# Microperforated absorber to reduce the tire cavity mode

12. Internationales Stuttgarter Symposium 14.03.2012

Wolfgang Herget

Fraunhofer Institute for Building Physics



FKFS

ATZ live

Fraunhofer IBP

# Motivation and Contents

Starting point

Annoyingly perceived noise in the car cabin, caused by the sound field in the enclosed cavity formed by the functional community of tire and rim.

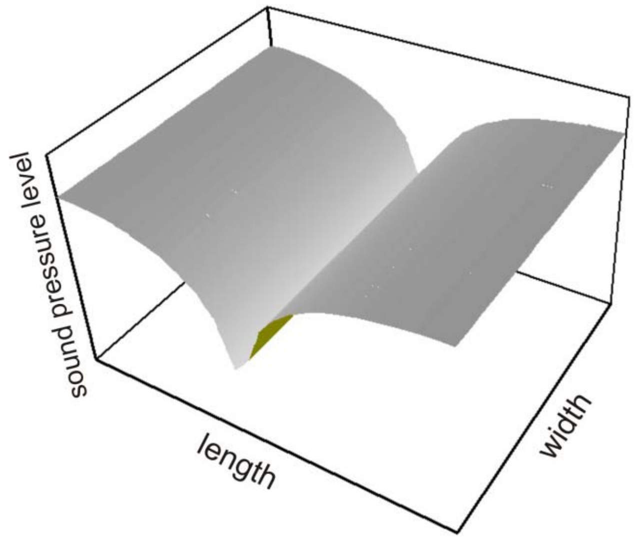
► *tire cavity mode*

Aim is to identify the tire cavity mode in the lab and to damp it with the help of a microperforated absorber.

- Theoretical basics
- Integration feasibility
- Identification of the tire cavity mode
- Dimensioning of the absorber
- Production of the tire-absorber
- Measurements with the tire-absorber at the vehicle

# Theoretical basics/Sound field rectangular room

- characterizes the physical sound propagation in rooms
- wavelength corresponds to the room size
  ▹ development of standing waves
- sound particle velocity at rigid walls has to be zero
  ▹ sound pressure is maximum at the wall surface
- periodicity: λ/2




Schematic plot of the sound pressure level distribution in a room, for the room mode 1,0,0.

- calculation of the eigenfrequencies in a room:

$$f_{(n_x,n_y,n_z)} = \frac{c}{2} \cdot \sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2} \quad [Hz]$$

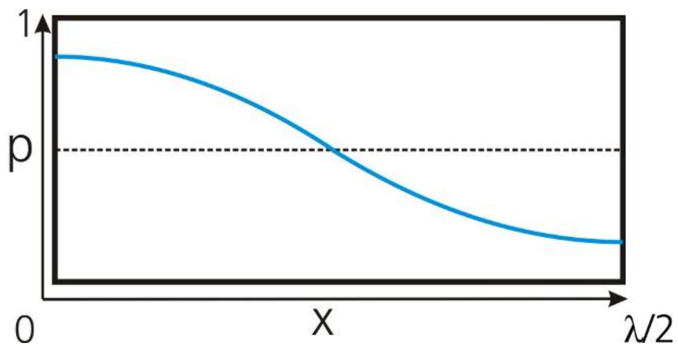
- lowest room mode: $f_{(n_x)} = \frac{c}{2} \cdot \frac{n_x}{L_x} \quad [Hz]$



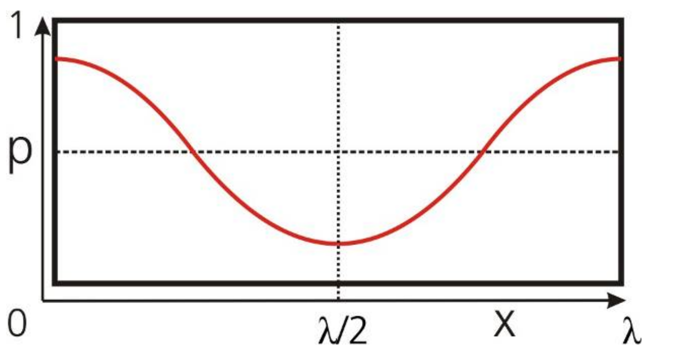
FKFS ATZ live Fraunhofer IBP

# Theoretical basics/Sound field tire cavity

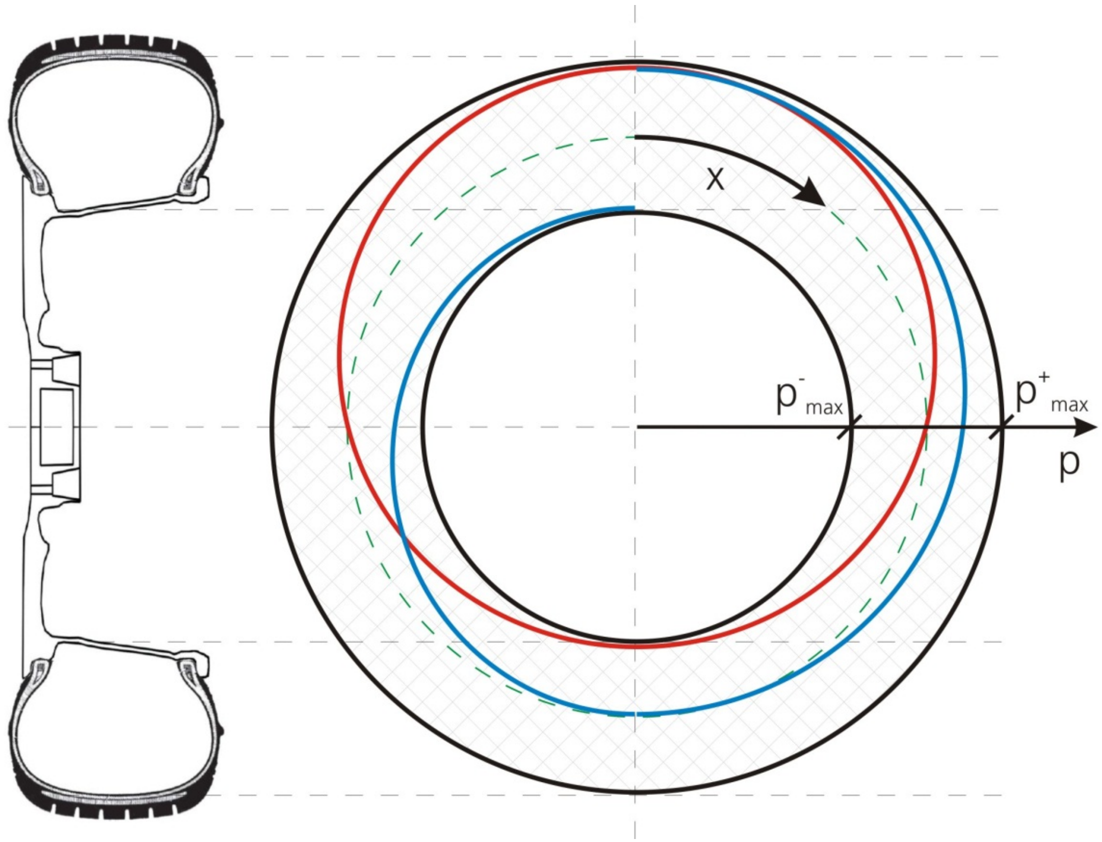
Adaptation of rectangular room sound field to the tire cavity:




Sound pressure between two hard walls.




Sound pressure of the mode in the ring-shaped tire cavity.

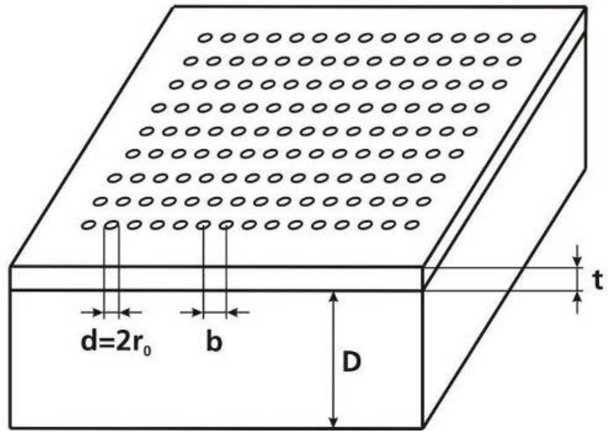



- lowest tire cavity mode: $f_{(n_x)} = c \cdot \frac{n_x}{L_x} \quad [Hz]$

The longitudinal section (on the right) with schematic profile of the sound pressure.

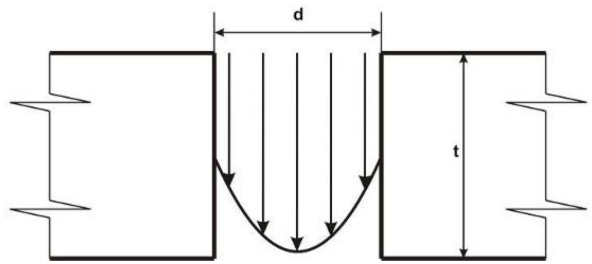
# Theoretical basics/Microperforated absorber

- reactive absorber (Helmholtz-Resonator) with inherent damping
- surface with many small holes
  - hole diameter less than 1 mm
  - perforation ratio less than 1%
- mass-spring-system
  - mass: air in the holes
  - spring: air volume between plate and wall




Parameters of the microperforated absorber.

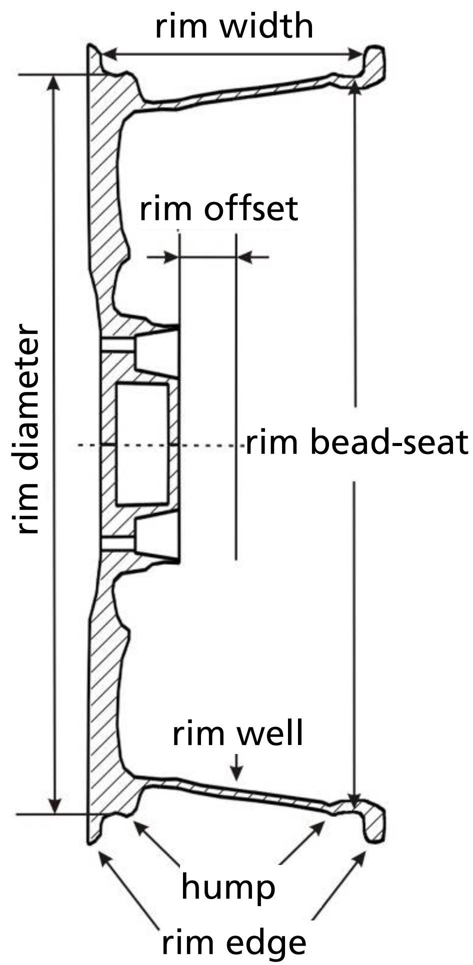
- laminar air flow profile in a hole
  - velocity is not constant over the cross-section
  - higher friction due the viscosity of the air
  - dissipation of sound to thermal energy




Flow profile in a hole.

# Integration feasibility/Possibilities

- 1st approach (not realized):
  - deepening in the rim well offers place for the absorber
  - Problem: rim well-base is required for the tire assembly
- 2nd approach (prototype 1, 2 versions produced):
  - integration of microperforated absorber directly into the structure of the rim
  - installation of a chamber on the inside of the rim
  - Problem: brake calliper limits the construction space
  - ▷ Solution: using available space optimally
- 3rd approach (actual prototype 2)
  - a new design of the rim profile includes the chamber
  - separate metal strip with microperforation

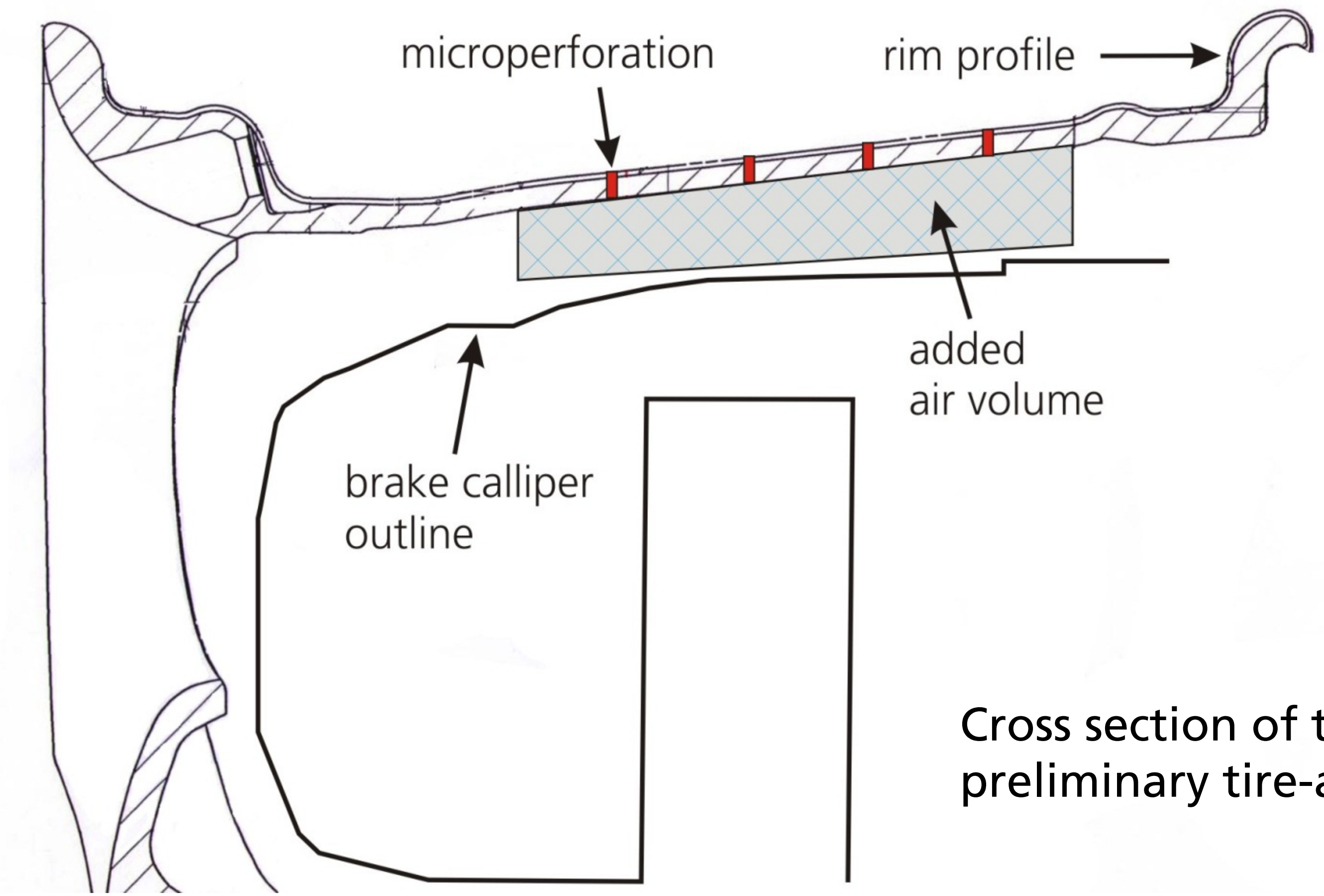





FKFS ATZ live Fraunhofer IBP

# Integration feasibility/Implementation

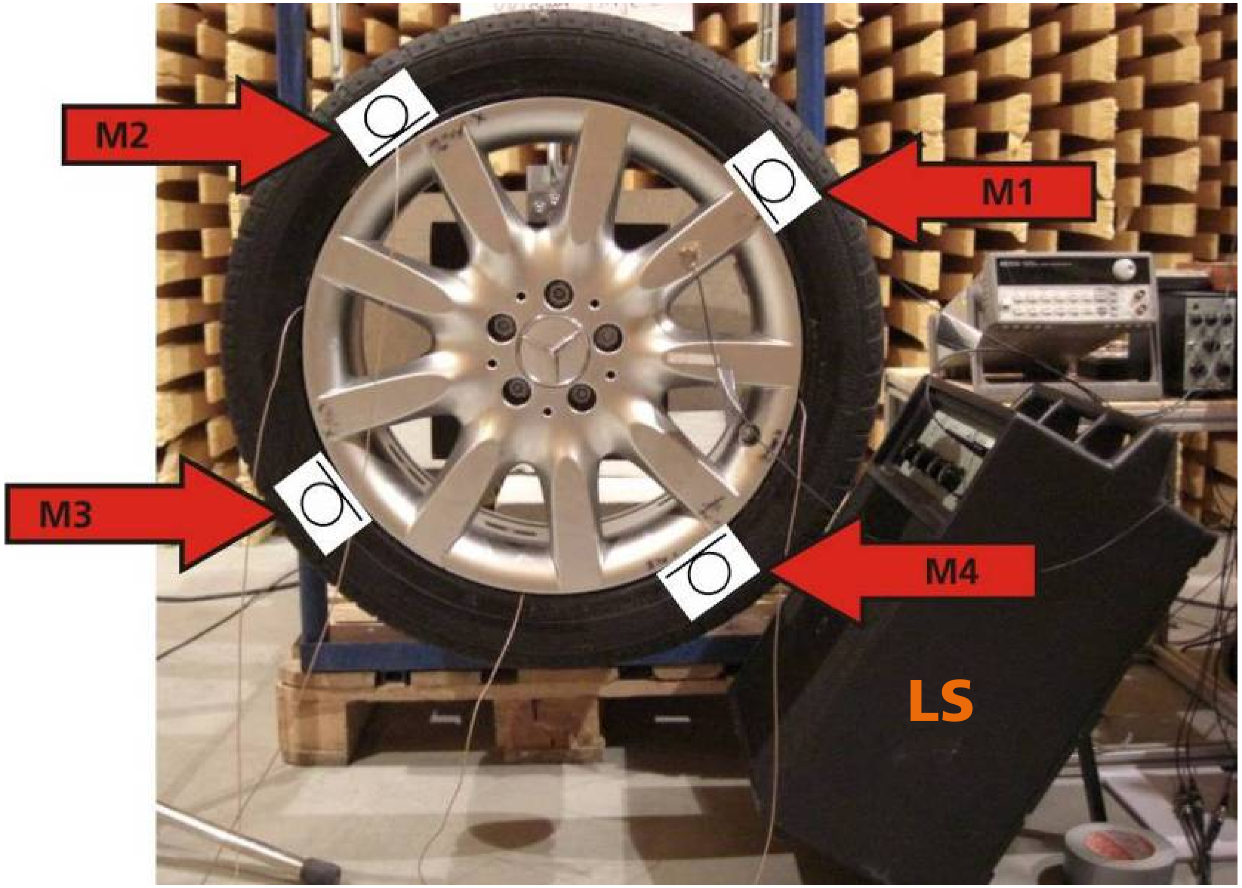
- prototype 1, microperforation in the rim structure
  - the chamber (needed as air volume for the absorber and to seal the tire air cavity) is placed on the inner side of the rim.




Cross section of the preliminary tire-absorber.

# Identification tire cavity mode/Laboratory test setup

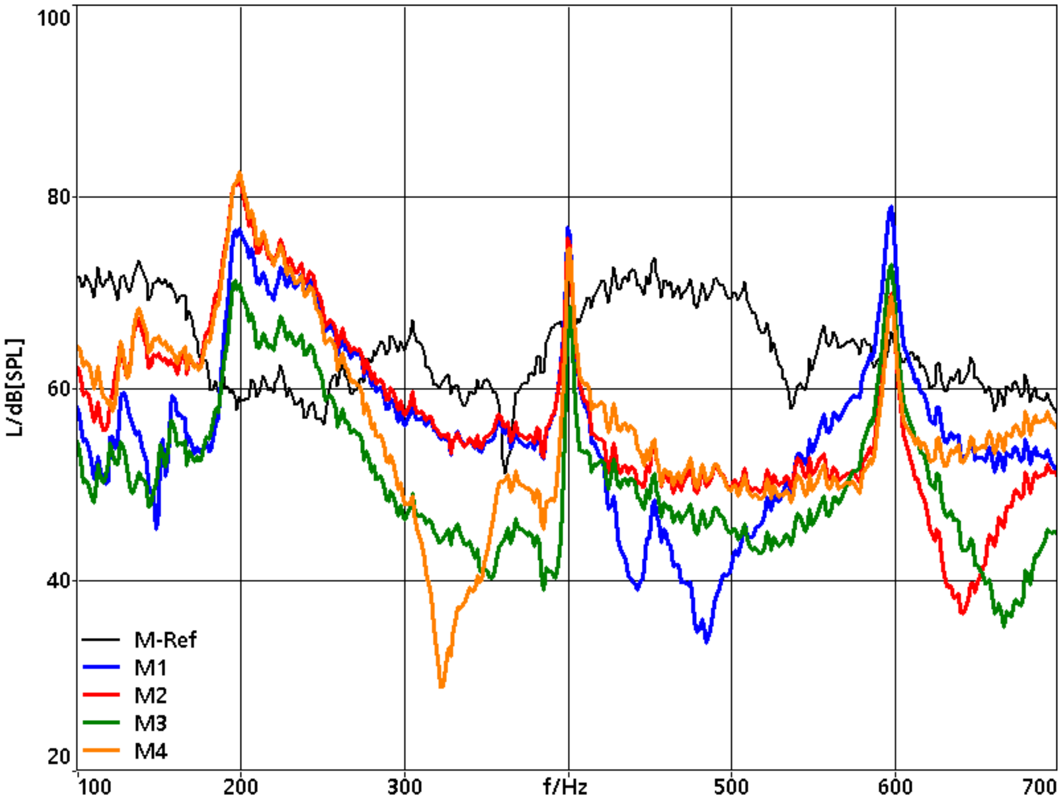
- 4 microphones M1 – M4 in the tire cavity at a spacing of 90 degrees
- acoustical excitation with loudspeaker LS in direct proximity of the suspended wheel



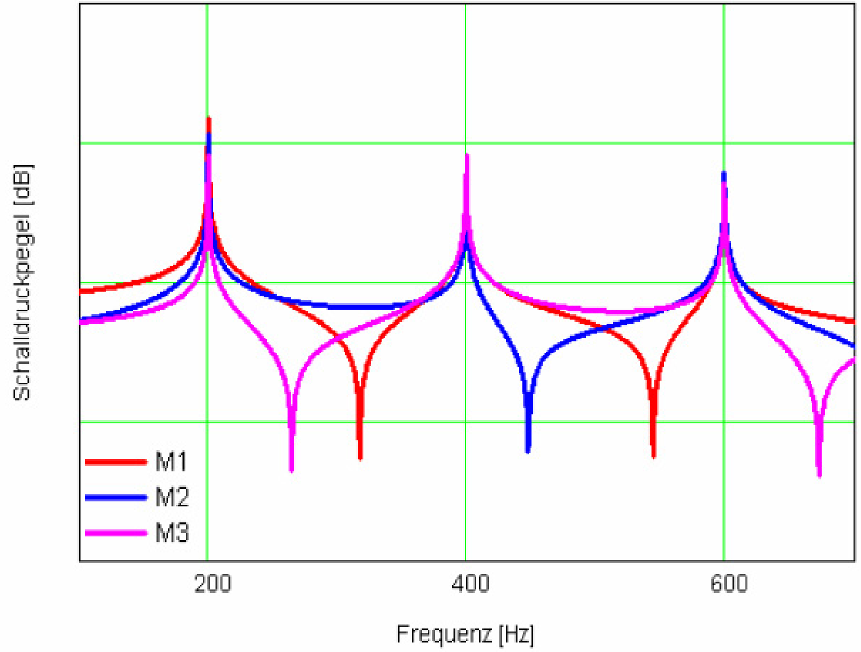
Picture of the laboratory test setup.

# Identification tire cavity mode/Results part I

## Comparison between theory and measurement (prototype 1.1):




Sound pressure levels measured in the tire cavity with microphone M1-M4 and outside reference (M-Ref).

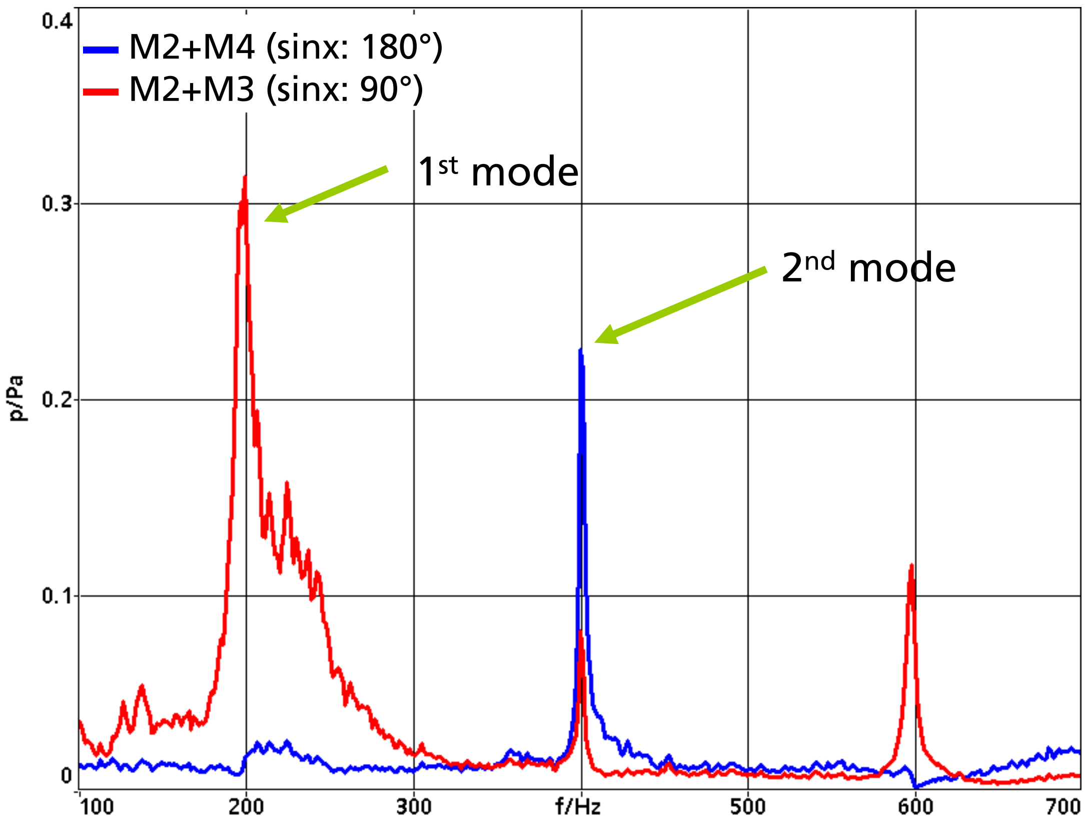


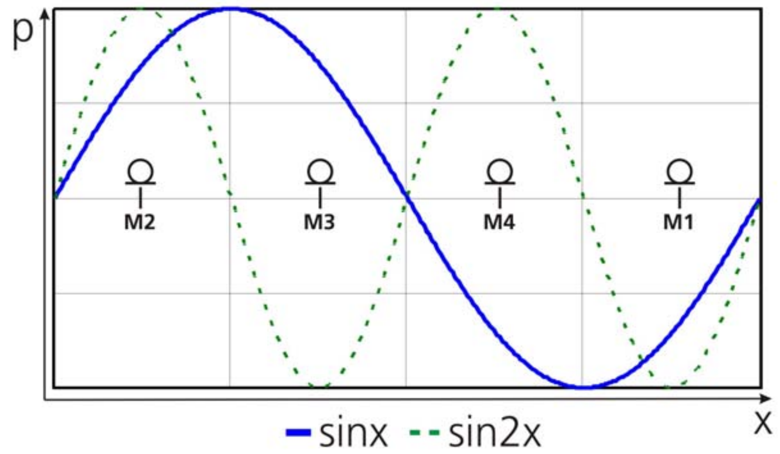

Theoretical eigenfrequencies in the tire cavity.

► Indication of the tire cavity mode.

# Identification tire cavity mode/Results part II

Identification via selected microphone positions in the tire cavity:



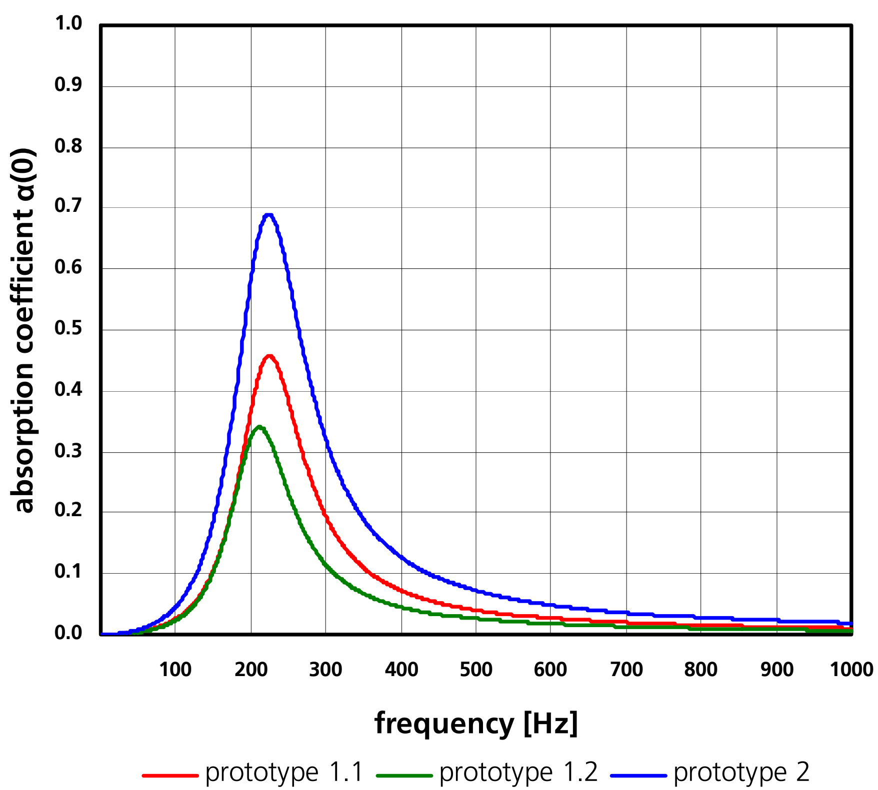

Resulting spectra from added sound pressure in the time domain (left) and standing wave pattern relative to the microphone positions (right).

- added time domain signals $\xrightarrow[\text{formation}]{\text{Trans-}}$ FFT
- 1st mode: (sin x) — at *180°* ▹ cancellation; at *90°* ▹ pressure increase
- 2nd mode: (sin 2x) — at 360° ▹ pressure increase; at 180° ▹ pressure reduction

► Clear identification of the first tire cavity mode with 200 Hz.

# Dimensioning of the absorber/Parameter

- Due to the space restrictions for the absorber (page 7), the parameters for dimensioning are limited.
- A perforation ratio of approximately 0.15 % was chosen in order to tune the absorber to 200 - 250 Hz.

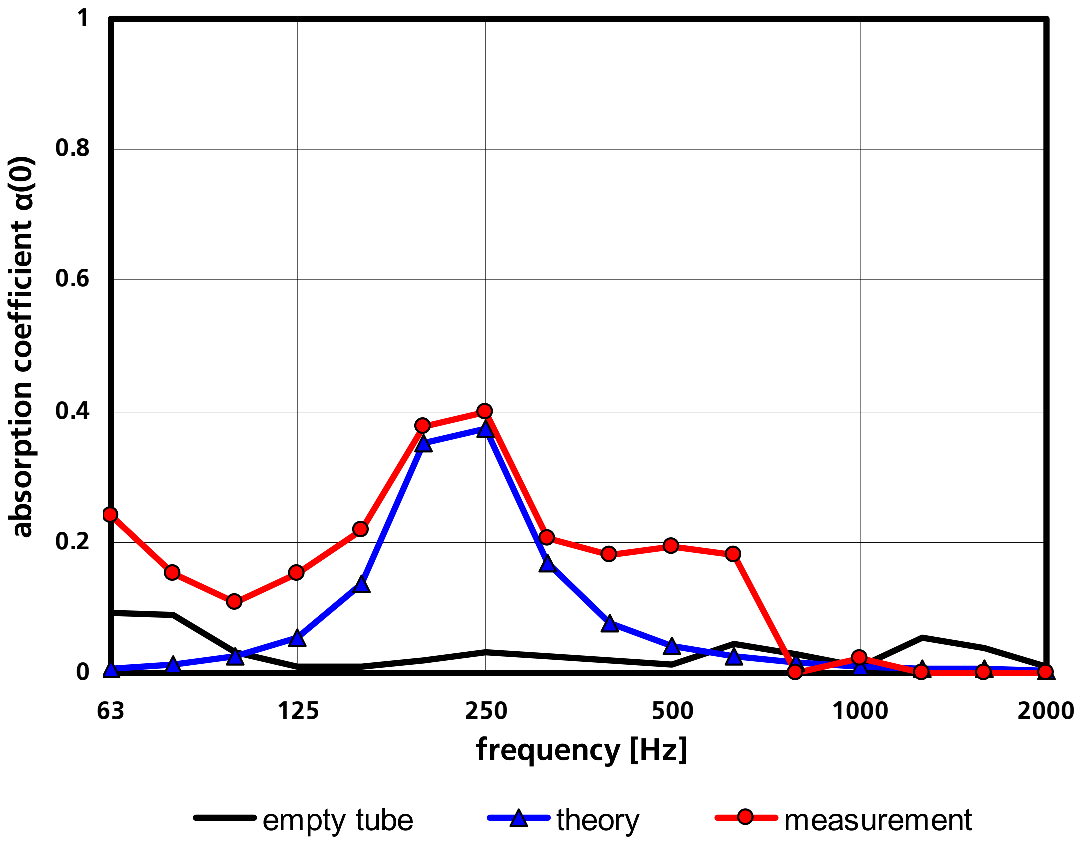


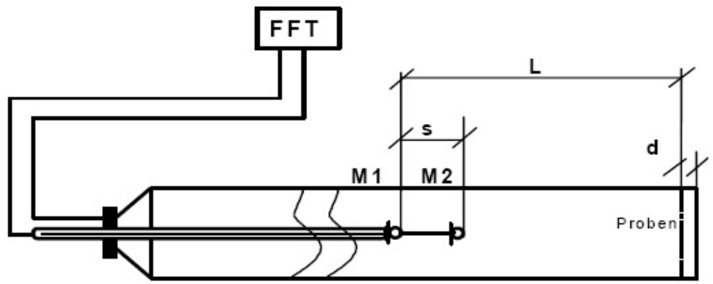

These three versions differ primarily by a changed wall distance D:

- prototype 1.1 — D ≈ 15 mm
- prototype 1.2 — D ≈ 11 mm
- prototype 2, latest version — D ≈ 28 mm

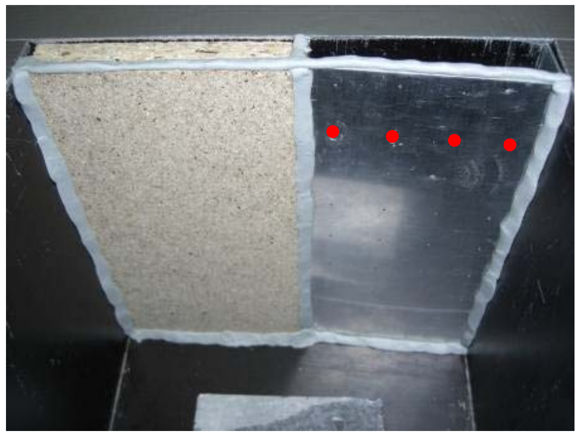
# Dimensioning of the absorber/Absorption coefficient

- Measurements were carried out in the impedance tube.
- Comparison between theoretical and measured values.




Schematic plot of the impedance tube.



▶ Theory and measurement agree well.

Installation of the test sample in the impedance tube.

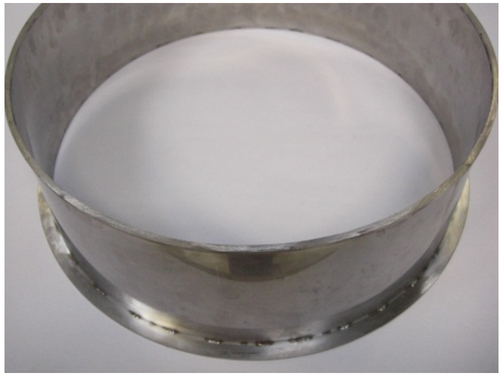



FKFS ATZ live Fraunhofer IBP

# Production of tire-absorber prototype 1

- The holes for the microperforation are in the rim.
- Circumferential absorber chamber is mounted inside the rim.

+

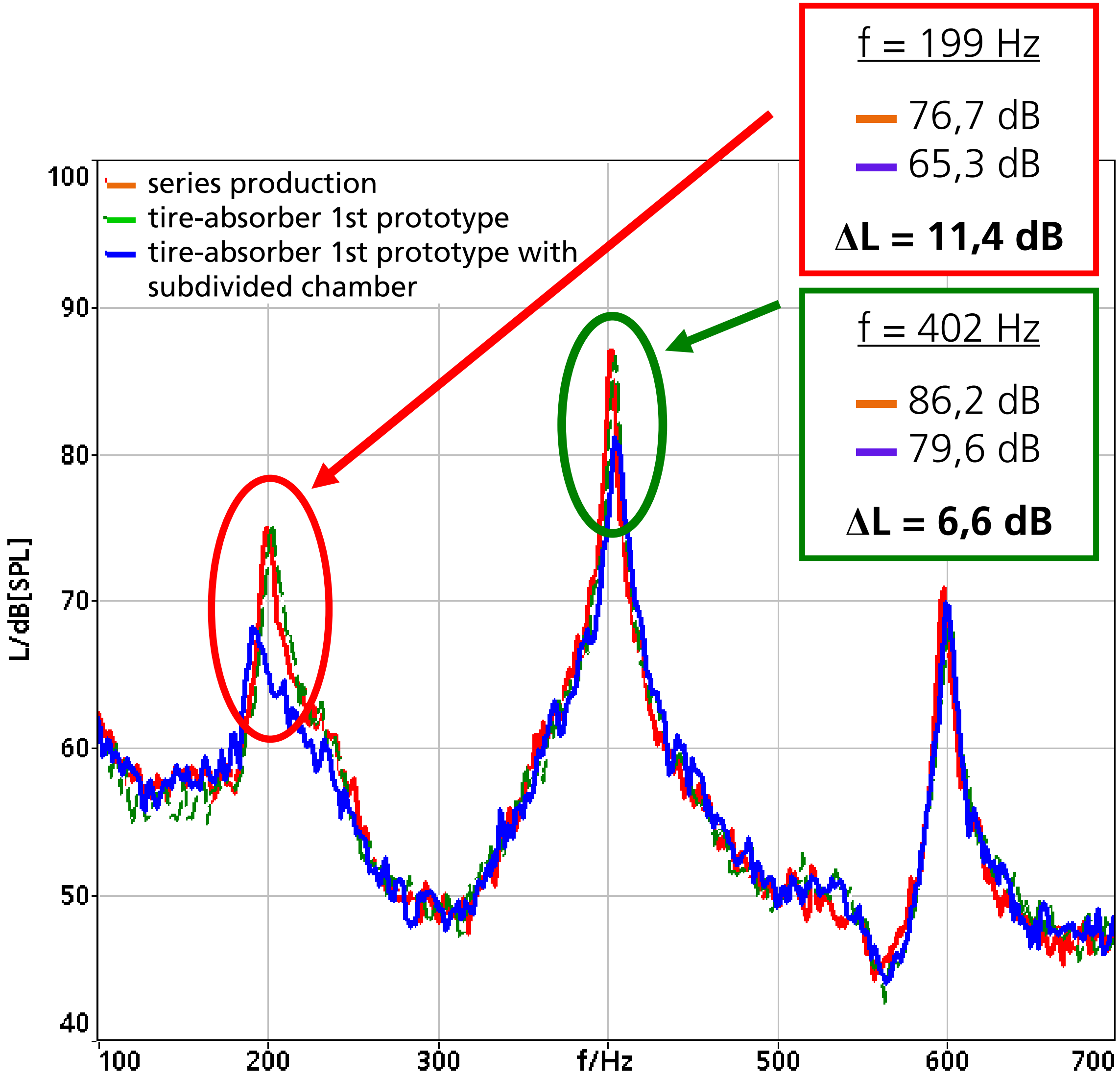


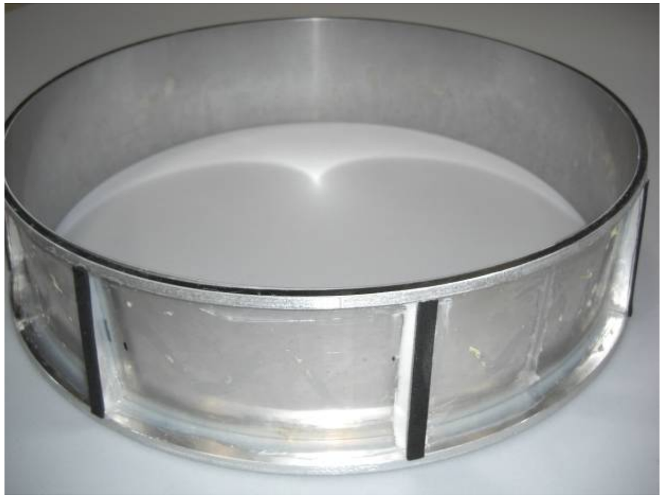



FKFS ATZ live Fraunhofer IBP

# Tire-absorber/Laboratory measurements

Comparison between series rim and tire-absorber:



Subdivided chamber.

Sound pressure level averaged over the four microphone positions in the tire cavity.

▶ Tire cavity mode is damped by the absorber.

# Tire-absorber/Four-wheel roller test bench

Four-wheel roller test bench in a semi-anechoic room at Fraunhofer IBP.

# Tire-absorber/Roller test bench configurations

Safety walk.

Rough-textured asphalt simulation.

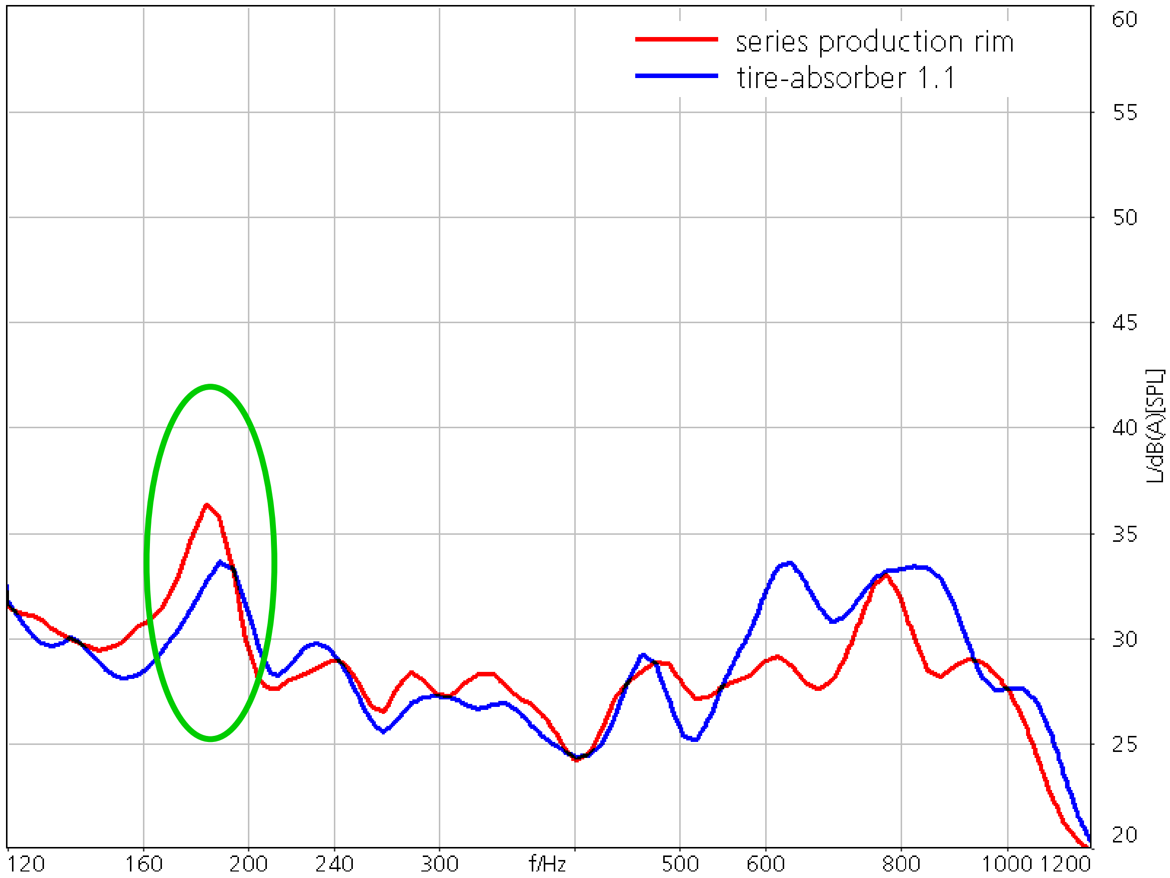
Dummy head at passenger seat inside the vehicle.




FKFS ATZ live Fraunhofer IBP

# Tire-absorber/Measurement results/Safety walk I

## Prototype 1.1 – dummy head at passenger seat inside the vehicle powered by the engine; v = 60 km/h




Measurement at IBP roller test bench

- Effect of absorber is visible, but repeatability of measurements is low.
- Effect is not clearly visible at other speeds on the roller test bench with safety walk (smooth surface).
- Effect is more clearly measurable on the street.
- Assumption:

Force excitation of the tire cavity mode on the smooth safety walk is too low.

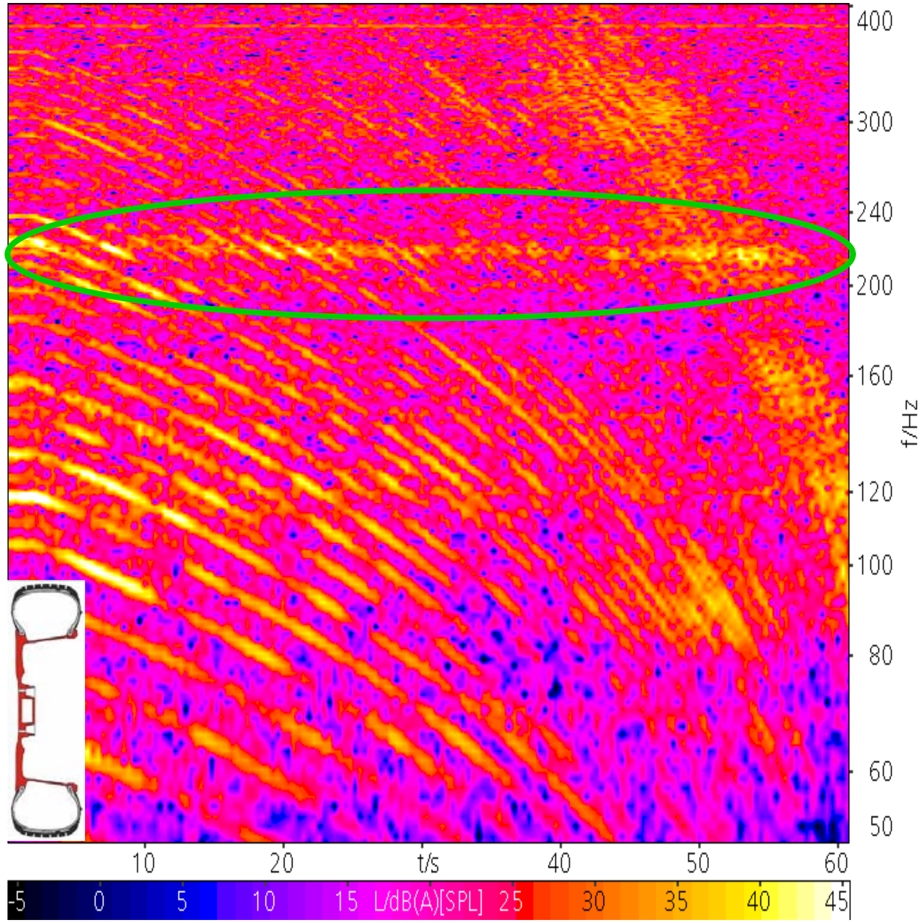




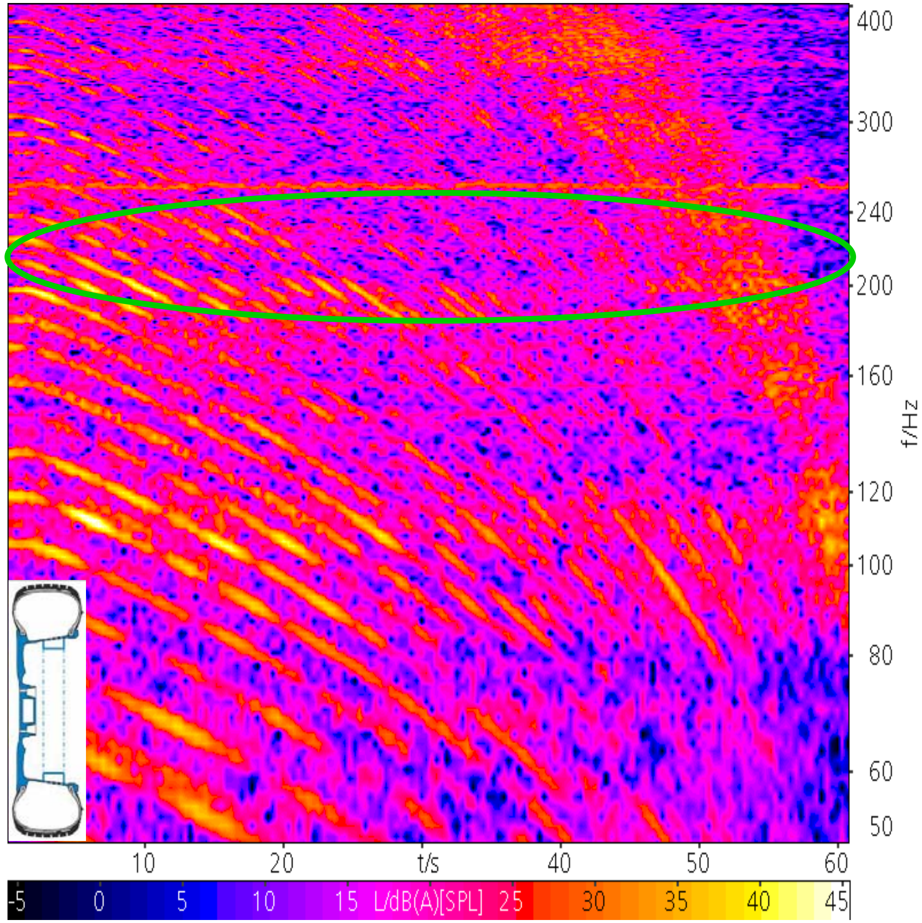
FKFS ATZ live Fraunhofer IBP

# Tire-absorber/Measurement results/Safety walk II

Prototype 1.1 – dummy head at passenger seat inside the vehicle
powered by the test bench; Run-Down v = 100 to 10 km/h




Series production.



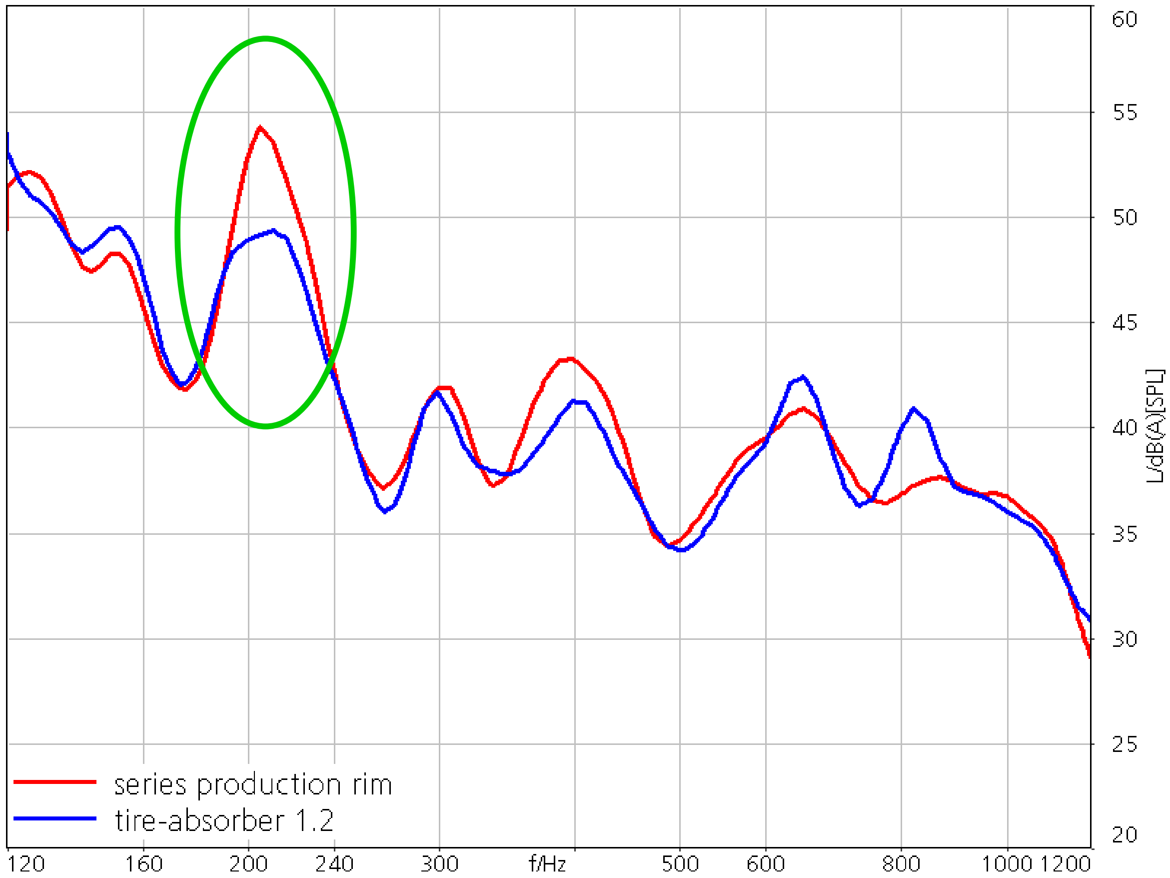

Tire-absorber – prototype 1.1.




FKFS ATZ live Fraunhofer IBP

# Tire-absorber/Measurement results/Rough textured asphalt I

Prototype 1.2 – dummy head at passenger seat inside the vehicle powered by the test bench (engine off); v = 90 km/h diagram shows A-weighted FFT

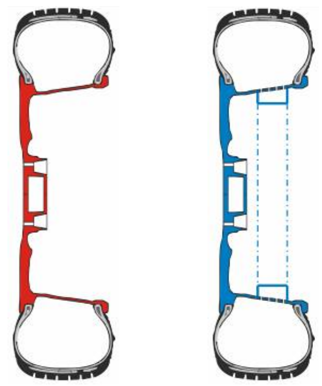



Measurement at IBP roller test bench

Maximum SPL at f = 205 Hz

$L_{series}$ = 54,3 dB(A)

$L_{tire\text{-}absorber}$ = 49,1 dB(A)



Series production

Tire-absorber – prototype 1.2

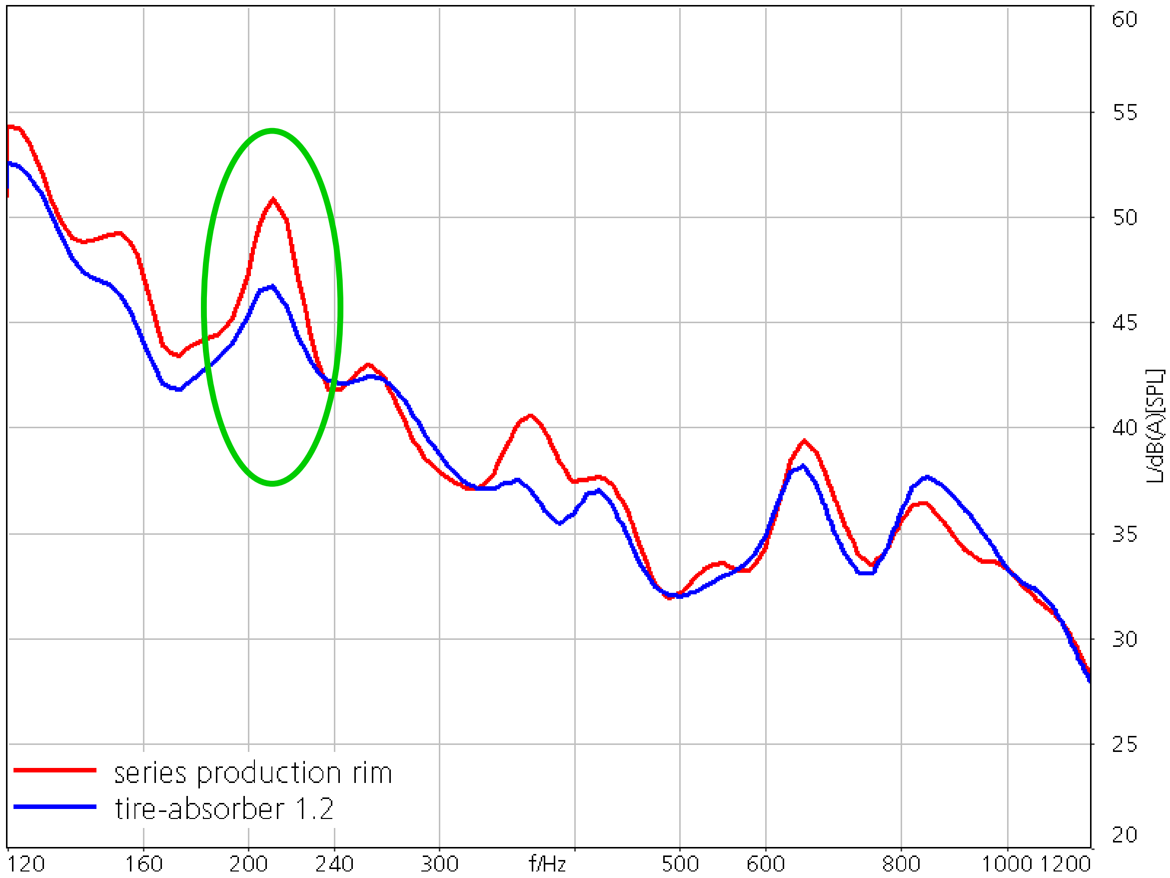




FKFS ATZ live Fraunhofer IBP

# Tire-absorber/Measurement results/Rough textured asphalt II

Prototype 1.2 – dummy head at passenger seat inside the vehicle
powered by the engine; v = 60 km/h
diagram shows A-weighted FFT

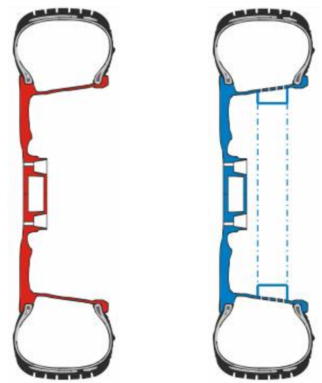



Measurement at IBP roller test bench

Maximum SPL at f = 210 Hz

$L_{series}$ = 50,9 dB(A)

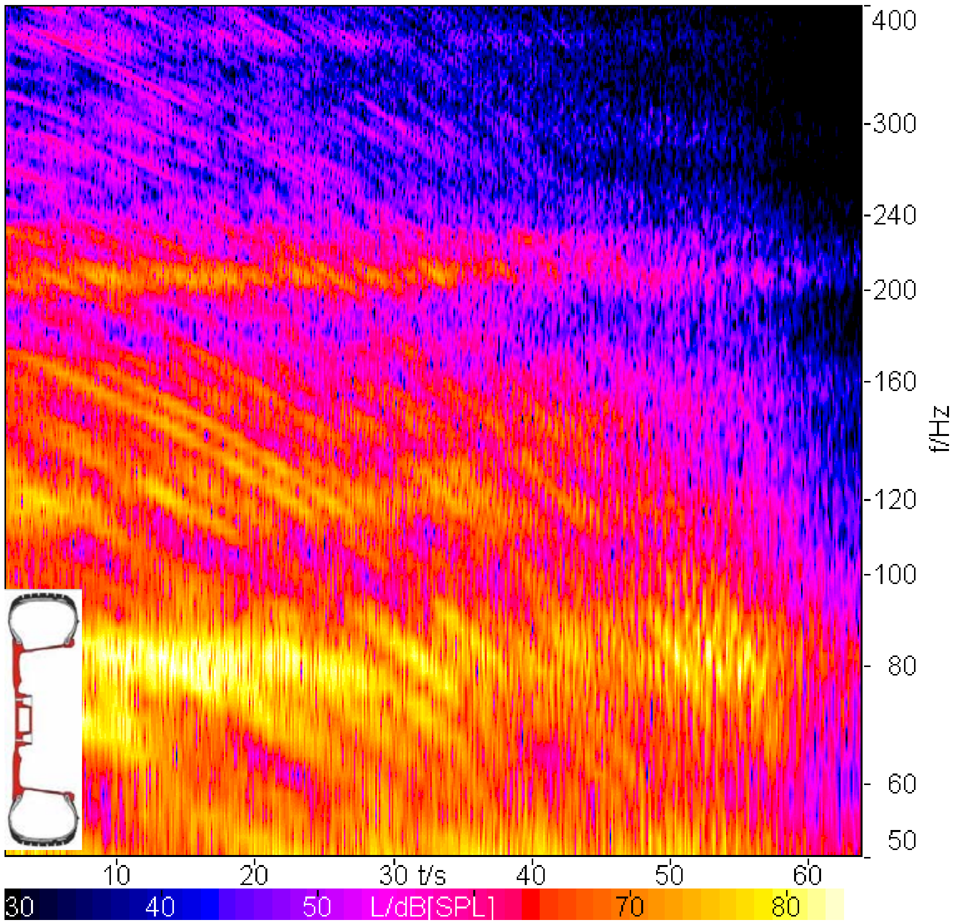
$L_{tire\text{-}absorber}$ = 46,8 dB(A)



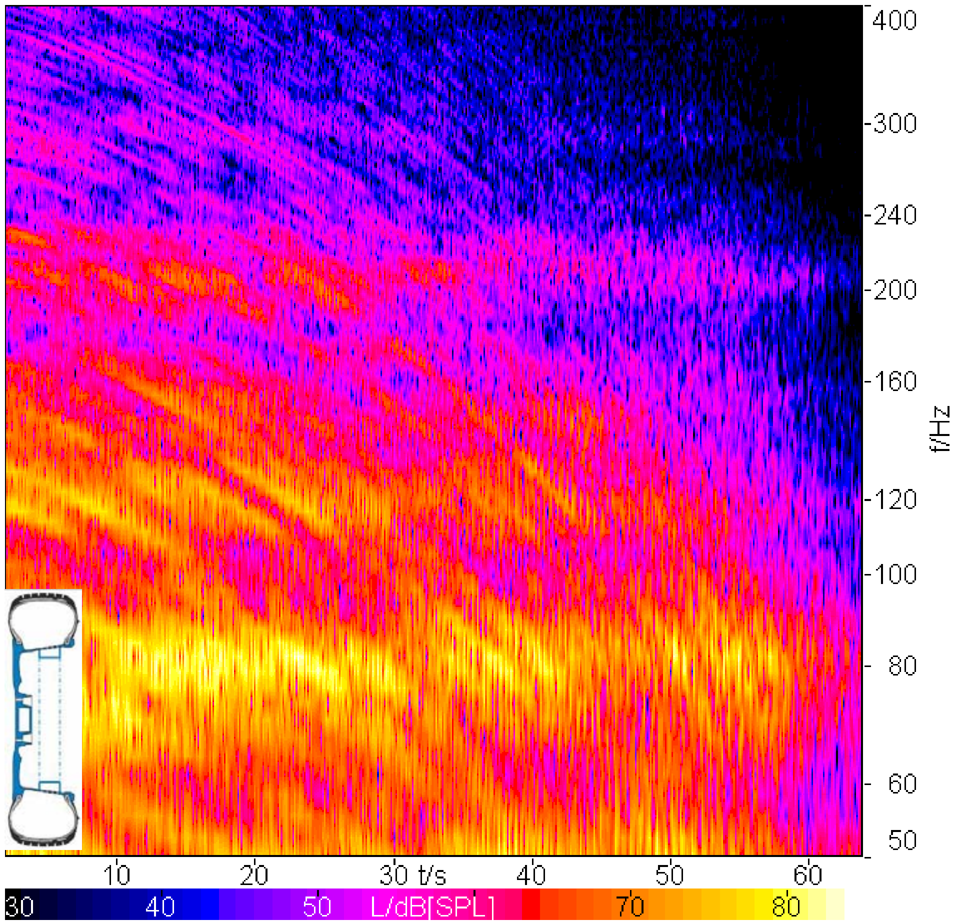
Series production  Tire-absorber – prototype 1.2

# Tire-absorber/Measurement results/Rough textured asphalt III

Prototype 1.2 – dummy head at passenger seat inside the vehicle powered by the test bench; Run-Down v = 120 to 10 km/h




Series production.



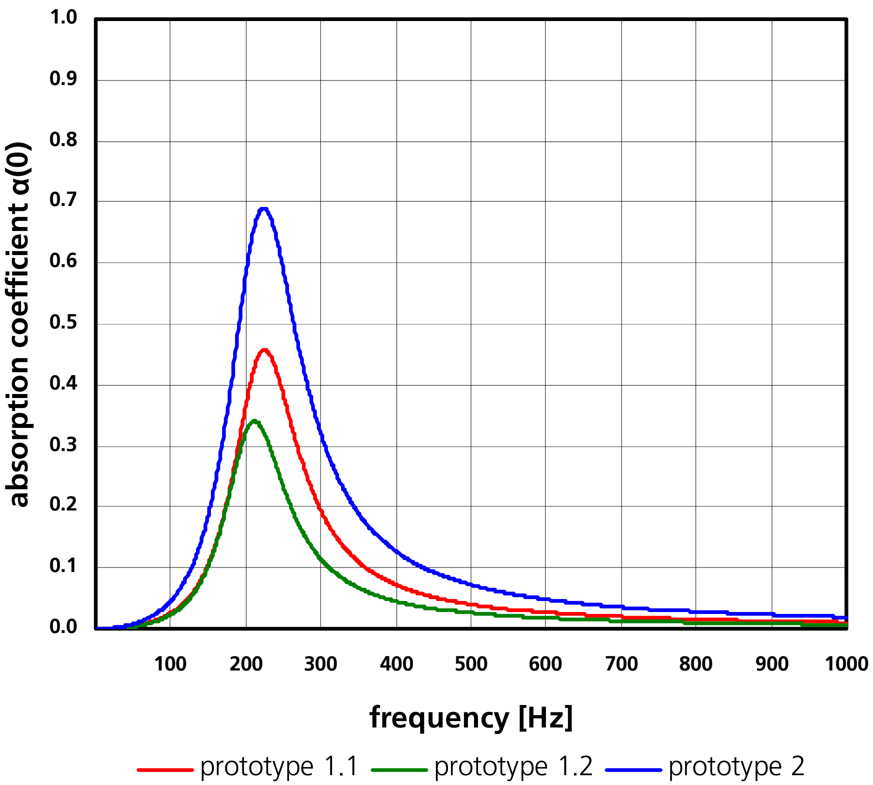

Tire-absorber – prototype 1.2.

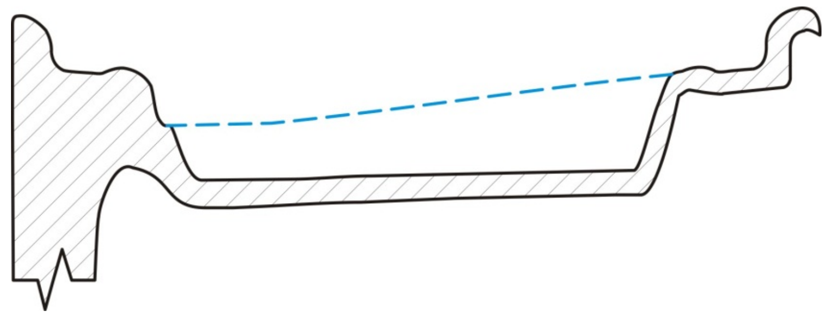
# Tire-absorber/Measurement results/Prototype 2

Prototype 2

topically produced rim

measurement results not yet available



- Increased wall distance should lead to increased absorption (blue curve)
- Higher damping of the tire cavity mode is expected

# Summary

- The tire cavity mode was determined theoretically and identified by experiments
- Dimensioning of the microperforated absorbers for peak absorption at 200 - 250 Hz
- Measurements in the impedance tube verified the absorber design
- Realization of the absorbers in a rim well
- Measurements in the laboratory resulted in a noise reduction of the tire cavity mode by 11 dB in narrow bands and 4.5 dB in 1/3-octaves with a partitioned air volume
- Comparative measurements with an artifical head in the car showed a level reduction of approx. 5dB (prototype 1.2) in the relevant frequency range
- These attenuation effects could be verified by measurements on the road and on the roller test bench
- The measurement results were also achieved for different vehicles and two absorber designs due to different brake callipers