Simulation of Couplers

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Brüel & Kjær

AES, Workshop 7, 2003 March 23rd

Agenda

- Introduction to Couplers
- Traditional Simulation using LPM
- FEM/BEM Simulation
- Comparison of Results
- Conclusion

Introduction to Couplers

Critical properties of Acoustic Couplers

- Must allow for REPEATABLE measurements
- Must be possible to CALIBRATE
- Must be ACCURATE and STABLE
- Should be STANDARDIZED

- Design to improve voice quality & intelligibility
- Design to meet telecom & audio standards
- Comparison of transducers, headsets, handsets, earphones etc.

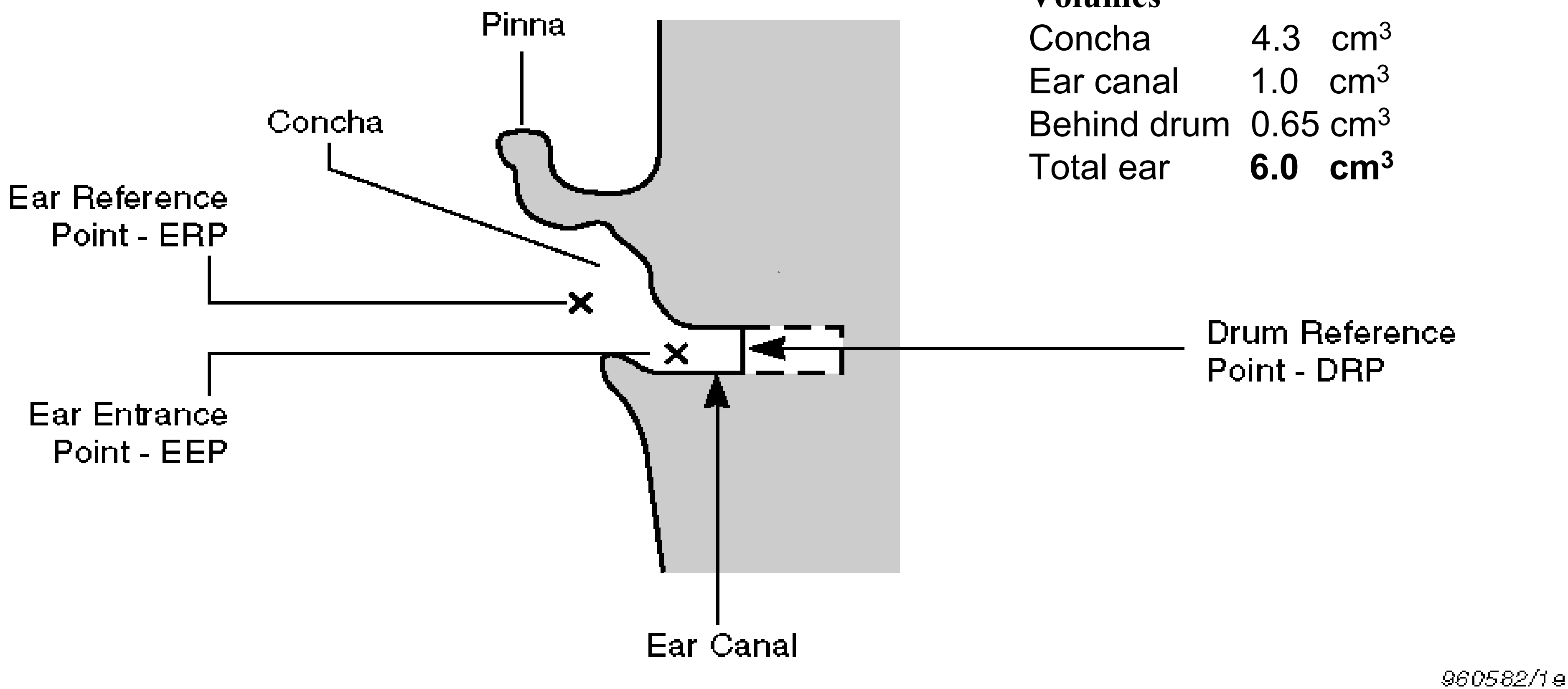
Acoustic Couplers overview

- **IEC 318 (ITU-T P.57 Type 1) Ear Simulator**
- **IEC 711 (ITU-T P.57 Type 2) Ear Simulator**
- **ITU-T P.57 Type 3.1 Concha bottom Simulator**
- **ITU-T P.57 Type 3.2 Simplified Pinna Simulator**
- **ITU-T P.57 Type 3.3 Pinna Simulator**

Increasing realism & complexity

Ear Simulators and Standards

Ear Anatomy and Definitions



Volumes

Concha	4.3	cm^3
Ear canal	1.0	cm^3
Behind drum	0.65	cm^3
Total ear	**6.0**	**cm^3**

Ear Simulators and Standards

ITU-T Type 2 - IEC 711 occluded ear simulator

- Standardized - accepted as a reference worldwide
- Bruel & Kjær Type 4157 (and used in 4158/59/95)
- Intented for calibration of insert earphones, sealed and unsealed (hearing aids) in the frequency range from 100-7.000Hz
- Simulates the ear canal from app. 10mm behind EEP and in

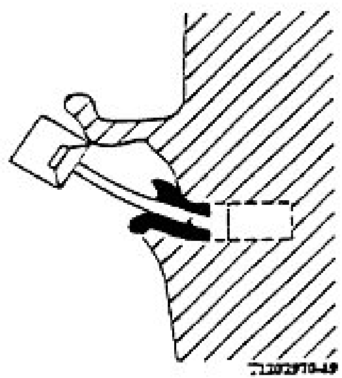


FIGURE 5b/P.57

Insert (closed)

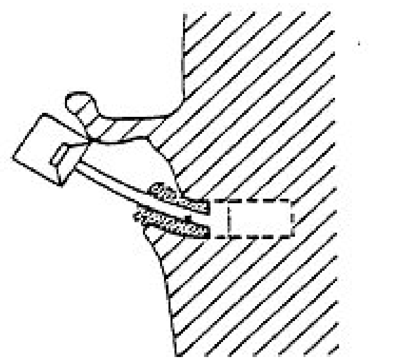
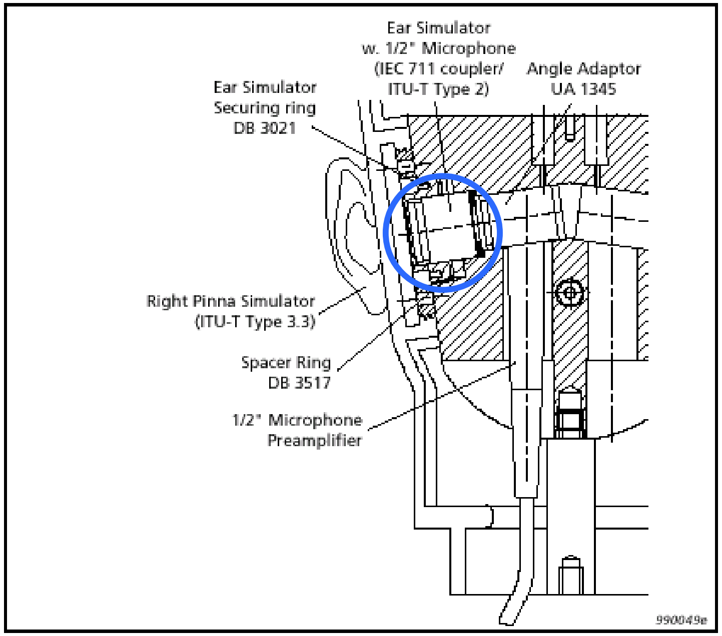


FIGURE 5a/P.57

Insert (open)



Ear Simulators and Standards

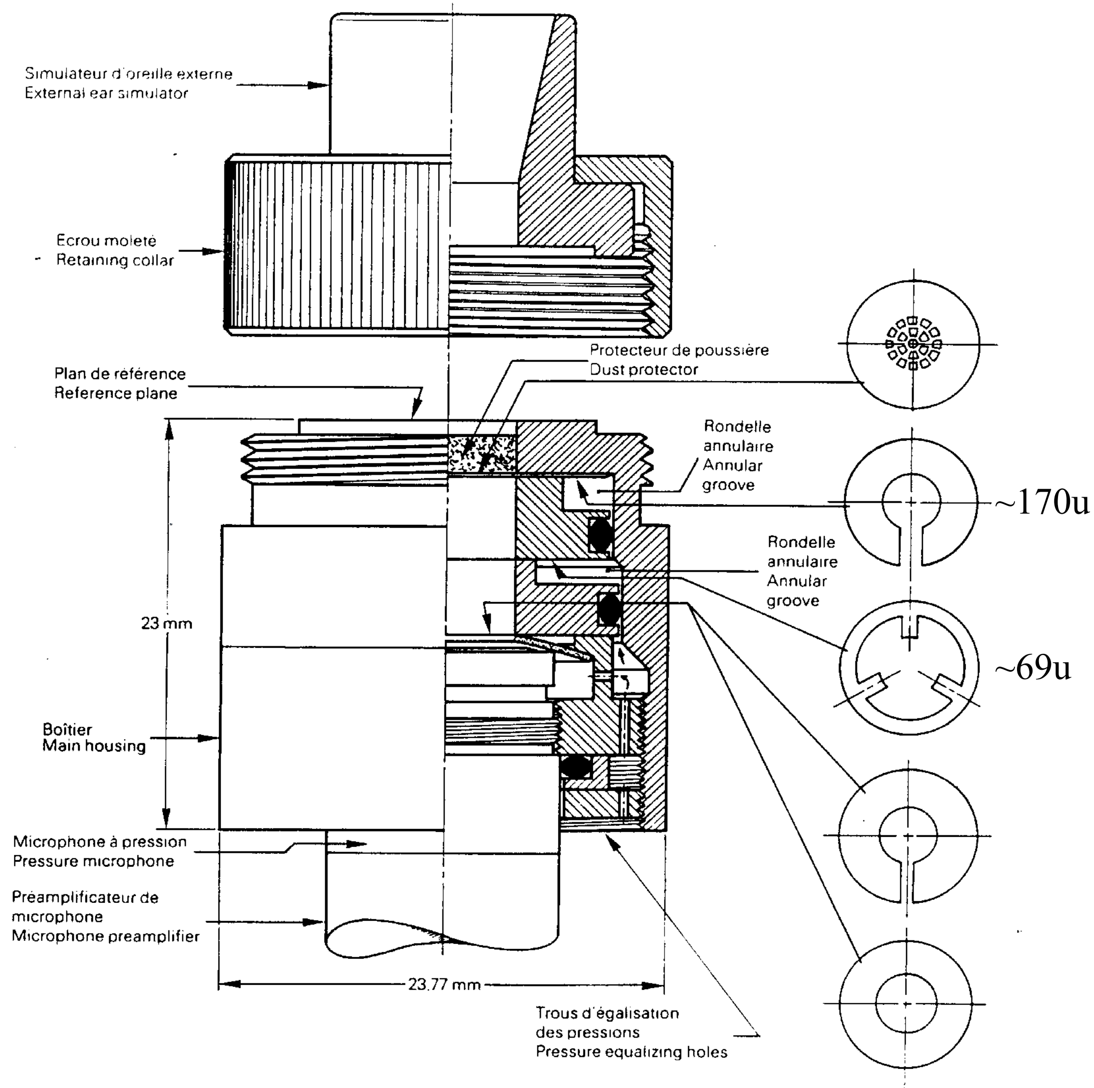
IEC 711 coupler:
Requirements in according to standard:

Acoustical transfer impedance specified

Equivalent volume at 500Hz equal to 1.26cm3

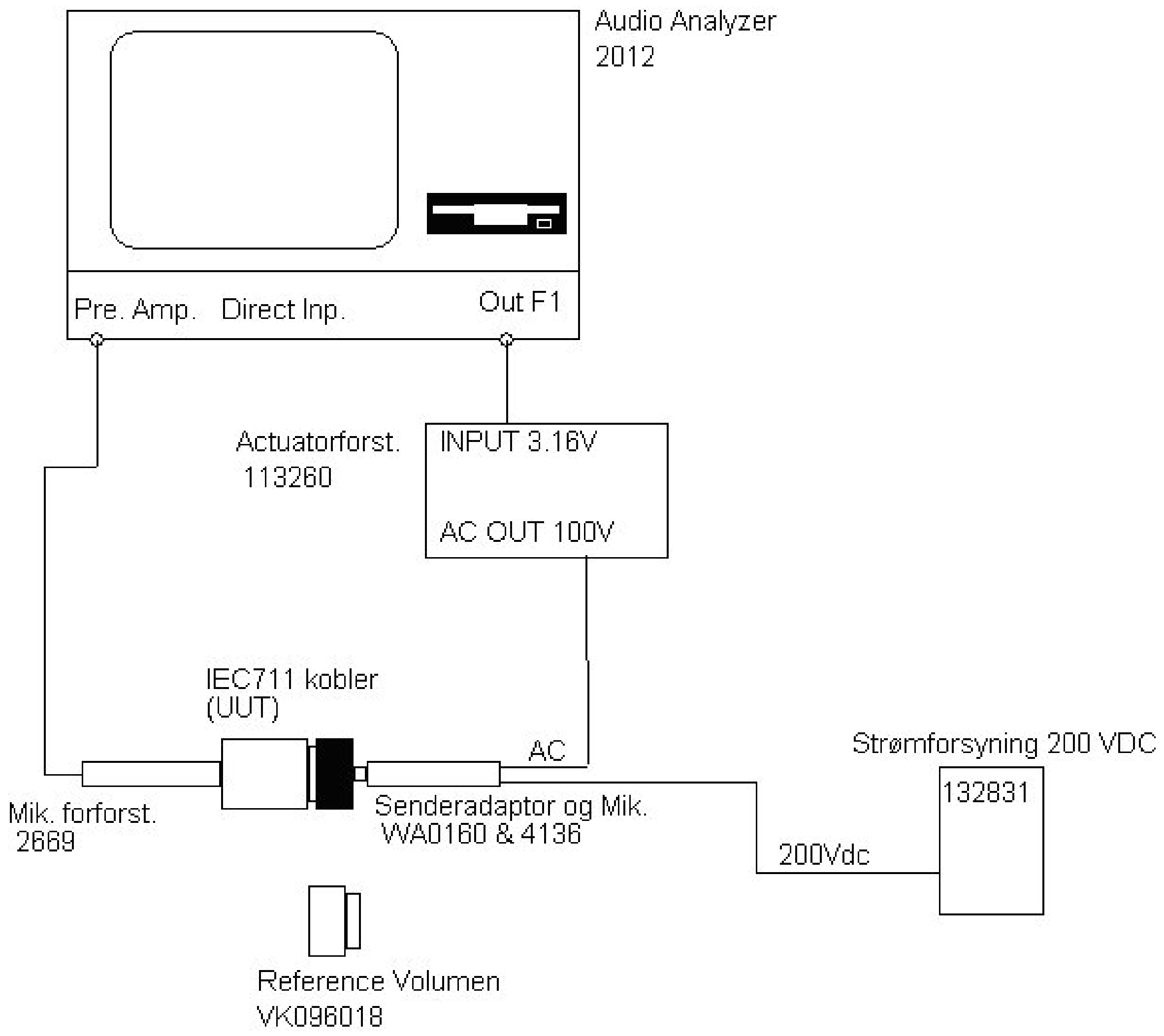
With of principal volume 7.5mm

Length of principal volume must produce ½-wavelength resonance at 14kHz, i.e. ~12.4mm

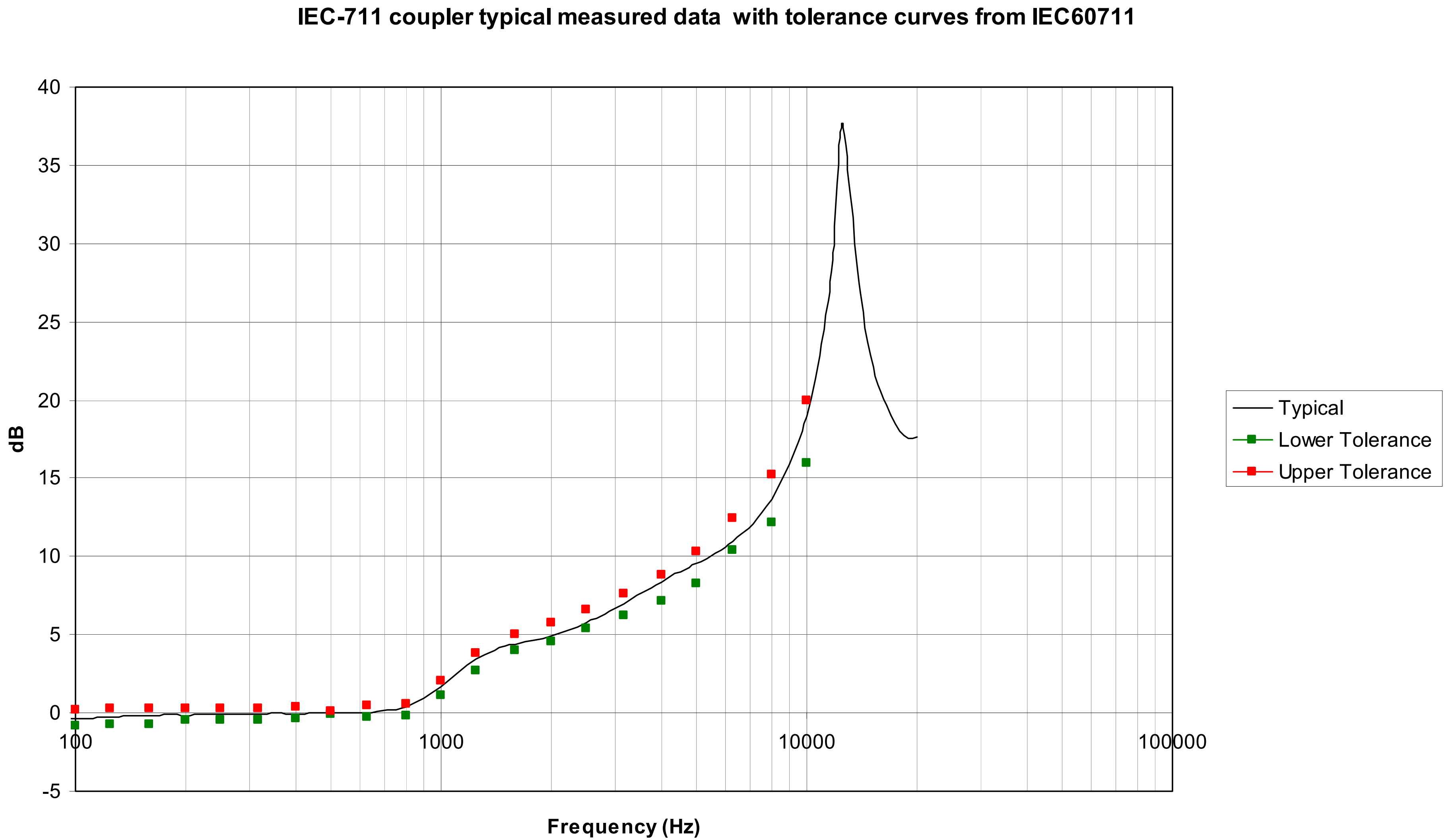


Ear Simulators and Standards

IEC711 coupler
Setup for measuring transfer impedance

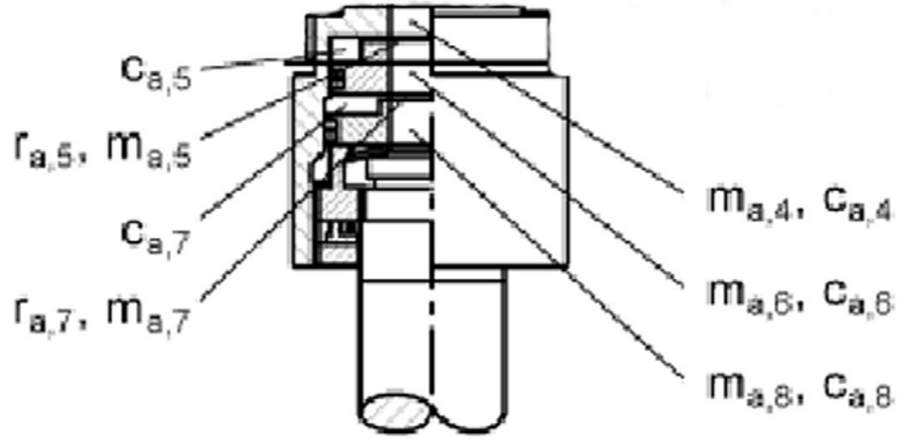


Ear Simulators and Standards



Traditional Simulation Using LPM

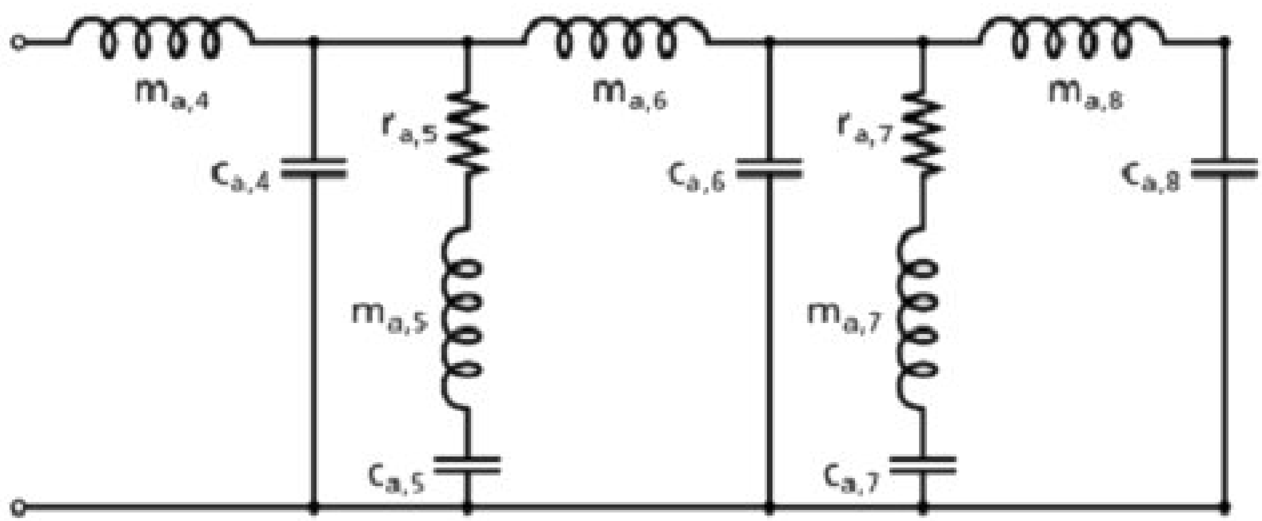
Ear-canal impedance:
Tube w. ridgid walls analog
to an LC transmissionline, i.e:



$$C_{at} = \frac{V_{at}}{\rho c^2} = C_{a,4} + C_{a,6} + C_{a,8}$$

$$Z_c = \frac{\rho c}{A}$$

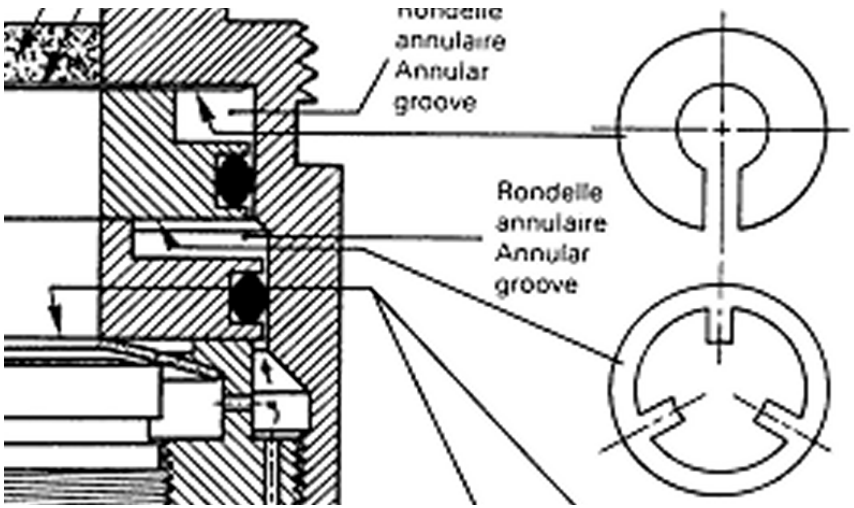
$$M_a = C_{a,n} Z_c^2$$



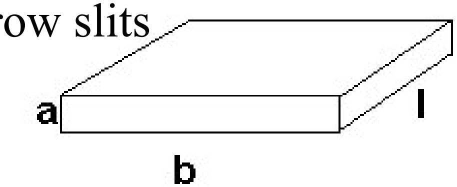
Traditional Simulation Using LPM

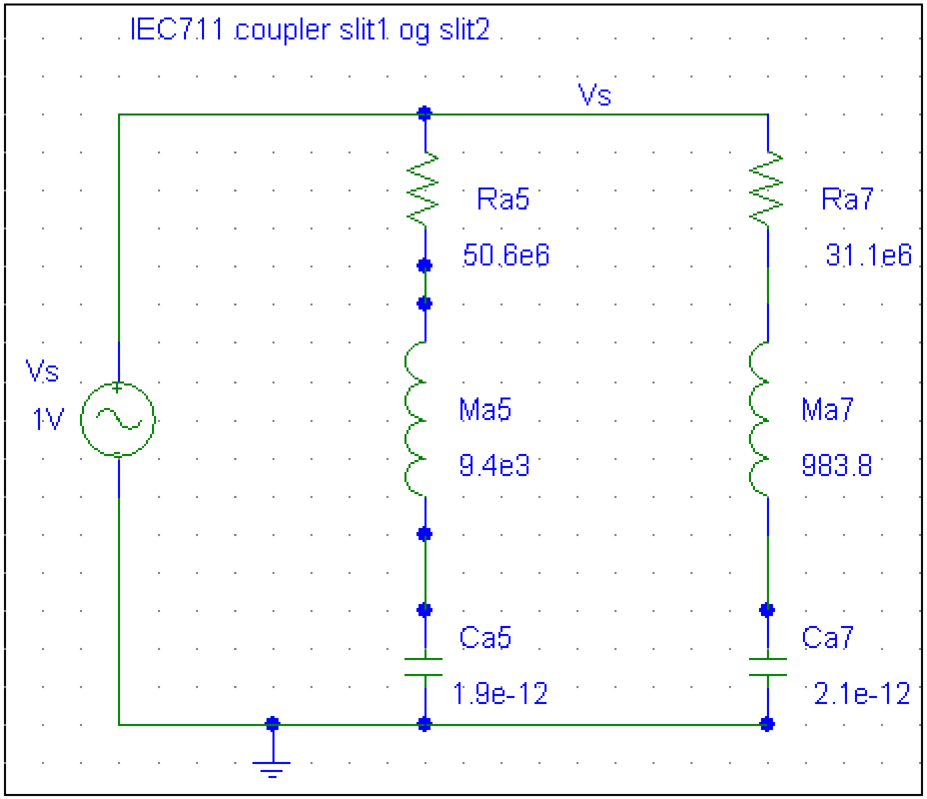
Ear drum impedance:
Two slits terminated by volumes,
i.e. RLC-helmholtz resonators
tuned to match drum-impedance

$$Z_a = \frac{12nl}{a^3 b} + j\omega \frac{6}{5} \frac{\rho l}{ab}$$

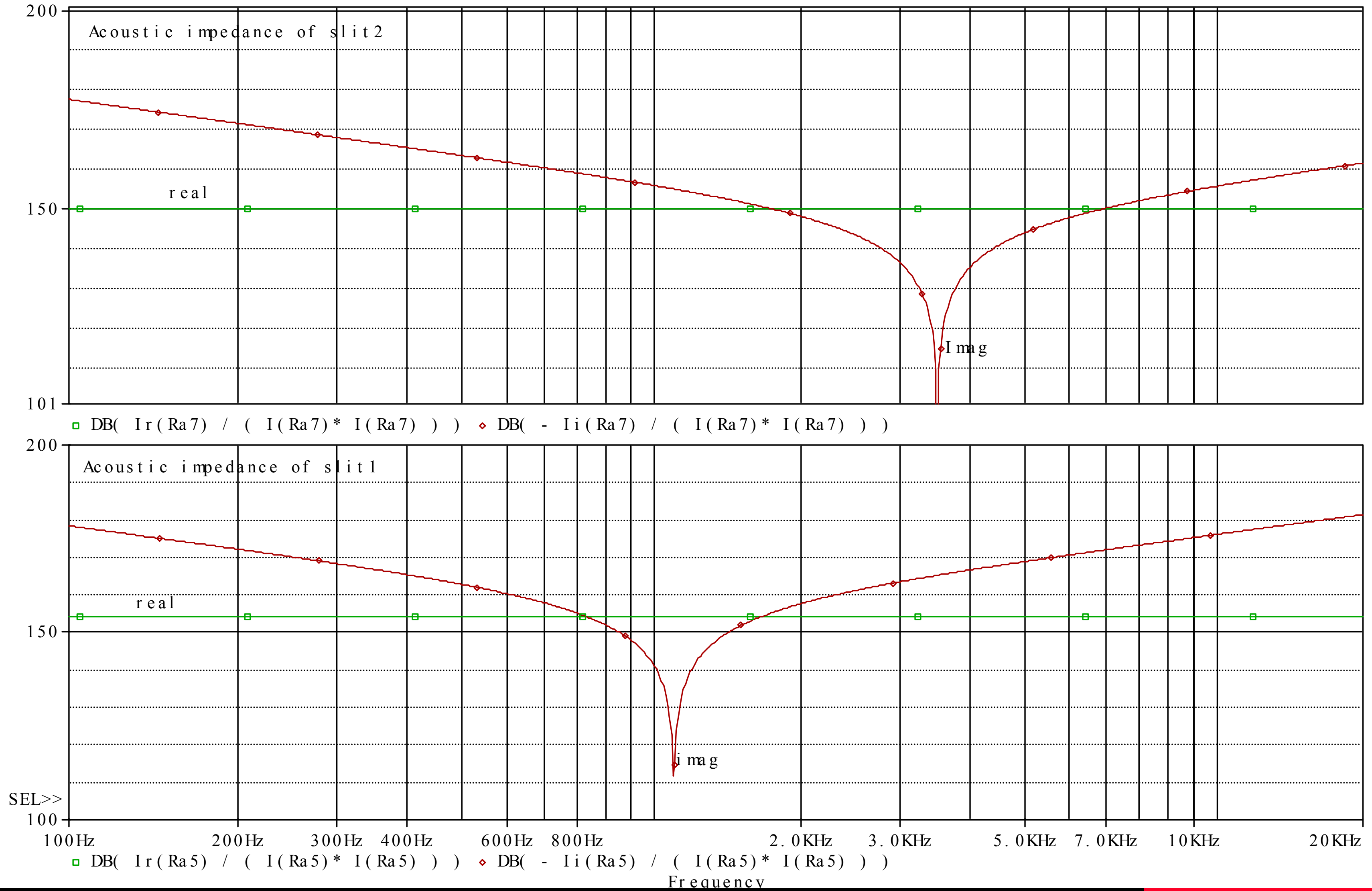


Narrow slits



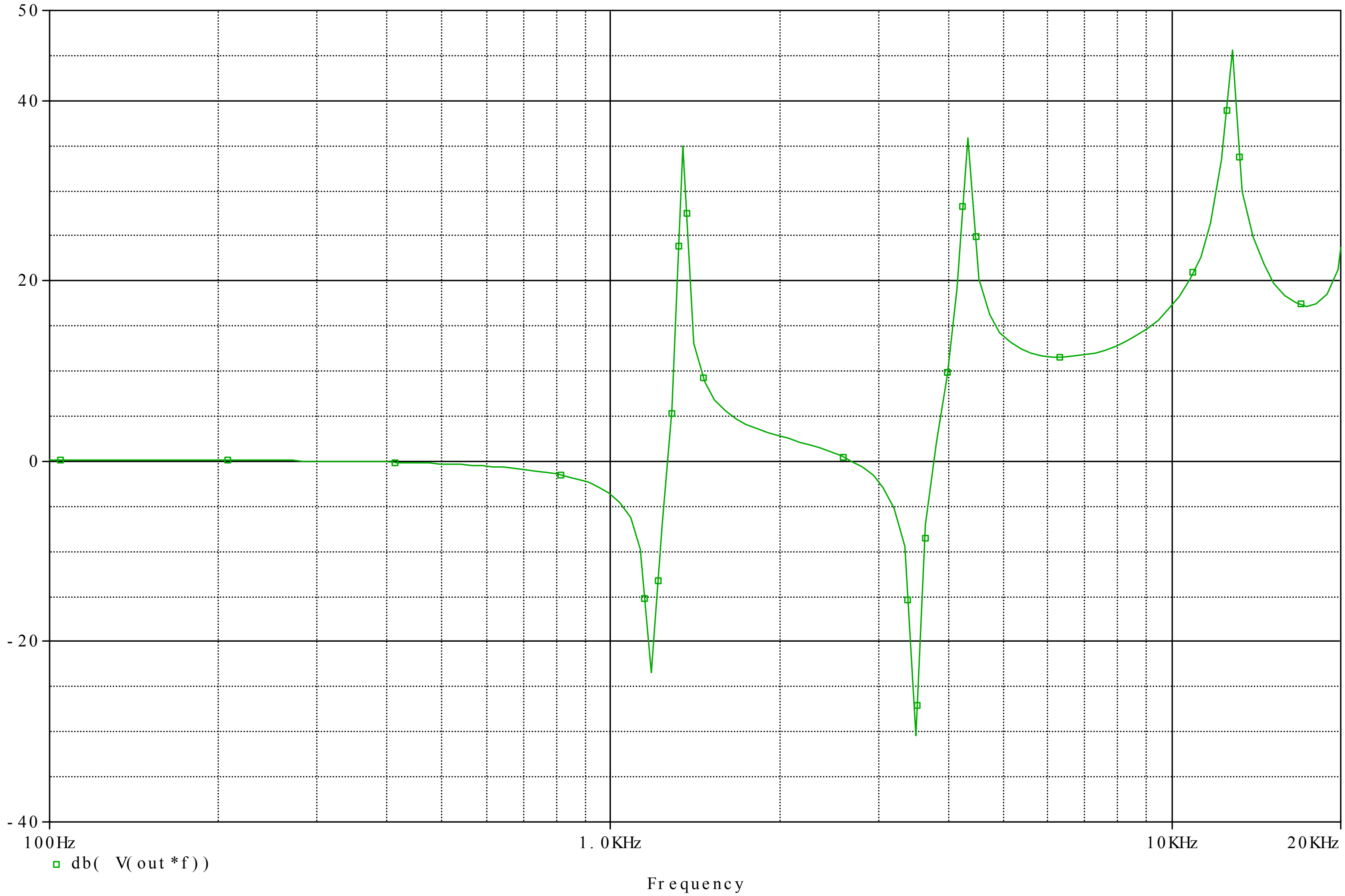


Traditional Simulation Using LPM



Traditional Simulation Using LPM

IEC-711 coupler
LPM simulation
Undamped resp.



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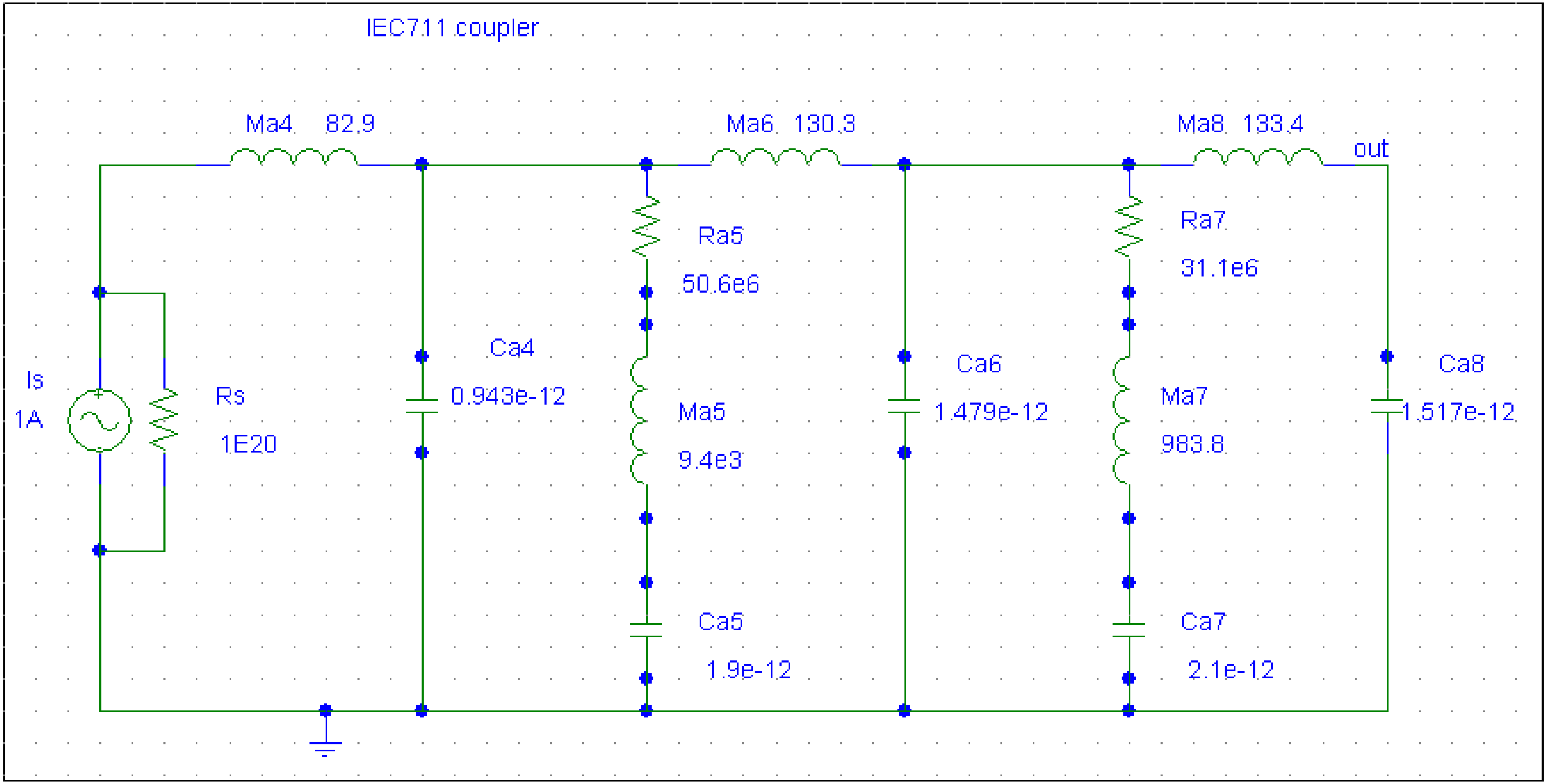
Traditional Simulation Using LPM



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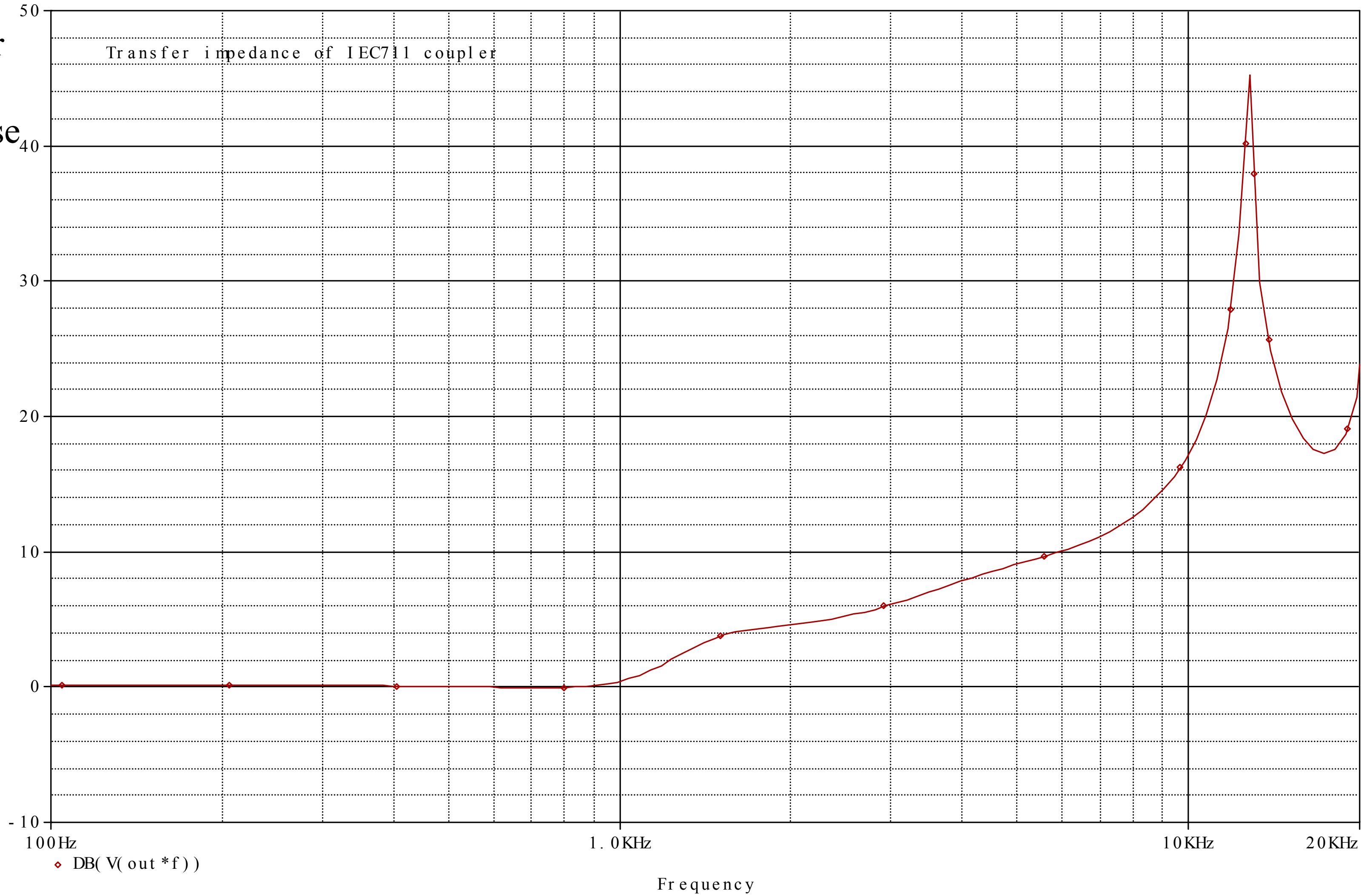
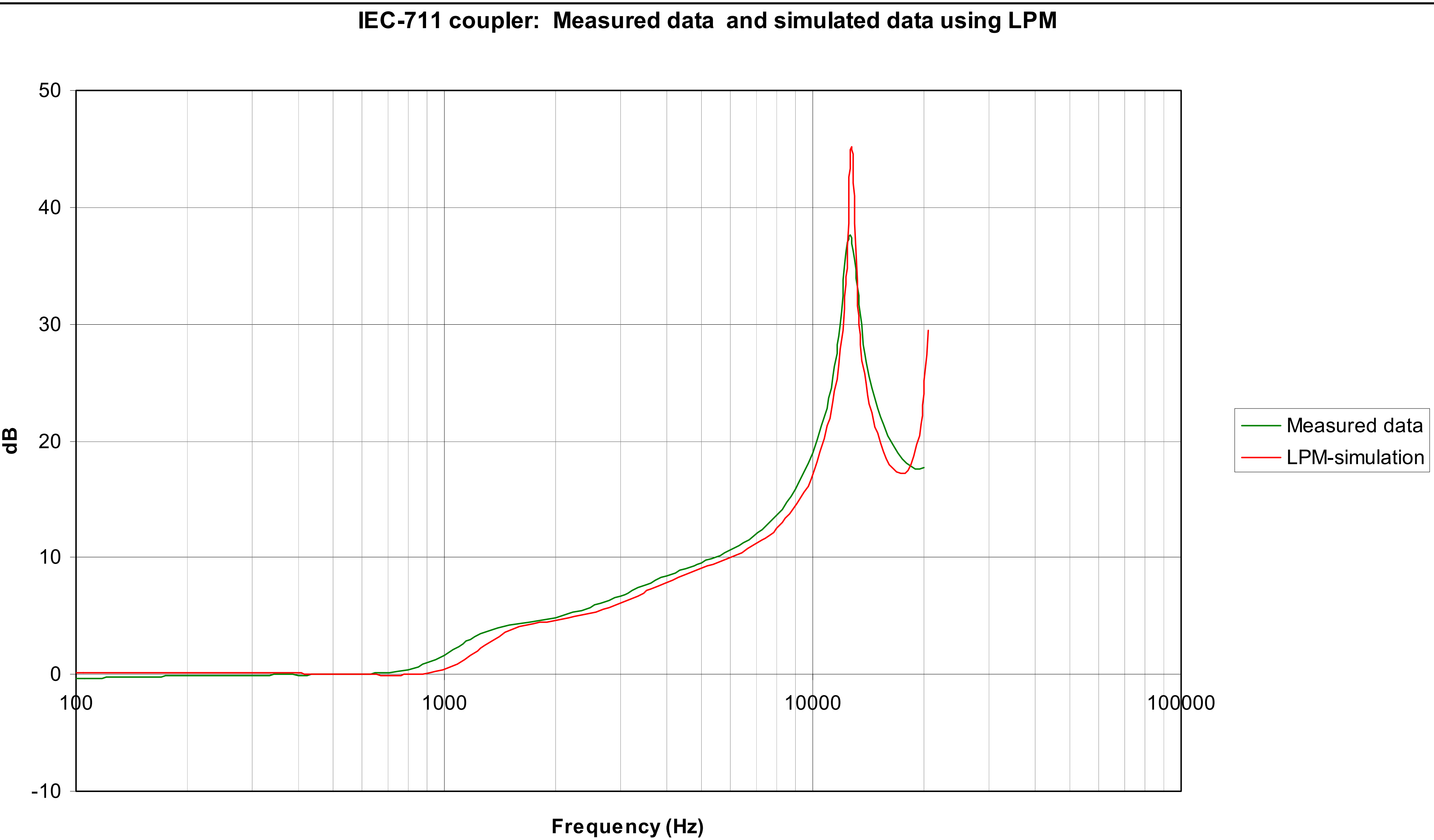
Traditional Simulation Using LPM

IEC-711 coupler
LPM simulation
Damped response



Transfer impedance simulation (LPM)



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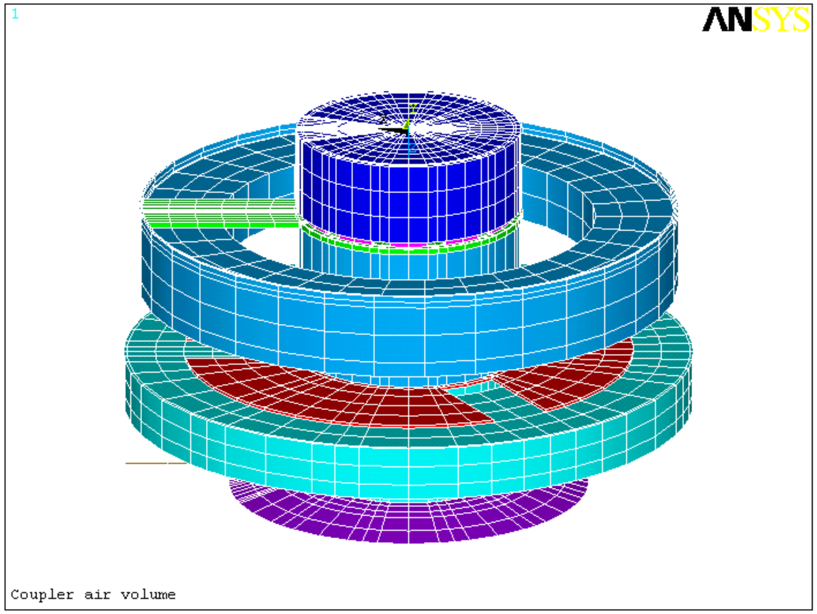
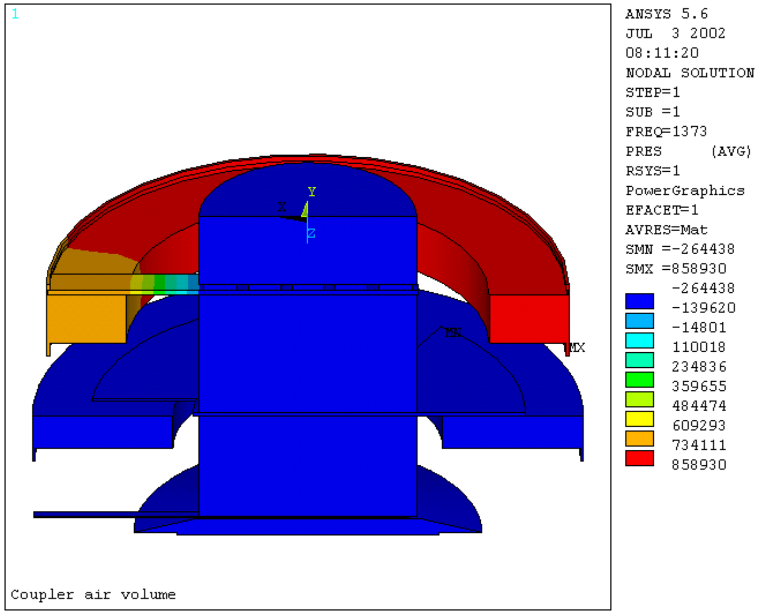
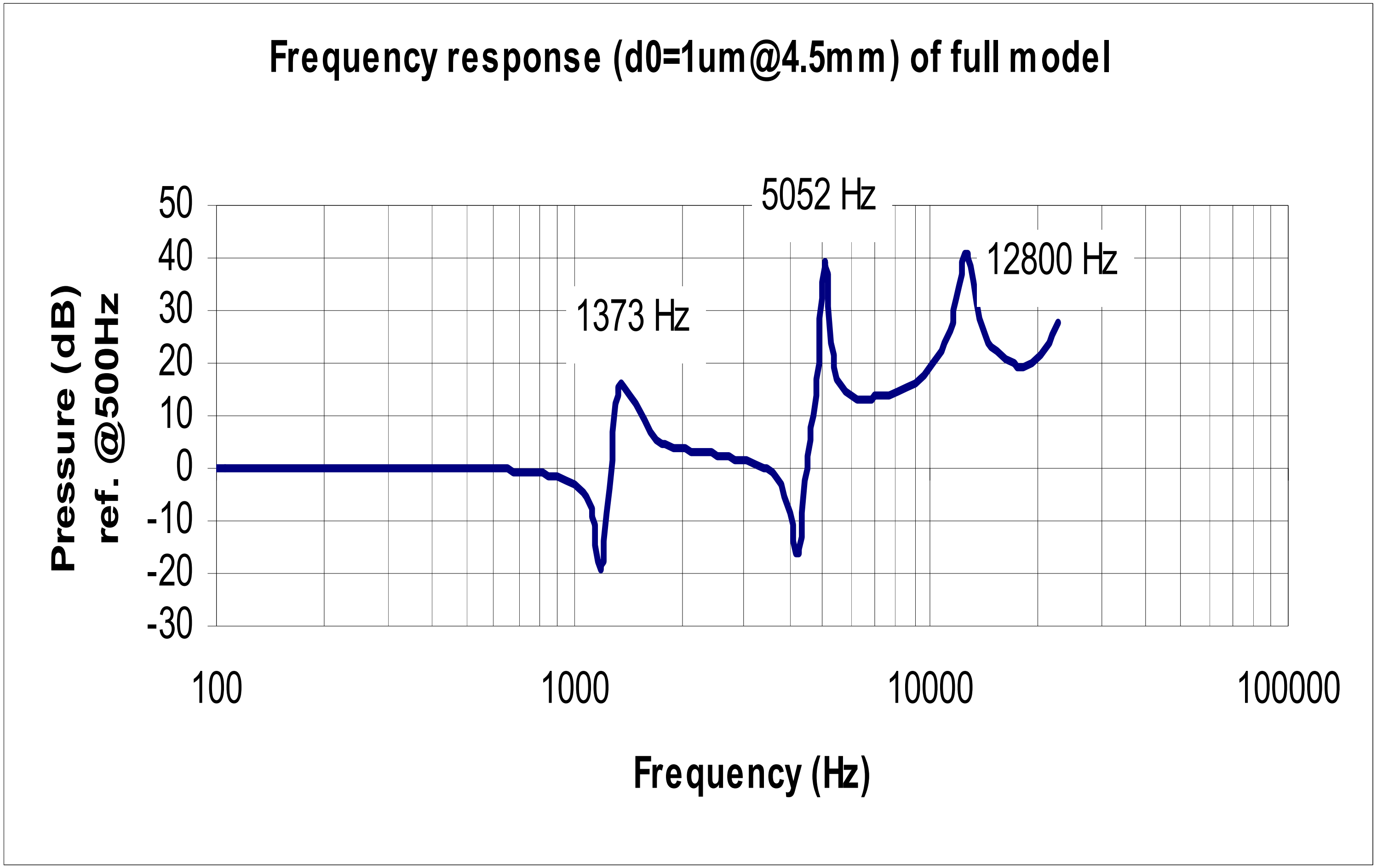
Standard FEM Simulation

- Numerical model solving the Helmholtz equation inside the coupler
- Models the air inside without visco-thermal effects (loss-free)
- Allows for computation of acoustic modes (frequency and mode shape)



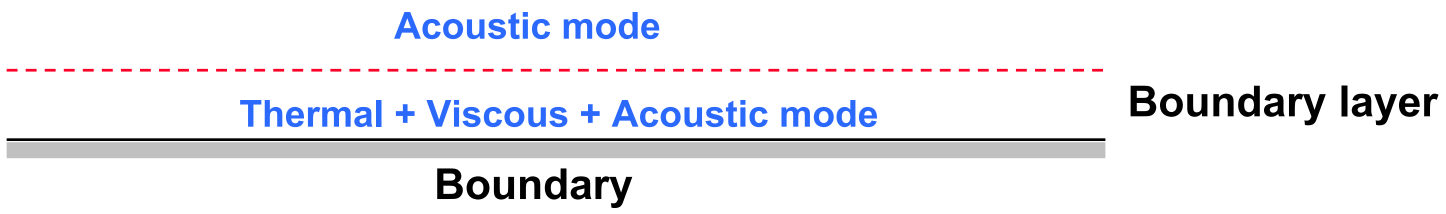


Transfer impedance simulation (FEM)



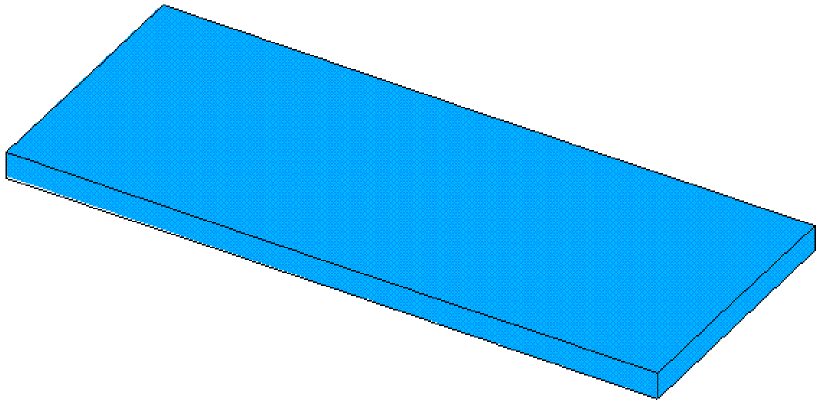
Visco-Thermal fluid

- Thermal conductivity and viscosity play a role near the boundaries
- The thermal & viscous mode only exist within a small boundary layer
- In large spaces, the acoustic mode dominates

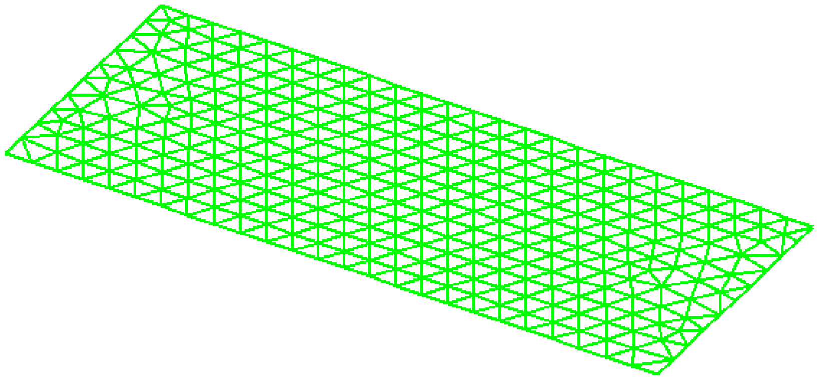


Visco-Thermal FEM

- Finite Element model based on the narrow gap equation
  - const. pressure/zero particle velocity in thickness direction
  - small gap width compared with acoustic wavelength
- No need to mesh in the thickness direction
- Includes visco-thermal effects

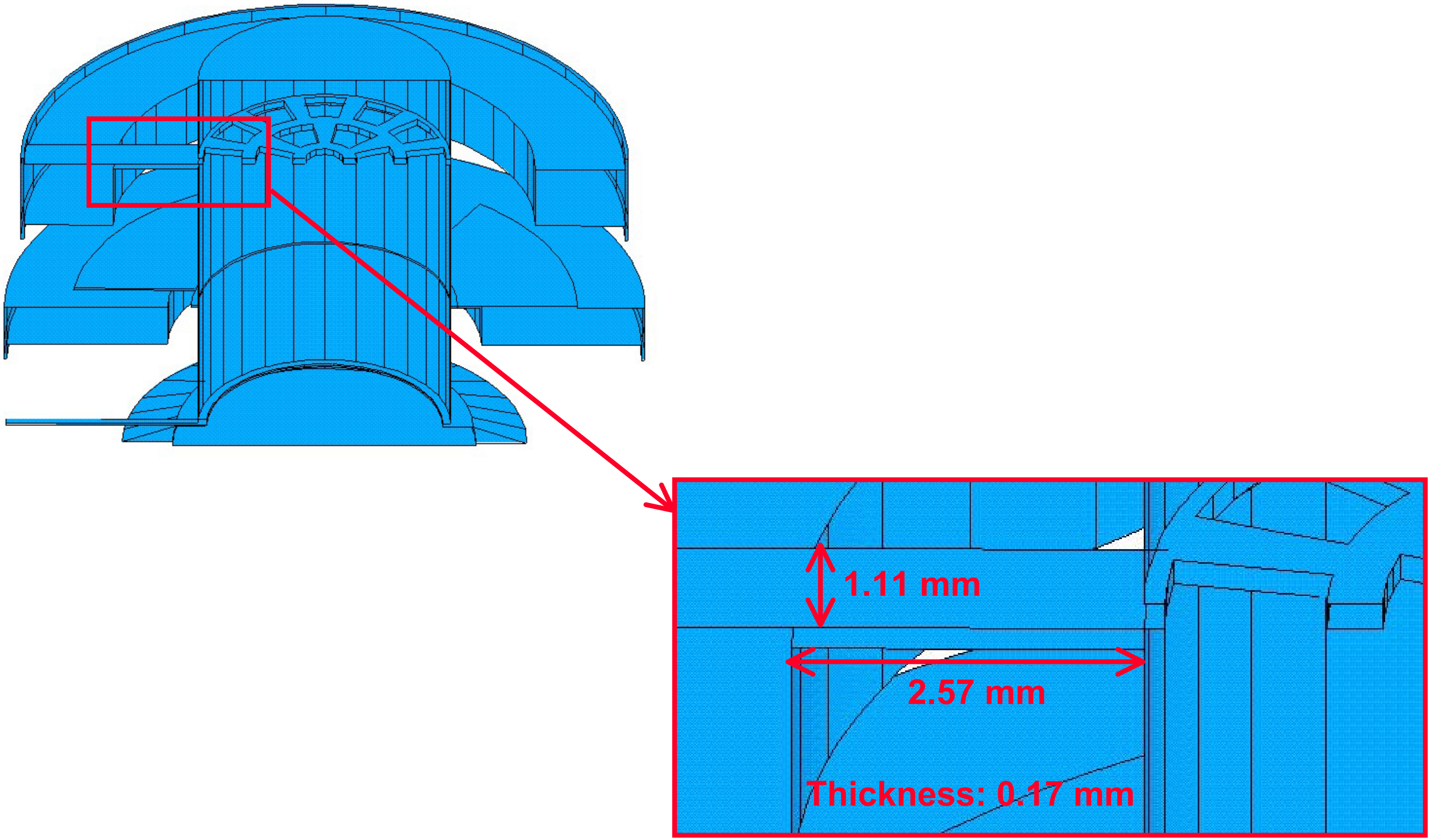


Thin Slit

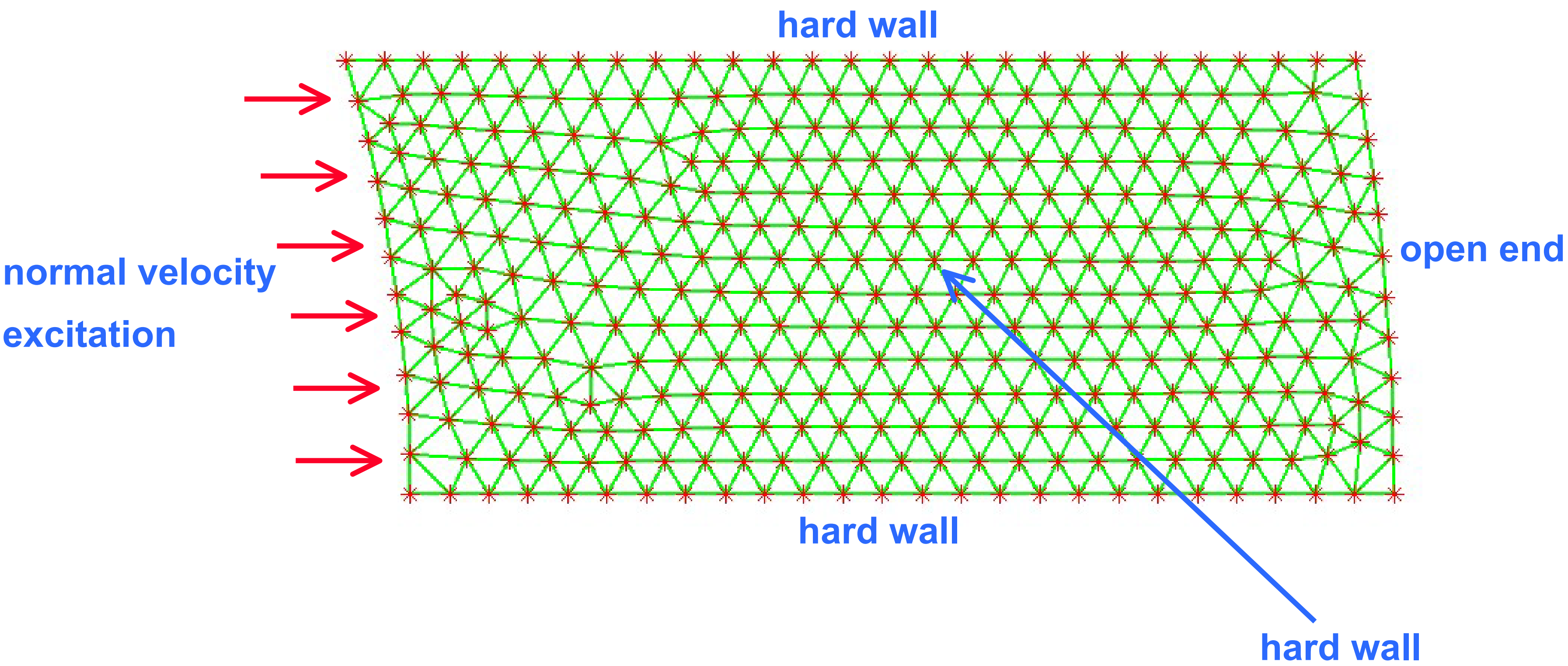


2D FE Model

Visco-Thermal FEM – Test Case



2D FE model of Slit



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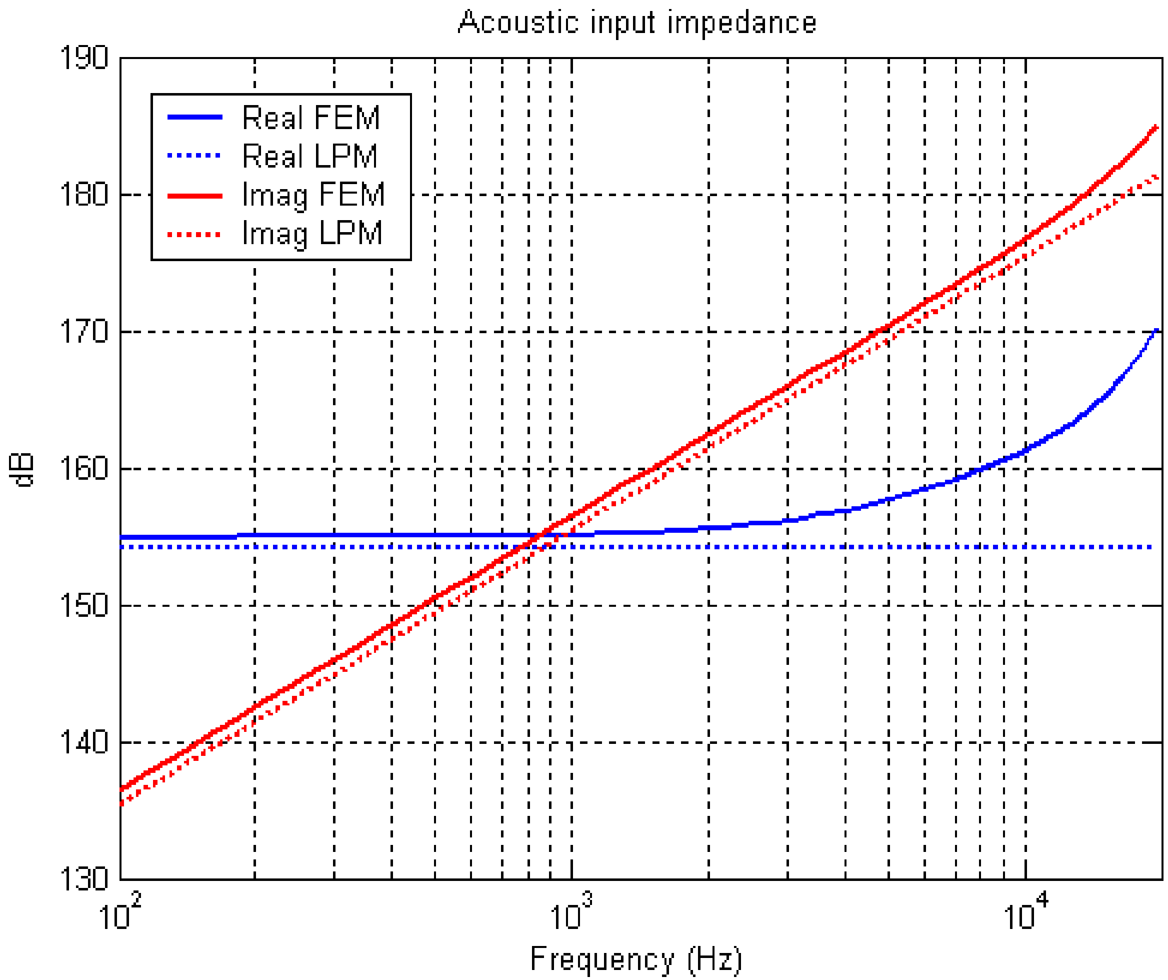
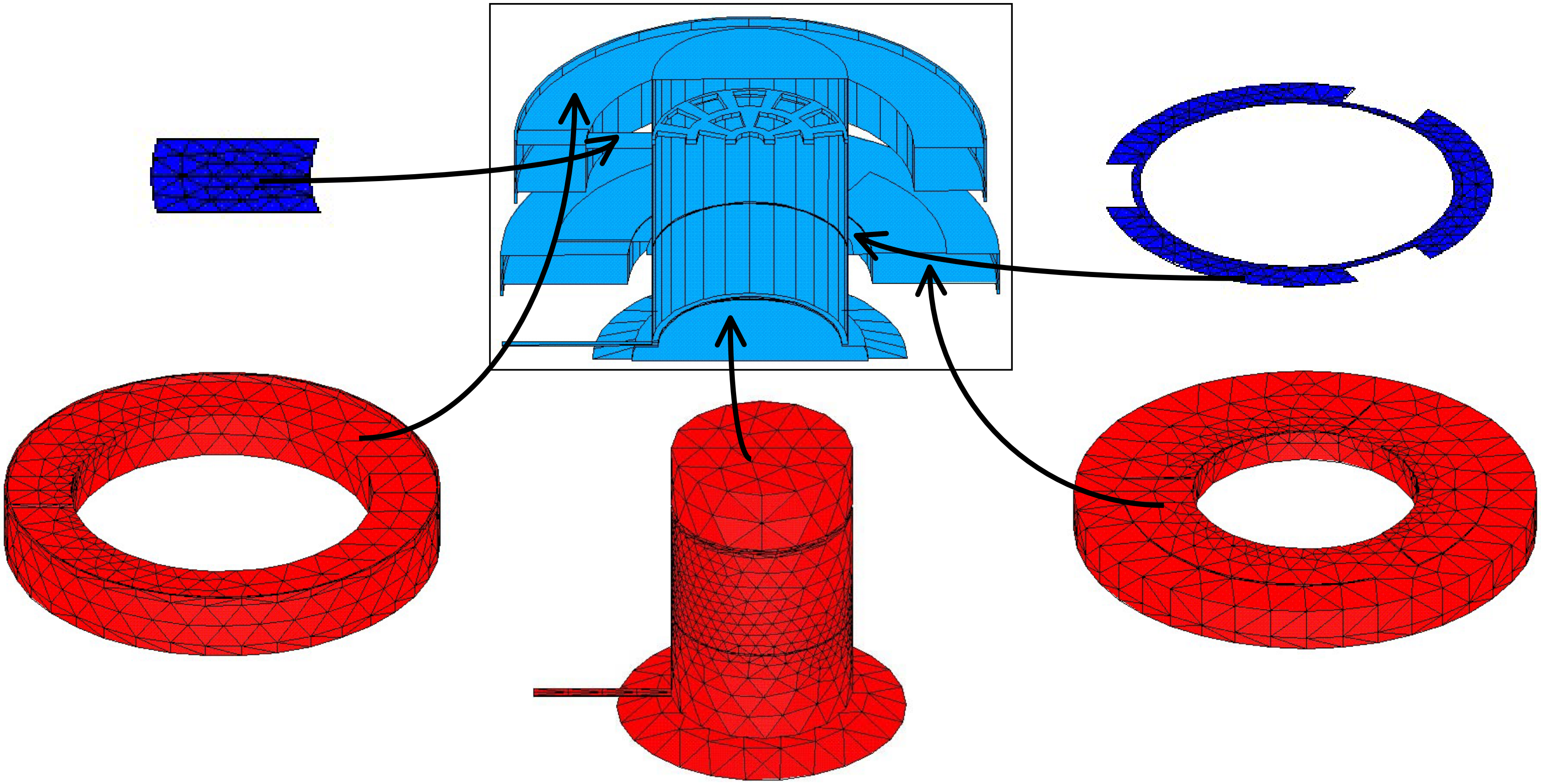
Simulation on Slit

- Acoustic input impedance – FE simulations vs. lumped-parameter model

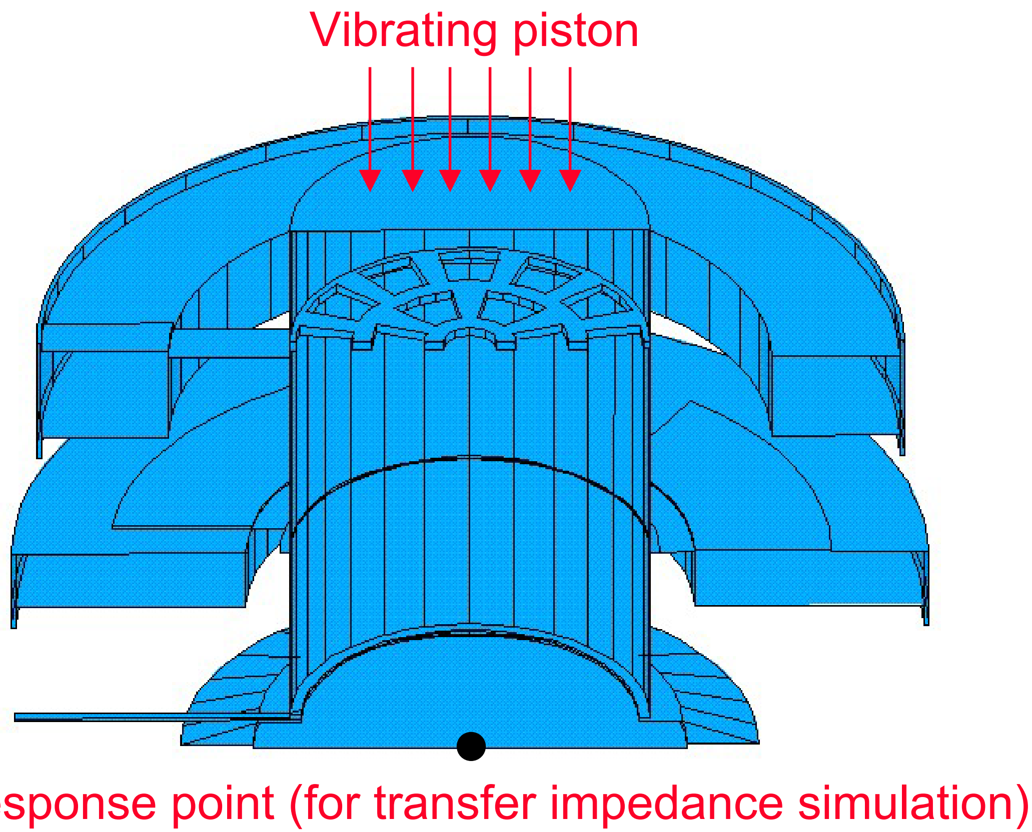


Coupler Model

- Mixed FEM/BEM model (4818 elements & 2337 nodes)

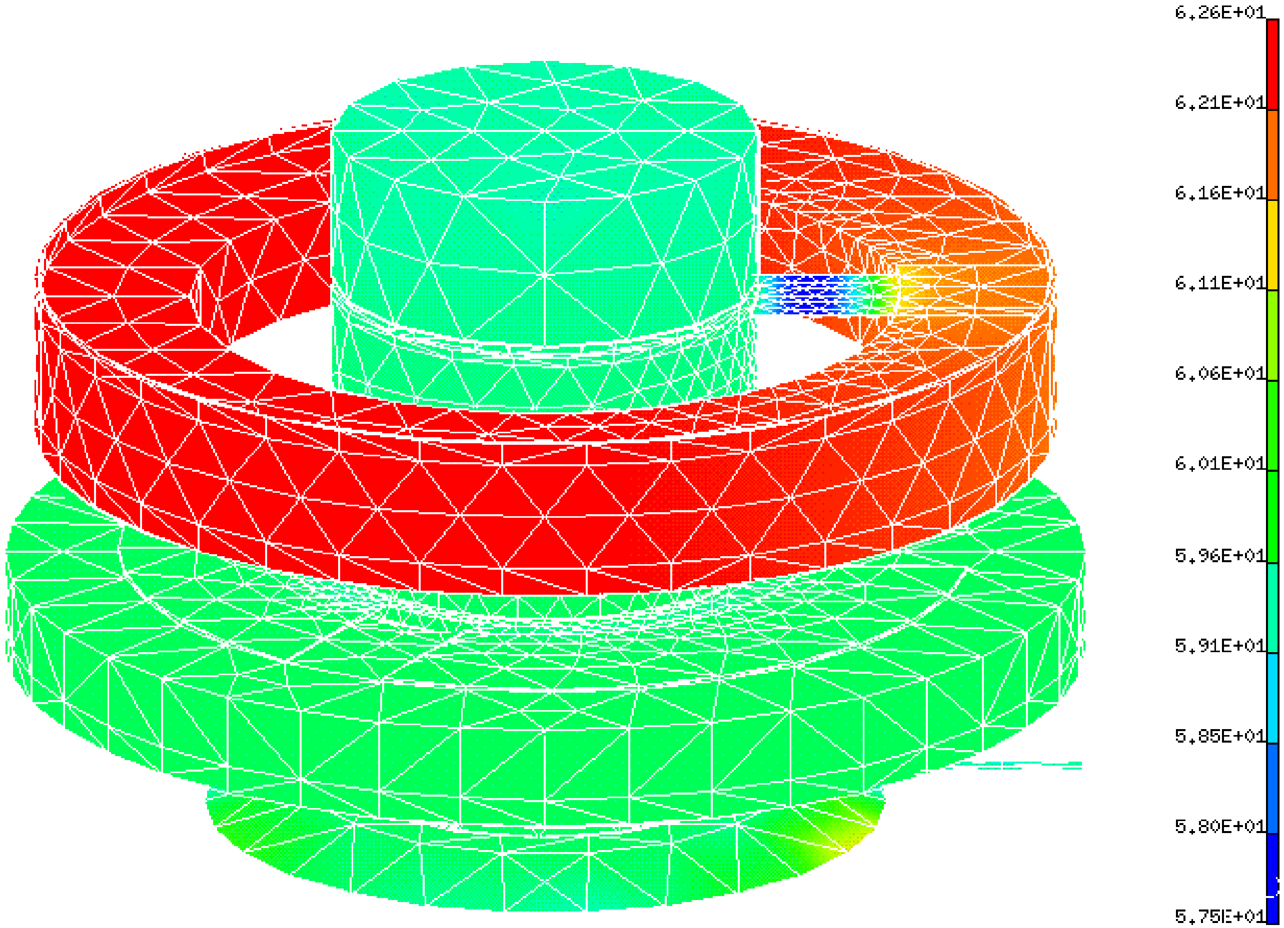


Model Setup

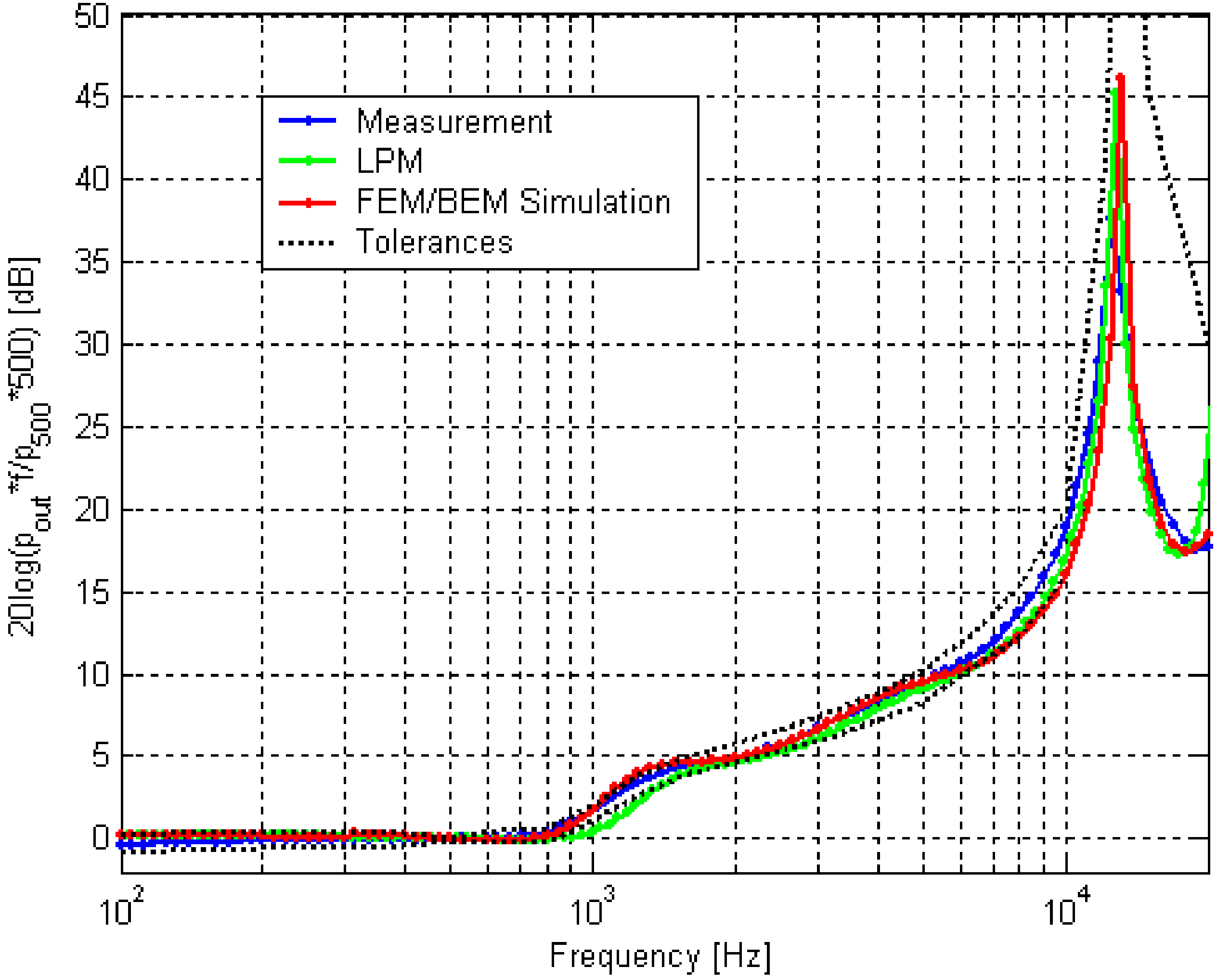

Vibrating piston
Response point (for transfer impedance simulation)

Coupler Response @ 1000 Hz

- Sound pressure map



Frequency Response



Conclusion

- A complete BEM/FEM model of the IEC 711 coupler (B&K Type 4157) taking visco-thermal effects into account was presented.
- Comparison between a measurement and simulation of the transfer impedance show excellent agreement.
- A more correct and detailed 3D simulation of the coupler can be done using BEM/FEM compared to traditional LPM.
- The performance of virtual couplers can be evaluated at the very early design stage using the proposed BEM/FEM technique.

Any Questions ?