7S3X0
Introduction Building Physics and Material Science

Lecture 8a Acoustics
Decibels and frequency

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Unit Building Physics and Services (BPS)

TU/e

Why studying sound in the built environment?

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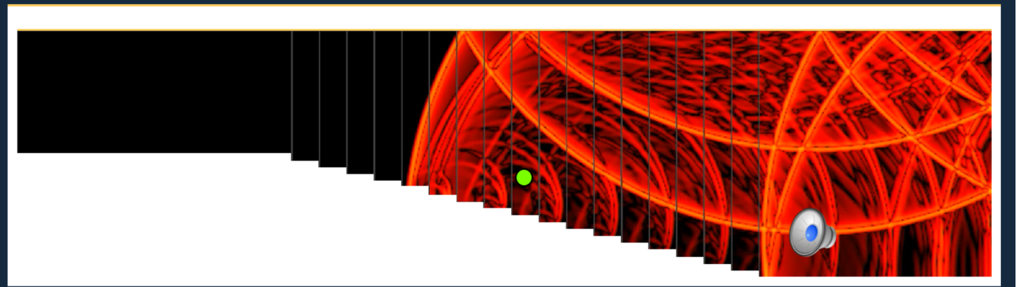
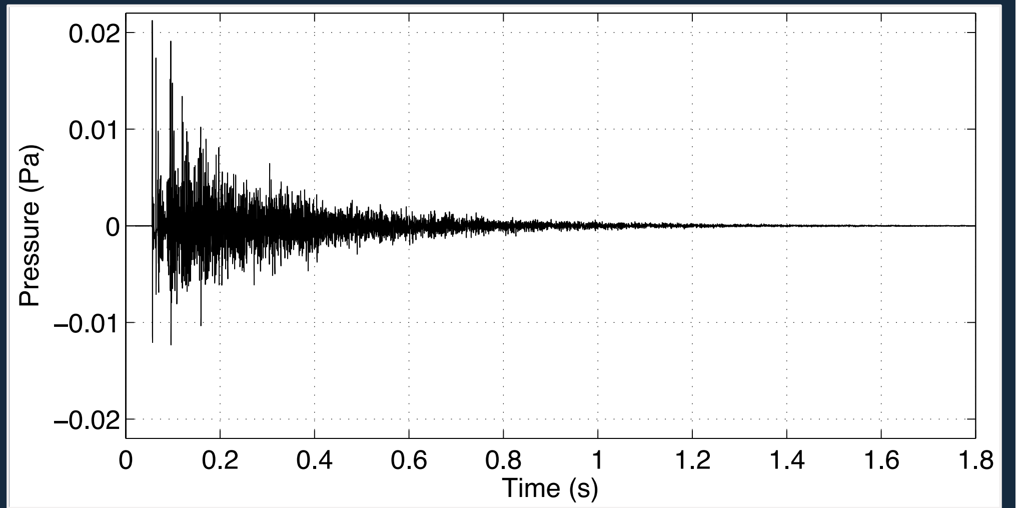
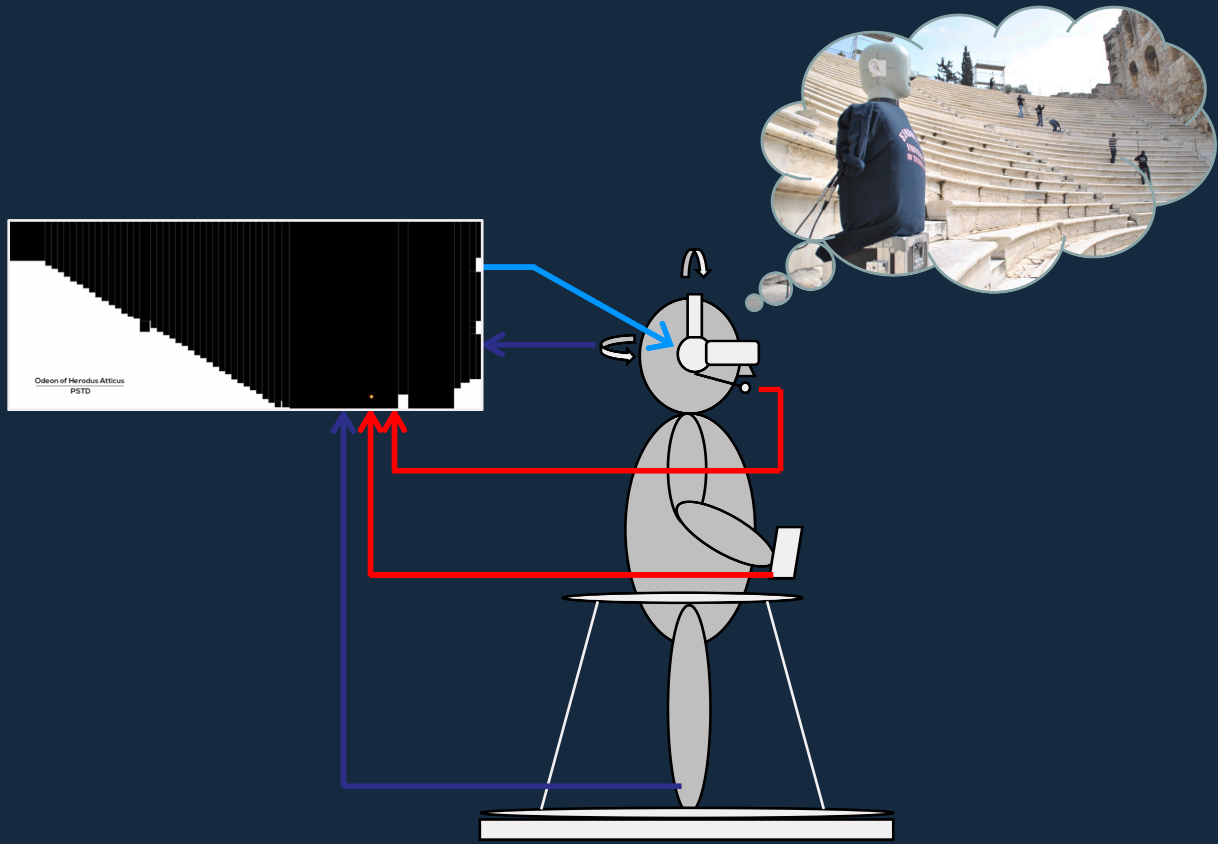




Our research



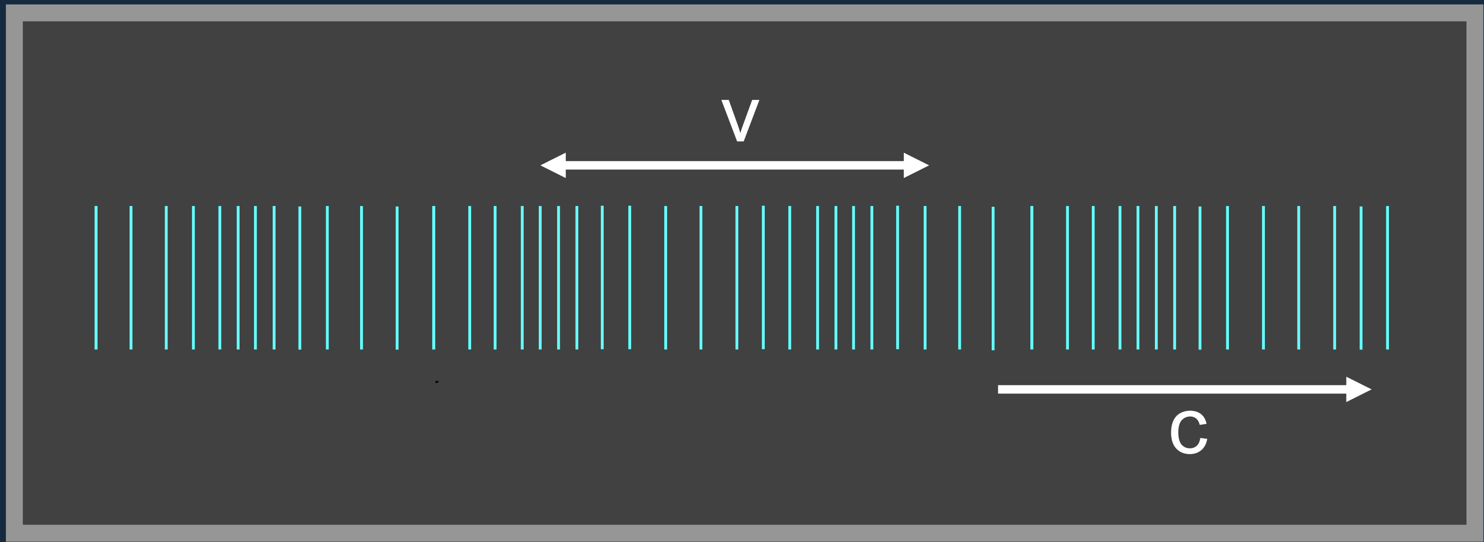
Our research

Contents

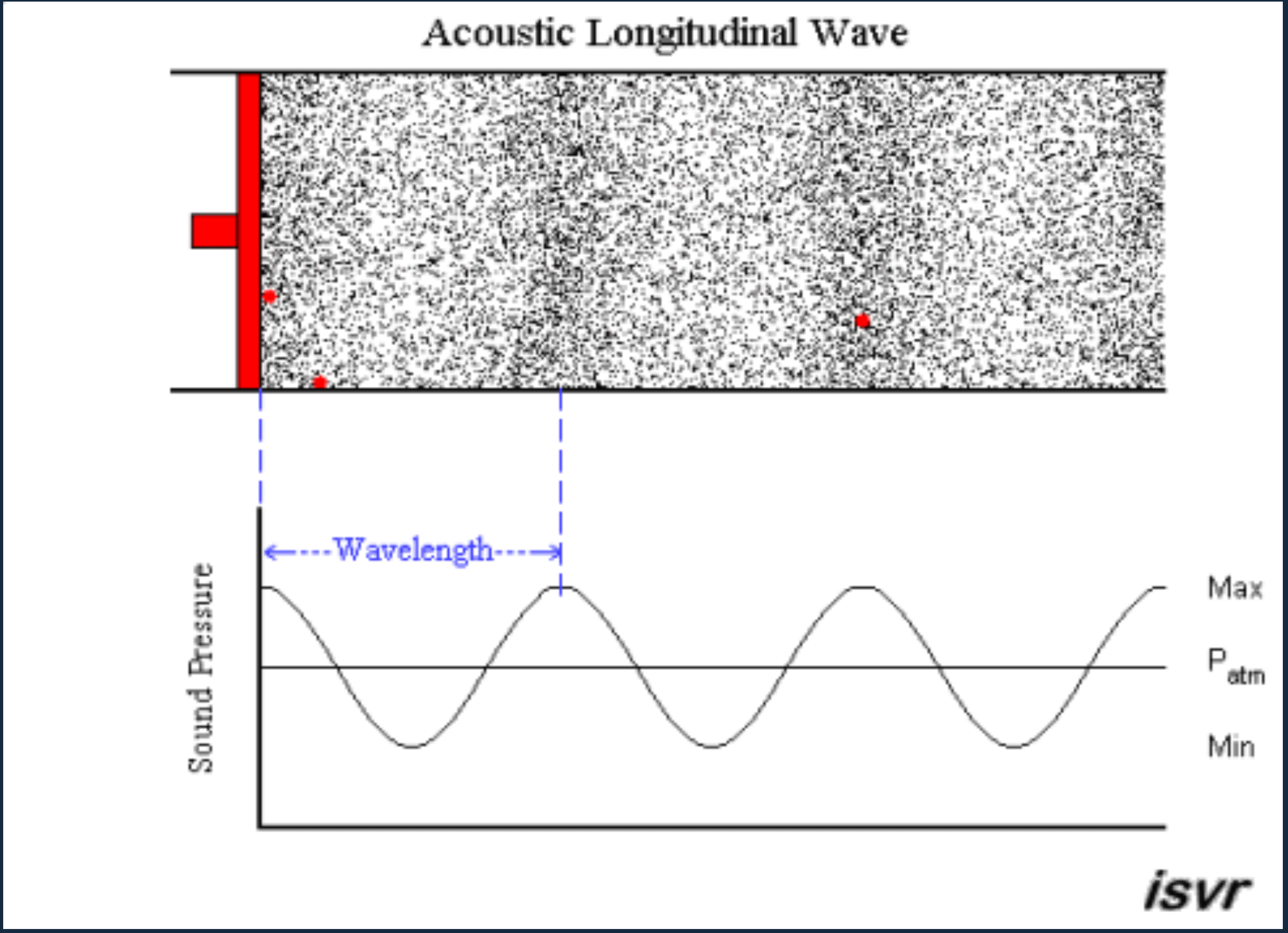
- Sound propagation
- Sound pressure level and decibel scale
- Calculation with decibels
- Frequency
- Equivalent sound (pressure) level

Sound Propagation

Longitudinal



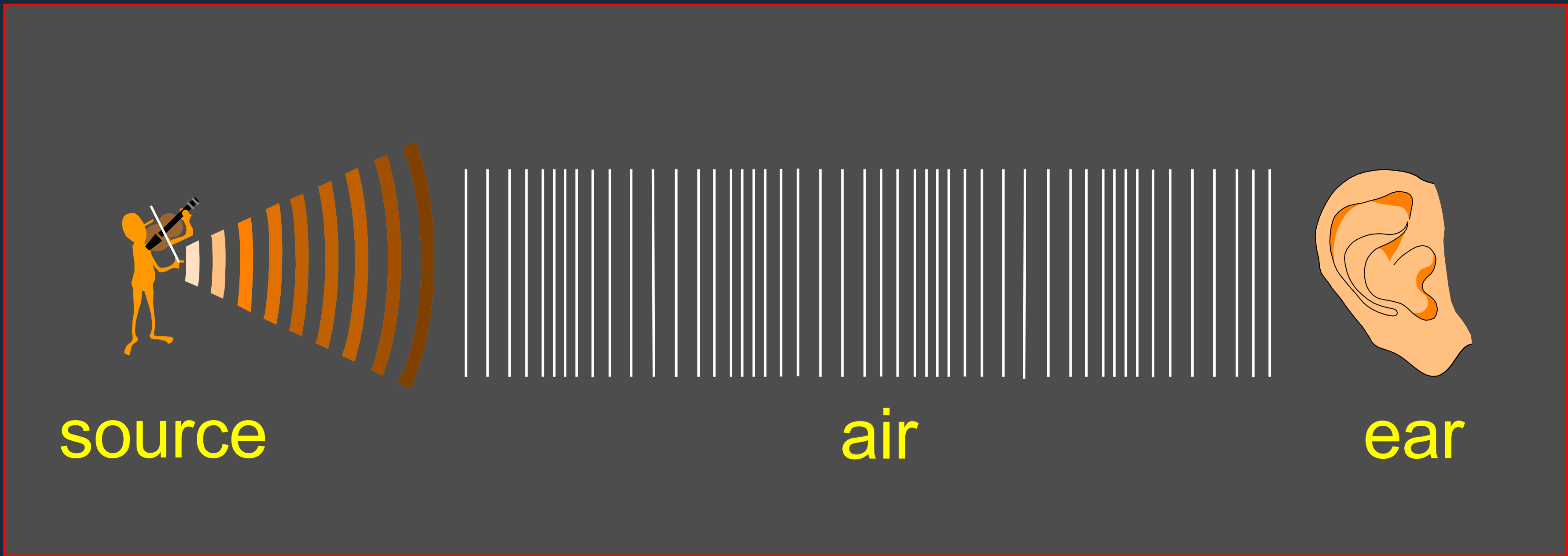
Propagation direction = Vibration direction of medium



http://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/Web-basics-nature.htm

Sound Propagation

Airborne sound



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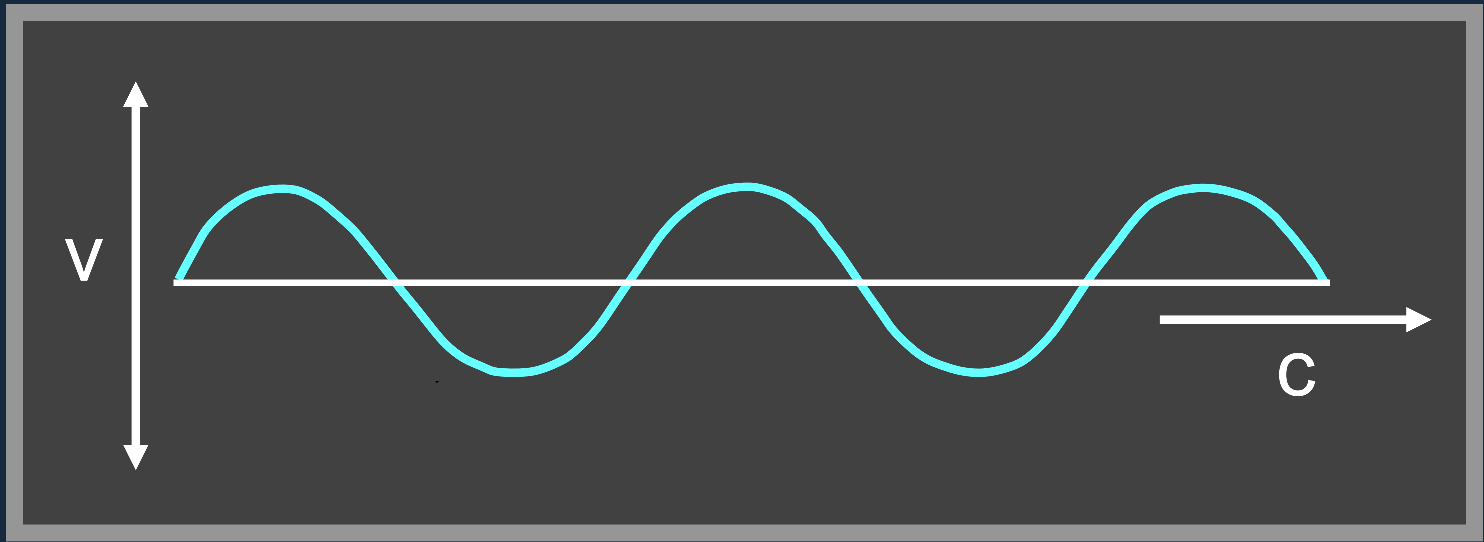
Sound Propagation

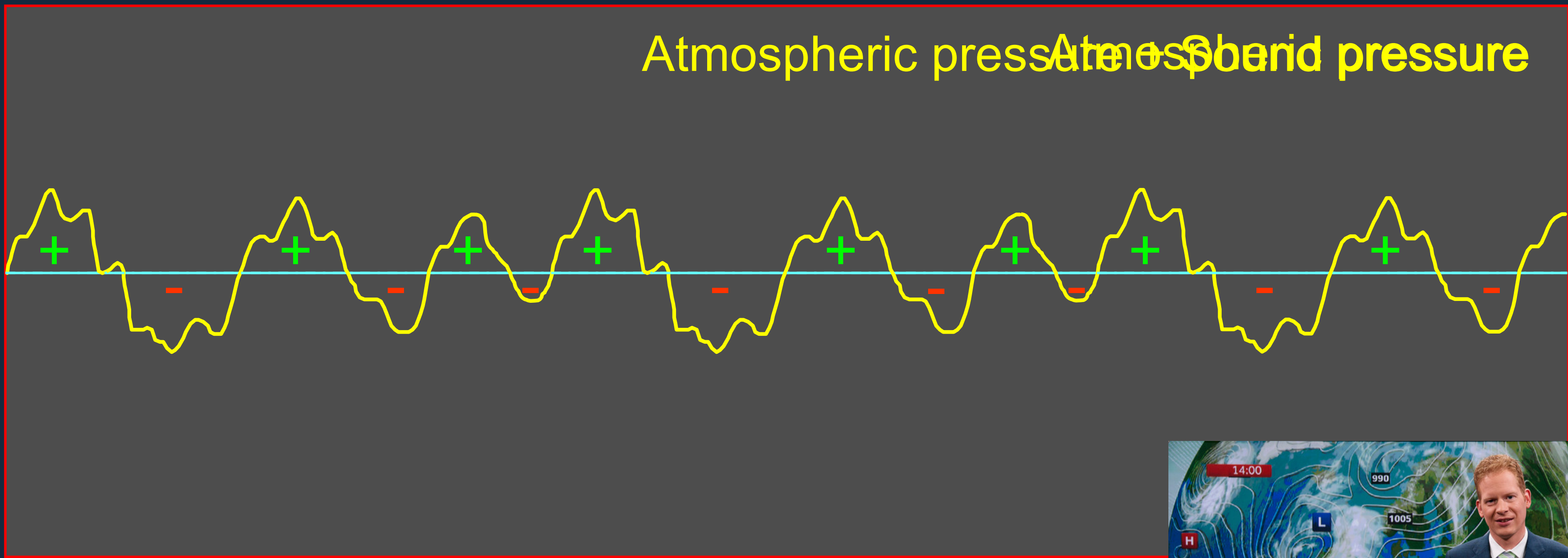
Transverse wave



Propagation direction ⊥ Vibration direction of medium

Airborne Sound

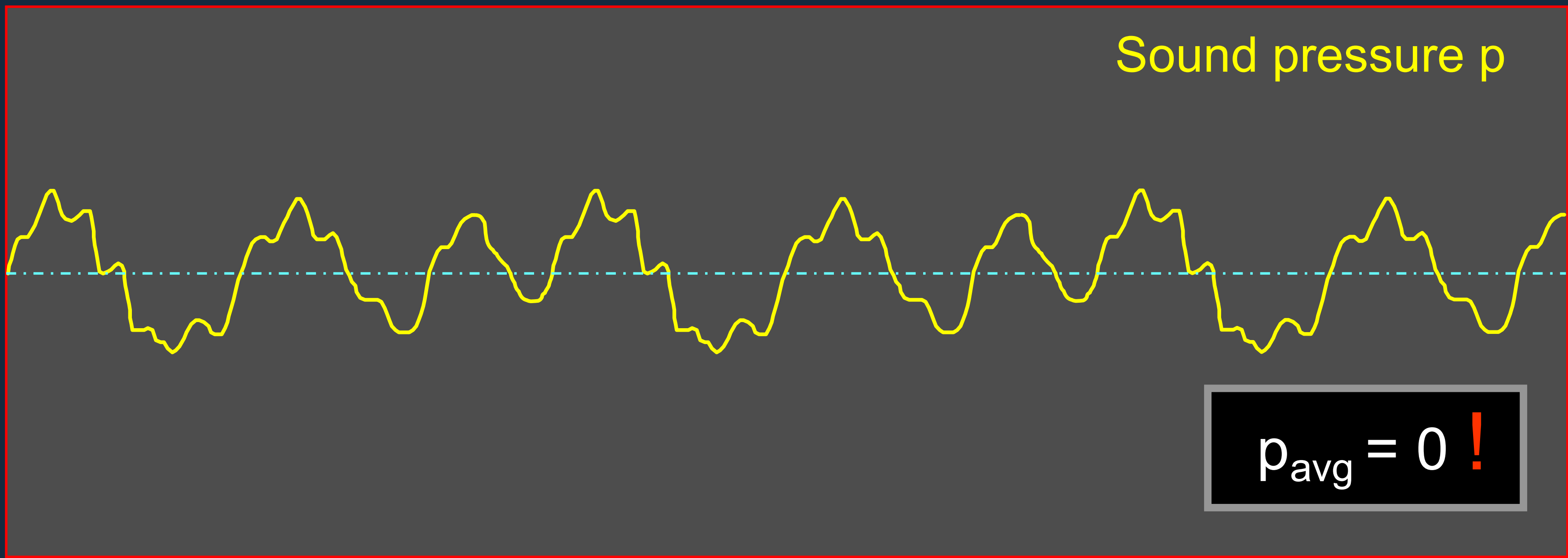
Sound pressure



ANP

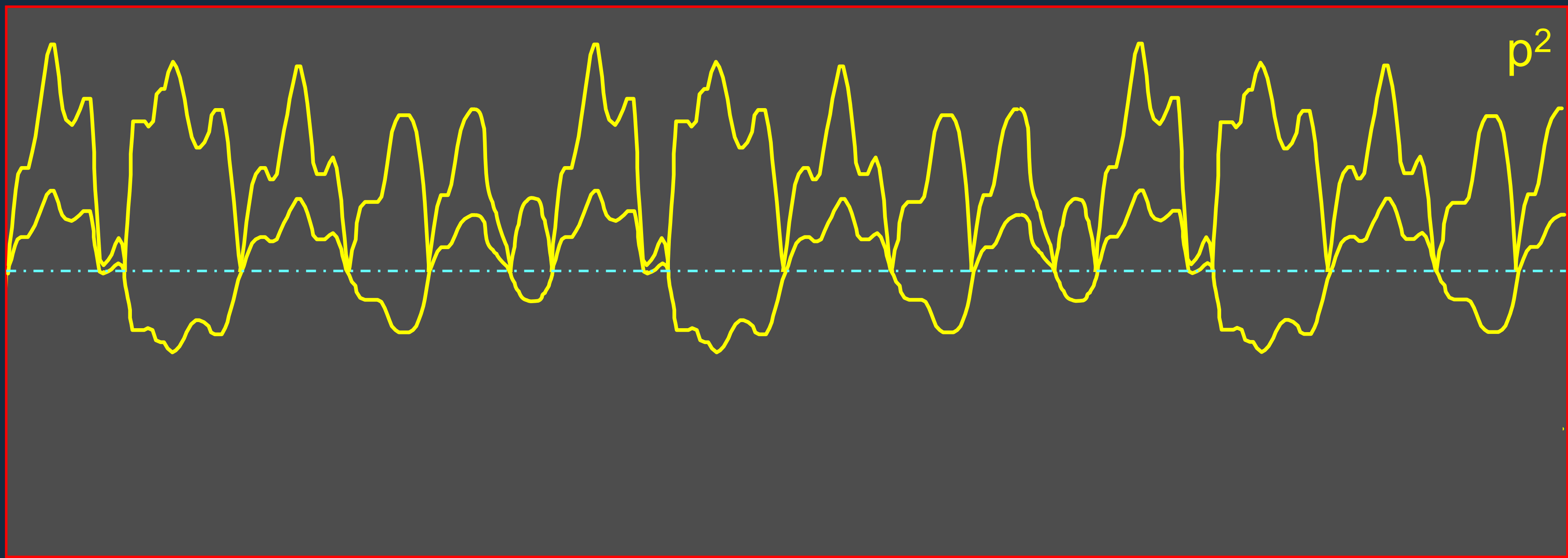
Airborne Sound

Sound pressure



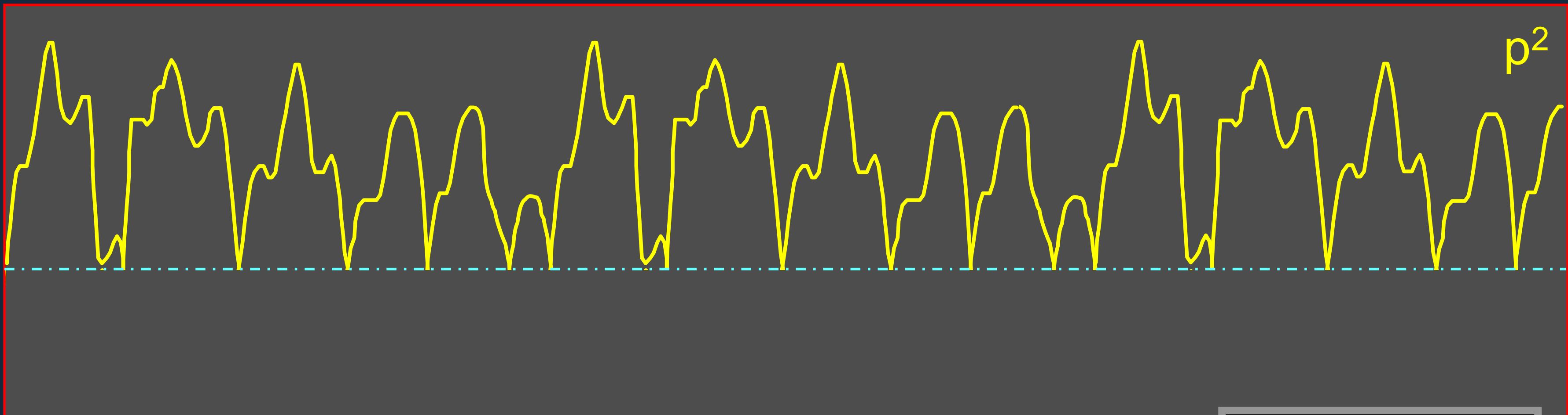
Airborne Sound

Sound "energy"



Airborne Sound

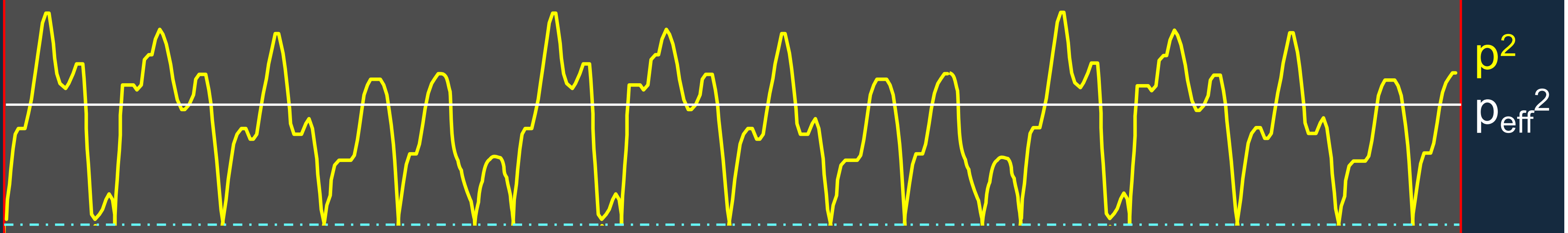
Sound "energy"



$$p^2_{avg} \neq 0 \;!$$

Airborne Sound

Sound “energy”



$$p_{eff}^2 = \frac{1}{T}\int_0^T p^2\,(t)\,dt$$

Sound Pressure Level

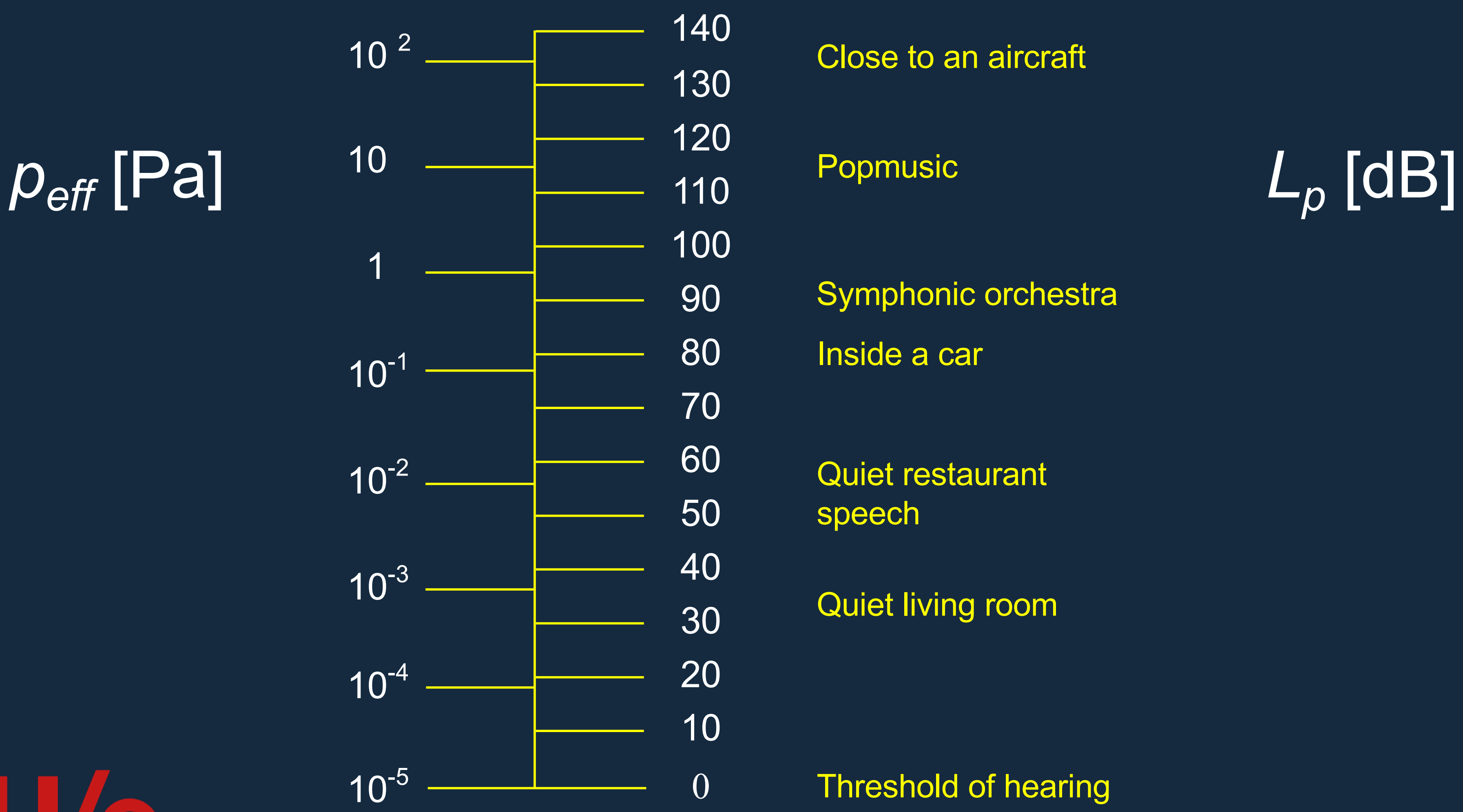
Main formula

$$L_p = 10\log_{10}\left(\frac{p_{eff}^2}{p_0^2}\right)$$

$p_0 =$ 2.10^{-5} Pa $=$ 20 μPa

Decibel Scale

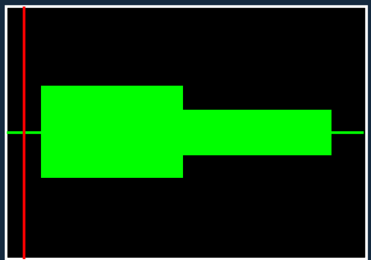
Sound Pressure vs Sound Pressure Level



Decibel Scale

Sound Level difference

Step

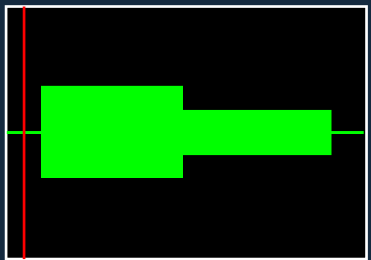


	Sine	Noise	Music
0.0 dB			
-0.5 dB			
-1.0 dB			
-1.5 dB			
-2.0 dB			
-2.5 dB			
-3.0 dB			

Decibel Scale

Sound Level difference

Step



	Sine	Noise	Music
0.0 dB			
-0.5 dB			
-1.0 dB			
-1.5 dB			
-2.0 dB			
-2.5 dB			
-3.0 dB			

	Extra Music
-5.0 dB	
-10.0 dB	

Calculation with Decibels

Addition

$$L_p = 10\log_{10}\left(\frac{p_{eff}^2}{p_0^2}\right)$$

L_{p1} = 60 dB and L_{p2} = 55 dB

$L_{p1} + L_{p2} \neq$ 115 dB

Sound pressure levels cannot just be added

Calculation with Decibels

Logarithms

$$\log_{10}(A \cdot B) = \log_{10}(A) + \log_{10}(B)$$

$$\log_{10}(A / B) = \log_{10}(A) - \log_{10}(B)$$

$$\log_{10}(A^n) = n \cdot \log_{10}(A)$$

Calculation with Decibels

Logarithms

$\log_{10}(1) = 0$

$\log_{10}(2) = 0.3010$ (rounded: 0.3)

$\log_{10}(3) = 0.4771$

$\log_{10}(4) =$

Calculation with Decibels

Logarithms

$\log_{10}(1) = 0$

$\log_{10}(2) = 0.3010$ (rounded: 0.3)

$\log_{10}(3) = 0.4771$

$\log_{10}(4) = 2 \,.\, \log_{10}(2) = 2 \,.\, 0.3 = 0.6$

Calculation with Decibels

Logarithms

$\log_{10}(1) = 0$

$\log_{10}(2) = 0.3010$ (rounded: 0.3)

$\log_{10}(3) = 0.4771$

$\log_{10}(4) = 2 \bullet \log_{10}(2) = 2 . 0.3 = 0.6$

$\log_{10}(5) = 0.7$

$\log_{10}(6) =$

Calculation with Decibels

Logarithms

$\log_{10}(1) = 0$

$\log_{10}(2) = 0.3010$ (rounded: 0.3)

$\log_{10}(3) = 0.4771$

$\log_{10}(4) = 2 \bullet \log_{10}(2) = 2 \,.\, 0.3 = 0.6$

$\log_{10}(5) = 0.7$

$\log_{10}(6) = \log_{10}(2) + \log_{10}(3) = 0.7771$

Calculation with Decibels

Logarithms

$\log_{10}(7) = 0.85$

$\log_{10}(8) =$

Calculation with Decibels

Logarithms

$\log_{10}(7) = 0.85$

$\log_{10}(8) = 3 \cdot \log_{10}(2) = 3 \cdot 0.3 = 0.9$

Calculation with Decibels

Logarithms

$\log_{10}(7) = 0.85$

$\log_{10}(8) = 3 \cdot \log_{10}(2) = 3 \cdot 0.3 = 0.9$

$\log_{10}(9) =$

Calculation with Decibels

Logarithms

$\log_{10}(7) = 0.85$

$\log_{10}(8) = 3 \cdot \log_{10}(2) = 3 \cdot 0.3 = 0.9$

$\log_{10}(9) = 3 \cdot \log_{10}(3) = 2 \cdot 0.4771 =$
$= 0.95$

Calculation with Decibels

Logarithms

$\log_{10}(7) = 0.85$

$\log_{10}(8) = 3 \cdot \log_{10}(2) = 3 \cdot 0.3 = 0.9$

$\log_{10}(9) = 3 \cdot \log_{10}(3) = 2 \cdot 0.4771 =$
$= 0.95$

$\log_{10}(10) = 1$

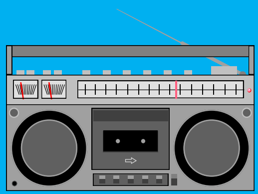
$\log_{10}(100) = 2$

$\log_{10}(1000) = 3$

Calculation with Decibels

Addition

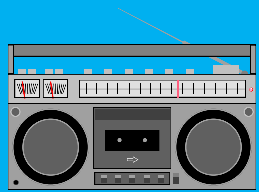
Source 1:



$$L_{p,1} = 10log_{10}\left(\frac{p_{eff,1}^2}{p_0^2}\right)$$

$$p_{eff,1}^2 = p_0^2 10^{\frac{L_{p1}}{10}}$$

Source 2:



$$L_{p,2} = 10log_{10}\left(\frac{p_{eff,2}^2}{p_0^2}\right)$$

$$p_{eff,2}^2 = p_0^2 10^{\frac{L_{p2}}{10}}$$

Calculation with Decibels

Addition

$$\frac{p_{eff,(1+2)}^2}{p_0^2} = \frac{p_{eff,1}^2}{p_0^2} + \frac{p_{eff,2}^2}{p_0^2}$$

$$10^{\frac{L_{p(1+2)}}{10}} = 10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}}$$

$$L_{p(1+2)} = 10log_{10}\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}}\right)$$

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Calculation with Decibels

Rules of thumb

If $\boldsymbol{L_{p,1} = L_{p,2}}$

$$L_{p(1+2)} = 10\log_{10}\left(2 \cdot 10^{\frac{L_{p,1}}{10}}\right)$$

$$= 10\log_{10}\left(10^{\frac{L_{p,1}}{10}}\right) + 10\log_{10}(2)$$

$$L_{p(1+2)} = \boldsymbol{L_{p1} + 3}$$

Calculation with Decibels

Rules of thumb

If $\boldsymbol{L_{p,1} = L_{p,2}}$ **+10 dB**

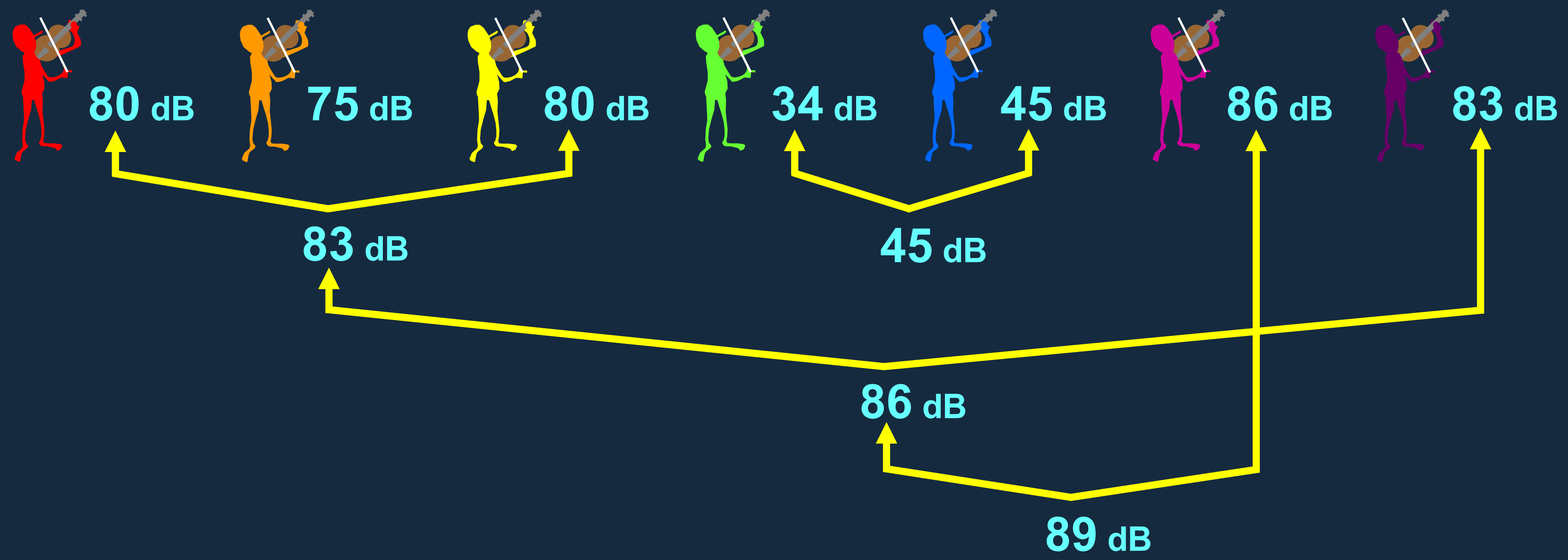
(e.g. $L_{p,1}$ = **60 dB**, $L_{p,2}$ = 50 dB)

$$L_{p(1+2)} = 10 \log_{10} (10^6 + 10^5)$$
$$= 10 \log_{10} (10^6 + 0.1 \cdot 10^6)$$
$$= 10 \log_{10} (1.1 \cdot 10^6)$$

$$L_{p(1+2)} = 0.4 + 60 \approx \mathbf{60\ dB}$$

Calculation with Decibels

multiple sound sources



$$10\log_{10}\left[10^{\frac{L_{p,1}}{10}} + 10^{\frac{L_{p,2}}{10}} + 10^{\frac{L_{p,3}}{10}} + \dots\right] = 89.2\ \text{dB}$$

Calculation with Decibels

Addition of n sound sources

n sources:

$$L_{p1} = L_{p2} = L_{p3} = \ldots = L_{pn} = L_p$$

$$L_{p,tot} = L_p + 10\log_{10}(n)$$

<u>Example:</u> 16 sources: $L_p = 45$ dB

$$L_{ptot} = 45 + 12 = 57 \text{ dB}$$

Introduction

Time domain

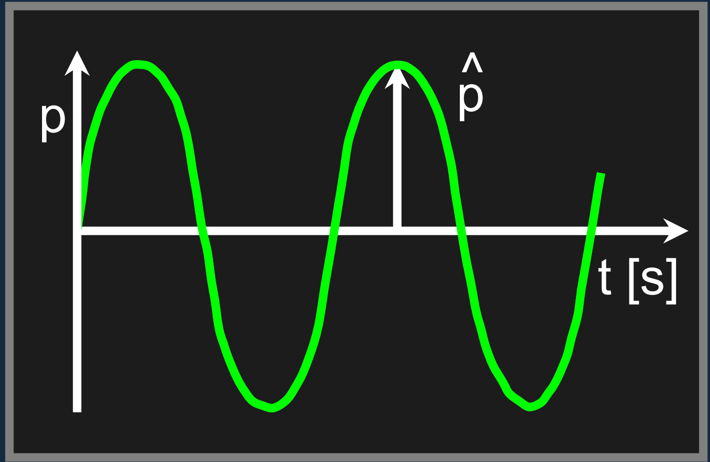
- Pure tone (sine)
  - Sine shape p(t)

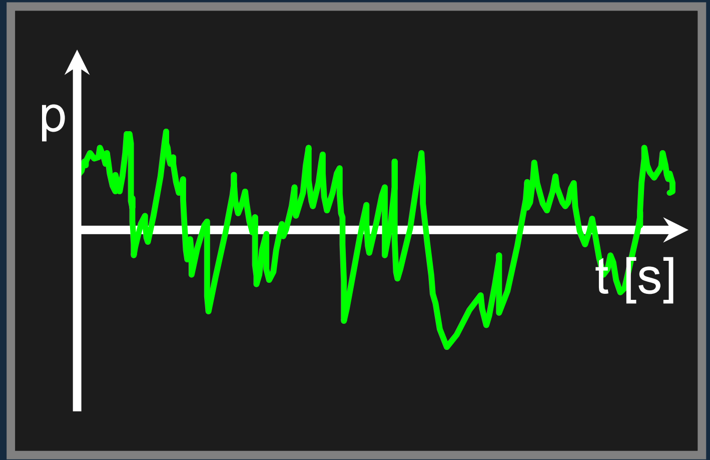
$$p(t) = \hat{p} sin\left(\frac{2\pi t}{T}\right)$$

  - $f = 1/T$ [1/s] [Hz]
  - $\lambda = c/f$

- Noise (white)

  20 - 20.000 Hz





Introduction

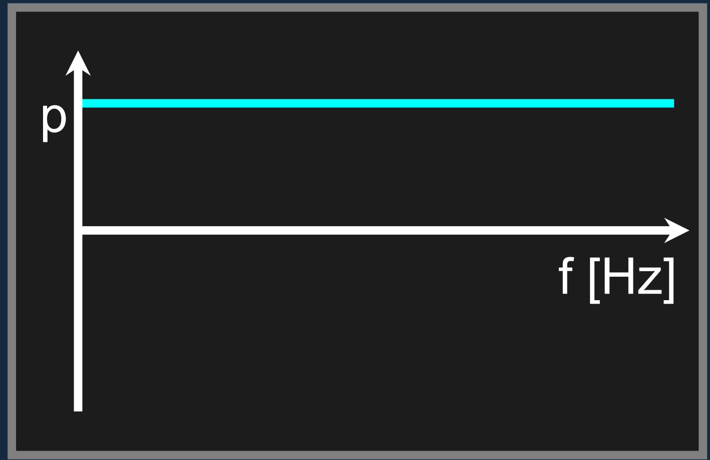
Frequency domain

- Pure tone
  - Sine shape p(t)

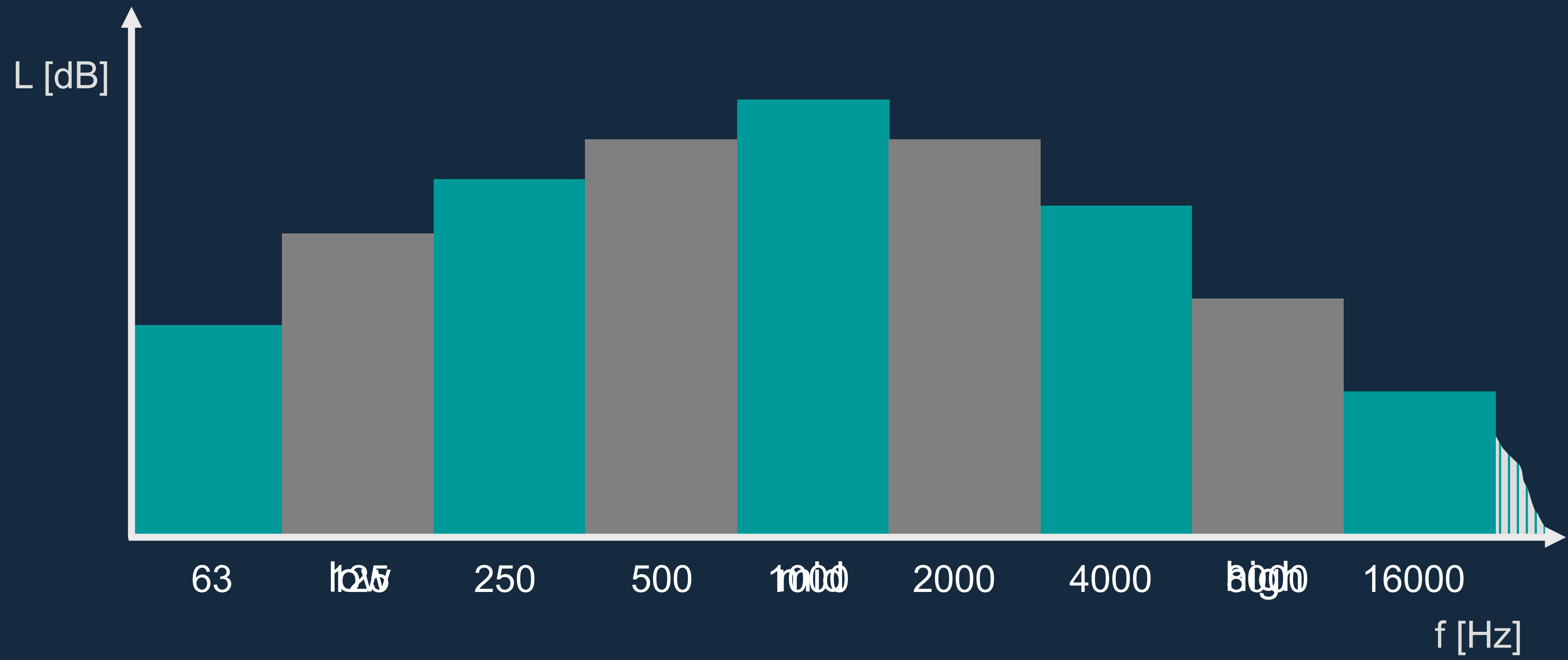
$$p(t) = \hat{p} sin\left(\frac{2\pi t}{T}\right)$$

  - $f = 1/T$ [1/s] [Hz]
  - $\lambda = c/f$

- Noise (white)
  - 20 - 20.000 Hz



Frequency

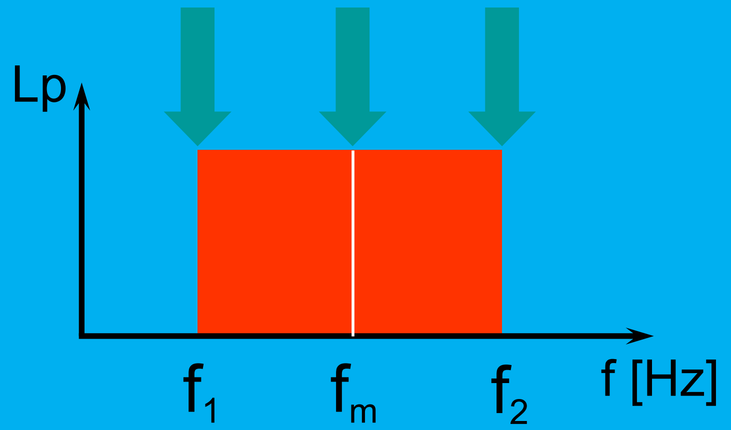


Frequency

Octave and 1/3 octave bands

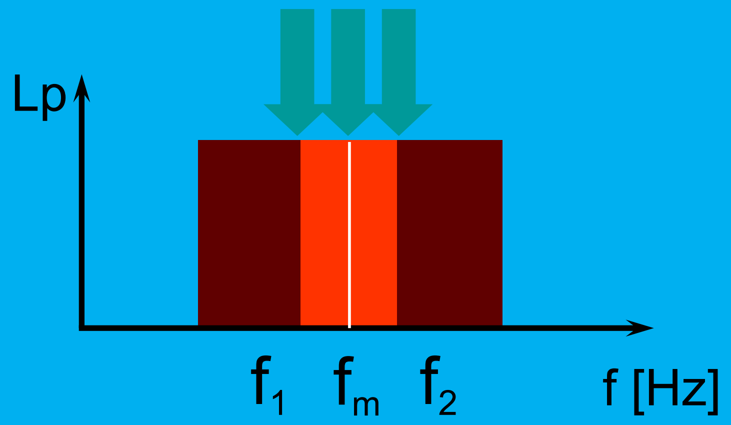
■ Octave band: $f_2 / f_1 = 2$

Example 1 kHz octave band	f_m = 1000 Hz f_1 = 707 Hz f_2 = 1414 Hz



■ 1/3 Octave band: $f_2 / f_1 = 2^{1/3}$

Example 1 kHz 1/3 octave band	f_m = 1000 Hz f_1 = 890 Hz f_2 = 1122 Hz



Frequency

Octave and 1/3 octave bands

$$L_{p,oct\,(1\,kHz)} = 10 \log_{10} \sum_{707}^{1414} \frac{p_{eff}^2(f_i)}{p_o^2}$$

$$L_{p,1/3\,oct\,(1\,kHz)} = 10 \log_{10} \sum_{890}^{1122} \frac{p_{eff}^2(f_i)}{p_o^2}$$

$$L_{p,1/3octave}(f_i) \leq L_{p,octave}(f_i)$$

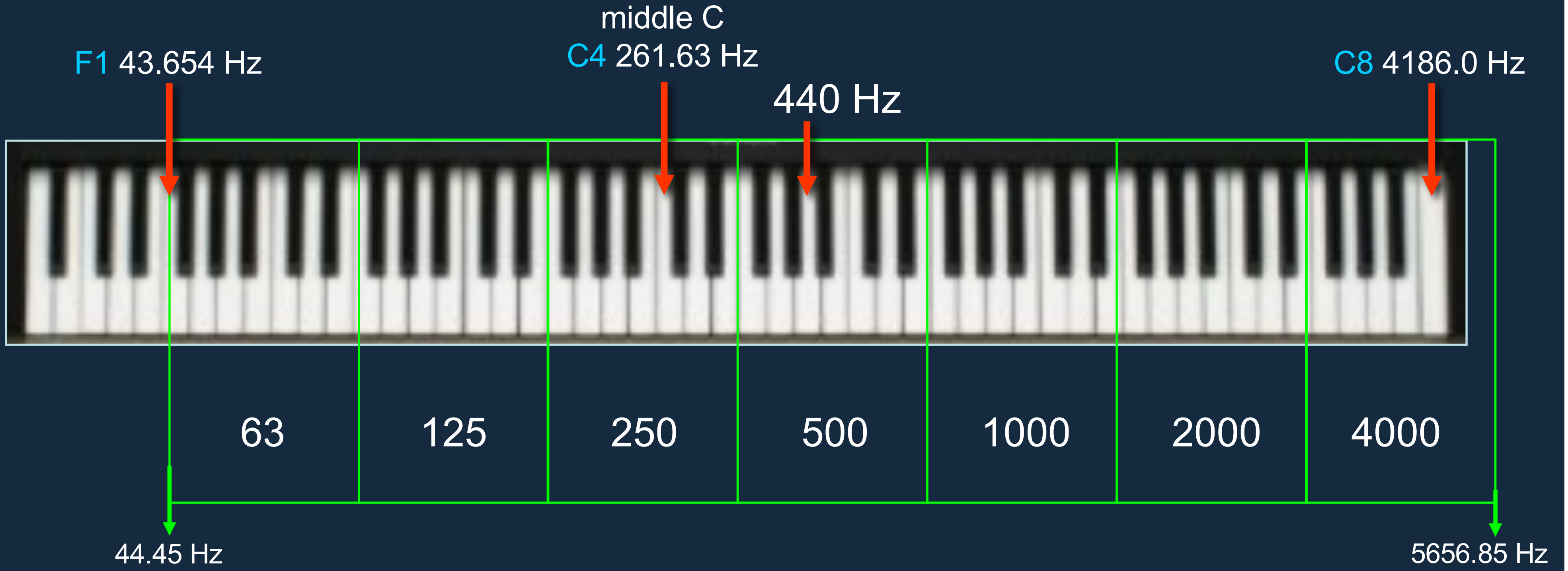
Frequency

Normalised frequency bands

Octave	1/3 Octave
63	50 63 80
125	100 125 160
250	200 250 315
500	400 500 630
1000	800 1000 1250
2000	1600 2000 2500
4000	3150 4000 5000

Frequency

Normalised frequency bands



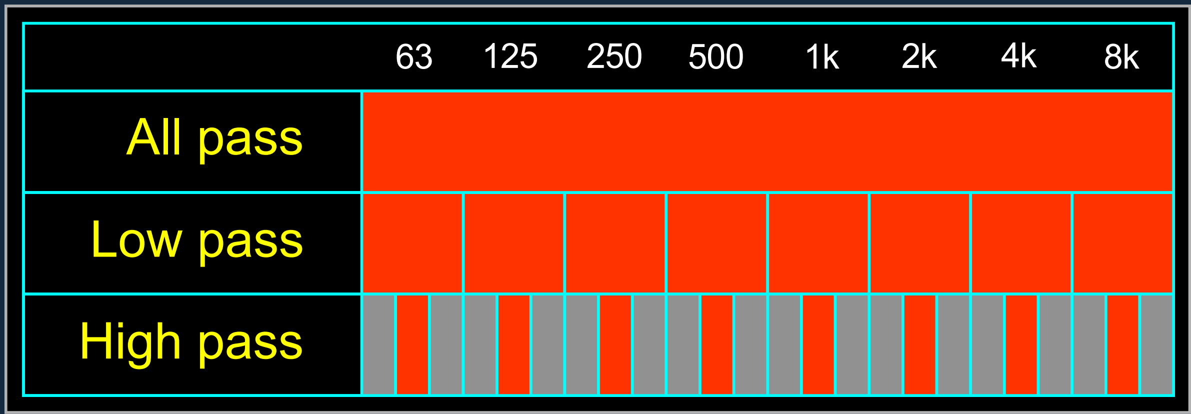
Frequency

High and low pass filtering

	63	125	250	500	1k	2k	4k	8k
All pass								
Low pass								
High pass								

Frequency

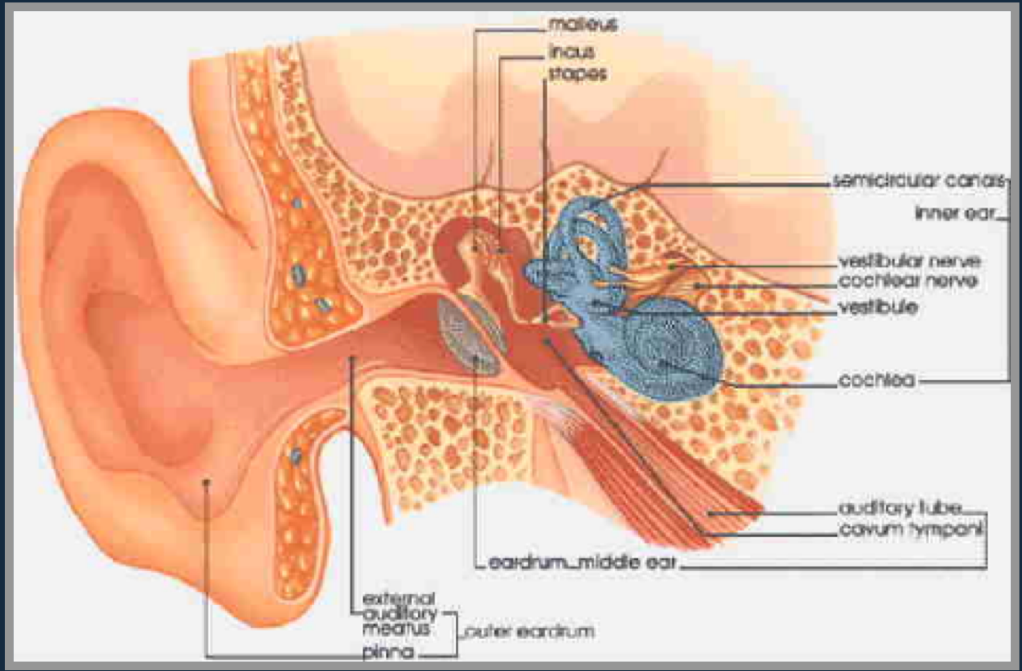
High and low pass filtering



The Ear

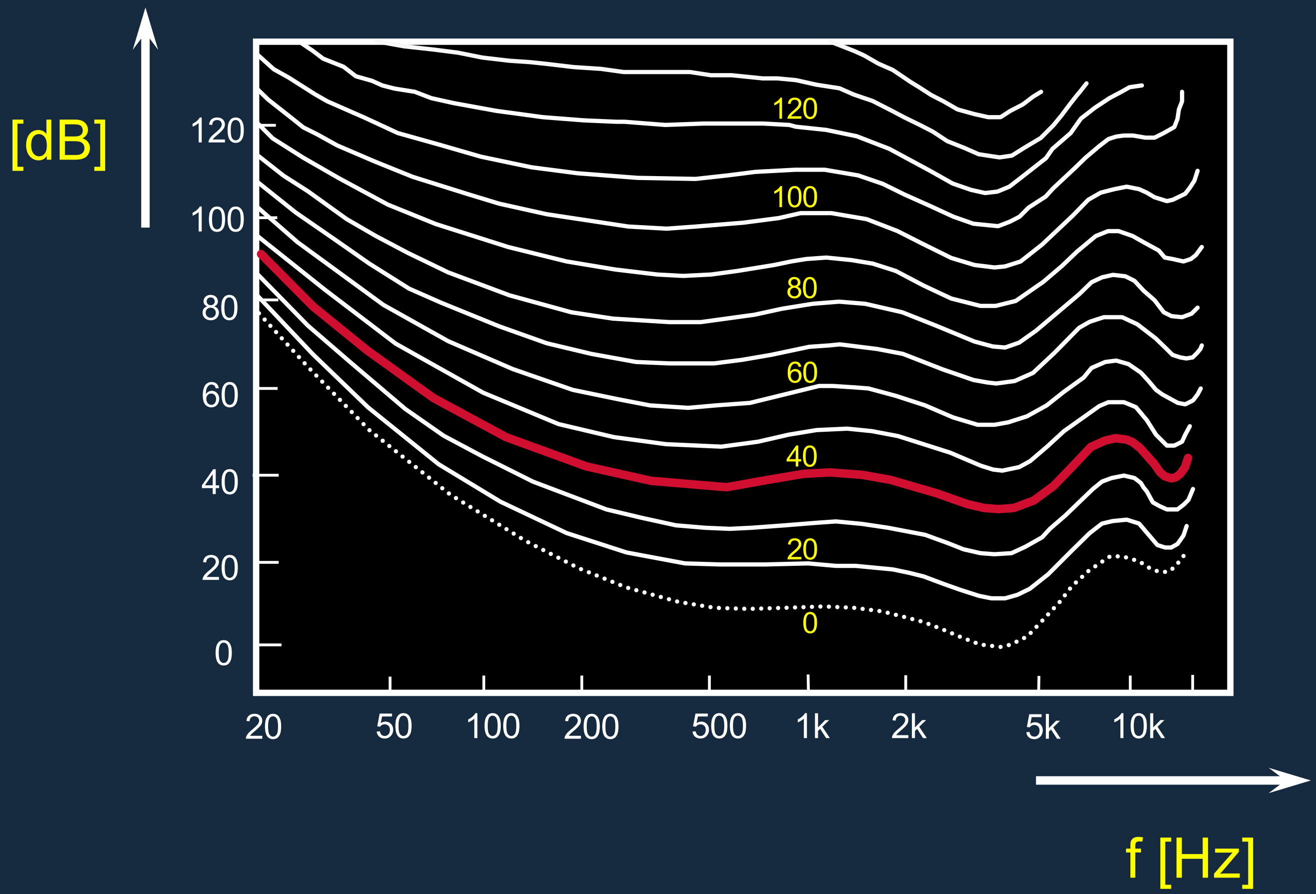
External, middle and inner ear

- 20 - 20000 Hz
- Averages fluctuating sound pressure levels
- Can distinguish time patterns
- Not equally sensitive to all frequencies



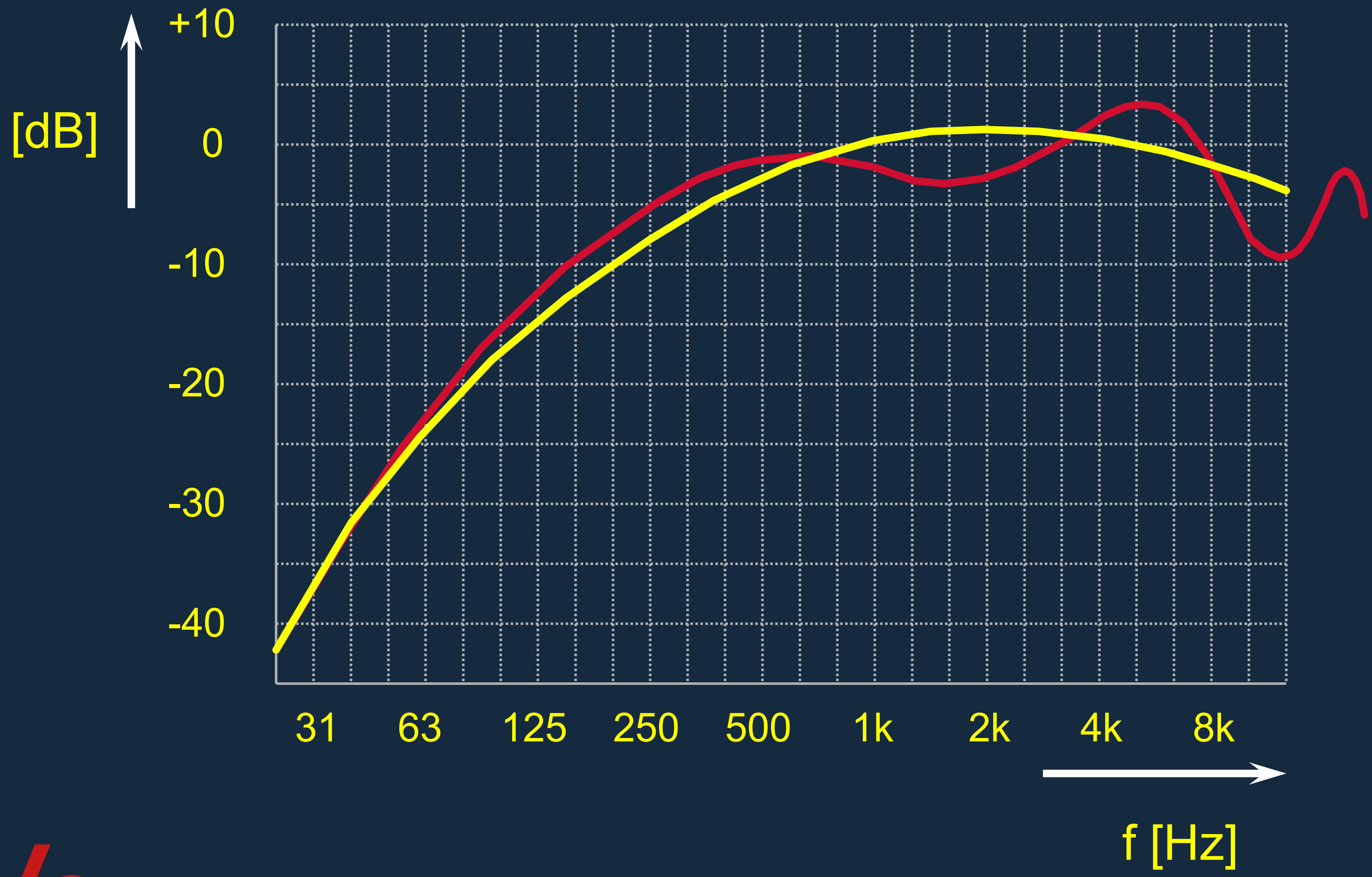
Isophones

Curves of equal loudness



A-Weighted Level

Normalised A-Curve



A-Weighted Level

Normalised A-values

fm_i [Hz]	L_p [dB]	A_i	L_p [A-weighted] [dB]
63	82.2		
125	88.0		
250	81.6		
500	73.5		
1000	66.3		
2000	61.3		
4000	54.0		
8000	47.3		

$$L_A = 10log_{10}\left(\sum_{i=1}^{i=n} 10^{\frac{(L_{pi}+A_i)}{10}}\right) \quad \text{dB(A)}$$

A-Weighted Level

Normalised A-values

fm_i [Hz]	L_p [dB]	A_i	L_p [A-weighted] [dB]
63	82.2	-26.2	
125	88.0	-16.1	
250	81.6	- 8.6	
500	73.5	- 3.2	
1000	66.3	0	
2000	61.3	+ 1	
4000	54.0	+ 1.1	
8000	47.3	- 1.0	

$$L_A = 10log_{10}\left(\sum_{i=1}^{i=n} 10^{\frac{(L_{pi}+A_i)}{10}}\right) \quad \text{dB(A)}$$

A-Weighted Level

Normalised A-values

fm_i [Hz]	L_p [dB]	A_i	L_p [A-weighted] [dB]
63	82.2	-26.2	
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250	81.6	- 8.6	
500	73.5	- 3.2	
1000	66.3	0	
2000	61.3	+ 1	
4000	54.0	+ 1.1	
8000	47.3	- 1.0	

$$L_A = 10log_{10}\left(\sum_{i=1}^{i=n} 10^{\frac{(L_{pi}+A_i)}{10}}\right) \quad \text{dB(A)}$$

A-Weighted Level

Normalised A-values

fm_i [Hz]	L_p [dB]	A_i	L_p [A-weighted] [dB]
63	82.2	-26.2	56.0
125	88.0	-16.1	71.9
250	81.6	- 8.6	73.0
500	73.5	- 3.2	70.3
1000	66.3	0	66.3
2000	61.3	+ 1	62.3
4000	54.0	+ 1.1	55.1
8000	47.3	- 1.0	46.3

$$L_A = 10log_{10}\left(\sum_{i=1}^{i=n} 10^{\frac{(L_{pi}+A_i)}{10}}\right) \quad \text{dB(A)}$$

A-Weighted Level

Normalised A-values

fm_i [Hz]	L_p [dB]	A_i	L_p [A-weighted] [dB]
63	82.2	-26.2	56.0
125	88.0	-16.1	71.9
250	81.6	- 8.6	73.0
500	73.5	- 3.2	70.3
1000	66.3	0	66.3
2000	61.3	+ 1	62.3
4000	54.0	+ 1.1	55.1
8000	47.3	- 1.0	46.3

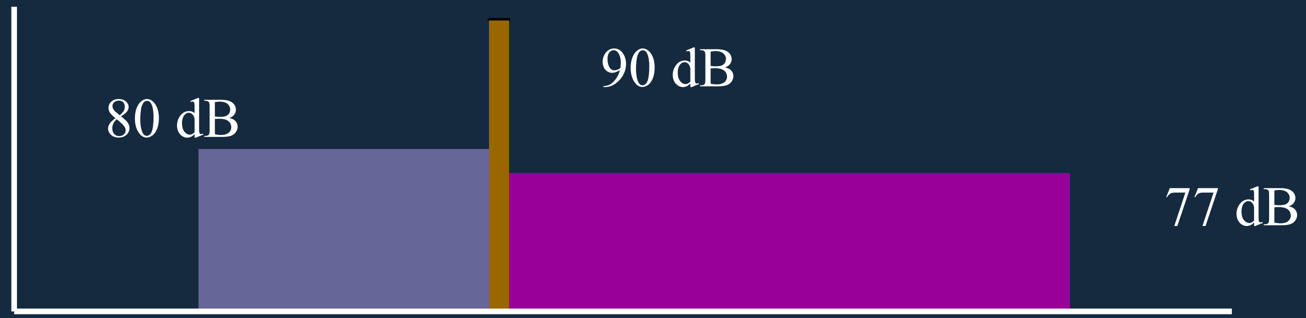
L_A=77.2 dB(A)

Equivalent sound level

$$L_{eq} = 10log_{10}\left(\frac{1}{T}\int_{0}^{T}\frac{p^2\,(t)}{p_0^2}\right) \quad \text{dB}$$

(L_{Aeq} = A-weighted L_{eq})

Equivalent sound level



1 minute $L_p = 80$ dB
1/10 minute $L_p = 90$ dB
2 minutes $L_p = 77$ dB

$$L_{eq} = 10log_{10}\left(\frac{1 \cdot 10^8 + 0.1 \cdot 10^9 + 2 \cdot 10^{7.7}}{1 + 0.1 + 2}\right) = 79.9 \approx 80 \text{ dB}$$