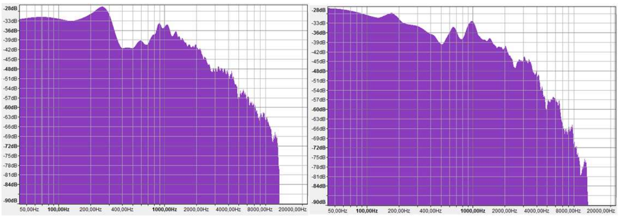

Fig.8. EV vs. ICE at 40km/h

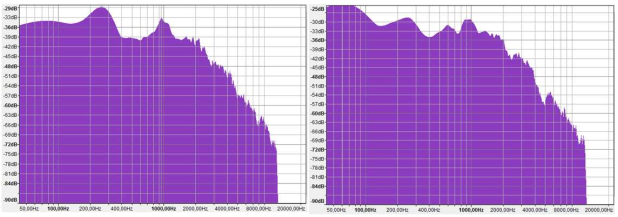

Fig.9. EV vs. ICE at 50km/h

Furthermore, an analysis of the AVAS system of the Renault Zoe has been done. In order to signal acceleration and velocity, Zoe uses different frequencies and frequency shift. It also has three different sound systems to be chosen by the driver. In the left part of the spectrogram depicted in Fig. 10 it is possible to see the frequency spectrum at 5km/h and in the right part the spectrogram for 15km/h. Further data is not presented as the AVAS from Renault Zoe gets deactivated when the car reaches the speed of 18km/h.

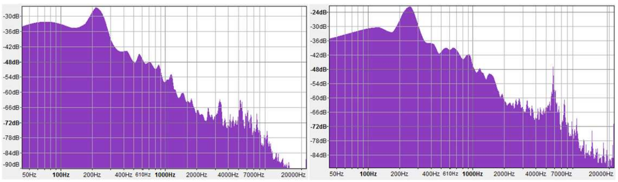

Fig.10. AVAS from Renault Zoe at 5km/h and 10km/h

It is possible to appreciate a shift in the frequencies with more power. Thus, from 215Hz when driving at 5km/h, frequency shifts to 258Hz when it increases its velocity to 15km/h. On the higher frequencies, the harmonics enhancing the main frequencies, there is also a remarkable shift from 5167Hz to 5770Hz. According to equation (2) the frequency shift is of 2% for the central frequency lobe and of 1.16% for the harmonics.

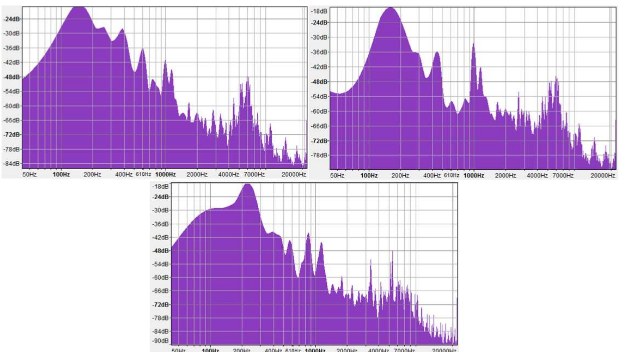

Fig.10. Different AVAS sound systems from Renault Zoe

Finally, Fig.11 shows the differences between the three AVAS provided by the Renault Zoe. The main frequency peak varies slightly, 149Hz, 166Hz and 223Hz, respectively. At higher frequencies, all three have a boost in 1000Hz and in the band 2000Hz to 7000Hz, giving some color to the sound through the use of more harmonics.

4. Conclusion

This paper analyzes the issue of the liability of silent EVs to cause personal damage to pedestrians and cyclist, specially the visually impaired, children and elderly.

Both EV and ICE vehicles circulating below the 50km/h threshold are most of the time within the maximum and minimum sound pressure ranges established by the EU, a minimum of 56db and a maximum of 74dB. ICE surpassed the maximum threshold slightly, by only 0.4dB and just in one of the measurements. However, a new EU regulation restricting this threshold to 69dB for 2024 which means all ICE circulating beyond 30km/h wouldn't comply with the new regulation. On the other hand, the Renault Zoe did not approach the 56dB threshold until it is circulating at/over 10km/h. This makes especially dangerous, parking, starting and maneuvering, as it is completely silent. For all measured speeds the difference in sound pressure between ICE and EV remained almost constant in both measuring points P and P'. A reflection on this is necessary, as AVAS will only be mandatory up to a 20km/h speed. However, the difference between EV and ICE remains significant until 50km/h the threshold in which pneumatic noise takes over. As pedestrians obtain much information about speed and acceleration through the acoustics, it may be recommended that the AVAS is deployed until 50km/h or that the urban speed limit is reduced to 30km/h.

Another important factor on how we perceive the sound depends on the frequency spectrum produced. EV and ICE and AVAS have very different frequency spectrums. Thus, AVAS favors higher frequencies with plenty of harmonics in the band from 2000Hz to 7000Hz, whereas it lacks the lower frequencies that characterize combustion engines. This raises the question of its effectiveness, as the main purpose of the AVAS system is to be recognizable by the pedestrians. This paper concludes that frequencies in the band of 60Hz to 120Hz should be incorporated by AVAS systems.

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