Ole Wolff Virtual prototyping 2023



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



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 ٠
- Klippel[™] analyzers and scanners with near-field add-on •
- Listen SoundCheck[™] ٠
- Anechoic chambers •
- B&K and Gras microphones, artificial ears, HATS etc. ٠



Brüel & Kjær







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





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





Magnetic analysis (1/4)

Axisymmetric simulation includes:

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







Magnetic analysis (2/4)

2D plots provide information about

- Static flux density ٠
- Induced current density at various ٠ frequencies
- Saturation of steel ٠
- Also very useful for optimizing ٠ magnet and iron for performance and cost.









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.







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



>> 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.





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



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.



>> 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



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 m ²
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

Meressure Acoustics, Frequency Domain (acpr)
Electrical Circuit (cir)
Mermoviscous Acoustics, Frequency Domain

13x18 mm microspeaker



System integration

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



Side porting

Front porting

owolff.com





Side porting



Front porting



>> 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.



>> 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



>> 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







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







Good agreement between measurement and simulations.



>>> Bluetooth speakerbox with 2x passive radiators

- Lumped speaker
- PR modelled using Shell and Solid mechanics



Physical prototype





>> 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 m ²





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





Tube connecting front vol. to rear vol.

Earphone simulations

>> (3/3)

Background pressure (plane wave)

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). Closedback 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

Full system design (buzzer installed in end product)

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

Front resonator optimization

Piezo disc design Optimize resonance frequency, capacistance etc.

