# Acoustic FEA modeling of mobile computing devices frequency response

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## Introduction

The innovation in audio quality enables organizations to increase efficiency and business value by offering crystal-clear voice calls. Strong growth in use of voice over internet, need for cost reduction and shorter time to market promote demands for an accurate acoustic simulation tool.

The quality of human voice depends on digital encoding and decoding processes. Driven by competitive efforts the range from full band audio to near ultrasonic frequencies is becoming available for innovative use applications such as voice quality improvement, gesture recognition, surveillance, remote positioning systems, *etc*.

Loudspeakers and receivers are embedded inside the phone having front and back volumes. Bearing similarity to the function of nasal cavity and vocal tract in early talking machines [1], back volume predominantly helps the diaphragm movement, while front volume alters the frequency response and propagates pressure waves to a listener. Like human vocal tract the front volume adds articulation and coloration to emanating sounds, finding historical correlation with bel canto principle allegedly uncovered by Leonardo Da Vinci in the studies of how voice resounded in a head. Respectively, the geometry of the front volume has a strong influence on how the device sounds. Small changes to the front cavity, that originate from geometrical rearrangement of densely packed surrounding components, alter the sound quality and loudness of the final product. These changes can be detected and quantified by finite element simulation. Whether it is speech, music, discrete frequency alerts or ultrasonic intelligence signaling the front cavity adds its own spectral coloration. to the output sound. Front volumes with multiple resonances can be created and optimized to boost the sensitivity at ultrasonic frequencies.

In telecommunication the sound quality is assessed inside anechoic chambers using integrated test systems that meet officially recognized specifications [2]. Such systems conduct numerous tests with automated signal conditioning, data acquisition and sound quality analysis. The magnitude of the frequency response is one of the most informative tests about device integral performance [3]. Implementation of the frequency response measurement over full audio and ultrasonic range is technically challenging. Typical loudspeakers work well in audio range and fall short of producing sufficient air volume movement at high frequency. While piezoelectric tweeters are predominantly used to provide high frequency stimuli they are easily damaged at low frequencies.

The purpose of this work is to present the computer simulation that provides the frequency response computations as a guide to design and development before an actual physical device is produced.

## Theory

The front volume and the front acoustic porting control the high frequency region of the frequency response. Smaller front volumes and shorter, larger acoustic ports are required for broadband audio. Smaller front volumes also makes it much easier to seal the front of the loudspeaker which is often a concern. Shorter and larger acoustic ports mean trying to use holes directly through the front housing without other parts in the way. It is also preferred that the front volume and acoustic ports be symmetrically located over the front of the loudspeaker so that the acoustic load presented by the air does not cause the loudspeaker diaphragm to wobble when it moves, creating harmonic distortion perceivable by humans.

A known idealization for the case of small pressure or volume velocity variation compared to wavelength, a lumped-element model has long been used to estimate the frequency characteristics of loudspeakers [4, 5]. Corresponding acoustical, mechanical and electrical networks of a Helmholtz resonator are shown in Figure 1.

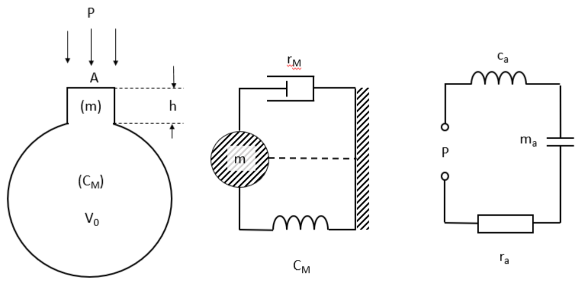


**Figure 1**. The schematic representation of the acoustical (left), mechanical (middle) and electrical (right) networks of Helmholtz resonator; reproduced after [6].

The resonance frequency of a Helmholtz volume is given by

$$f_H = \sqrt{\frac{A}{V_0 h}} \qquad (1)$$

where A is surface area of the ports, $V_0$ is internal volume and h is the length of the porting neck.

With accurate Thiele parameters [7] a lumped element model is capable of accurately predicting low to mid frequency response of relatively simple volumes. It is limited to account only for the porting volume dimensions but not its shape or its relative position to the moving speaker diaphragm. If a substantial portion of the porting is not aligned with the front volumes it will likely to be less effective than presumed. Only a finite element simulation confirmed with a measurement can determine the frequency response over a wide range of frequencies.
In cases where accurate comparison between simulation and measurement is necessary, loudspeaker measurementa are used as an input to the simulation model. Applying Huygens-Fresnel principle to a flat circular piston approximation the far field axial acoustic pressure $p$ can be converted into loudspeaker diaphragm velocity $v$ or displacement $x$ using equations:

$$v = \frac{p}{2\rho c * \sin\left(\frac{\pi f\left(\sqrt{z^2 - a^2} - z\right)}{c}\right)} \qquad (2)$$

$$x = \frac{v}{2\pi f} \qquad (3)$$

where a is effective radius of a loudspeaker and z is an axial distance.

## Method

We limit the scope to the acoustic finite element modeling of the speaker front porting enclosures. The main objective of this work is to develop a reliable process that provides a computer model to calculate the frequency response using Computer aided design package [8] models. The secondary objective is to promote the multidisciplinary interaction between mechanical and acoustic teams in large corporate environment and contribute to the enhancement of knowledge sharing culture between engineers.

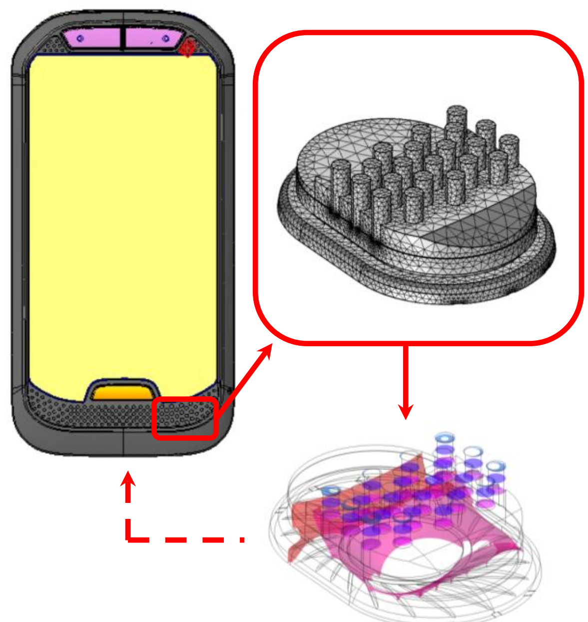

**Figure 2**. Flow chart of FEA acoustic modeling with feedback loop (dashed arrow) from simulation results into mechanical CAD design.

The typical process flow is shown in Figure 2. First, the air volume of a loudspeaker front porting enclosure is extracted as a single solid part by mechanical team and delivered to the acoustic team. In this step both teams become aware of the design limitation and interdisciplinary requirements. Second, the acoustic team imports the model into COMSOL Multiphysics software, configures boundary conditions, mesh, solver and computes the frequency response. The isosurfaces of acoustic pressure are shown in the Figure 2. Subsequently, information about resonances is communicated back to the mechanical team and recommended design adjustments are assessed and implemented.

## Experimental and simulation results

Optimization of the front cavity acoustic performance using finite element simulation is enabled by the Pressure Acoustic module with boundary conditions of the porting volume set to fully reflective and neglecting structural interaction or air absorption. The latter was evaluated to have insignificant effect on the end results and the former constitute a work in progress. For the complex shape front volume the modeling predicted resonances that matched experimental measurements better compared with Helmholtz and lumped element approximation.

As an example, FEA modeling of a dual ported front porting enclosure shown by the dashed red curve in Figure 3 reveals two resonances in agreement with experimental (solid red curve) observations.

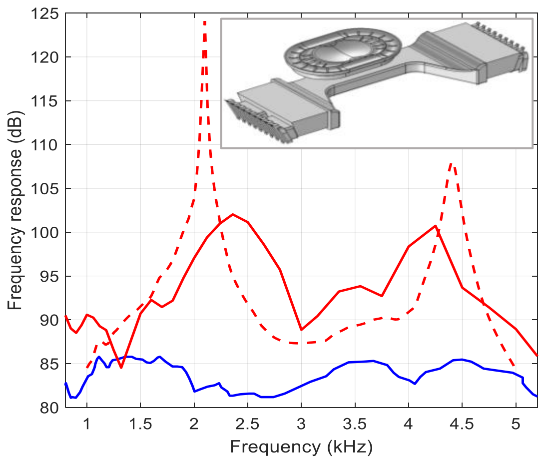


**Figure 3**. Frequency response of dual ported front cavity: dashed curve – simulation, red solid curve – measurement, blue solid curve – speaker in a baffle frequency response measurement.

The simulated response in Figure 3 was computed using equations (2) and (3) with free field loudspeaker measurements.

## Conclusions

In this paper we have presented the computation of frequency response using computer aided design model. After a short overview of telecommunication trends we presented the process and finite element computation technique for the front porting volume frequency response. Computed for several devices it provided good confidence in reliability and accuracy of simulation results, also in good agreement with the measurements. The advantages of the simulation in comparison with traditional bake and test method are the reduced development time and cost, flexibility in design options and the choice of loudspeakers, and increased frequency range. The disadvantage is having the need for several design iterations.

Conducted in the early stage of development FEA modeling offers a reliable custom design tool to improve audio performance, minimize sound attenuations, and maximize loudness.

Further work will focus on interaction between solid frame components and air acoustics.

## References


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