

# Possibilities in finite element simulating of the electroacoustic sound absorber

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**Abstract.** You should leave 8 mm of space above the abstract and 10 mm after the abstract. The heading Abstract should be typed in bold 9-point Arial. The body of the abstract should be typed in normal 9-point Times in a single paragraph, immediately following the heading. The text should be set to 1 line spacing. The abstract should be centred across the page, indented 17 mm from the left and right page margins and justified. It should not normally exceed 200 words.

## 1 Introduction

This work continues a series of research by the authors and is devoted to studying the electroacoustic sound absorbers [1, 2]. Such an absorber is generally active, since along with active systems based on the destructive interference principle it requires additional electric energy for its operation, which makes it possible to flexibly adjust acoustic characteristics of this absorber bringing it closer to the optimal.

The idea of constructing an active sound absorber apparently appeared in the middle of the last century and subsequently was further developed in our time. It should be noted that a conventional speaker is used as an absorber in such systems, which input receives a signal through the correction circuit from a microphone registering sound pressure at the radiating surface. Such inclusion leads to alteration in the speaker acoustic impedance in general. In this case, characteristics of the shunt circuit should be selected in such a way that the speaker acoustic impedance in the frequency range under consideration should reach the air wave resistance, which ideally provides ideal absorption of the incident sound.

In addition to the works mentioned above containing both the results of theoretical analysis and the results of experimental studies, a number of studies [3–7] should be noted, which are based on finite element simulation of active sound absorbers. This was made possible due to introducing modern software that allows integrating process simulation of various physical nature. Authors of paper [3] describe the key concepts of a shunted speaker and demonstrate an example of simulating such a system. Paper [4] studies simulation of sound attenuation characteristics in a channel using a shunted speaker. It was established that the shunted speaker position should be carefully selected, since it affects those positions, where the distance between the solid end and the “soft boundary” is the odd multiple numbers with the wavelength of  $1/4$ . Paper [5] notes the industrial potential of introducing a shunting speaker and the differences from simulation results. Paper [6] identifies features of simulating

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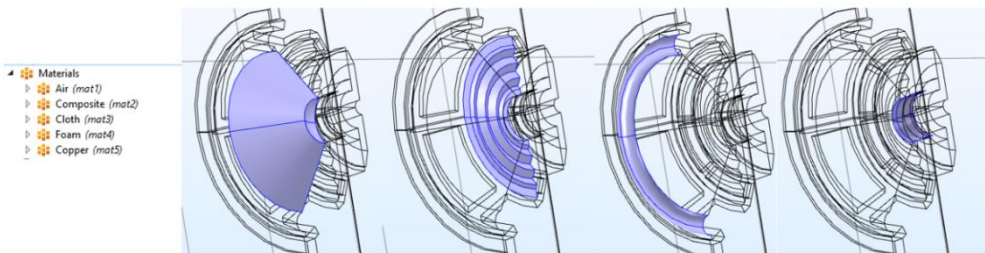
shunted speakers as noise absorbers in premises. Paper [7] provides fundamental research in studying active sound absorbers and identifies key features of their finite element simulation. It should be noted that most of the articles mentioned were referred to studies conducted on the basis of finite element simulation in the COMSOL Multiphysics medium. Finite element simulation methods are opening wide possibilities and are increasingly used in various types of engineering calculations [8-15].

The aim of this work is to analyze possibilities of a speaker finite element simulation being a sound emitter in the COMSOL medium and to identify characteristic features of using this medium in studying active sound absorbers.

## 2 Speaker simulation in the COMSOL medium

Model design and simulation are carried out in modern software packages, such as COMSOL Multiphysics. COMSOL is a cross-platform finite element analysis and simulation software. Workflow is being introduced for electrical, mechanical, fluid, acoustic and chemical applications. Application designer could be used to develop independent user applications. To get acquainted with designing a speaker, it is advisable to use the COMSOL model library. The library contains ready-made templates for various objects that could be downloaded and examined, or reused in the proprietary models.

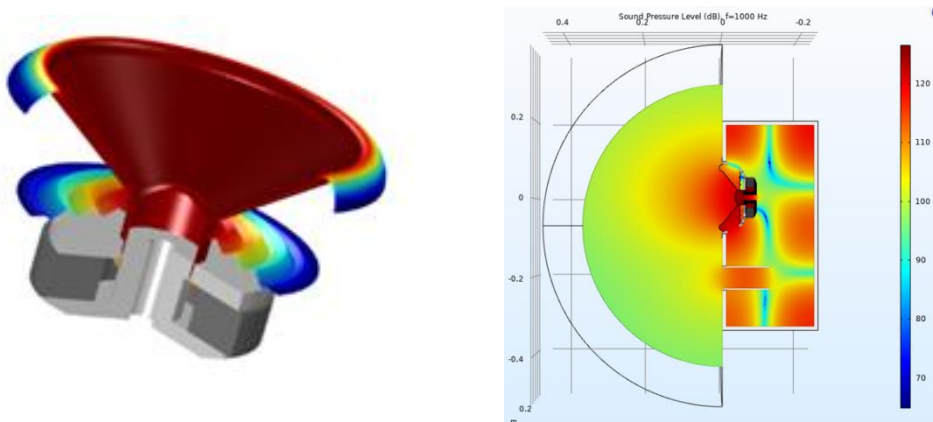
Figure 1 shows the speaker dynamics and its moving elements in the COMSOL medium. When selecting a particular speaker element in the program interface on the left, it would be highlighted on the speaker drawing in the window on the right.



**Fig. 1.** Work with the speaker moving elements in COMSOL medium.

Speaker characteristics calculation and analysis is carried out in the frequency domain. Calculation includes construction of both the speaker general electrical impedance and the sound pressure level in the axial direction at nominal supply voltage as the frequency function. Magnetic Fields and Acoustic-Structure Interaction Multiphysics interfaces are used in constructing the speaker model.

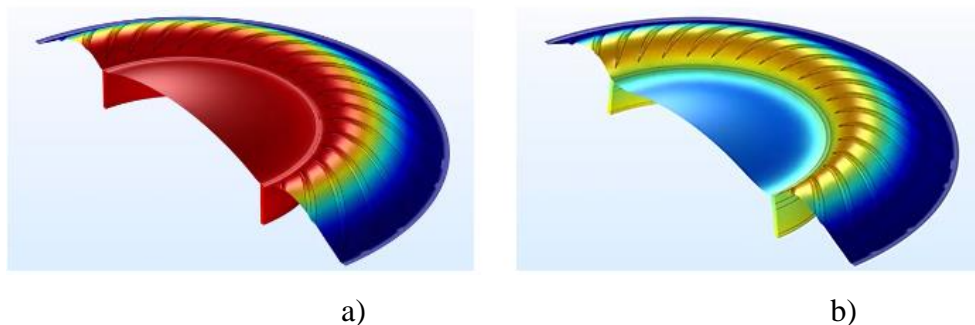
This approach is illustrated in Figure 2, on the left side is the picture of the speaker moving elements oscillation amplitudes distribution. Then, based on these data, the program determines the sound pressure levels created by the speaker oscillating membrane. As an example, Fig. 2b provides results of calculating the sound pressure levels that would be created by a speaker installed in the box at a frequency of 1,000 Hz.



**Fig. 2.** Results of speaker simulation in the COMSOL medium in the form of the patterns of the speaker moving elements oscillation amplitudes (a) and of the sound pressure levels in the speaker vicinity (b).

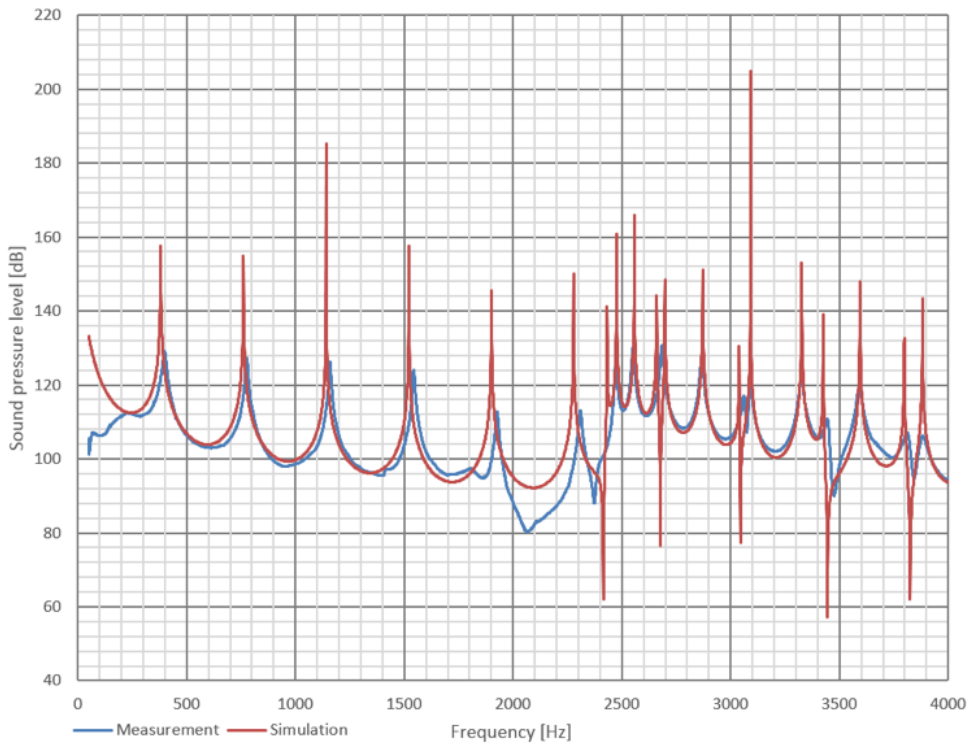
Authors in the COMSOL blog [16-19] are considering not only the theory, but also share practical results of speaker simulation noting that modelling even their simplest configurations requires knowledge and experience, understanding how acoustic waves are propagating in space, which is extremely important in the active noise suppression systems. Works [17, 18] describe modern simulation challenges for acoustic engineers; consumers would always expect the best sound quality, even as their devices are becoming smaller and more compact. Superior sound quality is achieved through carefully planned and well-thought-out micro speakers. Small size of micro speakers makes it difficult to design them. Thin membrane could even break at too high sound pressure leading to damage. In addition to taking into account a fragile membrane, acoustic engineers also need to create a structure that eliminates the voice coil and membrane burnout caused by excessive current. Using simulation software, engineers are able to test and improve their micro speaker designs by several times reducing design time and saving expenses. At the same time, simulation provides much more information on the micro speakers' operational characteristics, which could not be obtained using physical tests.

Figure 3 presents data obtained as a result of vibro-acoustic analysis showing a picture of the membrane motion alteration with the increasing frequency. At low frequencies, most of the membrane central part operates as a rigid piston expelling air as it moves back and forth. As the frequency increases, higher-order modes could be excited, which makes the diaphragm less efficient and thus degrades the sound emitted by a micro speaker.



**Figure 3.** Pictures of the speaker membrane oscillation amplitude distribution at the frequency of 1,000 Hz (a) and at the frequency of 11,200 Hz (b).

Paper [16] provides results of noise measurements in a test experimental installation and their comparison with the results of such noise calculation in the COMSOL Multiphysics medium. A pipe with an adjustable length was used as the test installation. A speaker was installed at one end of the pipe, which generated sinusoidal signals with the frequency of 50 Hz to 5,000 Hz. The resulting sound pressure level was measured by a microphone at the other end of the pipe. A corresponding model was created in COMSOL Multiphysics using the Pressure Acoustics (Scalar Acoustics) physical interface. The pipe walls were specified by the Sound Hard Boundary terminal conditions. The speaker in simulation was set in various ways: as a monopole point source or as a distributed emitter using the normal acceleration node, for which a diffuser of various shapes (flat, spherical or cone shaped) was specified. As expected, the best results were achieved with the cone shaped diffuser.

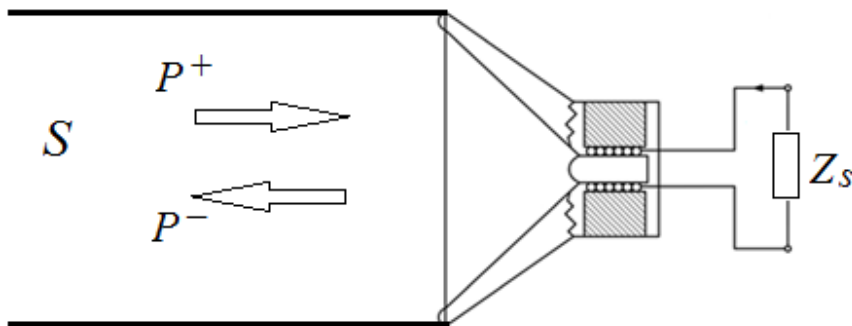


**Fig. 4.** Caption of the Figure 1. Below the figure.

Figure 4 illustrates data obtained for the pipe length of 450 mm. As the provided graphs demonstrate, simulation results agree quite well with the measured data. Mismatching in certain peaks could be associated with the fact that installation was slightly different in length compared to the model, or the walls elasticity was not taken into account, which could produce an insignificant effect on the effective speed of sound in the system. When comparing, some additional losses present in the real system are also noticeable, which is evidenced by the large width of the resonance peaks in the experimental dependence. These effects could be included in a more detailed model. But in general, it could be noted that speaker radiation simulation in the COMSOL Multiphysics medium provides perfect results and ensures great potential.

### 3 Characteristic features of the active sound absorber simulation

Implementation of an active sound absorption system is based on using a speaker with shunting element. Diagram of such a speaker installed in the channel end section with the  $S$  cross-section area is shown in Figure 5. Speaker windings are connected through a shunt with the  $Z_s$  impedance. A sound wave with the  $P^+$  amplitude incidents on the speaker and is partially reflected. The  $P^-$  reflected wave amplitude would determine the  $R = P^-/P^+$  reflection coefficient. In turn, reflection coefficient would determine the  $\alpha$  sound absorption coefficient by the speaker,  $\alpha = 1 - |R|^2$



**Fig. 5.** Shunted speaker in the duct end section.

In case under consideration, reflection coefficient is determined by the following formula:

$$R = \frac{Z - \rho c S}{Z + \rho c S}, \tag{1}$$

where:  $\rho c$  is the air wave resistance;  $\rho$  is the air density;  $c$  is the air sound speed;  $Z$  is the speaker total impedance.

It follows from (1) that when the  $Z$  speaker total impedance tended to the  $\rho c S$  value, reflection coefficient value was tending to zero, and the absorption coefficient was tending to unity, i.e. complete sound absorption was taking place. It follows that it is necessary to find the  $Z_s$  shunt impedance such that the speaker impedance should be  $Z = \rho c S$ . This makes it possible to find the following expression for the shunt impedance providing total sound absorption by the speaker [2]:

$$Z_s = \frac{(Bl)^2}{\rho c S - i\omega m + \gamma + k/i\omega} - (R_e + i\omega L_e), \tag{2}$$

where:  $B$  is the magnetic induction;  $l$  is the conductor length (wires in the speaker coil);  $R_e$ ,  $L_e$  are, respectively, the speaker coil resistance and inductance;  $m$  is the mass of the speaker moving elements;  $k$  is the speaker membrane stiffness;  $\gamma$  is the damping coefficient;  $\omega$  is the circular frequency.

It should be noted that practical implementation of the required shunt impedance determined by formula (2) and providing total sound absorption is an extremely difficult task that could be solved only in a limited way.

Work by Lissek [3] could be called a starting point in simulating an electroacoustic absorber. Authors show the basic concept for electroacoustic absorbers and also carry out simulations using the COMSOL Multiphysics® acoustic module. This work presents a finite

element model of an electroacoustic absorber, which demonstrates similarity with the impedance pipe real measurements.

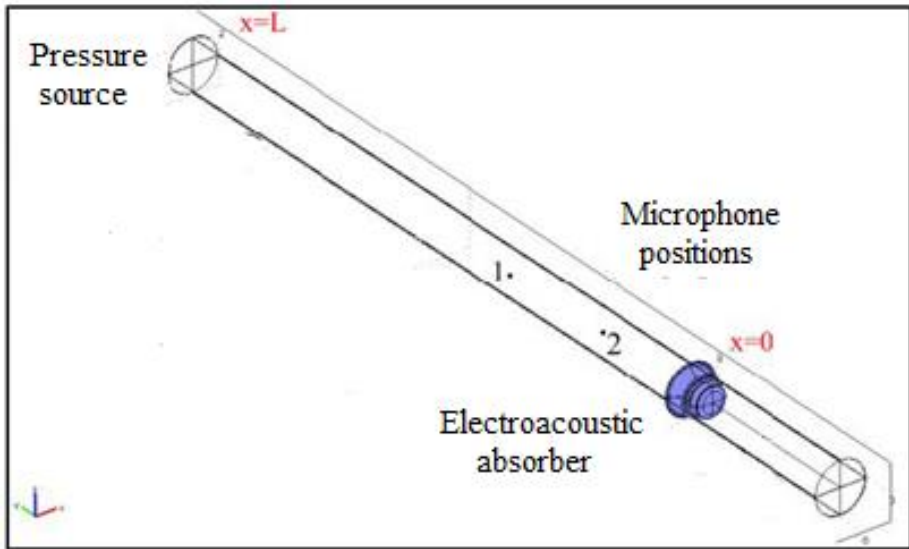


Fig. 6. Speaker simulation diagram.

The method of two microphones was used to calculate the sound absorption coefficient. Reflection coefficient was calculated as the ratio between the complex amplitudes of incidents and the reflected acoustic waves, based on the assumption that any attenuation inside the pipe was missing.

Figure 7 illustrates calculated and measured values of the speaker absorption coefficients with shorted and open windings.

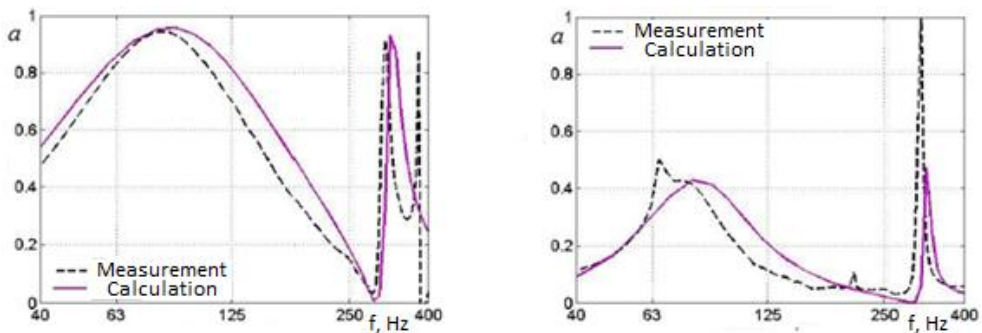
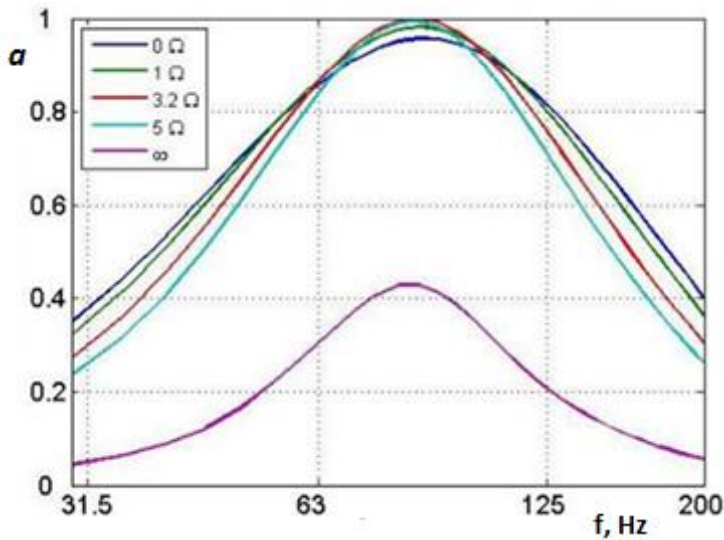


Fig. 7. Measured and calculated absorption coefficient dependences on frequency for a speaker with short-circuited (a) and open (b) windings.

Graphs presented demonstrate that calculated and measured curves are rather perfectly coinciding. This allows us to substantiate a model for studying and evaluating the electroacoustic absorber characteristics.

Fig. 8 shows graphs of the absorption coefficient calculated values for various values of the shunt resistance demonstrating that speaker shunting makes it possible to vary the quality factor and to ensure complete absorption at resonance.



**Fig. 8.** Calculated dependences between the absorption coefficient and the shunt resistance.

Authors in [5] investigate industrial application of electroacoustic absorbers. Based on simulation results in the COMSOL Multiphysics medium, it was concluded that electroacoustic absorbers would make it possible to significantly reduce noise inside an air duct, thus potentially reducing noise also outside the building even at low frequencies. However, significant noise reduction was achieved by them only in a rather narrow frequency band.

## 4 Conclusion

Review conducted on possibilities to use the finite element simulation for an electroacoustic absorber based on a shunted speaker in the COMSOL Multiphysics medium made it possible to conclude that this approach possesses great prospects. Simulation using the COMSOL resources allows calculating and analyzing such a complex device as the speaker, which operation integrates processes of various physical nature, and at the same time obtaining results that stay in good agreement with the measurement results.

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