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NAG
NEDERLANDS AKOESTISCH GENOOTSCHAP

# IN-SITU MEASUREMENTS using the LOCAL PLANE WAVE method for POWER, ABSORPTION and TRANSMISSION

NAG Masterclass: Meten van Geluid

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# INTRODUCTION

- Sound power

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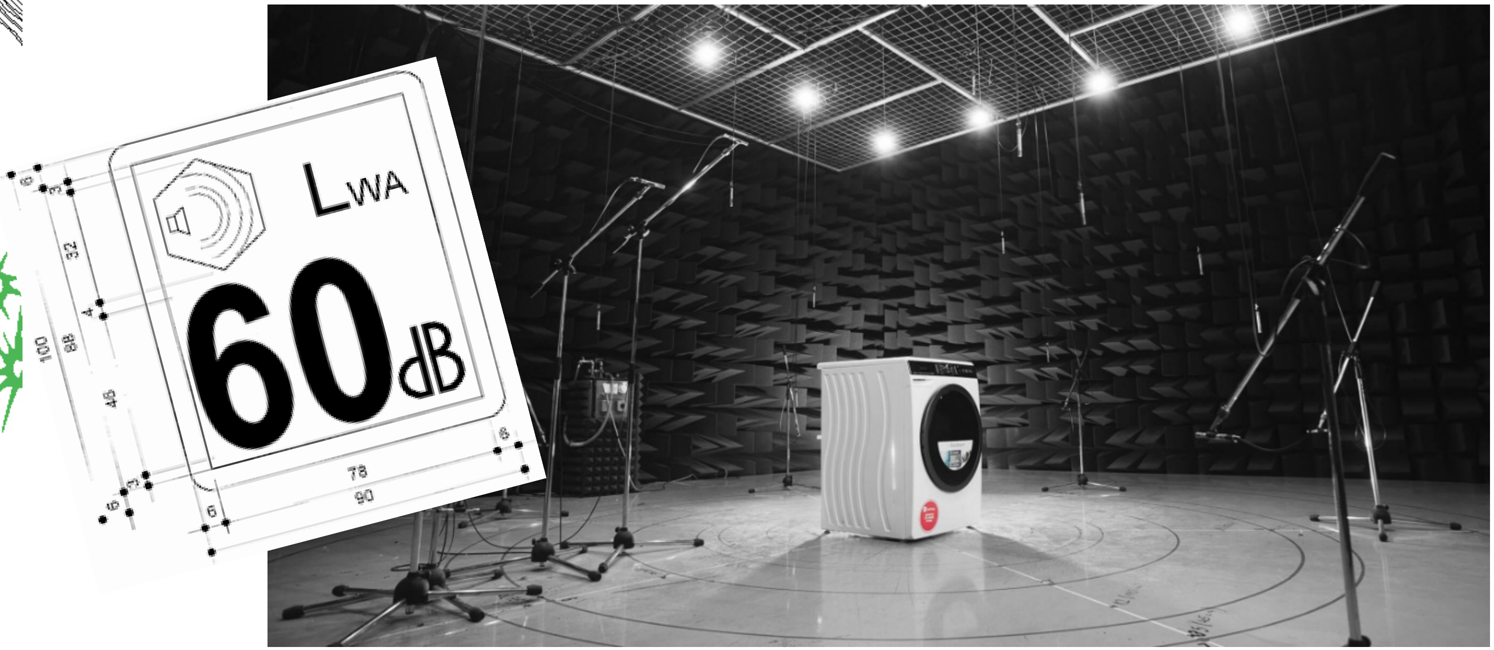
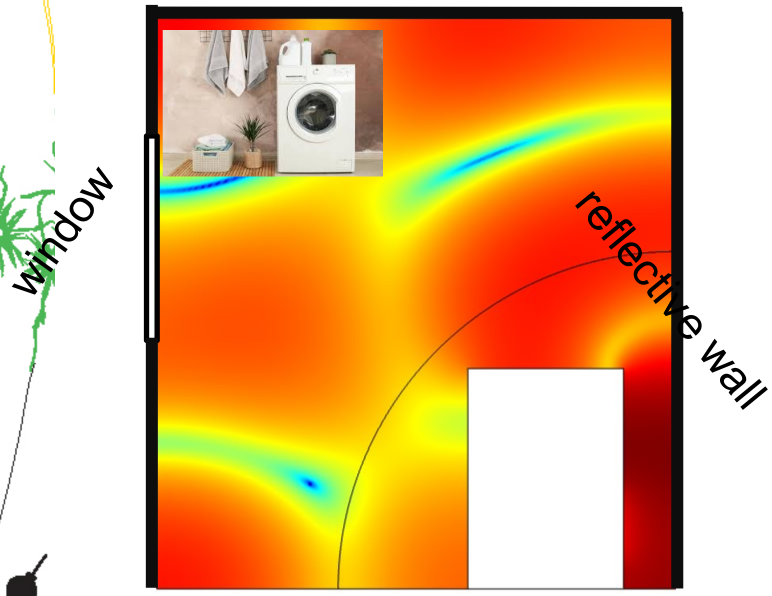
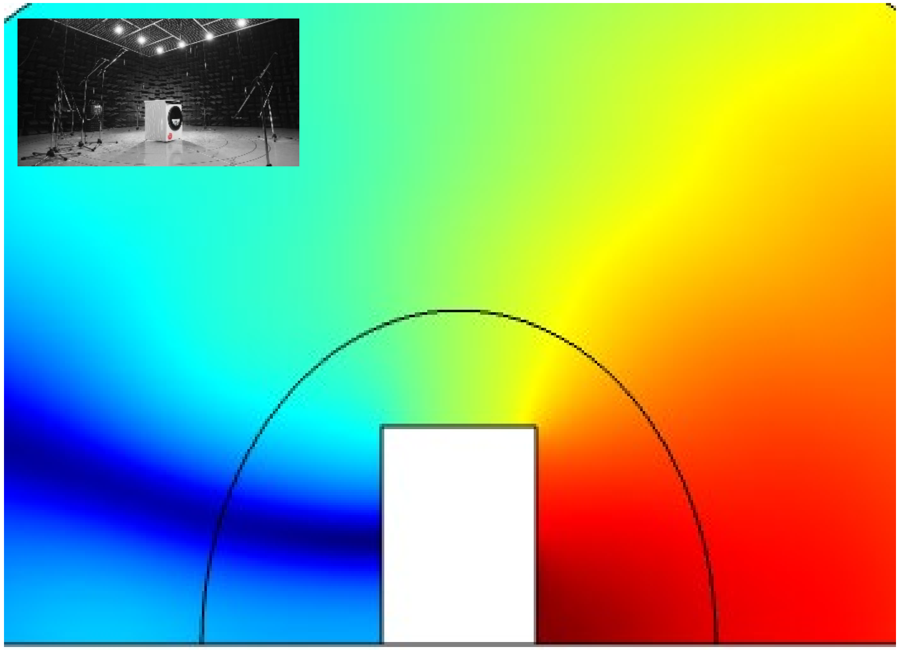
- Sound power



# INTRODUCTION

- Sound pressure level (@200 Hz)
  - Same source … different acoustic environment … large differences



# SOUND POWER

- Sound intensity = Active intensity = Net energy flux radiated to the environment

$$\mathbf{I}_{ac} \cdot \mathbf{n} = \frac{1}{2}\Re\left(P\overline{\mathbf{U}} \cdot \mathbf{n}\right)$$

in Watts/m$^2$

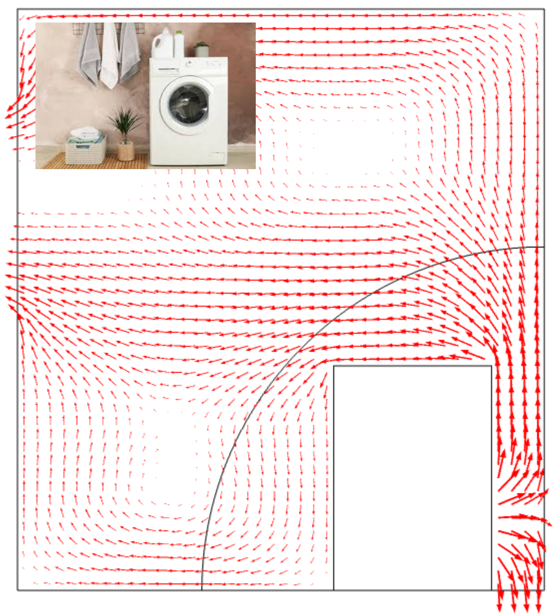
- Sound power = Active power = Net power radiated to the environment

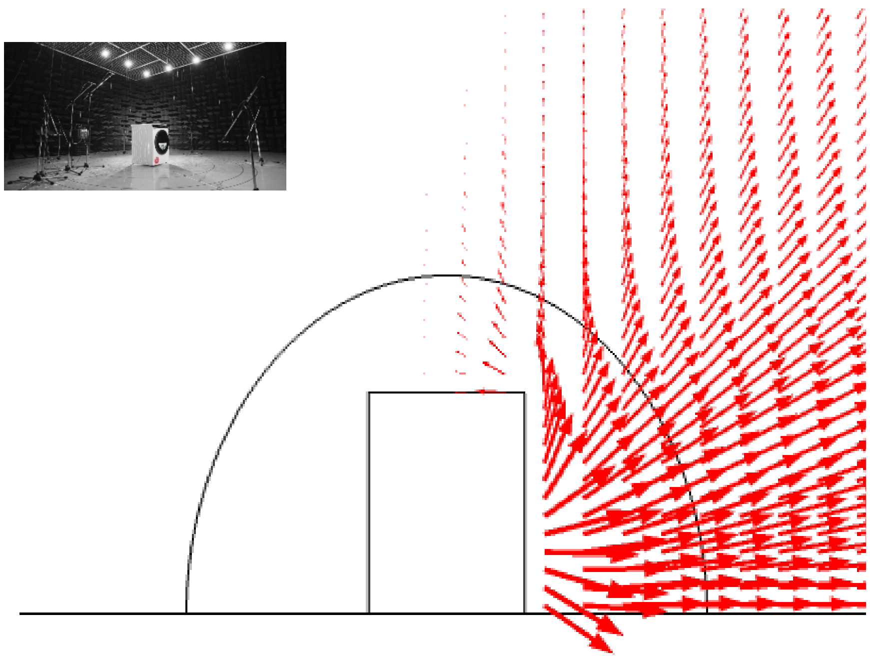
$$P_{ac} = \int \mathbf{I}_{ac} \cdot \mathbf{n} dS$$

in Watts

# SOUND POWER

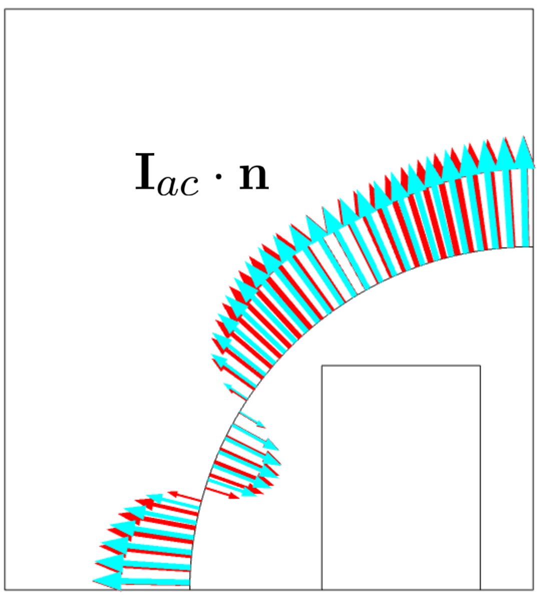
- Sound intensity vectors …
  - Same source … different acoustic environment



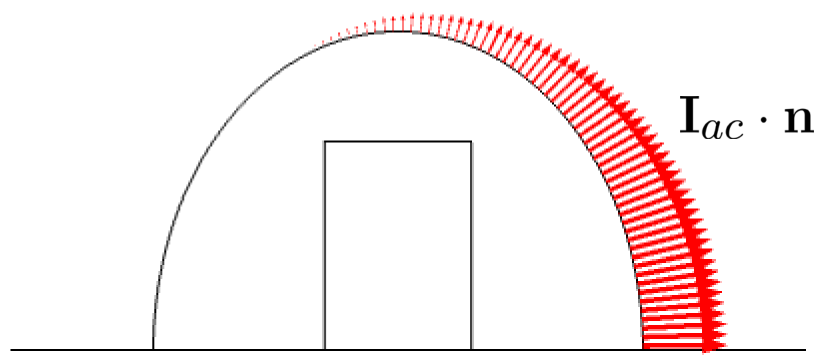


# SOUND POWER

- Intensity (normal component)
  - Evaluated on a surface/line completely surrounding the source




$$P_{ac} = \int \mathbf{I}_{ac} \cdot \mathbf{n} dS$$

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# SOUND POWER

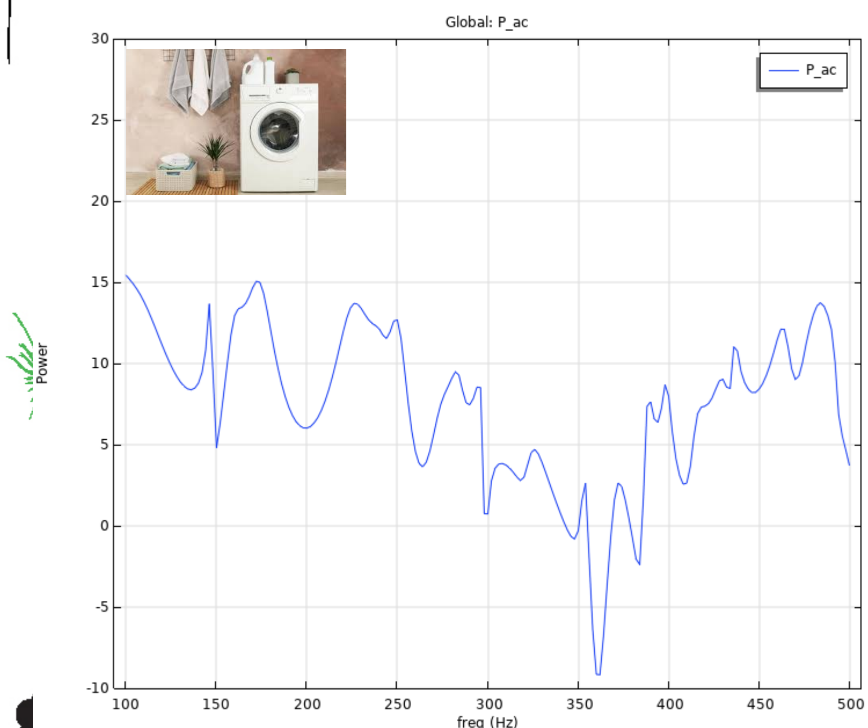
- Sound power to Sound power level

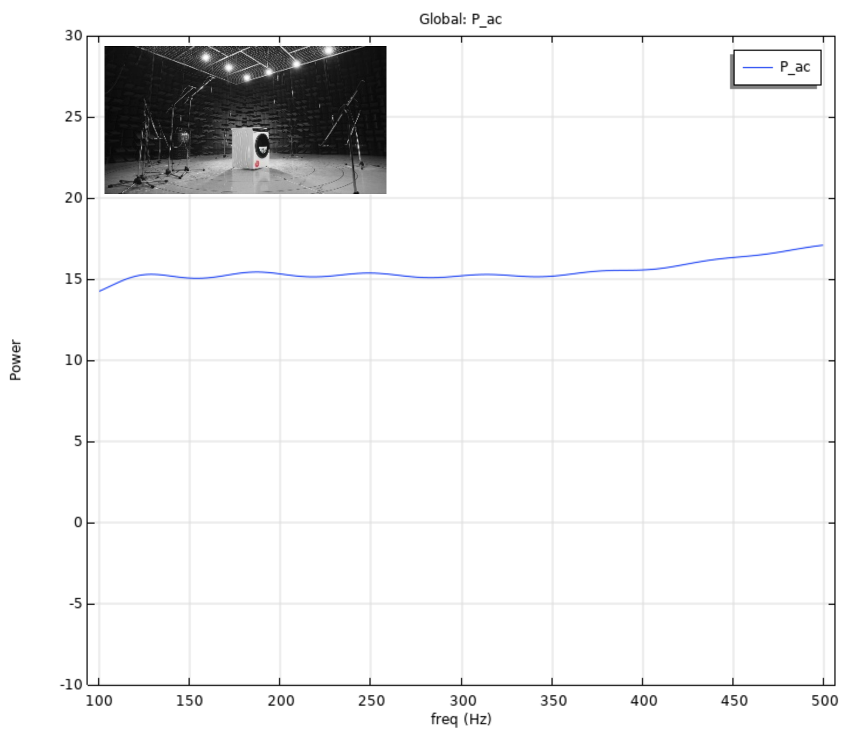
$$L_W = 10log_{10}\left(\frac{P_{ac}}{P_{ref}}\right)$$ in dB

$$P_{ref} = 1[pW] = 10^{-12}[W]$$

# SOUND POWER

- Sound power level ???



# IN SITU SOUND POWER

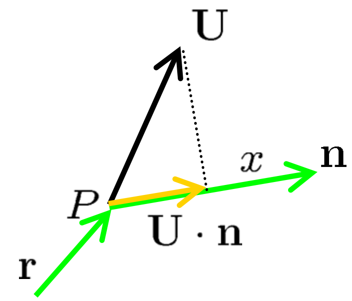
- Sound power is quite different …
  - Sound power depends on the acoustic environment the source is in!
  - Sound power measured in an anechoic room is not equal to the in situ sound power emitted!
    - … So why determine the sound power in an anechoic environment?
- but …
  - What is then the actual, in situ, power emitted by the source?
  - And how much of this power is being reflected by its surroundings?

# LOCAL PLANE WAVE (LPW) EXPANSION

- … you can get the answer using a Local Plane Wave expansion of the sound field

  - The sound field at the measurement surface is approximated by **two local plane waves** propagating in direction **n** (an emitted and a reflected wave)

# LOCAL PLANE WAVE EXPANSION




- ... the measured pressure and normal velocity component (or two pressures) are mapped onto this model

$$
\begin{aligned}
P &= Ae^{-ikx} + Be^{ikx} = A + B \\
\mathbf{U} \cdot \mathbf{n} &= \frac{1}{\rho c}\left(Ae^{-ikx} - Be^{ikx}\right) = \frac{1}{\rho c}(A - B)
\end{aligned}
$$

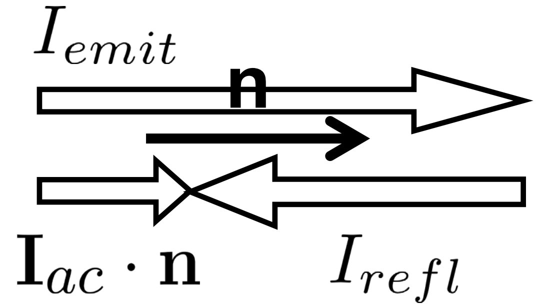
- … to determine the (complex) amplitudes of both waves

$$
\begin{aligned}
A(\mathbf{r}, \mathbf{n}) &= (P + \rho c \mathbf{U} \cdot \mathbf{n})/2 \\
B(\mathbf{r}, \mathbf{n}) &= (P - \rho c \mathbf{U} \cdot \mathbf{n})/2
\end{aligned}
$$

# LOCAL PLANE WAVE EXPANSION

- … to determine the emitted intensity

$$I_{emit} = A\bar{A}/(2\rho c)$$



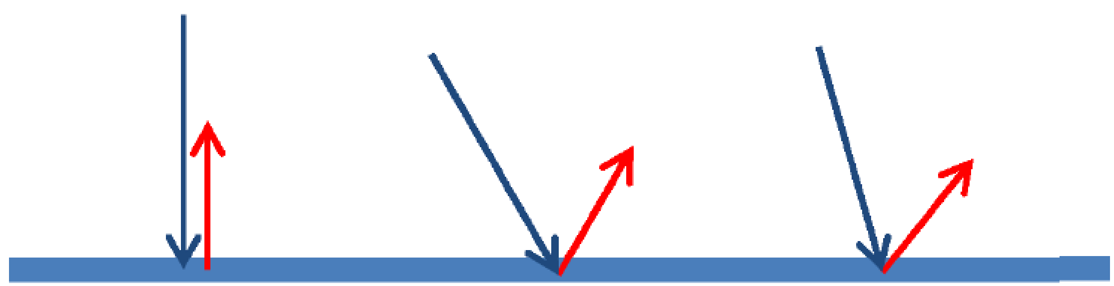

- … and emitted power

$$P_{emit} = \int I_{emit}\, dS$$

- and of course … $P_{refl} = \int I_{refl}\, dS$

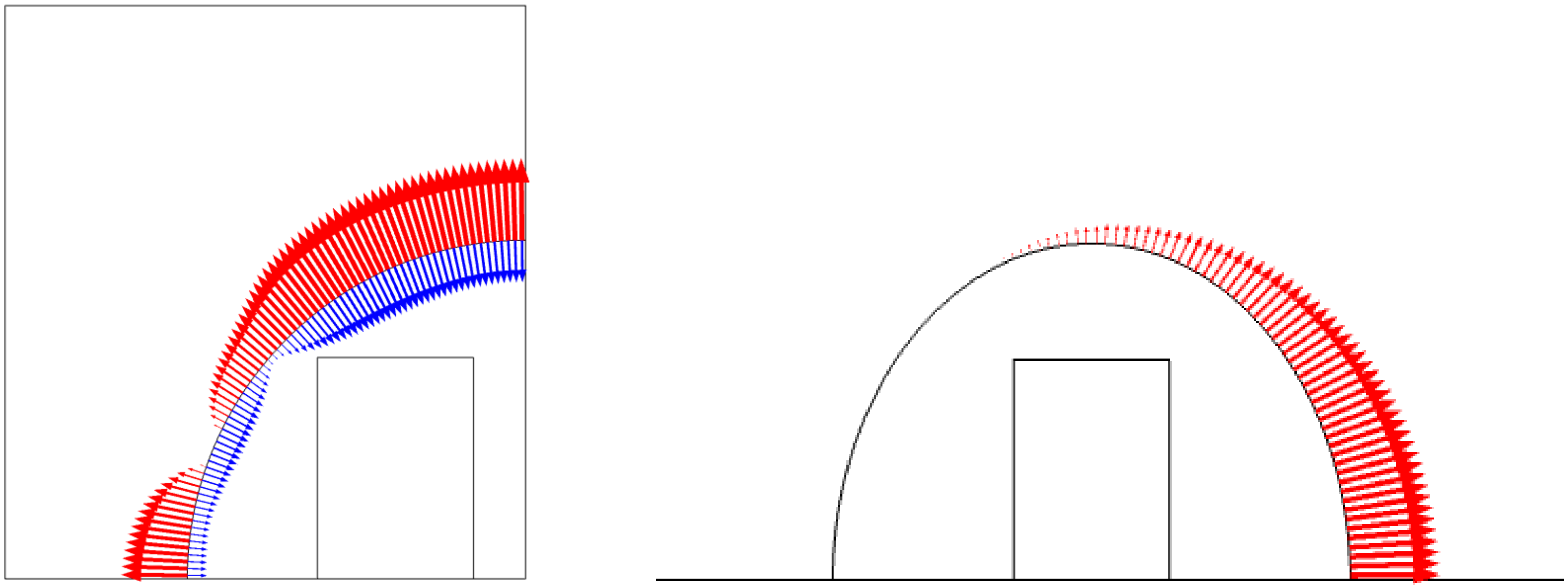
# LOCAL PLANE WAVE EXPANSION

- Family of methods …
  - LPW Local Plane Wave (simple)
  - LSPW Local Specular Plane Wave (complex)
  - LAPW Local Arbitrary Plane Wave (~*;-)_?)



# IN SITU SOUND POWER

- Emitted intensity (red) and reflected intensity (blue), based on the local plane wave expansion



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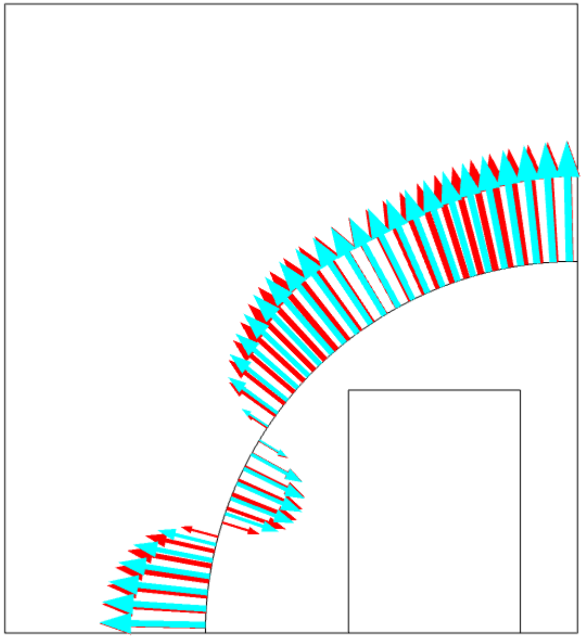
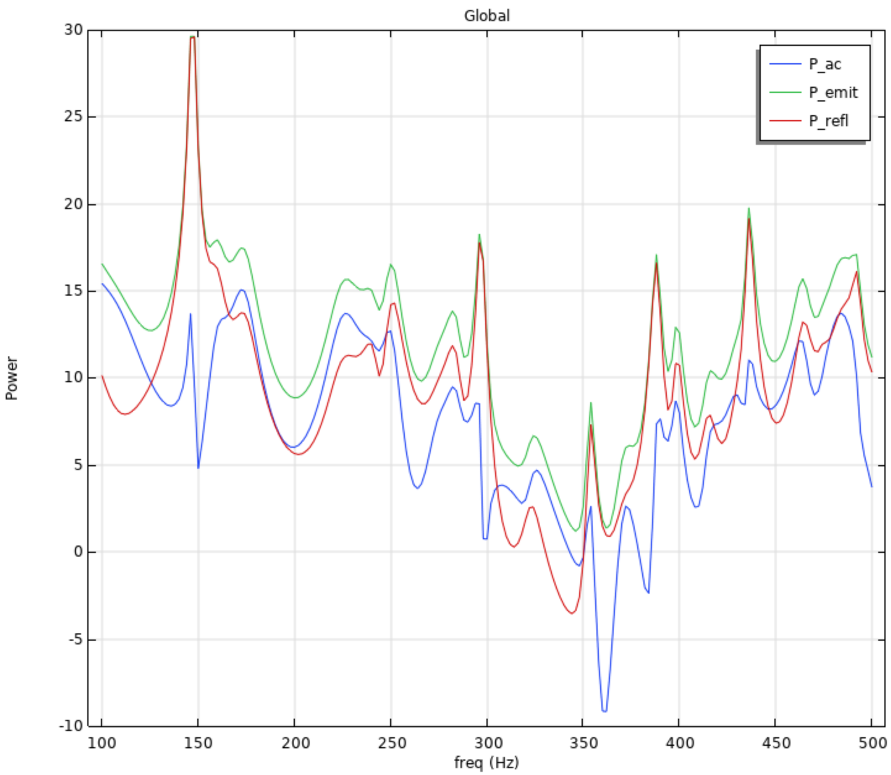
# IN SITU SOUND POWER

- Active intensity (cyan) = Emitted intensity - Reflected intensity (red)



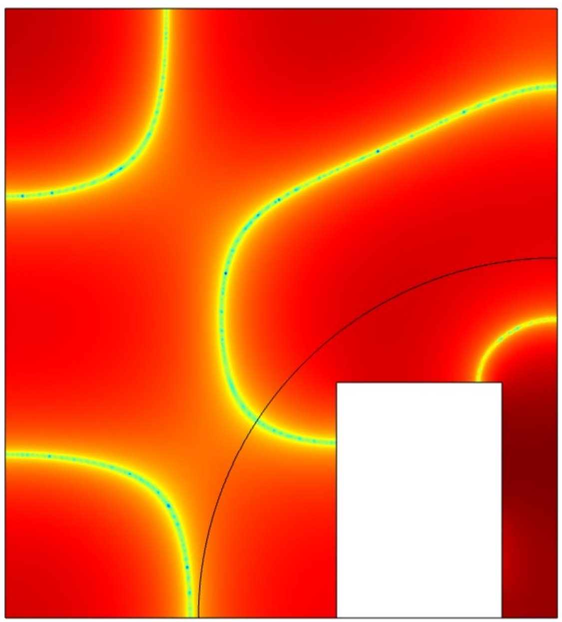
# IN SITU SOUND POWER

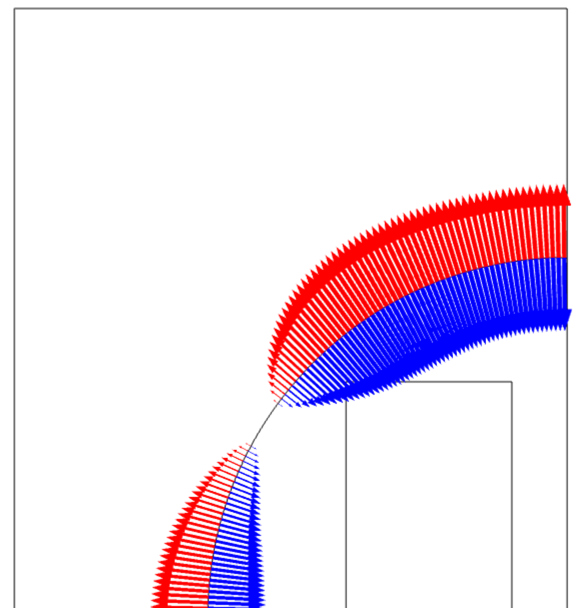
- Emitted power (green), Reflected power (red), Active power (blue)



# IN SITU SOUND POWER

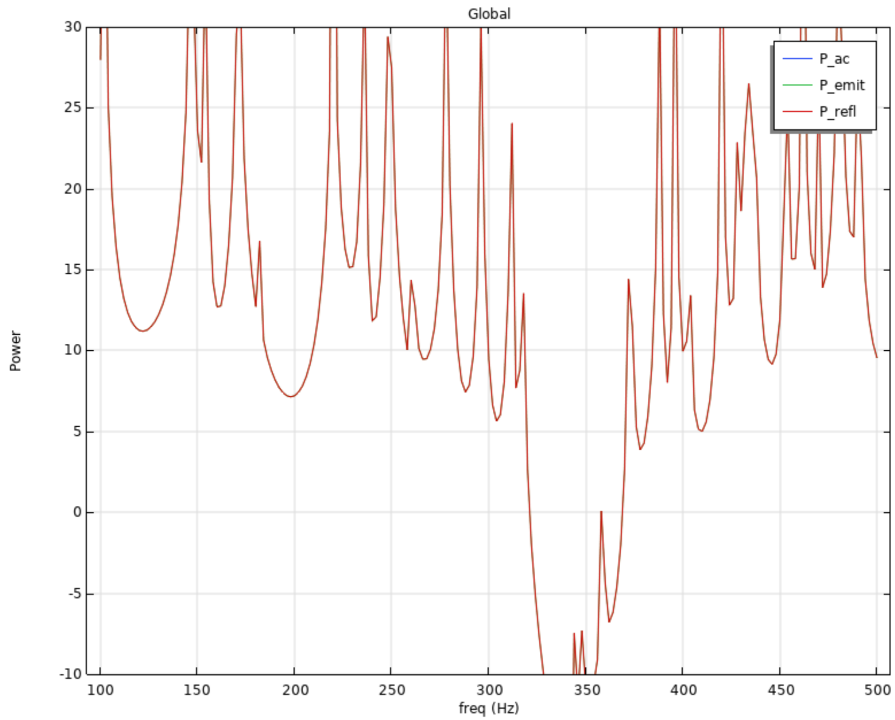
- Closing the window (= reverberant room)
  - Sound pressure level is high … sound power level is zero !





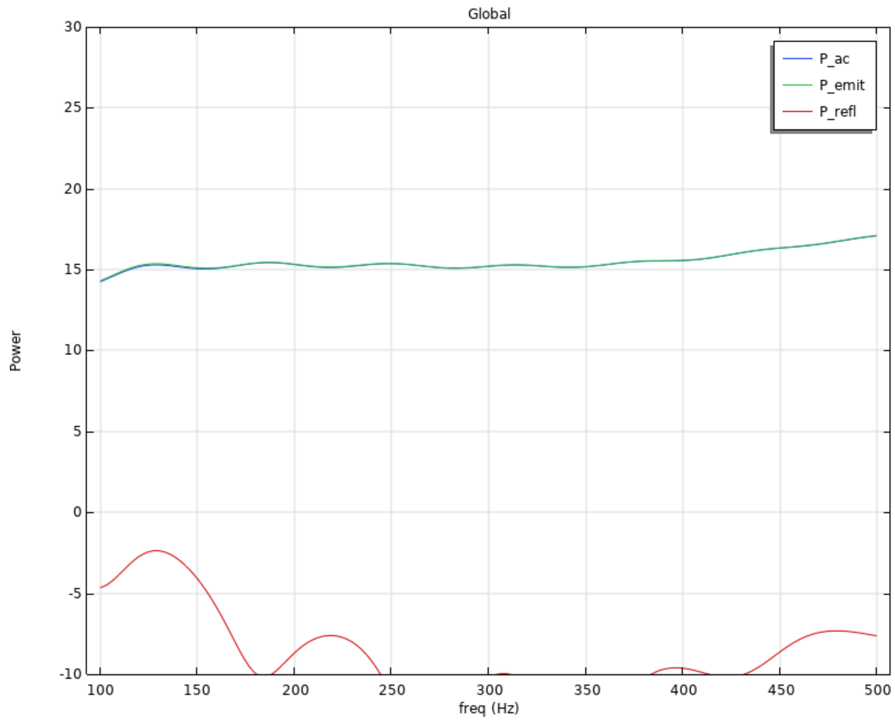
# IN SITU SOUND POWER

- Closed window. Emitted power = Reflected power, Active power = 0



# IN SITU SOUND POWER

- Anechoic room. Emitted power = Active power, Reflected power = 0



# SOUND ABSORPTION

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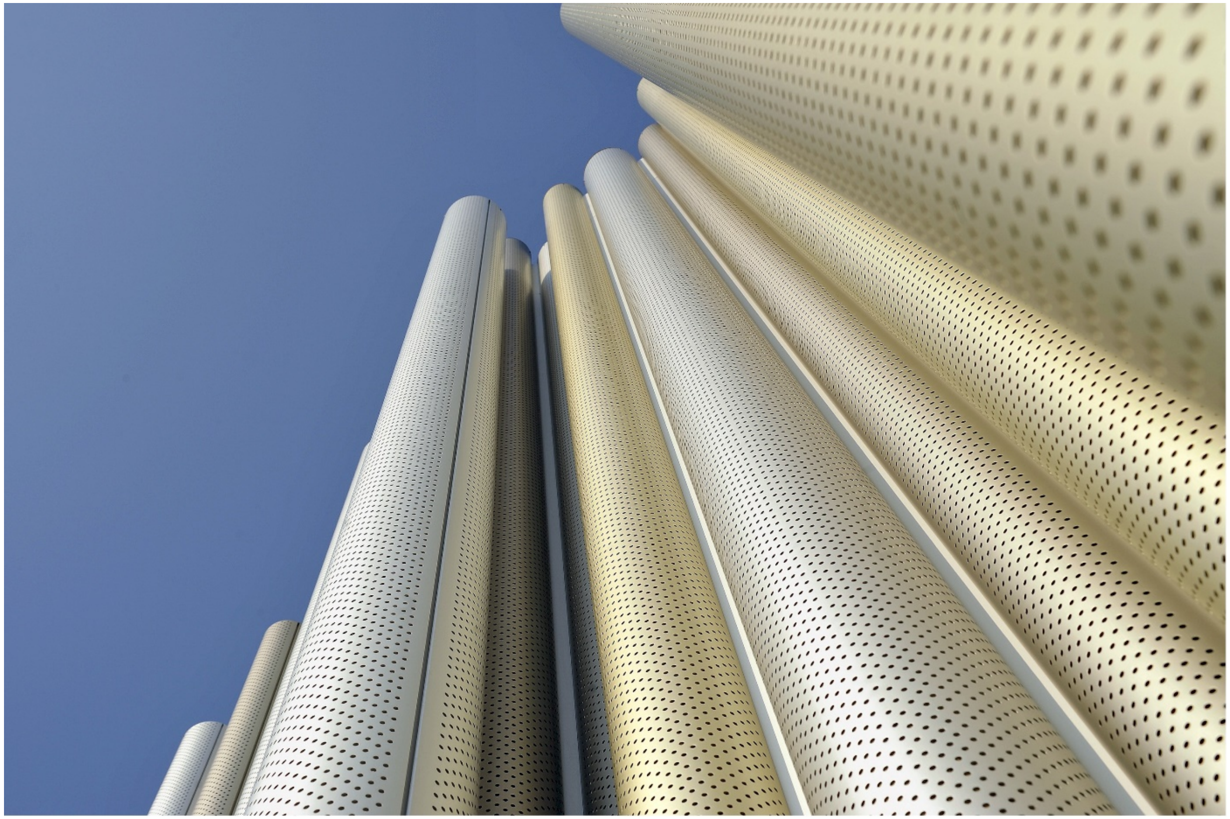
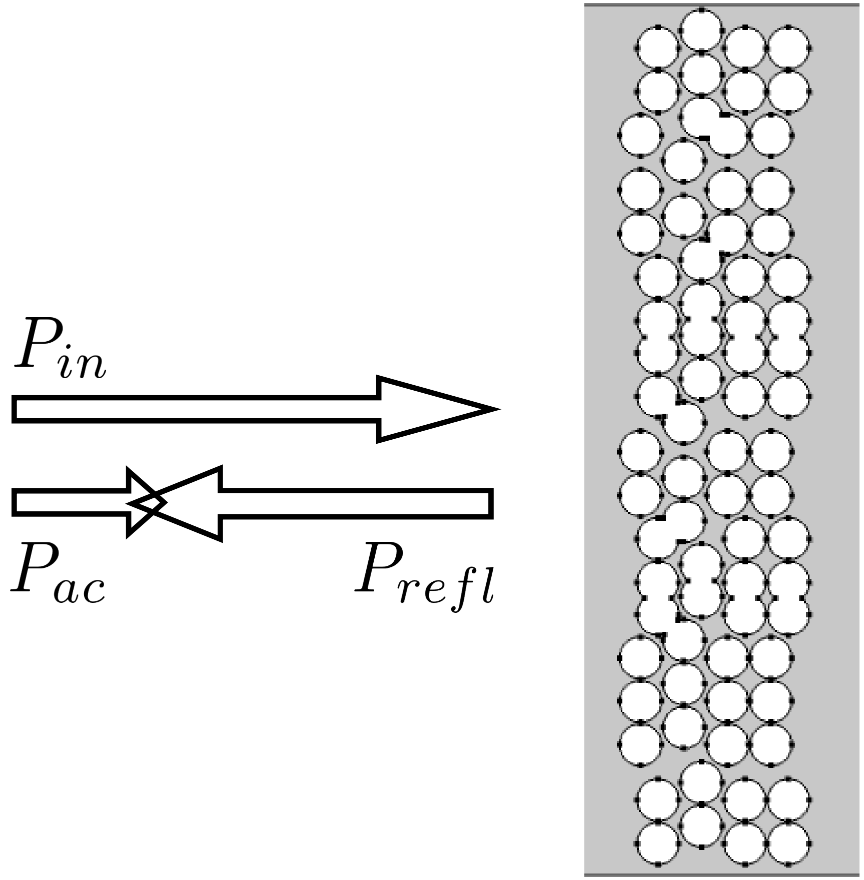


# SOUND ABSORPTION




$$\alpha \equiv \frac{P_{ac}}{P_{in}}$$

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# IN SITU SOUND ABSORPTION

- The LPW approach …

$$
\begin{aligned}
A(\mathbf{r},\mathbf{n}) &= (P + \rho c \mathbf{U}\cdot\mathbf{n})/2 \\
B(\mathbf{r},\mathbf{n}) &= (P - \rho c \mathbf{U}\cdot\mathbf{n})/2
\end{aligned}
$$

$$
\begin{aligned}
I_{in} &= A\overline{A}/(2\rho c) \\
I_{refl} &= B\overline{B}/(2\rho c)
\end{aligned}
$$

# IN SITU SOUND ABSORPTION

- The LPW approach …

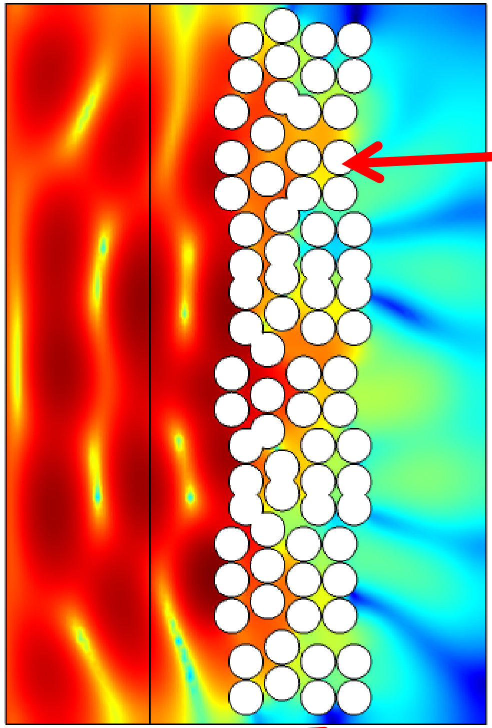
$$P_{in} = \int I_{in} dS$$

$$\alpha \equiv \frac{P_{ac}}{P_{in}}$$

# IN SITU SOUND ABSORPTION

- Sound pressure level

Sound hard wall



Impedance boundary condition
Z = 5*ρc

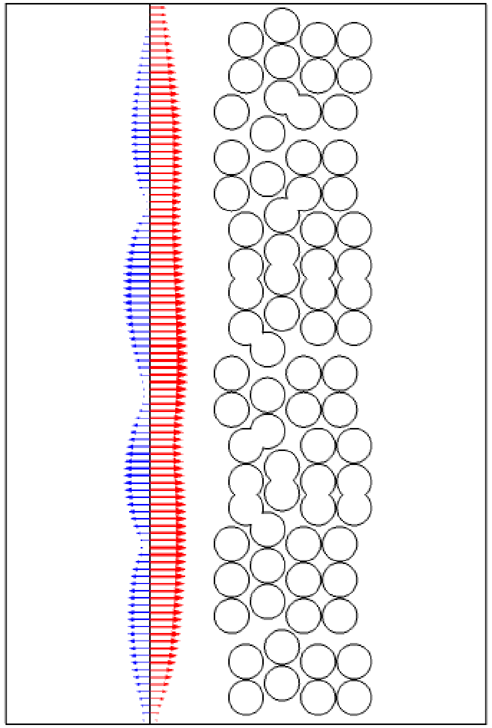
Boundary condition
P = 1

Impedance boundary condition
Z = ρc

Sound hard wall

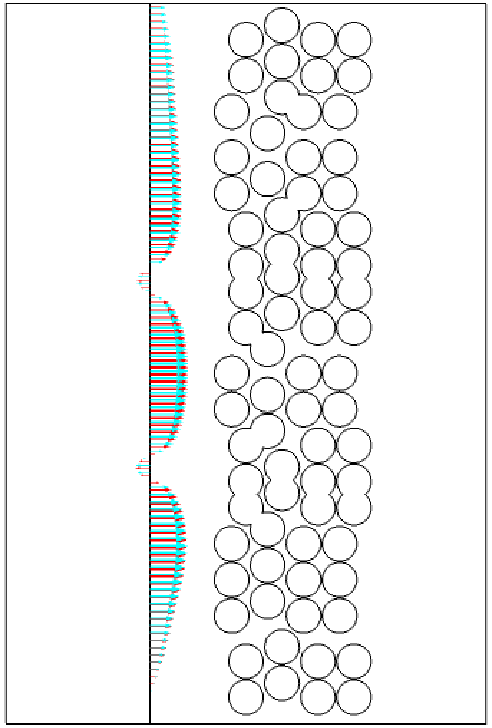
# IN SITU SOUND ABSORPTION

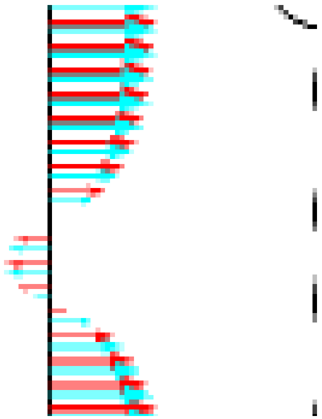
- Incident intensity (red), Reflected intensity (blue)



# IN SITU SOUND ABSORPTION

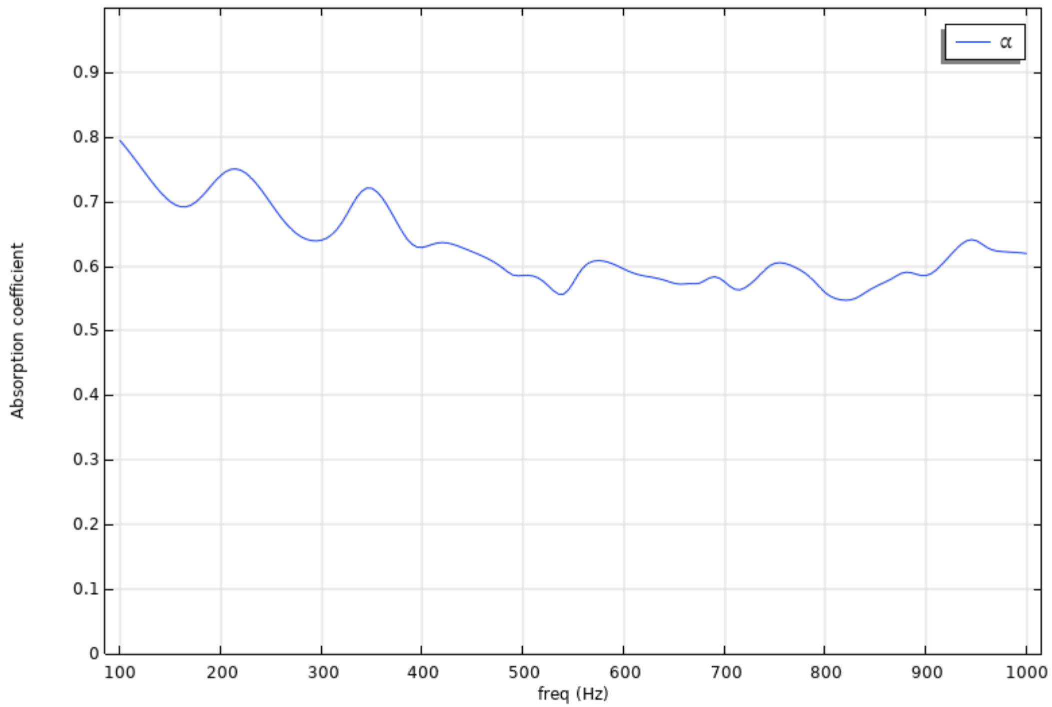
- Active intensity (cyan) = Incident intensity - Reflected intensity (red)





# IN SITU SOUND ABSORPTION

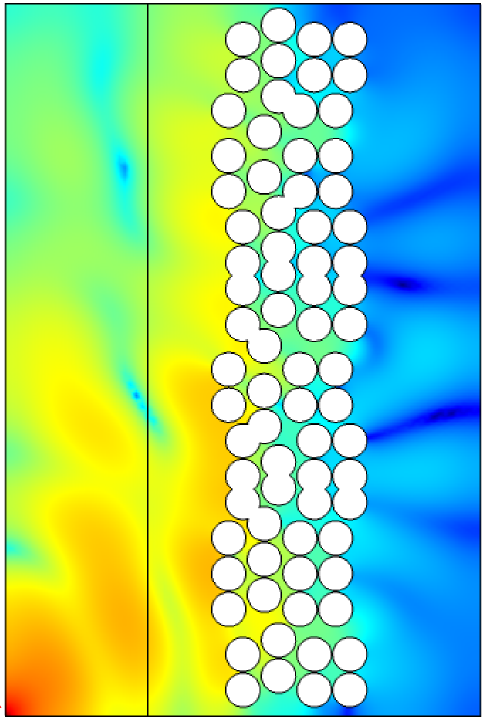
- Sound absorption coefficient



# IN SITU SOUND ABSORPTION

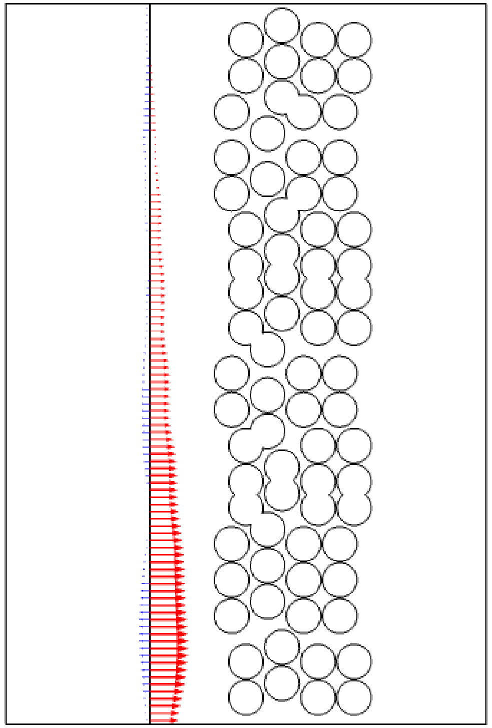
- Sound absorption coefficient

Boundary condition
P = 1



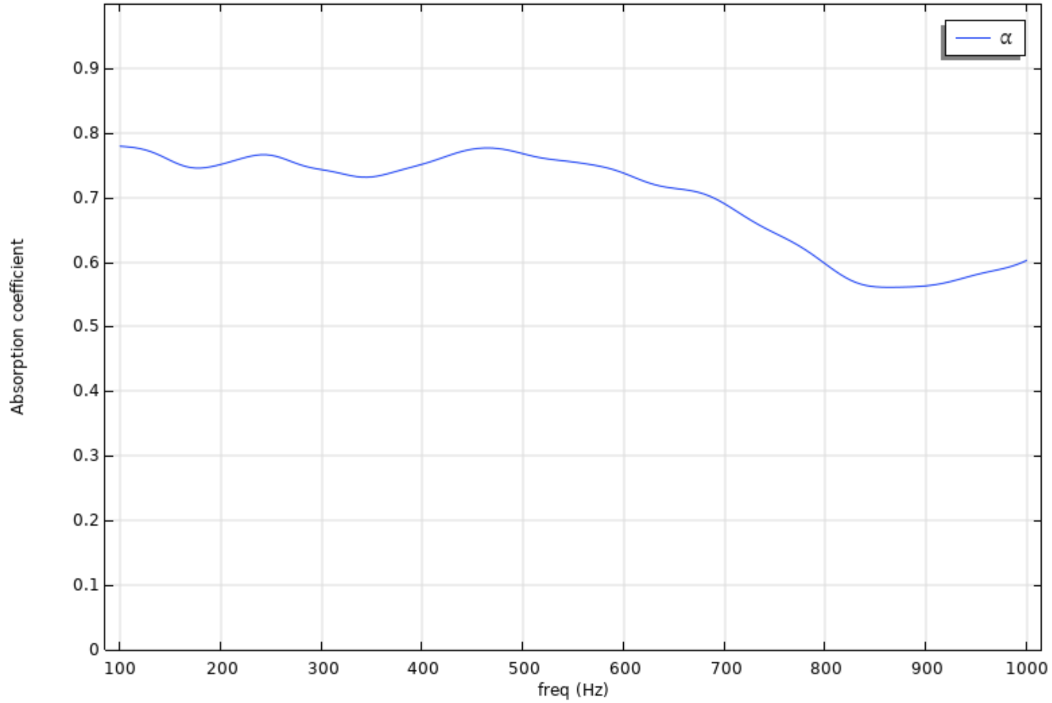
# IN SITU SOUND ABSORPTION

- Incident intensity (red), Reflected intensity (blue)



# IN SITU SOUND ABSORPTION

- Sound absorption coefficient



# IN SITU SOUND ABSORPTION

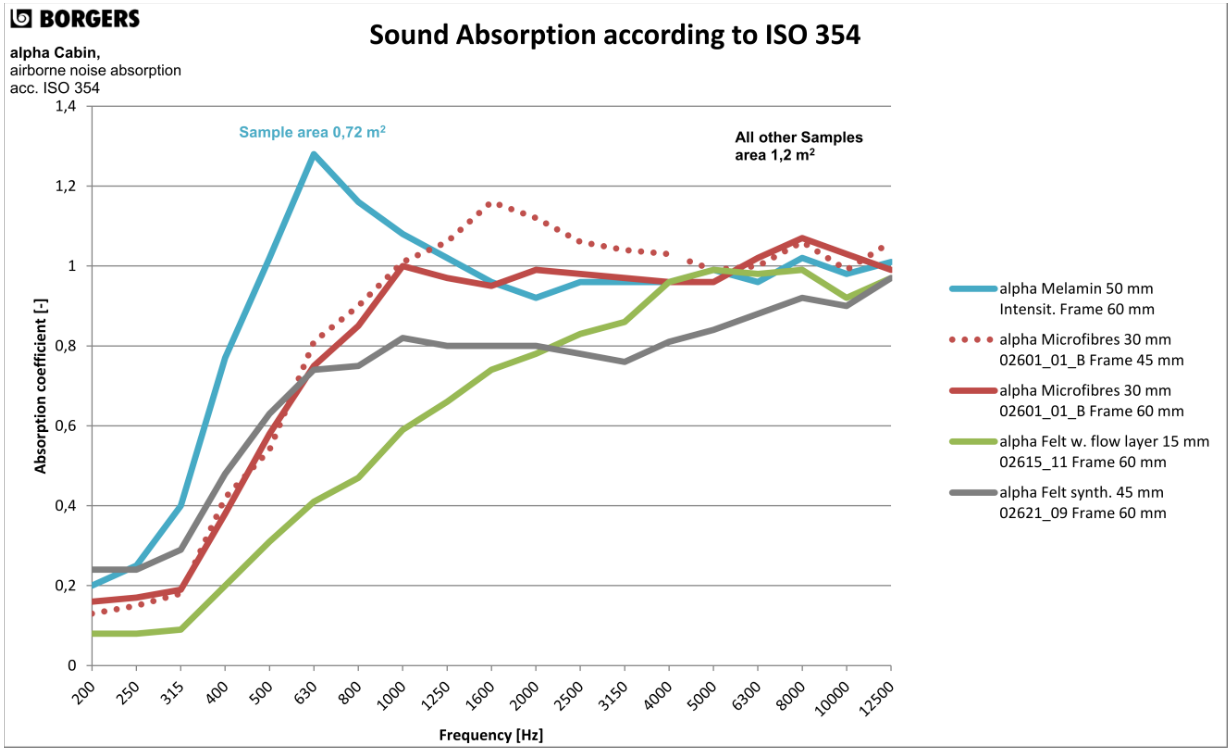
- Measurements (Sonocat)

# IN SITU SOUND ABSORPTION

- Measurements

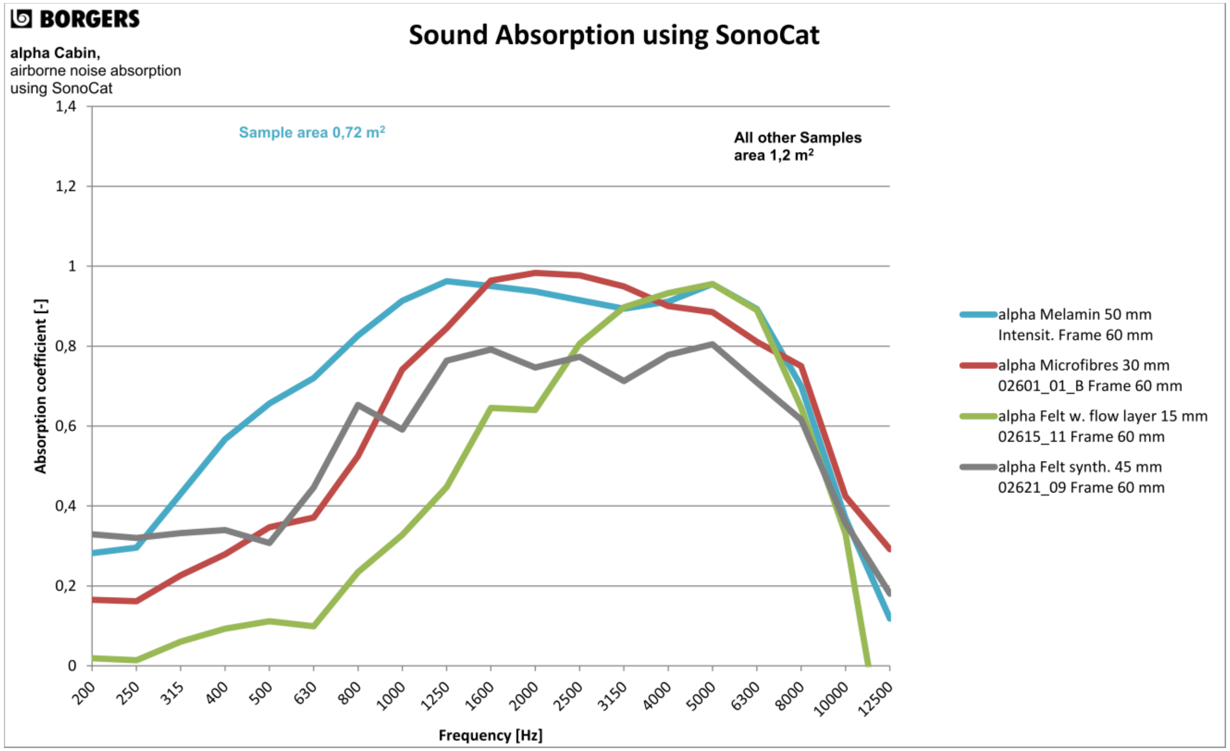
# IN SITU SOUND ABSORPTION

- Measurements



# IN SITU SOUND ABSORPTION

- Measurements

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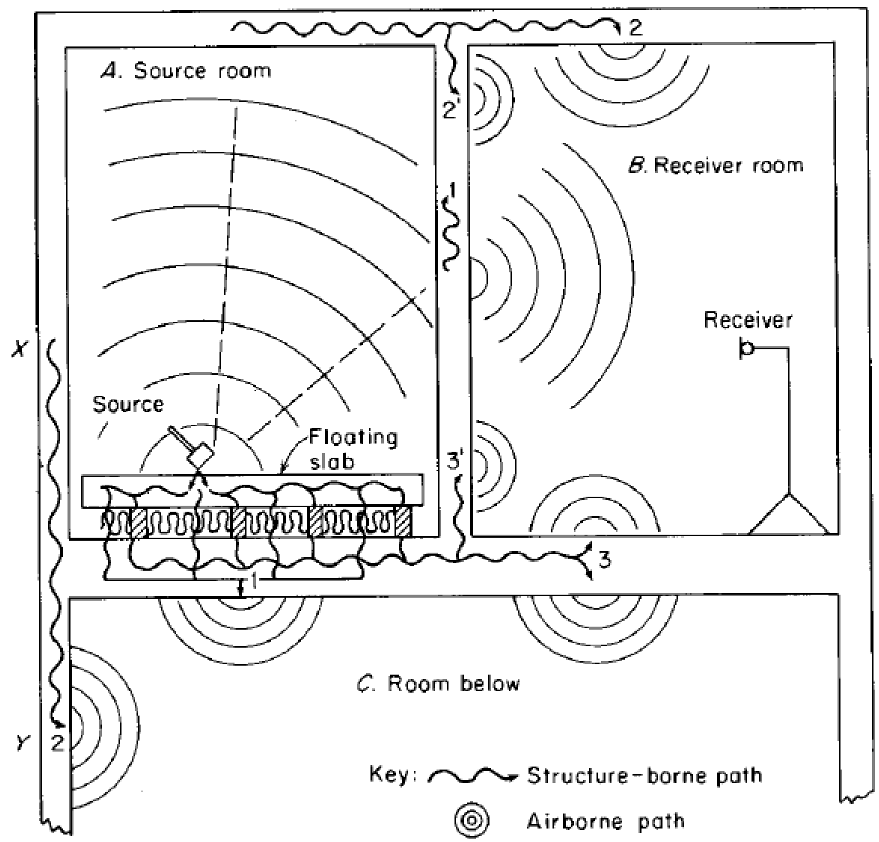
# IN SITU SOUND ABSORPTION

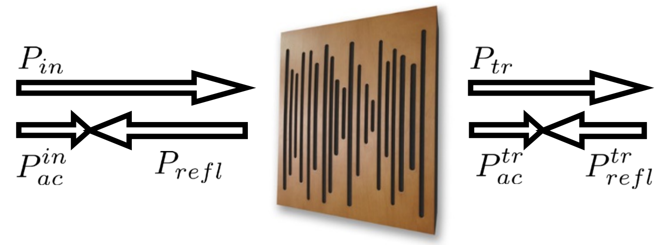
- Based on a LOCAL plane wave assumption (LPW), the incident and reflected sound intensity in a specified direction **n**, at any position can be measured in-situ, for any sound field and any acoustic environment (reflections)

- The incident intensity can be integrated over the surface of interest to obtain the incident power, from which the absorption coefficient of that particular surface can be obtained

# SOUND TRANSMISSION

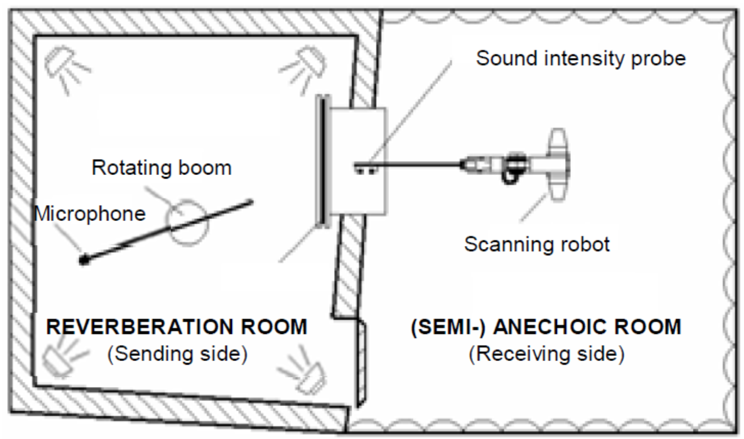
# SOUND TRANSMISSION






# SOUND TRANSMISSION

- Transmission measurement in a reverberation/anechoic room:

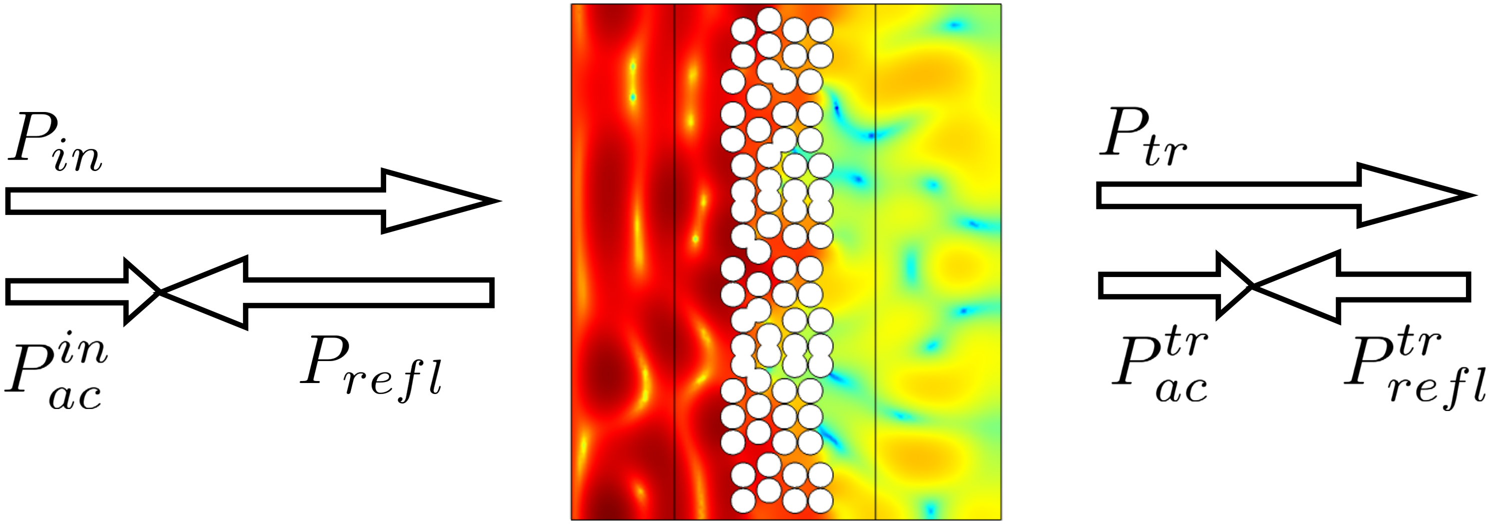



Sending room is reverberant: Because the sound field is diffuse, the incident power can be approximated

Receiver room is anechoic: Because there are no reflections, the transmitted power equals the active power

# SOUND TRANSMISSION

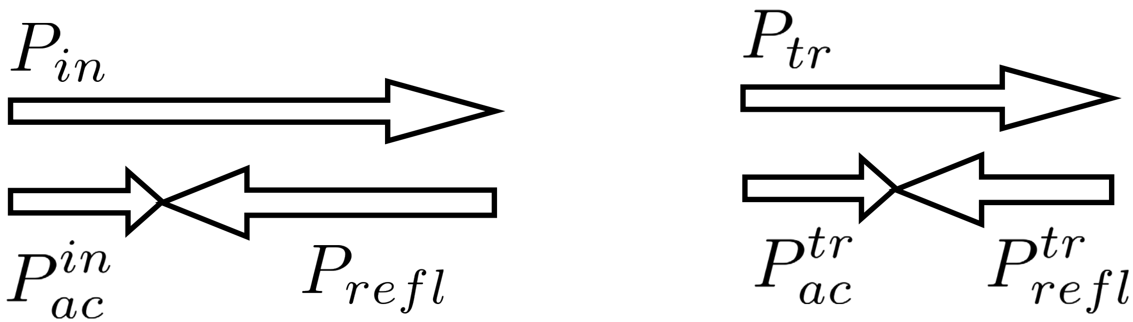
- But how do we measure the transmission coefficient of the noise barrier?




$$\tau \equiv \frac{P_{tr}}{P_{in}} \qquad TL = -10log_{10}\left(\frac{P_{tr}}{P_{in}}\right)$$

# IN SITU SOUND TRANSMISSION

- Again we can use the LPW approach … on the incident side and on the transmitted side …



# IN SITU SOUND TRANSMISSION

- The LPW approach on the **incident** side …

$$\begin{aligned} A(\mathbf{r},\mathbf{n}) &= (P + \rho c \mathbf{U}\cdot\mathbf{n})/2 \\ B(\mathbf{r},\mathbf{n}) &= (P - \rho c \mathbf{U}\cdot\mathbf{n})/2 \end{aligned}$$

$$\begin{aligned} I_{in} &= A\overline{A}/(2\rho c) \\ I_{refl} &= B\overline{B}/(2\rho c) \end{aligned}$$

# IN SITU SOUND TRANSMISSION

- The LPW approach on the **transmitted** side …

$$\begin{aligned} A(\mathbf{r},\mathbf{n}) &= (P + \rho c \mathbf{U} \cdot \mathbf{n})/2 \\ B(\mathbf{r},\mathbf{n}) &= (P - \rho c \mathbf{U} \cdot \mathbf{n})/2 \end{aligned}$$

$$\begin{aligned} I_{tr} &= A\overline{A}/(2\rho c) \\ I_{refl}^{tr} &= B\overline{B}/(2\rho c) \end{aligned}$$

# IN SITU SOUND TRANSMISSION

- The LPW approach …

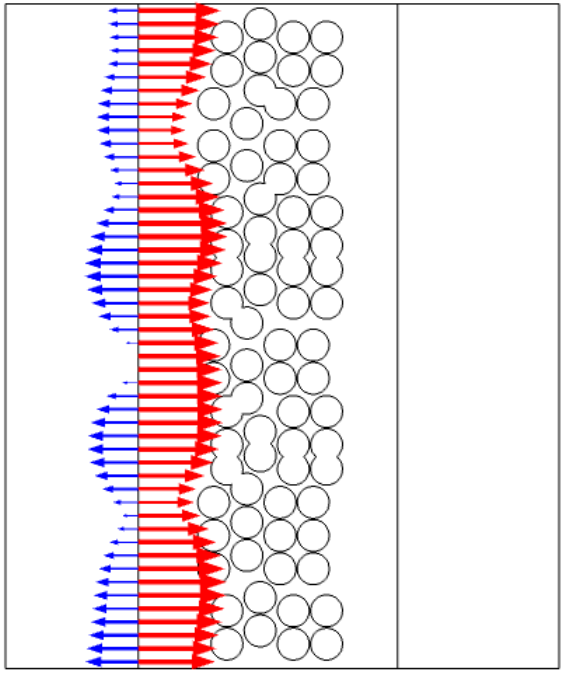
$$P_{in} = \int I_{in} dS$$

$$P_{tr} = \int I_{tr} dS$$

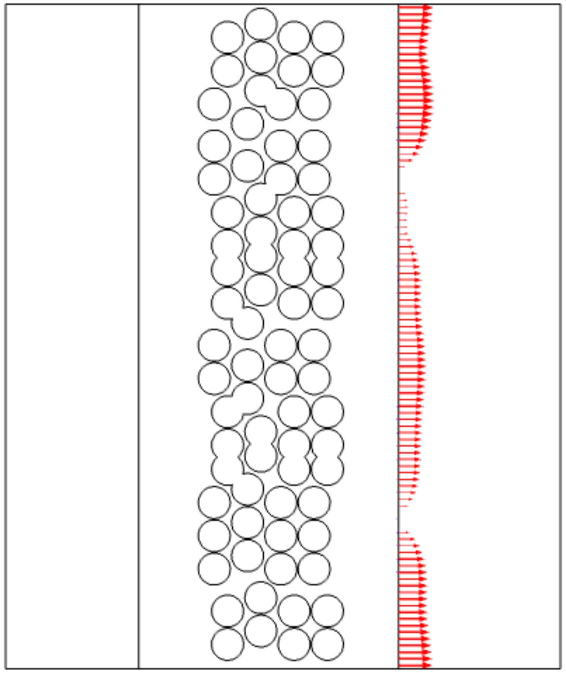
$$\tau \equiv \frac{P_{tr}}{P_{in}}$$

# IN SITU SOUND TRANSMISSION

- Incident (red), Reflected (blue)

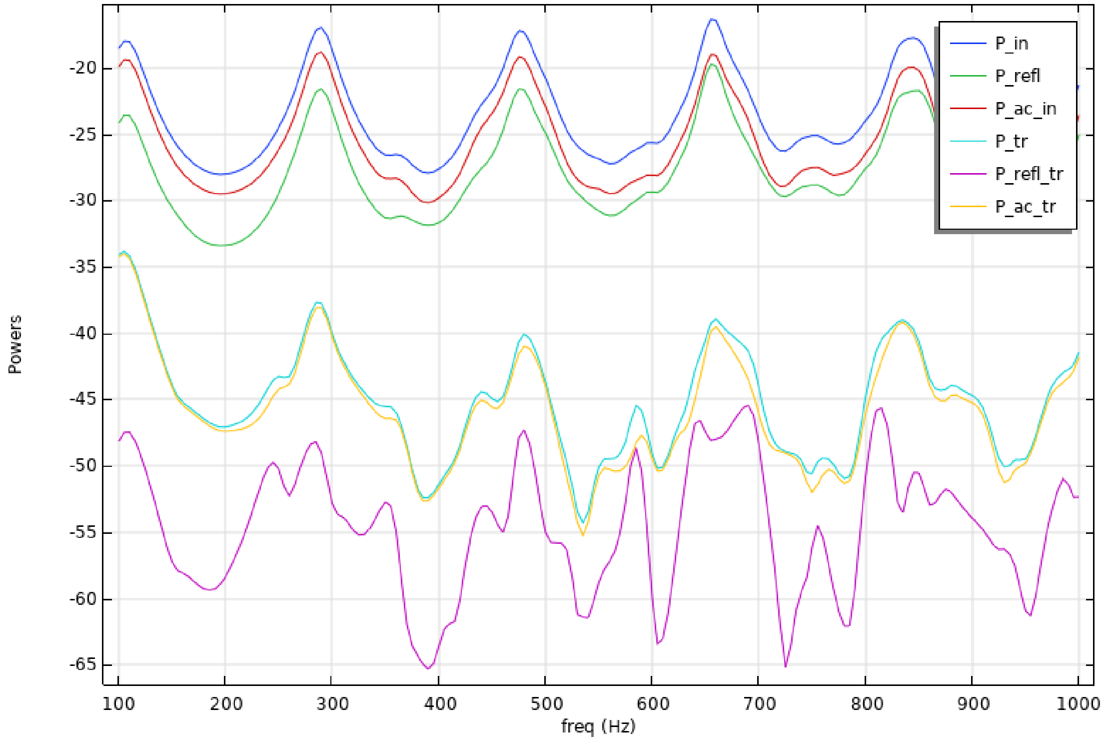


Transmitted (red), Reflected (blue)



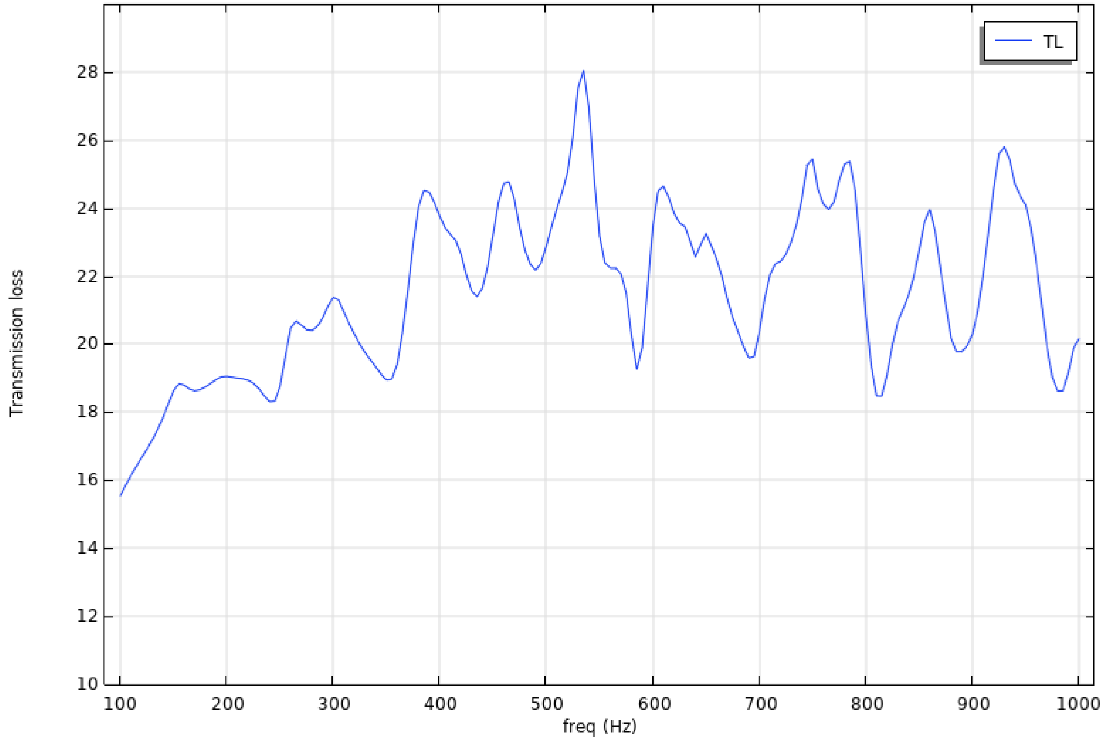
# IN SITU SOUND TRANSMISSION

- POWERZZZ …



# IN SITU SOUND TRANSMISSION

- Transmission loss



# IN SITU SOUND TRANSMISSION

- Measurements (with M+P)

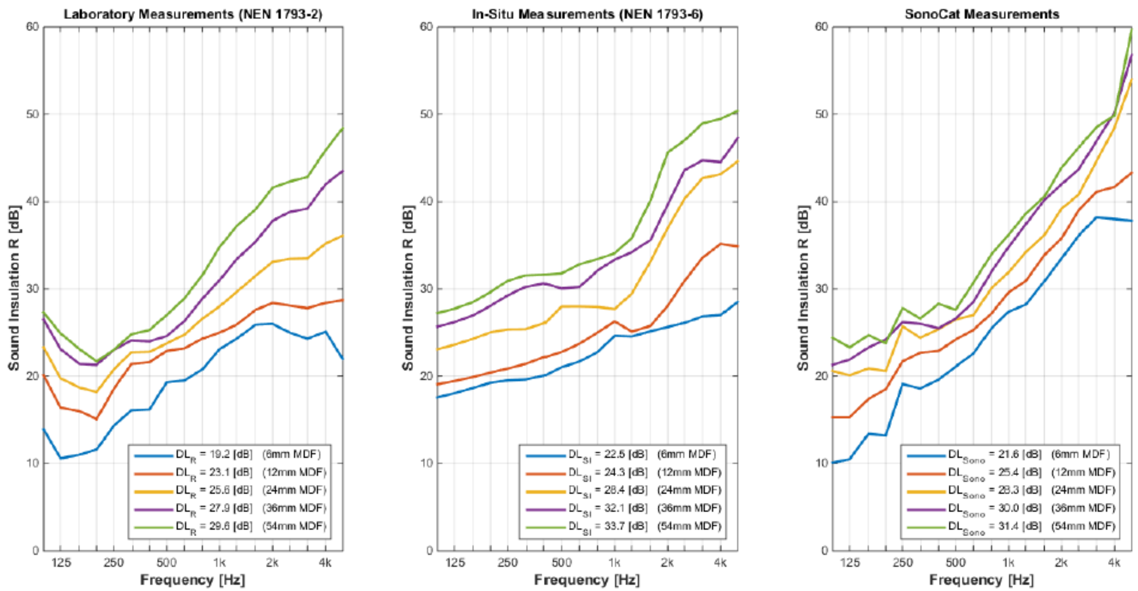
# IN SITU SOUND TRANSMISSION

- Measurements (with Fons Peeters and Bert Peeters from M+P)

11 Determination of acoustic properties of Noise Barriers

—

## Results (Spectral)

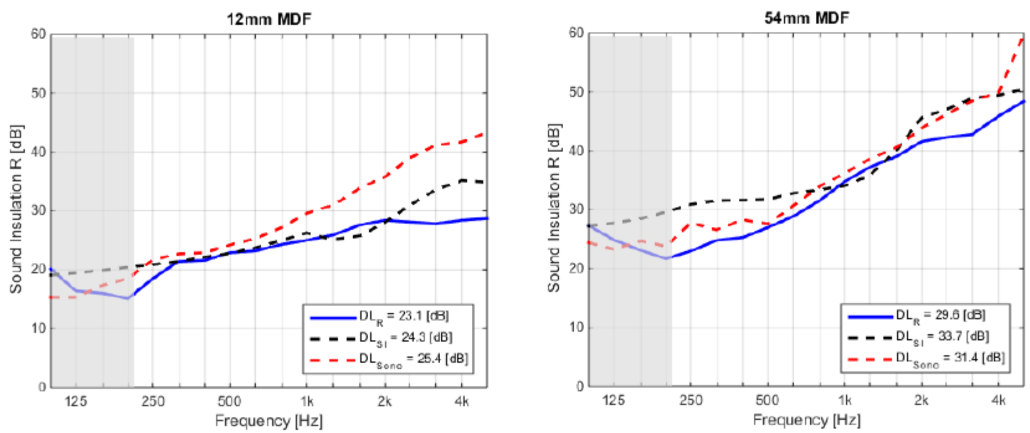


# IN SITU SOUND TRANSMISSION

- Measurements

12 Determination of acoustic properties of Noise Barriers

## Results (Spectral)




- Blue: Laboratory Measurements (1793-2)
- Black: In-Situ (1793-6)
- Red: SonoCat

- High frequencies: lab very sensitive for leakage

# IN SITU SOUND TRANSMISSION

- The LPW method can be used to approximate the incident and transmitted powers in a transmission experiment, and hence provides an estimate for the transmission loss of the partition

- The method does not rely on any assumption about the acoustic field in the sending room or receiving room, nor does it rely on any assumption about the source. It can thus be used to find the in-situ transmission loss of the partition (how it performs in the real world!)

# THANK YOU FOR YOUR ATTENTION

- QUESTIONS?