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The Electric Vehicle: Solving the Silent Problem

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Abstract. Electric Vehicles (EV) are key stakeholders for a Green House Gas (GHG) emission free future. However, the integration of these vehicles in our society can create some collateral damage. The lack of noise of electric motors compared to Internal Combustion Engines (ICE) can lead to more accidents, as the acoustic signals from vehicles raise awareness of its presence. Pedestrians, Cyclists and very especially blind and partially sighted people are the groups at risk

Thus, sound systems for EVs have to be designed and for that a study on the noise intensity in the frequency spectrum has to be made. This paper presents an experimental research on how to approach this problem.

Key words. Electric Vehicles, Acoustic Vehicle Alerting Systems (AVAS), environmental noise, pedestrian security

1. Introduction

The presence of Electric Vehicles (EV) has started to increase during the last years. In some countries, such as Spain, Portugal, Germany and Finland EV sales have grown more than a 100% in 2017, which shows an increasing tendency to expansion. At first, silent vehicles were supposed to contribute on the actual problem of noise in big cities. However, another issue has emerged; as the EV presence in our societies grows, the risks associated with its lack of noise become more noticeable. (1)

- Quiet hybrid and electric vehicles are 40% more likely to collide with pedestrians than cars with a regular combustion engine
- A study reveals that pedestrians need to be a 74% closer to EV´s in order to hear them compared to the fuel ones.
- People's perception is that these cars make roads less safe for older people and three quarters say the same for children.
- 76% agreed the same referring to pedestrians with sight loss. (6)
- EVs usually get involved in 37% more accidents. (6)

As a consequence of these problems, some laws had to be set for the purpose of finding a solution as soon as possible. On the one hand, the EU requires EVs and hybrids to do noise by incorporating an Acoustic Vehicle Alerting System (AVAS), starting the 1st of July 2019. (2) The AVAS achieve that vehicles that do not make any noise can be able to reproduce it. Even though some other systems were tried in order to solve this problem, such as urban warning devices, (similar to horns but with softer sound), but they did not turn to be as effective as needed.

On the other hand, The EU in its Directive 96/20/CE demands that EVs that circulate under 20km/h must overcome a minimum level of decibels, which is set on 56dB, without exceeding the maximum of 74dB. On speeds higher than 20km/h the rolling sound should be noticeable enough. (2-3)

When the combustion motor is replaced with the electric one, a lot of acoustic information is removed from pedestrians and road users. With the AVAS system, this information could be returned. This acoustic cue reflects the behavior of the car as it accelerates, decelerates, starts and stops, as well as indicating the speed the vehicle has. The background of this is that we do probably get more information listening than we do looking. (4-5)

The goal of this study is to analyze the requirements the AVAS system needs for fulfilling its aim. To achieve this, some measurements will be made, so that the noises will be reproduced with the exact same frequencies as the noises reproduced by Internal Combustion Engine (ICE) cars.

2. Methodology used for measuring the sound

The measurements will be done following Addendum 137 of UN Regulation Nº138 (4), Uniform provisions concerning the approval of Quiet Road Transport Vehicles with regard to their reduced audibility. This section specifies the aspects to be taken into account and the procedure that this paper will use for the measurements.

The devices used for measuring meet the requirements of Class 1 described in IEC 61672-1-2013, IEC 60942-2003 and IEC 61260-1-2004. In this case, sound meters, spectrum analyzers and microphones.

At the beginning and at the end of every measurement session, the measurement system will be checked and differences beyond 0,5dB have been discarded. During the tests, the road speed of the vehicle has been measured.

The meteorological conditions such as temperature, wind-speed, barometric pressure and relative humidity have been taken into account. Representative values of those were taken during the measurement interval. Air temperature is within the range from 5°C to 40°C. The tests cannot be done for the wind speeds, including gusts, at microphone height exceeding 5m/s.

The chosen vehicle, a Renault Zoe, is a representative of vehicles to be put on the market. If the vehicle is equipped with multiple driver selectable operating modes, the mode which provides the lowest sound emission shall be selected, in this case, this means using the Eco function of the Zoe. The tires were inflated to the pressure recommended by the vehicle manufacturer

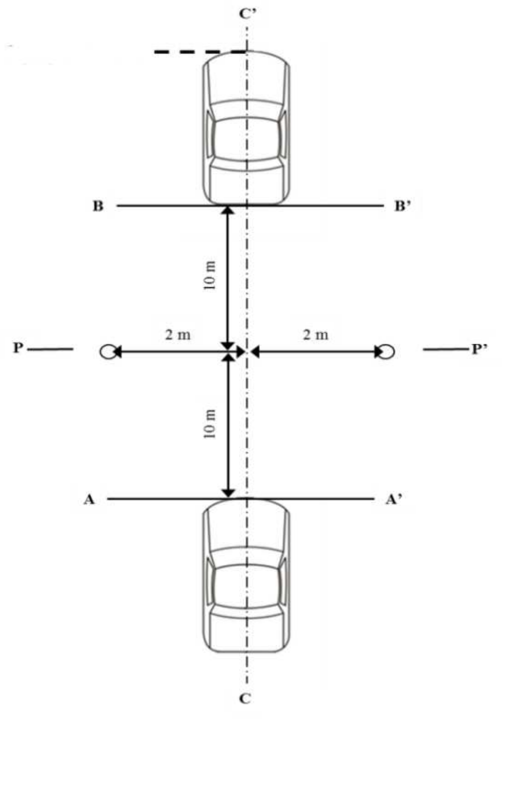

Fig.1 Measurement unit position

For outdoor testing in a radius of 50m around the centre of the track, the space was free of large reflecting objects. No obstacle was present near the microphones so that the acoustic field will not be influenced. As seen in Fig.1, the distance from the microphone positions on the microphone line PP' to the perpendicular reference line CC' is 2,0m ± 0,05m.

The background, or ambient noise, has to be measured for at least 10s, without any disturbances.

The measured result within a test condition, $L_{test,j}$, shall be corrected according to the table $L_{testcorr,j} = L_{test,j} - L_{corr}$, when background noise A-weighted sound pressure levels are 2dB(A) or less.

$$\begin{aligned} &\text{If } L_{bgn>2},\ L_{testcorr} = L_{test} - L_{corr} \\ &\text{If } L_{bgn}<2,\ L_{testcorr}=L_{test}-L_{bgn}-L_{corr} \\ &\text{If } \Delta L_{bgn,p\text{-}p}>2,\ L_{test}-_{bgn}<10, \quad \text{invalid measurement} \end{aligned} \tag{1}$$

Where:

$L_{test,j}$: A-weighted sound pressure level result of jth test run
$L_{testcorr,j}$: A-weighted sound pressure level result of jth test run
L_{corr}: Background noise correction
L_{bgn}: Background A-weighted sound pressure level
$\Delta L_{bgn,\ p\text{-}p}$: Range of maximum to minimum value of the representative background noise A-weighted sound pressure level over a defined time period

When a sound peak or disturbance that is very different from the general sound pressure level has been observed, that measurement has been discarded.

There is a change of background noise requirements when analyzing in one-third-octave bands. In this case, the level of background noise in each one-third octave of interest, shall be at least 6dB(A) below the measurement of the vehicle or AVAS. The A-weighted sound pressure level of the background noise shall be at least 10dB(A) below the measurement of the vehicle or AVAS under test.

The first test consists of a constant speed in forward motion test. The path of the centre of the vehicle has to follow the central line CC' as seen in Fig.1 with constant speed v_{test}=10km/h with a +/- 1km/h and v_{test}=20km/h with a +/-2km/h tolerance. This paper includes higher velocities of up to a 50km/h. In concordance with the regulation the velocity will have a 10% tolerance.

At least four measurements for each test condition have to be made on both sides of the vehicle. The first four valid consecutive measurement results for each test condition will be used for the calculation of the final result. If there is any disturbance or sound peak, that measurement will not be valid.

For each test condition $L_{testcorr,j}$ and the corresponding one third octave spectra shall be arithmetically averaged and rounded to the first decimal place. The final A-weighted sound pressure level results to be reported are the lower values of the two averages of both sides, rounded to the nearest integer

A second part of the study will consist of measuring the frequency shift will then be used by AVAS to signal acceleration or deceleration. In this case, the background noise and circulation speed requirements are different.

Frequency shift will be used by AVAS to signal acceleration or deceleration.

The vehicle sound emission is measured at target speeds of 5 km/h to 20 km/h in steps of 5 km/h with a tolerance of ±2 km/h for the speed of 10 km/h or less and of ±1 km/h for any other speeds. The speed of 5 km/h is the lowest target speed. (4)

The frequency of the lowest reported test speed rounded to the nearest integer is the reference frequency f_{ref}. For other speeds the corresponding frequencies f_{speed} rounded to the nearest integer will be taken from the spectra analysis. Thus, the frequency shift can be calculated as:

$$\Delta f=\{[(f_{speed}-f_{ref})/(v_{test}-v_{ref})]/f_{ref}\}.100 \qquad (2)$$

Where:

f_{speed}: single frequency component at a given vehicle speed

f_{ref}: single frequency value at reference speed (5km/h)

v_{test}: vehicle speed

v_{ref}: reference speed of 5km/h

3. Results

The measurements for this study were made on the 3rd of December 2019 in Bilbao, the Meteorological conditions were favourable, with neither wind nor rain, as can be seen in Table I

Table I. – Meteorological Data

Temperature	9º
Wind-speed	Calmed (0km/h)
Barometric Pressure	1022hPa
Relative humidity	76%

The vehicles used were an Electric Renault Zoe, driven in ECO mode in order to provide the lowest sound emission possible and an ICE Volkswagen Touran 1.9 TDI.

Tests were made at 5, 10, 20, 30,40 and 50km/h speeds for positions P and P'. The measured data collected during test conditions can be seen in Table II. All measures are A-weighted sound pressure.

The background noise measured during the tests was established in Lbgn =52dB, variation of background noise was ΔLbgn,p-p=1.35dB. According to said background noise pressure level, ΔL is calculated as seen in Table III. At this point, the correction factors to apply in each case in accordance to UN ECE Reg.138, Annex 3, Table, 3 can be determined, as shown in Table IV.

Table II. – Ltest,j measurements

Speed (km/h)	ICE_left P (dB)	ICE_right P' (dB)	EV_left P (dB)	EV_right P'(dB)
5	60,5	59	55,7	55,6
10	62,6	61,4	58,5	57,8
20	64,5	64	61,5	59,8
30	68,7	67,5	65,5	65,2
40	72,2	71,8	67,9	68,3
50	74,4	73,3	70,9	69,6

Table III. – $\Delta L=L_{test,j}-L_{bgn}$

Speed (km/h)	ICE_left (dB)	ICE_right (dB)	EV_left (dB)	EV_right (dB)
5	8,5	7	3,7	3,6
10	10,6	9,4	6,5	5,8
20	12,5	12	9,5	7,8
30	16,7	15,5	13,5	13,2
40	20,2	19,8	15,9	16,3
50	22,4	21,3	18,9	17,6

Table IV. – Lcorr

Speed (km/h)	ICE_left (dB)	ICE_right (dB)	EV_left (dB)	EV_right (dB)
5	0,5	1	2,5	2,5
10	0	0,5	1	1,5
20	0	0	0,5	1
30	0	0	0	0
40	0	0	0	0
50	0	0	0	0

Finally, applying the correction factors, the functional sound pressure values are calculated for both EV and ICE at positions P and P'. These values are valid as long as $\Delta L_{bgn,p\text{-}p}>2$ and $L_{test}-_{bgn}<10$, as it is in this case.

Table V. – Ltestcorr,j values

Speed (km/h)	ICE_left (dB)	ICE_right (dB)	EV_left (dB)	EV_right (dB)
5	60	58	53,2	53,1
10	62,6	60,9	57,5	56,3
20	64,5	64	61	58,8
30	68,7	67,5	65,5	65,2
40	72,2	71,8	67,9	68,3
50	74,4	73,3	70,9	69,6

Fig.1 and Fig.2 compare the sound pressure level for EV and ICE. It is possible to see that the difference between both vehicles is very similar between 0km/h and 50km/h. The same conclusion can be drawn from Fig.3 where the one third octave frequency spectra analysis is presented. The difference is around 2dB for all speeds, which is remarkable (consider that decibel is a logarithmic unit).

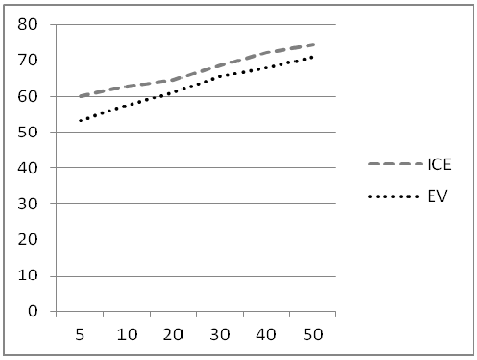

Fig.1. ICE vs. EV from position P

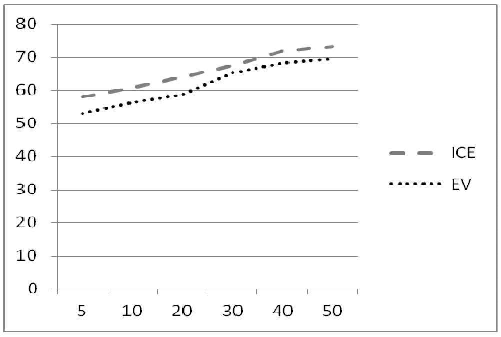

Fig.2. ICE vs. EV from position P'

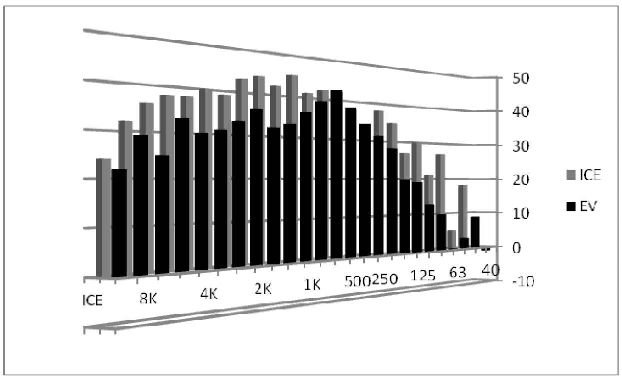

Fig.3. One third octave frequency spectra

Finally, the analysis of the frequency spectrum has been done. In this case, a Fast Fourier Transform (FFT) and a hanning window have been used to represent the audio signal in the frequency domain. Fig.4, Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9 show the frequency spectra, the EV's spectrum is depicted on the left side and the ICE's on the right. The noise of vehicles driving up to 50km/h is produced mainly by its engine. From 50km/h to 80km/h the noise is produced by the pneumatics and from 80km/h on it is aerodynamic noise. So for ICE's the motor noise has a dense frequency spectrum in the frequency band from 50Hz to 20Hz, that is not replicated by the EVs.

EVs noise production comes mainly from the pneumatics and traction system. This boost the low frequencies below 200Hz with harmonics around 1000Hz. When driven at very low velocities (Fig.4 and Fig.5) a frequency boost around 380Hz can be seen, this is due to the electric motor that produces a humming sound at this frequency. The humming persists at all speeds and is observable in the spectrogram in Fig.6, but then the frequencies from the pneumatic noise have a higher sound pressure so it is no longer observable in Fig.7, Fig. 8, Fig. 9.

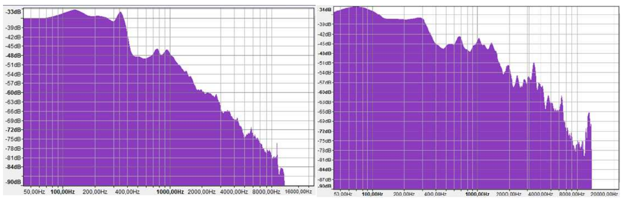

Fig.4. EV vs. ICE at 5km/h

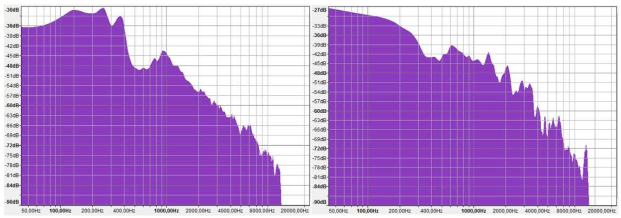

Fig.5. EV vs. ICE at 10km/h

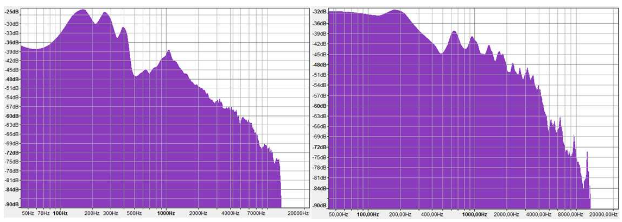

Fig.6. EV vs. ICE at 20km/h

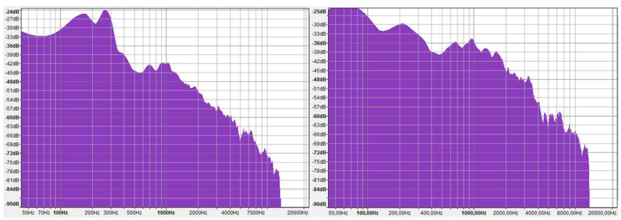

Fig.7. EV vs. ICE at 30km/h

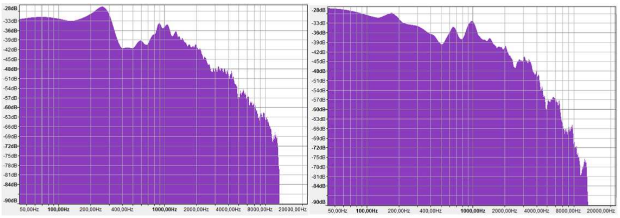

Fig.8. EV vs. ICE at 40km/h

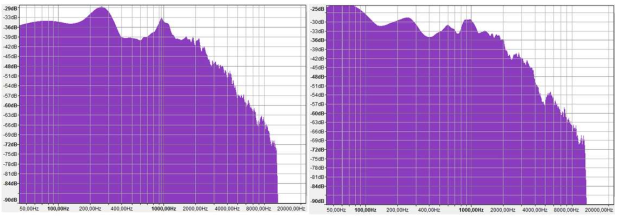

Fig.9. EV vs. ICE at 50km/h

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.

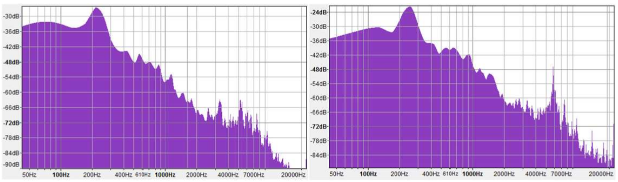

Fig.10. AVAS from Renault Zoe at 5km/h and 10km/h

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.

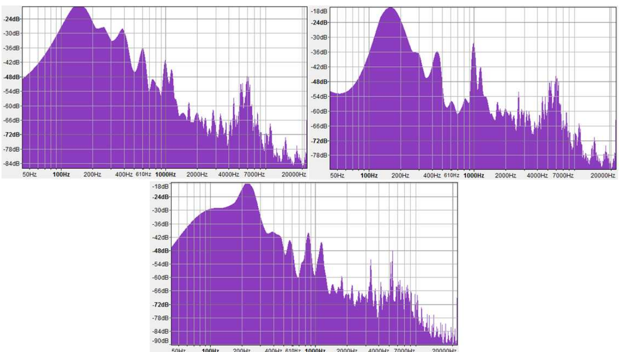

Fig.10. Different AVAS sound systems from Renault Zoe

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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