Urban Physics

7S0X0, 2021-2022 Quartile 3

prof.dr.ir. Maarten Hornikx

EINDHOVEN UNIVERSITY OF TECHNOLOGY

www.tue.nl/buildingacoustics

Urban Acoustics

Week 1

- Acoustics quantities
- Acoustic pressure and velocity
- Sound pressure level
- A-weighting
- Octave bands

prof.dr.ir. Maarten Hornikx

EINDHOVEN UNIVERSITY OF TECHNOLOGY

www.tue.nl/buildingacoustics

Contents

- Acoustic pressure and velocity

- L_p : sound pressure level dB
- L_w : sound power level dB
- L_I : sound intensity level dB

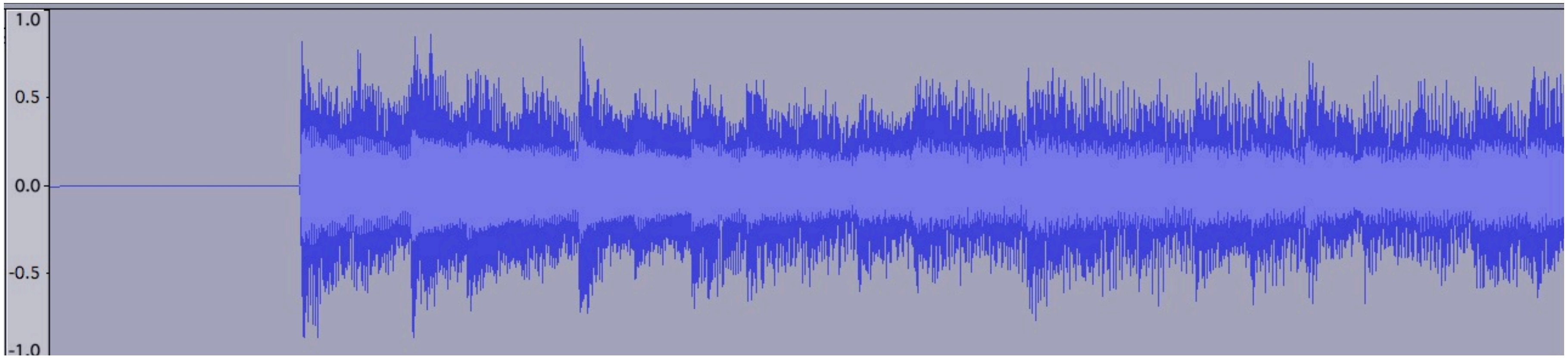
- Frequency, speed of sound

- Octave band analysis
- L_A : A-weighted sound level dB(A)

Sound propagation in air

$$p_{tot}(t) = p_0(t) + p(t)$$

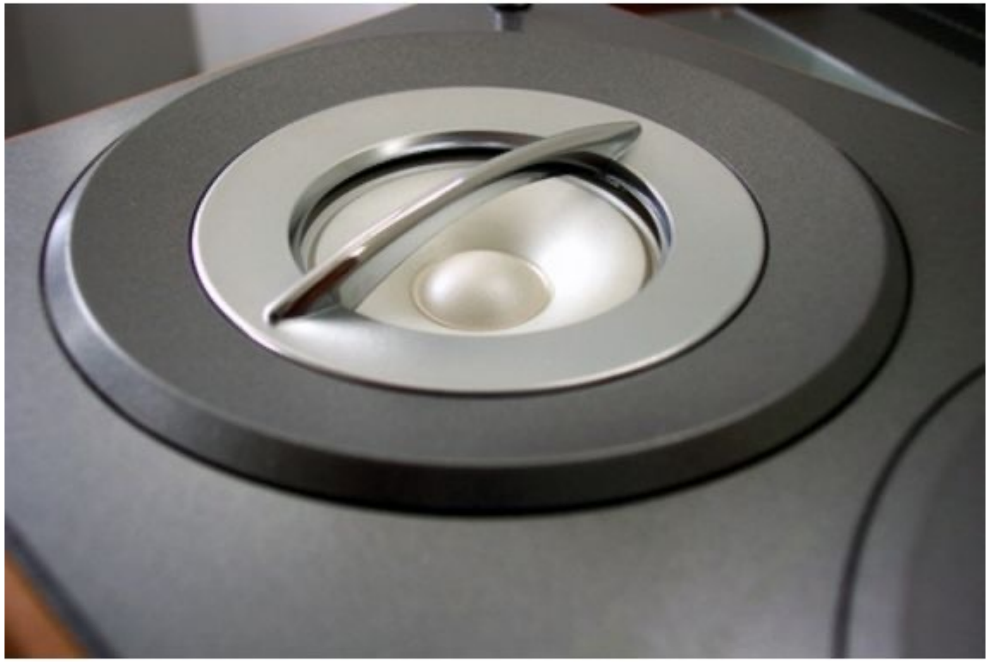
$$\rho_{tot}(t) = \rho_0(t) + \rho(t)$$



Sound propagation in air

$$\vec{u}_{tot}(t) = \vec{u}_0(t) + \vec{u}(t)$$

$$p(t) \sim \vec{u}(t)$$

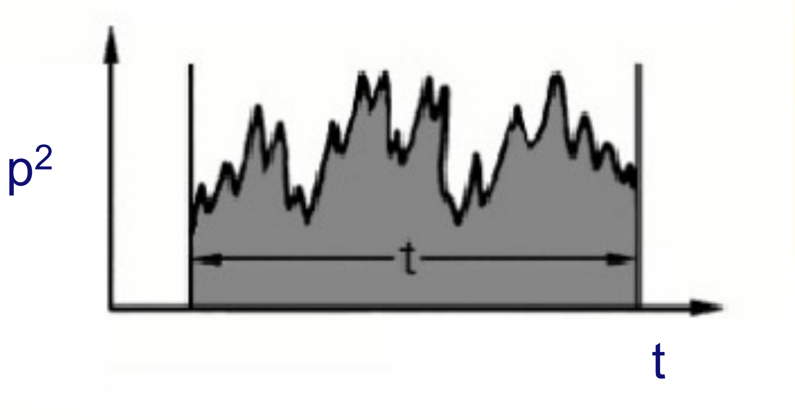


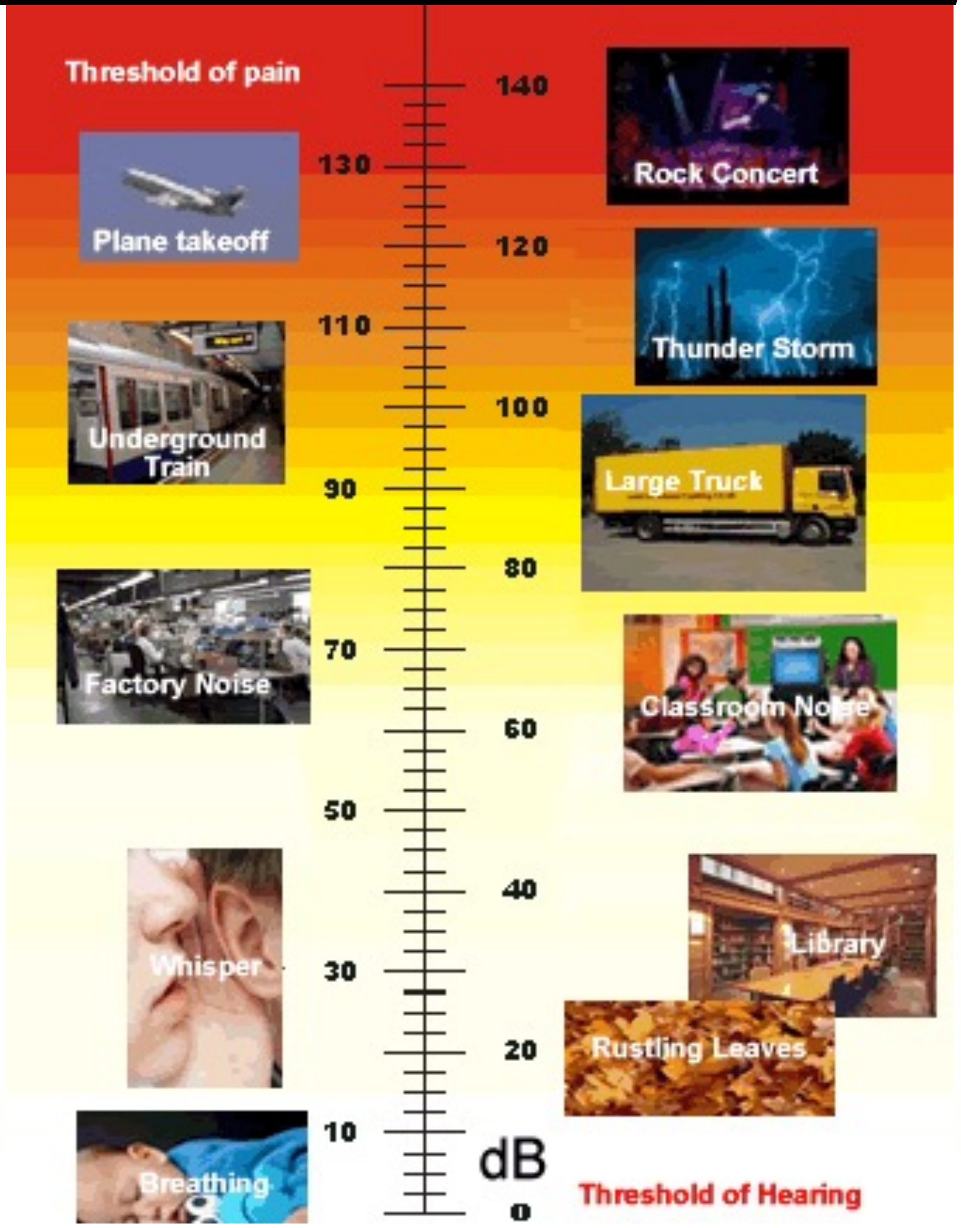
http://img.ehowcdn.com/article-new-intro-modal/ehow/images/a06/ep/vp/fix-vibrating-audio-speakers-800x800.jpg

Sound pressure level $L_p(t)$

$$L_p(t) = 10\log_{10}\left(\frac{p^2(t)}{p_{ref}^2}\right) \quad [\mathrm{dB}]$$

$$p_{ref} = 2\cdot 10^{-5}\ [\mathrm{Pa}]$$



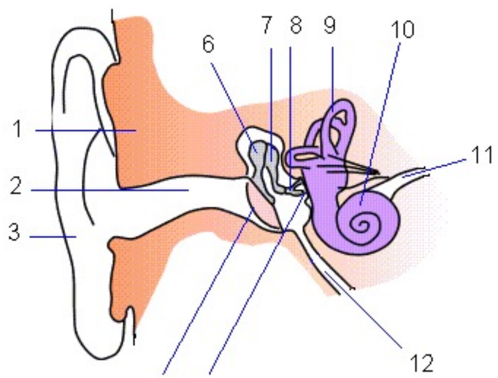


http://www.cyberphysics.co.uk/topics/waves/sound/decibel.html

Sound pressure level $L_p(t)$

$$L_p(t) = 10\log_{10}\left(\frac{\frac{1}{T_{\text{int}}}\int_0^{T_{\text{int}}} p^2(t)\,dt}{p_{ref}^2}\right) \quad [\text{dB}]$$

$$T_{\text{int}} = \text{time of integration [s]}$$



http://upload.wikimedia.org/wikipedia/commons/6/65/Ear-anatomy.png

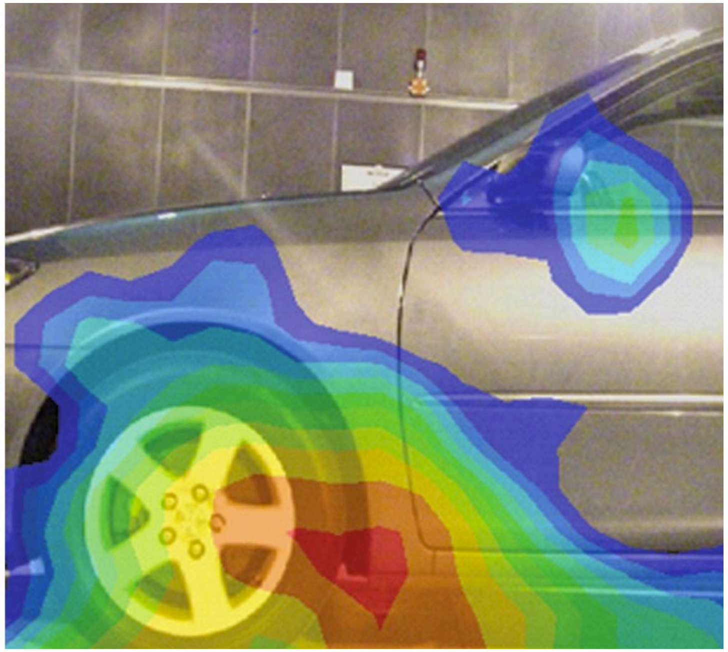
www.bksv.com

Sound intensity

- *Sound intensity*: describes the rate of flow of acoustic energy per unit area in a certain direction [W/m^2]
- Sound intensity level:

$$L_I(t) = 10\log_{10}\left(\frac{I}{I_0}\right) \quad [\text{dB}]$$

$$I_0 = 1\cdot 10^{-12}\ [\text{W}]$$



http://www.bksv.jp

Sound power

- *Sound power*: the acoustic energy emitted by a sound source over time and is a property of the sound source alone. It is measured in terms of Watts [W]
- Sound power level:

$$L_W(t) = 10\log_{10}\left(\frac{W}{W_0}\right) \quad [\text{dB}]$$

$$W_0 = 1 \cdot 10^{-12}\ [\text{W}]$$

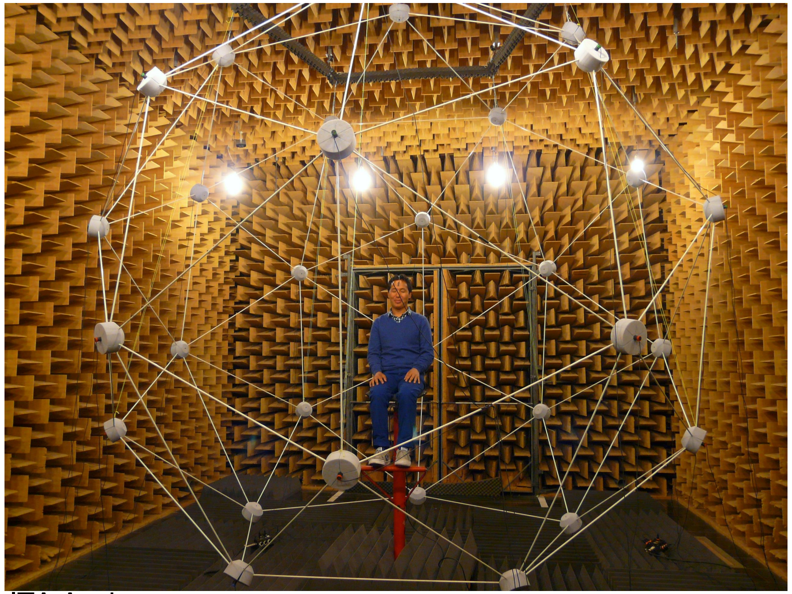
http://www.southampton.ac.uk

Sound power

- *Sound power*: the acoustic energy emitted by a sound source over time and is a property of the sound source alone. It is measured in terms of Watts [W]
- Sound power level:

$$L_W(t) = 10\log_{10}\left(\frac{W}{W_0}\right) \quad [\mathrm{dB}]$$

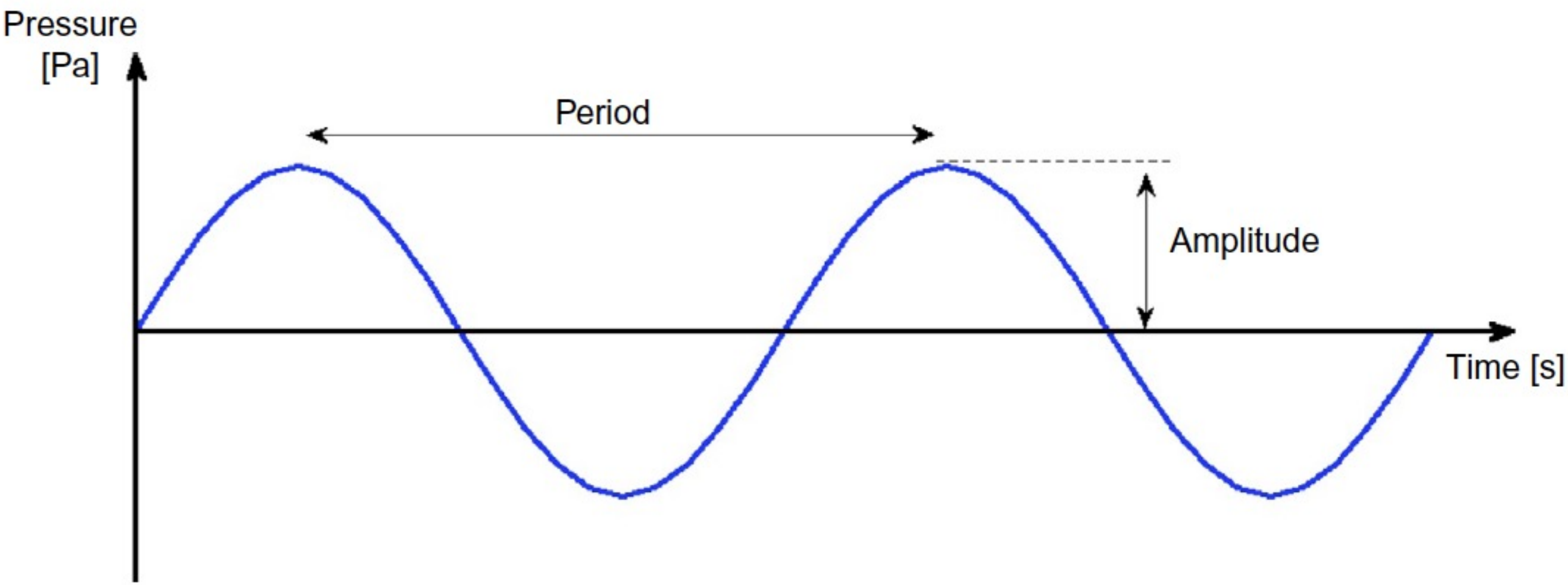
$$W_0 = 1 \cdot 10^{-12}\ [\mathrm{W}]$$



ITA Aachen

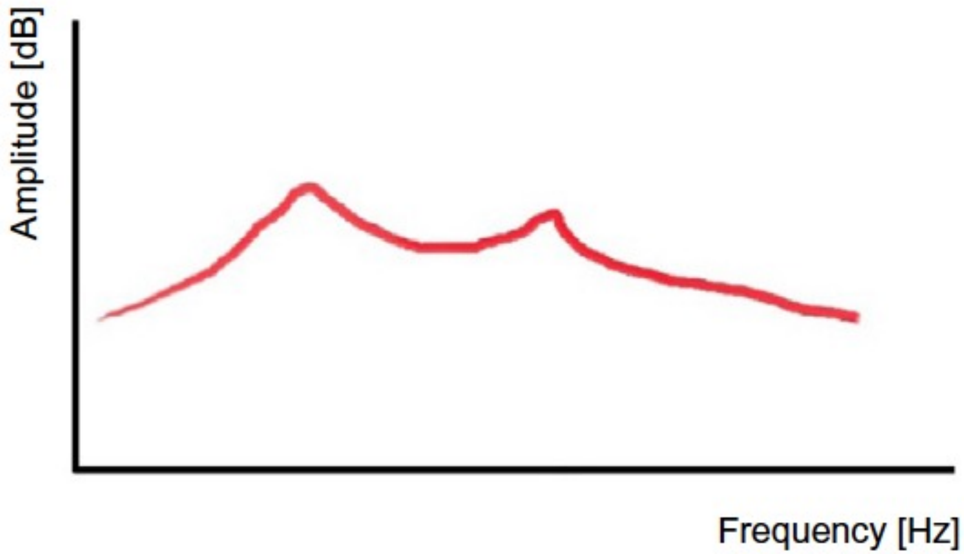
Frequency

- Frequency = 1/period [Hz] ($f = 1/T$)
- $c = f\lambda$



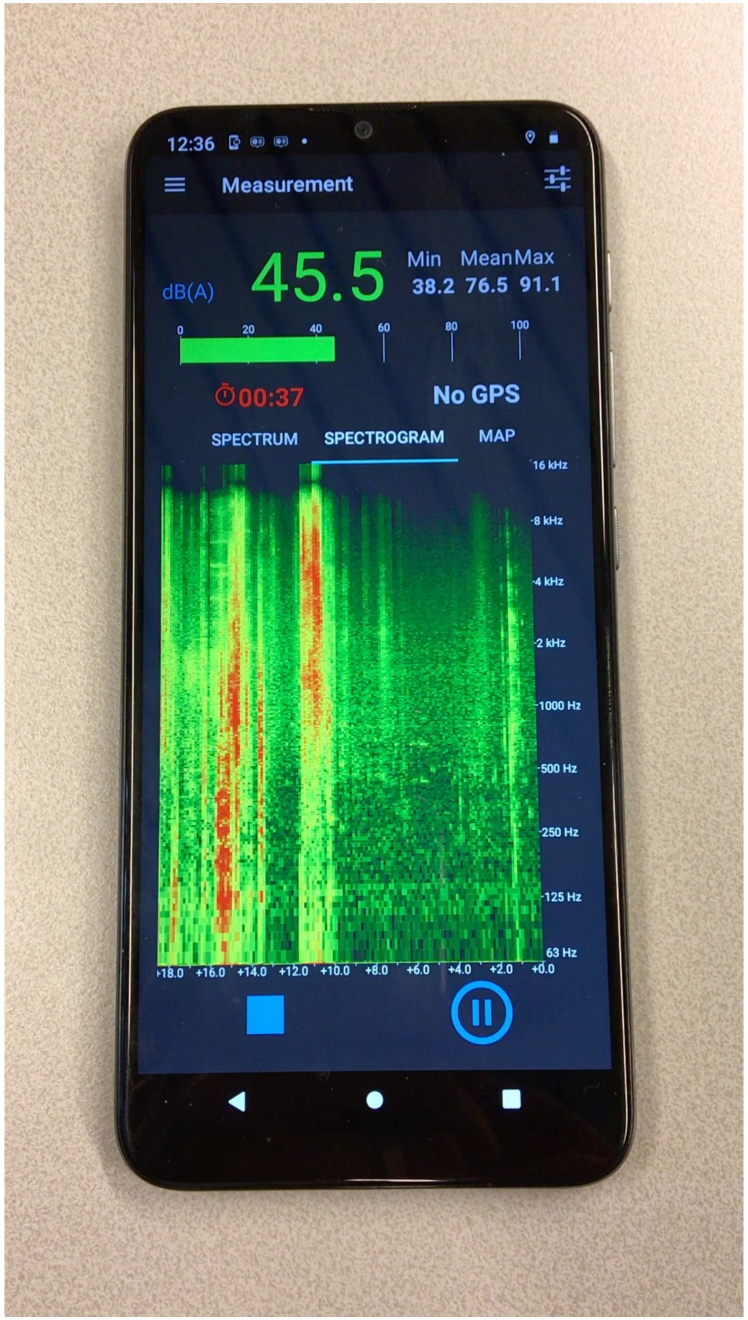
Murphy, E., & King, E. (2014). *Environmental noise pollution: Noise mapping, public health, and policy.* Newnes.

Broadband versus tonal sounds



Murphy, E., & King, E. (2014). *Environmental noise pollution: Noise mapping, public health, and policy*. Newnes.

Broadband versus tonal sounds

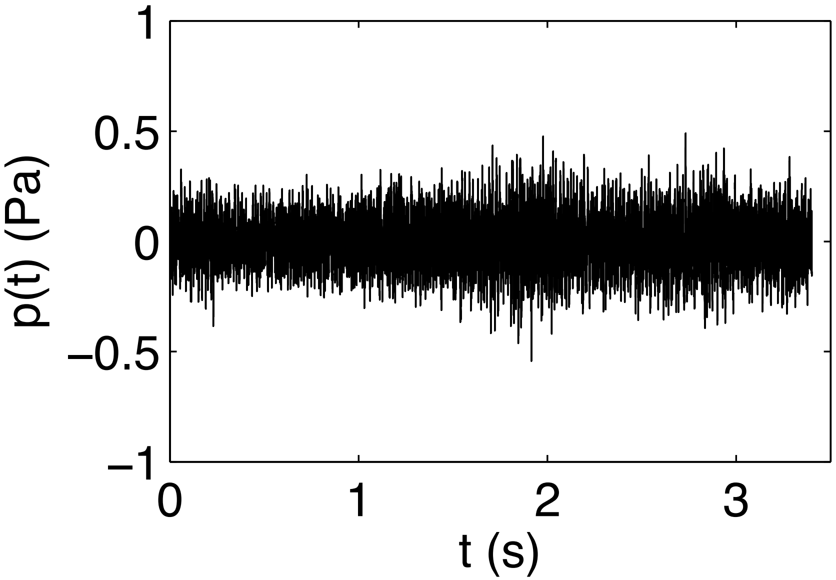


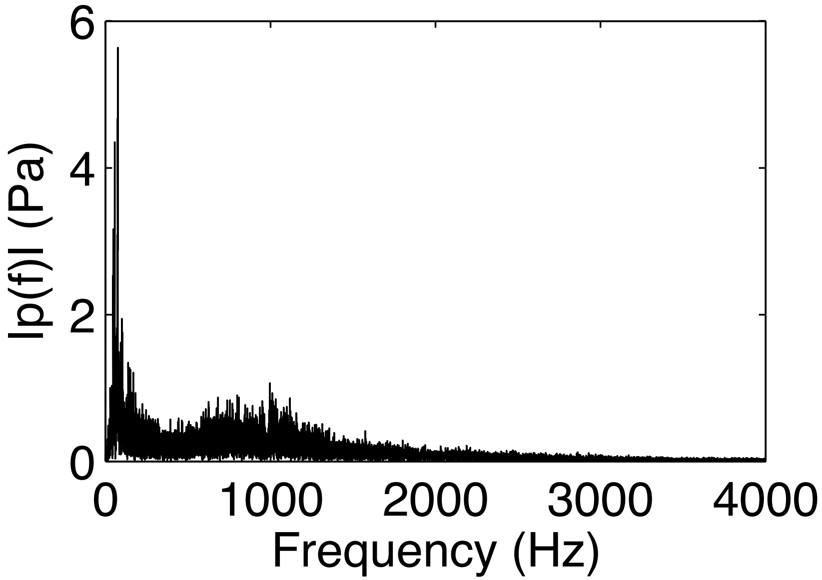
From p(t) to p(f): the Fourier transform

$$p(f) = \int_{-\infty}^{\infty} p(t) e^{j\omega t} dt$$

$$\omega = 2\pi f \quad (1/s)$$

$$f = \text{frequency} \quad [\text{Hz}]$$





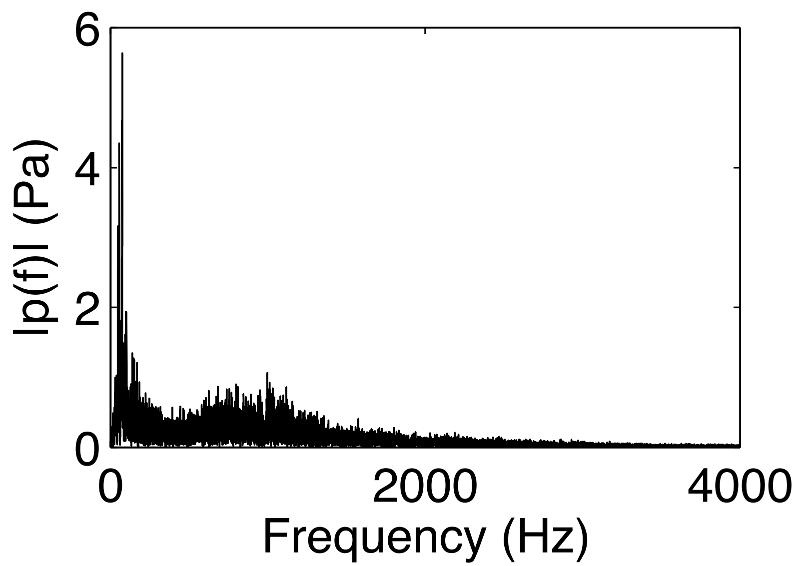
Sound pressure level $L_p(f)$

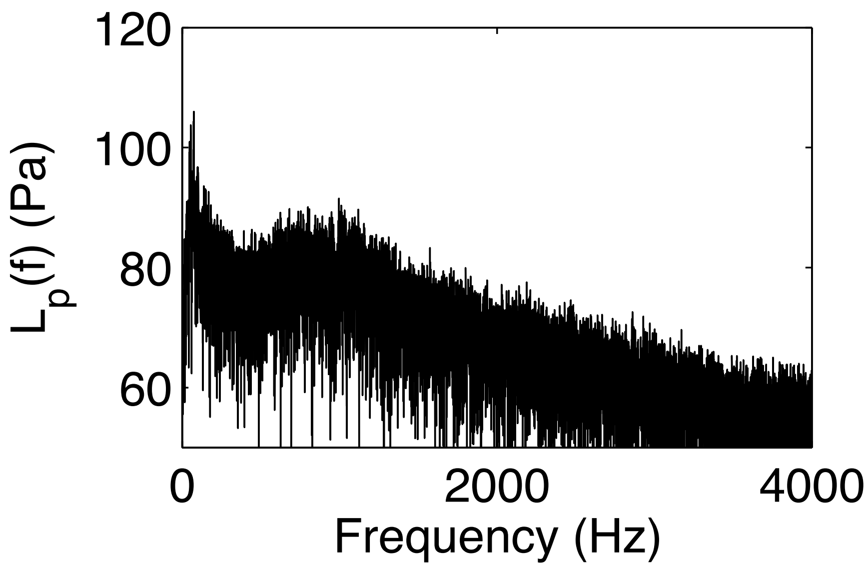
$$p(f) = A(f)\sin(\omega t + \varphi)$$

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

$$L_p(f) = 10\log_{10}\left(\frac{\frac{1}{T}\int_0^T p^2(f)dt}{p_{ref}^2}\right) \quad [\mathrm{dB}]$$

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





1/3 octave band sound pressure level $L_p(f)$

Lower Band Limit [Hz]	Centre Frequency [Hz]	Upper Band Limit [Hz]
44	63	88
88	125	177
177	250	355
355	500	710
710	1000	1420
1420	2000	2840
2840	4000	5680
5680	8000	11,360

Murphy, E., & King, E. (2014). *Environmental noise pollution: Noise mapping, public health, and policy.* Newnes.

1/3 octave band sound pressure level $L_p(f)$

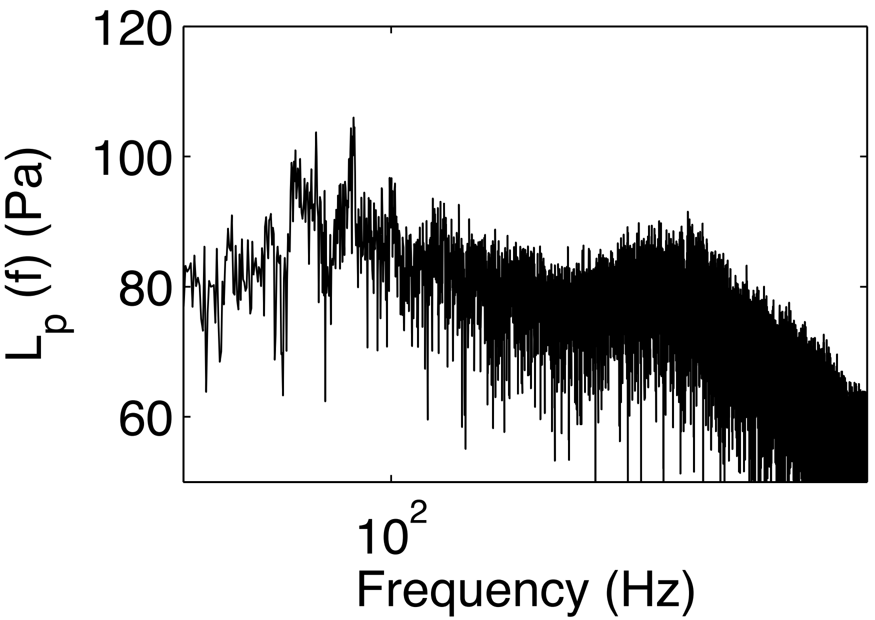
$$L_{p,1/3octave,j} = 10\log_{10}\left(\frac{\sum_{i=1}^{i=N_j} p_{eff}^2\left(f_{j,i}\right)}{p_{ref}^2}\right) \quad [\text{dB}]$$

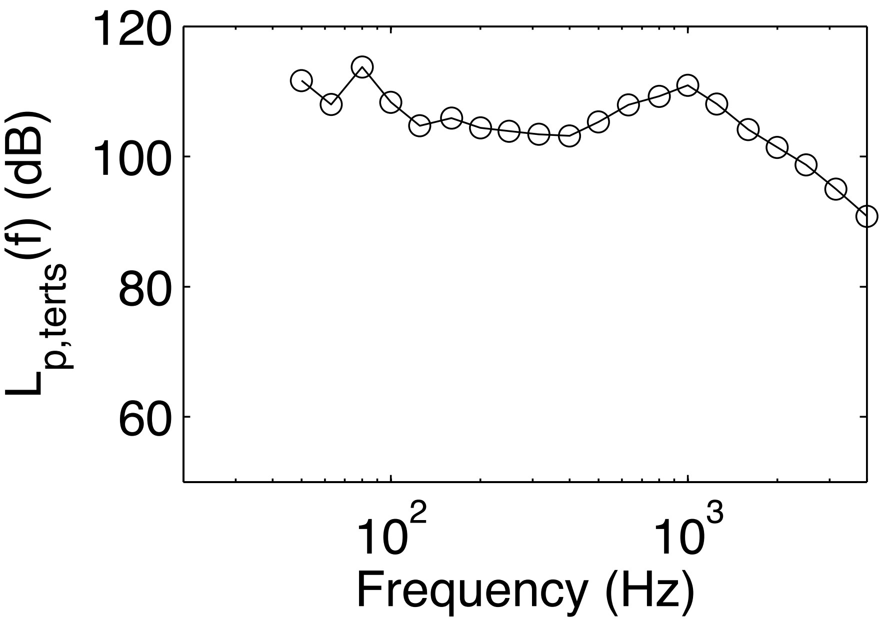
$$= 10\log_{10}\left(\sum_{i=1}^{i=N_j} 10^{\frac{L_p(f_{j,i})}{10}}\right) \quad [\text{dB}]$$

j = 1/3 octave band index [-]
i = frequency number within 1/3 octave band [-]
N_j = number of frequencies in 1/3 octave band j [-]

1/3 octave band sound pressure level $L_p(f)$

$$L_{p,1/3octave,j} = 10\log_{10}\left(\frac{\sum_{i=1}^{i=N_j} p_{eff}^2\left(f_{j,i}\right)}{p_{ref}^2}\right) \quad [\text{dB}]$$



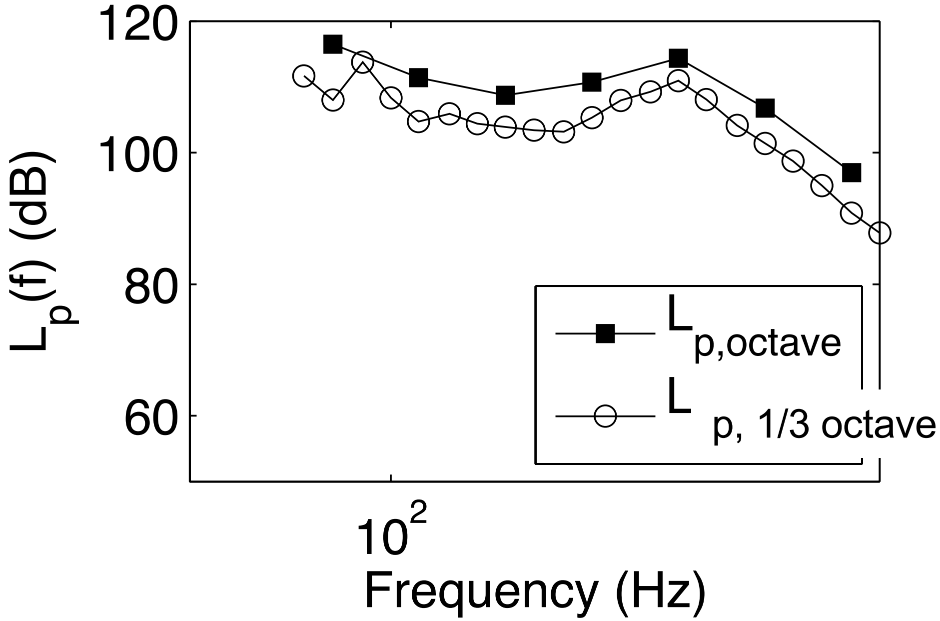


1/1 octave band sound pressure level $L_p(f)$

$$L_{p,m} = 10\log_{10}\left(\sum_{i=1}^{i=3} 10^{\frac{L_{p,1/3\,octave,3m-1+i}}{10}}\right) \quad [\text{dB}]$$

m = 1/1 octave band index [-]

$3m-1+i$ = 1/3 octave band number [-]

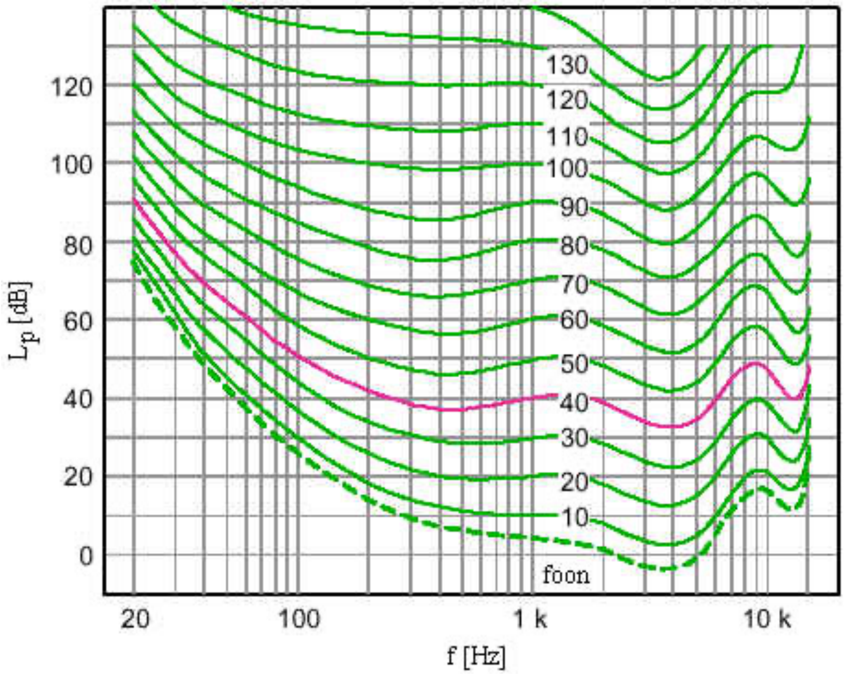


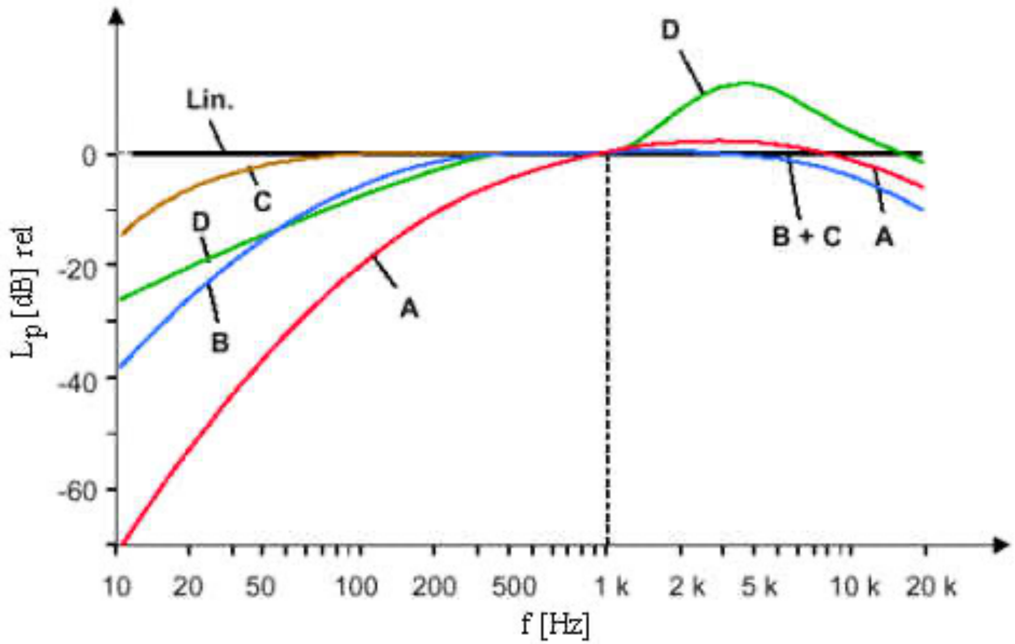
1/1 octave and 1/3 octave band frequencies

Octave band center frequency f_m (Hz)	1/3-octave band center freq. f_m (Hz)
125	100 125 160
250	200 250 315
500	400 500 630
1000	800 1000 1250

A-weighting

- Weighted to human sensitivity: A-corrections

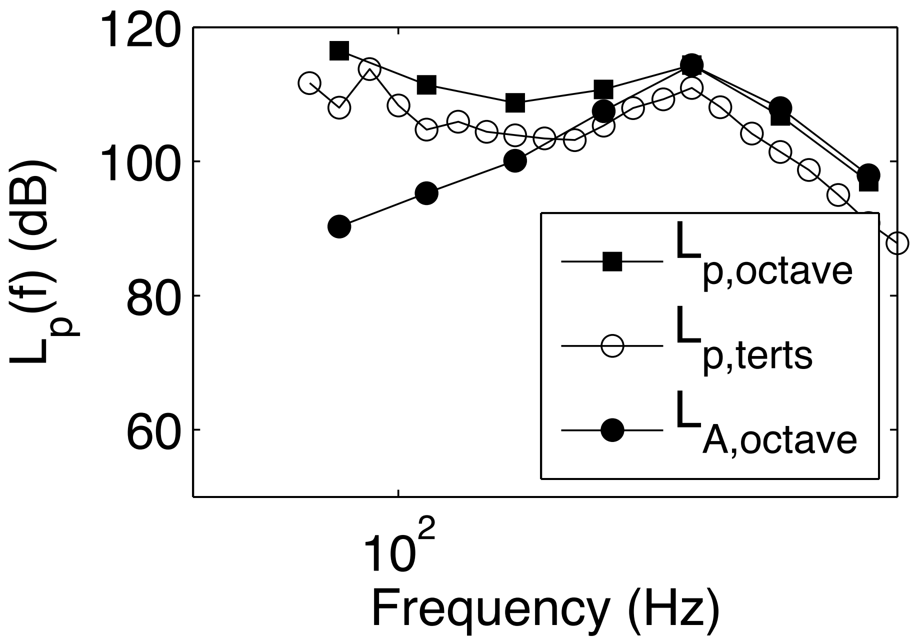




L_A: A-weighted sound level dB(A)

$$L_A = 10\log_{10}\left(\sum_{m=1}^{m=M} 10^{\frac{L_{p,m}+W_m}{10}}\right) \quad [\text{dB}]$$

$m = 1/1$ octave band index [-]
$M =$ number of 1/1 octave bands [-]
$W_m =$ A - weighting [-]



References

- Murphy, E. and King, E., 2014. *Environmental noise pollution: Noise mapping, public health, and policy*. Newnes.