The Acoustic Behavior of a Loudspeaker Mounted on Different Types of BIW Frames

Niranjan Ambati[1], François Malbos[2], Michal Bogdanski[3], Michael Strauss[3]
[1] Harman India, [2]Harman France, [3]Harman Becker Automotive Systems, [3]Harman Becker Automotive Systems
[1] Prestige Tech Park, Bangalore-560103, India, niranjan.ambati@harman.com
[2] 12 bis, rue des Colonnes du Trône, Paris, 75012, France, francois.malbos@harman.com
[3] 135 Schlesische Straße, Straubing, D94315, Germany, michal.bogdanski@harman.com
[3] 135 Schlesische Straße, Straubing, D94315, Germany, michael.strauss@harman.com

1. Introduction

In OEM premium audio systems, packaging of any subwoofer is a challenging task due to size of the component and of the required air coupling volume. The position of a subwoofer has to be optimized in a very constrained space to achieve the best acoustic performances. One solution is to use particular part of the body in white (BIW) cavities as the subwoofer enclosure. The geometry of the BIW and the speaker location influences the behavior of the loudspeaker. This paper presents a Comsol App (=application) based on a fully parametrized loudspeaker and BIW (single or multiple beams designs) model. The validation of the simulation model is performed by using theoretical results. The Comsol App is a quick reference tool to predict the interaction between the speaker and the BIW structure. Based on these preliminary studies, simulations on a very accurate BIW geometry with increased grade of details can be performed for final optimum configuration.

Keywords: BIW, Subwoofer, Comsol Apps

2. Theory

The acoustic modes in BIW enclosure are due to sound reflections between end surfaces. At certain frequencies (eigenfrequency), standing waves occur when the reflected and incident wave frequencies are matched.

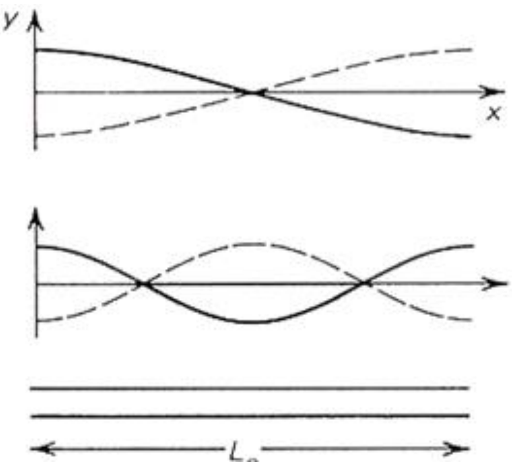


Figure 1: Standing waves Pressure distribution for 1st and 2nd normal modes

For a parallelepiped BIW with a length equals to L, the eigenfrequency can be computed as:

$F_n = n*c/2L$ where

- c - sound velocity
- n – mode number

If the speaker is located at a node (minimum sound pressure amplitude), the corresponding mode will not be excited [1] [3]).

3. Comsol Model

3.1 Geometry and Mesh Designs

The BIW geometry integrated with speaker is different in size and configuration each time for every new car audio development. In this case, building a fully parametrized model of BIW with speaker is the best way to address this type of projects. The Comsol app is developed for system engineers to analyze and generate the simulation report quickly.

The BIW geometry can be categorized into two types of configurations, which are single serial beam and multi parallel beam configurations. Figures 2 and 3 show some of the sample BIW and speaker geometry configurations. Figure 4 shows the meshed model of multi beam geometry.

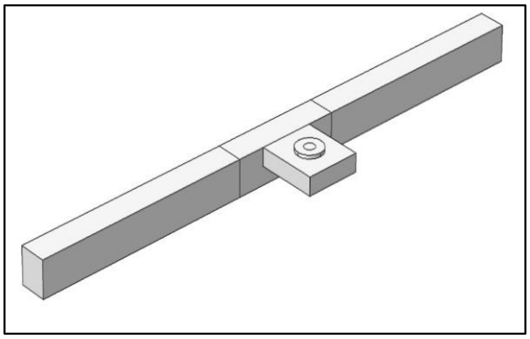


Figure 2: Single beam configuration

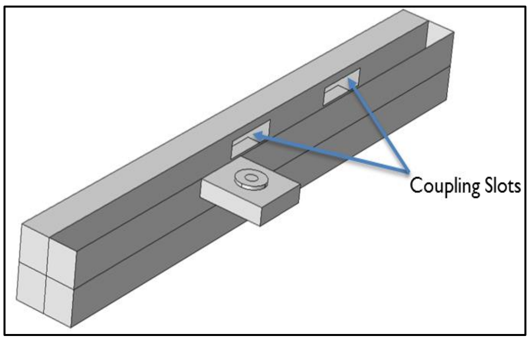


Figure 3: Multi parallel beam configuration with coupling slots between beams

The speaker location, beam size and number of beams, coupling slot size and location are the influencing factors, which are considered for building parametric model of BIW geometry.

The speaker parameters including membrane diameter, coil dimensions, surround stiffness, magnetic forces and electrical voltage parameters are considered for parametric modelling of speaker.

The tetrahedral meshing elements are used to mesh the acoustic domains. Triangle elements are used to mesh the speaker membrane. The hexahedral swept mesh is used for PML (Perfectly matched layer) geometry. The mesh is fully parameterized.

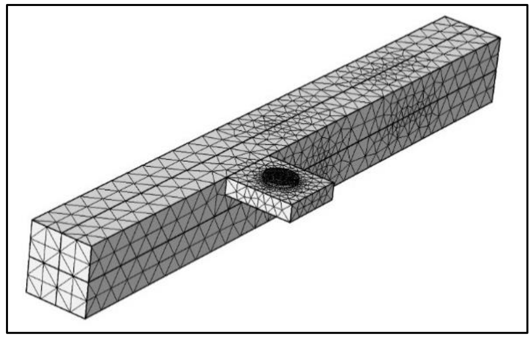


Figure 4: Meshed model of multi beam

3.2 Multiphysics Approach

Two different physics are combined for the BIW simulation

- Pressure Acoustic for the BIW, speaker adaptor and PML air volumes. A far field calculation is used to optimize the calculation time.
- Structural / shell domain for the speaker membrane including the speaker membrane (cone, surround, voice coil wiring, voice coil former).

The Pressure Acoustic Shell Interaction analysis is used to predict the speaker displacement, the sound pressure on axis and the impedance curve.

4. Validation of the Simulation

4.1 Eigenfrequency

For a parallelepiped BIW with a length 2 meters, the FEM eigenfrequencies are equal to 85.8 Hz and 171.6 Hz (figure 5). As we can see, simulation results correspond to the theory.

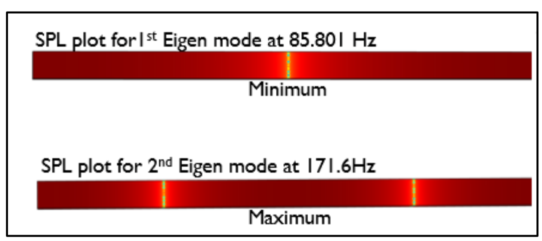


Figure 5: Simulated Acoustic modes of a BIW (2 meters length)

4.2. Influence of the speaker location

Simulations were performed with a single beam (length of 2 meters) with combination of different speaker locations. Speaker location at 0 mm means that the speaker is at the middle of the beam and 500 mm means that the speaker is at a quarter of the beam. As we can see, the first mode is not excited and the second mode is excited for the 0 mm configuration (opposite for the 500 mm configuration). These simulation results are in line with the theory.

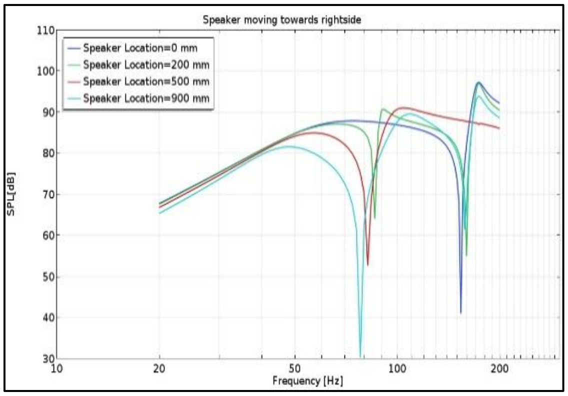


Figure 6: predicted SPL plot for Single Beam case

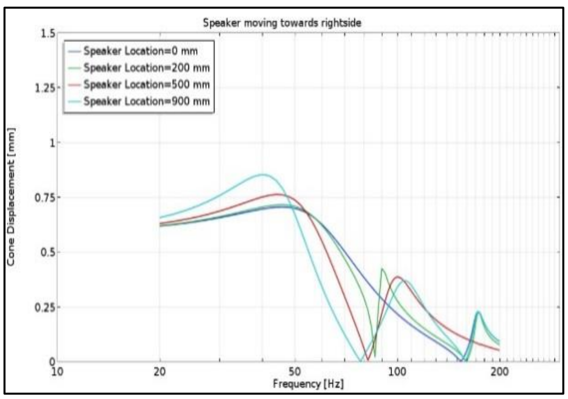


Figure 7: predicted displacement plot for Single Beam Case

5. Comsol App

The Comsol App has been developed for analyzing different cases quickly. The Comsol App includes all parameters, which influence the speaker performance in BIW integration. Figure 8 shows the required parameters in GUI.

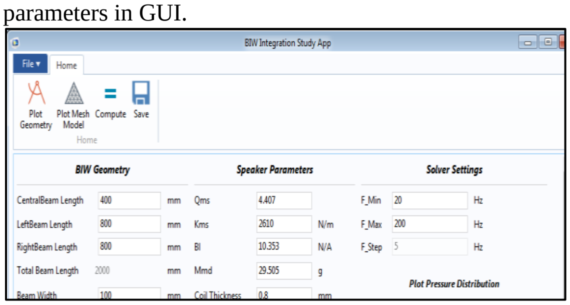


Figure 8: Comsol App GUI with Input parameters

The required "Input" parameters for building BIW beam geometry, Speaker locations, Beam types, Beam configurations including coupling slots are parameterized. The user is given the option to change these parameters using Comsol App GUI. The beam length is one of the deciding factors of the eigenfrequency of BIW enclosure. The 'Speaker Position' parameter is the location, where speaker integrated with BIW frame. If speaker position is 0 mm, this means the speaker is located at center of the beam. The 'BeamType' indicates whether it is single beam or Multi beam. The 'CoupleBeams' shows the number of volumes in BIW enclosure that are considered for simulation. The 'Vol_1' in 'CoupleBeams' indicates that only one volume is considered. The 'CouplingSlotLocation' parameter indicates the location of coupling slot openings in between beams.

The required outputs are SPL at 1m axis from membrane center, electrical impedance and displacements are plotted in each different graphics window. Moreover, the user has the option to plot the surface pressure at user-defined frequencies. Finally, the user can also create automated simulation report with plots, input parameters, solution parameters and user details.

The Solver settings including start frequency (F_Min) and end frequency (F_Max) of simulation are user controlled.

The solution time for single beam is around 2 mins and for multi-beam with multiple couplings is around 3 mins in 64GB RAM machine.

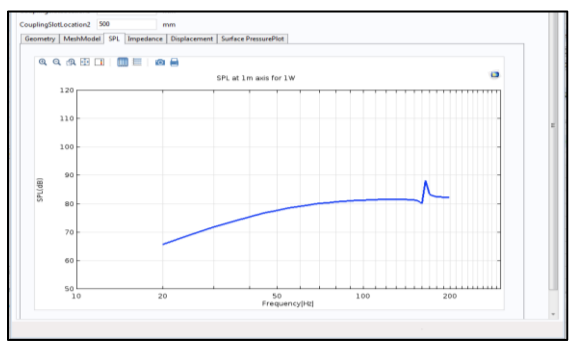


Figure 9: SPL plot

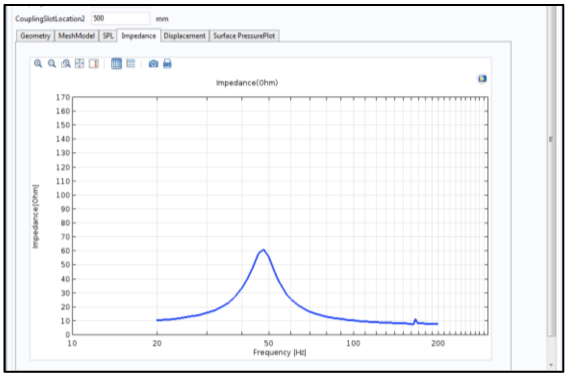


Figure 10: Impedance plot

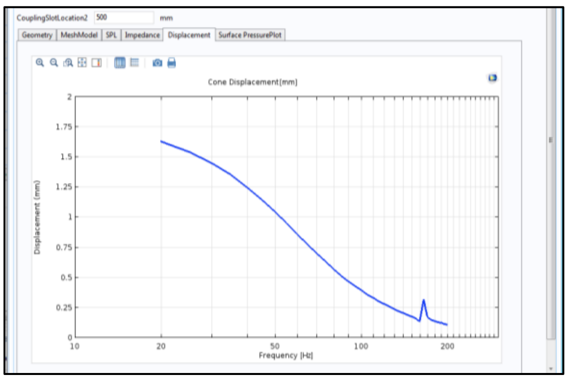


Figure 11: Displacement plot

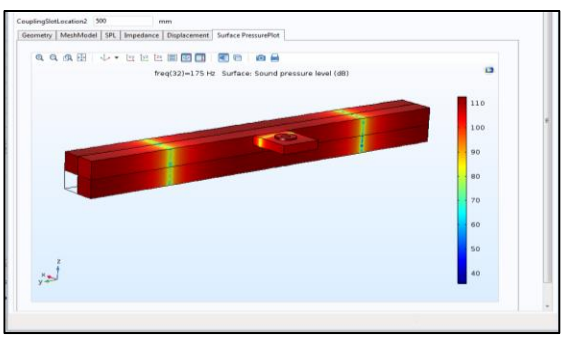
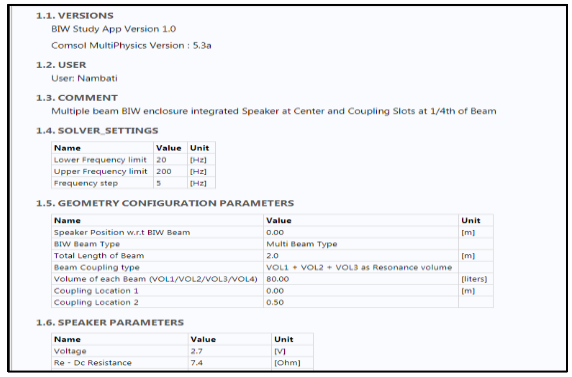


Figure 12: Pressure level distribution plot for 3-beam BIW volume enclosure

6. Customized Simulation Report

The custom simulation report is generated using Comsol App. The simulation report includes all simulation plots, BIW geometry parameters, speaker parameters, user details, date and version details. It is an automated report which generates automatically by click of button.



1.1. VERSIONS

BIW Study App Version 1.0

Comsol MultiPhysics Version : 5.3a

1.2. USER

User: Nambati

1.3. COMMENT

Multiple beam BIW enclosure integrated Speaker at Center and Coupling Slots at 1/4th of Beam

1.4. SOLVER_SETTINGS

Name	Value	Unit
Lower Frequency limit	20	[Hz]
Upper Frequency limit	200	[Hz]
Frequency step	5	[Hz]

1.5. GEOMETRY CONFIGURATION PARAMETERS

Name	Value	Unit
Speaker Position w.r.t BIW Beam	0.00	[m]
BIW Beam Type	Multi Beam Type	
Total Length of Beam	2.0	[m]
Beam Coupling type	VOL1 + VOL2 + VOL3 as Resonance volume	
Volume of each Beam (VOL1/VOL2/VOL3/VOL4)	80.00	[liters]
Coupling Location 1	0.00	[m]
Coupling Location 2	0.50	

1.6. SPEAKER PARAMETERS

Name	Value	Unit
Voltage	2.7	[V]
Re - Dc Resistance	7.4	[Ohm]

Figure 13: Auto generation custom report

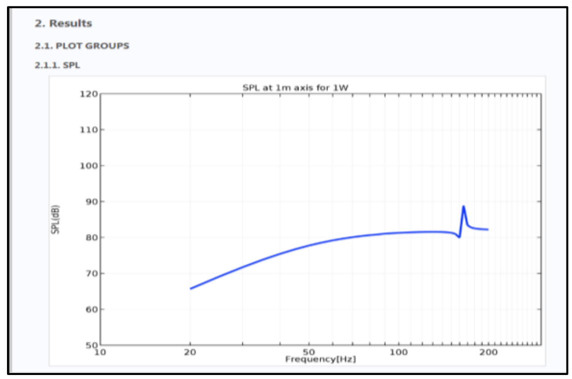


Figure 14: SPL plot in auto generated report

7. Conclusion

The HARMAN BIW app proof to be a helpful tool to quickly predict the performances of the subwoofer in a single or multiple BIW beam, because of which the app is made accessible to all relevant engineers across the company. Based on this preliminary study, a more detailed simulation on a very accurate BIW geometry would be performed for final optimum configuration. The Comsol App is a quick reference tool to predict the interaction between the speaker and the BIW structure. It allows to reduce the speaker and the BIW architectural design time by creating automated reports including sound pressure distribution, cone displacement and impedance plots. In general, Engineering Apps play an important role for the so called "Democratization" of numerical simulations across an organization.

8. References

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