

# Complete Modeling of a Vented Box Loudspeaker in COMSOL Multiphysics®

R. Vaucher  
NEXO, Plailly, France

\*Corresponding author: NEXO, parc du pré de la Dame Jeanne 60128 Plailly, France. remi.vaucher@nexo.fr

**Abstract:** This paper describes the use of COMSOL Multiphysics® during the design of a vented box loudspeaker. Several templates have been created to model the different needs of a complete design. Based upon those templates a real box has been prototyped, measured and confronted to simulation.

The cabinet prototyped may be described as a vented box design, featuring two low frequency drivers mounted in a "V Shape" with a horn loaded compression driver. Several uses of COMSOL Multiphysics® have been considered in this study.

- Optimization of the directivity of the V shape design with different configurations in 3D.
- Optimization of the tuning and shapes of the vent.
- Optimization of the horns polar pattern and radiating impedance.
- Calculation of the acoustic modes within the box.
- Calculation of the structural modes of the box itself.

Most of the models have been confronted to real measurements of a prototype made with a fast prototyping machine.

**Keywords:** Coverage, Impedance, Loudspeaker, Bass-Reflex, Directivity.

## 1. Introduction

The usual ways of designing speakers, by rule of thumb based on experience, 1D lumped elements design, equations modeling simple geometrical forms and successive prototyping has been pushed to their limits with the advent of more complex acoustic design and the necessity to minimize the prototyping stage for cost and time reasons.

Each of the covered topics could be (and perhaps will be) extended as a full paper. The aim of this presentation is more global and will not go into details.

The commercial product resulting of this study is not yet on the market; as a result the pictures of the prototype are not given in this document for confidentiality reason.

The tools used for this study are the COMSOL Acoustics module, the LiveLink for SolidWorks, MATLAB and VACS (R&D Team) as post processing.

## 2. General Use of COMSOL Multiphysics

A model template based on a COMSOL model [1] has been modified in order to obtain the following results:

- On Axis Response in the Far field
- Horizontal & Vertical Coverage in the Far field
- Displacement of the membrane
- Electrical Impedance
- Radiation Impedance

The coupling between the ACOUSTICS and the ODE module avoided the use of the AC/DC module (lumped element simulation to include the driver parameters).

All geometries are made in SolidWorks (including the Air Domain and PML) so every relevant parameter is driven within COMSOL. This was very useful to adapt seamlessly the width and distance of the PML and Far Field calculation according to the size of the mesh (itself driven by the frequency range).

## 2.1 Modeling versus Theory

To ensure the validity of the template, tests have been made on a well know cardioid pattern.

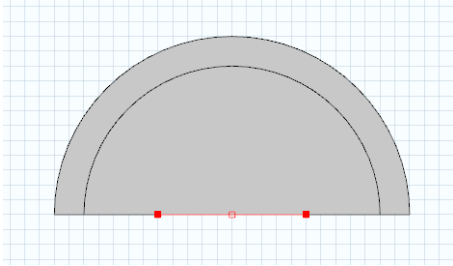


Figure 1. Cardioid Dipole & PML

One monopole is fed with an inverted polarity signal and a delay corresponding to the distance between the two sources. [2].

The MATLAB post processed coverage plot (degree in ordinate, frequency in abscissa, normalized with the maximum amplitude for each frequency) gives a clear graphical hint of the deviation versus the theory. That would be much harder to detect using standard polar plots.

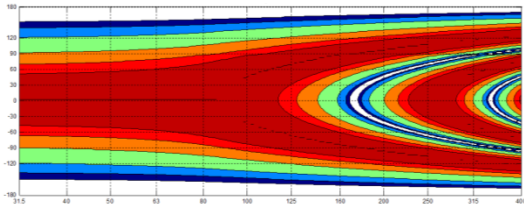


Figure 2. Theoretical Cardioid Coverage

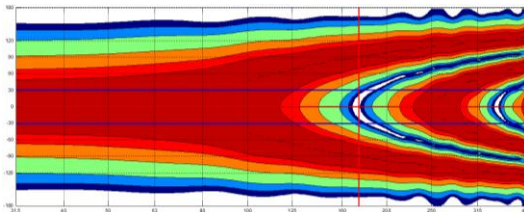


Figure 3. Result obtained with a Far Field calculation too close to the PML (linear discretization)

The notches in the response plot allow also to set the level of precision wanted and thus to minimize the degree of freedom of the study.

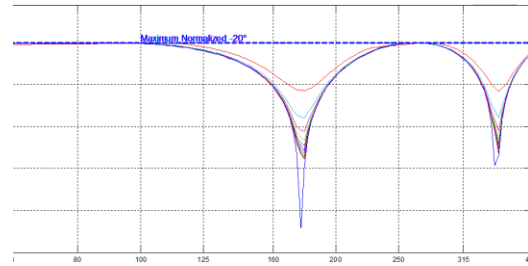


Figure 4. On Axis Far Field Response, Theoretical curve in blue

This pre-study allowed optimizing the calculation time versus the accuracy, playing with the following parameters

- Size of the mesh
- Influence of PML width
- PML distance to the DUT
- Distance Far Field / PML
- Influence of Far Field symmetry
- Linear or quadratic discretization
- Number of element per wavelength

## 3. Directivity of the V shape design.

### 3.1 Description

The aim of this study is to determine the best angle between the drivers and the influence of different devices that could be put between the drivers (the Horn for example) or in front of the drivers (Directivity Phase Device –not described in this document- [7])

The result of this study will optimize the Medium Frequencies (MF) coverage and response curve and determine the highest crossover point with the High Frequencies (HF) Horn

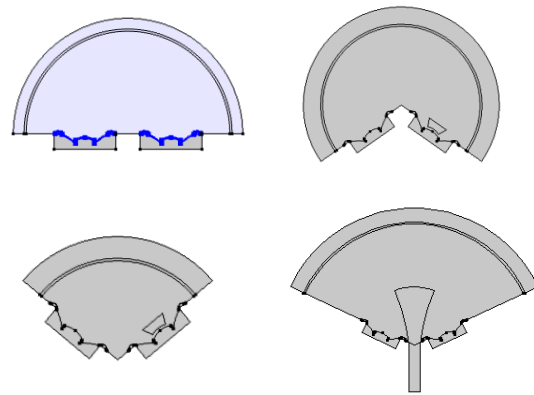


Figure 5. Several Case Studies

### 3.2 Influence of the Angle between the drivers

Different angles between the drivers have been evaluated. As an example the 90° allows a -6dB coverage of 70° up to 1720Hz; while a 120° overture allows a better frequency extension (2000Hz) but with a much narrower coverage (40°)

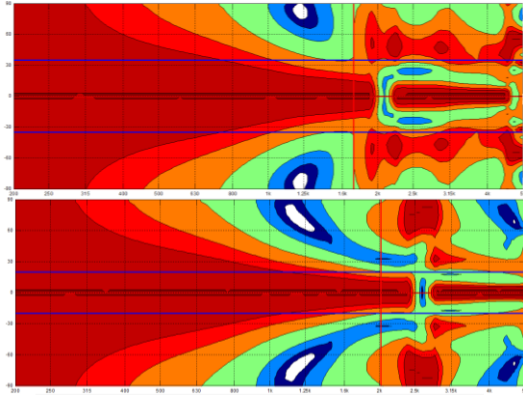


Figure 6. Opening 90° (above) vs. 120°(under)

A look on the response curve is also mandatory to take into consideration the efficiency of both solutions.

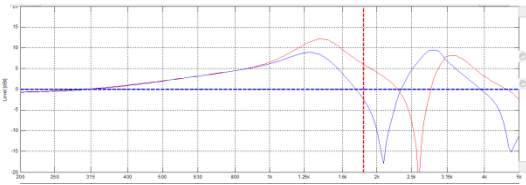


Figure 7. On Axis Response, 90° (Blue) vs 120°(Red)

On the above plot it is clear that the 120° will allow a better efficiency in the 1.25kHz-2.2kHz. This trade off between coverage and efficiency is most important as it will also affect the crossover point with the HF driver.

### 3.3 Influence of the Horn

The symmetry and compactness of the design lead to insert the HF Horn between both drivers. The influence of the outer shape is analyzed. The model is made on a quarter of the box, using the symmetry to reduce the calculation time.

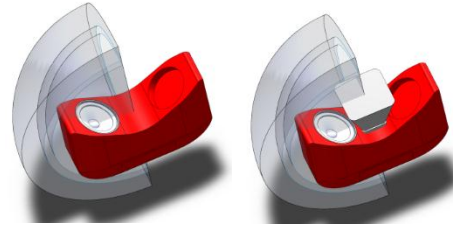


Figure 8 : With and without the horn (1/4 design)

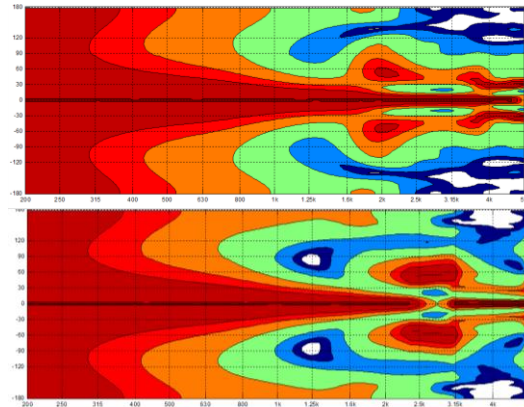


Figure 9. With (under) and without (above) the horn

### 3.4 Others

Once the model is set and linked with SolidWorks it is very easy to investigate any ideas that could otherwise have taken an enormous time and cost in term of iterative prototyping (and that would not have been done at the end).

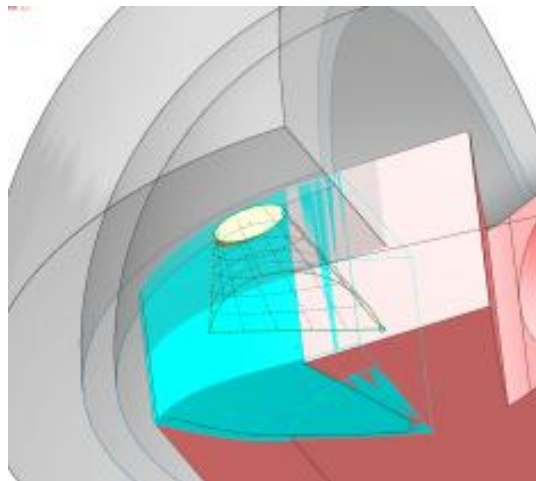


Figure 10. Cavity loading the Driver

### 3.5 Modeling versus Measurement

The measurement on the prototype shows a very match between the model and reality. The 850Hz difference is due to the vibration of the loosely mounted prototype

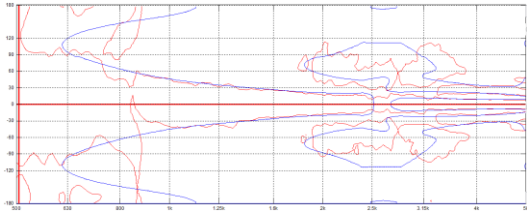


Figure 11. MF Coverage -12dB. Measured (Red) vs. Modeled (Blue)

## 4. Tuning and Shaping the vent

### 4.1 Description

Although it is very easy to tune a vent (port) for a conventional design with lumped element tools as AKABAK [7], things are more complicated when the vent is not a tube and has an arbitrary form.

Complex forms are implemented in recent designs [3] that require FEA analysis for a faster tuning

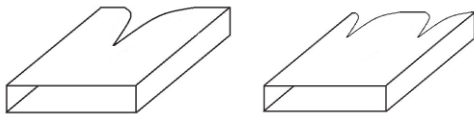


Figure 12. Example of Notched Vents (patent pending)

### 4.2 Use of COMSOL Multiphysics

Model has been made with a parametric study on the physical dimensions of the vent. The tuning frequency is obtained by the zero of cone velocity.

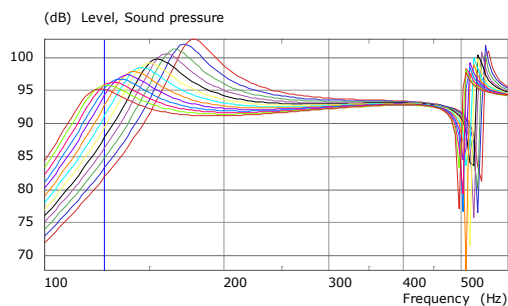
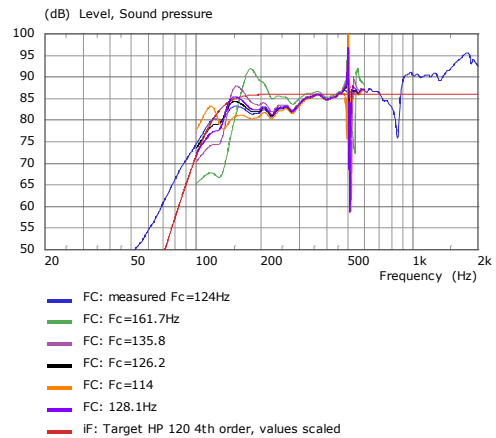


Figure 13. On Axis Far Field response for several Vents dimensions

## 4.3 Experimental results

The measurements made on the prototype allow extrapolating results for the other tuning frequencies given by the simulation.



## 5. Horn polar pattern

### 5.1 Description

2D, 2D axisymmetric and 3D models have been done and compared to a physical device.

Thanks to the LiveLink it is very easy to build a parametric spline horn in SolidWorks and run parametric sweep to identify the influence of each parameters.

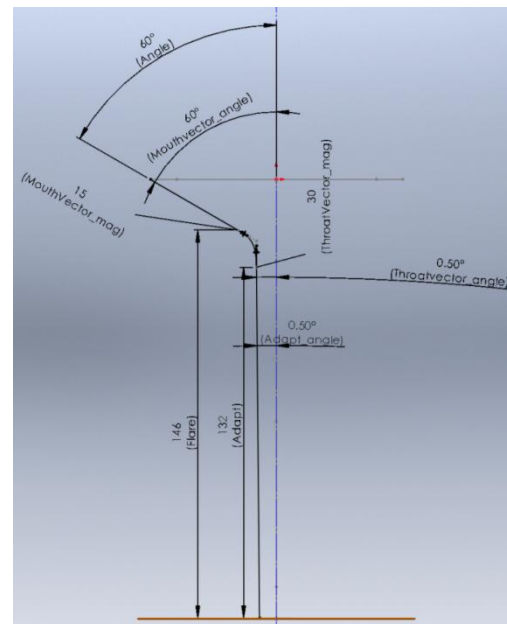


Figure 14. Horn Parameters, LiveLink SW.

It also allows to quit the exponential/conical expansions found in conventional horn designs for half a century [4,5].

### 5.2 2D versus 3D

Needless to say 2D study shall be preferred whenever possible (50 seconds versus 7 hours of computation). With the cross section function in COMSOL it is possible to mix 3D and 2D design sharing the same geometry. Rough tuning is made on the 2D model and then validated on the 3D model.

However great care should be taken as radial modes are impacting greatly the result and 2D is not accurate in some configurations.



Figure 15. 3D design of the Horn

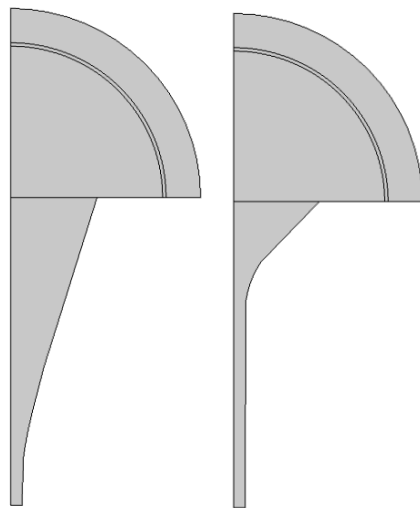


Figure 16. 2D Cross Sections

### 5.3 Modeling versus Measurement

The measured prototype gives similar coverage results than the model

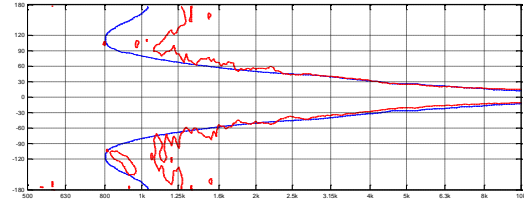


Figure 17. Coverage plot -6dB. Model (Blue) vs Measure (Red)

### 5.4 Geo Wave Guide

The model has also been run on one of our Geo Hyperboloid Reflective WaveSource™, the results matching the model up to -24dB (normalized versus maximum)

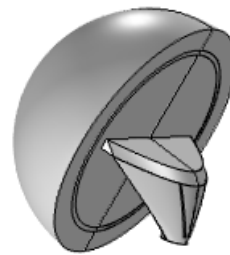


Figure 18. Geo Wave Source

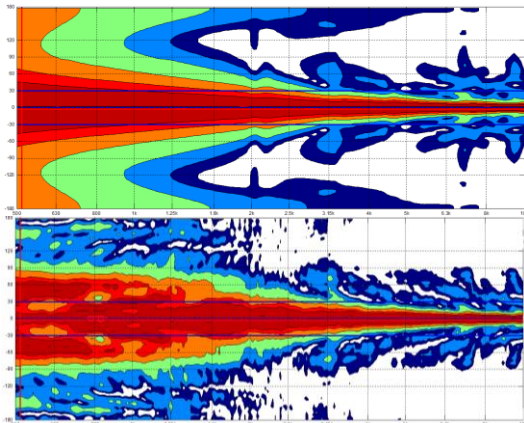


Figure 19. Modeled (above) vs Measured (under)

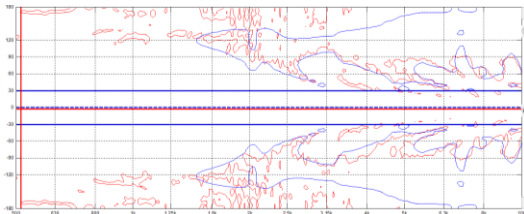


Figure 20. -24dB Cov. Plot of the above. (meas. Red)

## 5.5 Horn radiating impedance

An Integration operator is defined over the throat to implement the following normalized impedance  $z_{norm}$ . ( $\rho_0$  and  $c_0$  being the density and speed of sound)

$$z_{spec} = \frac{\int Sound\ Pressure}{\int Velocity}; z_{norm} = \frac{z_{spec}}{\rho_0 \cdot c_0}$$

Real and imaginary parts are exported and reconstructed in the graphing and processing VACS (from R&D-team) and compared to a measurement made with the CTTM impedance sensor [6]

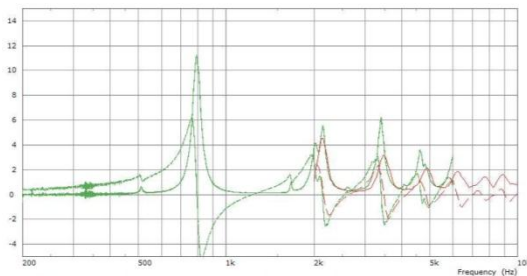


Figure 21. Radiation Impedance. Measured (Green), Modeled (Red)

## 6. Acoustic Eigen Frequencies.

### 6.1 Description

Modes inside an acoustic box may be responsible for alteration of the response curve and sometime imply non uniform forces on the driver cone creating rocking of the membrane (and finally destruction of the unit).

The theory behind Eigen Frequencies calculation implies a closed volume –which is by definition not the case of a bass reflex enclosure!-. Furthermore the Eigen Frequency analysis doesn't give indication on the amplitude of the mode and thus makes it difficult to sort them to know where the dominant modes are.

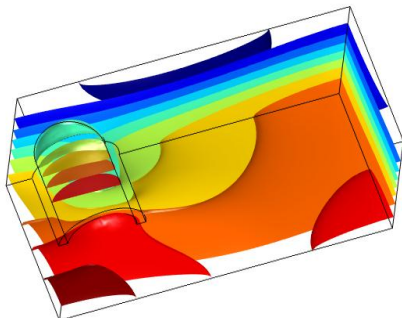


Figure 22. Simple model used to validate the template

## 6.2 Use of COMSOL Multiphysics

Tests have been conducted with several ways to terminate the vent in order to get a closed volume.

Closing the vent with a hard sound boundary is giving reasonable result (the mode inside the vent should been ruled out). In the other hand closing with a soft boundary or with an enlarged port gives less satisfying results.

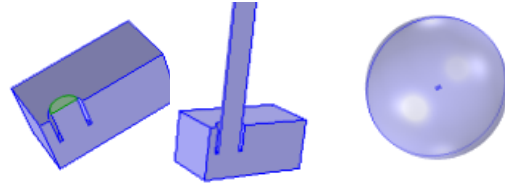


Figure 23. Different case Studies

For a more accurate result a second analysis is made for each of the frequencies found with the closed vent. This time the vent will not be closed but the cabinet itself will be enclosed in a bigger domain (4 times the size of the DUT). A manual check will be done to isolate the only node inside the box for each run (the other are related to the outer domain and have no interest). This creates a list of frequency (modes) that will be fed into an harmonic study. This second study will first help to determine if each mode is excited by the membrane and secondly it will give information on the relative amplitude of all modes and discard the lesser ones.

## 7. Structural modes of box

The structural analysis of the vented box allows determining the best location of ribs or locations where the structure must be reinforced to avoid vibration of the box.

As for the acoustic analysis the Eigen frequency algorithm is used to determine the possibility of a mode. This analysis is completed with a harmonic study to determine if the modes are excited by the membrane and their amplitude.

## 8. Conclusions

A panel of model templates have been developed and successfully confronted to reality. Thanks for the ease of use of COMSOL coupled to CAD design software as SolidWorks it is now possible to explore new design ideas very easily.

## 9. References

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## 10. Acknowledgements

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