Advanced Loudspeaker Calculator - an Example of COMSOL Apps Utilization

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Abstract: Developing a new loudspeaker design requires not only knowledge and experience in the field, but also an access to verified and efficient tools. HARMAN's Virtual Product Development (VPD) has developed a COMSOL Application to serve at the early stages of the loudspeaker design process. The COMSOL application is based on a linear and a nonlinear Lumped Parameter Model (LPM). Sound pressure, membrane displacement, electrical impedance, amplitude of harmonics pressure and membrane DC-Shift are predicted. The application was created in close collaboration with the end users. It was uploaded to an application server and is accessible globally to all HARMAN transducer engineers.

1. Introduction

Nowadays, plenty of simulation methods are used to support various aspects of a vehicle design. One of the most challenging ones is to design a superb sound system for a vehicle. The quality of the sound in the vehicle depends on the speaker designs, the speaker locations and orientation[1][2], the speaker packaging and the interaction between the loudspeaker and the car components[3]. To support the development of new loudspeakers technologies or designs, HARMAN's Virtual Product Development (VPD) has developed a COMSOL Application to serve at the early stages of the design process. This paper presents the COMSOL Application used as a quick reference tool to predict the linear and nonlinear acoustic performances of a speaker. The linear prediction allows simulating the sound pressure, the speaker displacement and the electrical impedance. The nonlinear simulation allows predicting the Total Harmonics Distortion (THD). The Application, simply called "HARMAN LPM/THD Speaker Simulator", has been created and validated in a close collaboration with the end users, i.e. transducer engineers.

Keywords: COMSOL, Application, Loudspeakers, Sound Pressure, Harmonics, Prediction

2. Theoretical Background

A linear LPM describes the interaction between a speaker and its enclosure. The use of such models allows predicting the anechoic sound pressure, the speaker displacement and the impedance. Many enclosure configurations can be included in the LPM model[4] (free air, closed, vented or including a passive radiator).

The amplitude of the harmonics cannot be predicted using equivalent linear speaker models where constant parameters of the lumped elements are used. Displacement varying parameters have been introduced in the equivalent circuit to describe time-variant and nonlinear mechanisms[5].

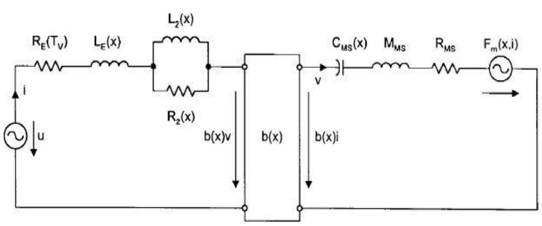

Figure 1: nonlinear equivalent circuit

The resulting model leads to a nonlinear differential equation[5] where:

- x is the speaker displacement
- b(x) is the instantaneous force factor of the motor defined by the integral of the magnetic flux density B over voice coil length l
- $C_{ms}(x)$ is the compliance of driver suspension including the air load (the inverse of stiffness)
- $L_e(x)$ is the part of voice coil inductance which is independent on frequency

$$u = R_e i + \frac{d\big(L(x)i\big)}{dt} + b(x)\frac{dx}{dt}$$
$$b(x)i = m\frac{d^2x}{dt^2} + R_m\frac{dx}{dt} + k(x)x + L_x(x)\frac{i^2}{2}$$

These differential equations can be solved using different mathematical approaches[5]. They allow predicting the fundamental and the harmonics for a speaker mounted on a closed enclosure where the SPL is measured in an anechoic room. The amplitude of the sound pressure allows computing the Total Harmonic Distortion (THD).

3. Numerical Model

Two different methods were used for the linear and nonlinear simulations. For the linear simulations, analytic functions are used. For the nonlinear simulations, the COMSOL Apps is used to create a speaker configuration file to communicate between the COMSOL Apps and a HARMAN Matlab code used to solve the nonlinear LPM model.

4. COMSOL Apps

The Comsol application allows to simulate and to compare:

- for the linear simulations, 2 speakers mounted on the same type of enclosures as free air, closed or vented. For the vented configurations, 2 additional ECS configurations (External Coupling Subwoofer) can be predicted where only the speaker or the vent is radiating in the listening area
- for the non linear simulations, 2 speakers mounted on a sealed enclosure

For both linear and nonlinear simulations, subwoofers, woofers and midranges can be predicted.

Amplitude of the harmonics levels in SPL, speaker membrane DC-Shift and nonlinear Q factors (electrical, mechanical and total) are predicted. The DC-Shift corresponds to the difference between the static and the dynamic voice coil rest positions.

4.1 Input parameters for a linear speaker simulation

The list of input parameters for a linear LPM is shown in figure 2. It includes electro magnetic (Bl, Re), mechanical (Cms, Rms) and geometrical parameters (Diam, Mms). The parameters Enclosure Vol, Vent length and Vent diameter correspond to the speaker enclosure.

Speaker 1	***Speaker1 #ID***	
Voltage	1.568	V
Re	2.46	ohm
Bl	5.871	N/A
Diam	163.9	mm
Sd	0.0804	m²
Mms	66.55	g
Cms	0.444	mm/N
Rms	1.367	kg/s
Enclosure Vol	60	l
Vent length	10	cm
Vent diameter	4.5	cm

Figure 2: input parameters for speaker and enclosure

4.2 Input parameters for a nonlinear speaker simulation

Additional inputs as the nonlinear force factor, suspension stiffness and voice coil inductance are required (see figures 3, 4 and 5). Derivative resistance and inductance (R2 and L2) for the voice coil are also required. The same voltage value is used for the linear and the nonlinear simulations.

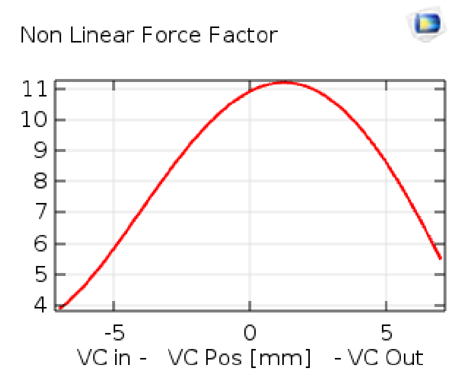

Figure 3: nonlinear force factor

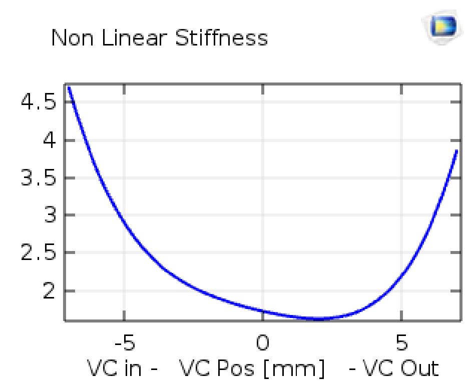

Figure 4: nonlinear suspension stiffness

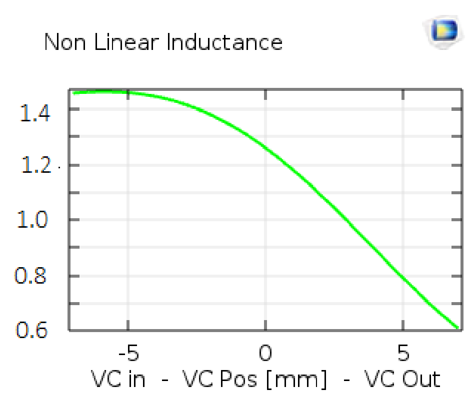

Figure 5: nonlinear voice coil inductance

These three nonlinear speaker components can be measured or simulated[6]

4.3 Solver Settings

For all simulations, the user can select the lower, upper frequency limits and the number of frequency bins defined on a logarithmic scale.

For the nonlinear simulation, the user can enable or disable the type of harmonics to be included in the simulation (force factor and/or suspension stiffness and/or voice coil inductance).

4.4 Import/Export Options

To support any speaker comparison, linear and nonlinear input speaker parameters can be exported and imported. For the linear simulations, SPL, displacements and impedance corresponding to the selected enclosure configurations are exported.

4.5 Display Settings

The user can enable, disable or highlight one of the two speakers. Every enclosure configuration can also be disabled or enabled (figure 6).

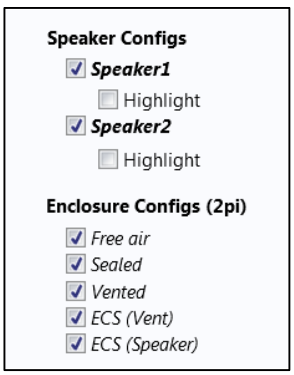

Figure 6: display settings

4.6 Calculation time

For the linear simulations, the calculation time is around 3 seconds to simulate the two speakers. For the THD simulation, the calculation time is around 35 seconds per speaker. The tests were performed on a Workstation with 64GB of RAM and an Intel® Xeon® CPU E5-2667 2.9 GHz (dual processors)

5. Measurement

For the linear simulation, no speaker measurement was done. The validation of the COMSOL application was performed by comparing the SPL, impedance and speaker displacement with simulation data delivered by a reference HARMAN prediction software.

For the nonlinear simulation, Total Harmonics Distortion was measured with a professional measurement system[7]. The loudspeakers were mounted on an infinite baffle in an anechoic room. The sound pressure was measured on axis at 1 meter.

6. Simulation Results

The simulated anechoic sound pressure, speaker displacement and impedance curves are displayed in figures 7, 8 and 9.

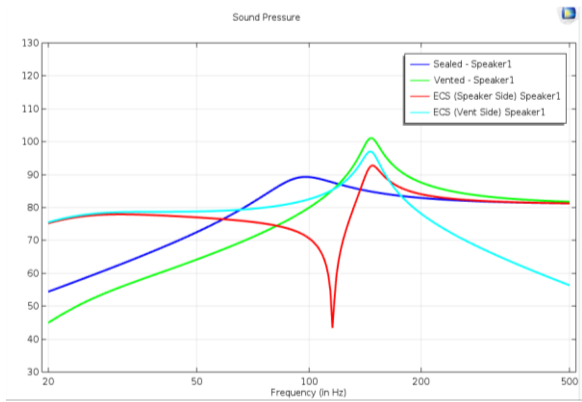

Figure 7. Simulated anechoic sound pressure

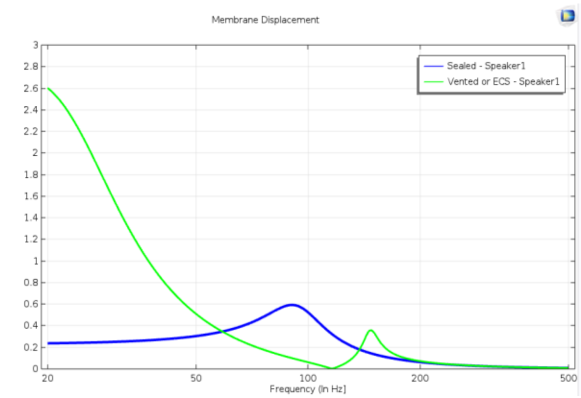

Figure 8. Simulated speaker membrane displacement

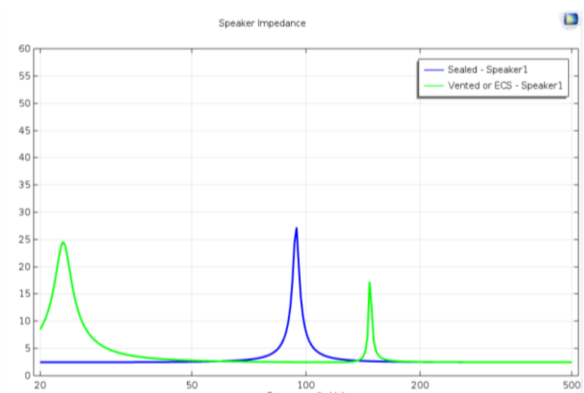

Figure 9. Simulated speaker impedance

The comparison of simulated and measured THD is shown in figure 10.

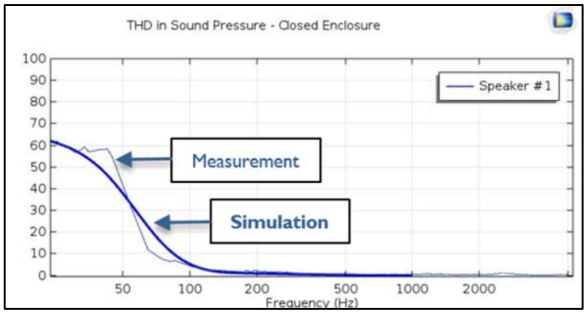

Figure 10. Simulated and measured THD

7. Automatic Simulation Report

The user can generate a fully automatic report saved as a .html or a Word document. The interest of this report is to instantaneously build a standardized report, which can be used in any customer meetings or shared between worldwide HARMAN R&D Centers. In the report, all linear and nonlinear speaker parameters are listed. Simulation results as the sound pressure, the speaker displacement, the impedance, the THD and the membrane DC-shift are included. For the THD, the types of harmonics included in the simulation are specified.

8. Conclusion

The LPM/THD App is a fully powerful and validated tool to serve at the early stages of the design process of a loudspeaker for OEM, Consumer or Professional purposes. Uploaded on a COMSOL server, the simulation software is accessible globally to all transducer engineers. It allows to use a unique tool in different R&D centers and to update at the same time and for all users the simulation software. It also allows standardizing the simulation report which is used for communication with customers if necessary, more advanced speaker simulations can be performed in COMSOL Multiphysics (influence of the speaker membrane modes or of the resonance of the air in the enclosure). In general, Engineering Apps play an important role for the so-called “Democratization” of numerical simulations across an organization.

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