Ole Wolff

Virtual prototyping

2023

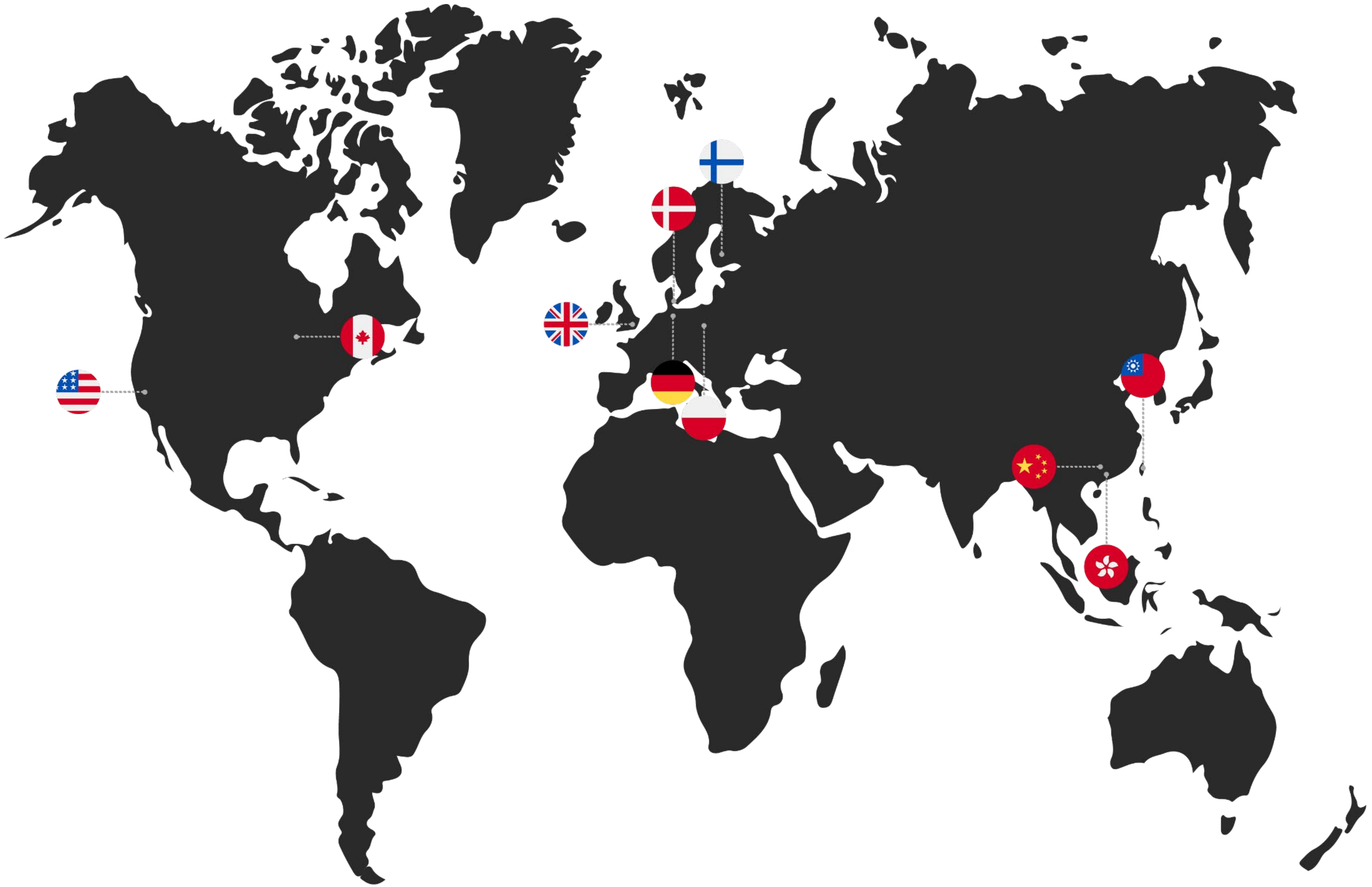
- Company introduction
- Product development cycle
- Modelling micro speakers
- Speaker system design
- Head- and earphones
- Buzzers and alarms

OLE WOLFF

owolff.com

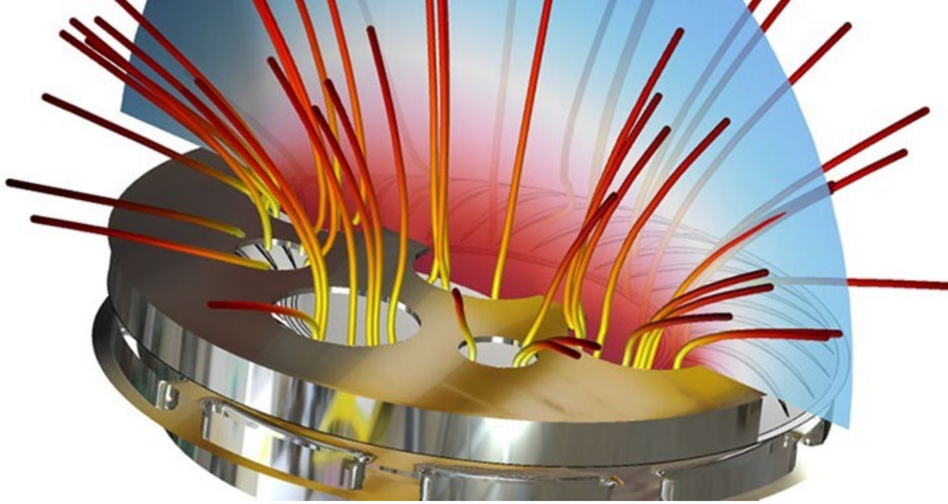
Ole Wolff Electronics

- Established in 1983
- Acoustics & Magnetics
- Sales offices in Europe, USA and Asia
- Development in DK and China
- Production facilities in China
- Headquarter in Sorø, Denmark



Simulations and performance verification

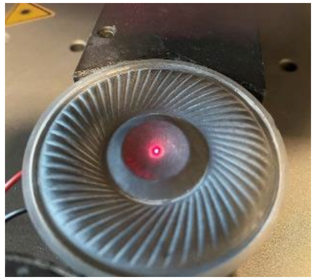
» Using state-of-the art tools

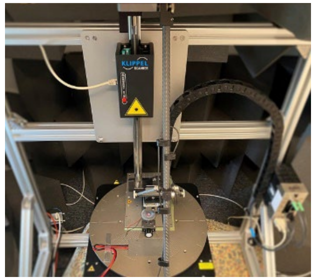


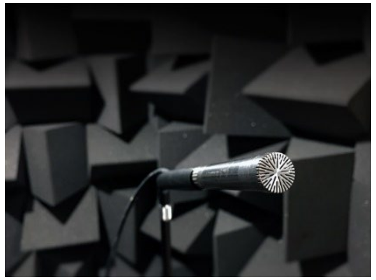
- COMSOL Multiphysics™ for simulations
- Klippel™ analyzers and scanners with near-field add-on
- Listen SoundCheck™
- Anechoic chambers
- B&K and Gras microphones, artificial ears, HATS etc.

KLIPPEL GRAS

Brüel & Kjær Listen

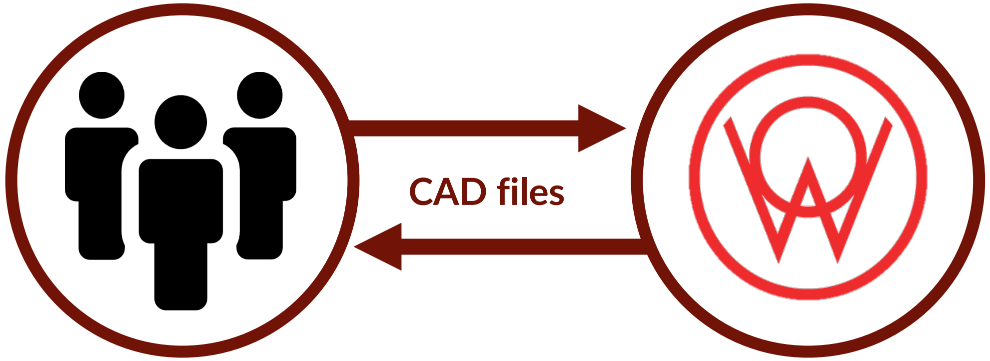


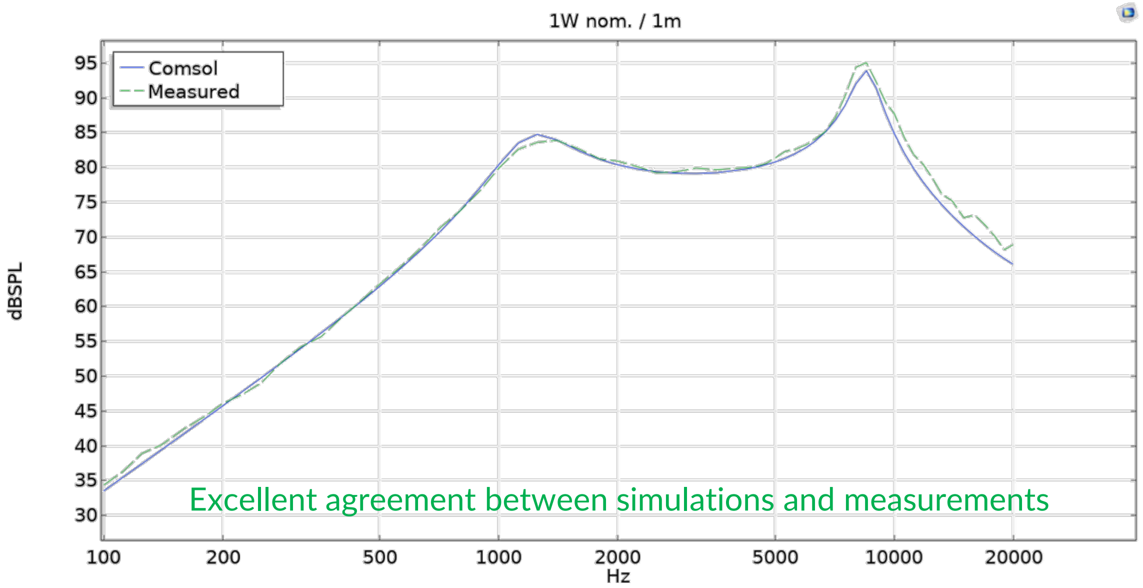




Virtual prototypes

- Speed up the development processes through advanced 3D simulations and virtual prototypes

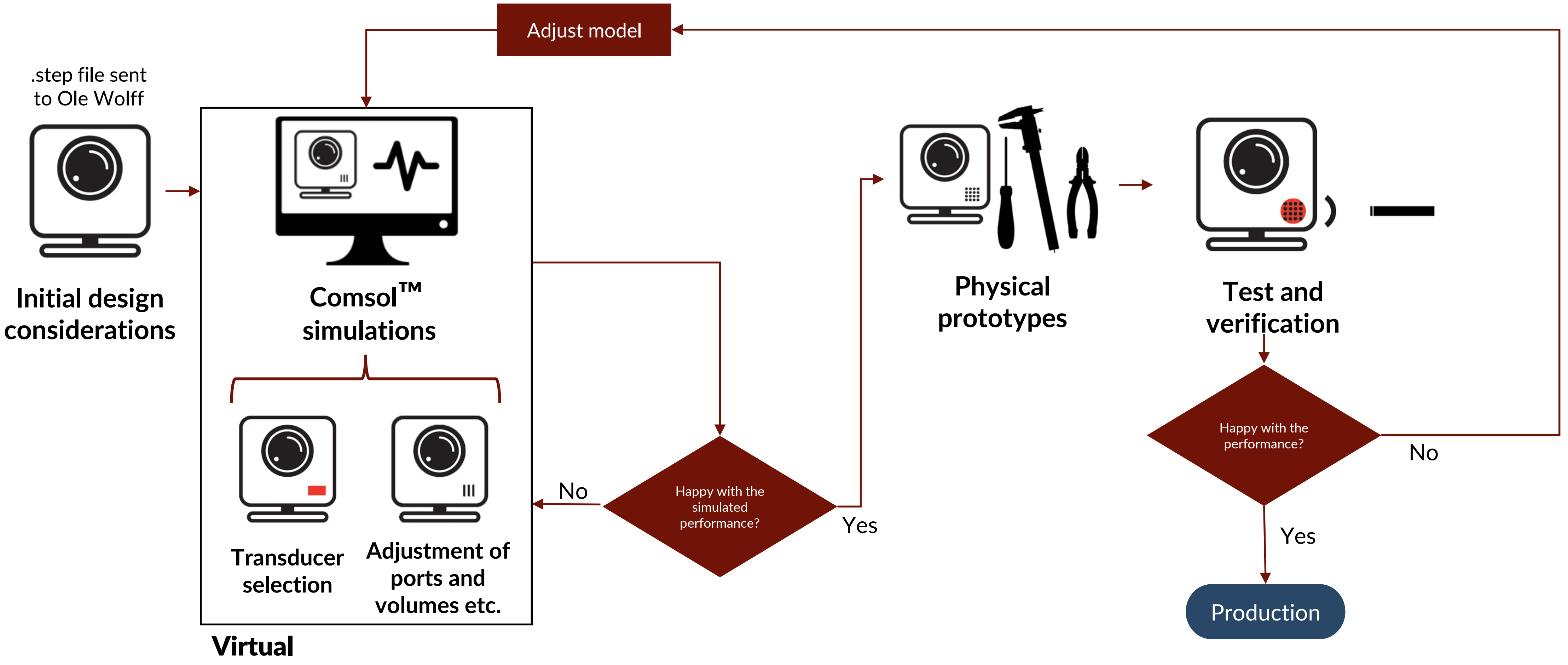




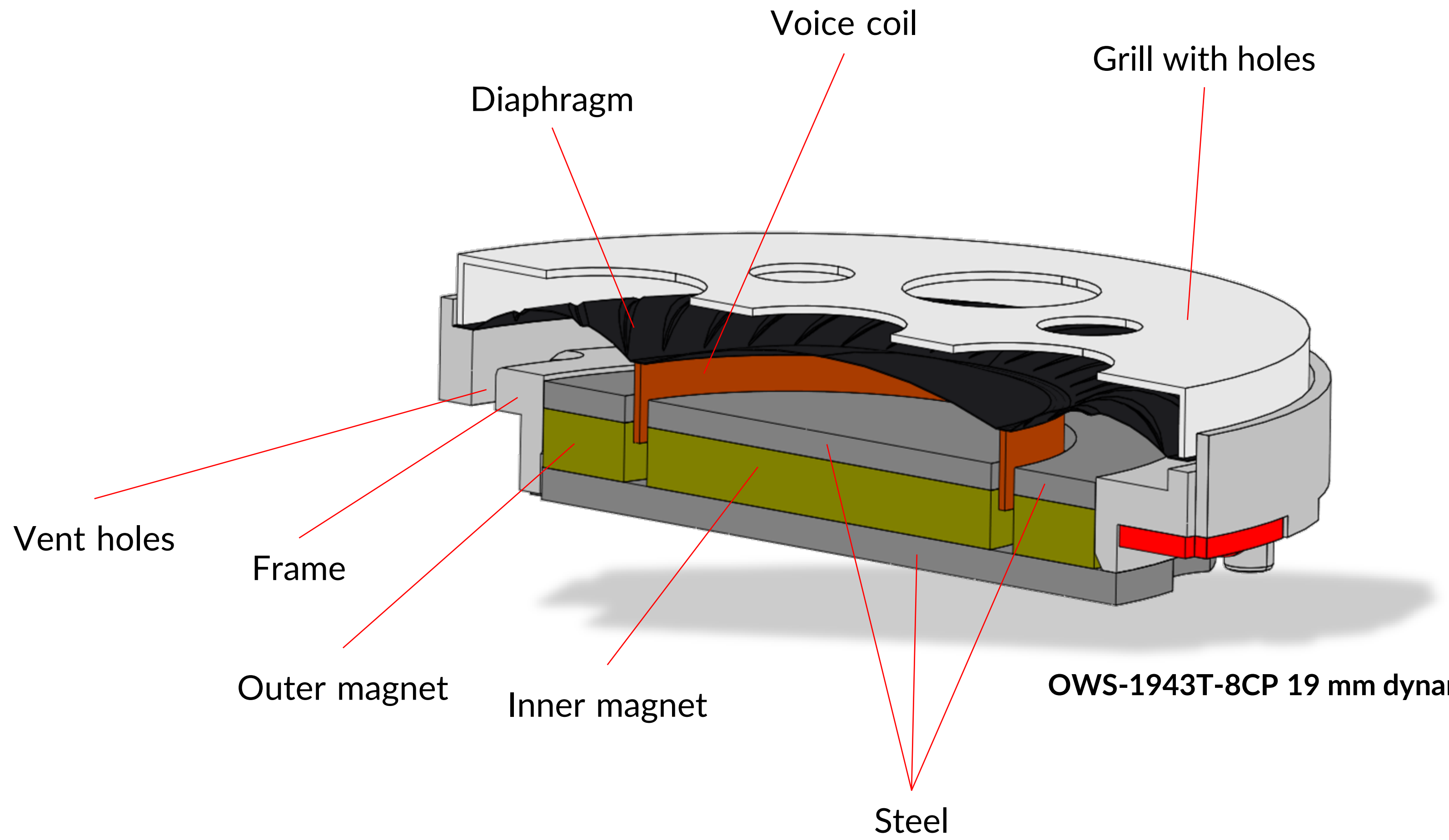
- CAD files are exchanged between OW and the customer
- Effect of design adjustments can be simulated before doing any physical prototypes

For best and fastest results: Get Ole Wolff on board early in the design process.

Ole Wolff simulation product development cycle



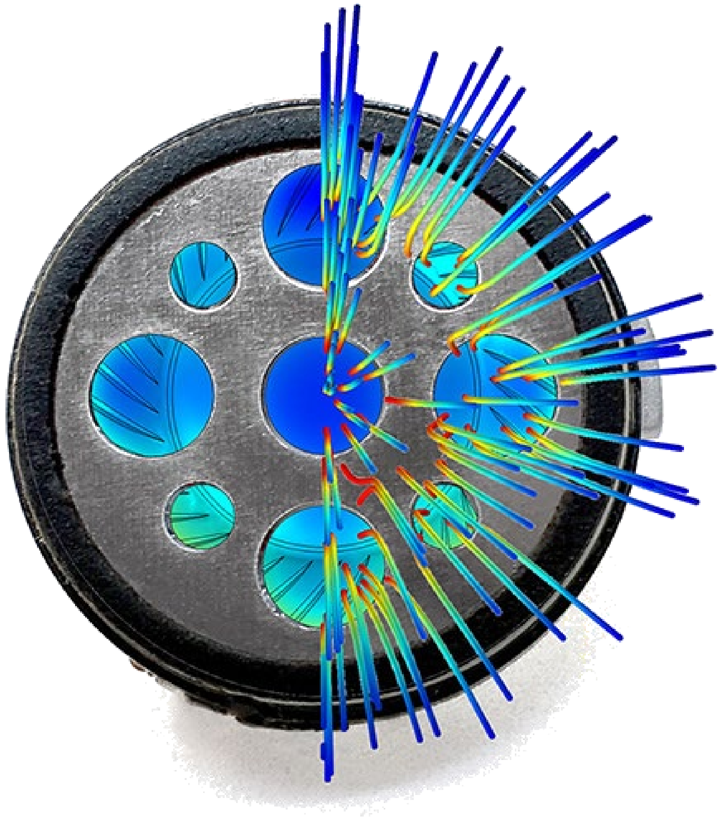
Modelling micro speakers



OWS-1943T-8CP 19 mm dynamic driver

Modelling micro speakers

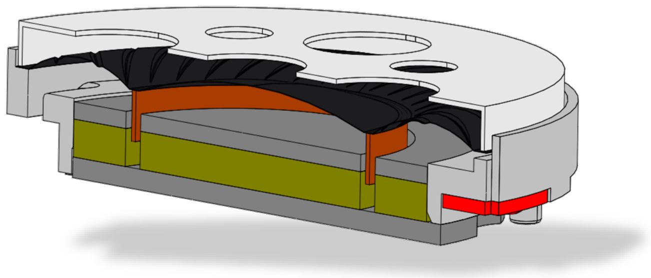
- **Magnetic analysis**
  - Derive BL(x)
  - Coil properties
- **Mechanical analysis**
  - Derive Cms(x)
  - View stresses on diaphragm
- **Acoustic analysis**



The Ole Wolff OWS-1943T-8CP (discontinued) driver
is included in the Comsol library

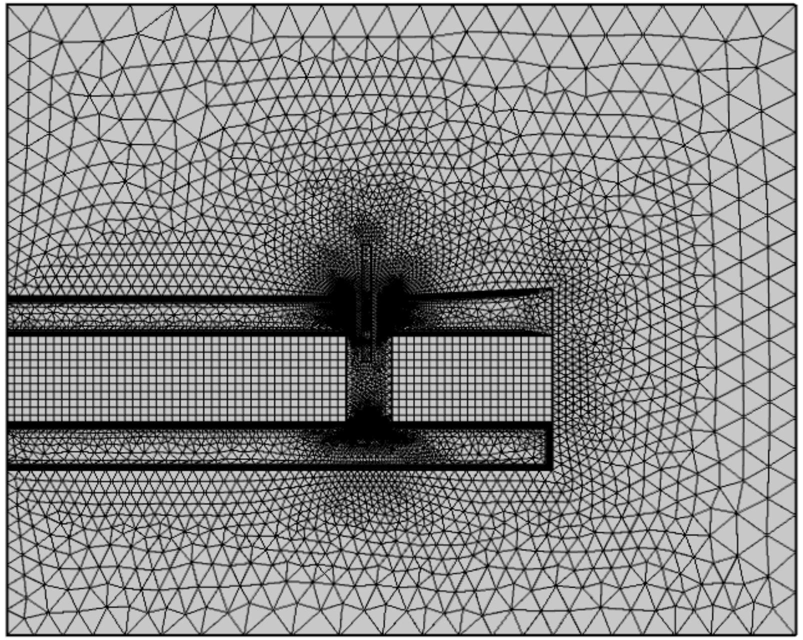
OWS-1943T-8CP

» Magnetic analysis (1/4)



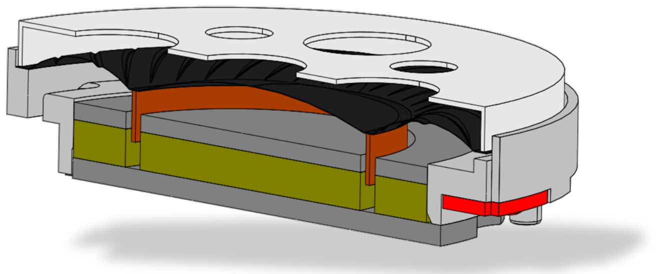
Axisymmetric simulation includes:

- Losses in steel
- Thin low permeability gaps between iron and magnets due to glue



OWS-1943T-8CP

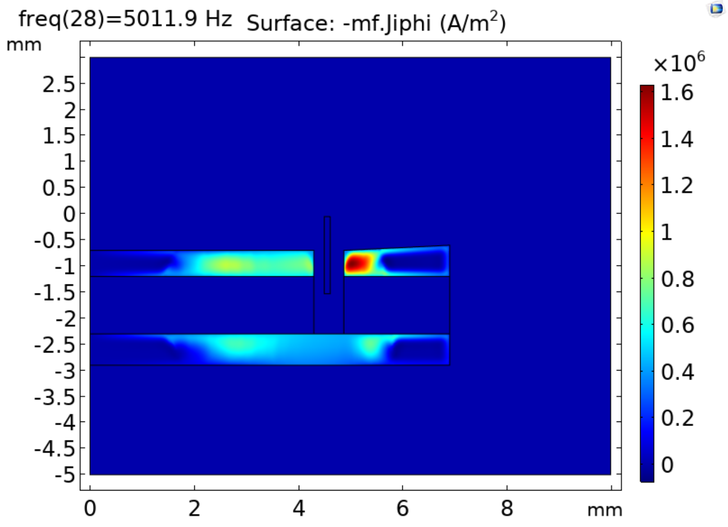
» Magnetic analysis (2/4)

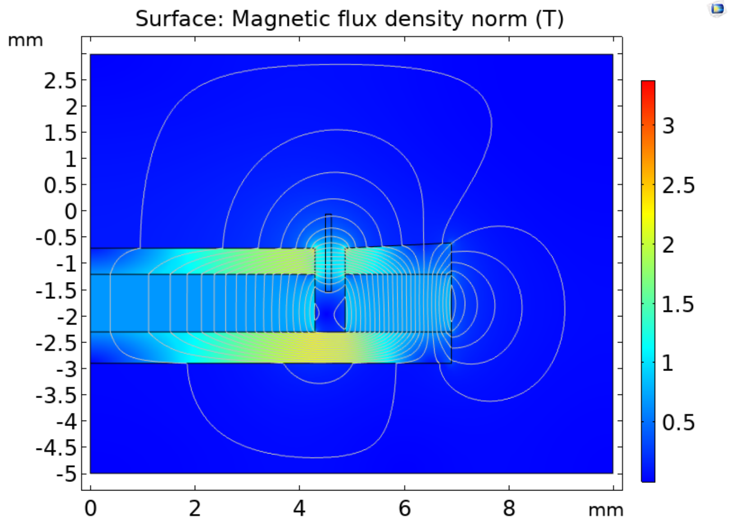


2D plots provide information about

- Static flux density
- Induced current density at various frequencies
- Saturation of steel

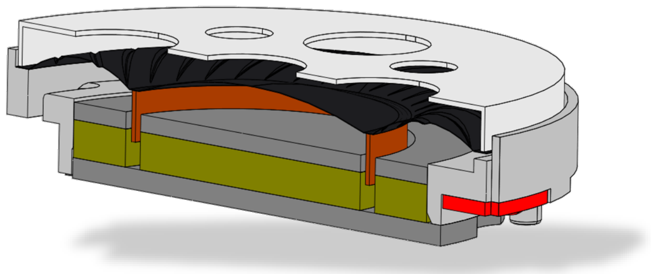
- Also very useful for optimizing magnet and iron for performance and cost.



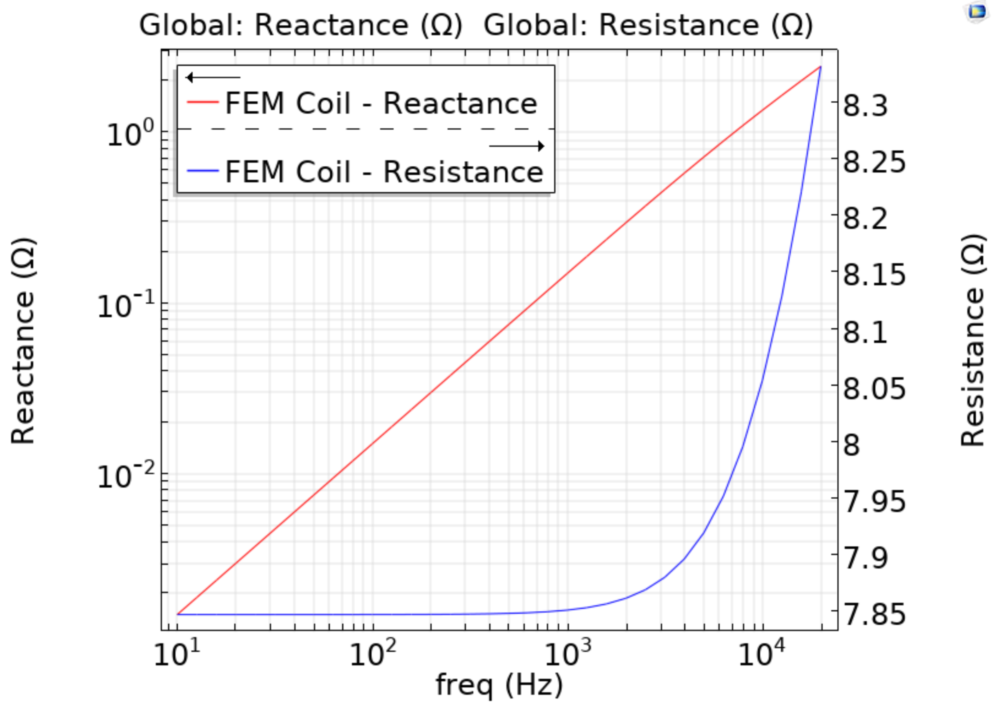


OWS-1943T-8CP

» Magnetic analysis (3/4)

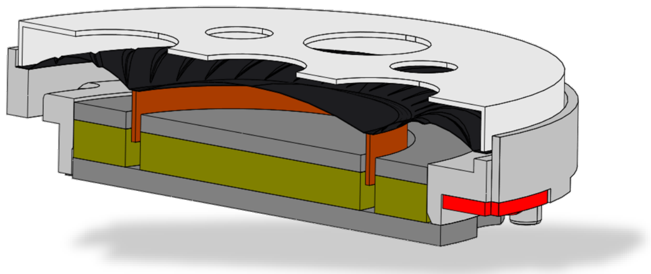


Coil resistance and reactance as function of frequency is derived. These analysis results are later used as lumped parameters in the acoustic analysis.

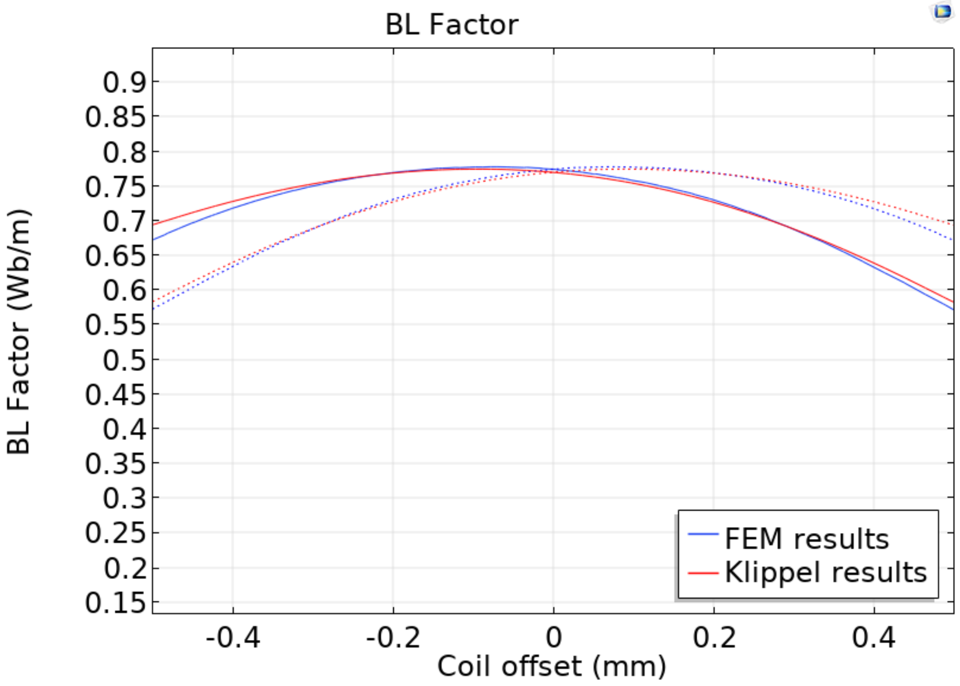


OWS-1943T-8CP

» Magnetic analysis (4/4)

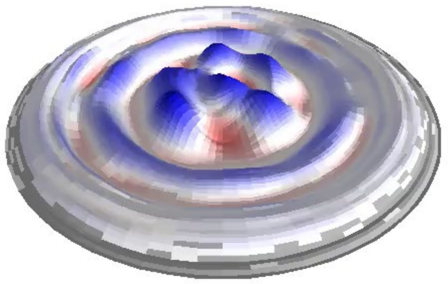


The BL(x) plot is very close to the measured Klippel response and reveals that the voice coil is slightly off-center.

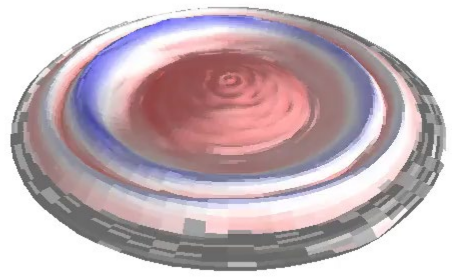


OWS-1943T-8CP
Mechanical analysis (1/2)

The diaphragm is modelled using a combination of Solid Mechanics for the voice coil and Shell physics using geometric nonlinearities for the diaphragm.



Paper, 16.5 kHz
Center part of cone is breaking up



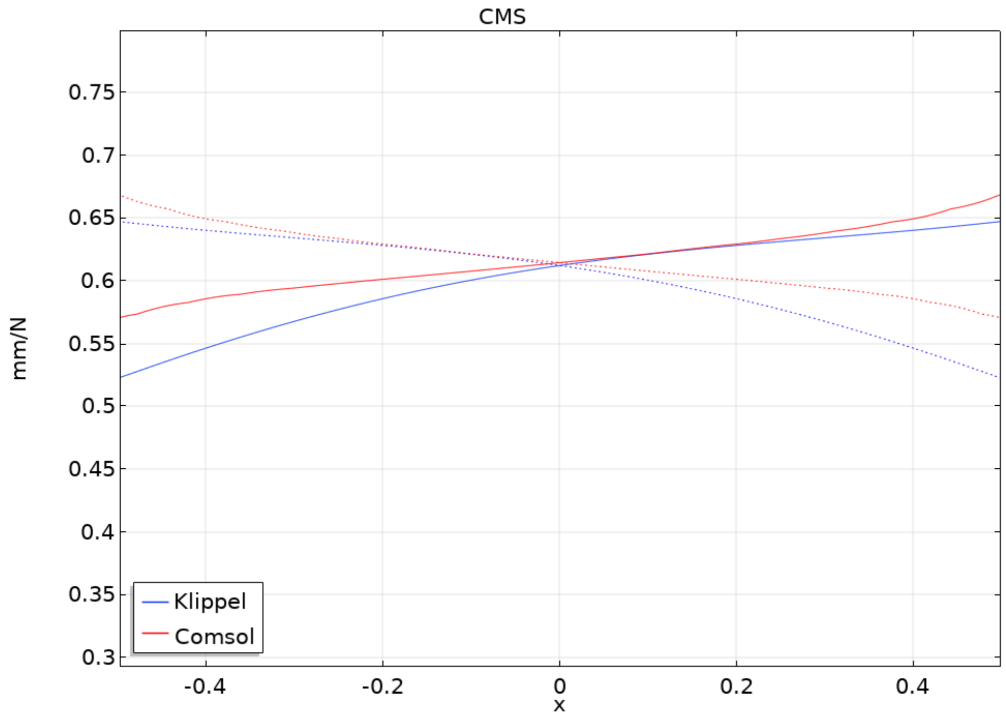
Graphene, 16.5 kHz
Center part of cone remains stiff

OWS-1943T-8CP

» Mechanical analysis (2/2)

The cms analysis has pretty good agreement with the Klippel data.

Correlation between simulation and test data will always depend on the initial accuracy of the CAD file and production tolerances of the tested unit.

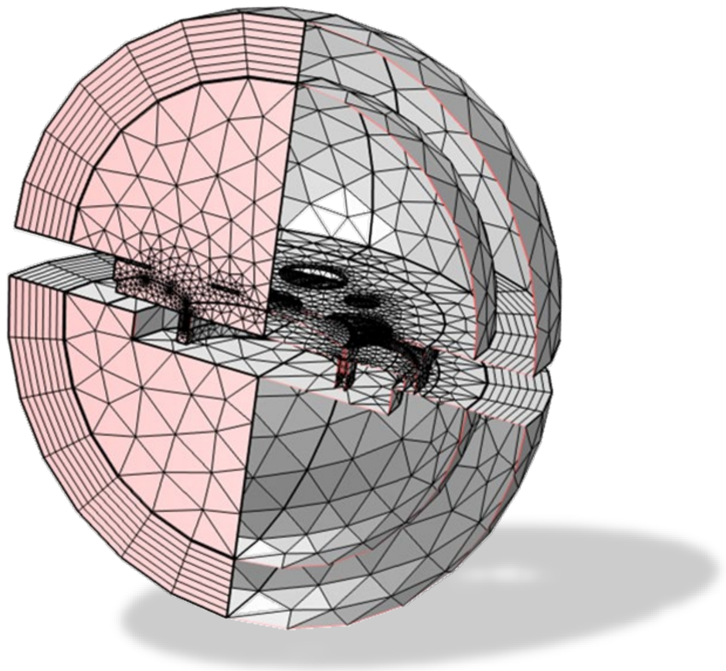


OWS-1943T-8CP

» Acoustic analysis (1/3)

The acoustic analysis is performed using the following physics:

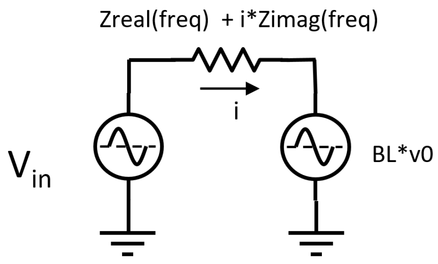
- Solid and Shell mechanics (for the diaphragm and voice coil)
- Electrical Circuit (for lumped parameters)
- Pressure acoustics
- Solid-Shell connection (for the diaphragm and voice coil)
- Acoustic-Structure boundary x2 (couples the diaphragm and voice coil to the air)
- In the pressure acoustics study, the front grill, rear holes and casing is set up as sound hard boundaries, to take internal resonances into account.



Pressure Acoustics, Frequency Domain *(acpr) {acpr}*
Solid Mechanics *(solid) {solid}*
Shell *(shell) {shell}*
Electrical Circuit *(cir) {cir}*
Multiphysics

OWS-1943T-8CP

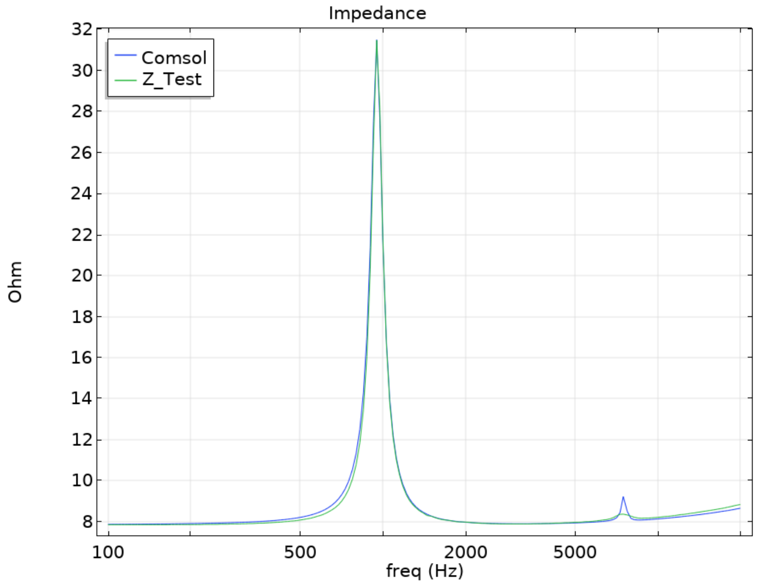
» Acoustic analysis (2/3)



The lumped motor of the speaker couples the voice coil impedance as well as the (static) BL value found in the magnetic study to the force on the voice coil in the mechanical study using the relation

Force = BL*i

Feedback to the motor is ensured via the voltage source with the voltage defined as **BL*v0**, with v0 being the voice coil velocity.



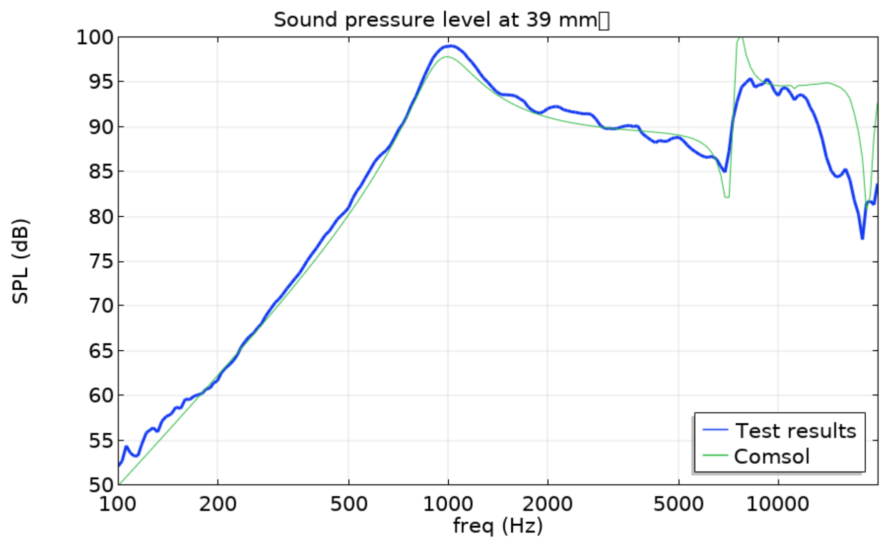
Simulated impedance curve shows very good agreement with test results. The rear hole resonance is visible at around 7.7 kHz due to the feedback to the lumped motor.

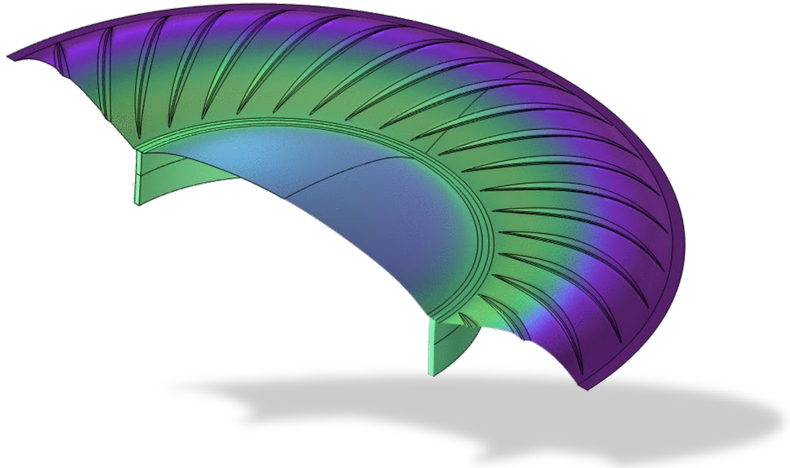
OWS-1943T-8CP

» Acoustic analysis (3/3)

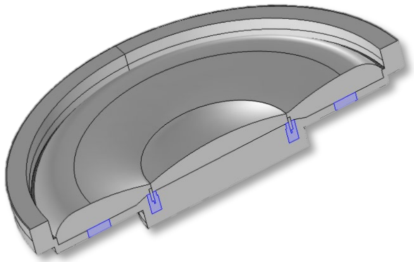
The sensitivity plot shows very good agreement with the measurement.

Using the Acoustic-structure physics, diaphragm breakups and rocking modes are included in the acoustic analysis.

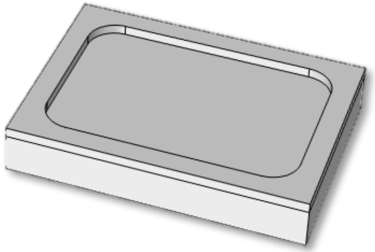




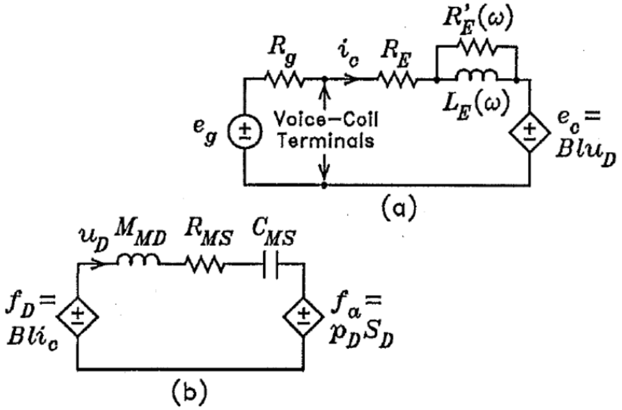
Modelling micro speakers using both lumped mechanical and electrical parameters



40mm headphone driver



13x18 mm microspeaker



No mechanical parts are being simulated – walls are 100% rigid (no absorbtion / transmission).

TS parameters (from Klippel)

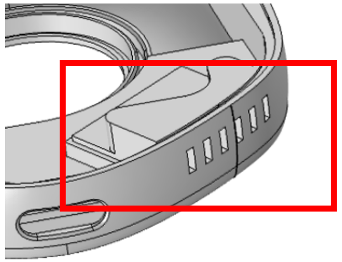
Name	Expression	Value
R_E	6.34[ohm]	6.34 Ω
L_e	0.028[mH]	2.8E-5 H
L2	0.005[mH]	5E-6 H
R2	0.37[ohm]	0.37 Ω
M_MD	0.071[g]	7.1E-5 kg
R_MS	0.126[kg/s]	0.126 kg/s
C_MS	0.732[mm/N]	7.32E-4 s²/kg
BL	0.838[T*m]	0.838 Wb/m
S_D	143[mm^2]	1.43E-4 m²
Fs	1/(2*pi*sqrt(C_MS*M_MS))	688.66 1/s
M_MS	M_MD+2*S_D^2*8*rho0/(3*...	7.2965E-5 kg
Q_ES	2*pi*Fs*M_MS*R_E/BL^2	2.8504
Q_MS	2*pi*Fs*M_MS/R_MS	2.5057
Q_TS	Q_MS*Q_ES/(Q_MS+Q_ES)	1.3335
V_AS	rho0*c0^2*S_D^2*C_MS	2.1133E-6 m³

- Pressure Acoustics, Frequency Domain *(acpr)*
- Electrical Circuit *(cir)*
- Thermoviscous Acoustics, Frequency Domain

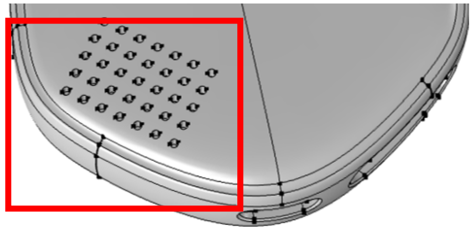
System integration

» Initial design considerations

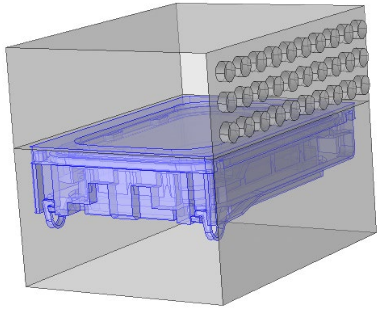
- For best results: consider the acoustics early in the design process!



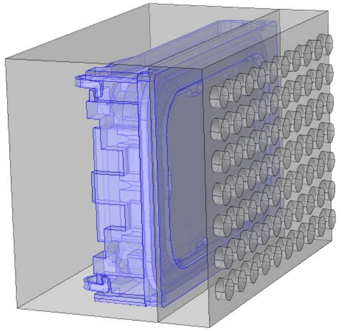
Side porting



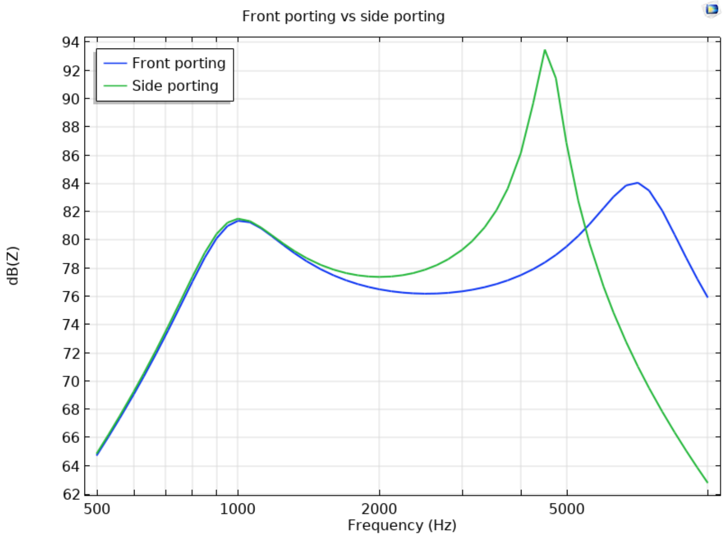
Front porting



Side porting



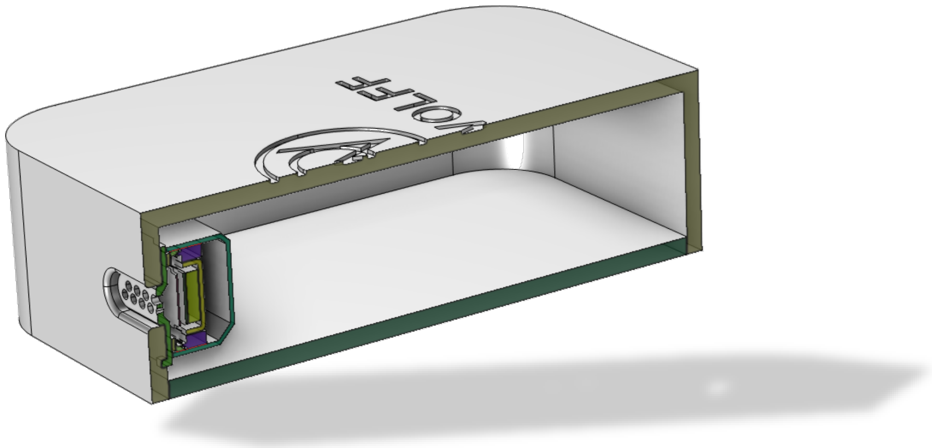
Front porting



Microspeaker application example 1

» IoT device with 13x18mm microspeaker (1/4)

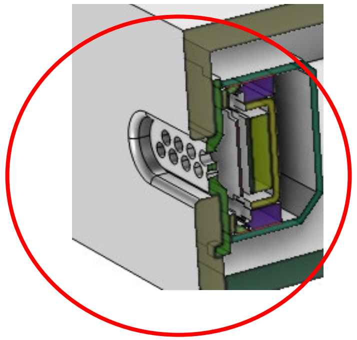
CAD sent to Ole Wolff

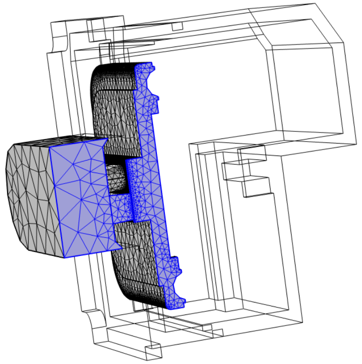


CAD only has to contain parts relevant to the acoustics – Pcb's, electrical components etc. can be omitted.

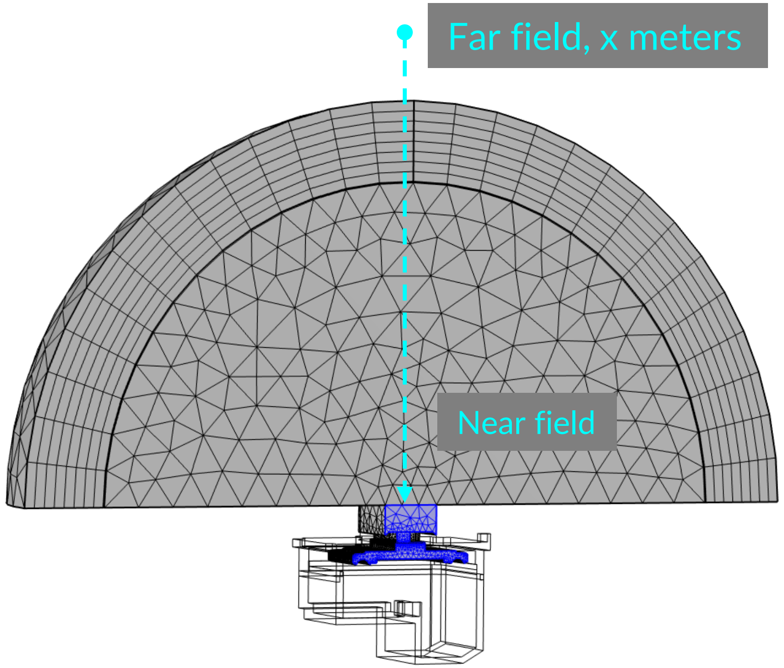
Microspeaker application example 1

» IoT device with 13x18mm microspeaker (2/4)





Air volume in front of speaker.
Symmetry used (reduced simulation time).

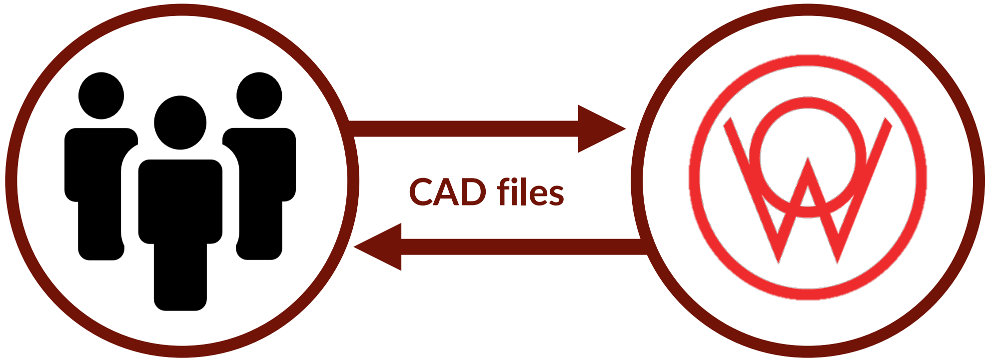


- By using a ”lumped speaker boundary” only the air volume in front of the driver needs to be modelled
- Reduced complexity means lower calculation time (typ. <20mins for 0.1-15kHz, 1/12 oct.)

- Typically the speakers are simulated in an ”infinite baffle”, anechoic conditions
- Pressure can be evaluated anywhere in the near field or far field

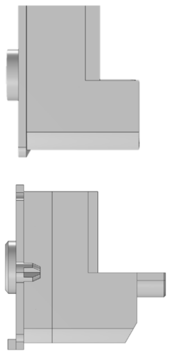
Microspeaker application example 1

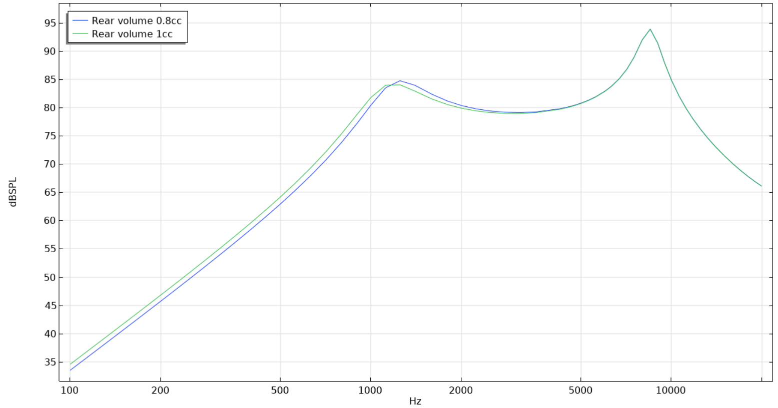
» IoT device with 13x18mm microspeaker, (3/4)



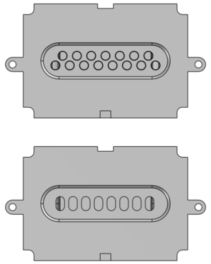
- CAD files are exchanged between OW and the customer
- Effect of design adjustments can be simulated before doing any physical prototypes

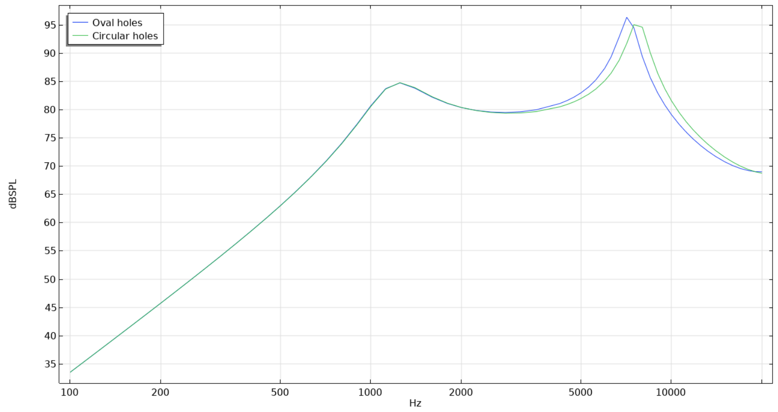
1cc vs. 0.8cc rear volume





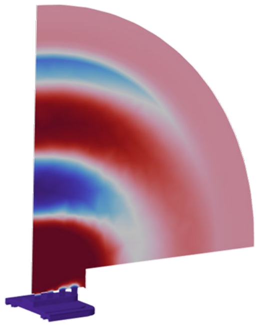
Circular vs. oval outlet holes

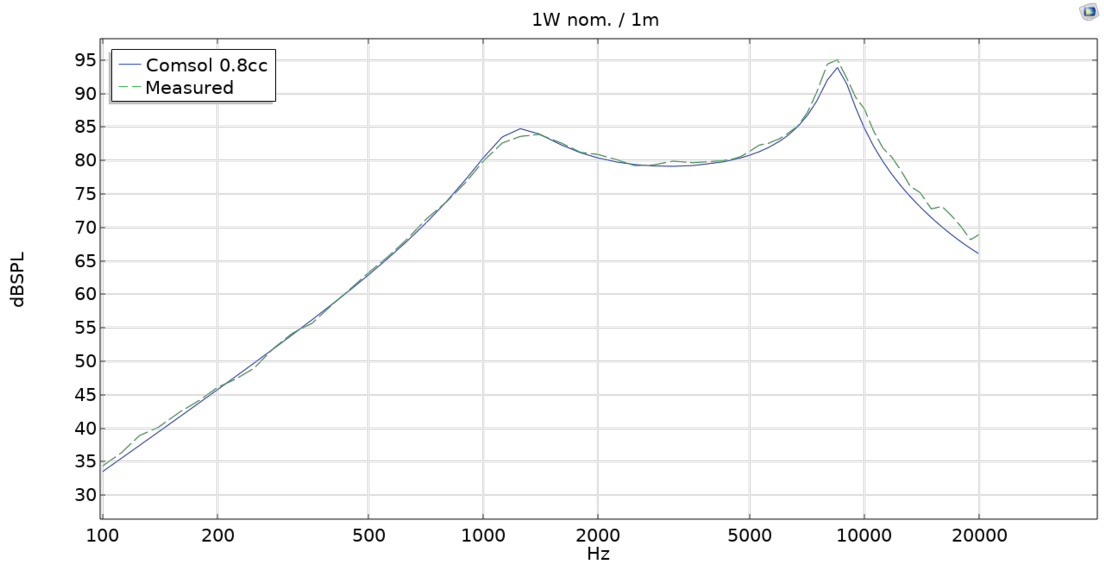




Microspeaker application example 1

- IoT device with 13x18mm microspeaker, (4/4)





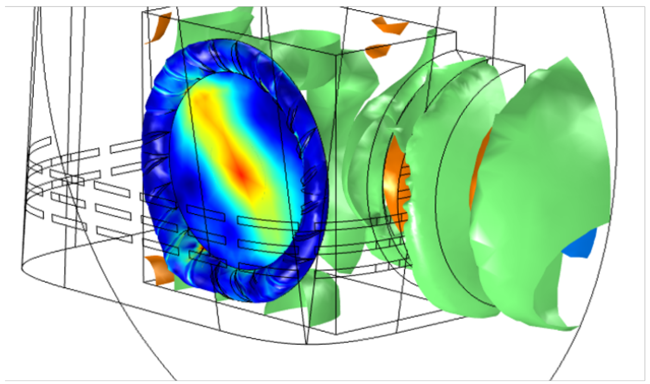
Good agreement between measurement and simulations.

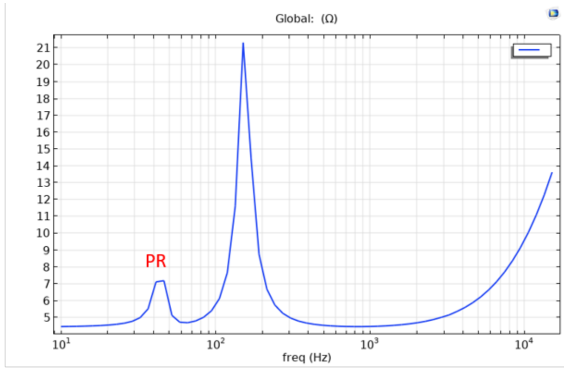
Microspeaker application example 2

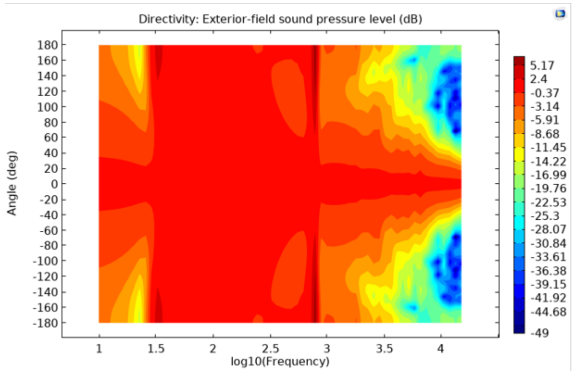
» Bluetooth speakerbox with 2x passive radiators

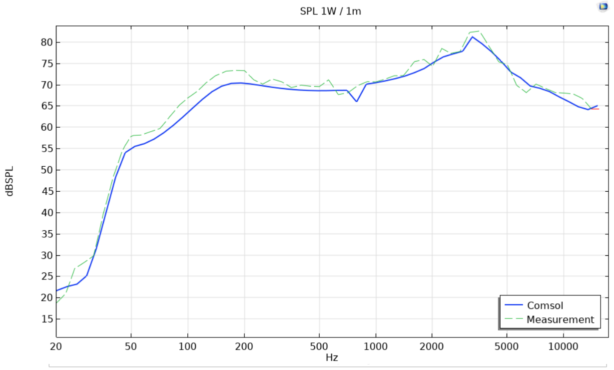
- Lumped speaker
- PR modelled using Shell and Solid mechanics

Physical prototype



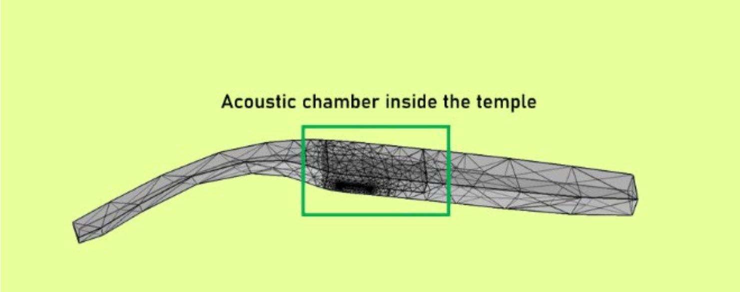


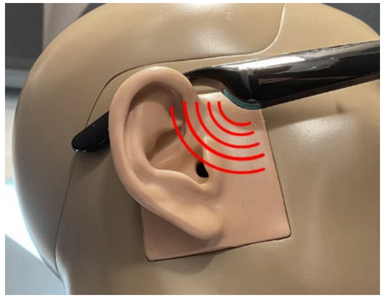




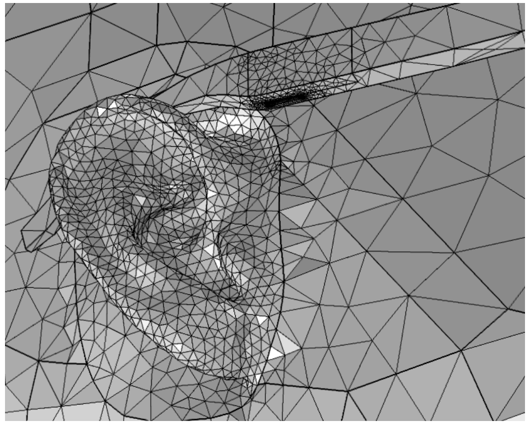
Microspeaker application example 3

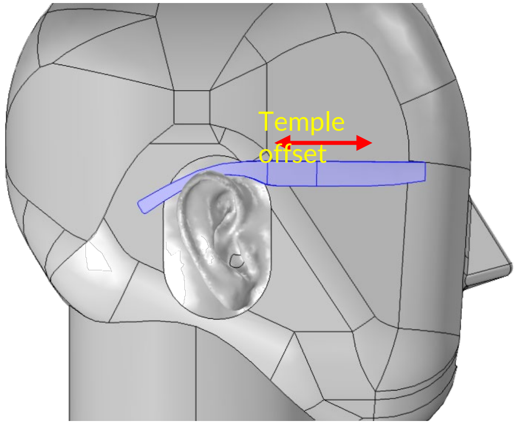
» Audio in “smart glasses”

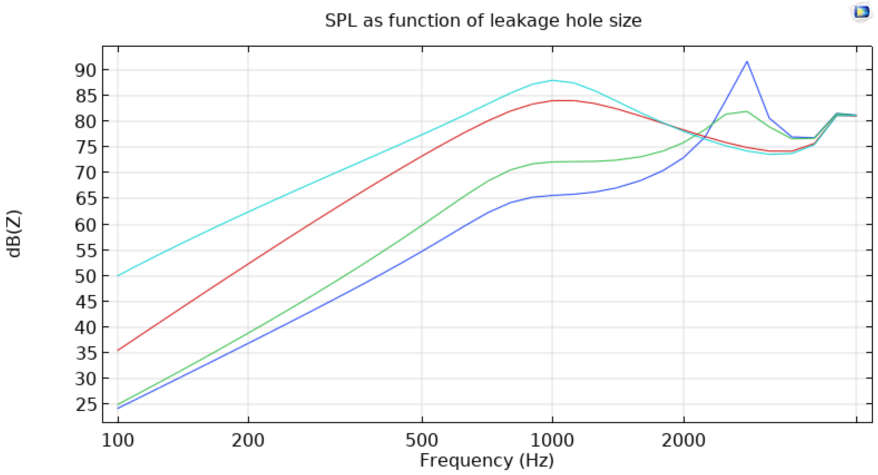




Name	Expression	Value
R_E	6.80[ohm]	6.8 Ω
L_e	0.033[mH]	3.3E-5 H
L2	0[mH]	0 H
R2	0[ohm]	0 Ω
M_MD	0.033[g]	3.3E-5 kg
R_MS	0.08[kg/s]	0.08 kg/s
C_MS	1.026[mm/N]	0.001026 s²/kg
BL	0.494[T*m]	0.494 Wb/m
Fs	1/(2*pi*sqrt(C_MS...	859.03 1/s
M_MS	M_MD+2*S_D^2*...	3.3456E-5 kg
Q_ES	2*pi*Fs*M_MS*R_E...	5.0317
Q_MS	2*pi*Fs*M_MS/R_...	2.2572
Q_TS	Q_MS*Q_ES/(Q_M...	1.5582
V_AS	rho0*c0^2*S_D^2...	4.2238E-7 m³
S_D	0.54[cm^2]	5.4E-5 m²

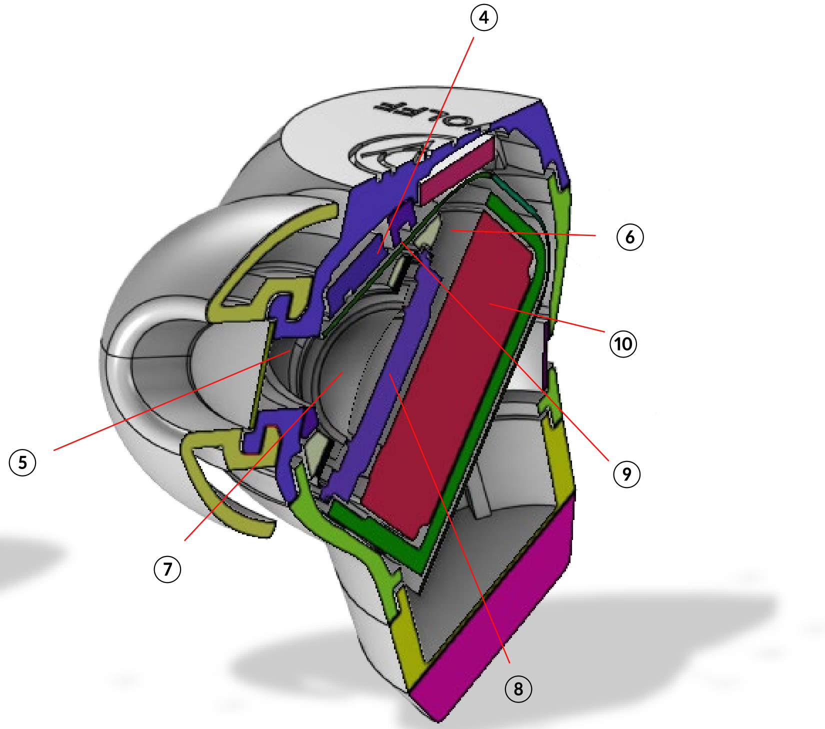






Earphone simulations

» (1/3)

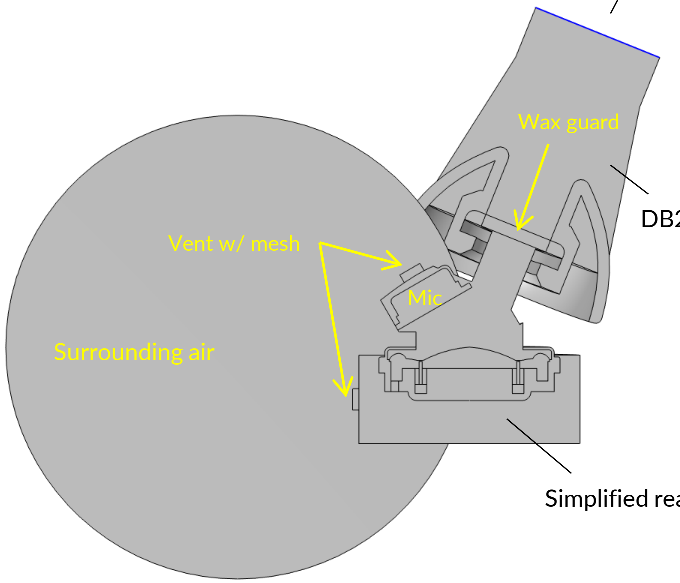


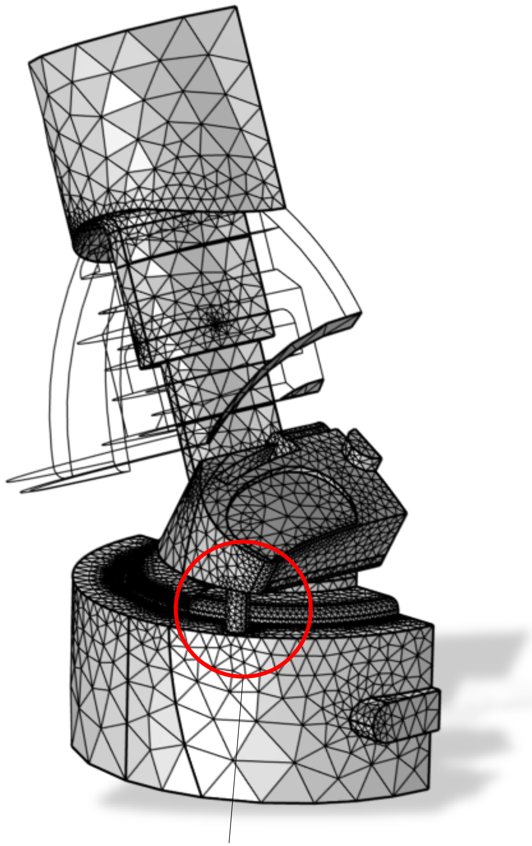
1. Nozzle mesh
2. Front leakage (for anti occlusion)
3. Rear leakage (for optimum bass response)
4. Feedback microphone for ANC (response modelled in Comsol)
5. Front volume
6. Rear volume
7. Ole Wolff earphone driver - modelled using TS parameters or using a full vibroacoustic model that includes diaphragm breakups etc.
8. Internal air volume in driver
9. Channel connecting front- and rear volume
10. Volume taken up by electronics, battery etc.

Earphone simulations

» (2/3)

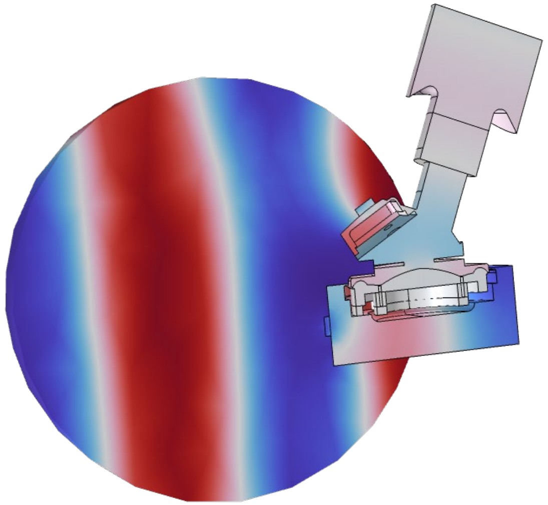
Only air volumes are included in the model





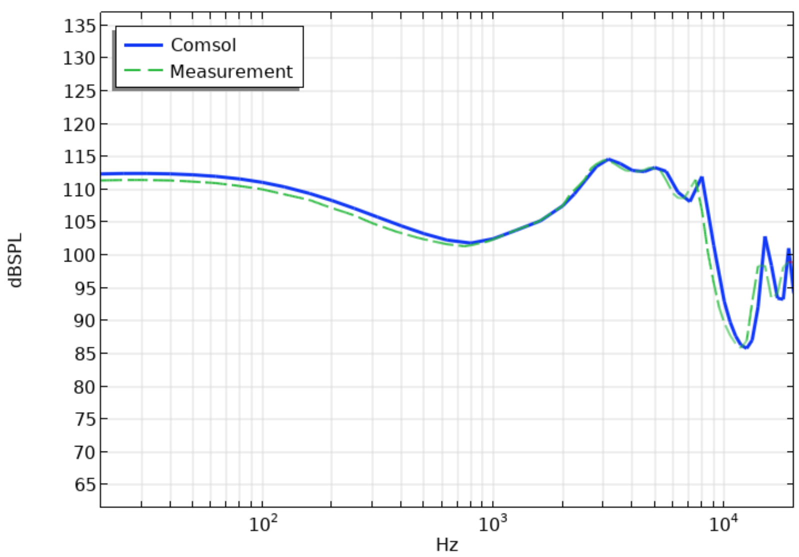
Earphone simulations

» (3/3)

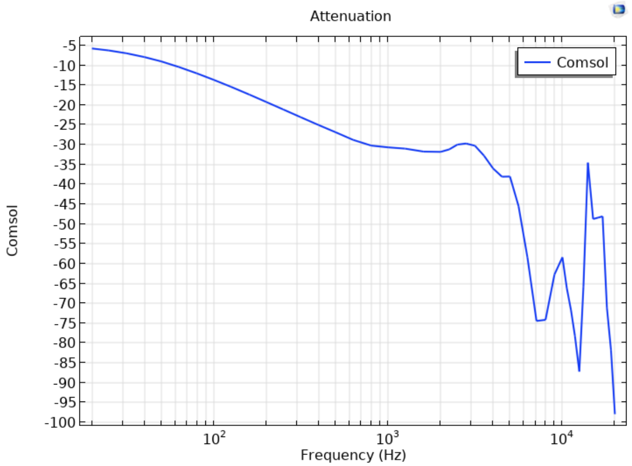


Background pressure (plane wave)

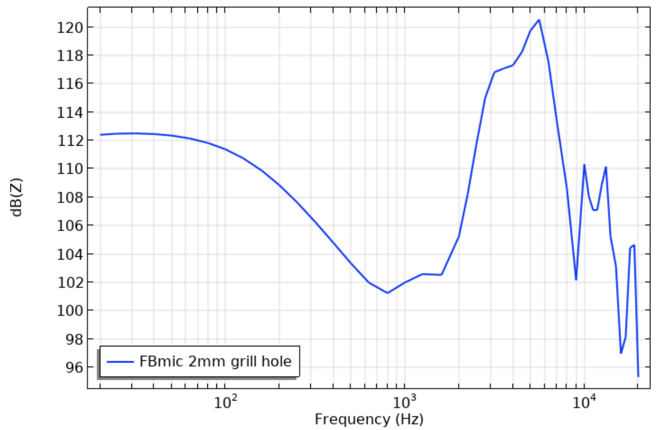
SPL, 711 coupler



Passive attenuation

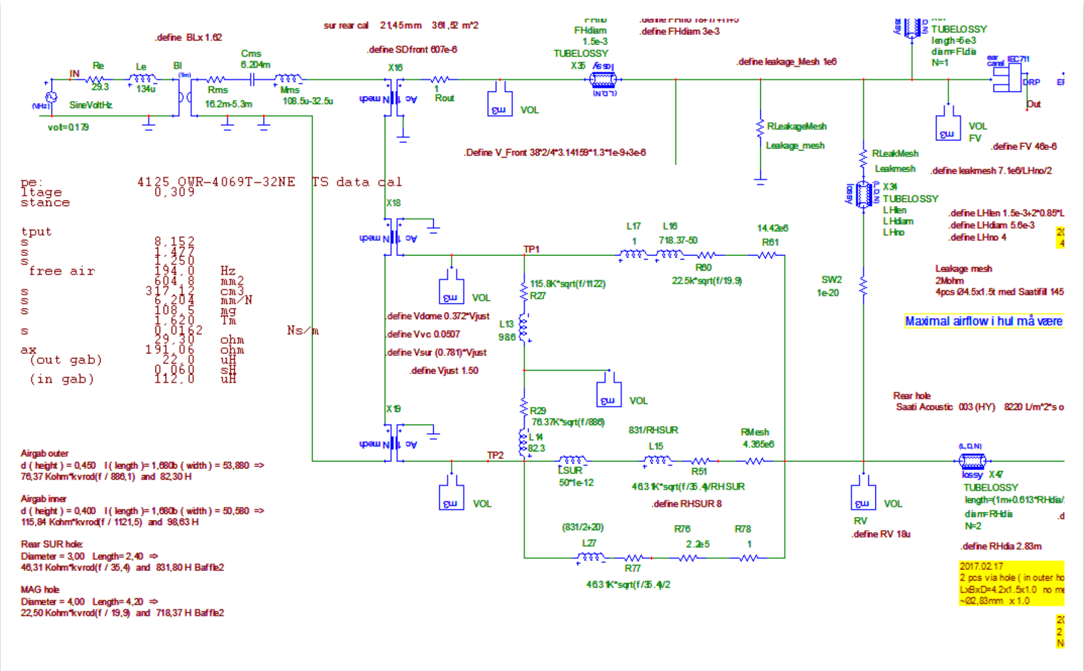


ANC feedback mic response



Headphone simulations

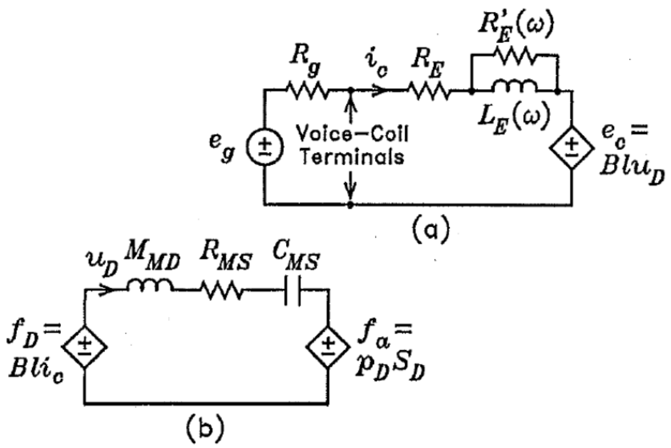
» Traditional method

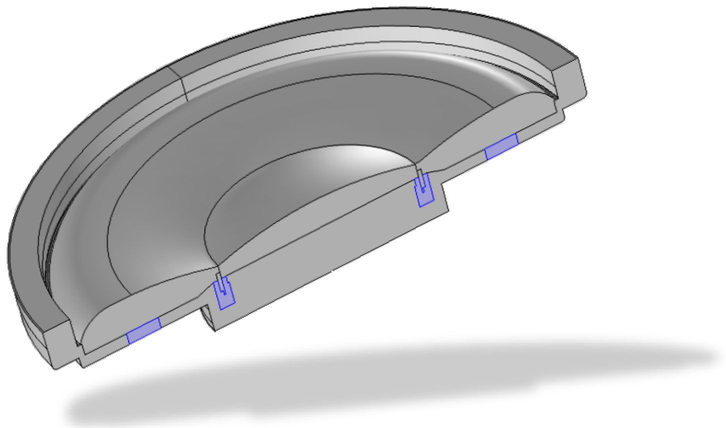


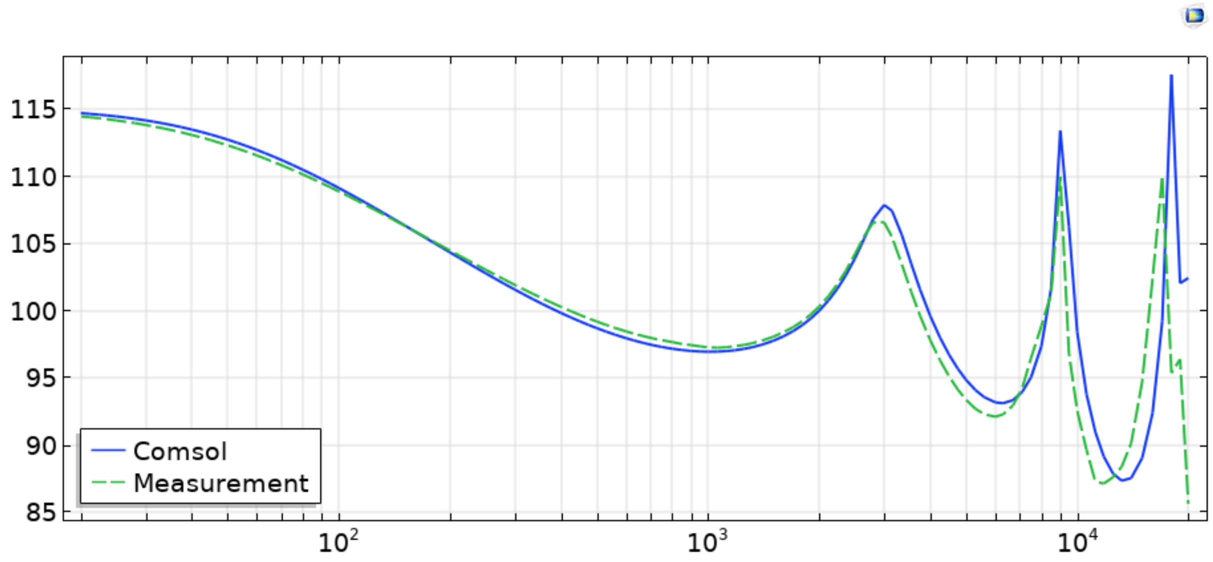
- Difficult to model complex geometries using lumped acoustic parameters
- Requires many physical prototypes

Headphone simulations

» Using Comsol, (1/2)





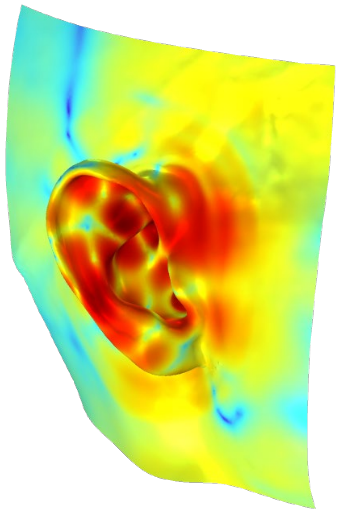


- Simple circuit model and geometry, easy to build into complex geometry

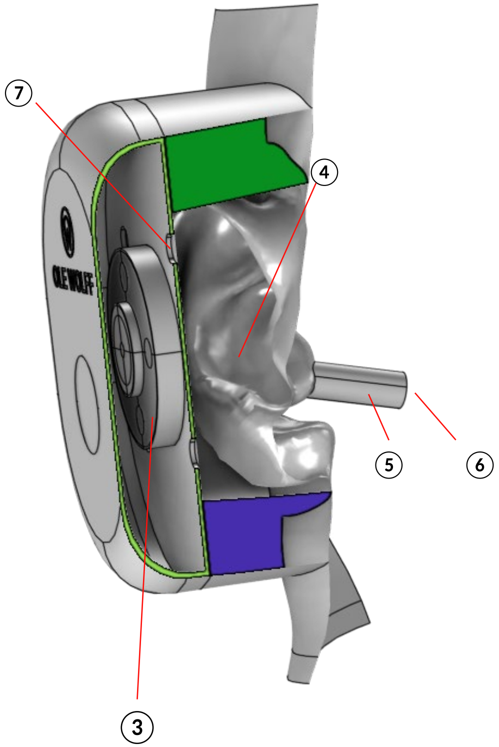
Headphone simulations

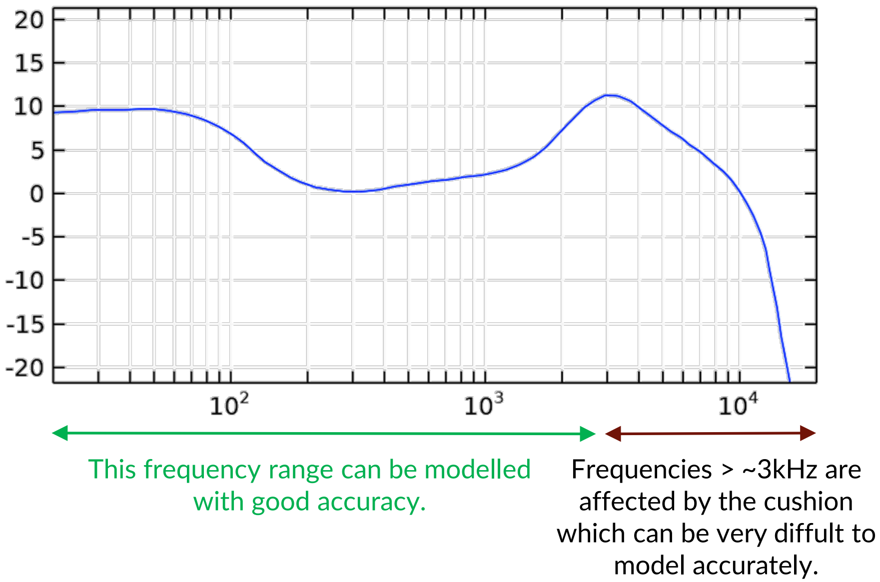
» Using Comsol, (2/2)

1. Rear mesh (if open back headphone). Closed-back headphones can also be modelled.
2. Cushion. Typically made from multiple layered materials and the acoustic properties varies with headband pressure. *Difficult to model accurately.*
3. Ole Wolff headphone driver - modelled using TS parameters or using a full vibroacoustic model that includes diaphragm breakups etc.
4. Ear with skin impedance
5. Ear canal
6. Eardrum impedance or 711 coupler model for verifying results in the lab.
7. Front-to-back leakage holes for bass tuning

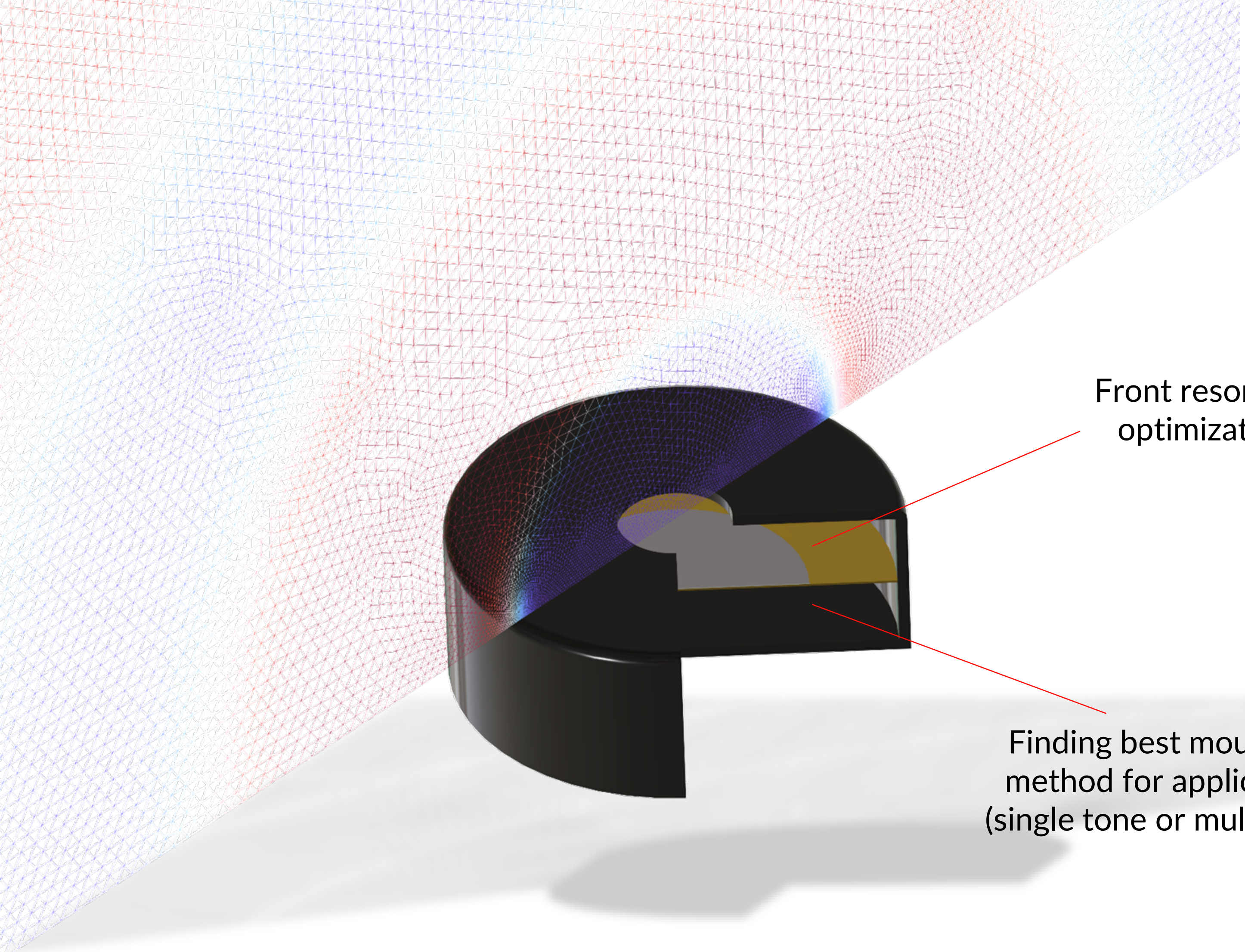


Sound pressure level on skin surface



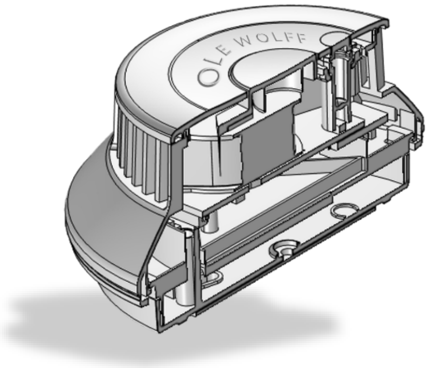


Buzzers

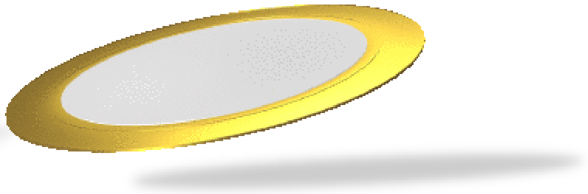


Front resonator optimization

Finding best mounting method for application (single tone or multi tone)



Full system design
(buzzer installed in end product)



Piezo disc design
Optimize resonance frequency, capacistance etc.