SPAU332
Hearing Aids I

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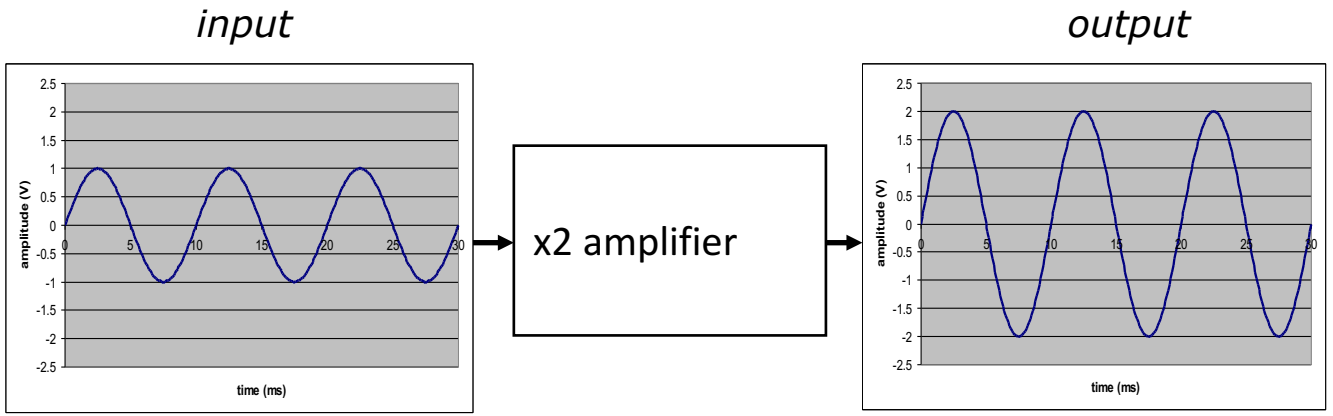
Physics of Sound and Acoustics

What are systems & signals?

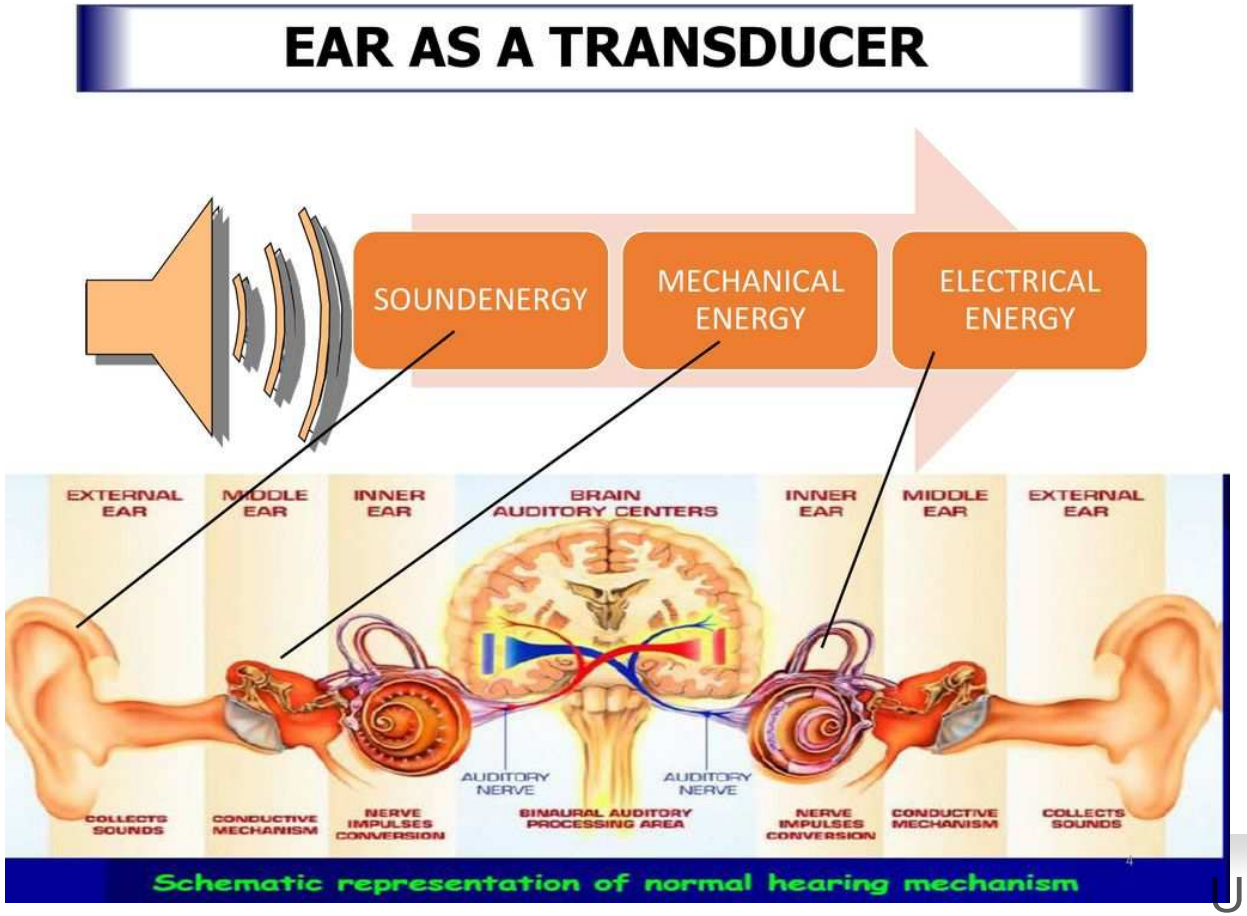
Systems perform an operation on, or transformation of, a *signal* (or *waveform*)

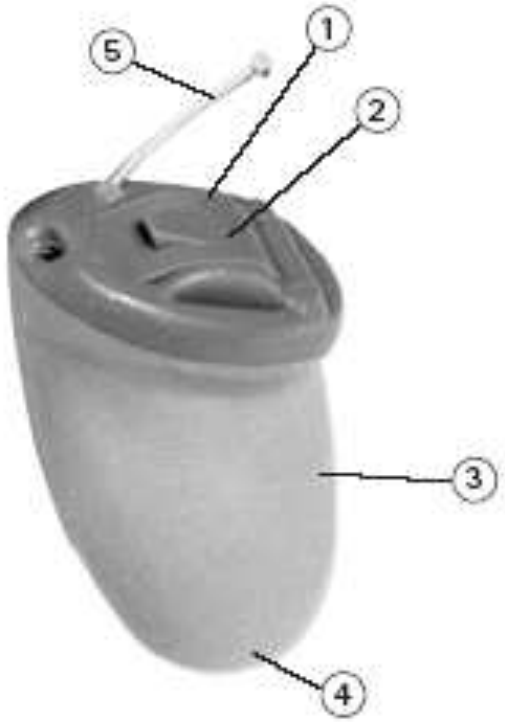
Concentrate on systems with one input and one output

Many useful examples in hearing and speech science



System = Ear





① Microphone
② Battery compartment and programming socket
③ Custom made shell
④ Receiver
⑤ Removal thread

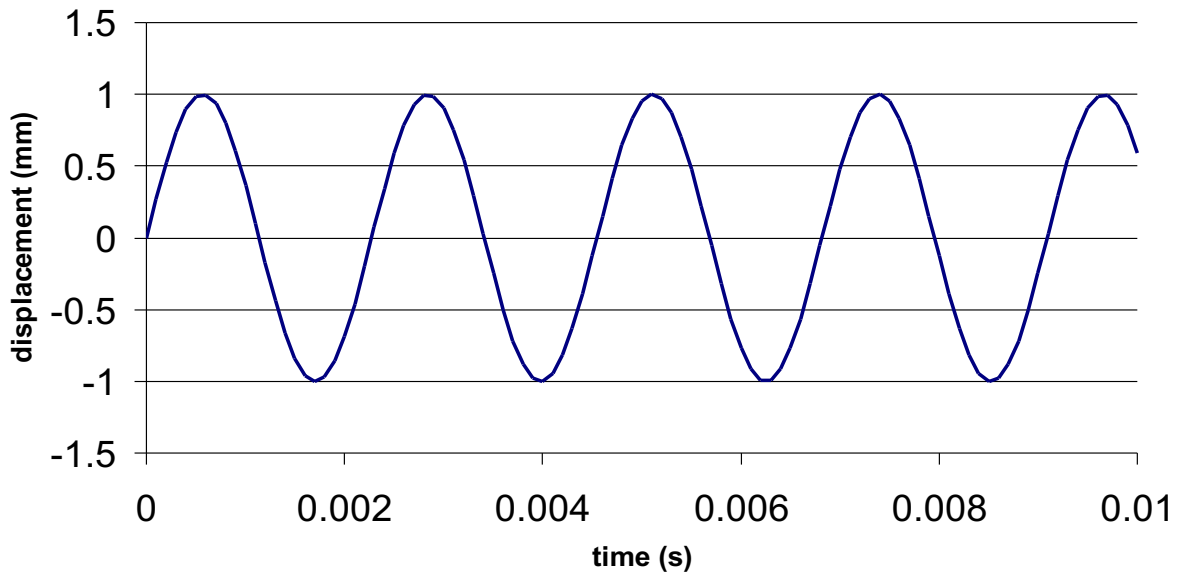
System = Hearing Aid

input = sound wave (variations in pressure)

output = sound wave (modified in some way)

Signals as waveforms

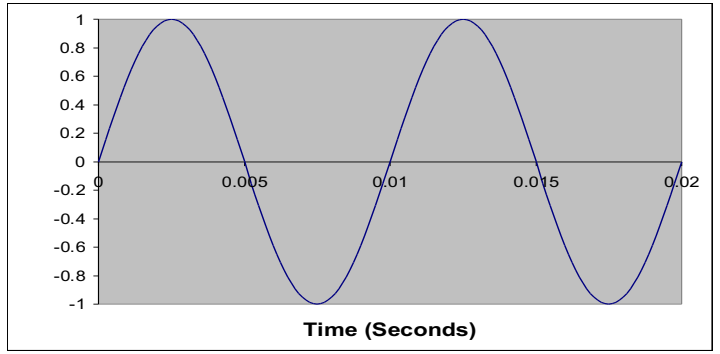
- A graph of the *instantaneous* value of amplitude over time
  - x-axis is usually time (s, ms, µs)
  - y-axis is usually a *linear instantaneous* amplitude measure (Pa, mPa, µPa, V, m)



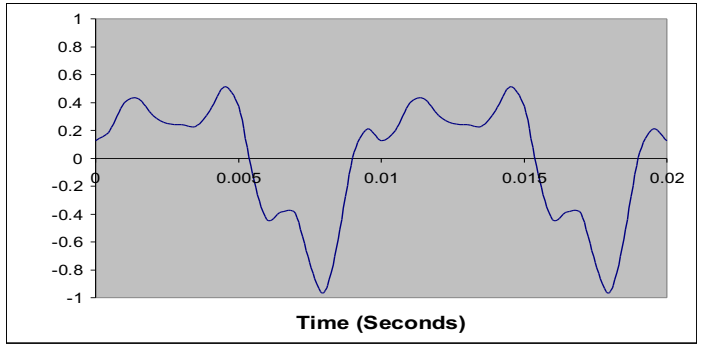
Waveforms are of two major types: periodic and aperiodic

- Periodic waveforms
  - Consist of a basic unit or *cycle* …
  - that repeats in time …
  - typically have a strong pitch …
  - and also come in two types

simple (= sinusoid)



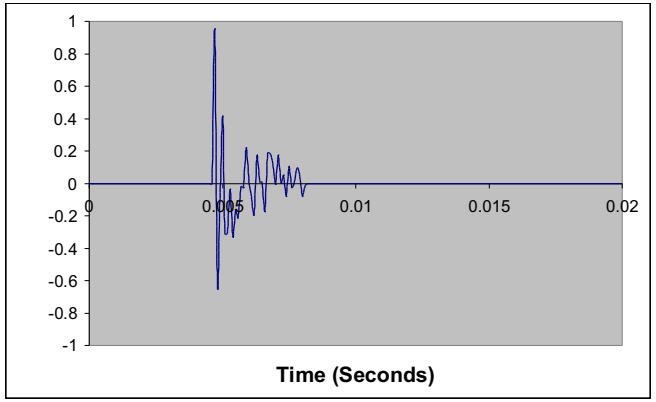
complex



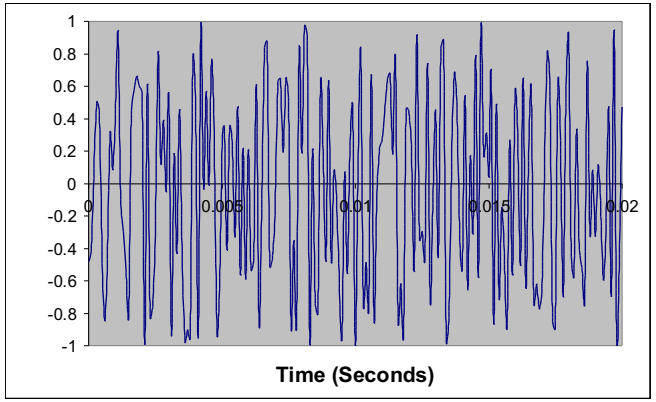
Waveforms are of two major types: periodic and aperiodic

- Aperiodic waveforms
  - do not repeat …
  - and also come in two types (but the distinction is not so important as for periodic waves)

transient

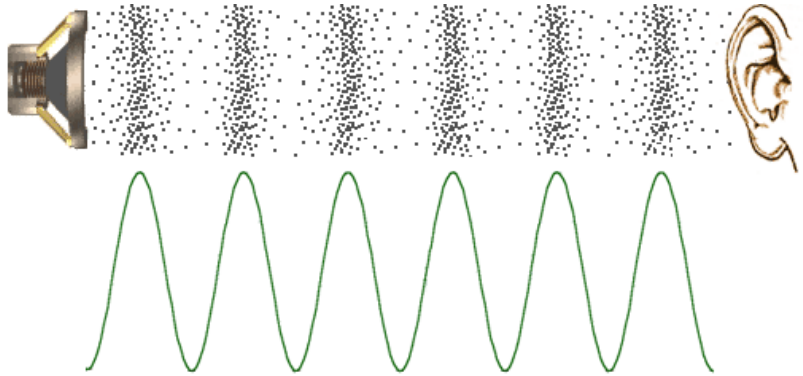


continuous (can be random)

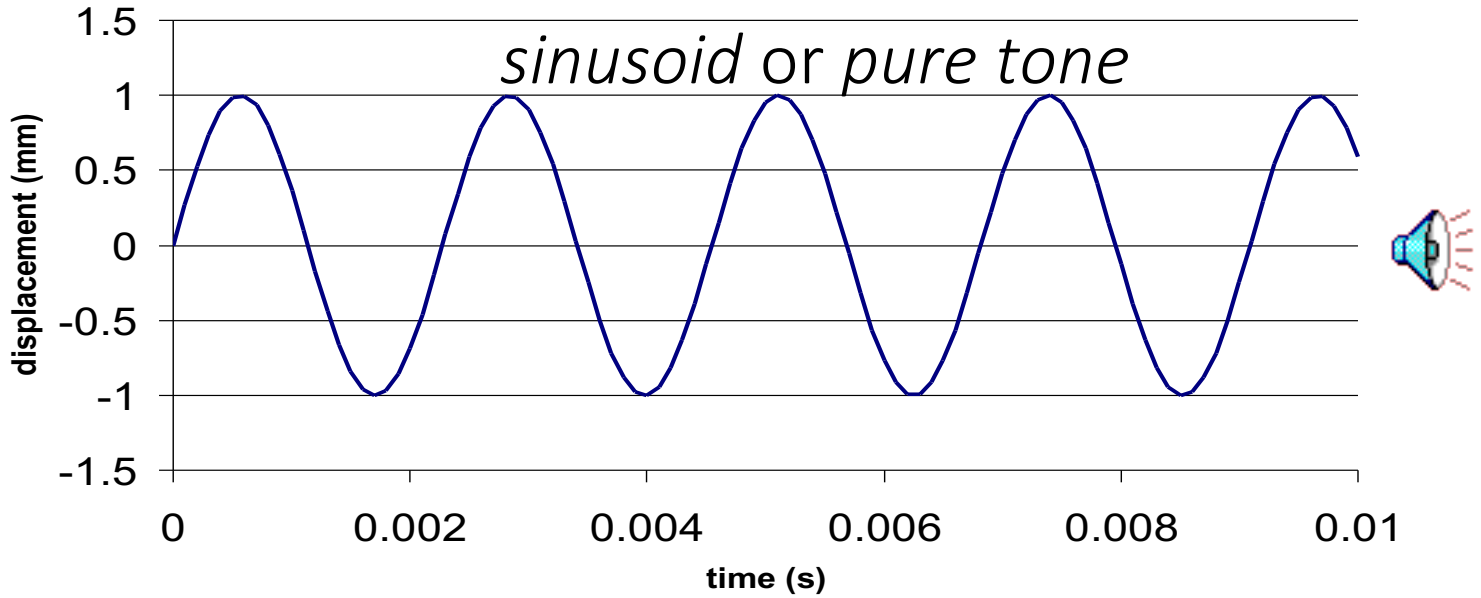


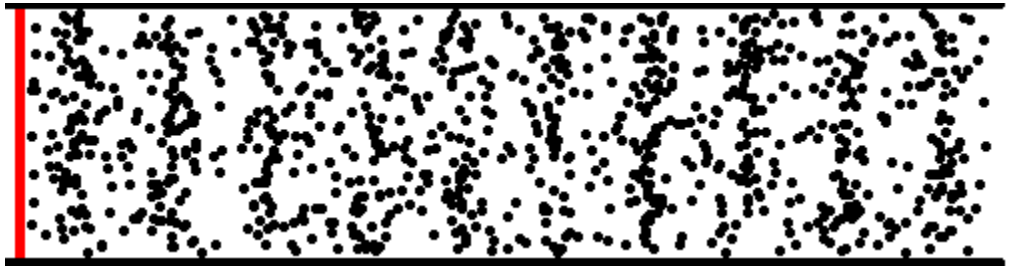
What is sound?

- Sound is a vibration that propagates as an audible mechanical wave of pressure and displacement, through a medium such as air or water.
- Sound is oscillation of air pressure (pressure wave)
- Sound travels as a series of **compression** and **rarefactions** (of air molecules)
- high pressure: air molecules bunched up
  low pressure: air molecules spread out
- Air molecules do **not** travel through space to carry sound



Sound is measured as the pressure changes over time at one point in space





Essential characteristics of sinusoids

- Sinusoids are a *unique* shape
  - not just any vaguely regular form, but the precise shape of many natural movements (e.g. a swinging pendulum)
  - are *periodic,* i.e. a basic *cycle* repeats over and over
  - can be constructed from *uniform circular motion*

Sinusoids can only differ in three ways

- Once you know a wave is sinusoidal, there are only three things to know about it:
  - frequency
  - amplitude
  - phase (generally less important because phase changes are typically not perceived)

I: Phase

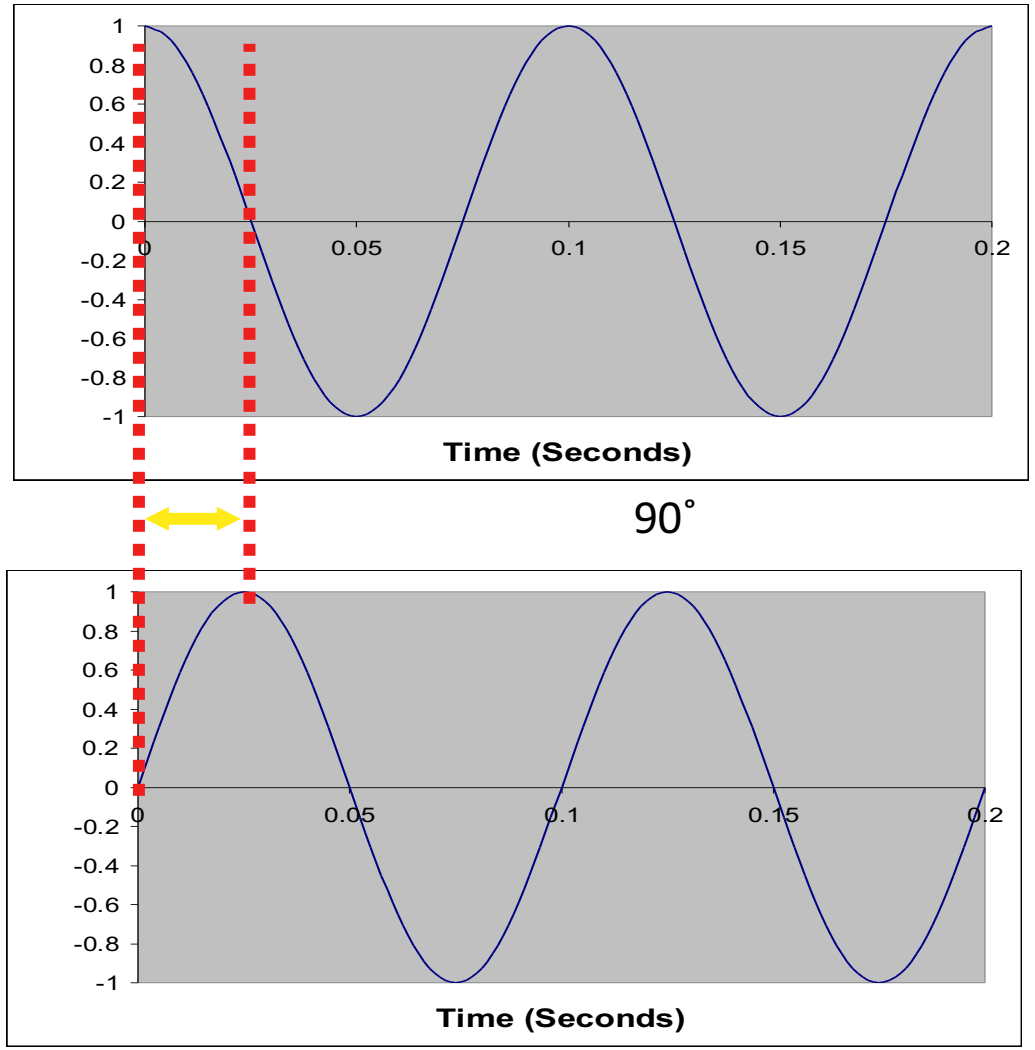
Where a sinewave *starts* relative to some arbitrary time

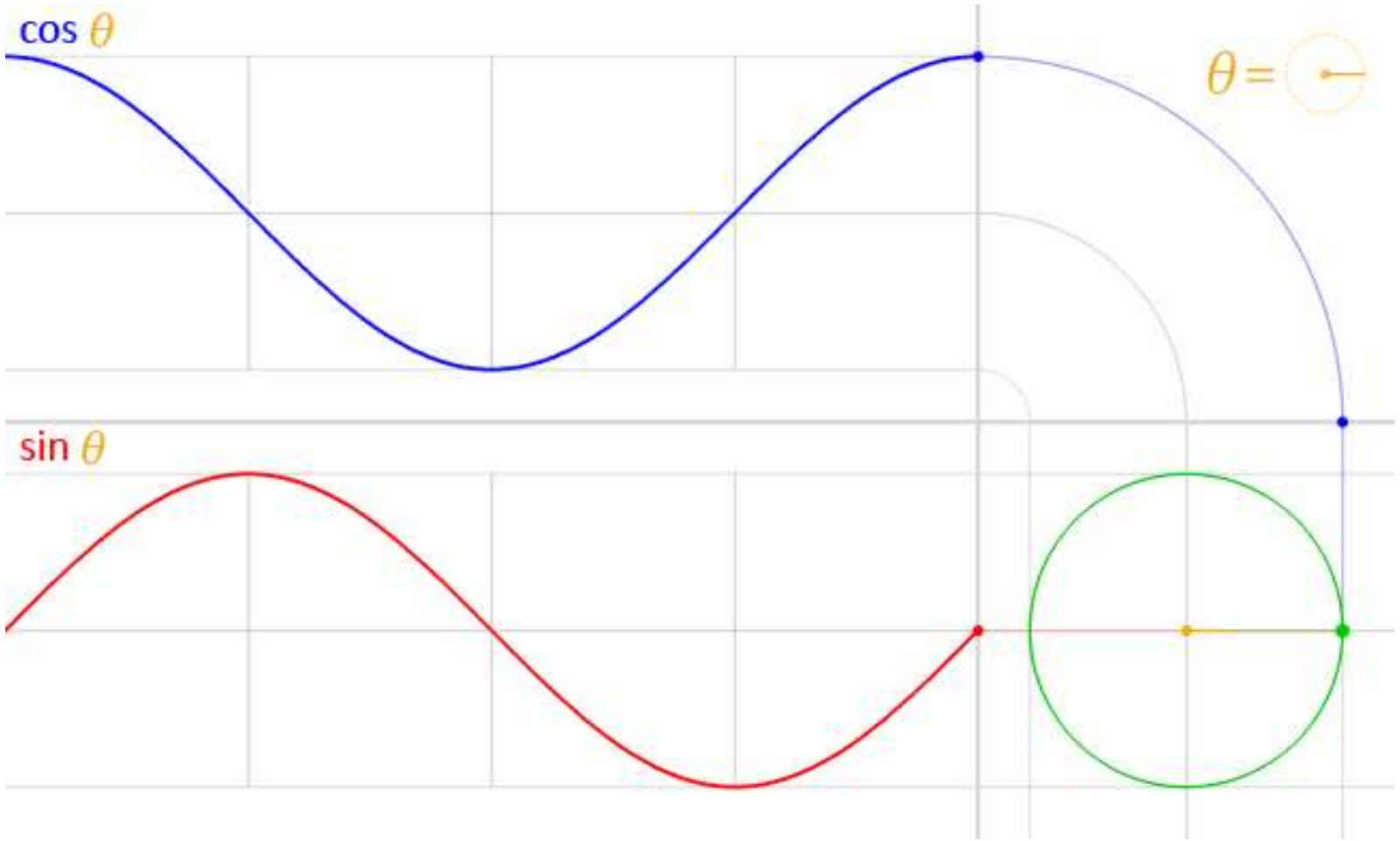
The angle of displacement at a specific point in time

Measured in cycles or degrees (or radians)

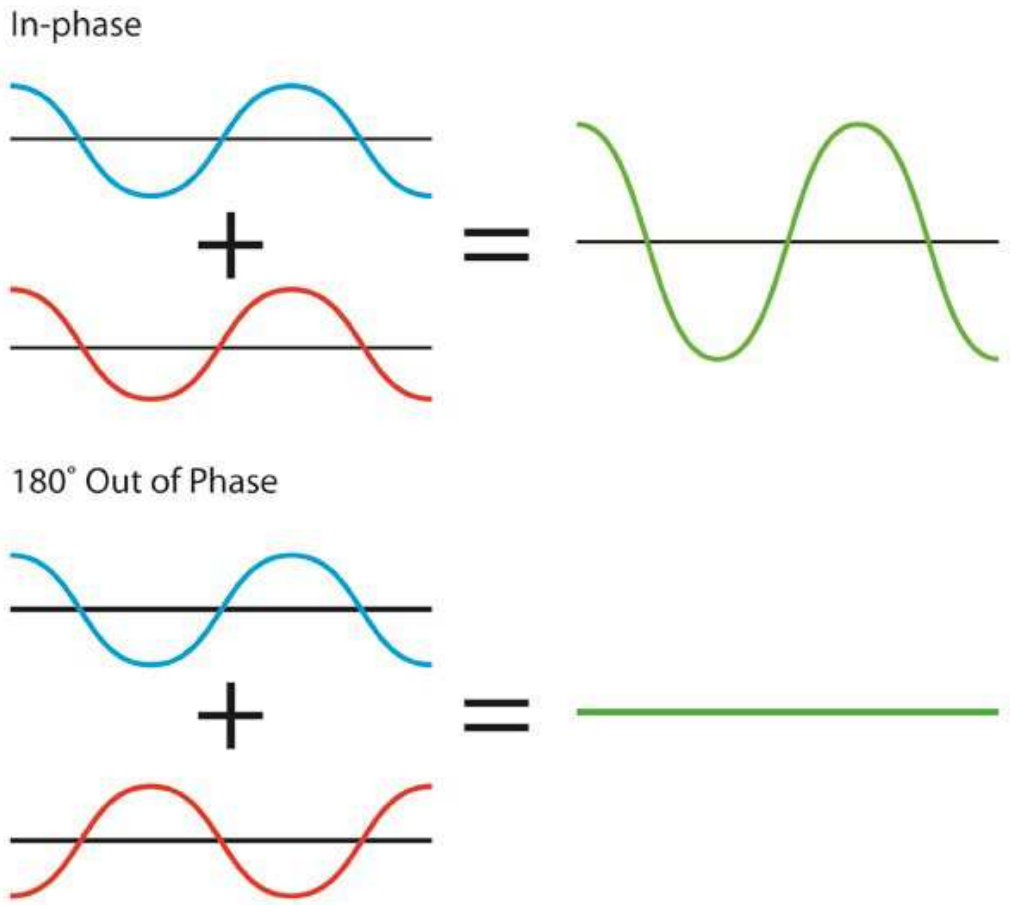
360˚ = 1 period = 2π rads
180˚ = ½ period = π rads
90˚ = ¼ period = π/2 rads

Relatively little effect on perception

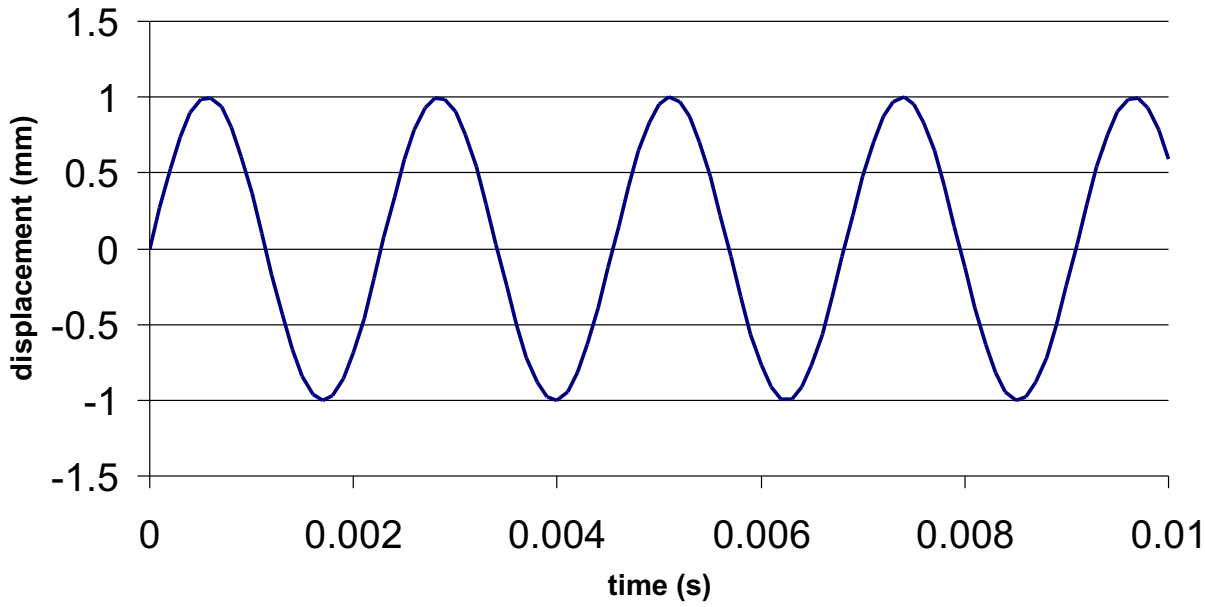



cos θ
θ =
sin θ

I: Phase



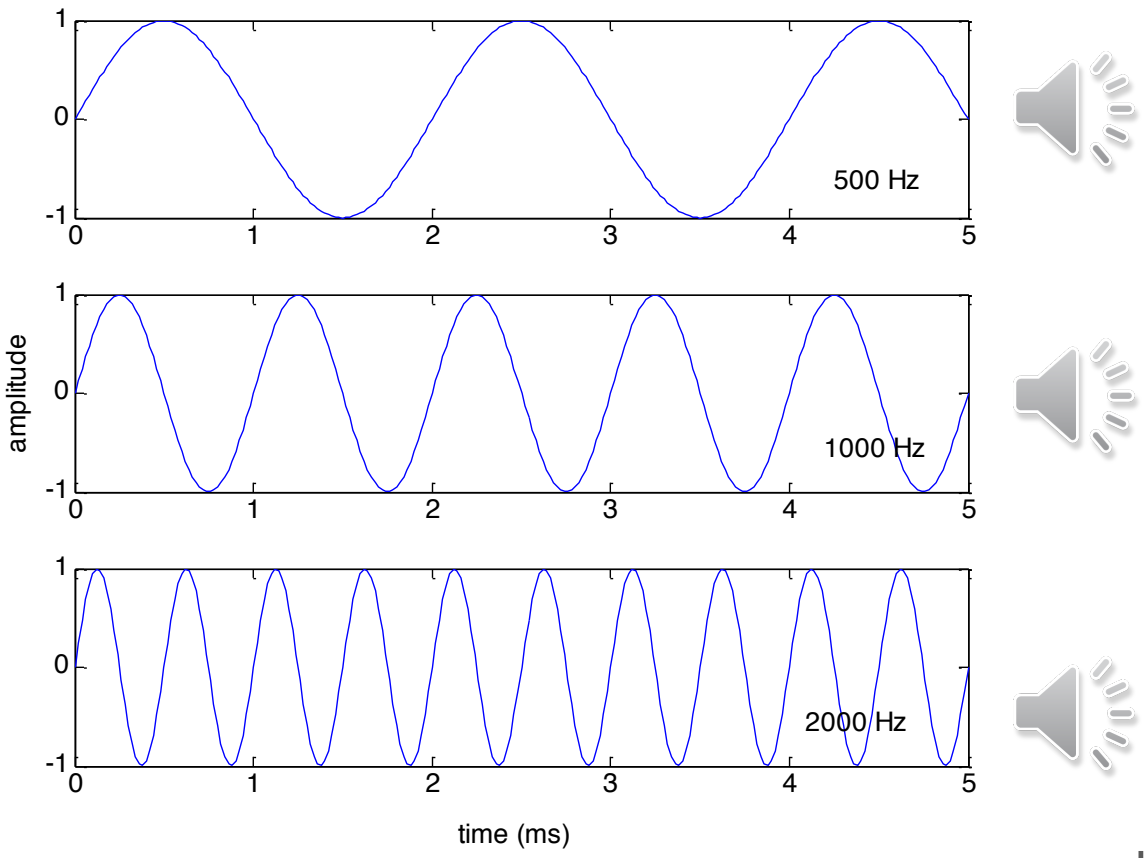
II: Periodicity (frequency)



Specifying periodicity

- The period (*p*) is the time to complete one *cycle* of the wave
- Alternatively, the number of cycles that are completed in one second, is the *frequency (f)*
- *f=1/p* and *p=1/f*
  - cycles per second (cps)
- But a special unit name is used: Hz

Increases in frequency (decreases in period) lead to increases in subjective pitch



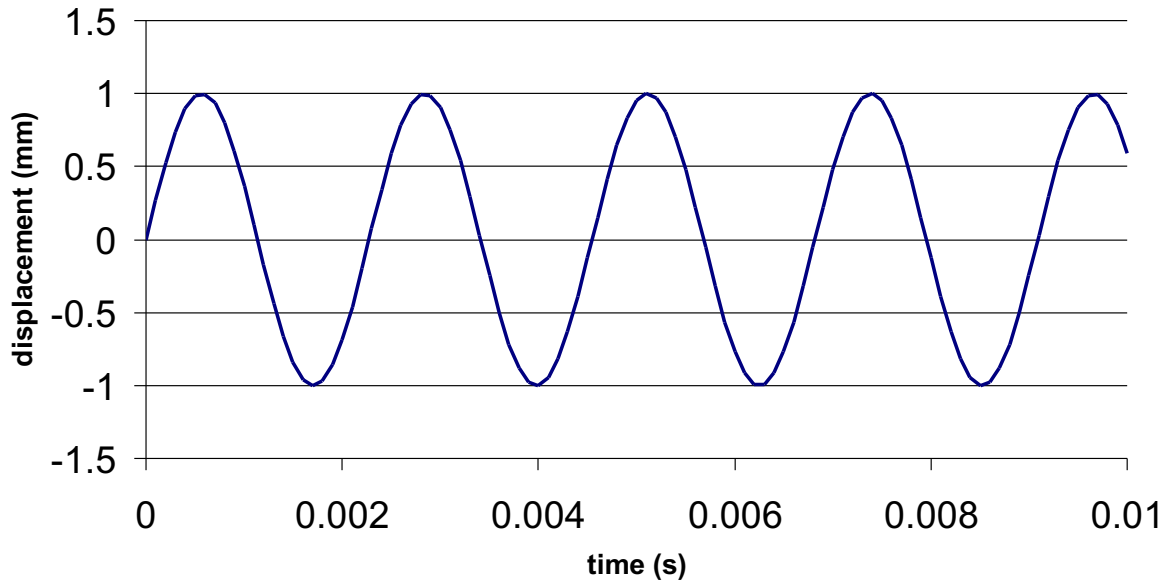
Keep your units consistent!

- period of 0.001 sec = 1 ms (millisecond)

  so:

- A period of 1 ms = A frequency of ?? Hz
- A frequency of 100 Hz = A period of ?? ms

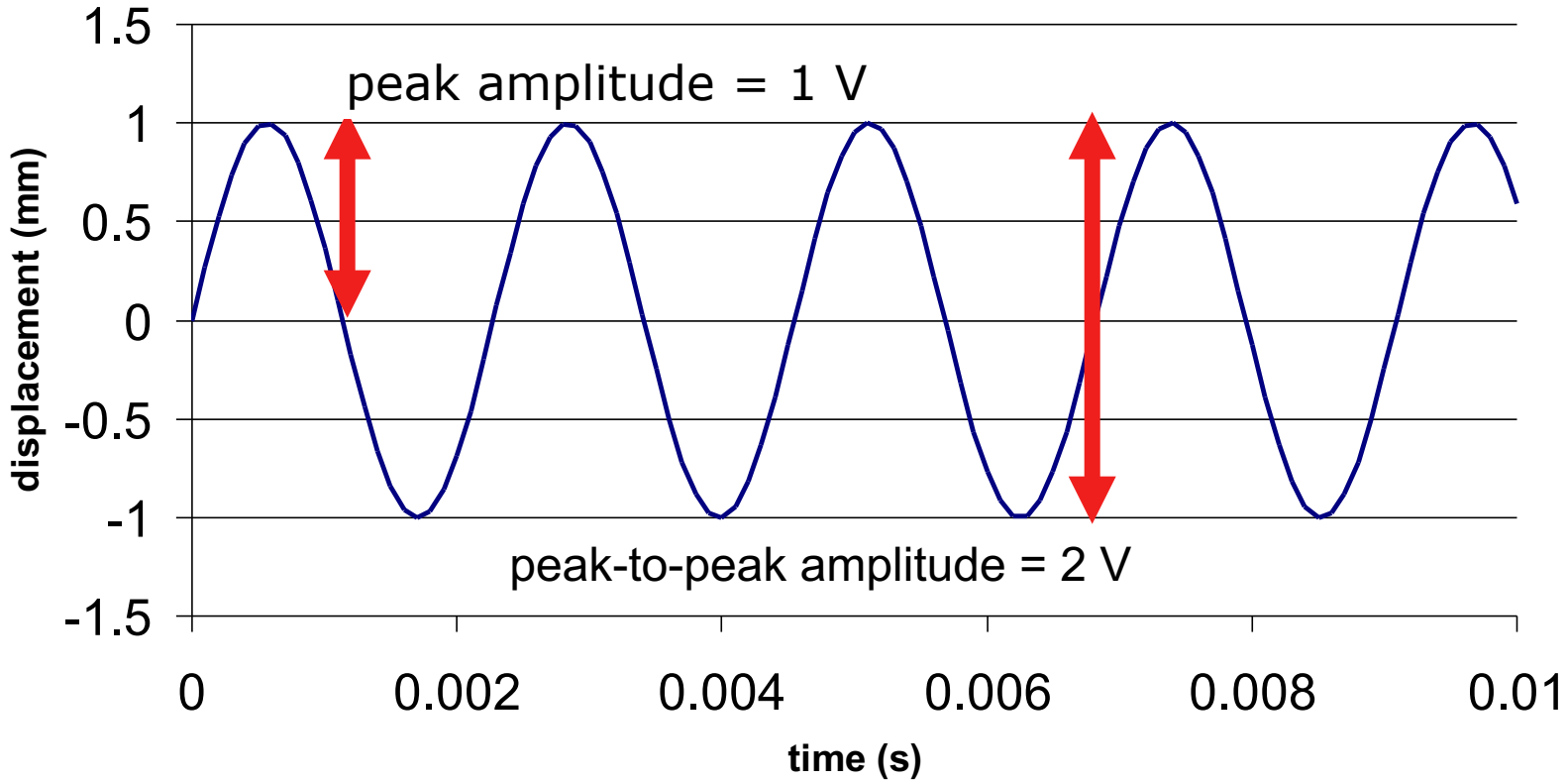
III: Amplitude



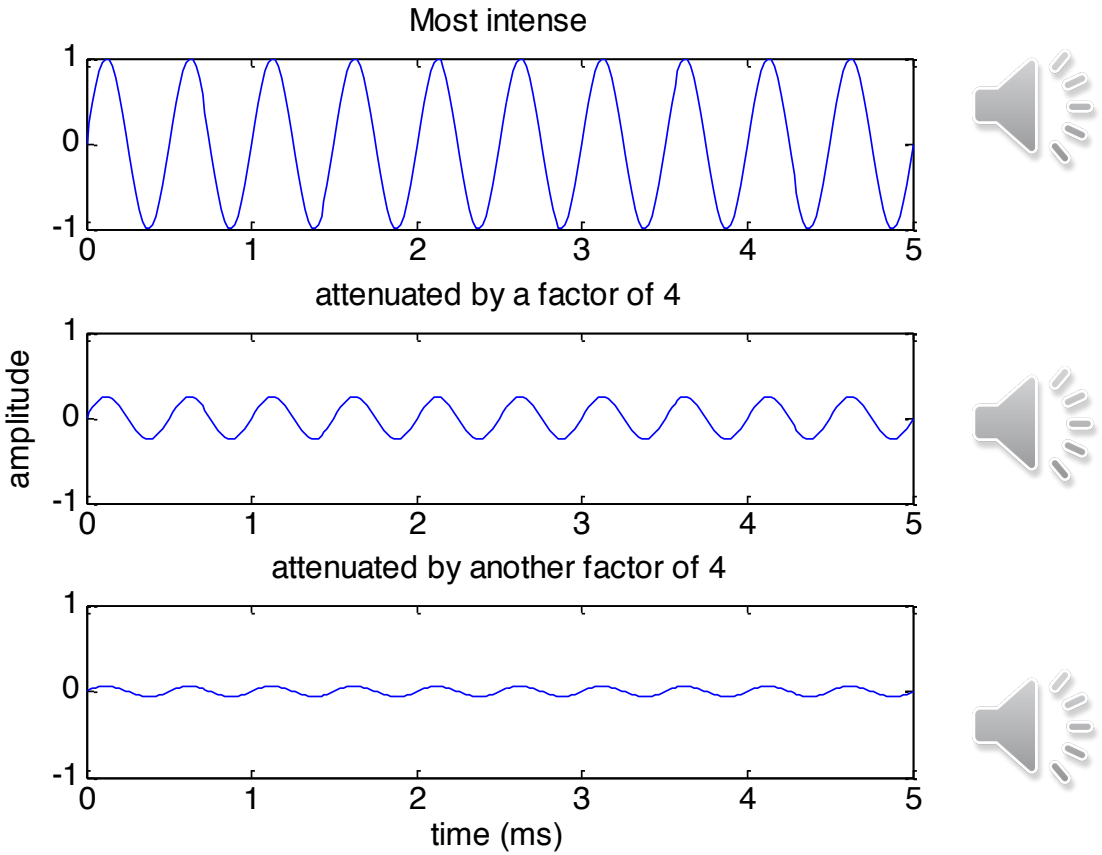
Measures of amplitude

- It is crucial to distinguish instantaneous measures (as in a waveform) from some kind of average
- Instantaneous measures always linear (e.g., pressure in Pa, voltage in V, displacement in metres)
- But also want a single number to be a good summary of the ‘size’ of a wave
- Average measures can be linear or logarithmic (dB)

Simple measures of amplitude

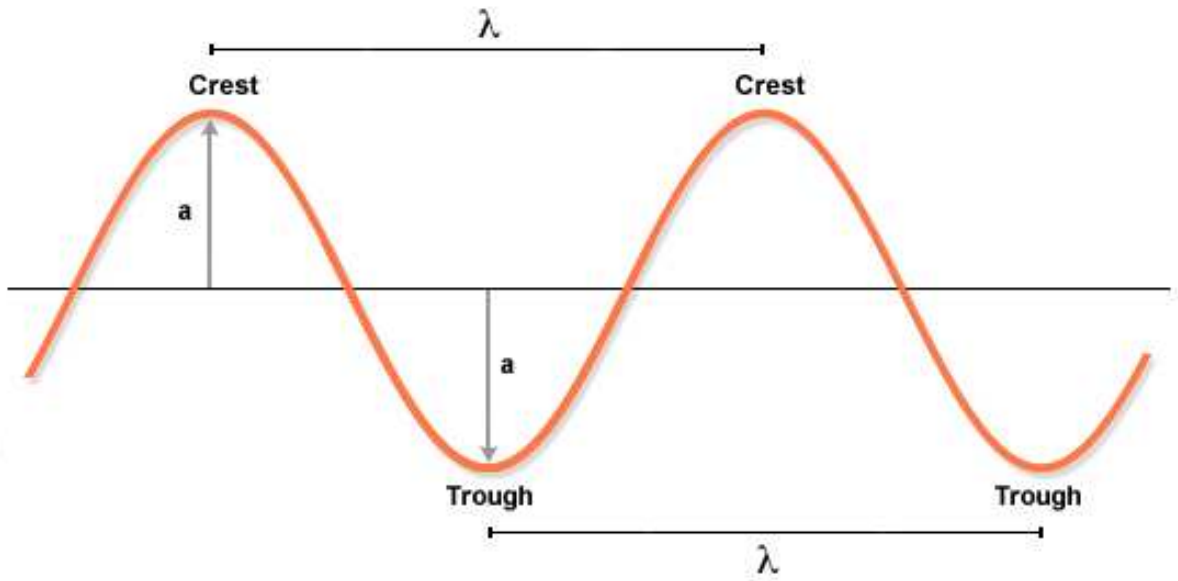


Increases in amplitude lead to increases in perceived loudness



IV: Wavelength (λ)

- The distance between any two successive points with the same phase (b/w crests, or troughs, or corresponding zero crossings)
- Measured in meters (m)



Speed of sound in Air

•The speed of sound in air is **343 m/s.** (it's different in other media)

•The following formula defines the relationship between speed, frequency and wavelength of sound:

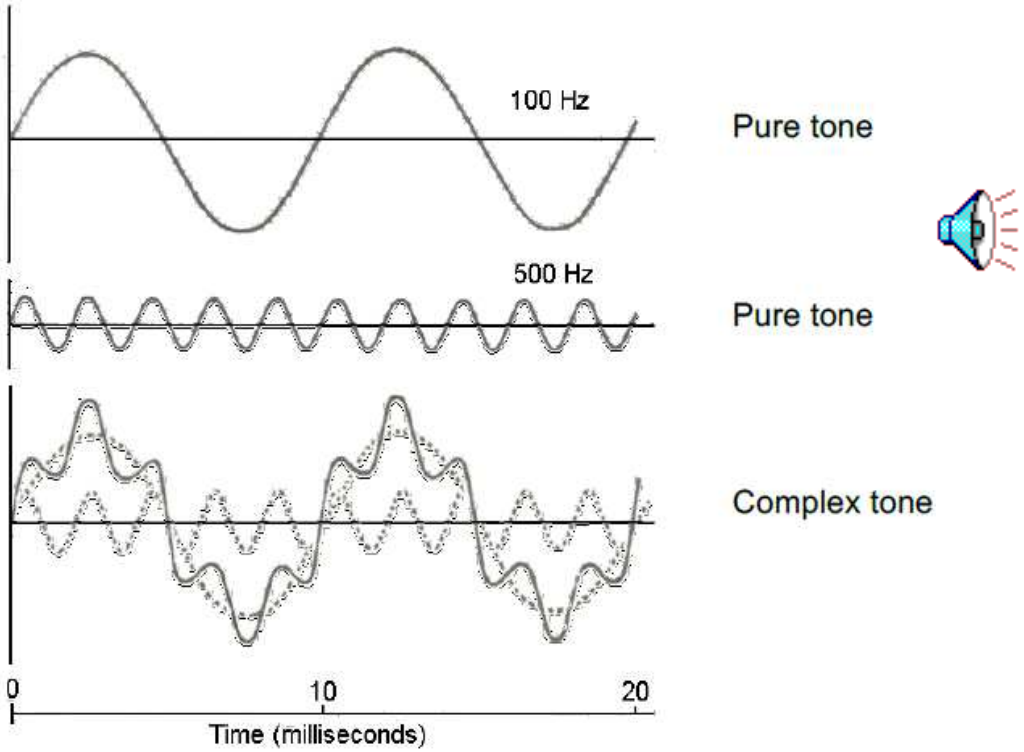
$$V = f * \lambda$$

V: velocity of wave **F**: Frequency **λ**: Wavelength

Example: what is the wavelength of a sound wave traveling at a speed of 400 m/s with a frequency of 250 Hz?

Types of Sound Waves

- **Pure tones**: a tone with a sinusoidal waveform (e.g. a sine or cosine wave).
- **Complex/Harmonic tones**: a tone composed of a mixture of different



Psychophysics

Psychophysics: refers to the branch of psychology that deals with the relations b/w physical stimuli (e.g. sound) and mental perception.

Loudness: is the human perception of sound **intensity**.

- **Soft** sound refers to **low** intensity sound.
- **Loud** sound refers to **high** intensity sound.

Pitch: is the perception of sound frequency.

- **High pitch** refers to **high frequency.**
- **Low pitch** refers to **low frequency**.

Measuring amplitudes with dB

- *Not* a linear unit like pascals
- A logarithmic measure with an arbitrary reference point
  - 0 dB does not mean no sound; it means the same level as the reference
  - Any positive number of dB means greater than the reference (e.g., 10 dB)
  - Any negative number of dB means less than the reference (e.g., -10 dB)
- Many different kinds of dB (SPL, HL, …) which differ essentially in the meaning of 0 dB.

Sound Pressure Level

- **20µPa** is the standard reference pressure
  - approximately equal to human threshold
- **$\log_{10}$(*ratio*)** turns ratio into power of 10.

$$\text{Intensity}(dB\ SPL) = 20\log_{10}\left(\frac{\text{Pressure}(Pa)}{20\,\mu Pa}\right)$$

dB SPL Examples

- Threshold of Hearing (20 µPa)

  $20 \times \log_{10}(20\ \mu Pa/20\ \mu Pa)$

  $= 20 \times \log_{10}(1) = 20 \times 0$

  = 0 dB SPL

- Distinct Pain! (200 Pa)

  $20 \times \log_{10}(200\ Pa/20\ \mu Pa)$

  $= 20 \times \log_{10}(10000000) = 20 \times 7$

  = 140 dB SPL

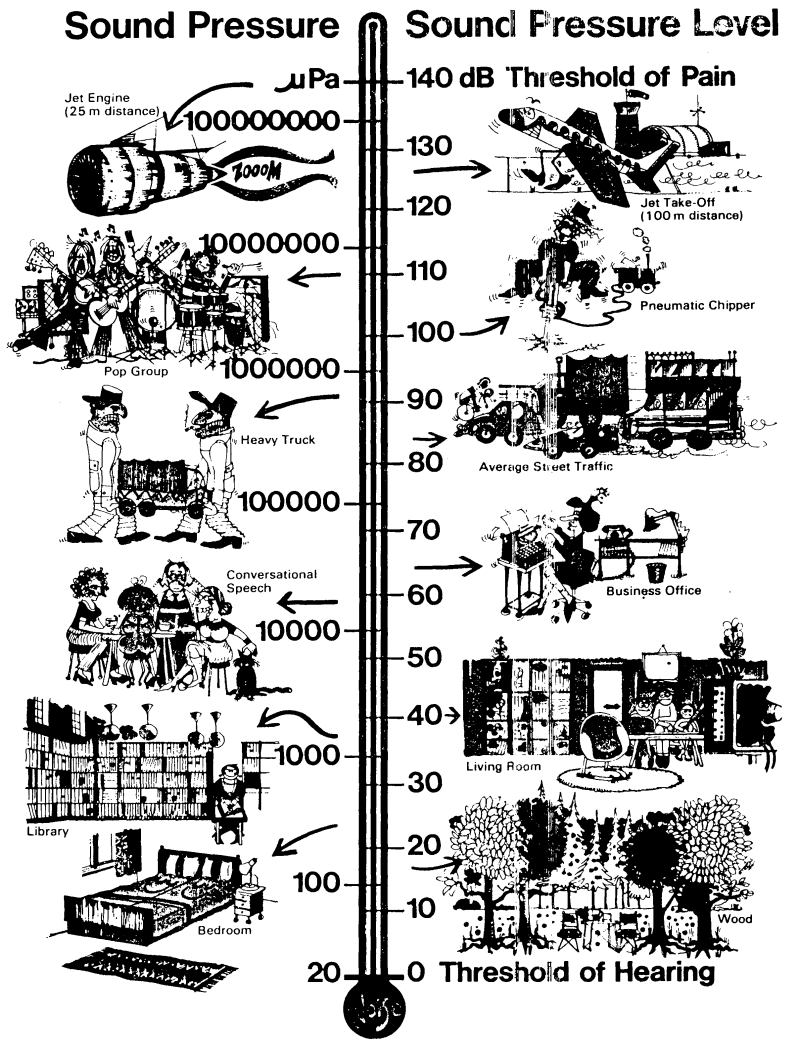
- An inaudible sound (2 µPa)

  $20 \times \log_{10}(2\ \mu Pa\ /20\ \mu Pa)$

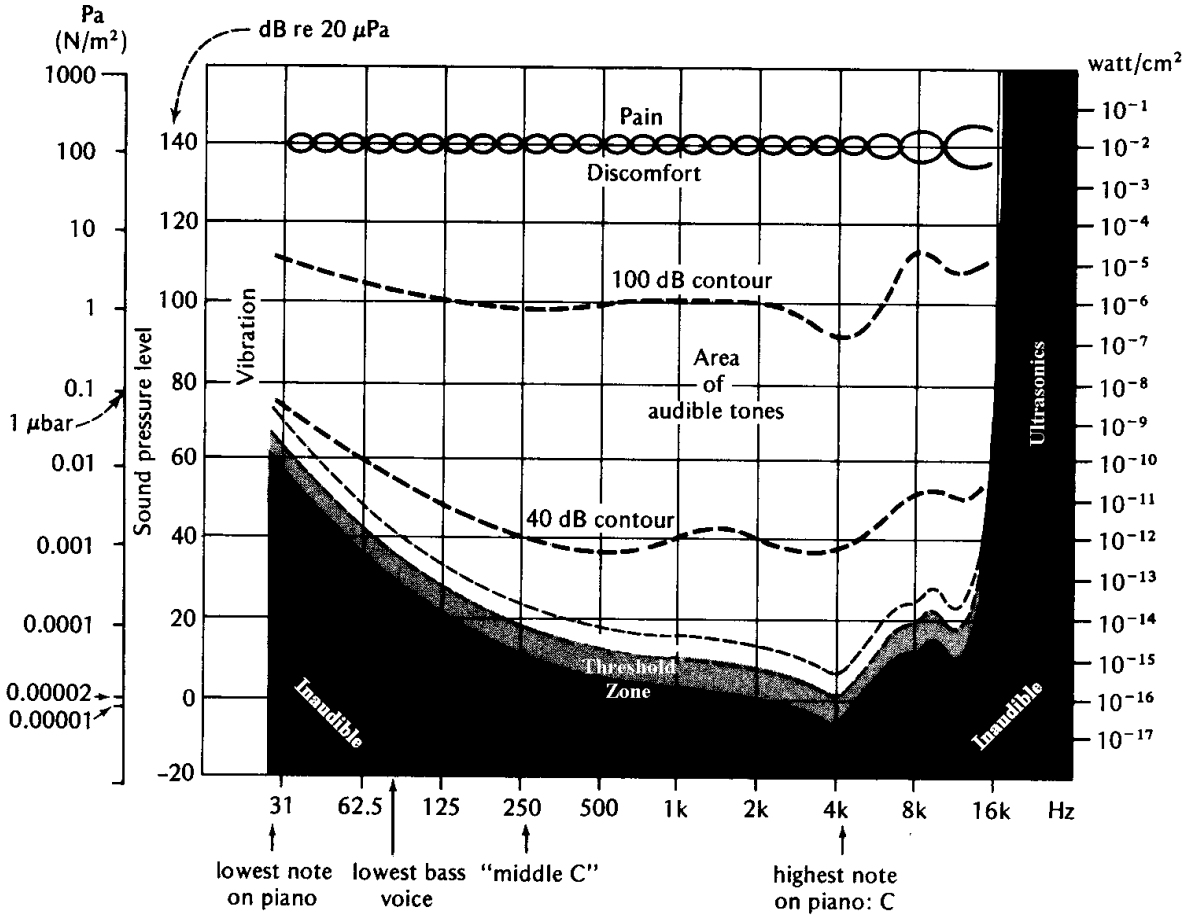
  $= 20 \times \log_{10}(0.1) = 20 \times -1$

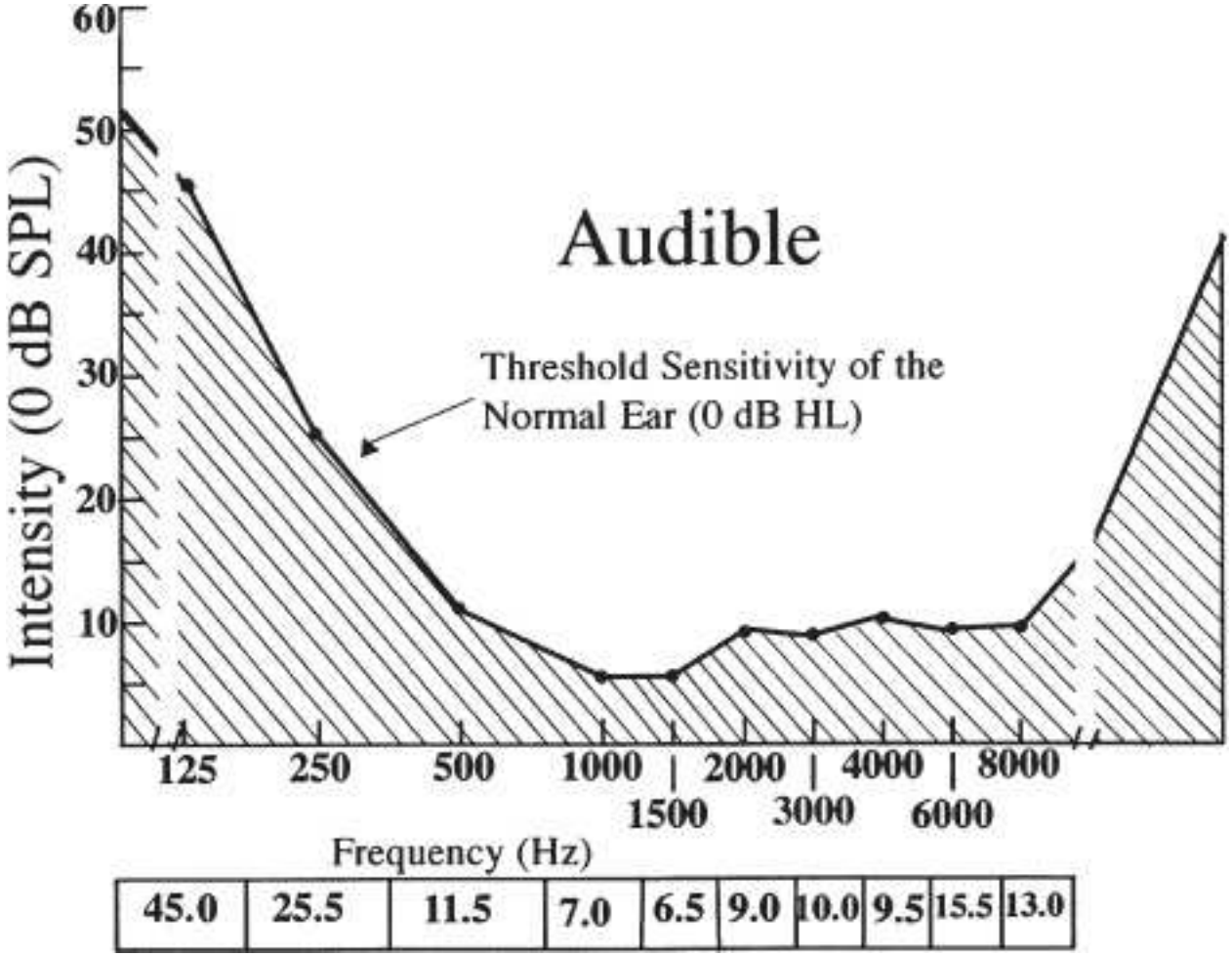
  = -20 dB SPL

Getting a feel for decibels (dB SPL)



Human hearing for sinusoids





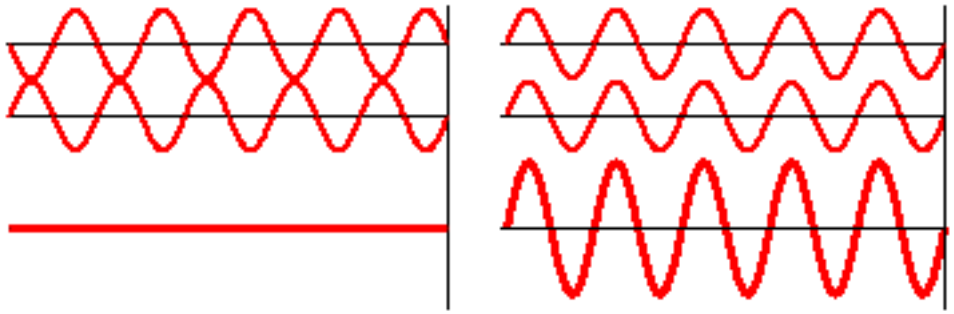
Here is the ANSI S3.6-1996 standard to convert dB SPL to dB HL.

Frequency Hz	dB SPL	dB HL
125	45.0	0
250	27.0	0
500	13.5	0
750	9.0	0
1000	7.5	0
1500	7.5	0
2000	9.0	0
3000	11.5	0
4000	12.0	0
6000	16.0	0
8000	15.5	0

Wave Interference

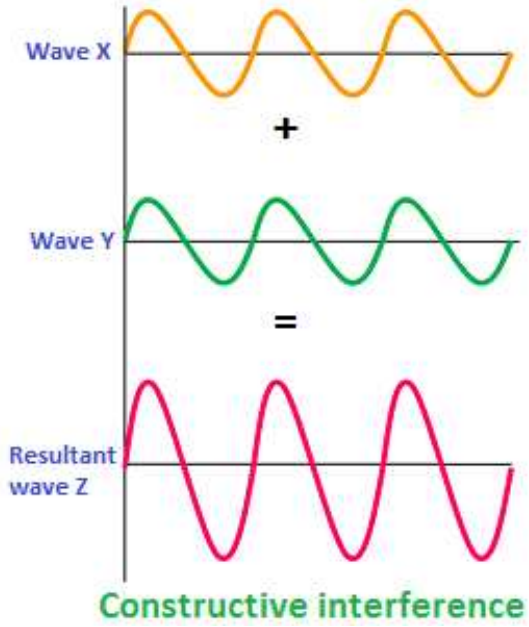
- Wave interference refers to the phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude.

- There are two types of interference:
  - Constructive interference.
  - Destructive interference.



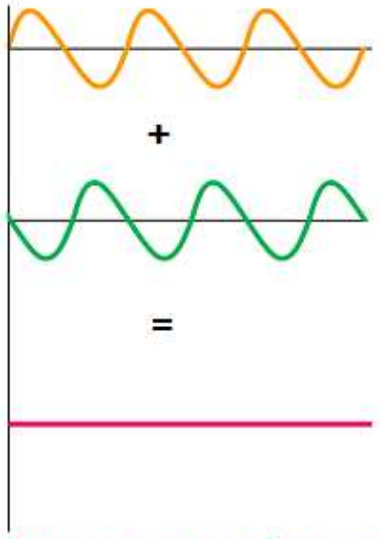
Constructive/ In-phase Interference

- Refers to the interference of two or more waves of equal frequency and equal phase.
- The result is a signal with an amplitude equal to the sum of the amplitudes of the individual waves.



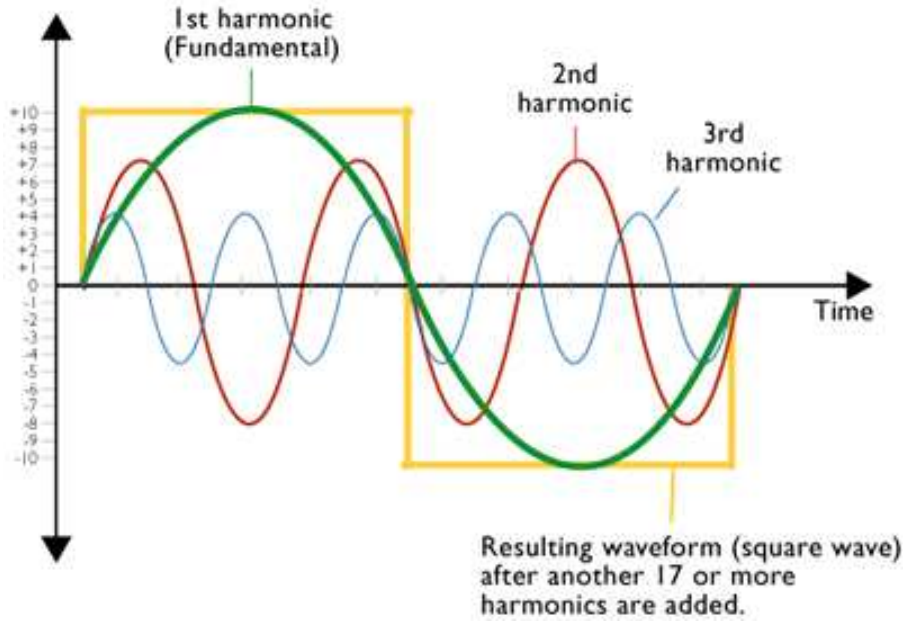
Destructive/ Out-of-phase Interference

- Refers to the interference of two waves of equal frequency and opposite phase.
- The result is cancellation of both waves, as the negative displacement of one wave always coincides with the positive displacement of the other wave.



Harmonics

- Harmonics are waves with a frequency that is a positive multiple of the frequency of the original wave, known as the fundamental frequency.
- The original wave is also called the 1st harmonic, the following harmonics are known as higher harmonics (2^{nd}, 3^{rd} harmonics etc.).



Octaves

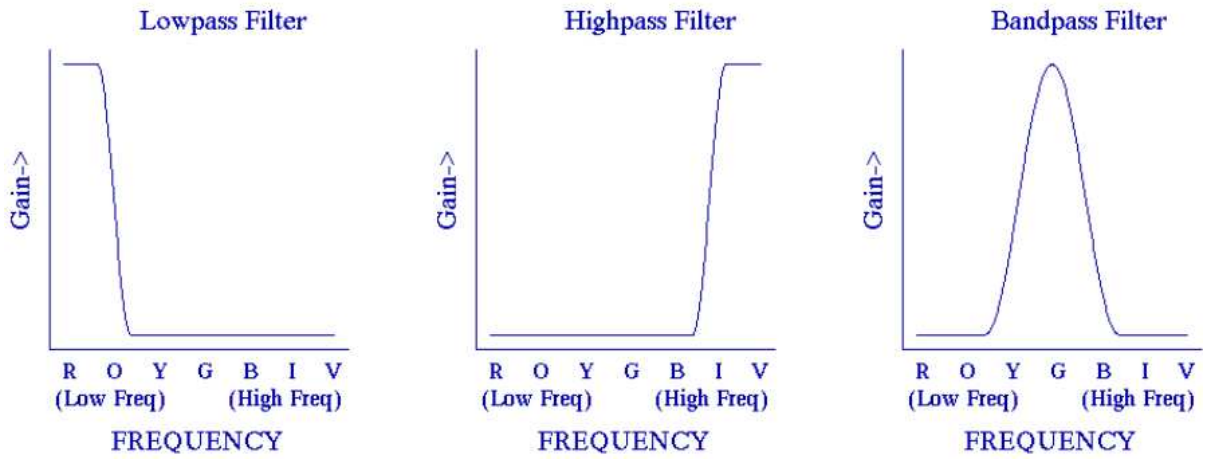
- An octave is a logarithmic unit for ratios between frequencies, with one octave corresponding to a **doubling of frequency**
- For example, the frequency one octave from (or above) 40Hz is 80Hz.

Acoustic Filters

- Acoustic filter: is a device that isolates a certain frequency band from a complex sound.
- There are three types of acoustic filters:
  - High-pass filters
  - Low-pass filters
  - Band-pass filters

Acoustic Filters

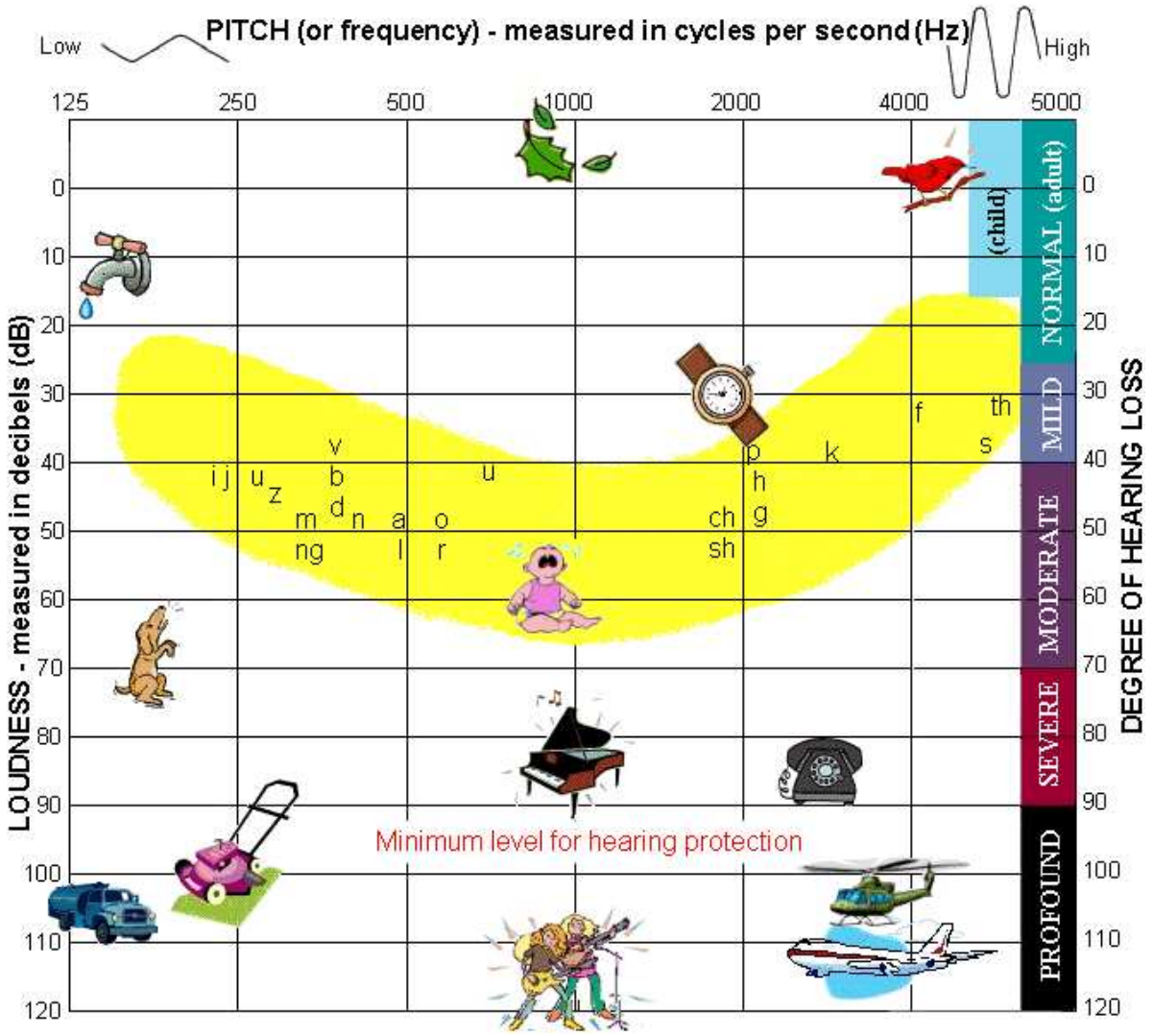
- High-pass filter: an acoustic filter that passes all frequencies above a specific frequency.
- Low-pass filter: passes all frequencies from a certain value up to some specified frequency.
- Band-pass filter: passes a more or less narrow frequency range b/w two specific frequencies.

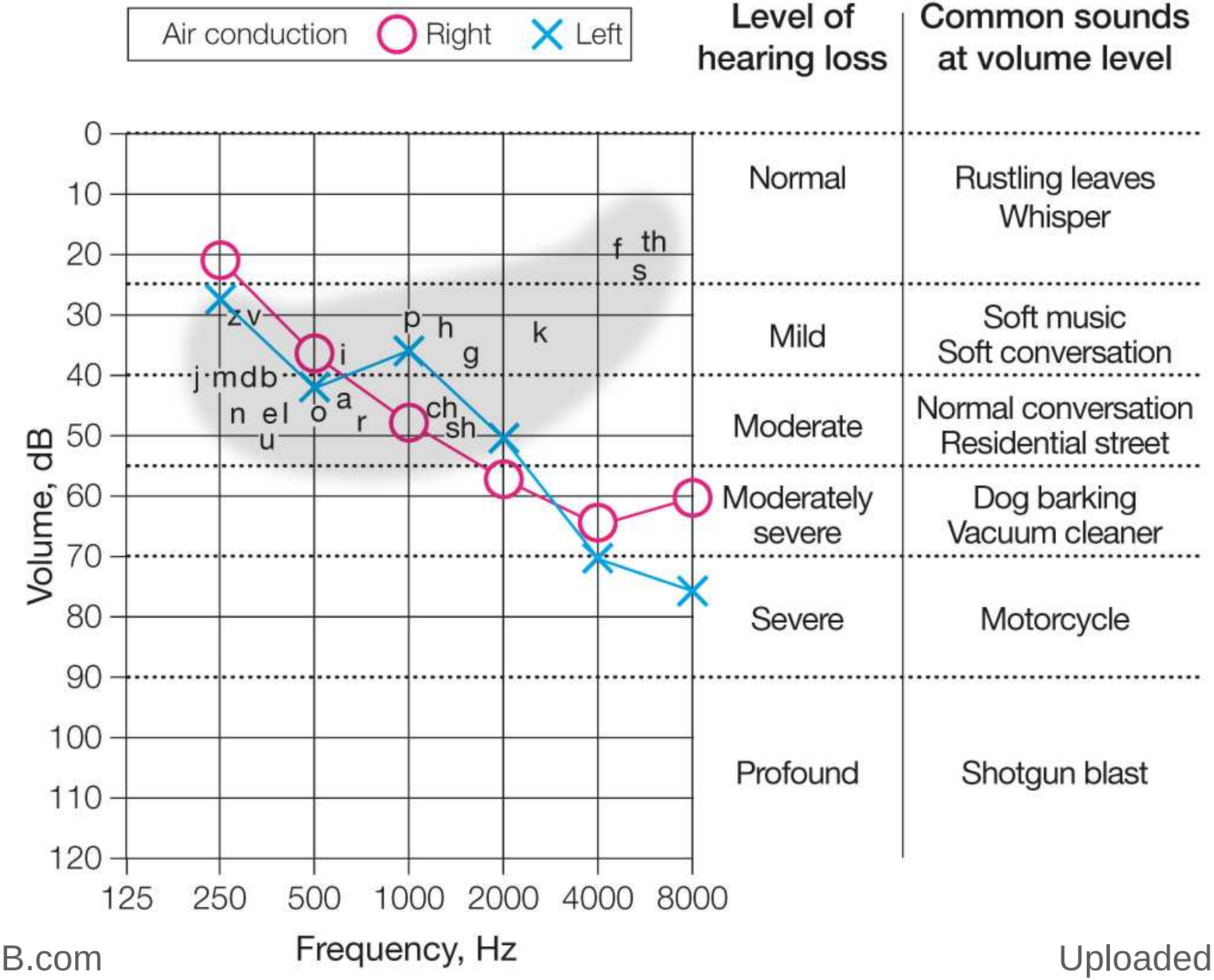


Acoustics of speech

- Speech sounds have a wide range of intensities.
  - Average sound level of vowels is **65-70 dB SPL** in conversation.
  - Average sound level of constants is **35-40 dB SPL** in conversation.
  - Speech may be imbedded in noise that is 10 to 20 dB higher and still be partially understood by normal hearing people.

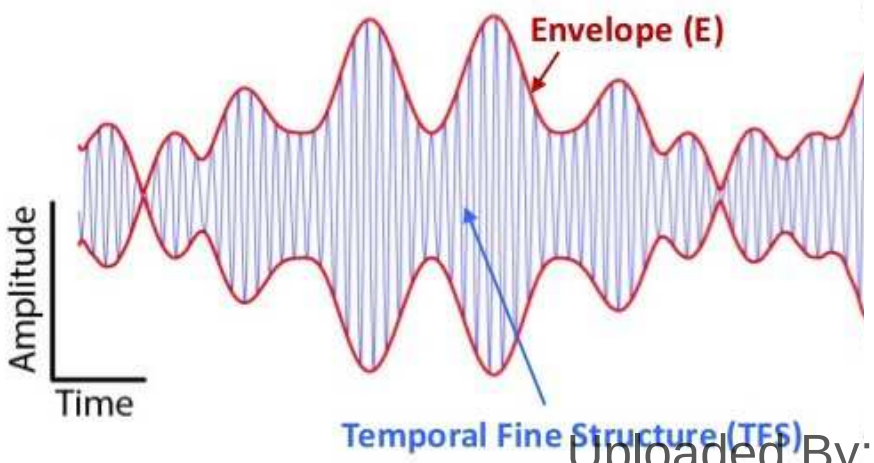
The Speech Banana





Speech Waves

- Speech waves are complex waves (composed of a mixture of frequencies)
- There are two components of speech that are important:
  - **The envelope of speech spectrum:** represents the loudness fluctuation of speech. It includes very important info to understand speech.
  - **The fine structure of speech:** provides details on the quality of sounds or timber.



https://www.youtube.com/watch?v=EYnNpuErlgQ