Full frequency simulation of performance of audible pedestrian safety warning system

A.Caillet[1], M. Calloni[2], O. Fatmi[1], A. Mejdi[3]

[1] *ENGINEERING SYSTEM INTERNATIONAL GmbH*, Germany, Email: Arnaud.caillet@esi-group.com
[2] ESI Group, Italy
[3] ESI US R&D, USA

Abstract

With the advent of electric vehicles, the usual audible sources from internal combustion engine has been removed, affecting pedestrian safety. New audible signals to inform them of the approach, presence, direction and/or departure of electric and hybrid road vehicles are required to alert the pedestrians. The use of the alert sound is required by several regulations all around the world normally at speeds below 30km/h. To design properly the audible pedestrian warning systems and make sure they conform to regulations, measurements can be done. However, it needs a lot of manpower and hardware.
BEM simulations are capable to predict accurately the transfer function between the source and the microphones used for the certification of the vehicle and evaluate the performances of the pedestrian safety device. The BEM model provides the flexibility to investigate design changes in terms of position of the loud speaker, type and variations in the sound package. Therefore, ray tracing technique can be used as an alternative for mid and high frequency analysis and can be used for faster prediction (from hours to minutes) and to reach higher frequency range. This paper aims to present a test case and comparison of the BEM and Ray Tracing predictions.

Introduction

Recently, the sales of electric and hybrid vehicles have boomed worldwide [1], almost doubling year on year. The appearance of these vehicles on our streets are creating new dangers. For example, the blind community raised that the reduction of noise due to the electrification of the vehicle is removing from them a possibility to detect an incoming vehicle. The banalization of the usage of smartphones in our streets, distracting our visual attention from our surroundings, is also a problem as only the hearing sense is used to detect a vehicle incoming. Studies done in the United States in 2008 [2] showed that pedestrians are much slower detecting the approach of hybrid or electric cars than ICE vehicles and this leaves them less time to react. To react to this situation, discussion started in different countries to create new legislation. For example, in 2017, the United Nations published a suggestion for a new regulation (R138R1 [3]) with target minimum noise levels for 10km/h and 20km/h speeds measured 2m away from the center of the vehicle at 1.2m height (the setup and target levels are shown on **Figure 1**). This paper will use the UN suggestion as a reference for the target level. Physical prototypes tests can be used to check if the pedestrian warning system of the car are performing well enough to fulfil the requirements. The trend in the industry, however, is to reduce the number of physical prototypes as test facilities and integrating design changes within a prototype have high costs. This paper proposes a process how to replace or support the physical tests by simulations.

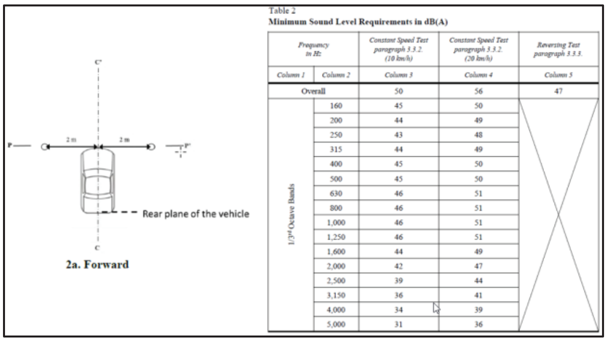


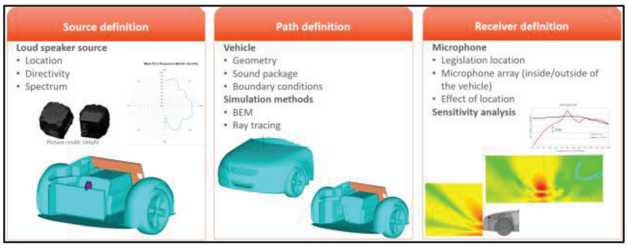
Table 2
Minimum Sound Level Requirements in dB(A)

Frequency in Hz		*Constant Speed Test paragraph 3.3.2. (10 km/h)*	*Constant Speed Test paragraph 3.3.2. (20 km/h)*	*Reversing Test paragraph 3.3.3.*
Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*
Overall		50	56	47
1/3rd Octave Bands	160	45	50	
	200	44	49	
	250	43	48	
	315	44	49	
	400	45	50	
	500	45	50	
	630	46	51	
	800	46	51	
	1,000	46	51	
	1,250	46	51	
	1,600	44	49	
	2,000	42	47	
	2,500	39	44	
	3,150	36	41	
	4,000	34	39	
	5,000	31	36	

Figure 1: UN R138R1 regulation, measurement setup and target levels in dB(A)

Prediction of the pedestrian safety device performances

This section intends to propose a process to calculate the performances of the pedestrian safety loudspeaker device mounted inside the vehicle. For this it is very important to define 3 parameters, the source, the path and the receiver. First, the source should be properly defined in terms of directivity, frequency content and location in the vehicle. Secondly, the path between the source and the receiver can be described using simulation techniques like BEM (boundary element method)[4] or Ray Tracing. For both those methods, the geometry of the vehicle, especially for the engine bay and the shape of the car body should be included. The sound package should also be taken into consideration, for example the hood absorber, outer dash insulator, under engine encapsulation, etc. Those absorbers can be considered as impedances within the BEM model. The application example will propose a way to evaluate and integrate the sound package in the simulation model. **Figure 2** illustrates the source/receiver/path process.


Source definition

Loud speaker source
- Location
- Directivity
- Spectrum

Picture credit: Delphi

Path definition

Vehicle
- Geometry
- Sound package
- Boundary conditions

Simulation methods
- BEM
- Ray tracing

Receiver definition

Microphone
- Legislation location
- Microphone array (inside/outside of the vehicle)
- Effect of location

Sensitivity analysis

Figure 2: Illustration of the source/path/receiver proposed to simulate the pedestrian safety problem.

Application example

This section will present how the source/path/receiver method was applied to analyze the performance of a pedestrian safety loudspeaker device using TU München DrivAer benchmark model [5]. The simulated results will be presented at several locations for the frequency range [200;4000] Hz. The analyses presented below were performed using ESI Group VA One software.

Source description:

The source is idealized as a monopole located at the actual position of the sound actuator (**Figure 3**). The excitation levels used are realistic and described in 1/3rd octave. A more complex description of the source could be potentially used if data becomes available.

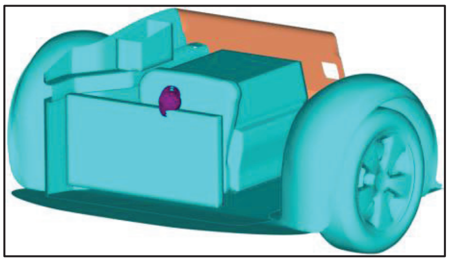


Figure 3: Source (sound actuator) position in the vehicle

Path description:

Three parameters are important to describe the path: the geometry of the vehicle, the sound package and the boundary conditions.

Geometry description

The geometry is the most important part of the model. A surface mesh is created describing the geometry of the exterior front of the car and the engine bay, including the internal components: engine, transmission, radiator, battery, etc. These parts will have a direct impact on the propagation of the sound waves from the actuator to the receiver microphone positions with the BEM method used to describe the exterior sound field [4]. The mesh used has 20mm element size which allows a calculation up to 4000Hz with 4 elements per wavelength which is a good compromise between the precision of the geometry, the results and the computation time and resources needed to solve the problem. In this example, the mesh is generated based on a CFD mesh. A coarsening operation is done to obtain the desired element size. The shape mesh could also be generated from CAD or a FEM NVH mesh with the help of shrink-wrapping algorithm to obtain a close mesh. To reduce the calculation time, it was decided to include only the front of the car within the model (from front end to A-pillar). As the microphone positions used for the evaluation of the performances of the pedestrian safety are all located in front of the car, it was assumed that the influence of the back of the vehicle will be negligible. The panels are also all assumed rigid to simplify the analysis. It is however possible to consider flexible panels. **Figure 4** shows the mesh used to model the vehicle.

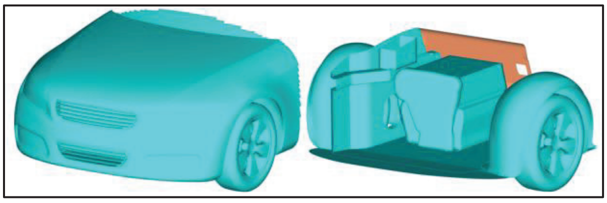


Figure 4: BEM mesh of the vehicle

Sound package description

The sound package within the engine bay is modelled as surface impedance. The surface impedances can be measured or calculated using the transfer matrix method which accounts for the material properties with the Biot parameters.

Boundary conditions description

To simulate the measurement environment which is semi-infinitely open (outdoor measurements) or a semi anechoic room (indoor measurement) a BEM fluid with a rigid baffle to model the floor is used. In addition to this, roads can be made of different types, one of the aspects of road asphalt, its porosity, means that the road surface has a direct impact on the acoustic response. This can be integrated as an impedance in the infinite baffle modelling the ground. As a first step, a rigid infinite baffle was used to model the ground in the model. During the design change analysis, a more realistic asphalt boundary condition was investigated and integrated as impedance in the infinite baffle.

The simulation assumes a non-moving vehicle. It can be expected that the levels of noise measured at the prescribed location may be lower than the regulation which assumes a vehicle driving at 10km/h or 20km/h.

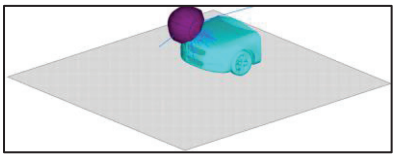


Figure 5: Vehicle BEM mesh and infinite baffle representing the ground

Receiver description:

The microphones are located at 1m and 2m from the car on the left and right side. The 2m microphones are located at the positions prescribed by the UN regulation. To better understand the propagation of the acoustic waves in front of the vehicle, extra microphones are created and data recovery planes which will provide a mapping of the sound pressure level (see **Figure 6** for the position of the microphones and the data recovery faces). It will be helpful to identify potential blind spots.

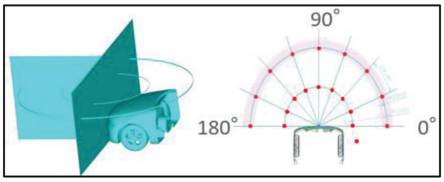


Figure 6: Microphone location in front of the vehicle and data recovery faces

Results:

The model was computed on high performance computer. The model was calculated from 176.77Hz till 4489.85Hz in 1/12th octave. An averaging was done to obtain the results in 1/3rd octave. **Figure 7** shows a comparison between the simulated levels and the one prescribed by the UN regulation. Below 800Hz, the levels are much too low. This is due to the source which is radiating less energy at low frequency. The simulation also does not take account of the possible extra sources radiating when the vehicle is moving at a speed of 10km/h. However, those are usually very low. Using a different frequency content for the source would help to reach the levels required by the regulation. **Figure 8** shows the sound pressure levels at 2 meters distance from the vehicle for a 5° increment. It is intended here to evaluate the directivity of the source and check if any blind spots could be generated by the setup. Two frequencies are displayed here, 800Hz and 1250Hz which are local maxima and minima of the curves displayed on **Figure 7**. In addition to the polar plot displayed on **Figure 8** shows the pressure distribution on 2 planes at 800Hz (maximum SPL measured. This can help also to diagnose and predict were pedestrians may have difficulties to hear the vehicle coming for the specified frequencies.

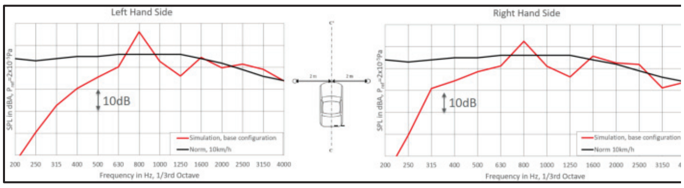


Figure 7: Comparison of simulated against UN regulation at prescribed positions

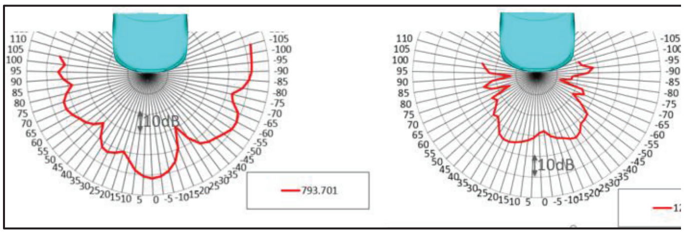


Figure 8: SPL at 793.7Hz and 1259.9Hz at a distance of 2m from the center of the car

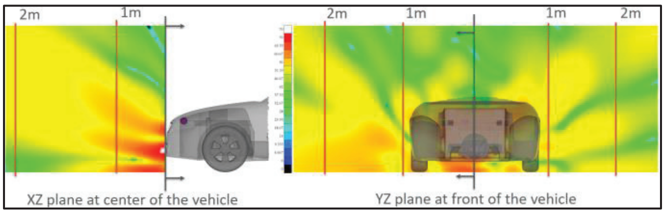


Figure 9: Contour plot of the pressure distribution at 793.7Hz

Design changes:

Design changes can be introduced into the model to analyse the effect of various parameters like:

- Floor impedance
- Characteristics of the source (location, frequency spectrum, directivity)
- Using various trims within the engine bay as impedances

The effect of several design changes was analysed in a different paper, the results can be found in [6]

Using Ray Tracing to simulate the performance of the acoustic pedestrian safety device:

BEM can predict with a lot of precision and details the acoustic response of a system. However, BEM is computationally challenging. Ray Tracing could be a good alternative to BEM to obtain faster results and test more design changes. The calculations are first made without considering the diffraction using VA One 2018 [4], [7].**Figure 10** illustrates the different zones of a ray tracing model. In blue, the non-shadow zone where the response can be properly predicted using classical ray tracing methods (direct and reflected fields are important), in orange, the shadow zone only the diffracted field exist. And in yellow all three fields (direct, reflected and diffracted) are important.

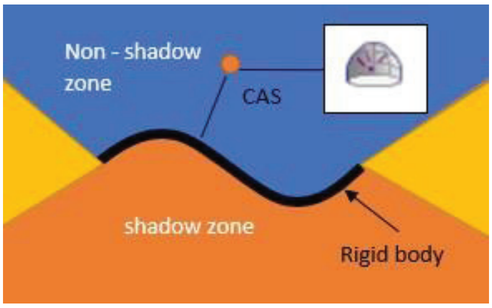


Figure 10: Definition of the different zones in a Ray Tracing model

Most of the time, the microphones used for the certification of the pedestrian safety device are in the shadow zone. A method to account for the diffraction is implemented in VA One 2019.

Diffraction in VA One

The laws of reflection in VA One 2018 enable us to follow the usual rays from the source when it hits reflecting faces. However, this law fails to specify what happens to a ray which hits an edge or grazes a boundary surface. Therefore, the diffraction low is implemented in VA One 2019 to give rise to diffracted rays when an incident ray hits an edge. The diffraction law states that when an incident rays hits an edge of the geometry with a given angle, the diffracted wave in Sommerfeld's solution is conical. This means that the diffracted wave fronts are parallel cones with the edge as their common axis.

Application to the pedestrian safety problem

To predict the performance of the pedestrian safety device using Ray-Tracing, the same geometry model can be used as previously for BEM. This section shows a comparison of the sound pressure level predicted using BEM, classical ray tracing and ray tracing with diffraction. **Figure 11** shows that the diffraction method is needed when the source is located behind the radiator and a microphone located on the right side of the vehicle. Without diffraction, no pressure is captured at the microphone. The microphone is located within the shadow zone. The ray tracing calculation with diffraction can capture in that case the trend of the curve, but the levels are too low compare to the BEM reference. An optimisation of the parameters used could be done (number of reflections, diffraction order…) **Figure 12** shows the case of a source located in front of the radiator. Without diffraction, the levels predicted are too low. The microphone is located in the region where only the reflected rays are present. Adding the diffraction, the levels and trend are much better captured. The ray tracing method with diffraction seems to be a good alternative to BEM to generate results faster.

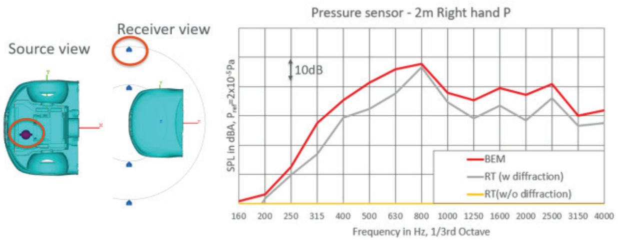


Figure 11: Pressure simulated at 2m right hand microphone for a source located behind the radiator

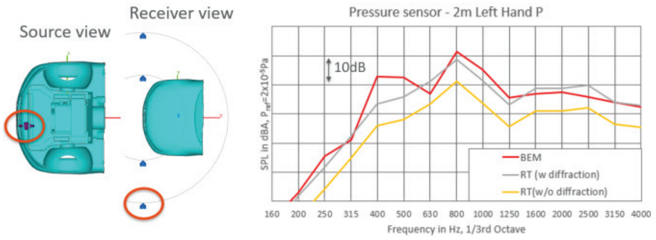


Figure 12: Pressure simulated at 2m right hand microphone for a source located in front of the radiator

Conclusion

This paper presented a process to simulate the behavior of the acoustic warning pedestrian safety installed on electric or hybrid cars. The ray tracing method in combination with diffraction can be used to get a first estimation of the performances of the device and run fast multiple iterations. To validate the best configuration found using the ray tracing method, BEM can be used to obtain results with more accuracy. The current models are using rigid faces. Introducing FEM flexible structure could help to model the transmission of energy through the hood or the plastic panel which can be significant, or the noise perceived by the passengers of the car.

References

[1] The global electric-vehicle marked is amped up and on the rise, McKinsey, May 20118: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise

[2] Hybrid cars are harder to hear, University of California, Riverside. *2008-04-28*. Retrieved 2010-07-03.

[3] Uniform provisions concerning the approval of Quiet Road Transport Vehicles with regard to their reduced audibility, UN regulation No 138, November 2017

[4] VA One 2018 user's guide, ESI Group, 2018

[5] TU München DrivAer benchmark model: https://www.aer.mw.tum.de/en/research-groups/automotive/drivaer/

[6] Caillet A., Calloni M., Fatmi O, Castel A., Audible pedestrian warning system design methodology based on source-path-receiver approach, Aachener Acoustics Colloquium, 2018

[7] Mejdi A., Gardner B., Musser C., Fiedler R., Novotny Z. Prediction of acoustic response and speech intelligibility based on a hybrid ray tracing/SEA technique, Internoise 2017, Hong-Kong