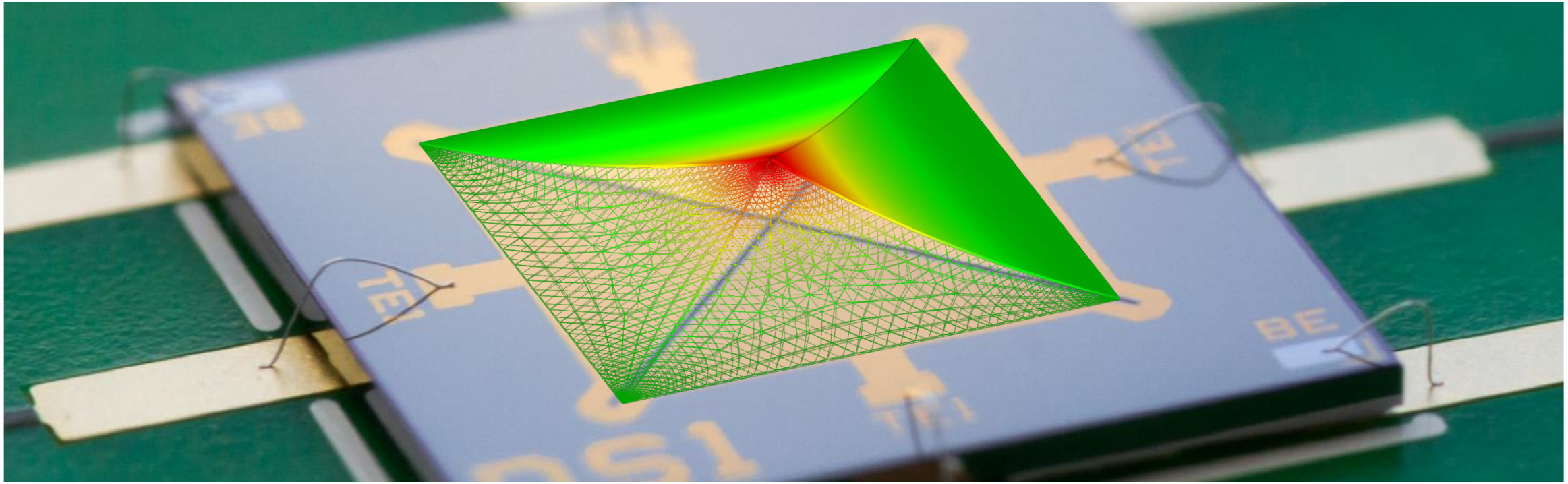
SIMULATING MEMS LOUDSPEAKERS

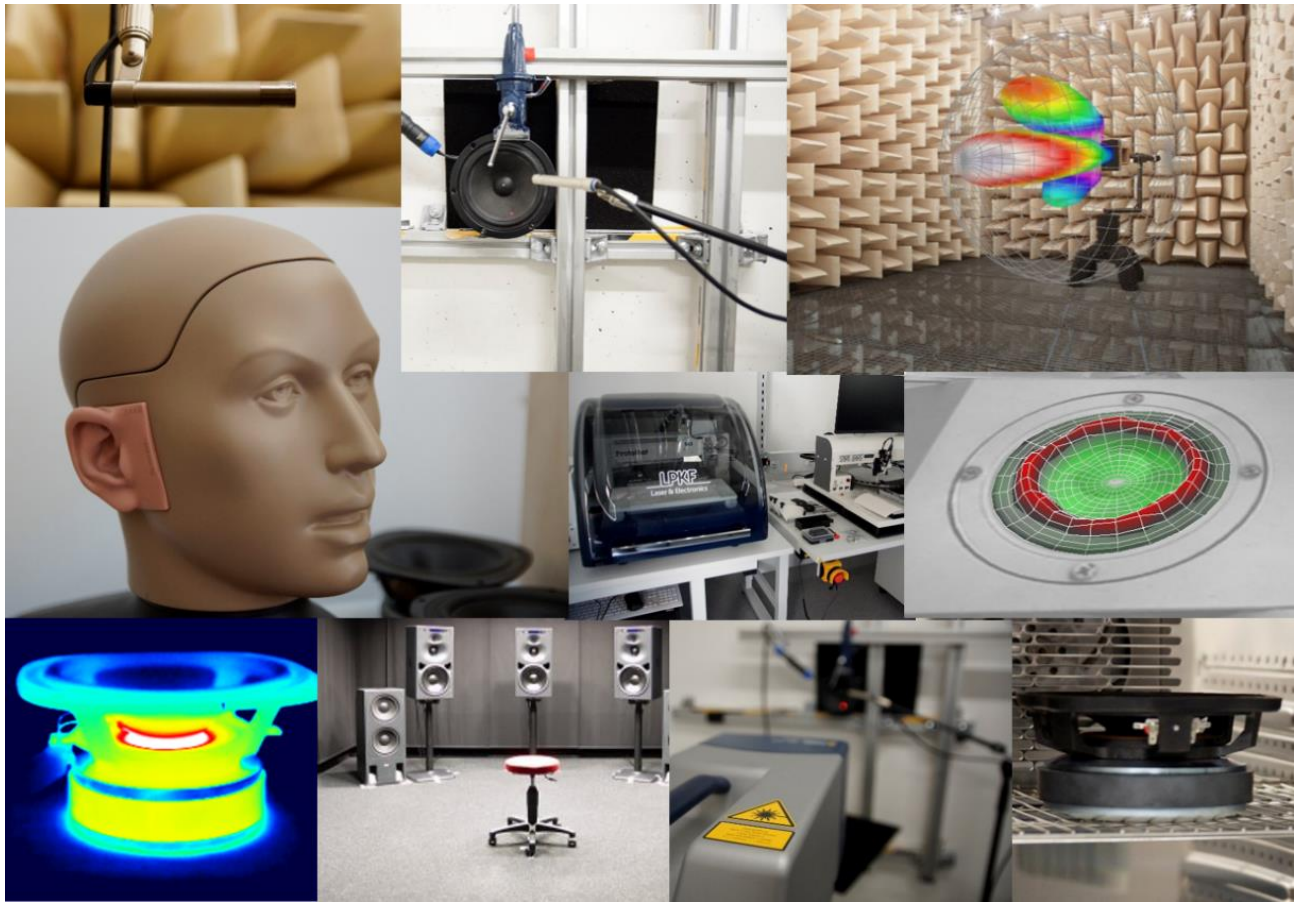
COMSOL Day: MEMS
25.03.2021

Jan Küller represented by Tobias Fritsch Fraunhofer IDMT



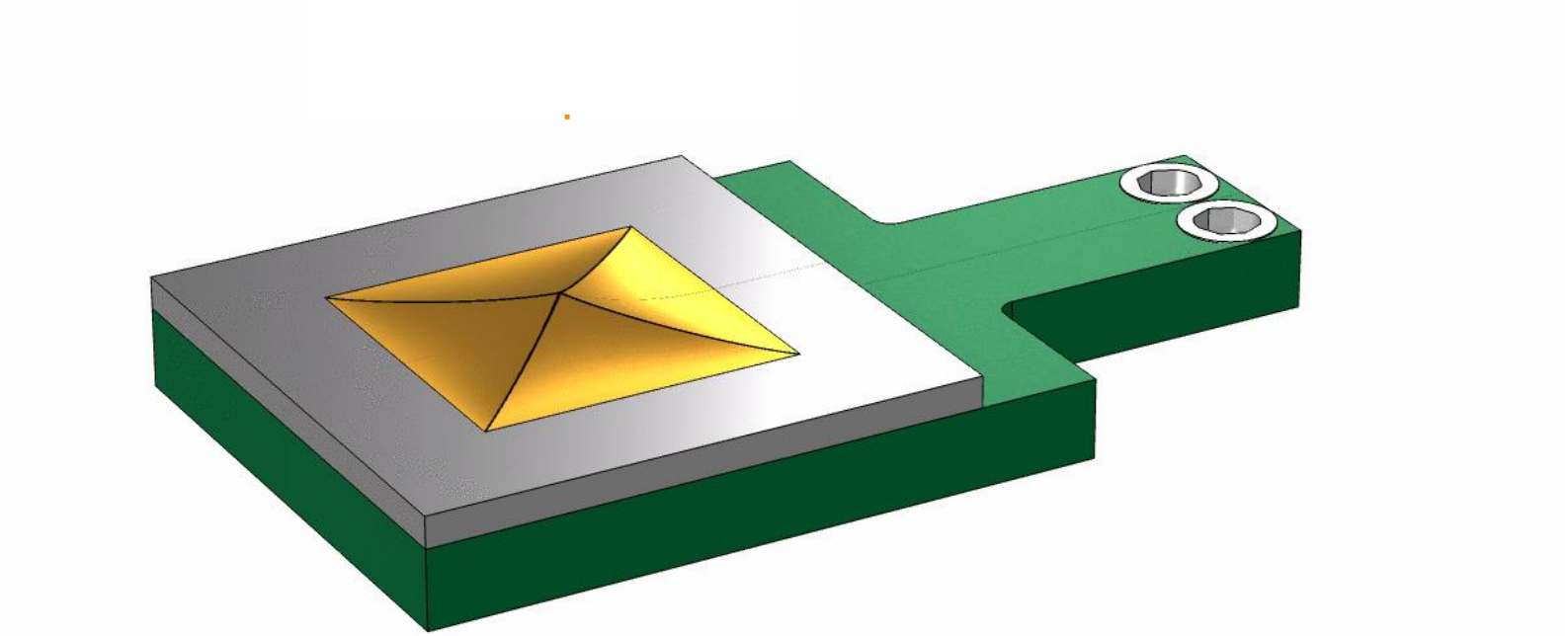
Fraunhofer Institute for Digital Media Technology IDMT
Electroacoustics

- signal processing for audio
  - sound and distortion optimization
  - thermal and mechanic protection
- simulation
  - optimization
  - models for adaptive control
- measurements
  - parameters for simulations
  - verify models
- prototypes
  - DSP + amp



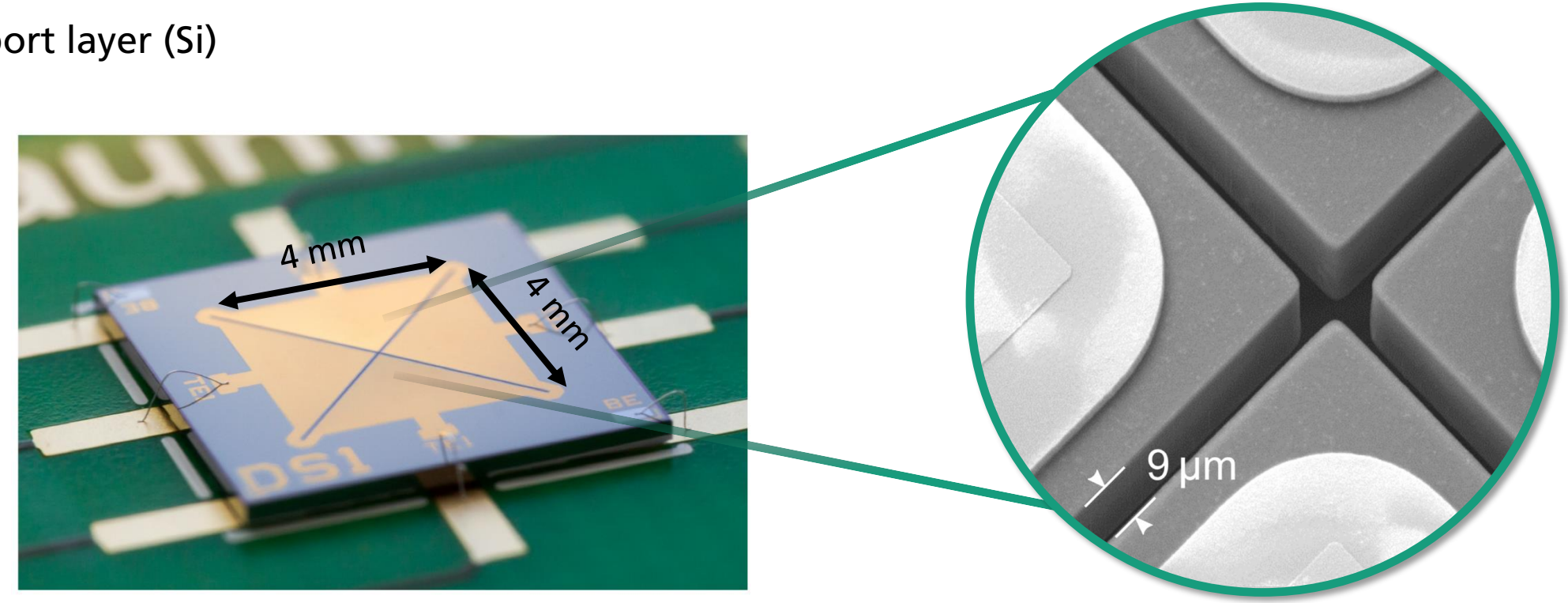
MEMS Loudspeaker

- bending motion at harmonic actuation
- for in-ear headphones or hearing aids
- covers audible frequency range



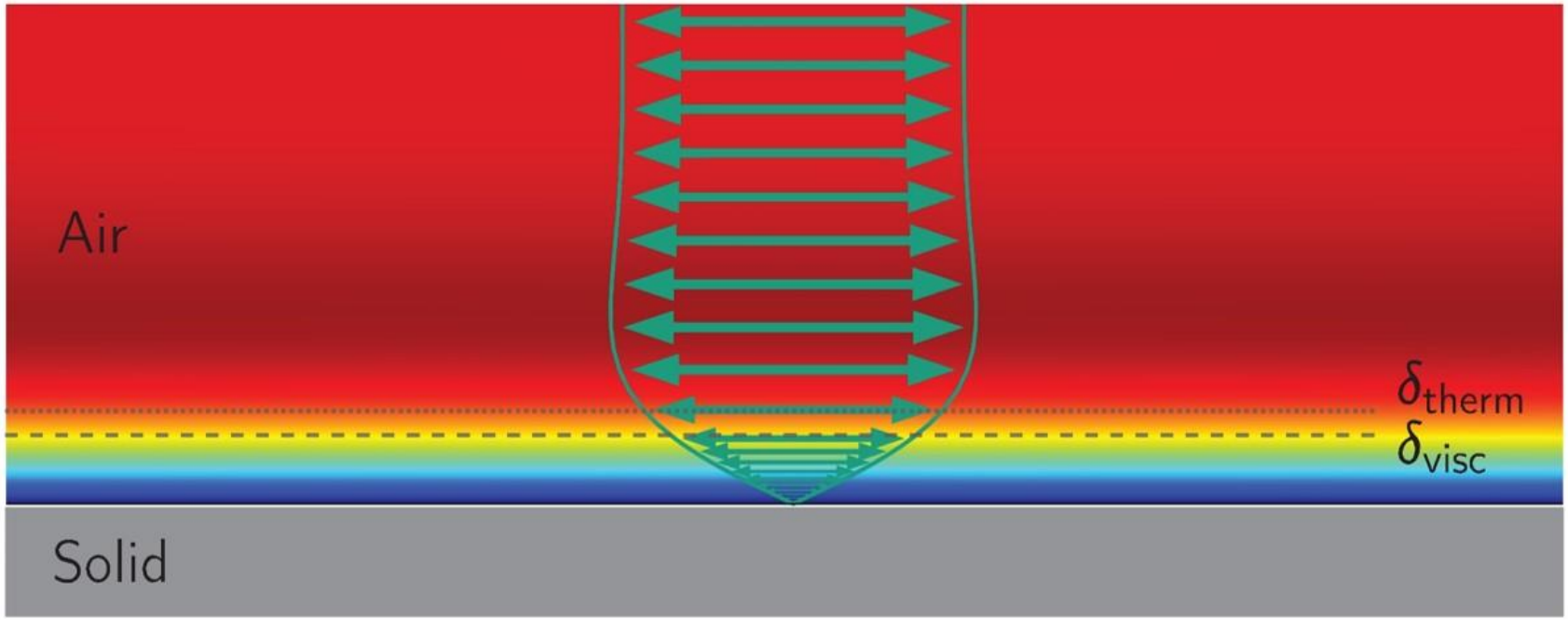
MEMS Loudspeaker

- MEMS chip consisting 4 membrane elements
- piezoelectric (PZT)
- support layer (Si)



Accounting thermoviscous effects

- oscillation on solids
- losses in narrow structures

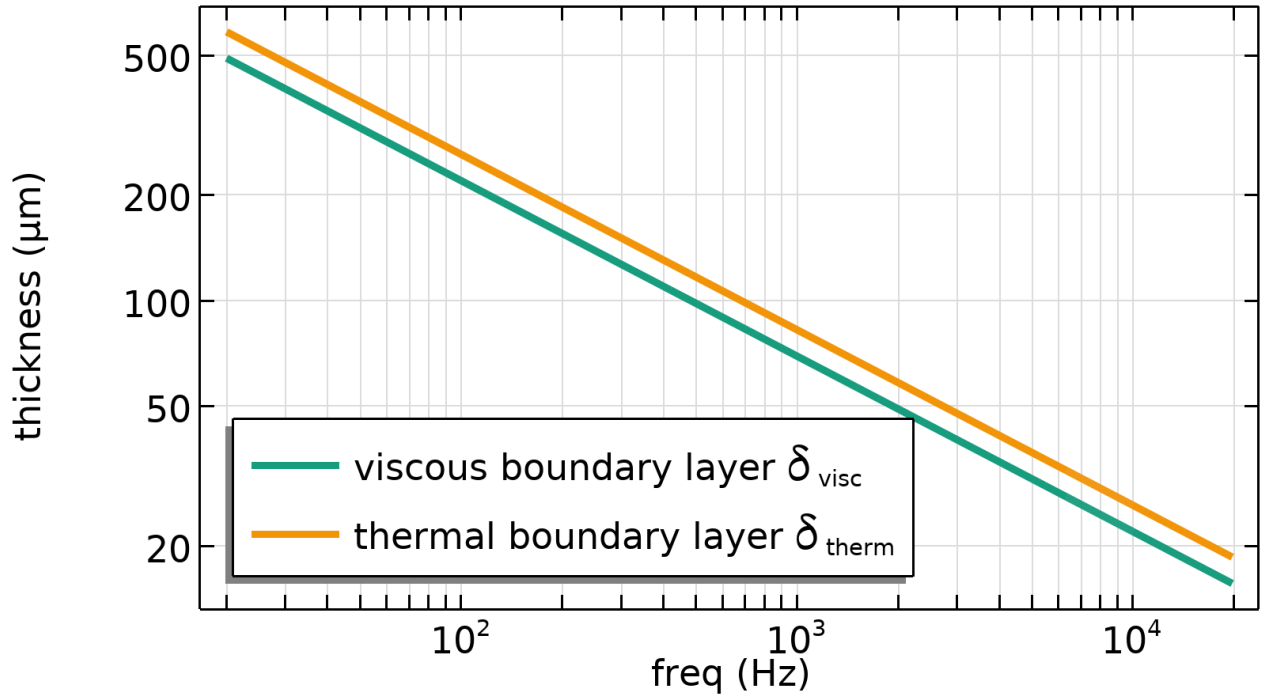


For more information refer to: Mads Herring Jensen, “Theory of Thermoviscous Acoustics: Thermal and Viscous Losses”, Comsol Blog, 27.02.2014

Accounting thermoviscous effects

viscous and thermal boundary layer in air

- internal friction → viscous boundary layer
- Heat transfer in medium → thermal boundary layer

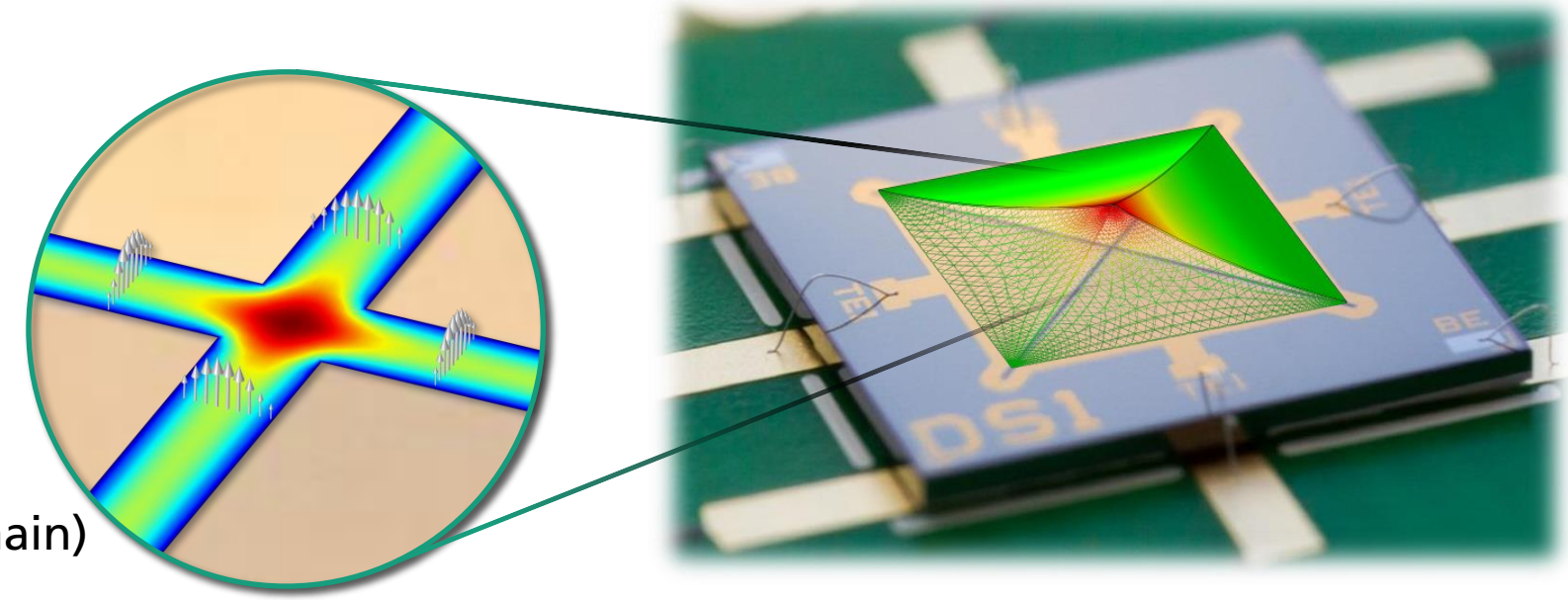


For more information refer to: Mads Herring Jensen, “Theory of Thermoviscous Acoustics: Thermal and Viscous Losses”, Comsol Blog, 27.02.2014

Simulation model
Multiphysics

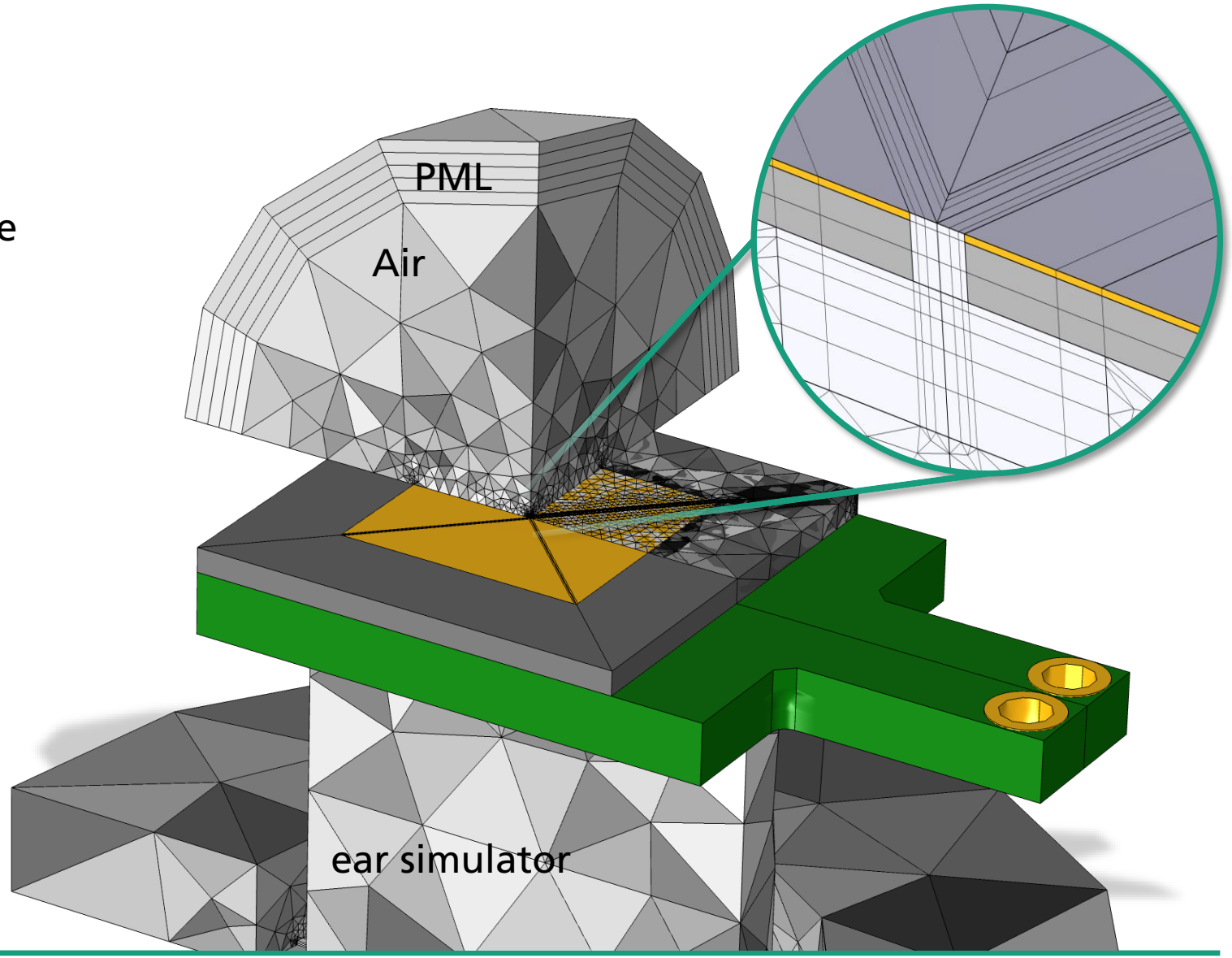
- thermoviscous acoustics in the air gap

- additional physics modules:
  - electrostatics
  - structural mechanics
  - pressure acoustics
  - electrical circuit (time domain)



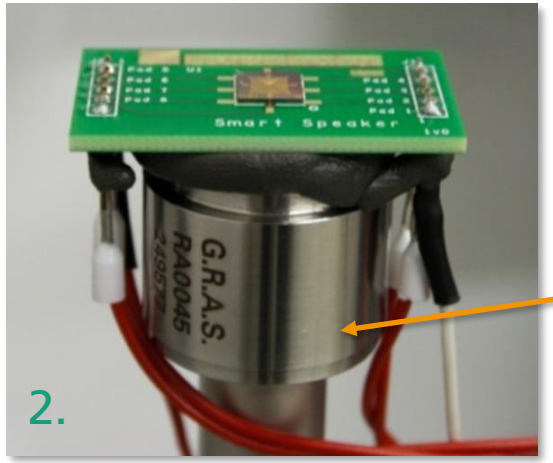
Simulation model
meshing technique

- challenge: accuracy vs. performance
- model
  - extruded
  - utilize geometric similarities
  - copy surfaces/domains
  - boundary elements
- moving mesh (time domain)



MEMS LOUDSPEAKER SIMULATION
CASE STUDY

1. MEMS loudspeaker in free field
2. MEMS loudspeaker on ear simulator
   - frequency domain
   - time domain
     - transmitter and receiver
     - THD
3. In-ear application

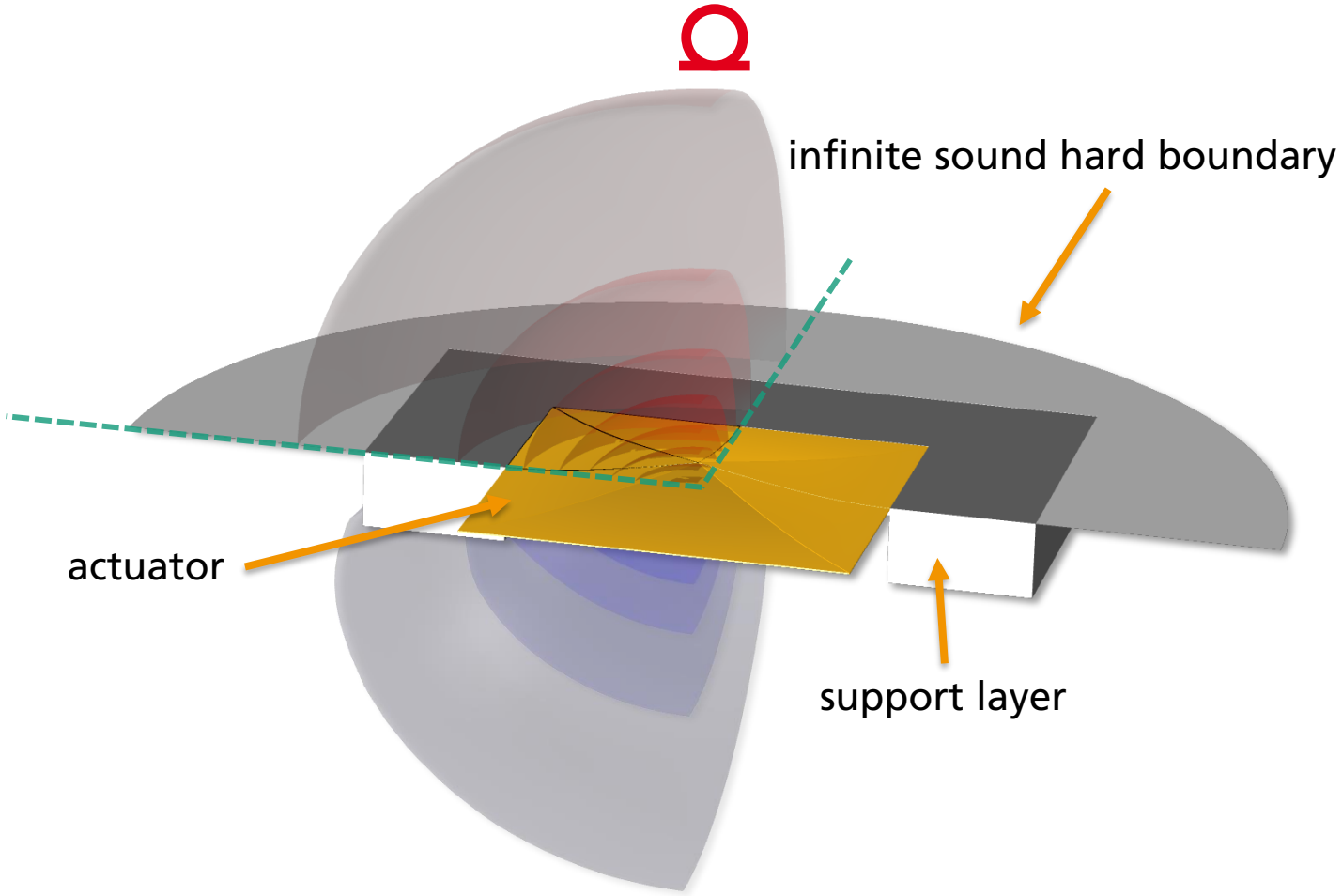


ear simulator

Simulation model

1. MEMS loudspeaker in free field

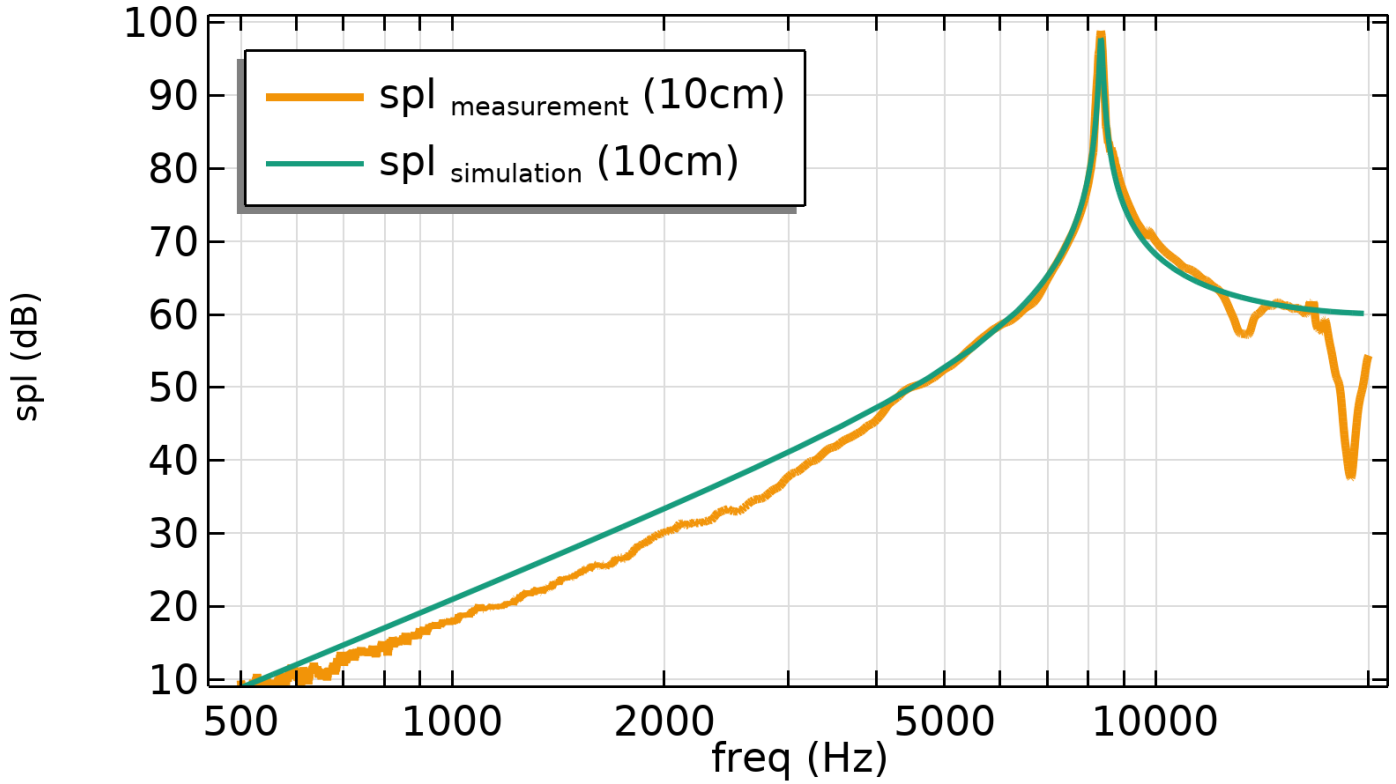
- simulation in free field
  - infinite sound hard boundary
  - quartered → symmetry
  - front and rear radiation
- PZT needs own coordinate System



Simulation model

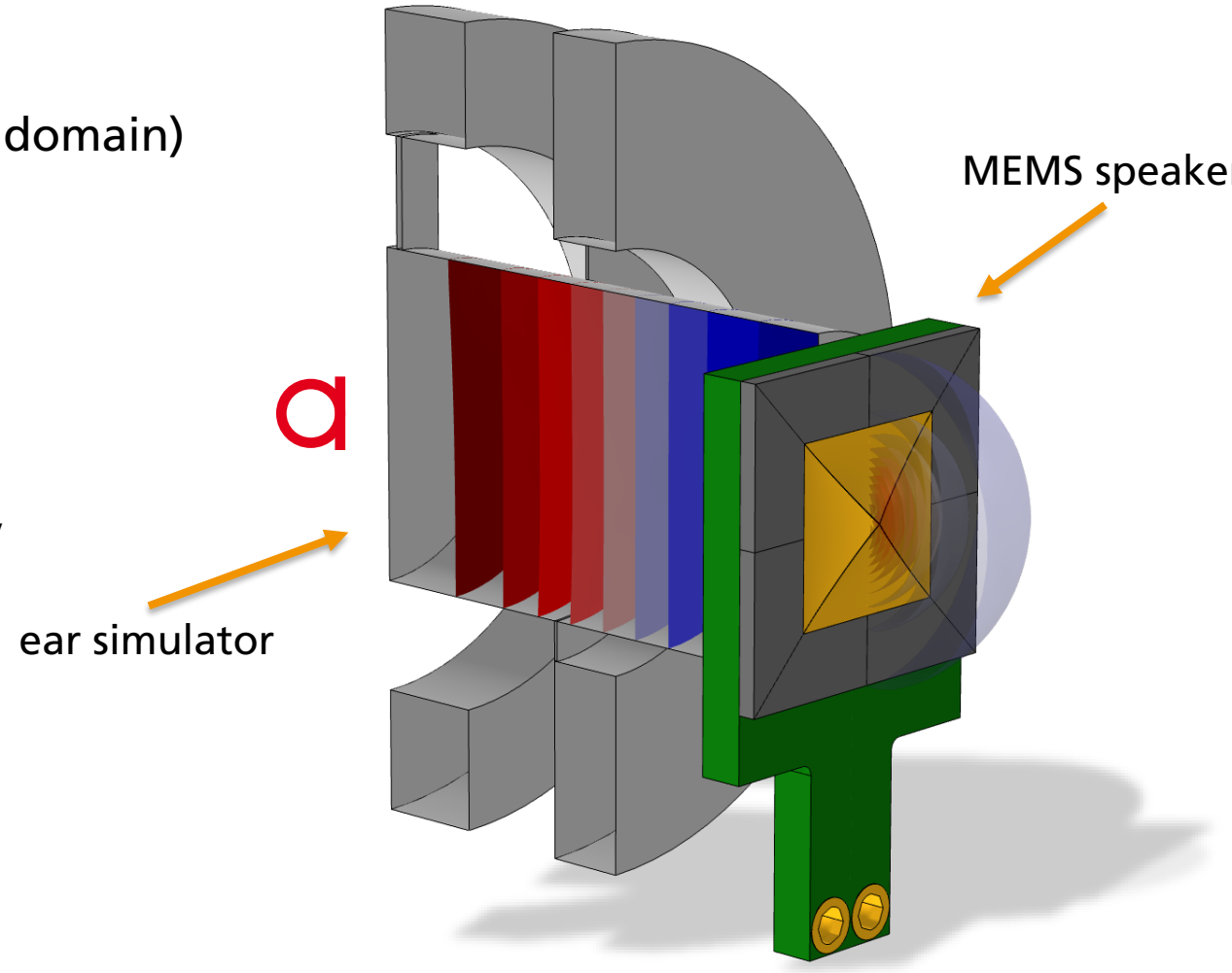
1. MEMS loudspeaker in free field

- simulation results



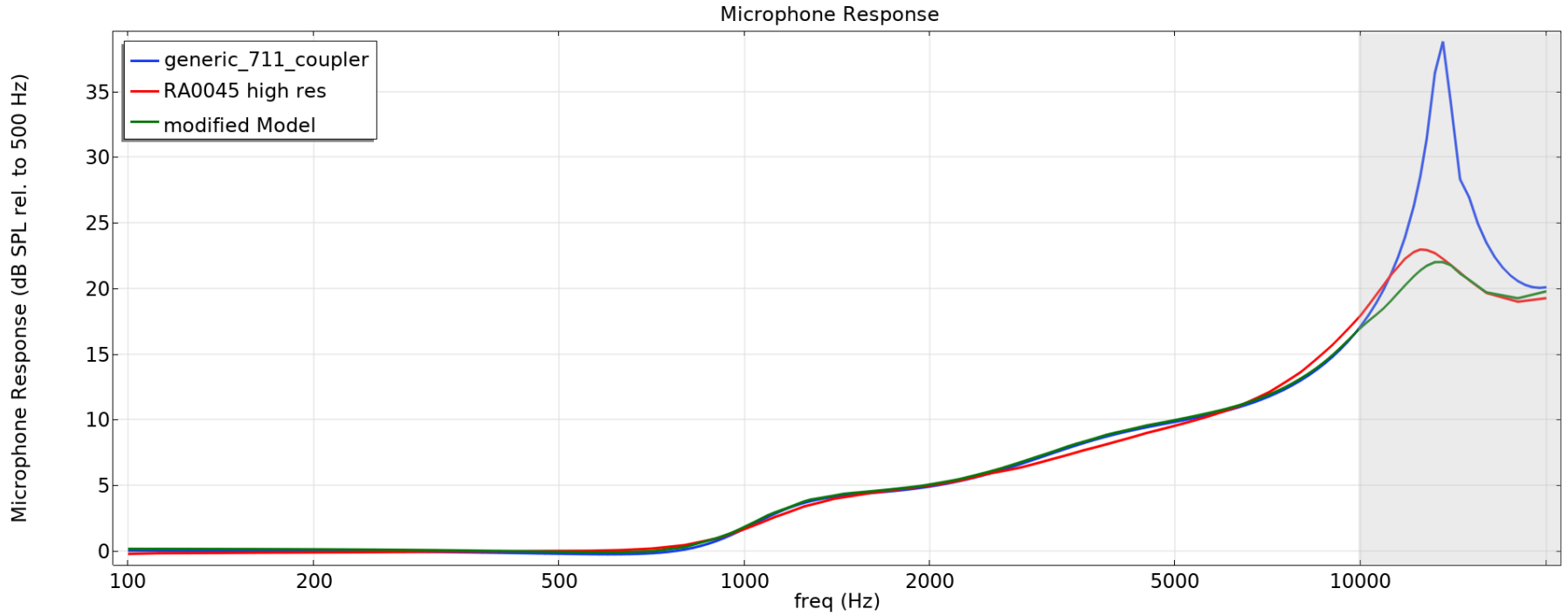
Simulation model
2. MEMS loudspeaker on ear simulator

- MEMS loudspeaker on ear simulator (time domain)
  - ear simulator at the rear side
  - front side radiates into the free field
  - halved → symmetry
  - additional circuit
    - ➢ transmit and receive simultaneously by utilizing the terminal feature



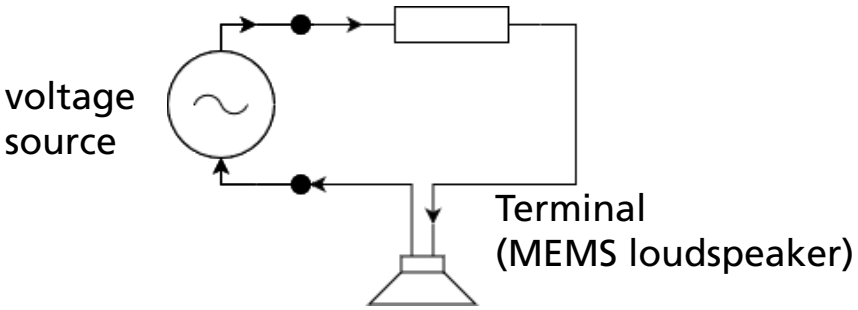
Simulating the ear simulator

- based on „generic_711_coupler“ in the Comsol application library
- Changed to fit high res version of IEC 60318-4 ear simulator

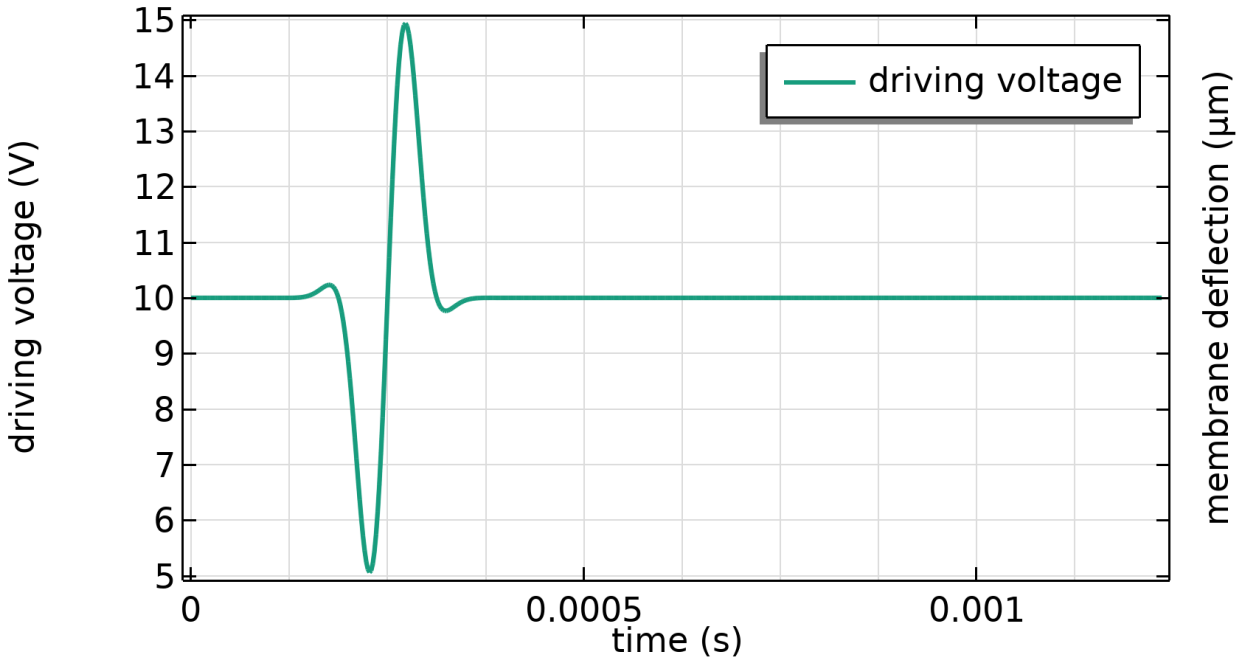


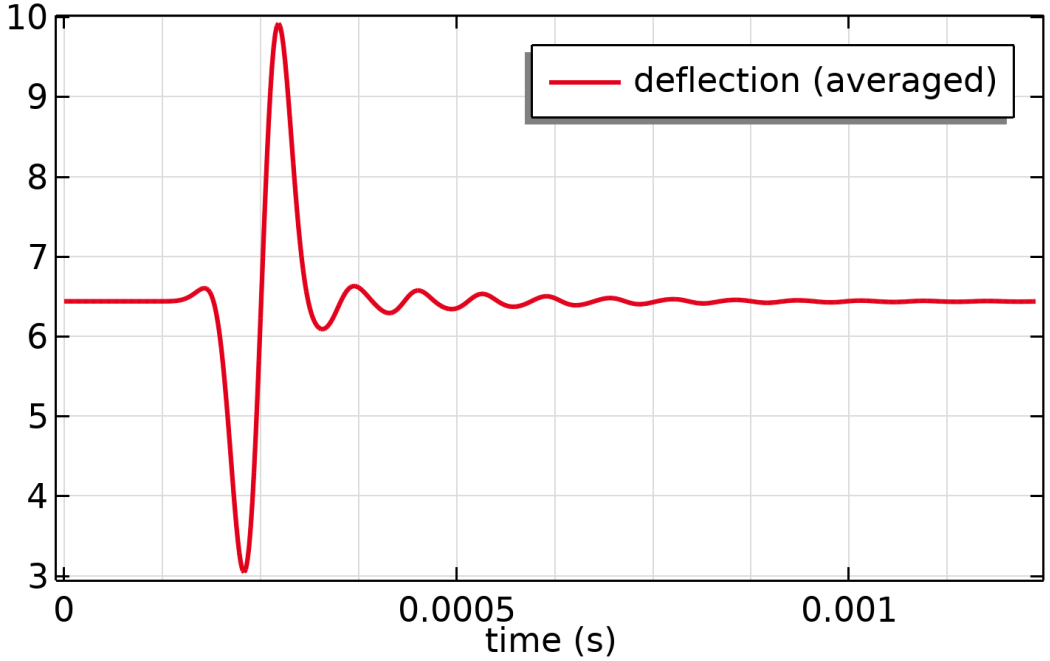
Simulation model

2. MEMS loudspeaker on ear simulator



- simulation results
- transmit and receive simultaneously

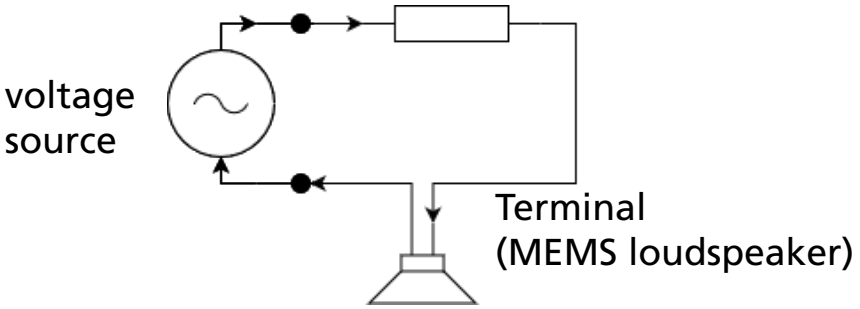




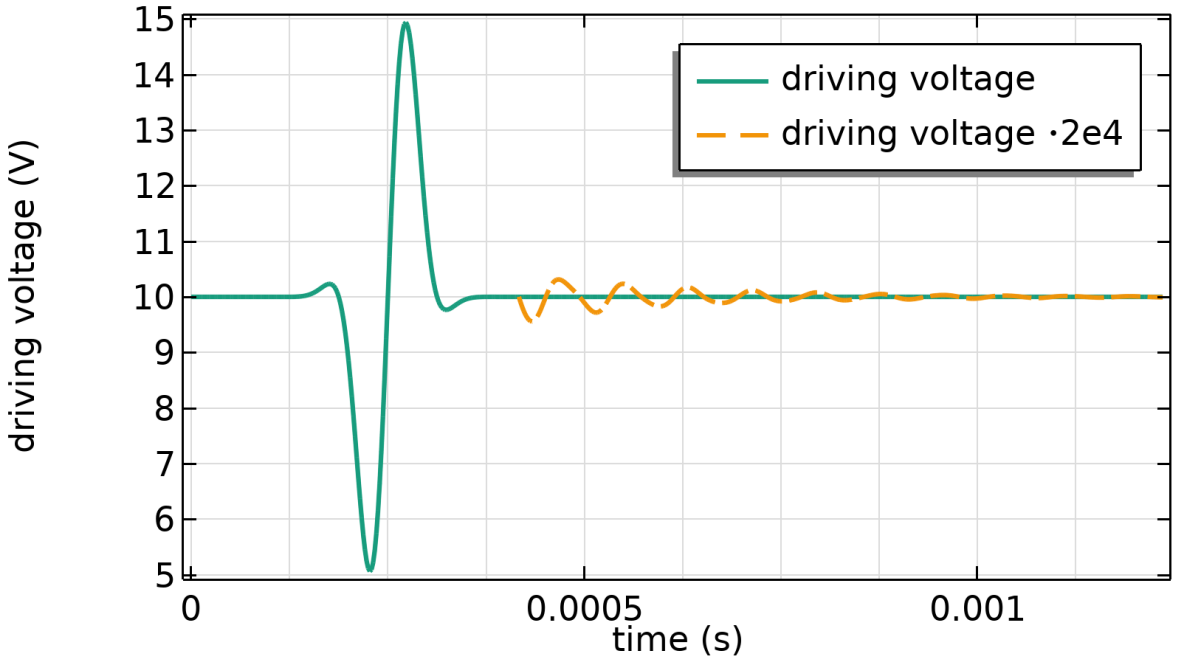
For more information refer to: Jinlan Huang, "How to Model Piezoelectric Devices as Both Transmitters and Receivers", Comsol Blog 20.12.2018

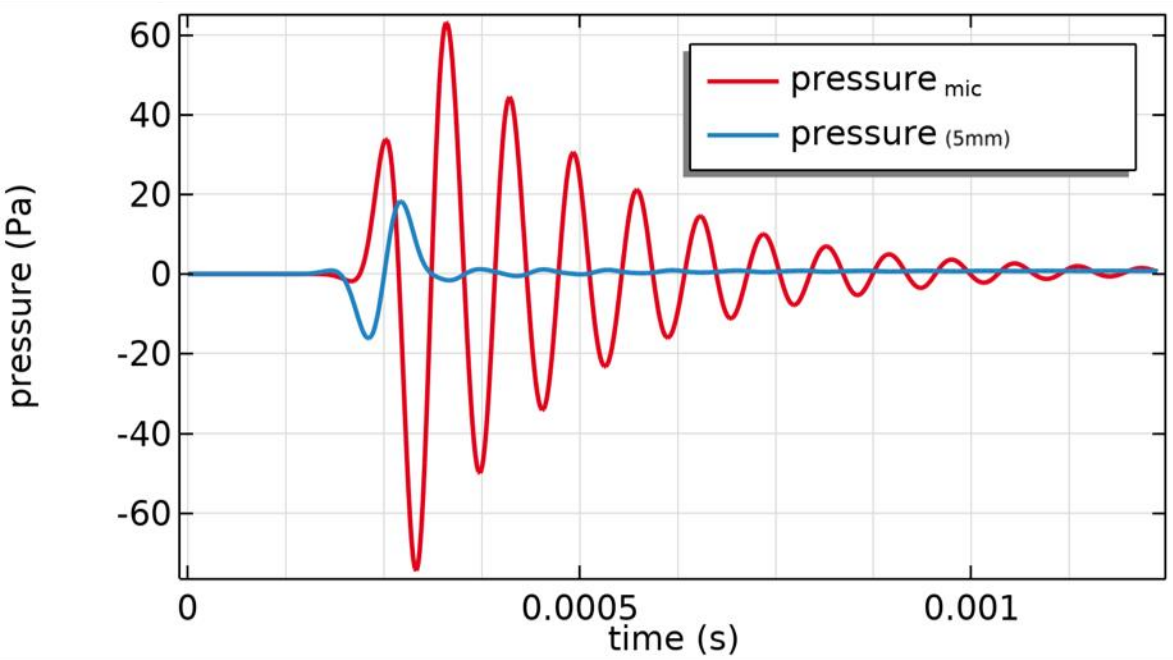
Simulation model

2. MEMS loudspeaker on ear simulator



- simulation results
- transmit and receive simultaneously



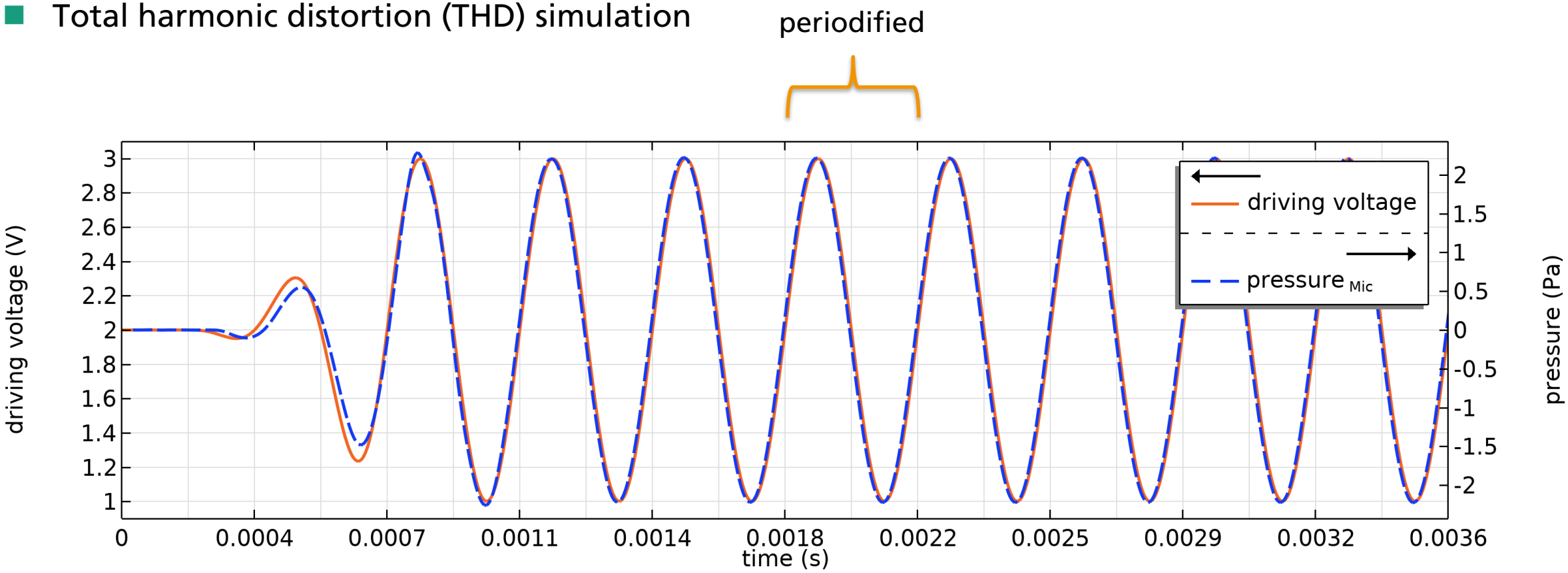


For more information refer to: Jinlan Huang, "How to Model Piezoelectric Devices as Both Transmitters and Receivers", Comsol Blog 20.12.2018

Simulation model

2. MEMS loudspeaker on ear simulator

- Total harmonic distortion (THD) simulation

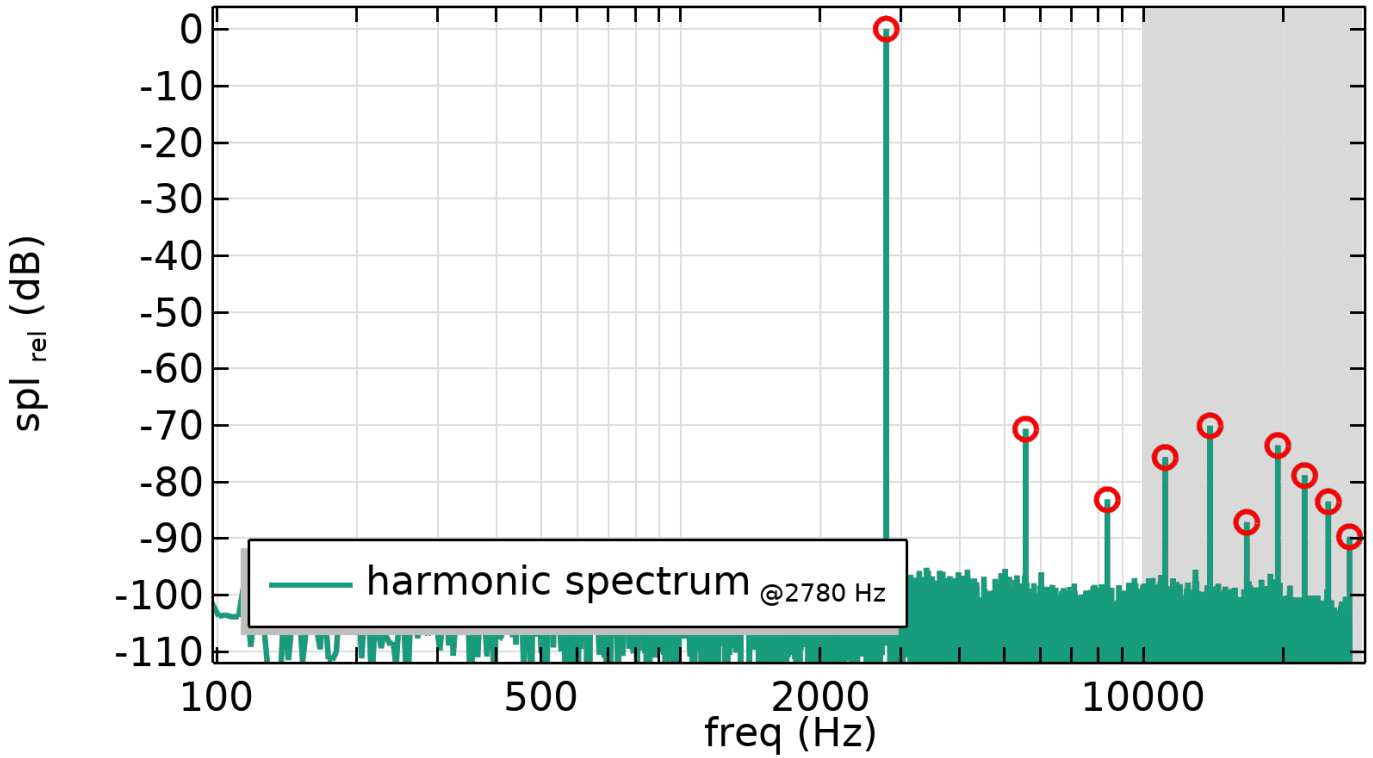


Fraunhofer IDMT

Simulation model
2. MEMS loudspeaker on ear simulator

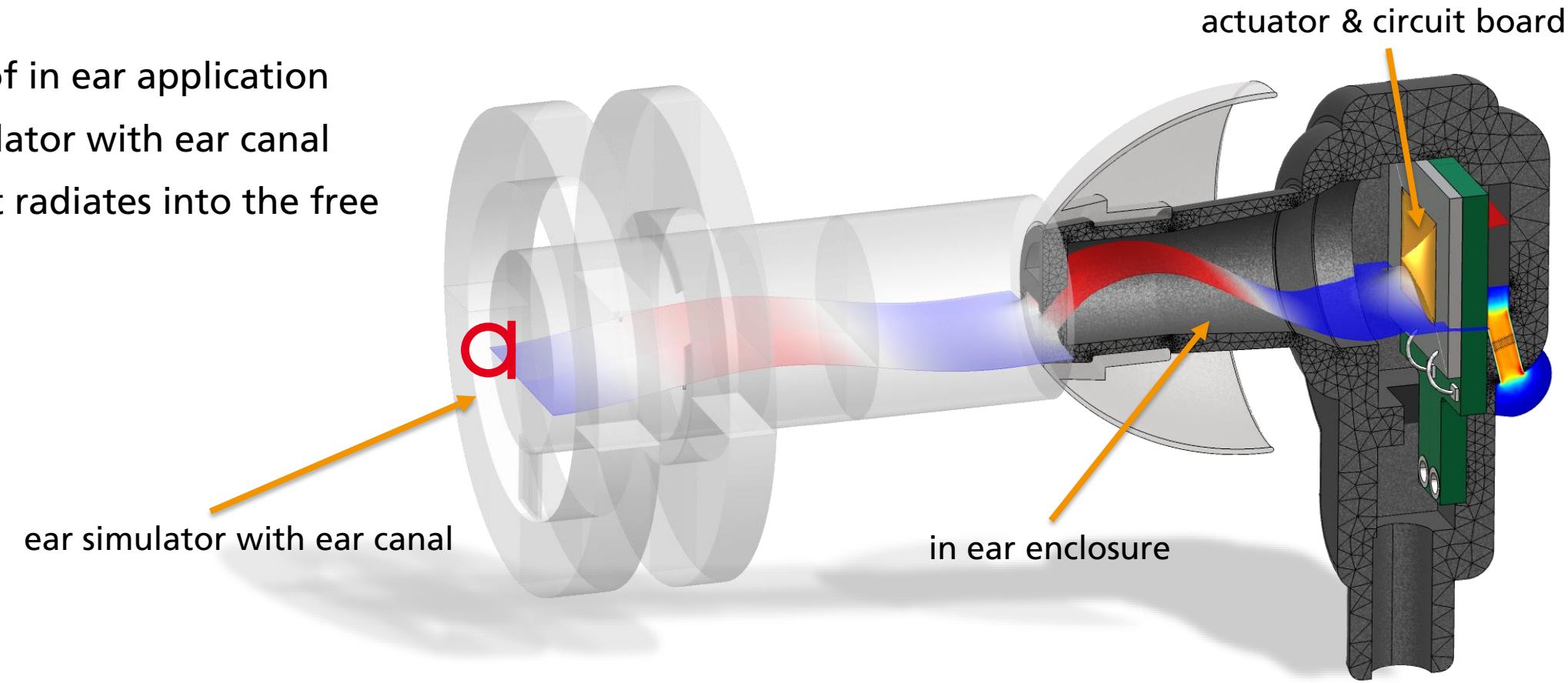
- THD simulation

- additional 1D-component
  - 1 period from mic-signal
  - periodified mic-signal
  - FFT



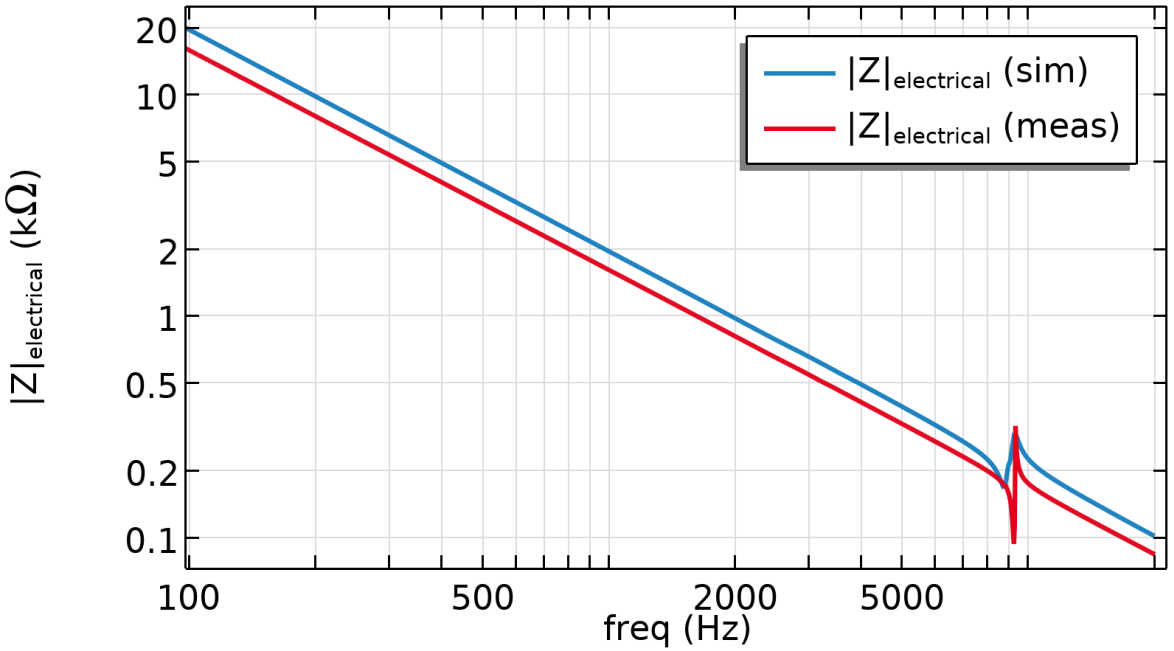
Simulation model
3. in-ear application

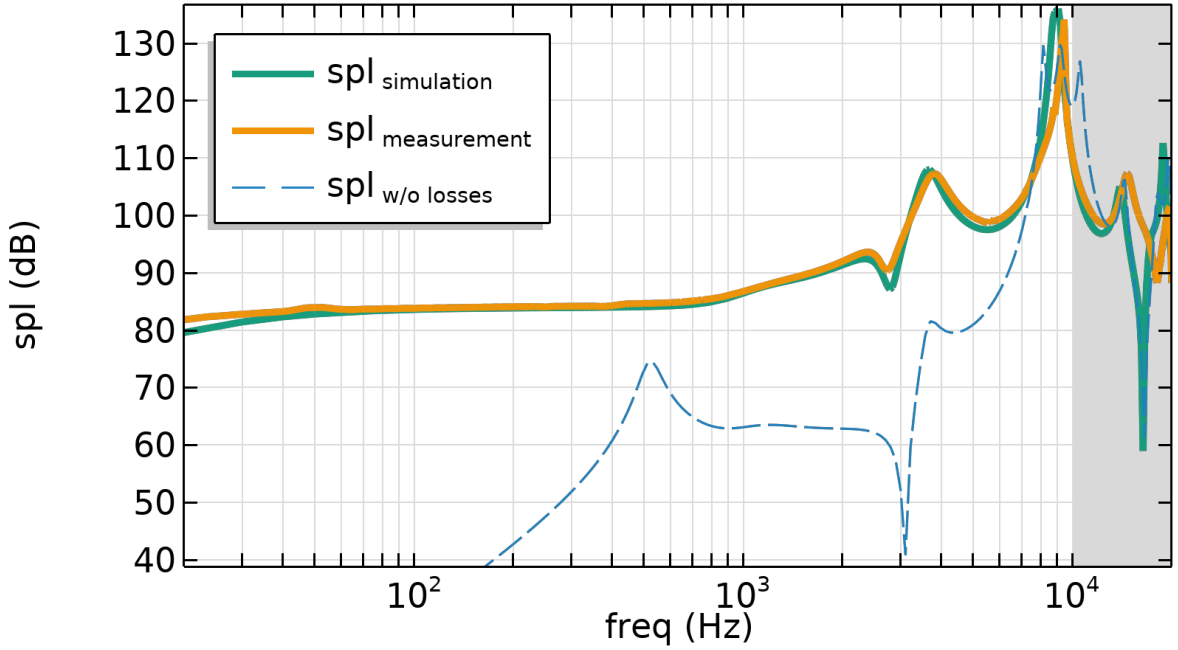
- simulation of in ear application
  - ear simulator with ear canal
  - rear vent radiates into the free field



Simulation model
3. in-ear application

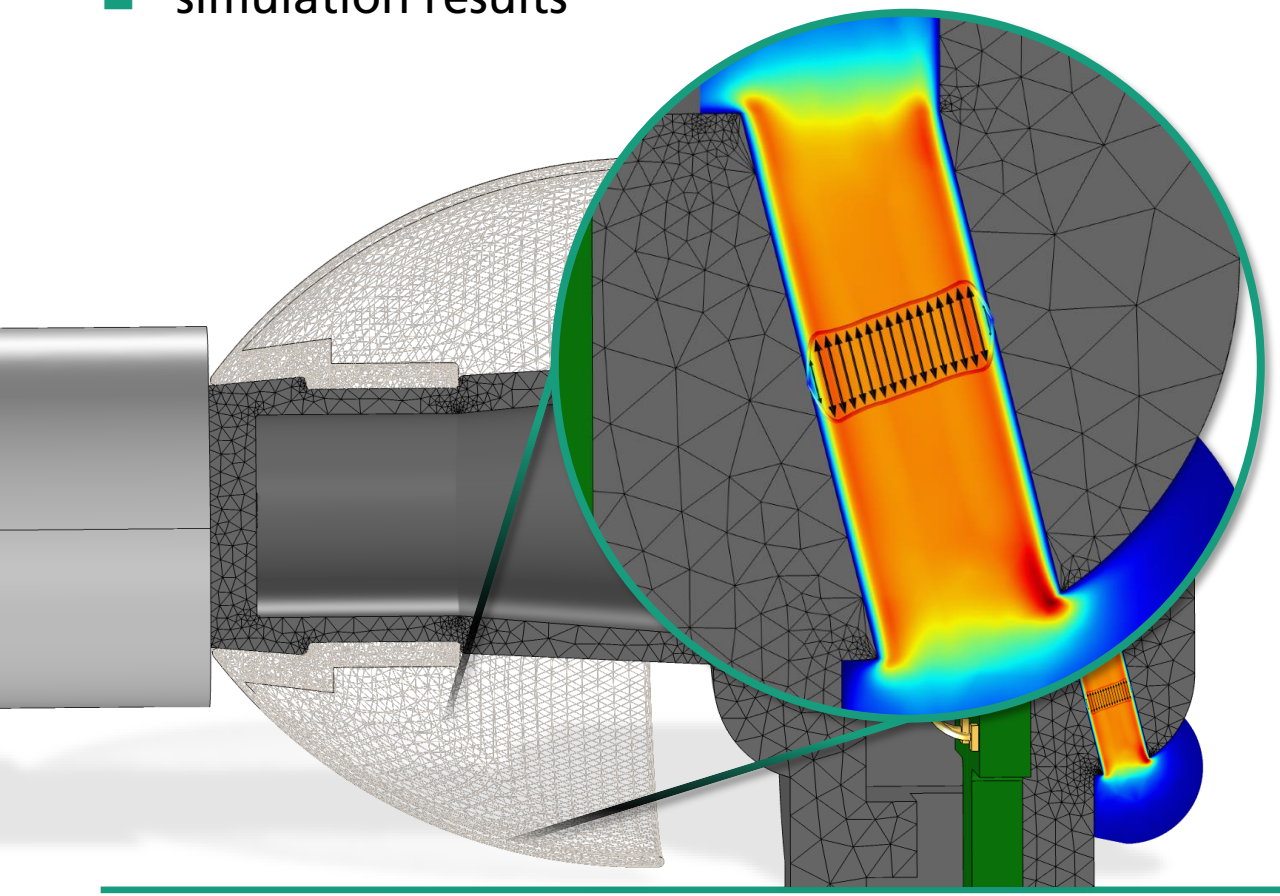
- simulation results

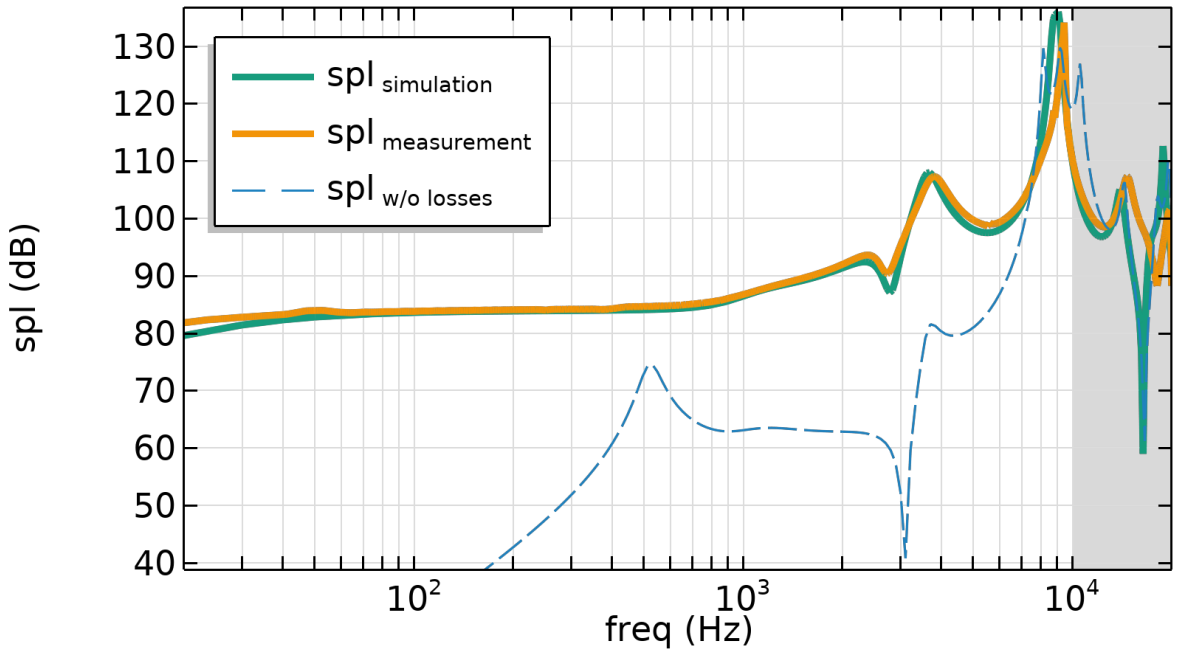




Simulation model
3. in-ear application

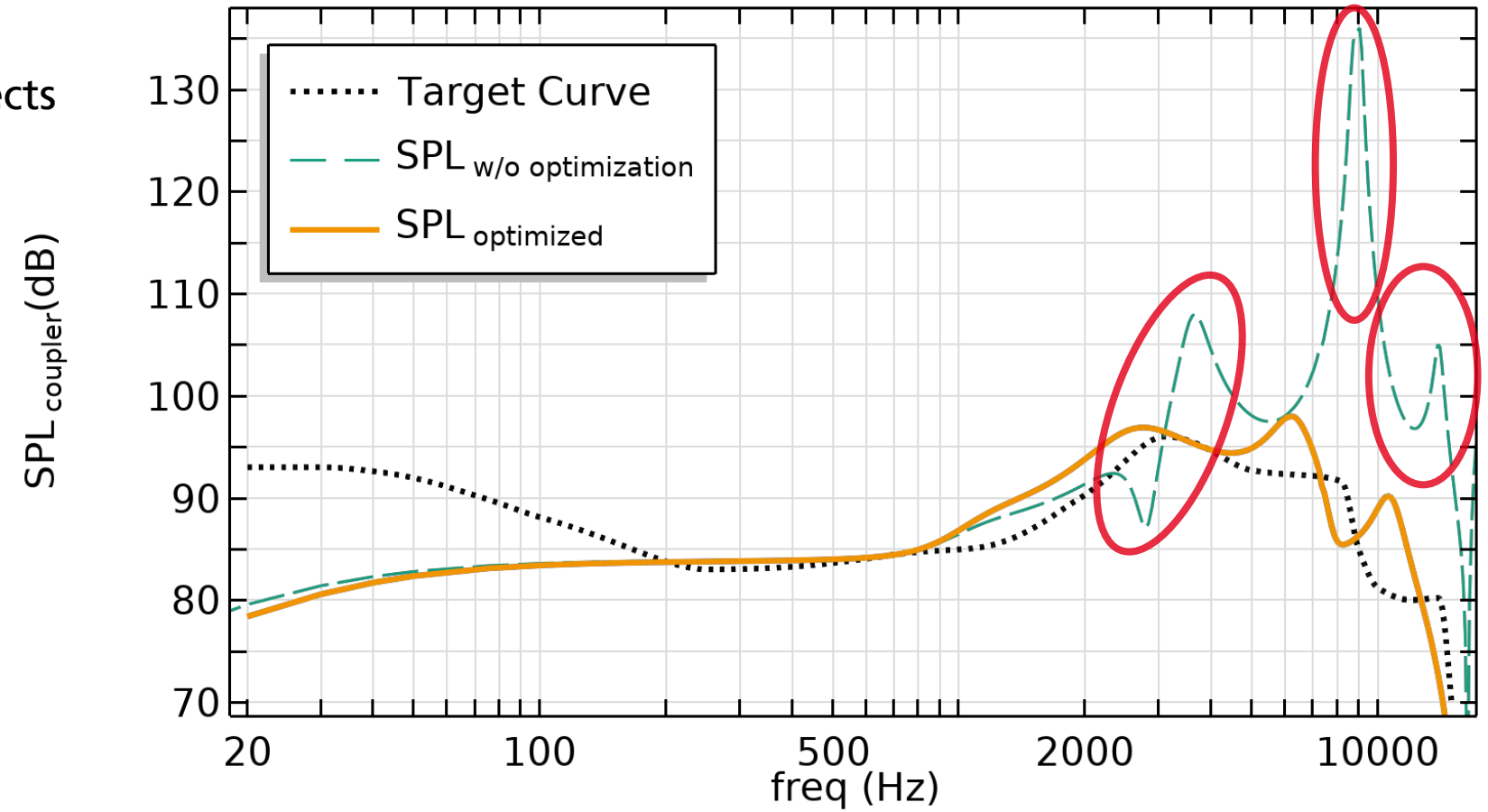
- simulation results





Simulation model
3. in-ear application

- Optimation using thermoviscous effects



SUMMARY

- working samples of early stages of MEMS can be sparse
  - importance of high quality models
- MEMS loudspeaker require combination of different areas of physics
- meshing can be challenging due to high deviation of geometrical dimension
  - µm MEMS structures vs. meters for free field radiation
- thermoviscous effects need to be considered which can be of high computational cost
- much potential for saving computation time with careful design
- THD important for human perception of sound quality
  - nonlinear time domain simulation required

➢ in the end the effort pays out! Very accurate simulations are possible

THANK YOU VERY MUCH FOR YOUR ATTENTION!

Jan Küller

E-Mail: jan.kueller@idmt.fraunhofer.de

Phone +49 3677 467-164

Tobias Fritsch

E-Mail: tobias.fritsch@idmt.fraunhofer.de

Phone +49 3677 467-211