by subjective evaluation.

![Figure 11: Third band octave spectra of exterior noise at pass by noise position at constant speed of 30 km/h.](image)

Terzspektren des Außengeräusch an der Vorbeifahrtposition bei einer Geschwindigkeit von 30 km/h.
From experience it is well known that electric vehicles (or hybrid vehicles in pure electric mode) are less conspicuous especially at low speeds, at drive off situation, at full load acceleration or maneuvering at the parking place. In these situations a warning tone might help to get the necessary attention of pedestrians. But still the latent danger of electric vehicles being “silent killers” is not proven yet. The integration of these vehicles into the current traffic will bring up more reliable data. Nevertheless a warning exterior noise generator being active up to 25km/h is already announced or realized by car manufacturers [5], [6]. It should be designed in a way that it becomes not more annoying than the exterior sound of conventional vehicles though in the authors’ point of view.

**Conclusion**

The effect of vehicle propulsion electrification on the interior and exterior noise and its subjective perception is described using the example of the FEV Liiondrive, compared with a series Fiat 500, what it is converted from.

Its main interior noise shares in the order of increasing frequencies are: wheel orders, E-motor orders, final drive toothing orders, 2nd gear toothing orders and E-motor pole orders. Due to the missing broad band combustion engine noise, the interior noise levels at full load are significantly reduced up to 12 dB(A), which improves pleasantness impression but also offers less masking possibilities. At constant speed and coast down noise levels of the internal combustion engine and electric driven vehicle are similar, because here the noise is dominated by the shares from road, wind and transmission noise. The missing load dependency of the sound causes a less dynamic impression of the Liiondrive, as the level difference of full load to coasting condition has proven to be the major driving factor regarding the dynamic impression.

The Liiondrive interior sound is subjectively evaluated regarding pleasantness, dynamic and preference in comparison to ICE-vehicle sounds and several virtually modified Liiondrive sounds. These virtual sounds are firstly tuned in direction of pleasantness by reducing annoying noise shares, secondly tuned in direction of dynamic by adding low and mid frequency engine orders and thirdly tuned in direction of masking unpleasant noise shares by admixing sounds of different frequency content.

The interior sound of the ICE-Fiat 500 is rated more dynamic, but less pleasant compared to the original Liiondrive sound. In all cases the adding of noise shares to the Liiondrive sound worsens the pleasantness and preference rating, whereas a reduction of the tonal high frequency noise shares from power electronics significantly improves pleasantness and preference. The reduction of unpleasant noise shares – “sound cleaning” – even for electric vehicles is still the major goal of the acoustic development work.

The dynamic impression – “sound design” – can be improved by a moderate admix of virtual engine orders known from sports car engines at acceleration only, while keeping pleasantness on an acceptable level. At least for the coming up customers of electric vehicles being used to ICE sounds this seems to be an option. For the next generation customers even more futuristic and branded sounds coming away from historic combustion engine sounds are likely. More complex admixes are thinkable, e.g. the change of order composition during speed increase simulating a gear shift for high speed vehicles or jet noise to further increase the dynamic impression.

The modified exterior noise of electric vehicles is widely discussed in the context of pedestrian safety. At constant speed the exterior noise levels of the Liiondrive and the series Fiat 500 are similar and close to pure rolling noise. Nevertheless at low speeds the exterior noise of the electric vehicle is subjectively less conspicuous and locatable, due to reduced levels in the high frequency range and due to the missing characteristic periodic combustion engine sound. In these situation an adequate tuned warning tone might help to get the attention of pedestrians.
References

Wittler, M., Abtahi, R., Pischinger, S., Eisele, G., Akustik und -Schwingungen von Hybridfahrzeugen, Aachener Kolloquium Fahrzeug und Motorentechnik 2009


Whoriskey, P., Nissan adds noises to Leaf electric vehicle as safety precaution, The Washington Post, 12th June 2010