

**7S3X0**

# **Introduction Building Physics and Material Science**

## **Lecture 8b Acoustics Insulation**

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Unit Building Physics and Services (BPS)



**TU/e**

# Contents

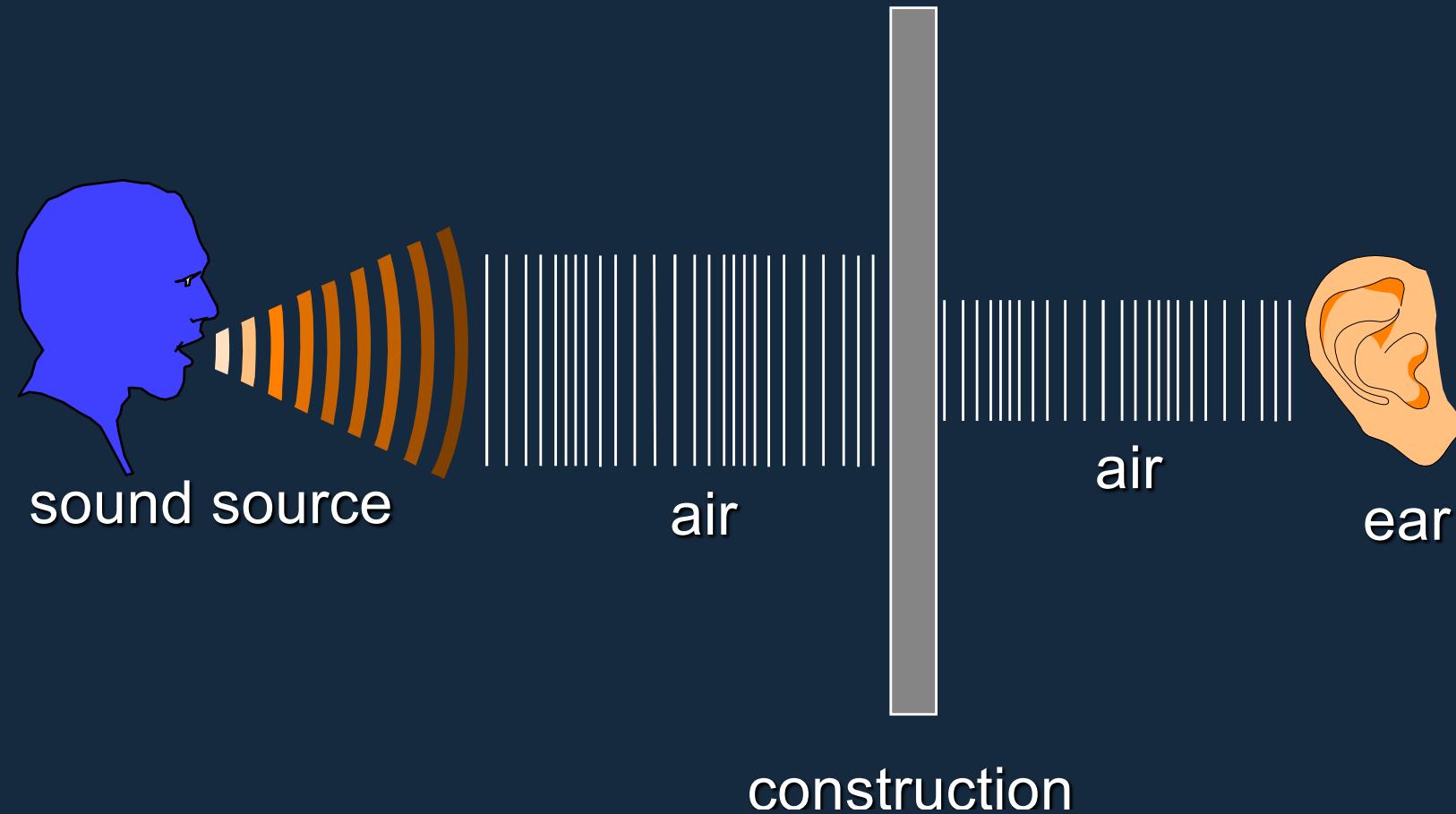
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## *Sound insulation*

- Introduction
- Airborne Sound Insulation
- Solid Constructions
- Double Leaf Constructions

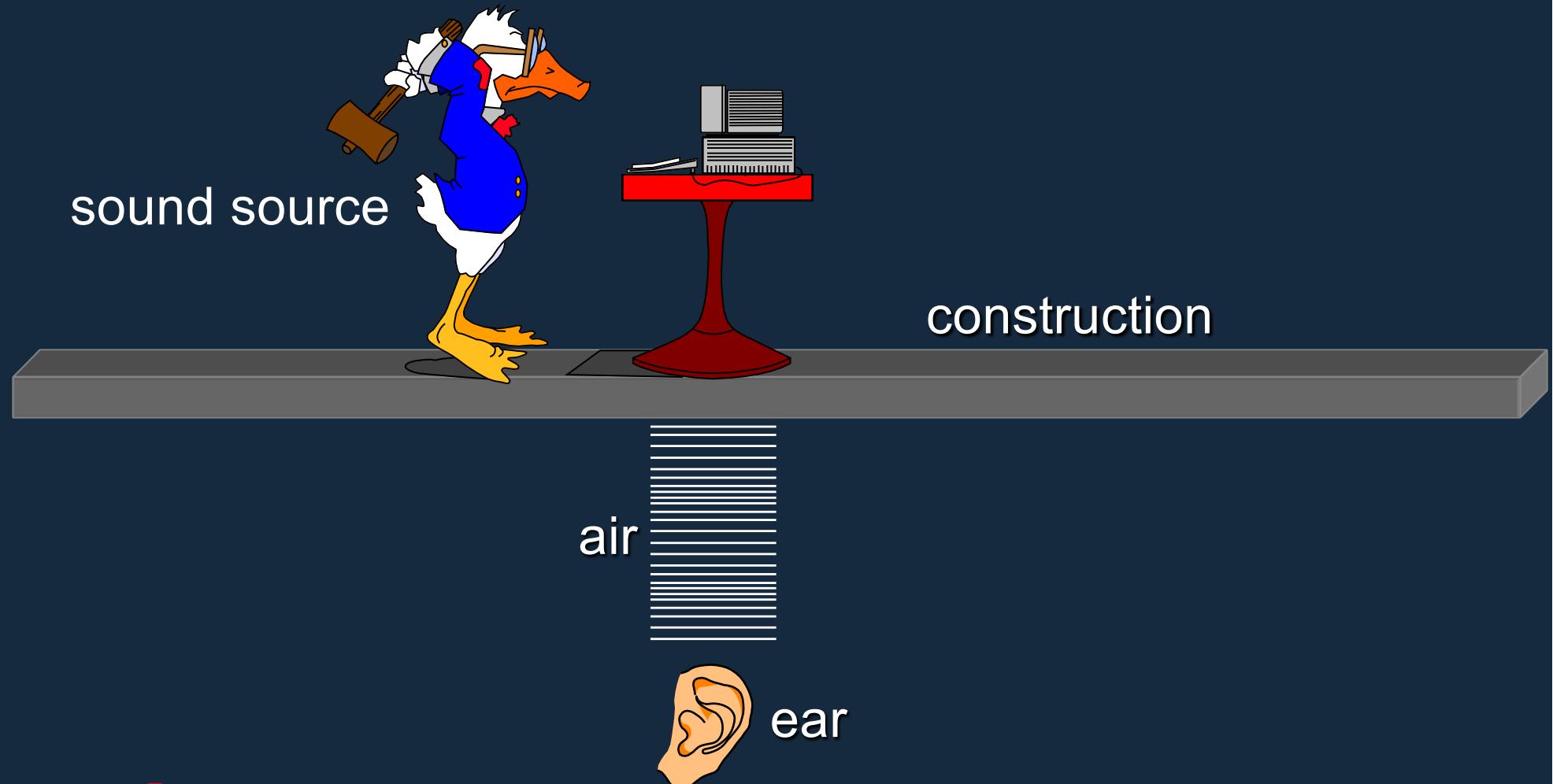
# Introduction

## *Airborne sound transmission*



# Introduction

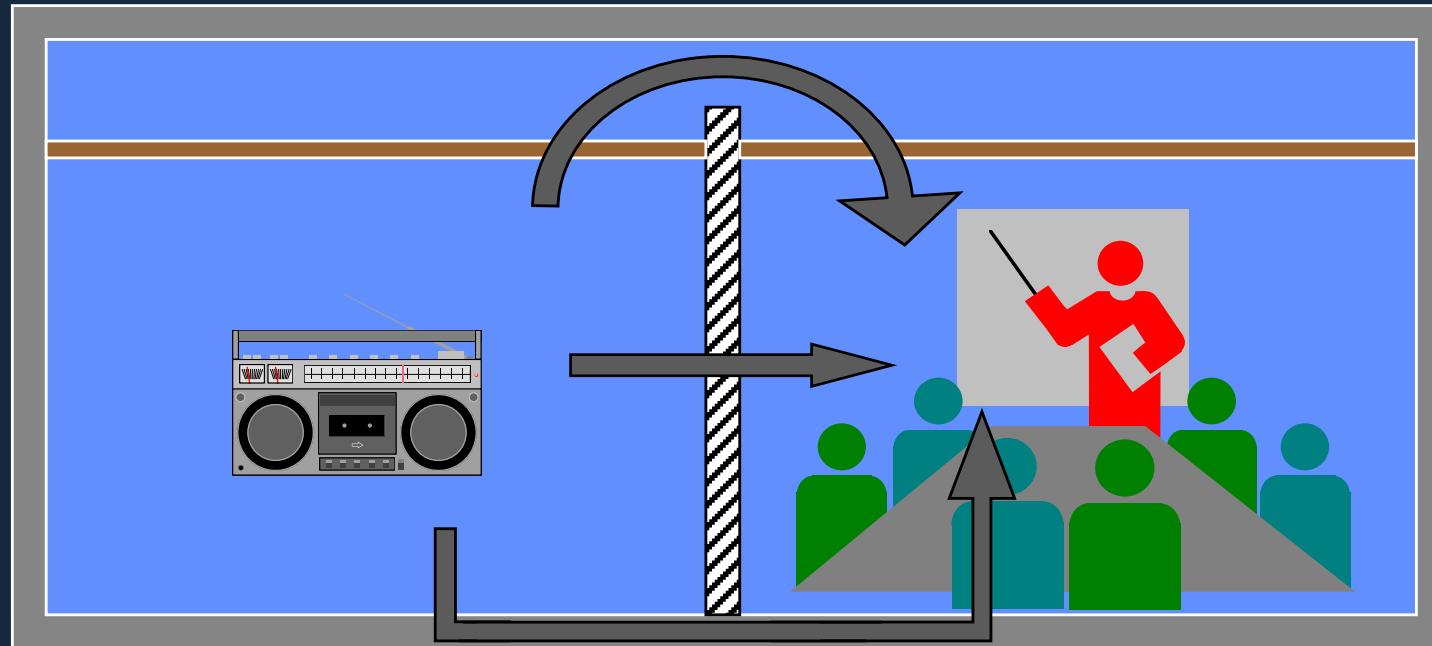
## *Impact sound transmission*



# Introduction

## *Transfer paths*

- direct
- flanking
- crosstalk



# Introduction

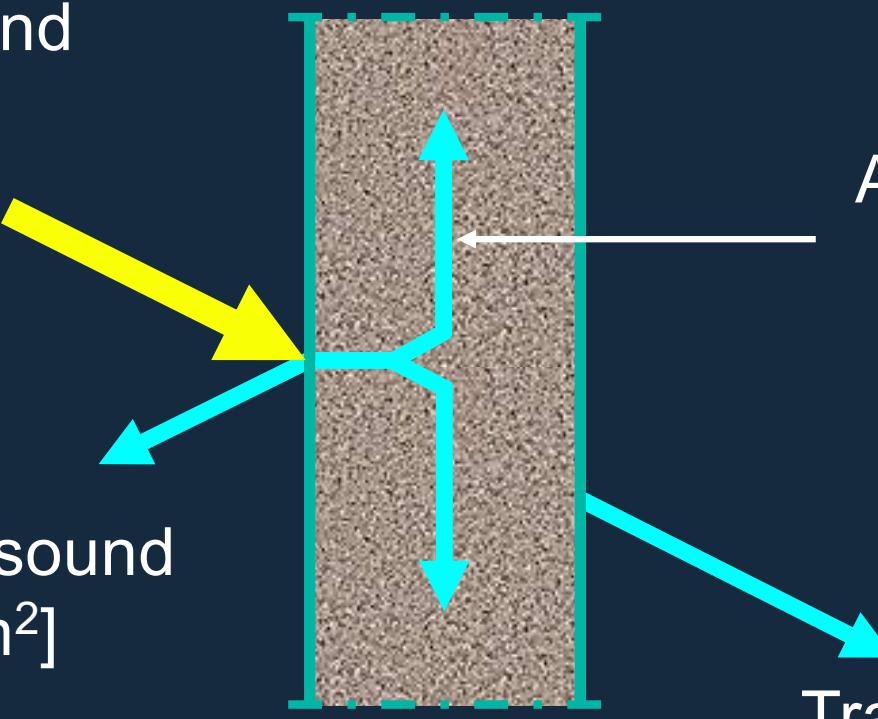
## *Definition*

Incoming sound  
 $I_i$  [W/m<sup>2</sup>]

Reflected sound  
 $I_r$  [W/m<sup>2</sup>]

Absorbed sound  
 $I_a$  [W/m<sup>2</sup>]

Transmitted sound  
 $I_\tau$  [W/m<sup>2</sup>]



$$I_i = I_r + I_a + I_\tau$$

# Sound absorbing materials ( $I_a$ )



Woodwool



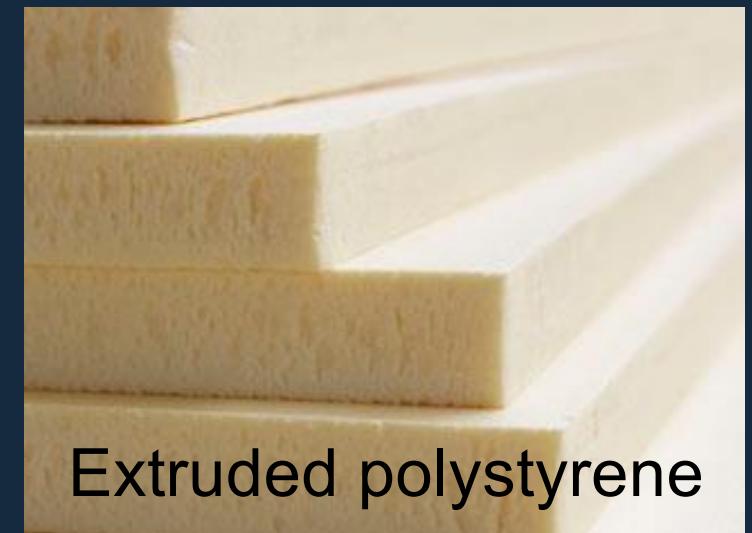
Foam glass



Glass wool



Mineral wool



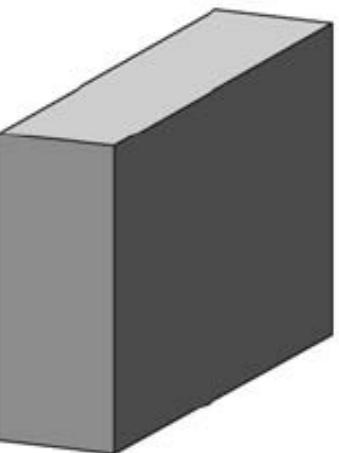
Extruded polystyrene

# Sound absorbing materials ( $I_a$ )

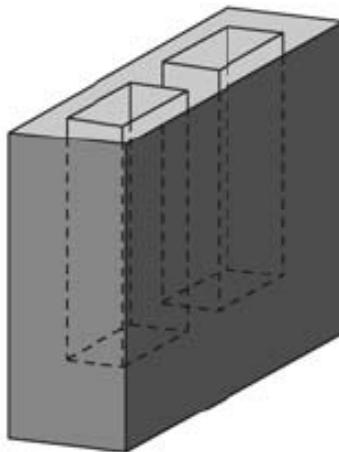
Material	Absorption coefficient		
	125 Hz	500 Hz	2000 Hz
Concrete	0.02	0.02	0.05
Brickwork	0.05	0.02	0.05
Plastered solid wall	0.03	0.02	0.04
Glass 6 mm	0.1	0.04	0.02
Timber boarding, 19 mm over air space against solid backing	0.3	0.1	0.1
Wood wool slabs, 25 mm, on solid backing, unplastered	0.1	0.4	0.6
Fibreboard, 12 mm on solid backing	0.05	0.15	0.3
Fibreboard, 12 mm over 25mm air space	0.3	0.3	0.3
Mineral wool, 25 mm with 5% perforated hardboard over	0.1	0.85	0.35
Expanded polystyrene board, 25 mm over 50 mm airspace	0.1	0.55	0.1
Flexible polyurethane foam, 50 mm on solid backing	0.25	0.85	0.9

Typical sound absorption coefficients at 125, 500 and 2000 Hz for various building materials

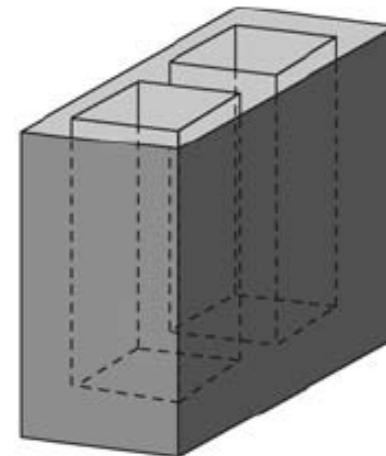
# Sound absorbing materials ( $I_a$ )



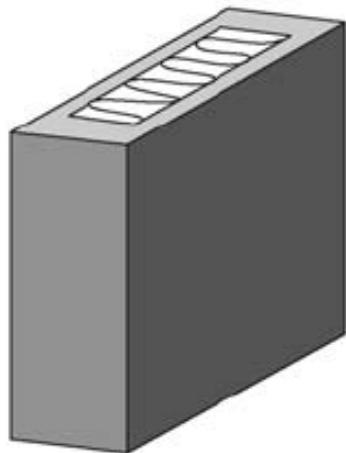
Solid



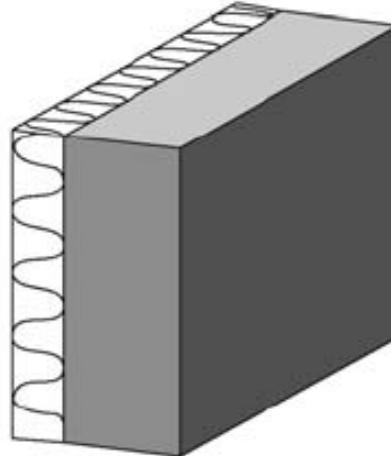
Cellular



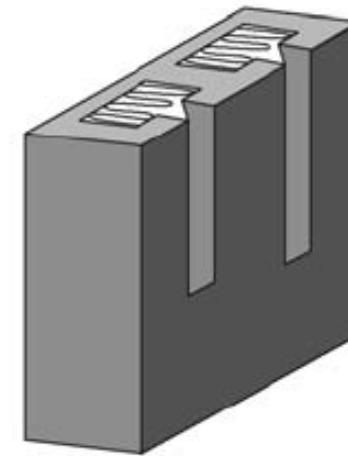
Hollow



Composite - insulation filled



Composite - bonded insulation



Sound absorbing - insulation filled

# Sound reduction index

## *Definition*

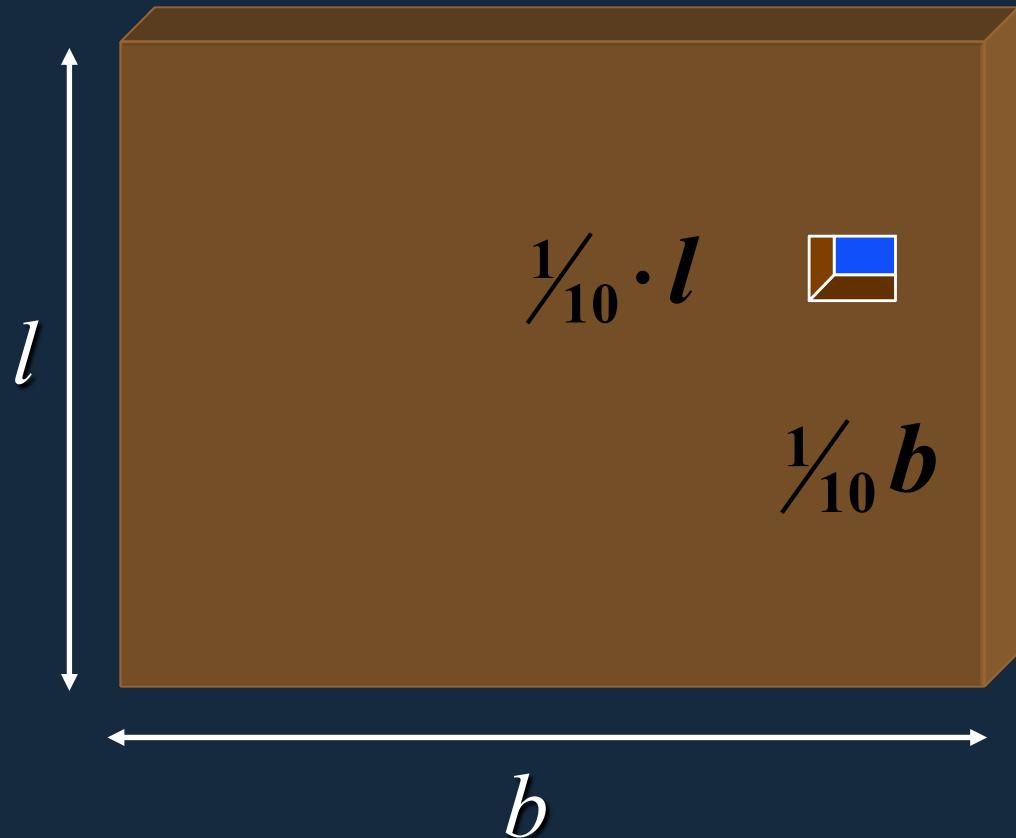
$$R = 10 \log_{10} \left( \frac{I_i}{I_t} \right) = 10 \log_{10} \left( \frac{1}{\tau} \right)$$

$$\tau = \frac{I_t}{I_i}$$

Transmission coefficient

# Airborne Sound Insulation

## *Calculation example*



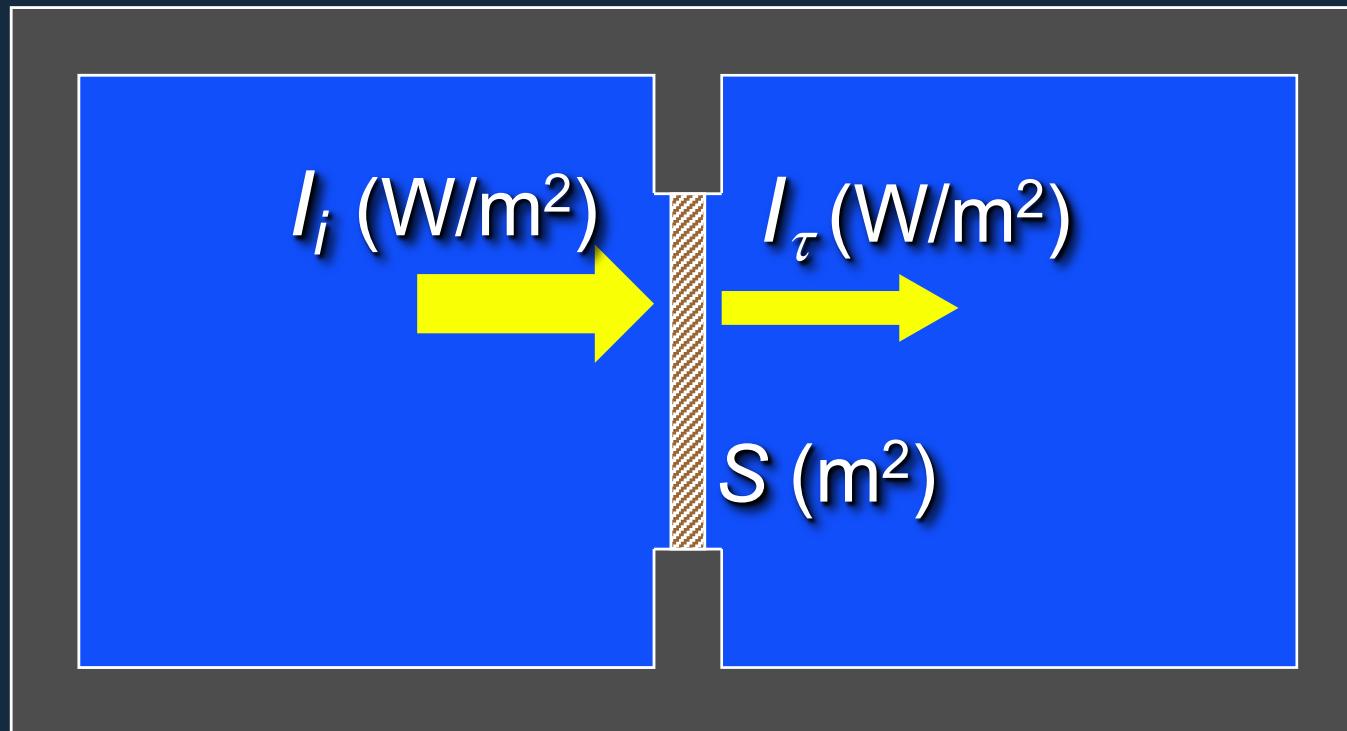
$$\begin{aligned}I_i &= Y \left[ \text{W/m}^2 \right] \\I_\tau &= \frac{1}{100} Y \left[ \text{W/m}^2 \right] \\ \frac{I_i}{I_\tau} &= \frac{Y}{\frac{1}{100} Y} = 100\end{aligned}$$

$$R = 10 \log_{10}(100) = 20 \text{ dB}$$

# Airborne Sound Insulation

## *Measurement*

building element in diffuse sound fields



$$R = 10 \log_{10} \left( \frac{I_i}{I_\tau} \right)$$

# Airborne Sound Insulation

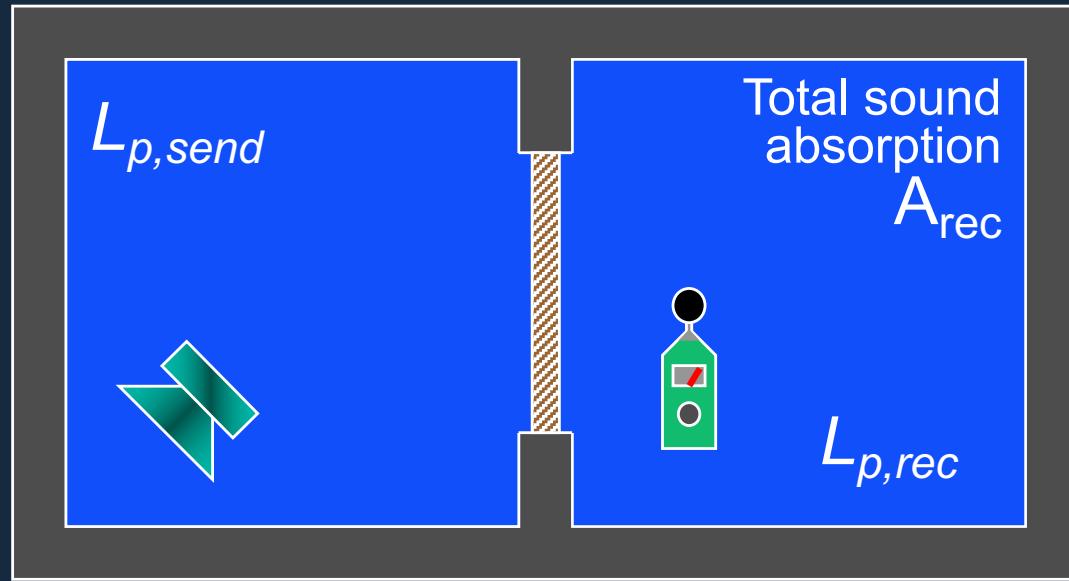
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## *Measurement*

$$R = L_{p,send} - L_{p,rec} + 10\log_{10}\left(\frac{S}{A_{rec}}\right)$$

# Airborne Sound Insulation

## *Measurement*

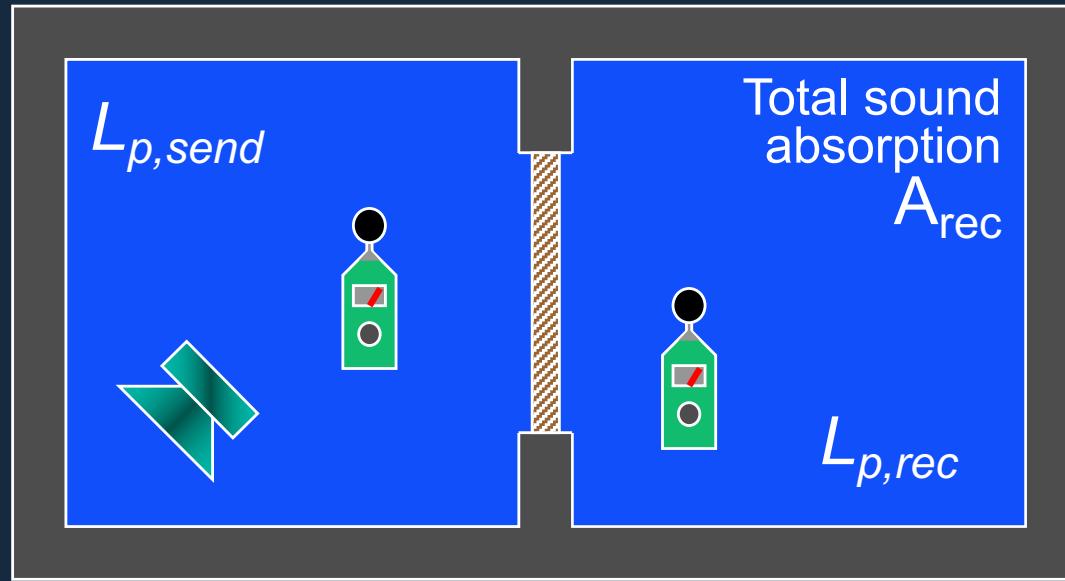


$$R = L_{p,send} - L_{p,rec} + 10\log_{10} \left( \frac{S}{A_{rec}} \right)$$

$$A_{rec} = \frac{V}{6T_{60,rec}}$$

# Airborne Sound Insulation

## *Measurement*



To determine  $R$  you have to measure:

- Sound pressure level in sound source room
- Sound pressure level in receiver room
- Reverberation time in receiver room

$L_{p,send}$   
 $L_{p,rec}$   
 $T_{60,rec}$

# Airborne Sound Insulation

## *Measurement example*

Receiving room volume:  $5 \times 4 \times 2,5 = 50 \text{ m}^3$

Common partition area:  $4 \times 2,5 = 10 \text{ m}^2$

	125	250	500	1k	2k
$L_{p,send}$	88	90	92	90	87 dB
$L_{p,rec}$	34	32	28	33	30 dB
$T_{rec}$	0.9	0.8	1.0	0.7	0.5 s

$$T = \frac{V}{6A}, \quad A = \frac{V}{6T} = \frac{50}{6T} = \frac{8,33}{T}$$

# Airborne Sound Insulation

## *Measurement example*

Receiving room volume:  $5 \times 4 \times 2,5 = 50 \text{ m}^3$

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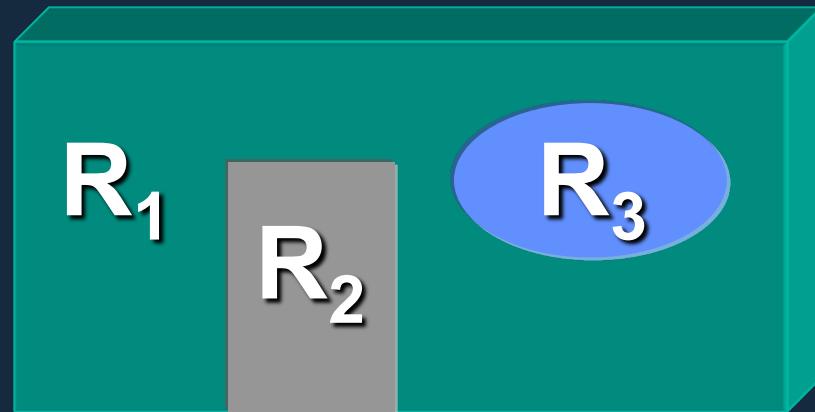
A	9.3	10.4	8.33	11.9	16.7	$\text{m}^2$
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$$R = L_{p,zend} - L_{p,ontv} + 10 \lg \frac{S}{A}$$

$10\log_{10}(S/A)$	0.3	-0.2	0.8	-0.8	-2.2	dB
R	54.3	57.8	64.8	56.2	54.8	dB

# Airborne Sound Insulation

*Combined construction*



$$R_{tot} = -10 \log_{10} \left( \frac{1}{S_{tot}} \sum_{i=1}^{i=n} S_i \cdot 10^{-\frac{R}{10}} \right)$$

# Airborne Sound Insulation

## *Calculation example*

$$S_{wall} = 12 \text{ m}^2$$

$$R_{wall} = 50 \text{ dB}$$

$$S_{glass} = 2 \text{ m}^2$$

$$R_{glass} = 30 \text{ dB}$$

$$R_{tot} = -10\log_{10} \left( \frac{S_{glass}}{S_{tot}} \cdot 10^{-\frac{R_{glass}}{10}} + \frac{S_{wall}}{S_{tot}} \cdot 10^{-\frac{R_{wall}}{10}} \right)$$

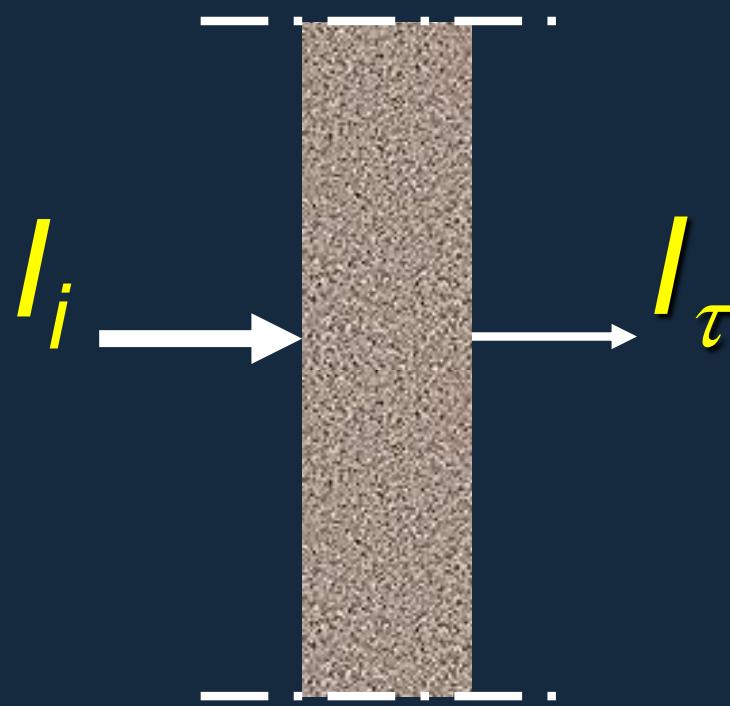
$$R_{tot} = -10\log_{10} \left( \frac{2}{14} \cdot 10^{-\frac{30}{10}} + \frac{12}{14} \cdot 10^{-\frac{50}{10}} \right)$$

$$R_{tot} = 38.2 \text{ dB}$$

# Solid Constructions

*Theoretical 'mass law'*

$$\Delta L_p = 10 \log_{10} \left( \frac{I_i}{I_t} \right)$$



- moving like a piston
- moving without friction

# Solid Constructions

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## *Theoretical 'mass law'*

Wall movement depends on:

- amplitude
- frequency
- mass

# Solid Constructions

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*Theoretical ‘mass law’*

$$R_{\perp} = 20 \log_{10} \left( \frac{\omega m}{2\rho c} \right)$$

# Solid Constructions

*Theoretical 'mass law'*

$$R_{\perp} = 20 \log_{10} \left( \frac{2\pi f m}{2\rho c} \right)$$

Doubling mass:  
Doubling frequency:

# Solid Constructions

*Theoretical 'mass law'*

$$R_{\perp} = 20 \log_{10} \left( \frac{2\pi f m}{2\rho c} \right)$$

Doubling mass:

R + 6 dB

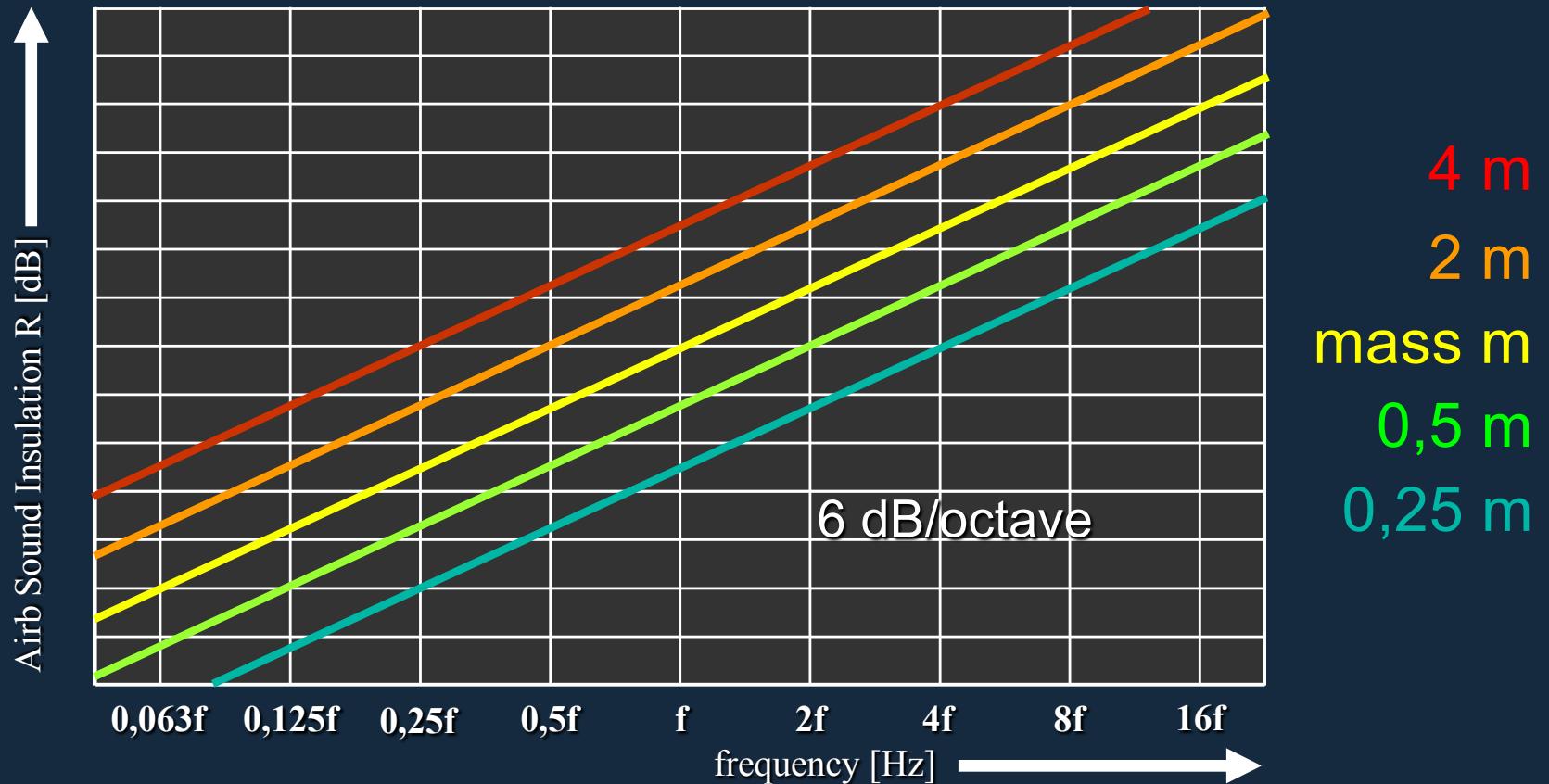
Doubling frequency:

R + 6 dB

# Solid Constructions

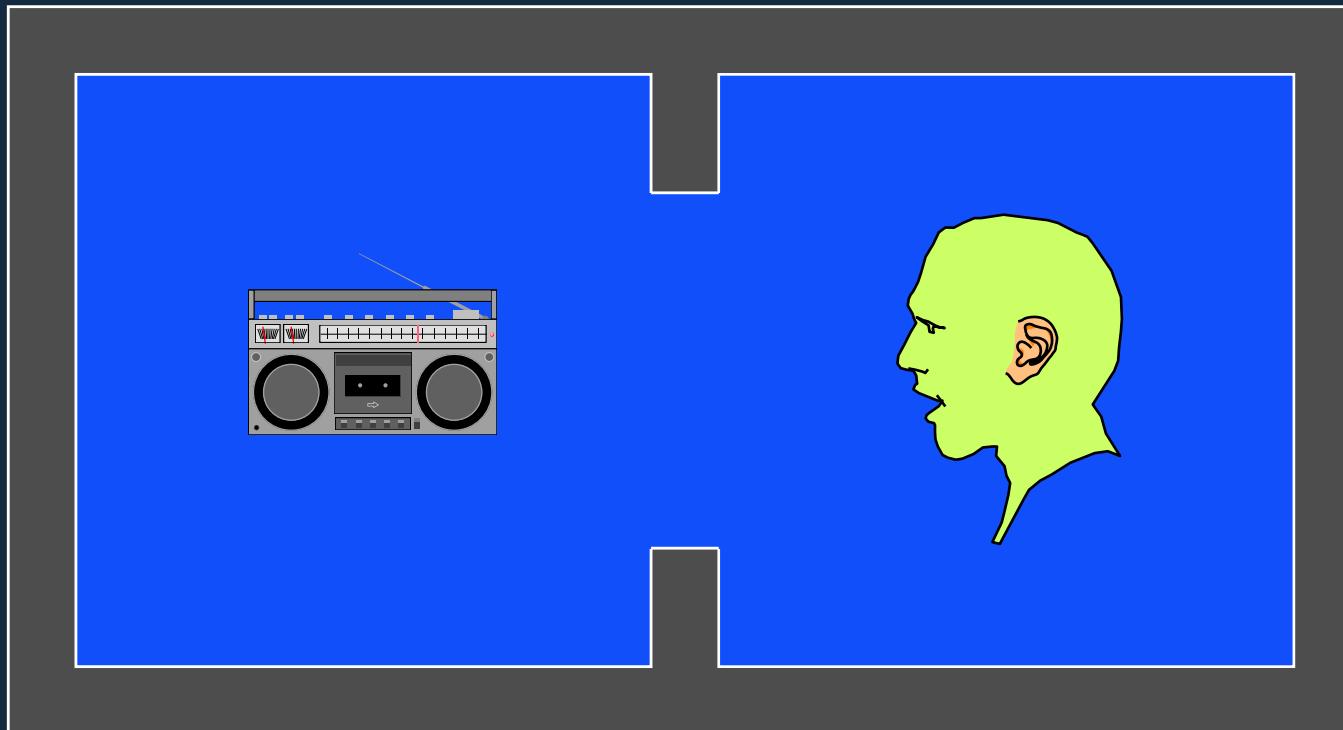
*Theoretical 'mass law'*

$$R_{\perp} = 20 \log_{10} \left( \frac{2\pi f m}{2\rho c} \right)$$



# Solid Constructions

## *Airborne sound insulation*

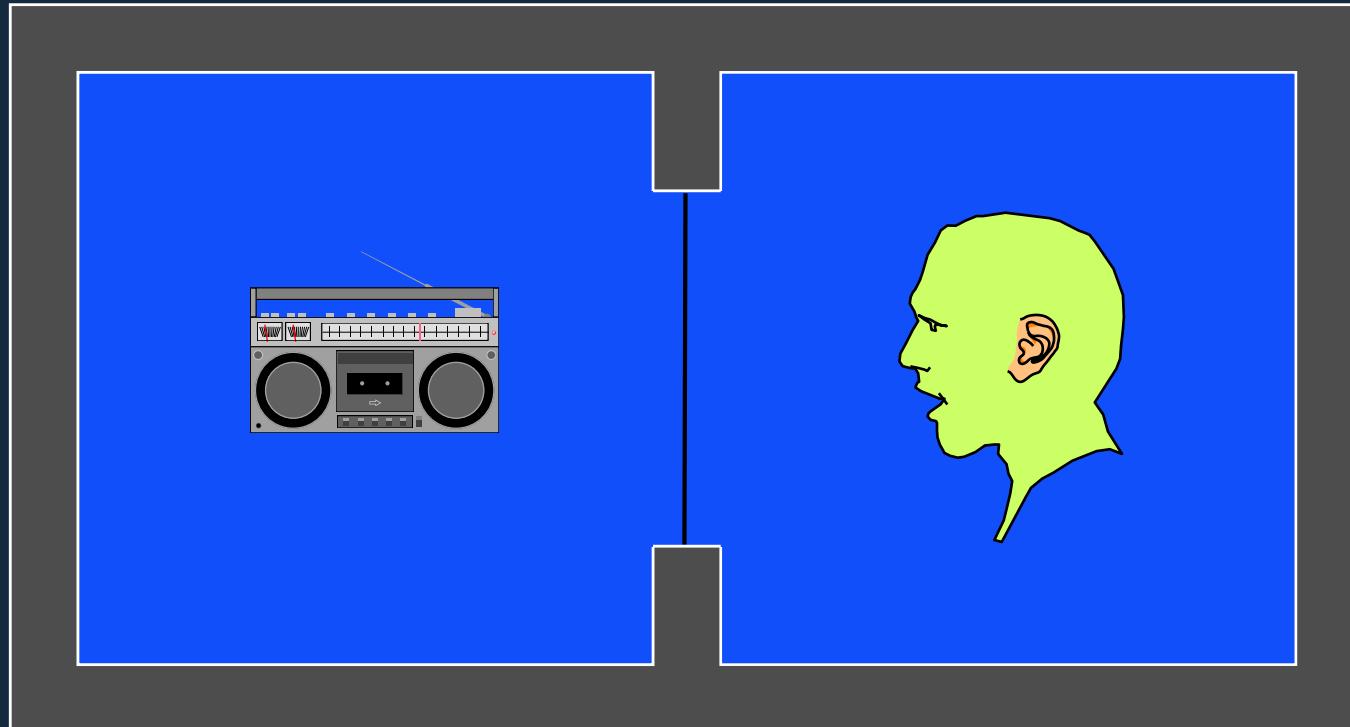


BB King

# Solid Constructions

## *Airborne sound insulation*

3 mm pvc (app. 3 kg/m<sup>2</sup>)

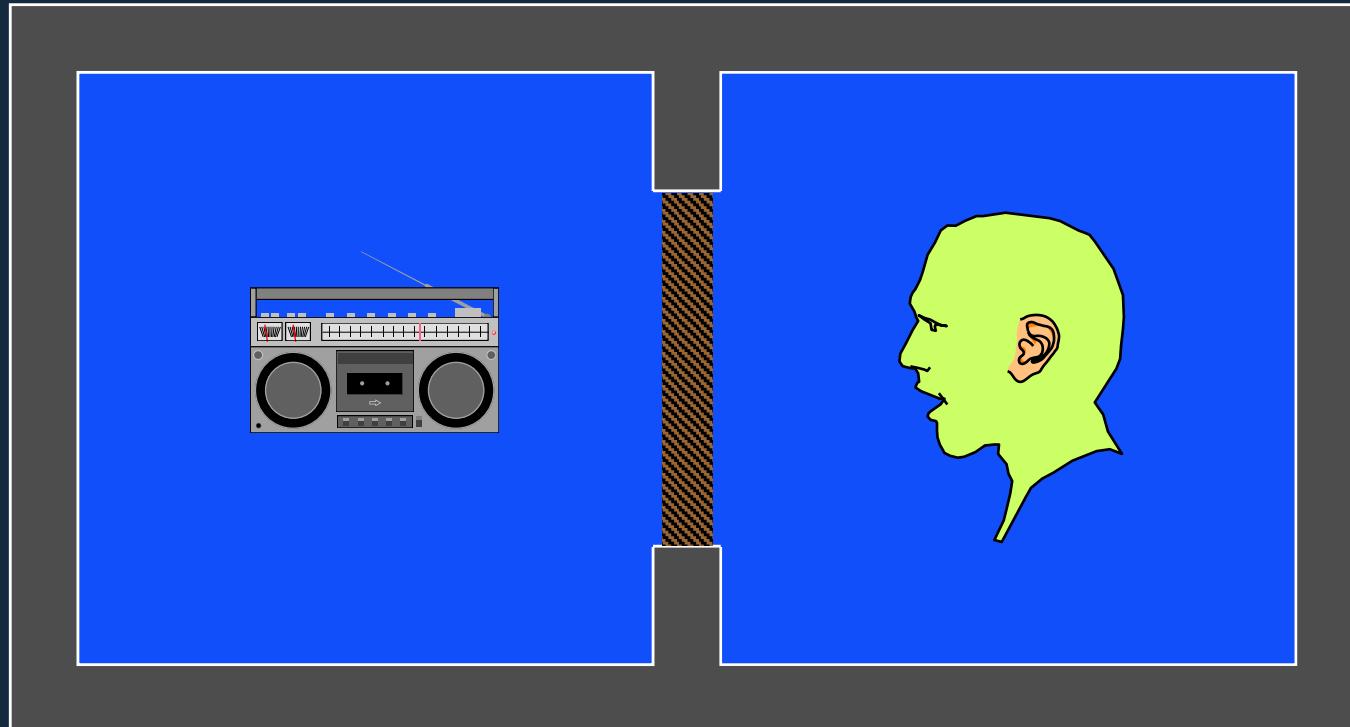


BB King

# Solid Constructions

## *Airborne sound insulation*

150 mm lime stone (approx. 250 kg/m<sup>2</sup>)



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# Solid Constructions

## *Practical ‘mass law’*

Theoretical ‘mass law’ assumptions:

- infinite dimensions
- moving like a piston

theoretical ‘mass law’ too optimistic !

# Solid Constructions

*Practical 'mass law'*

Doubling the density:

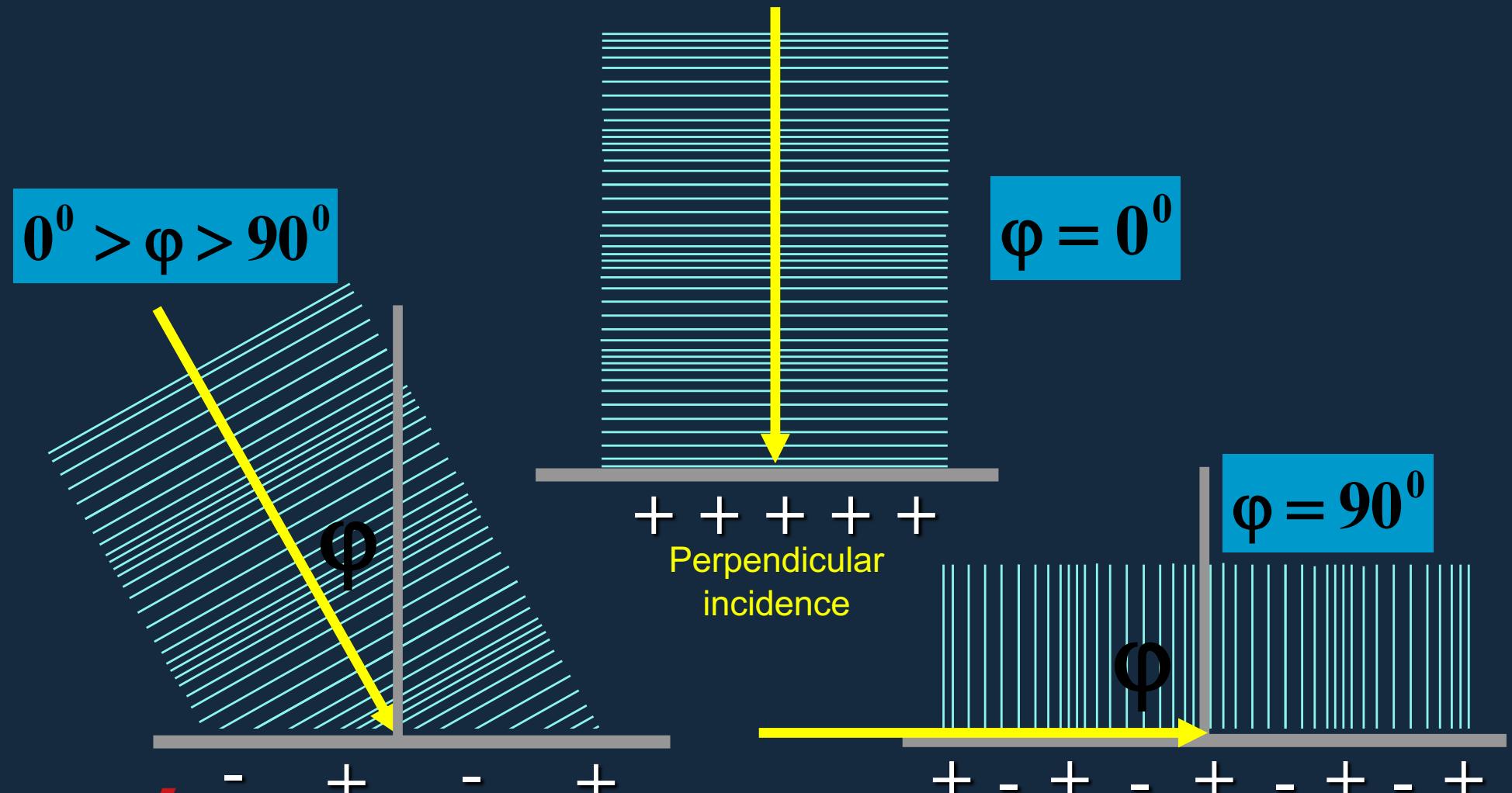
$R + 5\text{dB}$

Doubling the frequency:

$R + 5\text{dB}$

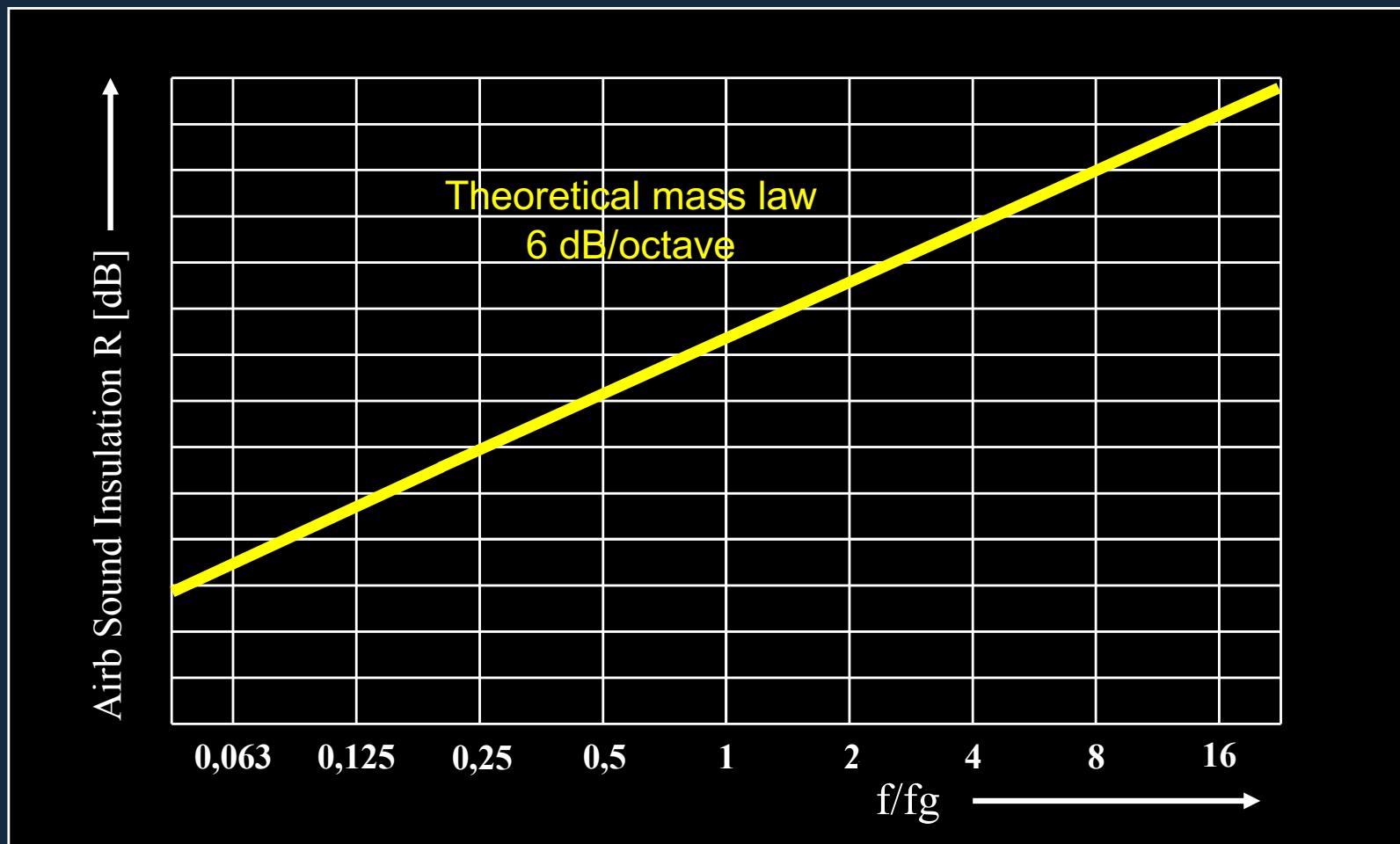
# Solid Constructions

## *Coincidence effect*



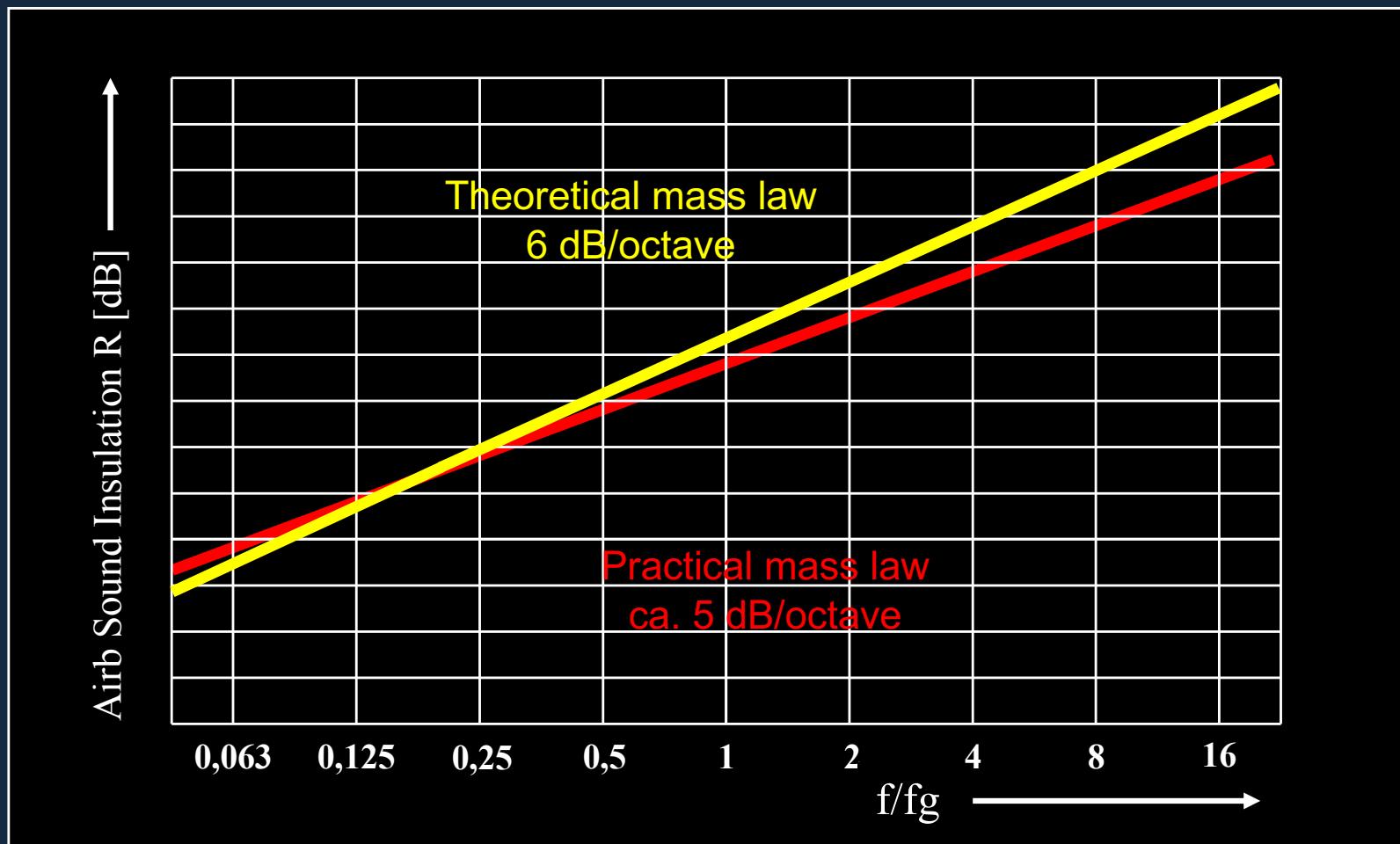
# Solid Constructions

## *Practical 'mass law'*



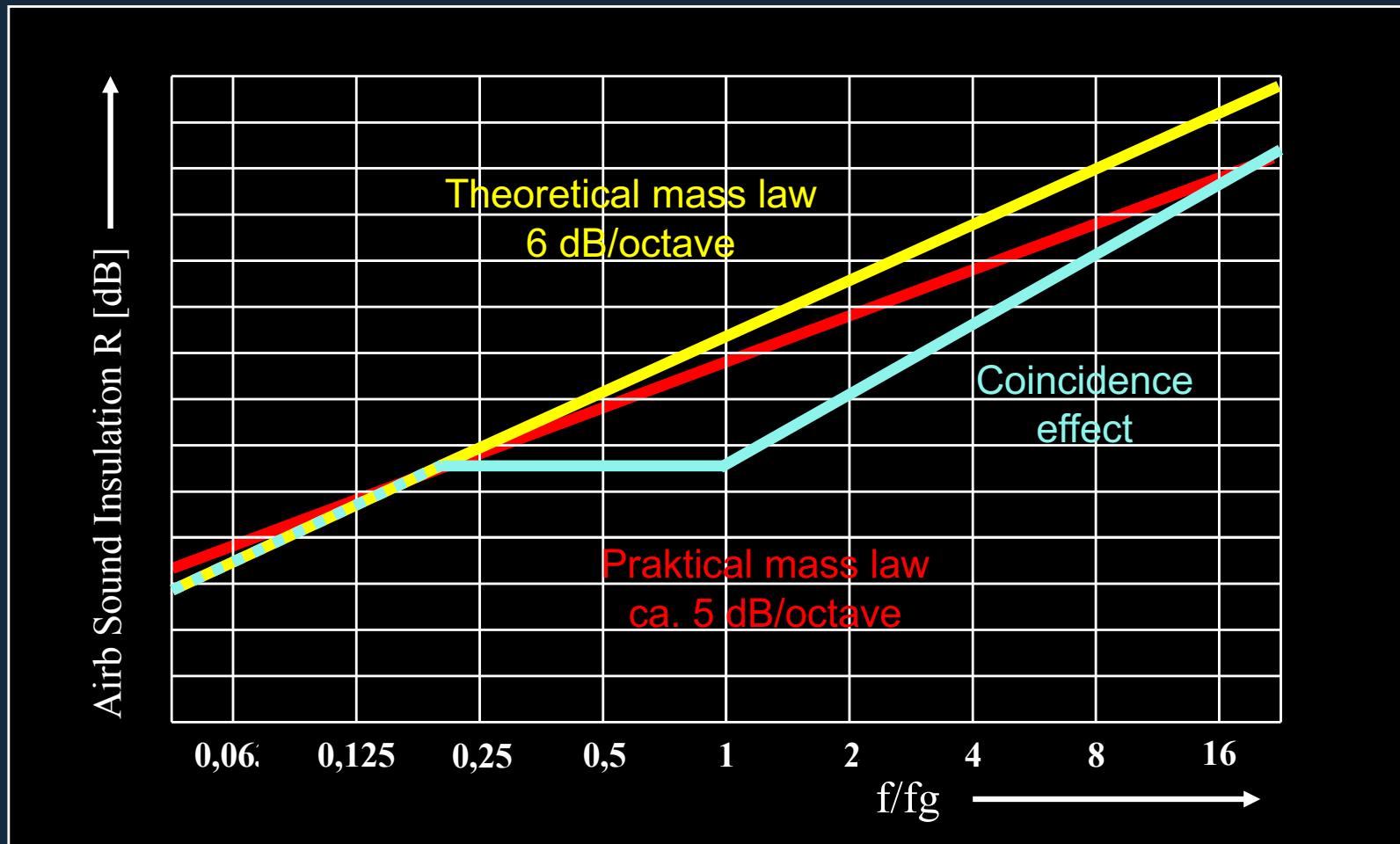
# Solid Constructions

## *Practical 'mass law'*



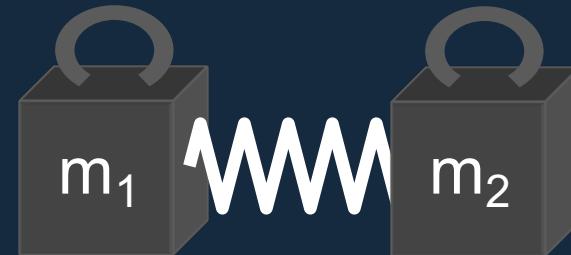
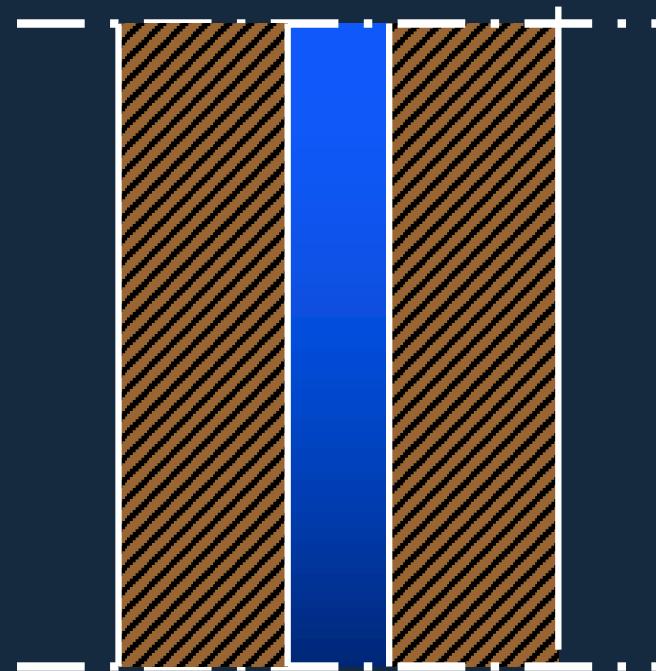
# Solid Constructions

## *Coincidence effect*



# Double Leaf Constructions

*Airborne sound insulation*



mass - spring - mass

# Double Leaf Constructions

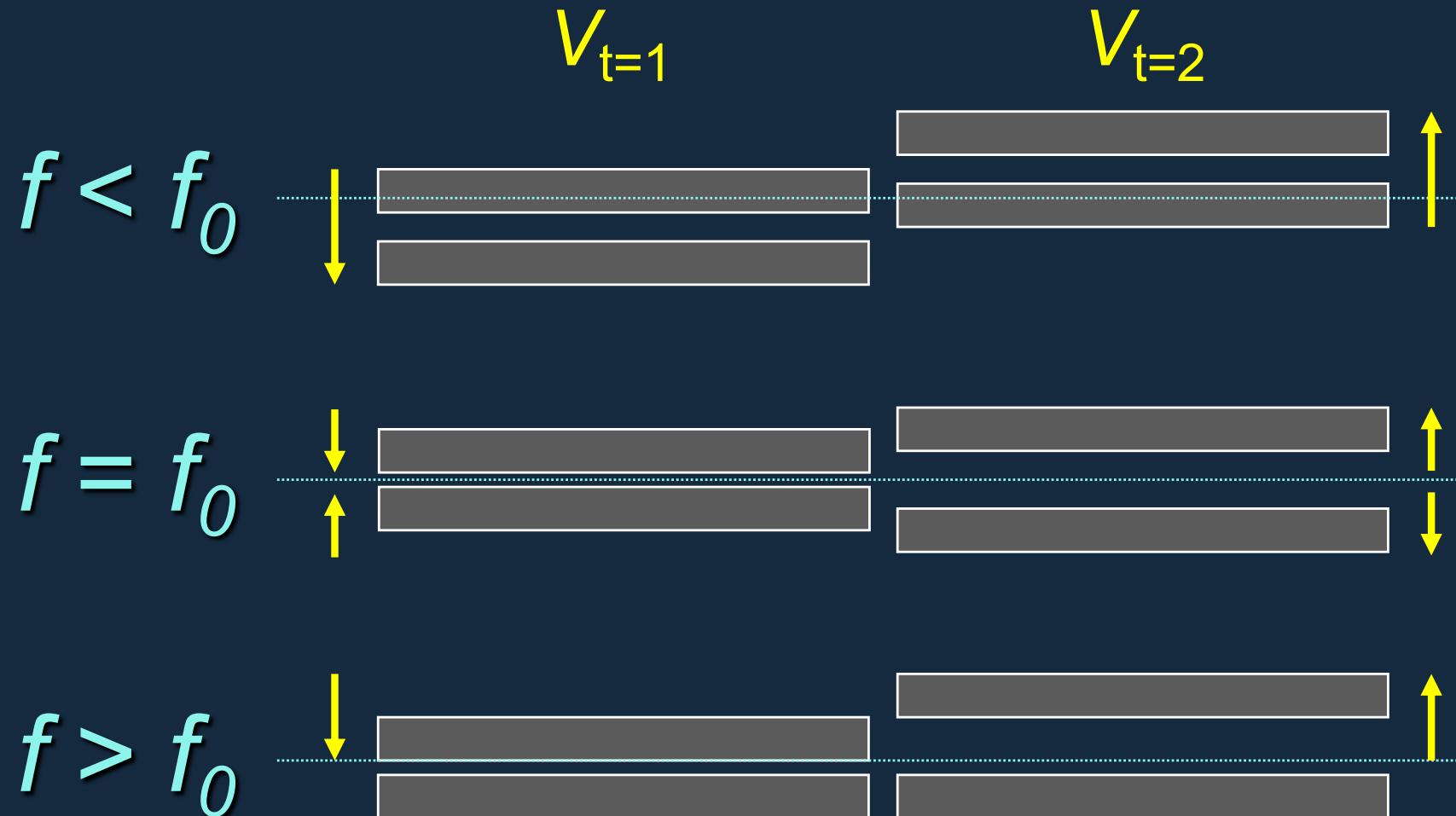
*Airborne sound insulation*

$$f_0 = \frac{c}{2\pi \cos(\varphi)} \sqrt{\frac{\rho}{d} \left( \frac{1}{m_1} + \frac{1}{m_2} \right)} \text{ Hz}$$

$c$	= speed of sound	[m/s]
$d$	= cavity depth	[m]
$\rho$	= air density	[kg/m <sup>3</sup> ]
$m_1$	= mass 1	[kg/m <sup>2</sup> ]

# Double Leaf Constructions

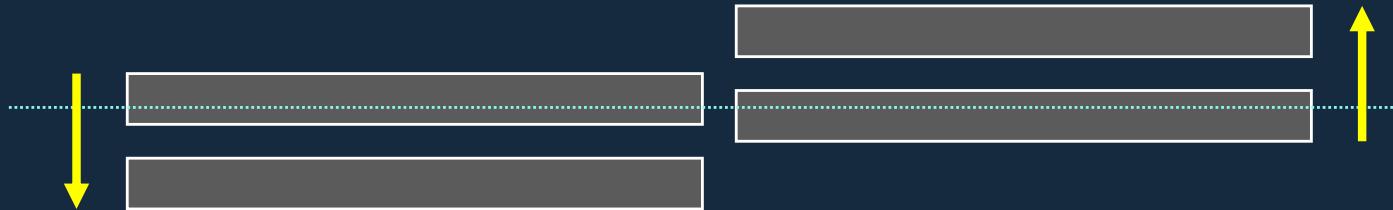
*Airborne sound insulation*



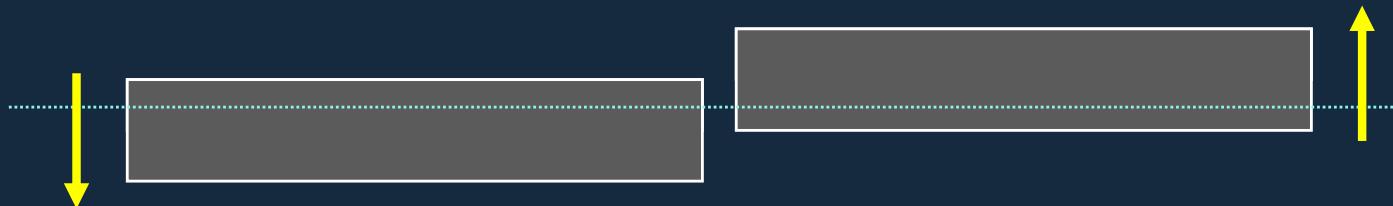
# Double Leaf Constructions

*Airborne sound insulation*

$$f < f_0$$



$$R_{double} = R_{single} (m_1 + m_2)$$

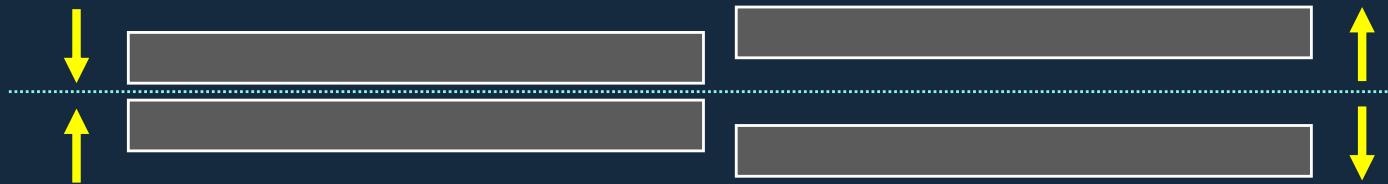


$f < f_0$ : Mass law

# Double Leaf Constructions

*Airborne sound insulation*

$$f = f_0$$



$$f_0 = \frac{c}{2\pi} \sqrt{\frac{\rho}{d} \left( \frac{1}{m_1} + \frac{1}{m_2} \right)} \quad \text{Hz}$$

# Double Leaf Constructions

*Airborne sound insulation*



$$f = f_0$$

if  $m_1 = m_2 = 1/2 m_{tot}$ :

$$f_0 = \frac{120}{\sqrt{m_{tot} \cdot d}} \text{ Hz}$$

# Double Leaf Constructions

*Airborne sound insulation*



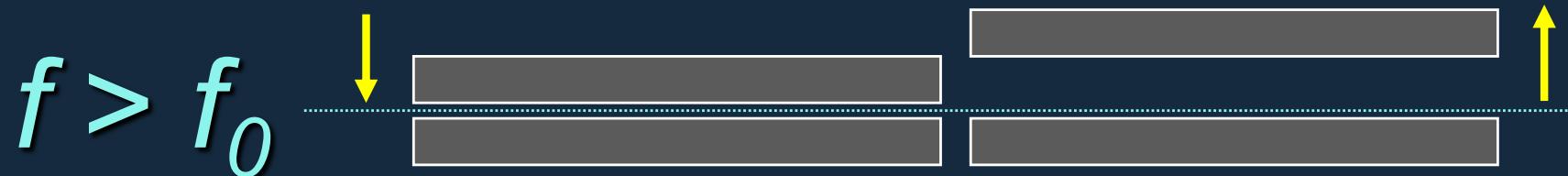
$$f = f_0$$

if  $m_1 \ll m_2$ :

$$f_0 = \frac{60}{\sqrt{m_1 \cdot d}} \text{ Hz}$$

# Double Leaf Constructions

*Airborne sound insulation*



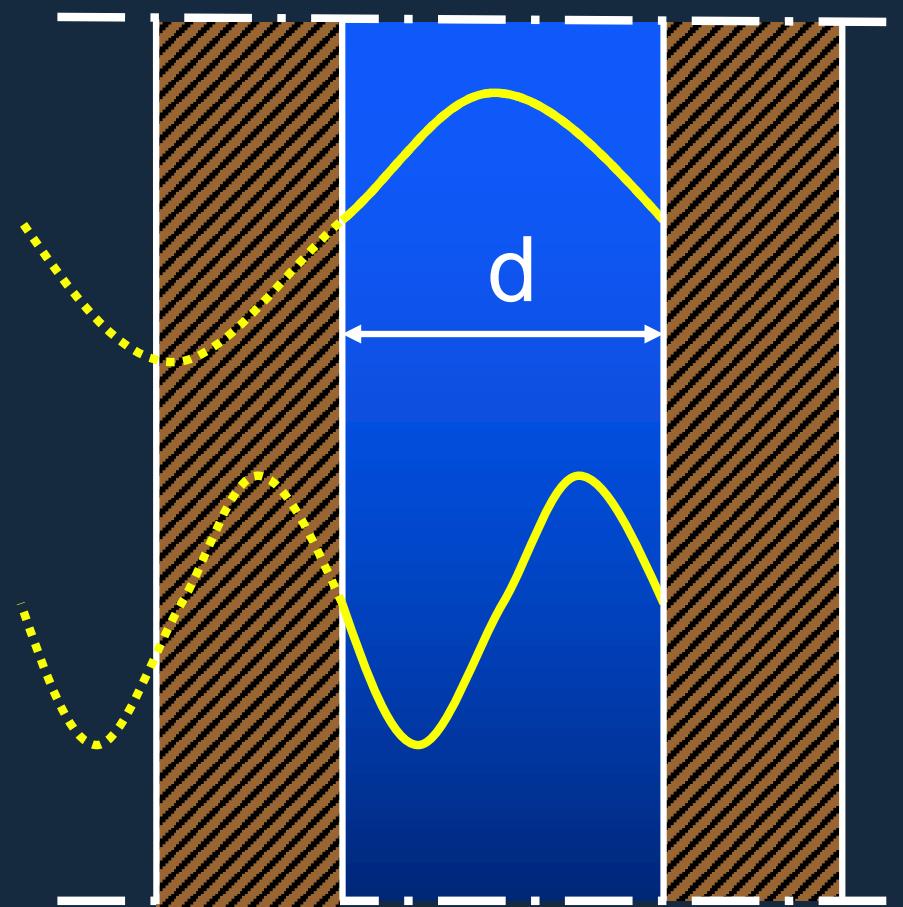
$f > f_0$

R  $f > f_0$ :

+18 dB per frequency-doubling

# Double Leaf Constructions

## *Cavity resonance*



$$\frac{\lambda}{2} = \frac{d}{n}$$
$$\lambda = \frac{2 \cdot d}{n}$$
$$c = \lambda \cdot f_n$$
$$c = \frac{2 \cdot d}{n} \cdot f_n$$
$$f_n = \frac{n \cdot c}{2 \cdot d}$$

# Double Leaf Constructions

## *Cavity resonance*

### Example

$$d = 0.05 \text{ m}$$

$$f_1 = 3400 \text{ Hz}$$

$$f_2 = 6800 \text{ Hz}$$

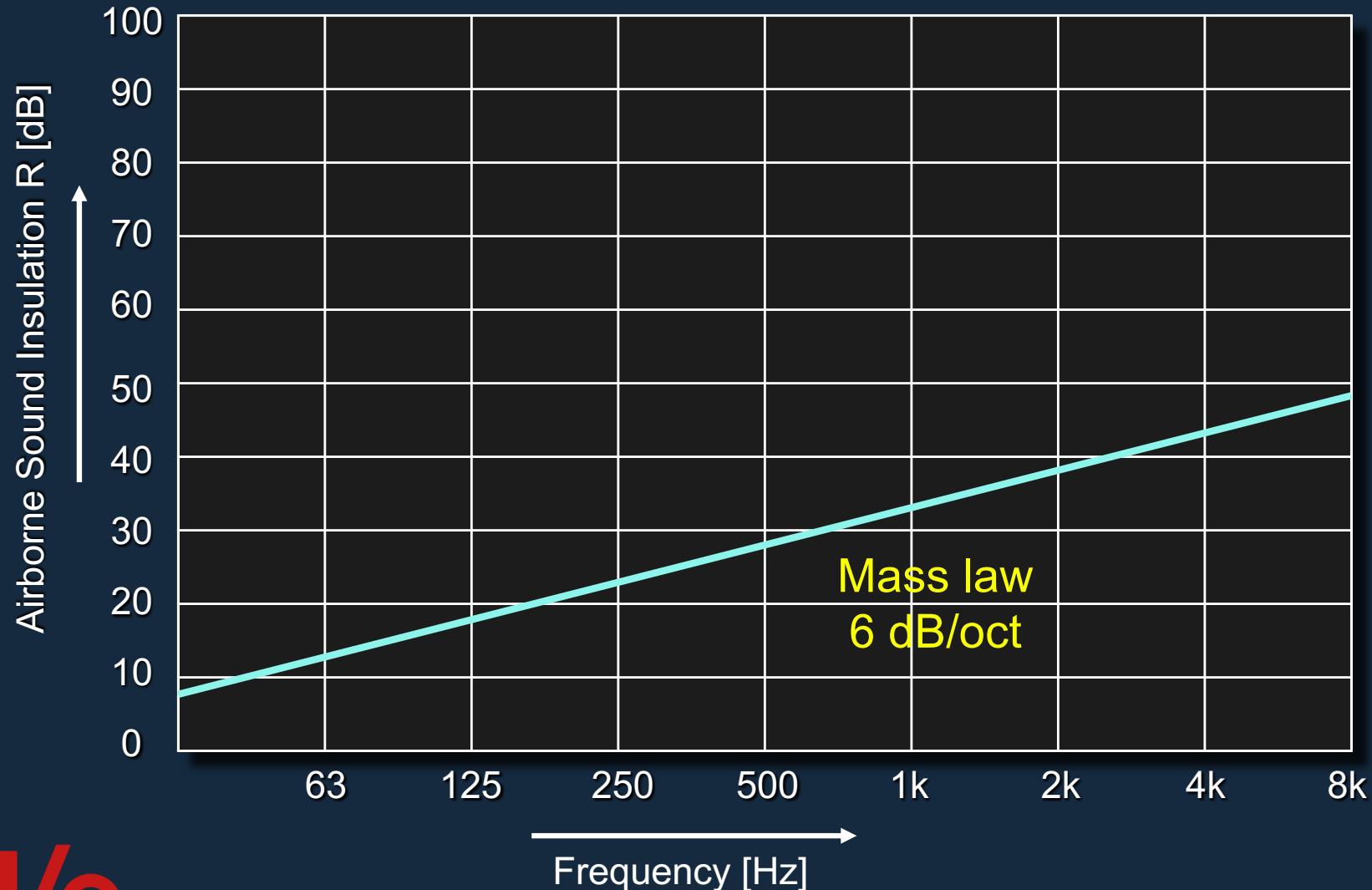
$$d = 0.10 \text{ m}$$

$$f_1 = 1700 \text{ Hz}$$

$$f_2 = 3400 \text{ Hz}$$

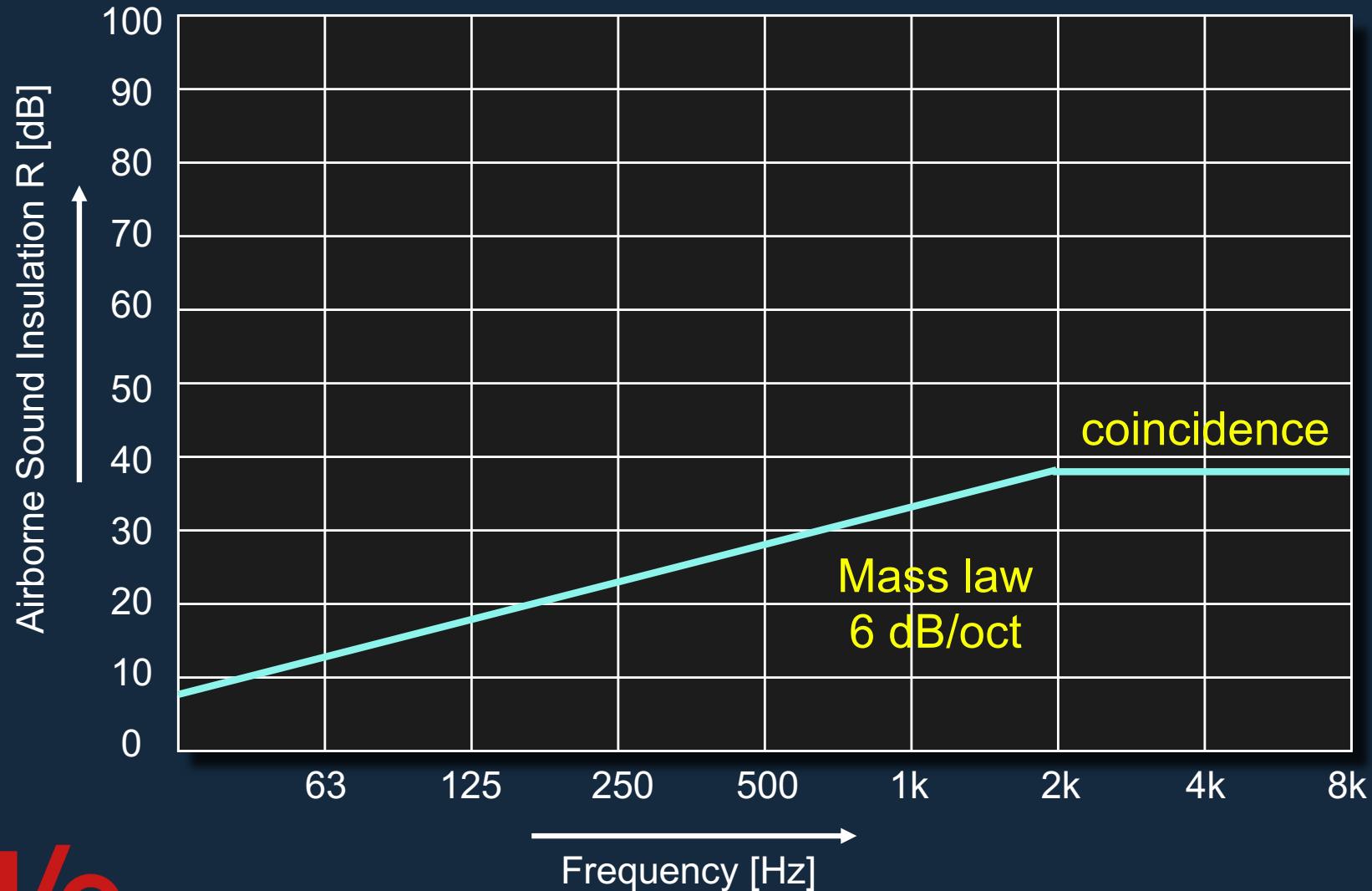
# Double Leaf Constructions

*2 mm steel sheet*



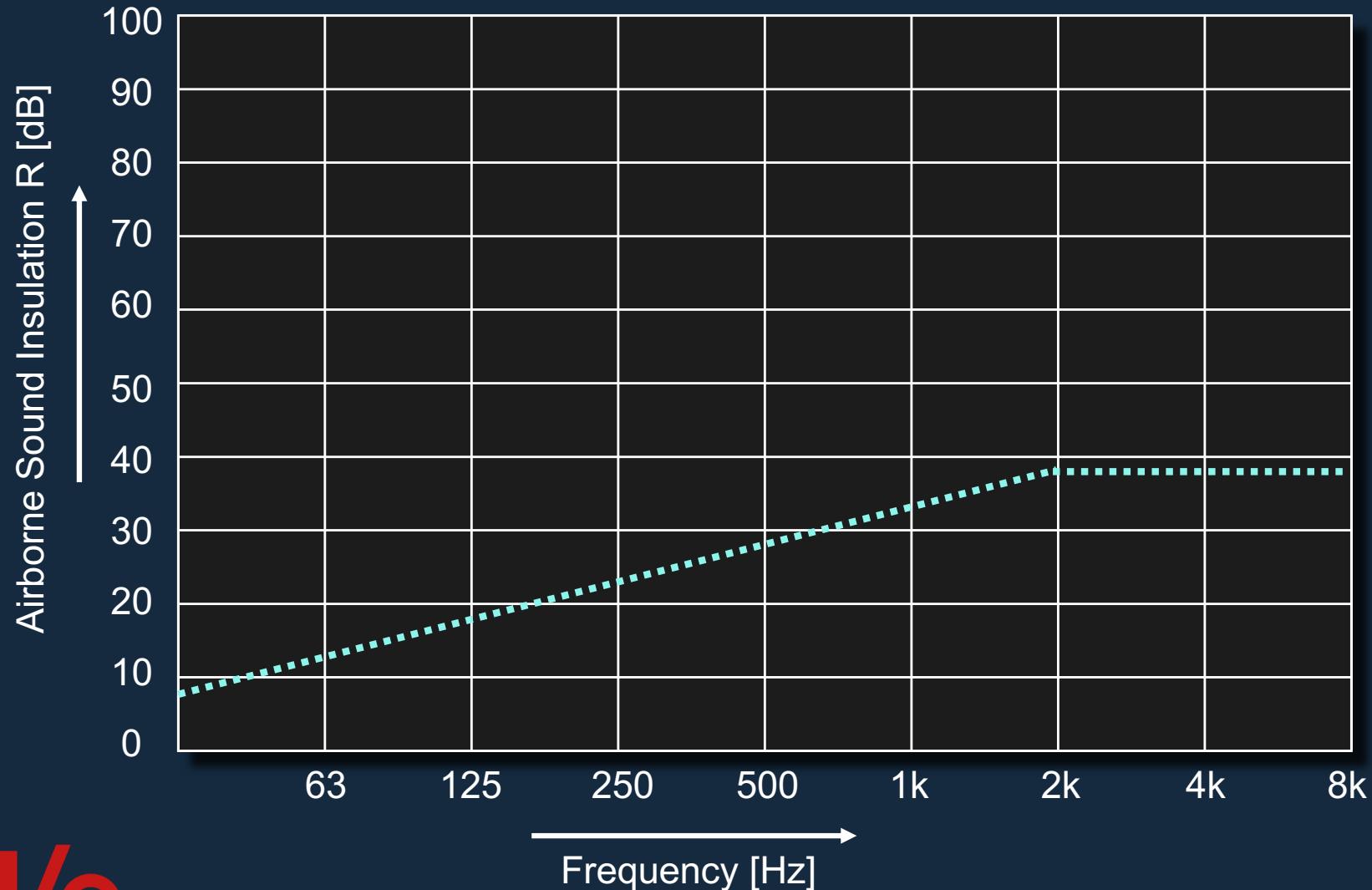
# Double Leaf Constructions

*2 mm steel sheet*



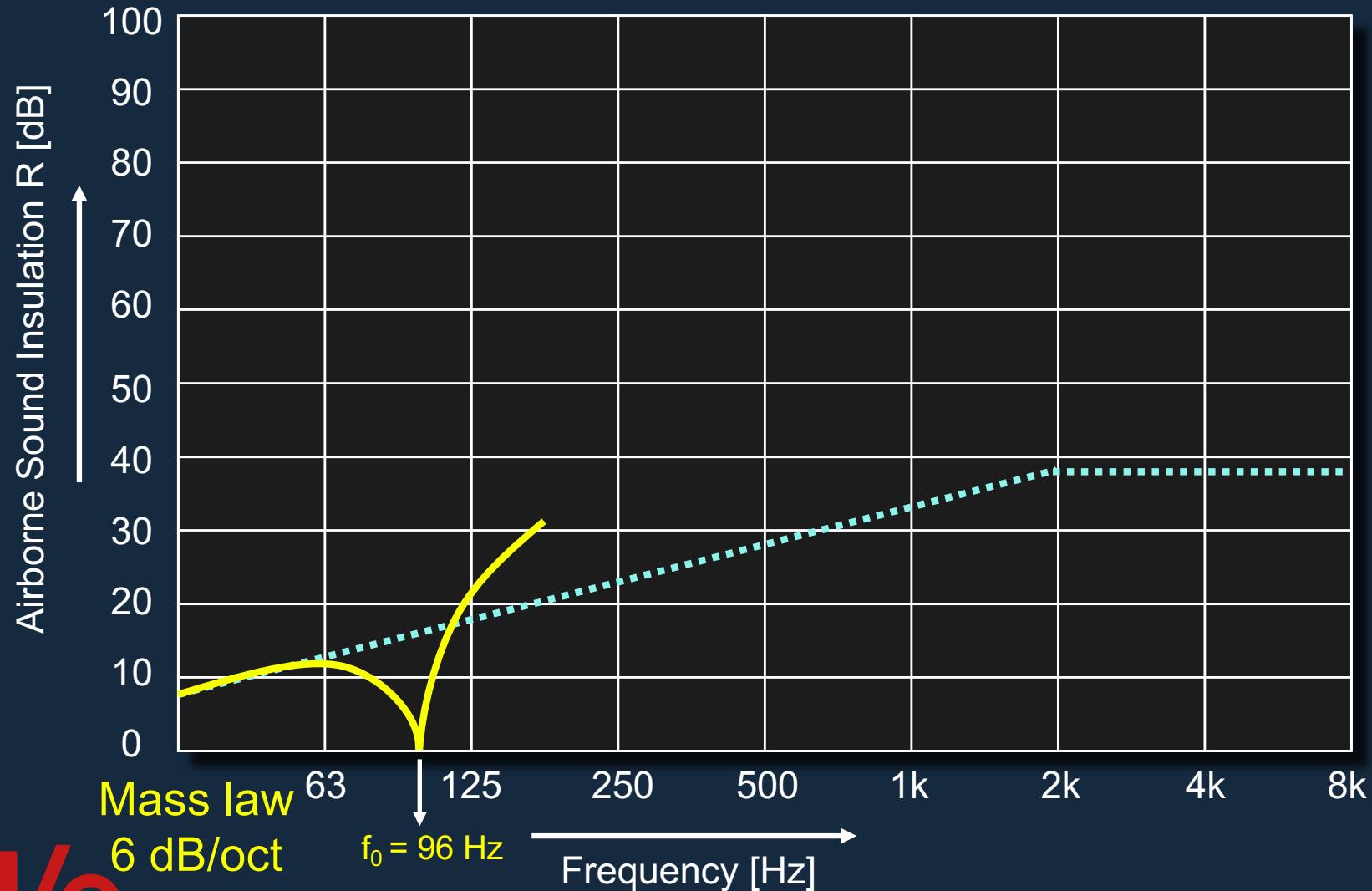
# Double Leaf Constructions

*2 x 1 mm steel sheet with 100 mm air cavity*



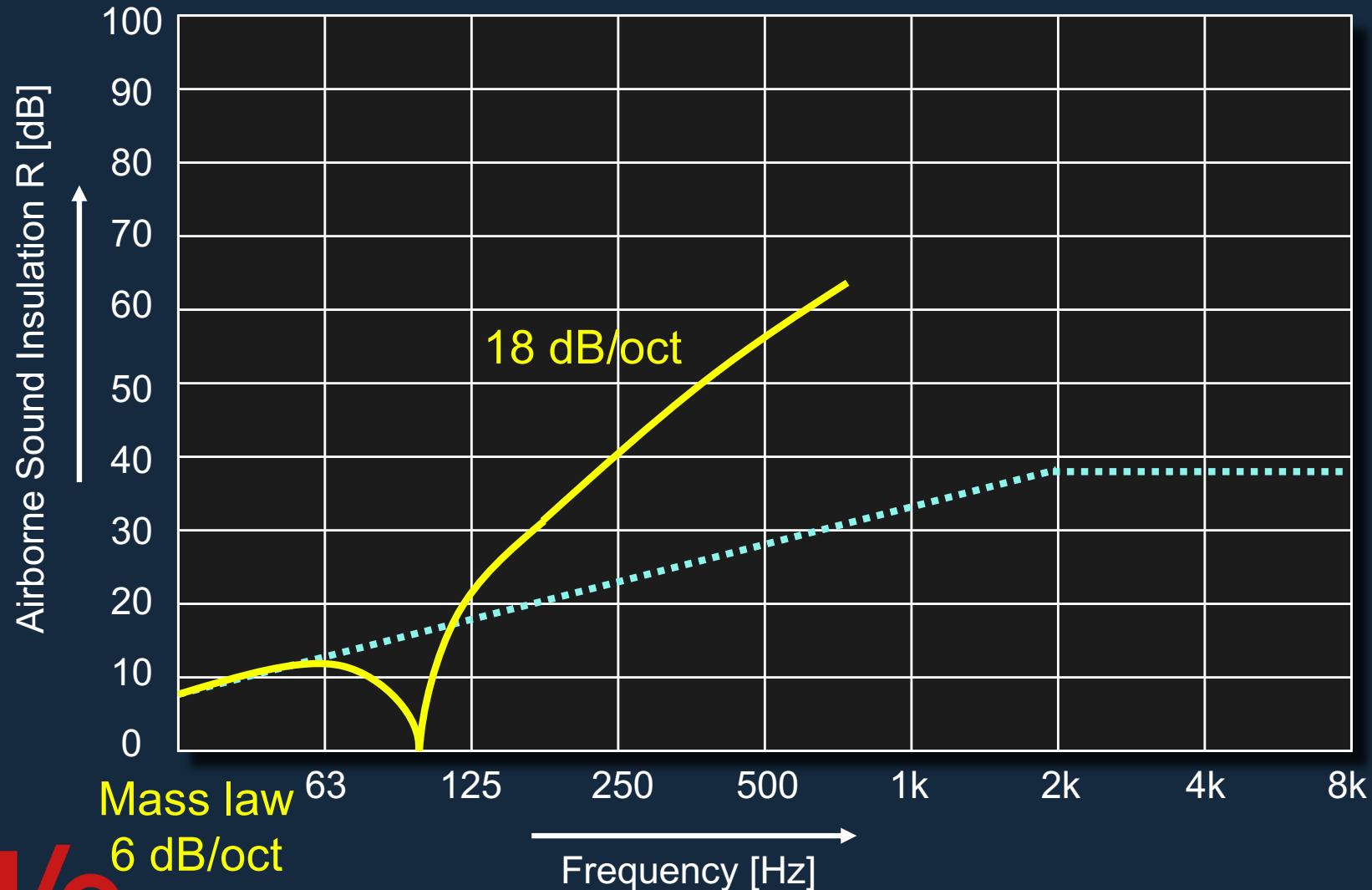
# Double Leaf Constructions

*2 x 1 mm steel sheet with 100 mm air cavity*



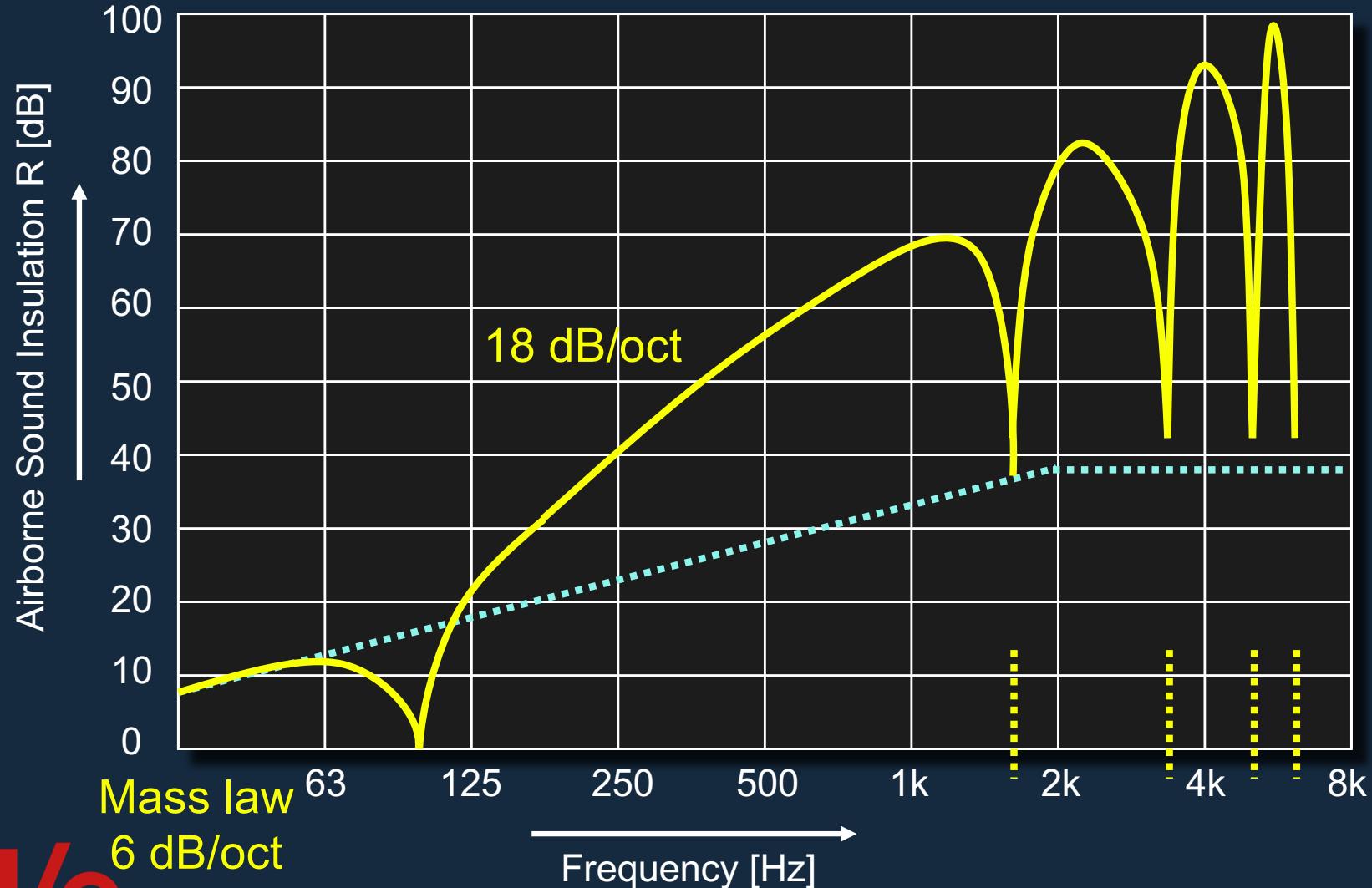
# Double Leaf Constructions

*2 x 1 mm steel sheet with 100 mm air cavity*



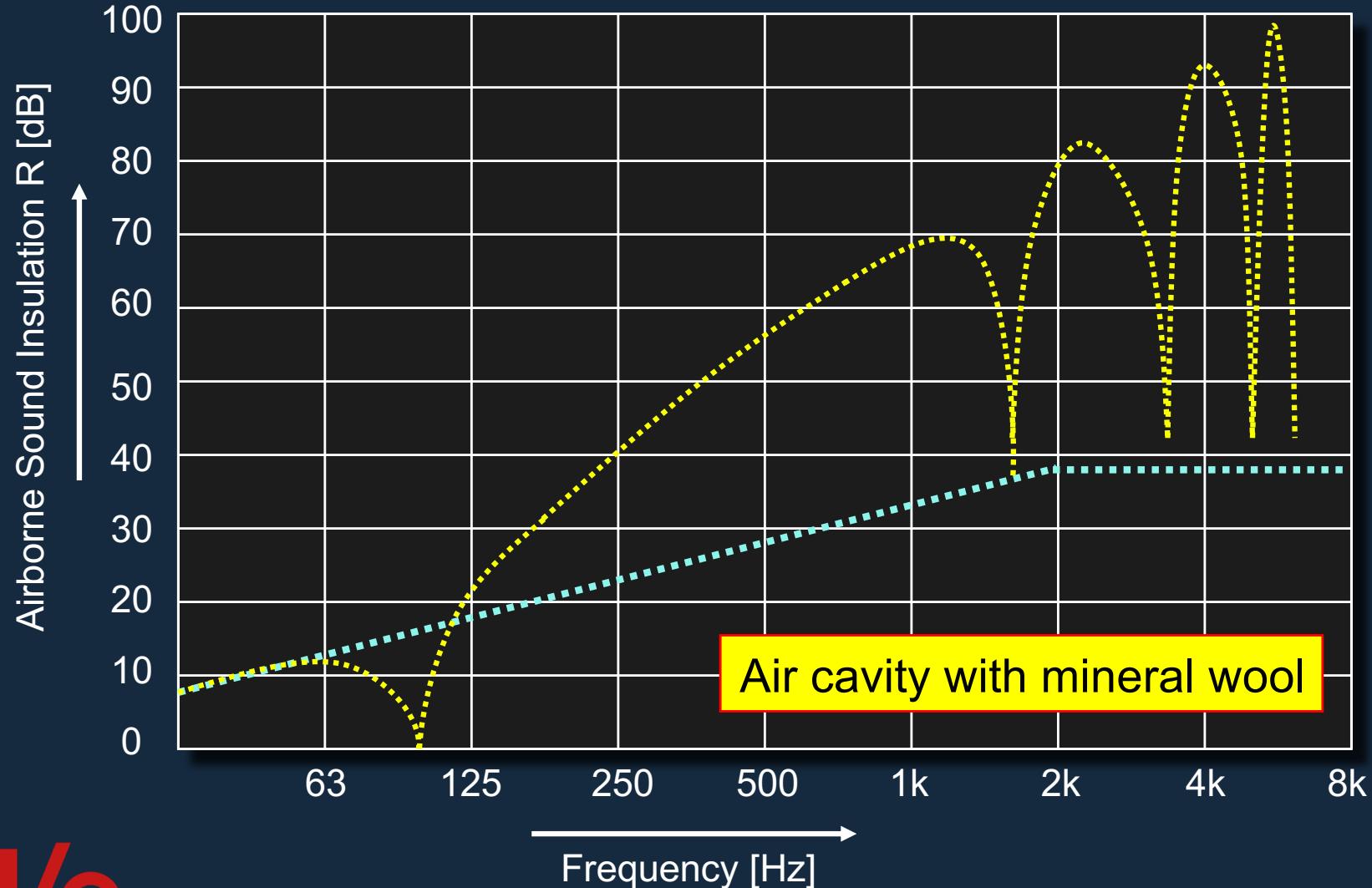
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*2 x 1 mm steel sheet with 100 mm air cavity*



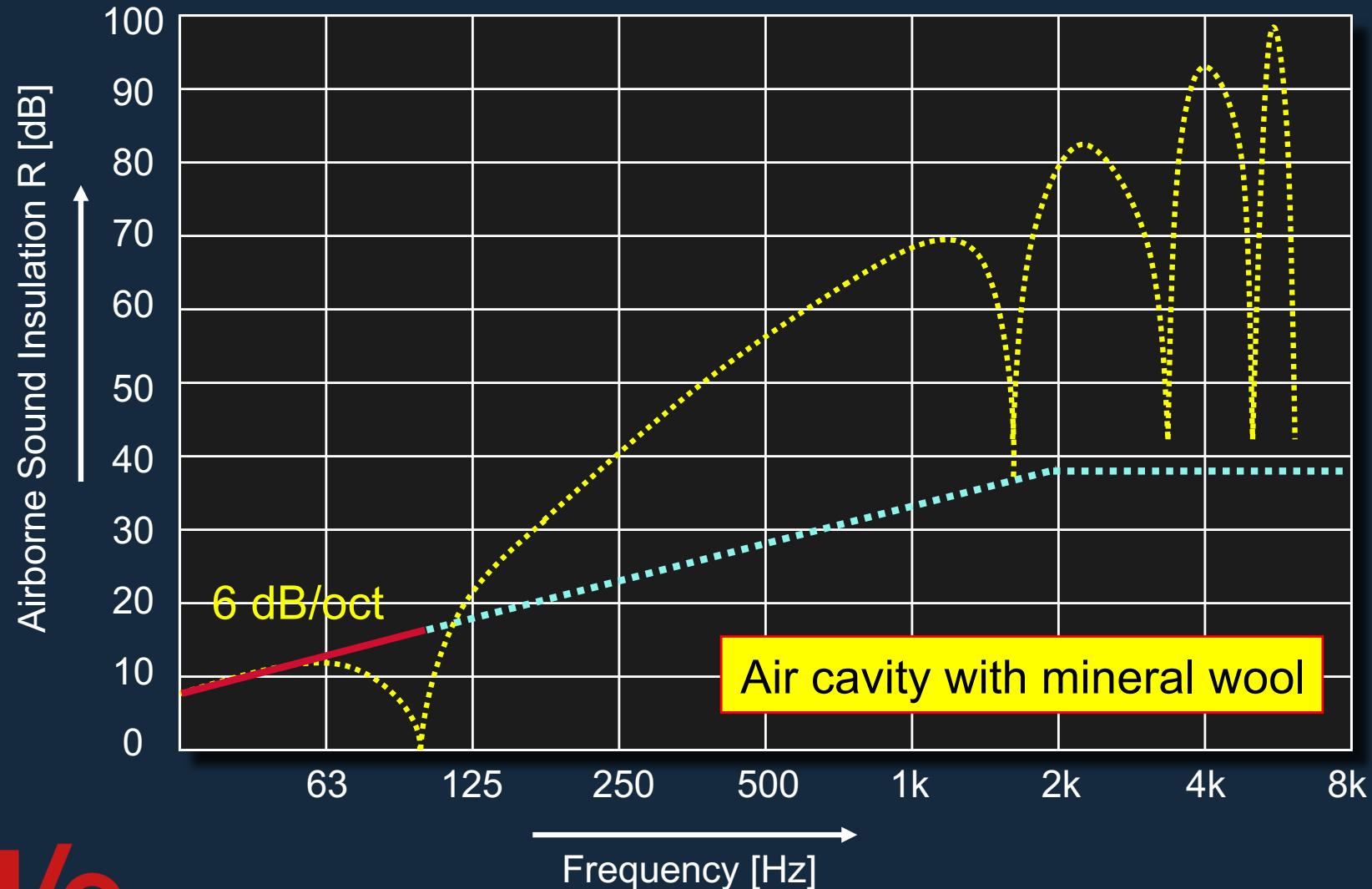
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*2 x 1 mm steel sheet with 100 mm air cavity*



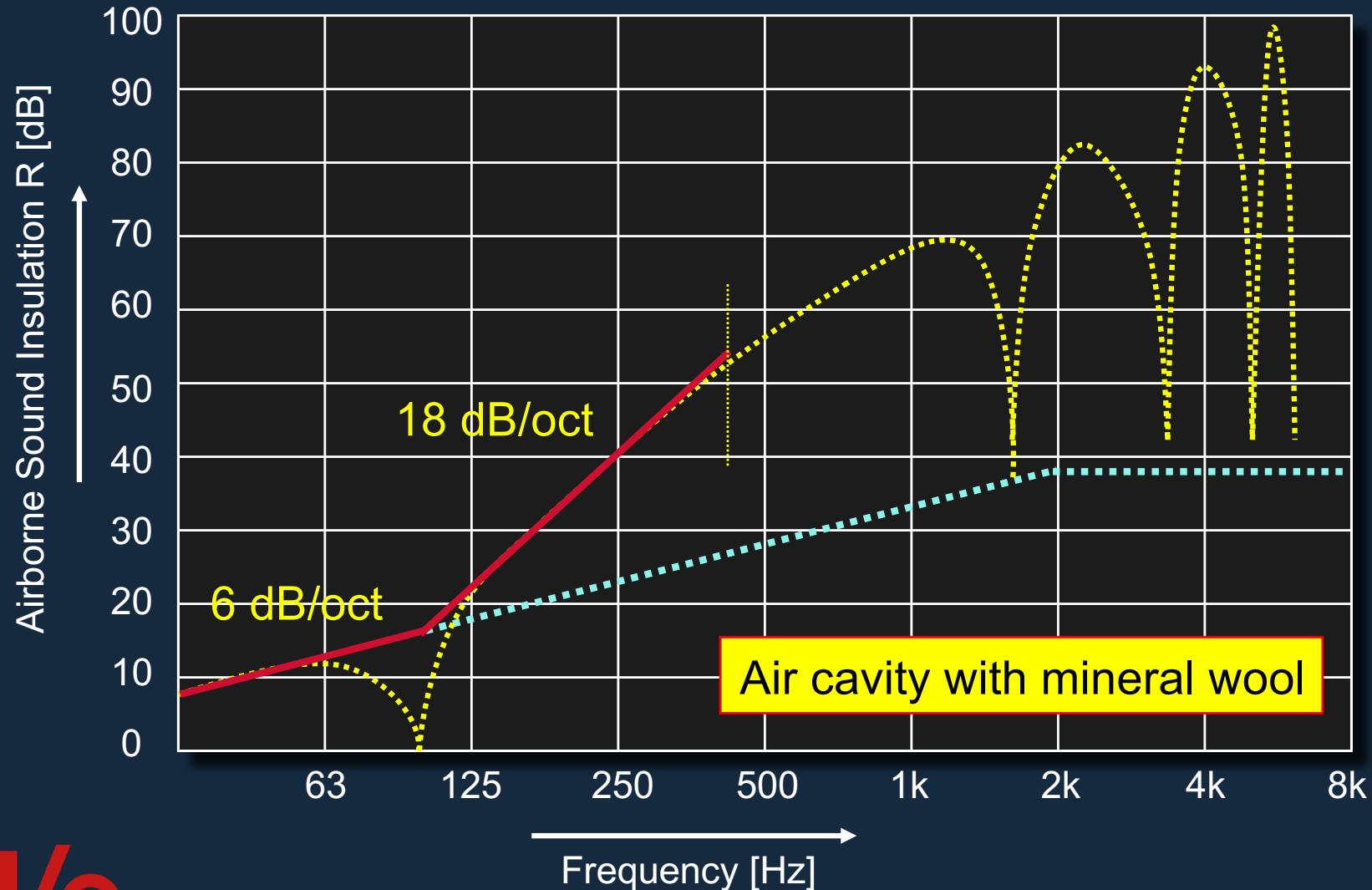
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*2 x 1 mm steel sheet with 100 mm air cavity*



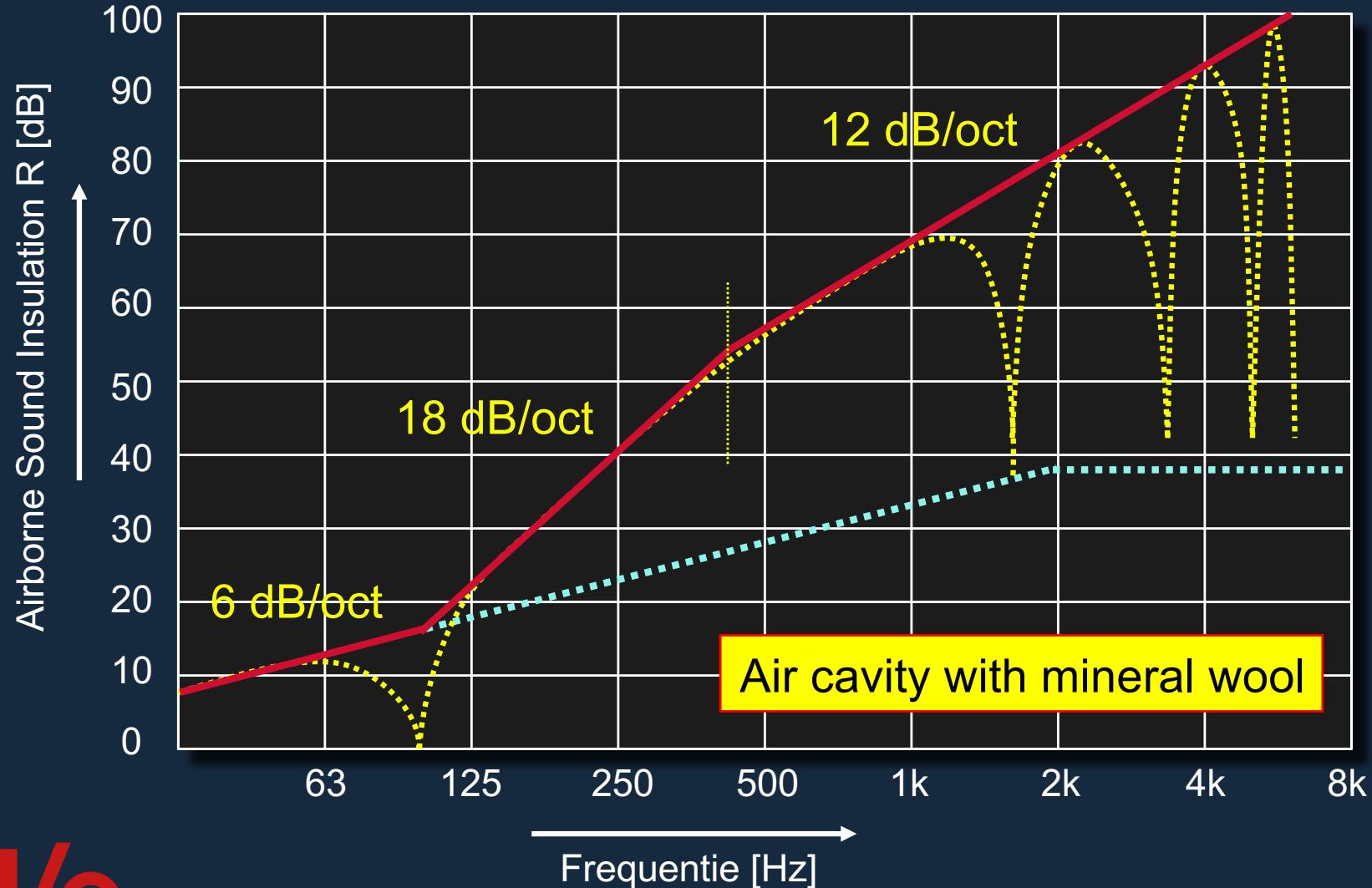
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*2 x 1 mm steel sheet with 100 mm air cavity*



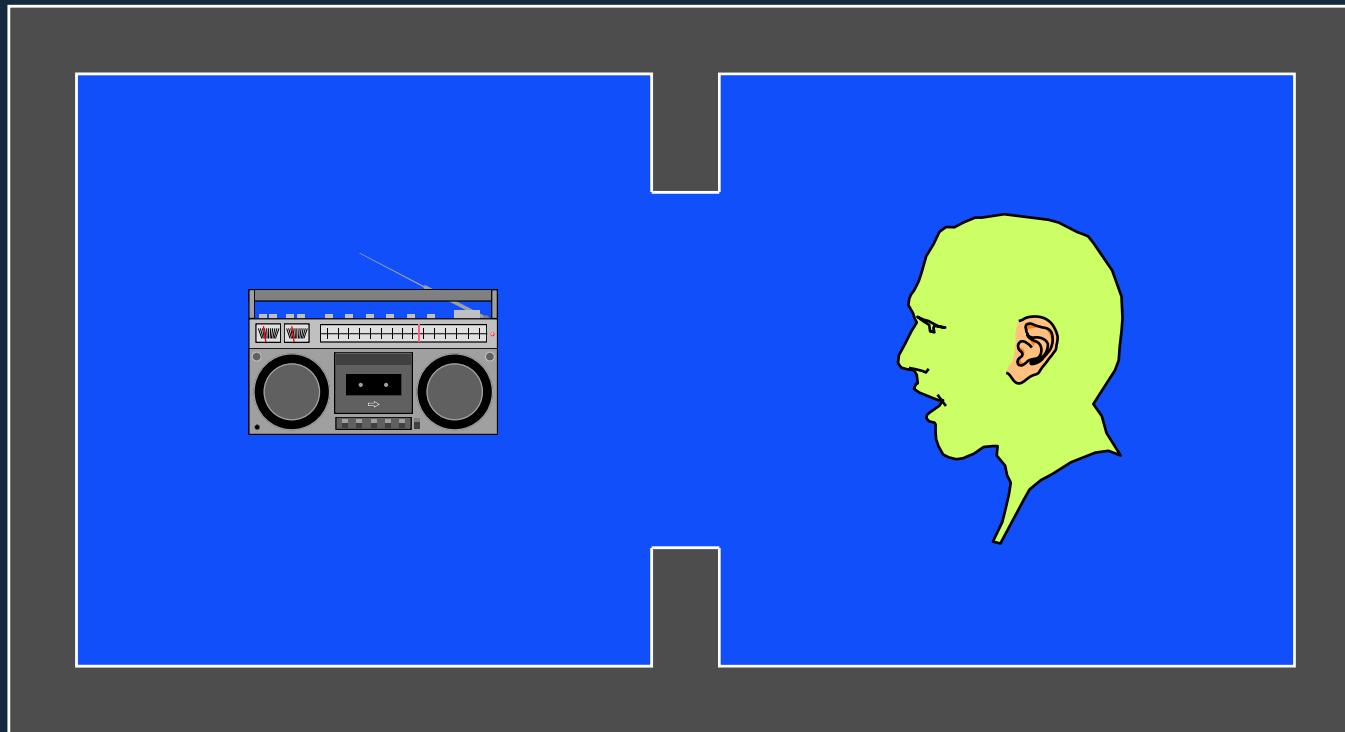
# Double Leaf Constructions

*2 x 1 mm steel sheet with 100 mm air cavity*



# Double Leaf Constructions

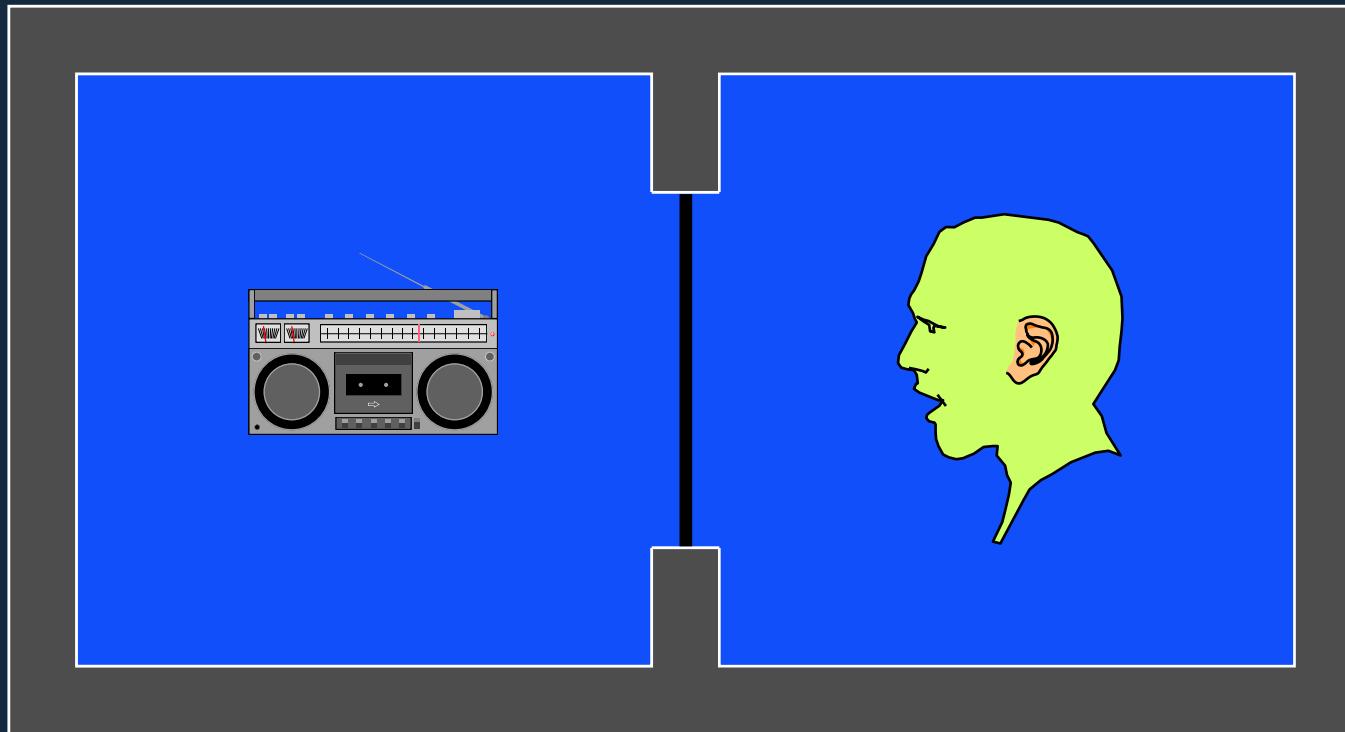
*Airborne sound insulation*



BB King

# Double Leaf Constructions

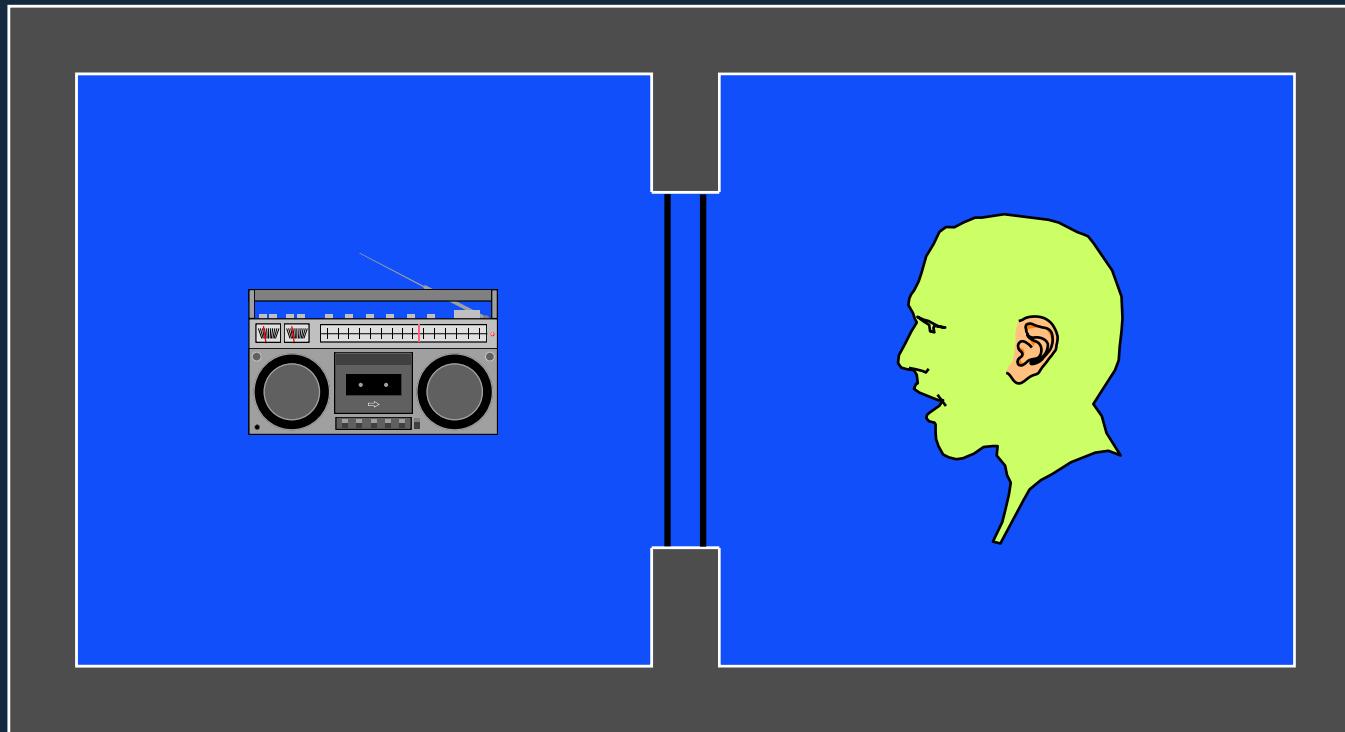
*Airborne sound insulation*



BB King

# Double Leaf Constructions

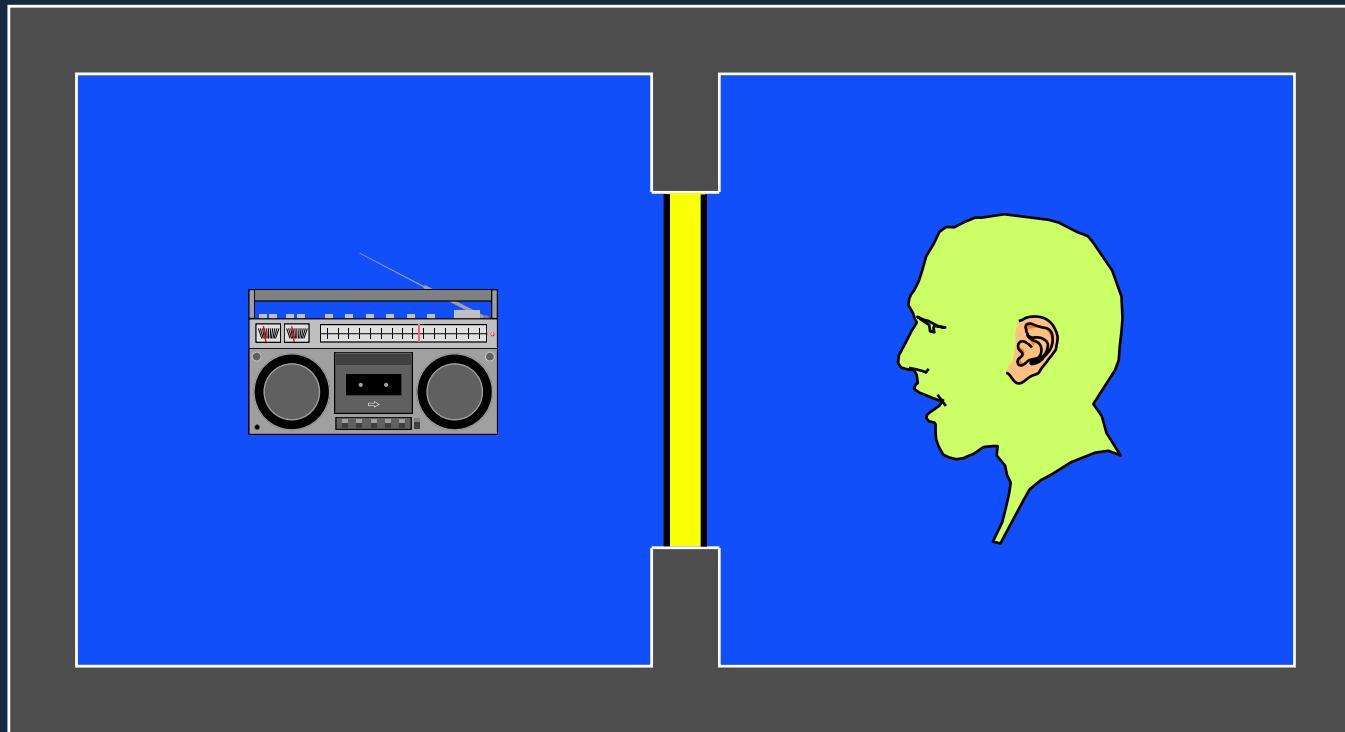
*Airborne sound insulation*



BB King

# Double Leaf Constructions

*Airborne sound insulation*



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