Music 175: Sound Level

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Power and Intensity

- The waveform shows how sound *pressure* varies over time.
- Related to sound **pressure** are:
  1. **sound power** emitted by the source:
     - a fixed quantity, in Watts (W),
     - analogous to the wattage rating of a light bulb.

  2. **sound intensity** measured a distance from the source:
     - power per unit area carried by wave (W/m^2),
     - influenced by interference and environment,
     - analogous to light brightness at different positions in a room.

Intensity and Pressure

- **Intensity** is the power per unit area,

$$\text{Intensity} = \frac{\text{Power}}{A},$$

expressed in Watts/square meter (W/m^2).

- **Sound intensity** is
  - a measure of the power in a sound that actually contacts an area (e.g. eardrum);
  - a quantity influenced by environment surroundings/surfaces and interference from other sources;
- Intensity is **related to pressure squared**:

$$I = p^2/(\rho c),$$

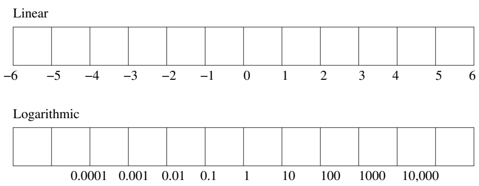
where ρ is the density of air (kg/m^3), and c is the speed of sound (m/s).

Sound Range of Hearing

- Amplitude (pressure) range of hearing (humans)
  - Threshold of audibility: 0.00002 N/m^2
  - Threshold of feeling (or pain!): 200 N/m^2
- Sound intensity range (humans)
  - $I_0 = 10^{-12}$ W/m^2 (threshold of audibility)
  - 1 W/m^2 (threshold of feeling)
- The intensity ratio between the sounds that bring pain to our ears and the weakest sounds we can hear is more than 10^{12}.

Linear vs logarithmic scales.

- Human hearing is better measured **logarithmically**.
- On a **linear** scale,
  - a change between two values is perceived on the basis of the **difference** between the values;
  - e.g.: a change from 1 to 2 would be perceived as having the same increase as from 4 to 5.
- On a **logarithmic** scale,
  - a change between two values is perceived on the basis of the **ratio** of the two values;
  - e.g.: a change from 1 to 2 would be perceived as having the same increase as a change from 4 to 8.
- Linear: moving one unit to the right adds 1.



- Logarithmic: moving right one unit multiplies by 10.

Decibels (dB)

- The decibel (dB) is a unit named after telecommunications pioneer, Alexander Graham Bell.
- To understand decibels DON'T **watch**.
- The decibel is a logarithmic scale, used to **compare two quantities** such as
  - the power gain of an amplifier;
  - the relative power of two sound sources.
- A decibel is defined as one tenth of a bel,

$$1 \text{ B} = 10 \text{ dB}.$$

(to convert from B to dB, multiply by 10)

- To compare quantities A and B:

$$\log_{10}\left(\frac{A}{B}\right) = \text{value (B)}$$

$$10\log_{10}\left(\frac{A}{B}\right) = \text{value (dB)}$$

Comparing Power and Intensity

- The decibel difference between two power levels ΔL is defined in terms of their power ratio W_2/W_1:

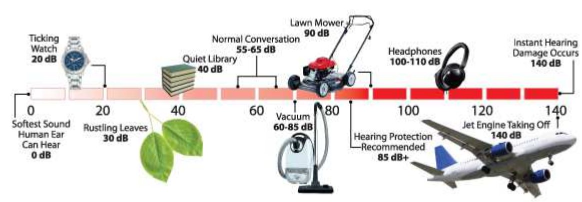
$$\Delta L = L_2 - L_1 = 10\log W_2/W_1 \quad \text{dB.}$$

- Since power is proportional to intensity, the decibel difference between two levels with intensities I_1 and I_2 is given by

$$\Delta L = L_2 - L_1 = 10\log I_2/I_1 \quad \text{dB.}$$

Power and Intensity Levels

- Decibels are often used as absolute measurements.



- There is an implied fixed reference (e.g. the threshold of audibility).
- **Sound power level** of a source:

$$L_W = 10\log\left(\frac{W}{W_0}\right) \text{ dB,}$$

where $W_0 = 10^{-12}$ W.

- **Sound intensity level** at a distance from the source

$$L_I = 10\log\left(\frac{I}{I_0}\right) \text{ dB,}$$

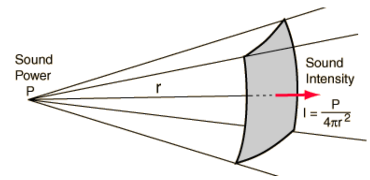
where $I_0 = 10^{-12}$ W/m^2.

Sound pressure Level (SPL or L_p)

- Recall: intensity is proportional to pressure squared:
$$I = p^2/(\rho c),$$
(where $\rho c \approx 400$).
- The *sound pressure level* L_p (SPL) is equivalent to sound intensity level in dB:
$$\begin{aligned} L_p &= 10 \log I/I_0 \\ &= 10 \log p^2/(\rho c I_0). \end{aligned}$$
- The product of ρ and c is often approximated by 400:
$$\begin{aligned} L_p = 10 \log p^2/(\rho c I_0) &= 10 \log \left(\frac{p^2}{4 \times 10^{-10}} \right) \\ &= 10 \log \left(\frac{p}{2 \times 10^{-5}} \right)^2 \\ &= 20 \log \left(\frac{p}{2 \times 10^{-5}} \right) \\ &= 20 \log \left(\frac{p}{p_0} \right) \text{ dB.} \end{aligned}$$
where $p_0 = 2 \times 10^{-5}$ is the threshold of hearing for pressure variations.

Increasing distance from a source

- Assuming radiation in free space (and equally in all directions) and a distance r from the source,
  - **intensity decreases** by $1/r^2$



- **Question**: If there is a **doubling** of distance from the source, by what factor will the intensity change?
- **Solution**:
  - Given an intensity at some initial distance:
$$I_1 = \frac{P}{4\pi r^2},$$
  - doubling the distance from the source yields,
$$I_2 = \frac{P}{4\pi(2r)^2} = \frac{P}{2^2 4\pi r^2} = \frac{1}{2^2} I_1,$$
a change in intensity by a factor of of $1/2^2$.

Sound Intensity Level with a Doubling of Distance

- How does the **sound level** change with a **doubling** of distance?
  - intensity will drop by a factor of $1/2^2$ or 2^{-2} and
$$\begin{aligned} L_I &= 10 \log \left(\frac{I}{I_0} 2^{-2} \right) \\ &= 10 \log \left(\frac{I}{I_0} \right) + 10 \log(2^{-2}) \\ &= 10 \log \left(\frac{I}{I_0} \right) - 20 \log(2) \\ &= 10 \log \left(\frac{I}{I_0} \right) - 20(.3) \\ &= 10 \log \left(\frac{I}{I_0} \right) - 6 \text{ dB.} \end{aligned}$$
  - doubling the distance from a source causes a **decrease of 6 dB** in the sound level.

SPL with a Doubling of Distance

- We should obtain the same result for pressure as with intensity.
- If intensity decreases by $1/r^2$, then
  - **pressure decreases by** $1/r$,
  - (intensity is proportional to pressure squared).
- With a doubling of distance, pressure will drop by a factor of $1/2$ or 2^{-1},
$$\begin{aligned} L_p &= 20 \log \left(\frac{p}{p_0} 2^{-1} \right) \\ &= 20 \log \left(\frac{p}{p_0} \right) - 20 \log(2) \\ &= 20 \log \left(\frac{p}{p_0} \right) - 6 \text{ dB.} \end{aligned}$$

Multiple sources

- When there are multiple sound sources, the total power emitted is the **sum of the power** from each source.
- By how much would the sound level increase when two sources sound simultaneously with equal power?
  - the sound power level would double,

$$\begin{aligned} L_W &= 10\log\left(\frac{2W}{W_0}\right) \\ &= 10\log\left(\frac{W}{W_0}\right) + 10\log(2) \\ &= 10\log\left(\frac{W}{W_0}\right) + 3 \text{ dB}, \end{aligned}$$

    and there would be an increase of 3 dB.
- Similarly, there would be a 3 dB increase in the sound intensity level measured at some distance away from the source.
- This accounts for most cases; the actual result depends on correlation (and interference) of sound sources.

Example SPL Levels

- The following is taken from Dan Levitin's, *Your Brain on Music*.
  - 0 dB: a mosquito flying in a quiet room, ten feet away from your ears
  - 20 dB: a recording studio
  - 35 dB: a typical quiet office with the door closed and computer off
  - 50 dB: typical conversation
  - 75 dB: typical comfortable music listening level (headphones)
  - 100-105 dB: Classical music concert during loud passages; the highest level of some portable music players
  - 110 dB: A jackhammer 3 feet away
  - 120 dB: A jet engine heard on the runway from 300 ft away; typical rock concert
  - 126-130 dB: Threshold of pain and damage; a rock concert by the Who
  - 180 dB: Space shuttle launch