SPAU332
Hearing Aids I

Dina Budeiri MSc

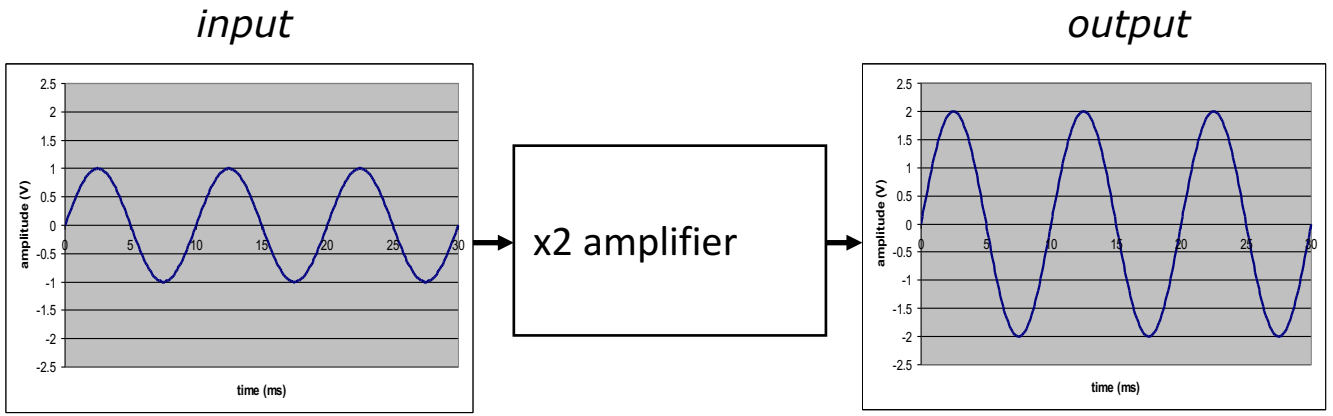
Physics of Sound and Acoustics

What are systems & signals?

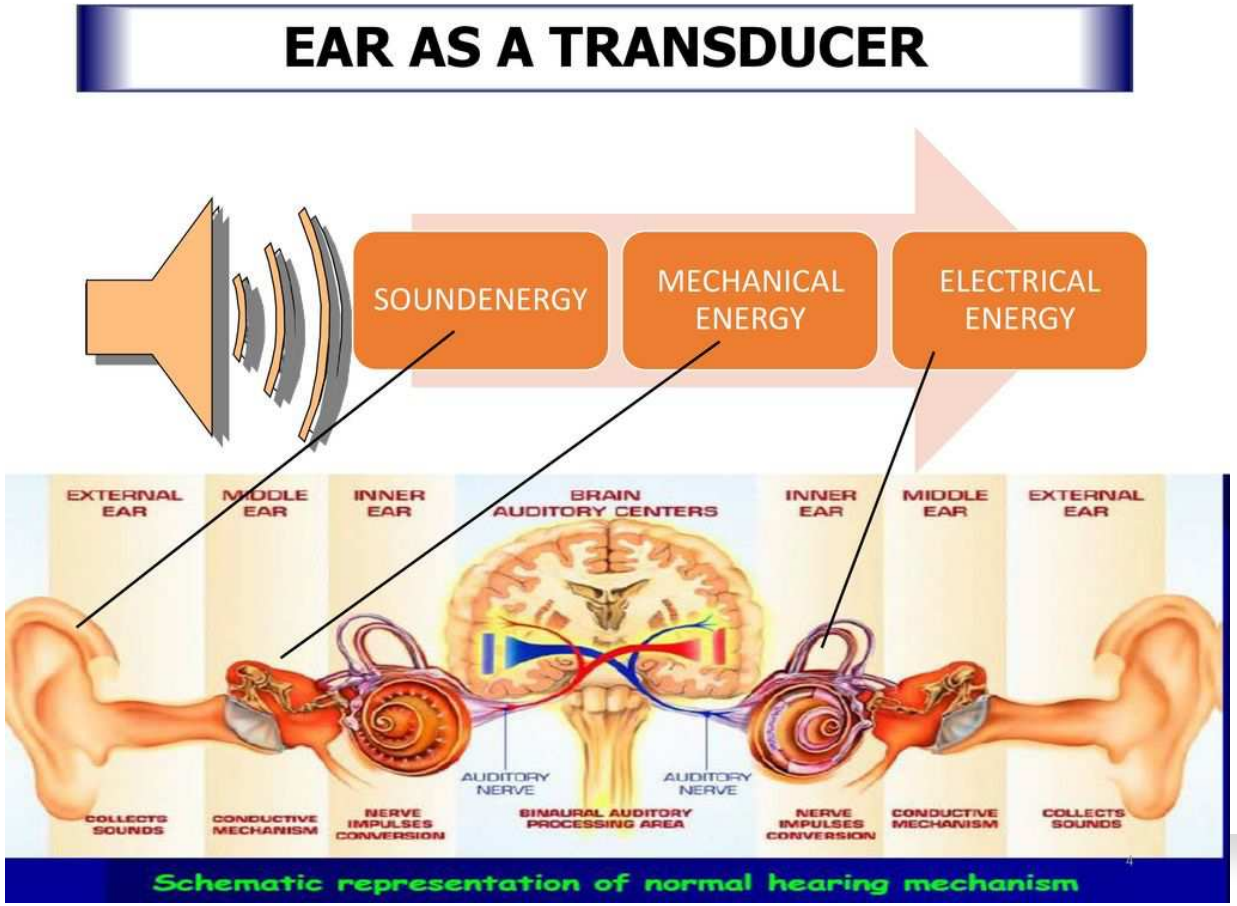
Systems perform an operation on, or transformation of, a *signal* (or *waveform*)

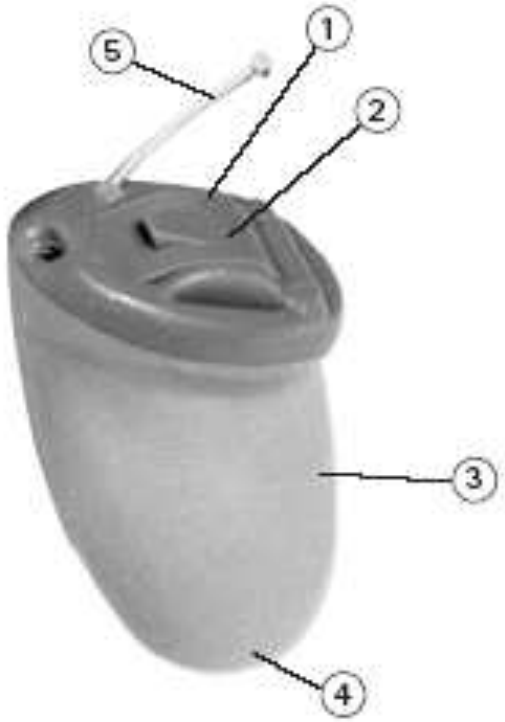
Concentrate on systems with one input and one output

Many useful examples in hearing and speech science



System = Ear


EAR AS A TRANSDUCER
SOUNDENERGY
MECHANICAL ENERGY
ELECTRICAL ENERGY
EXTERNAL EAR
MIDDLE EAR
INNER EAR
BRAIN AUDITORY CENTERS
INNER EAR
MIDDLE EAR
EXTERNAL EAR
AUDITORY NERVE
AUDITORY NERVE
COLLECTS SOUNDS
CONDUCTIVE MECHANISM
NERVE IMPULSES CONVERSION
BINAURAL AUDITORY PROCESSING AREA
NERVE IMPULSES CONVERSION
CONDUCTIVE MECHANISM
COLLECTS SOUNDS
Schematic representation of normal hearing mechanism



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

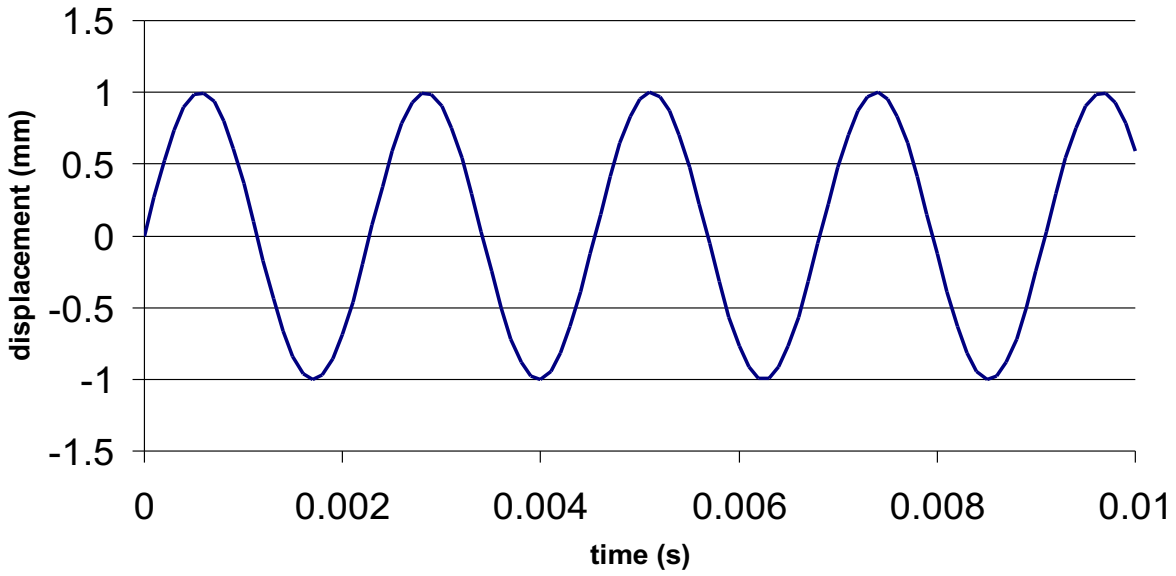
System = Hearing Aid

input = sound wave (variations in pressure)

output = sound wave (modified in some way)

Signals as waveforms

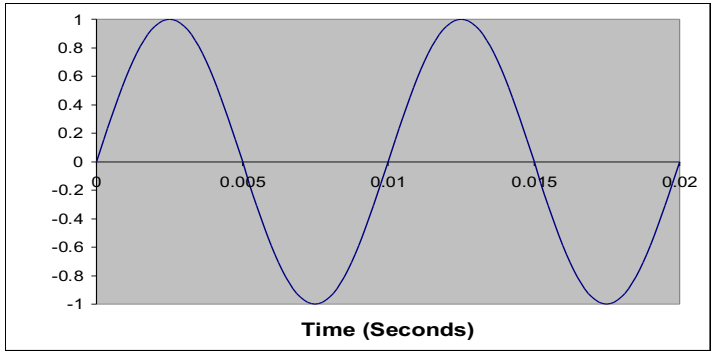
- A graph of the *instantaneous* value of amplitude over time
  - x-axis is usually time (s, ms, µs)
  - y-axis is usually a *linear instantaneous* amplitude measure (Pa, mPa, µPa, V, m)



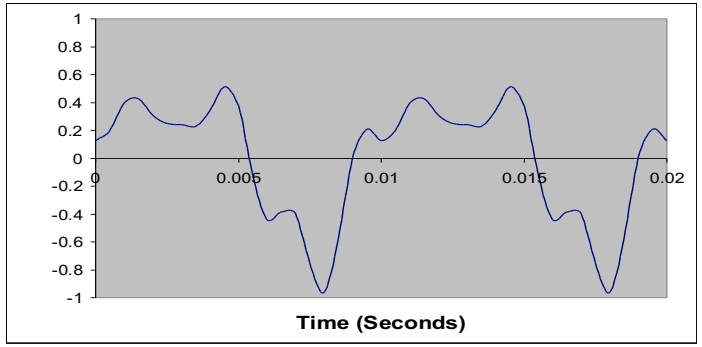
Waveforms are of two major types: periodic and aperiodic

- 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)



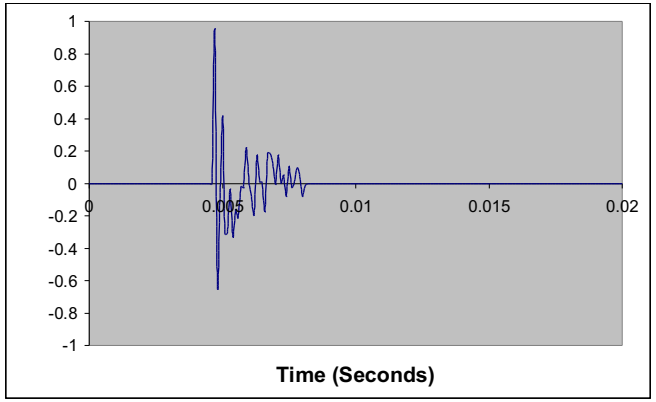
complex



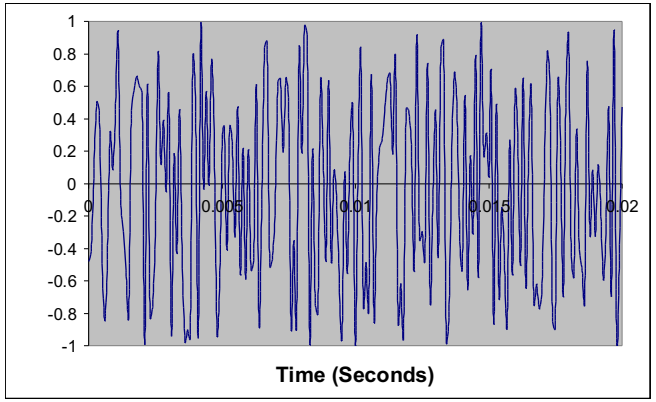
Waveforms are of two major types: periodic and aperiodic

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

transient

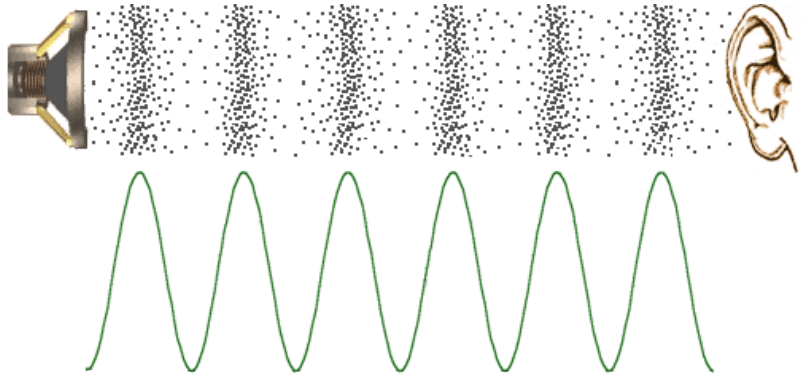


continuous (can be random)

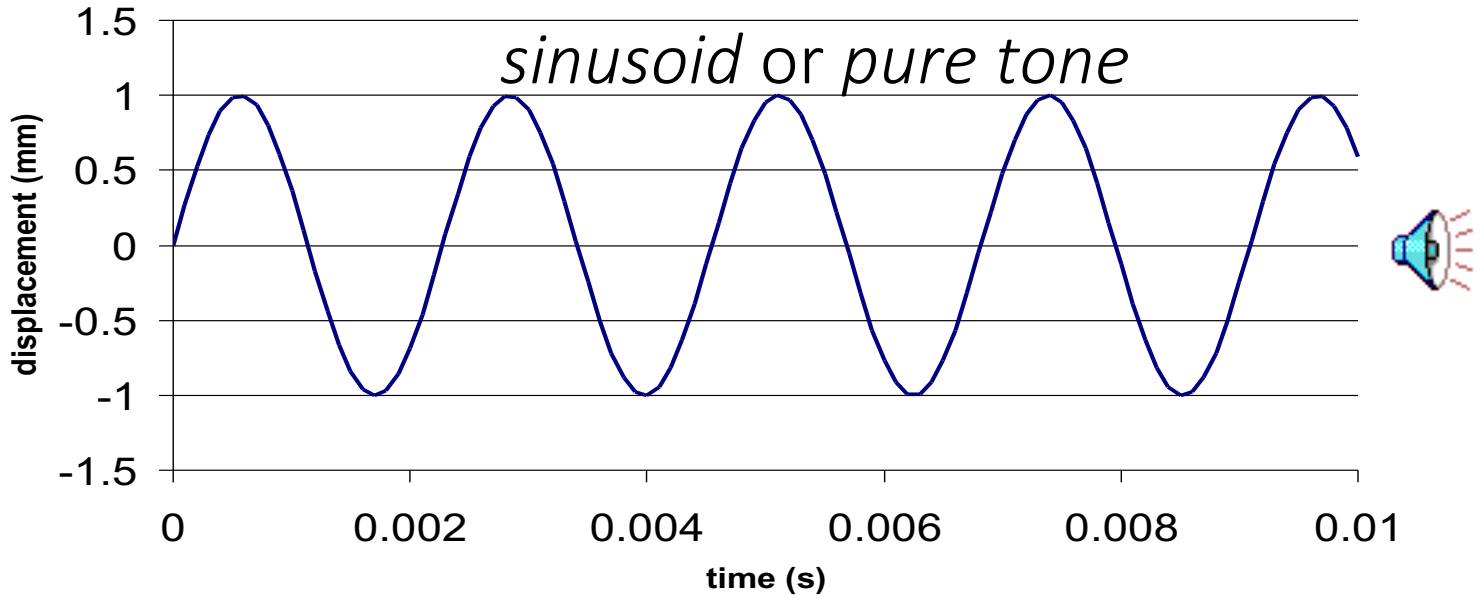


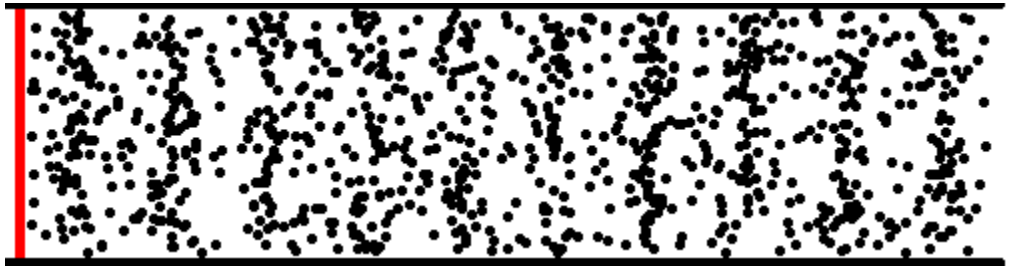
What is sound?

- 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

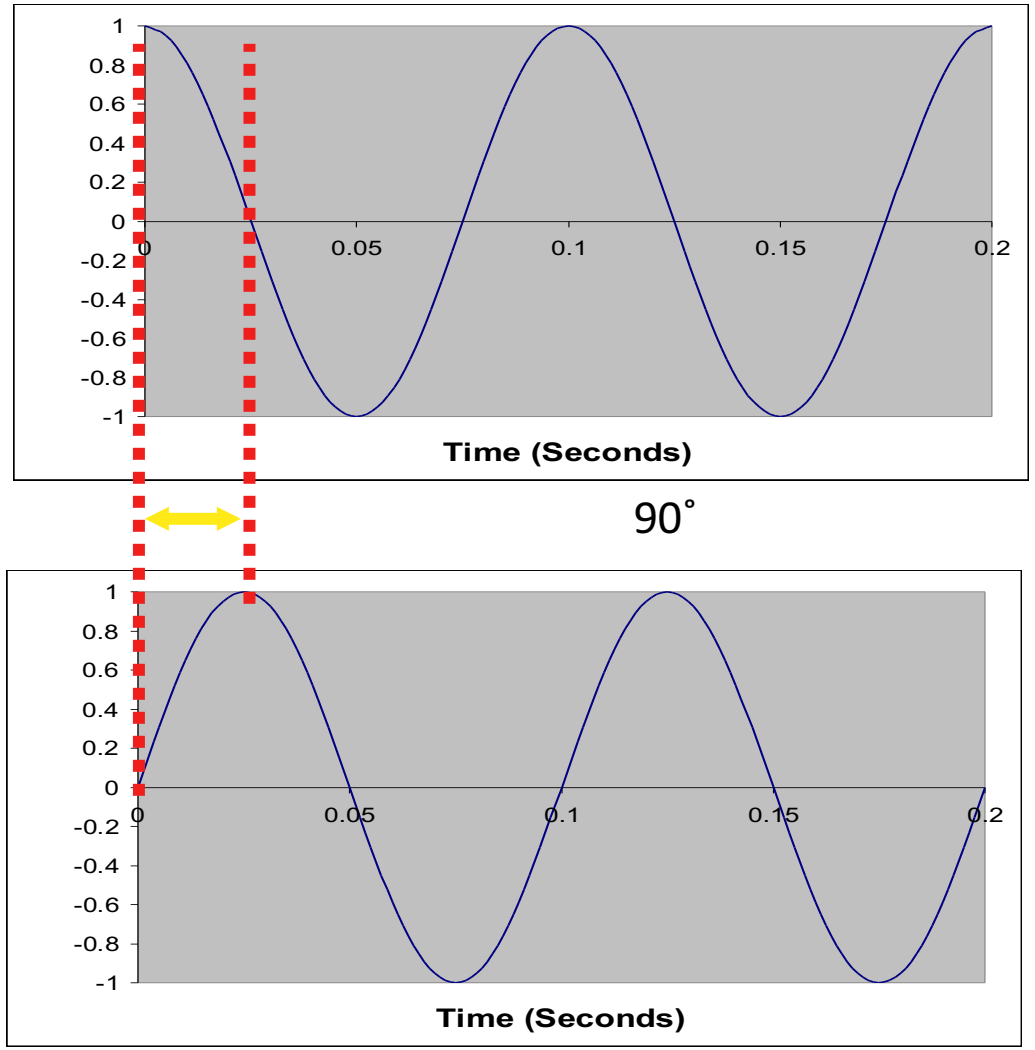
Where a sinewave *starts* relative to some arbitrary time

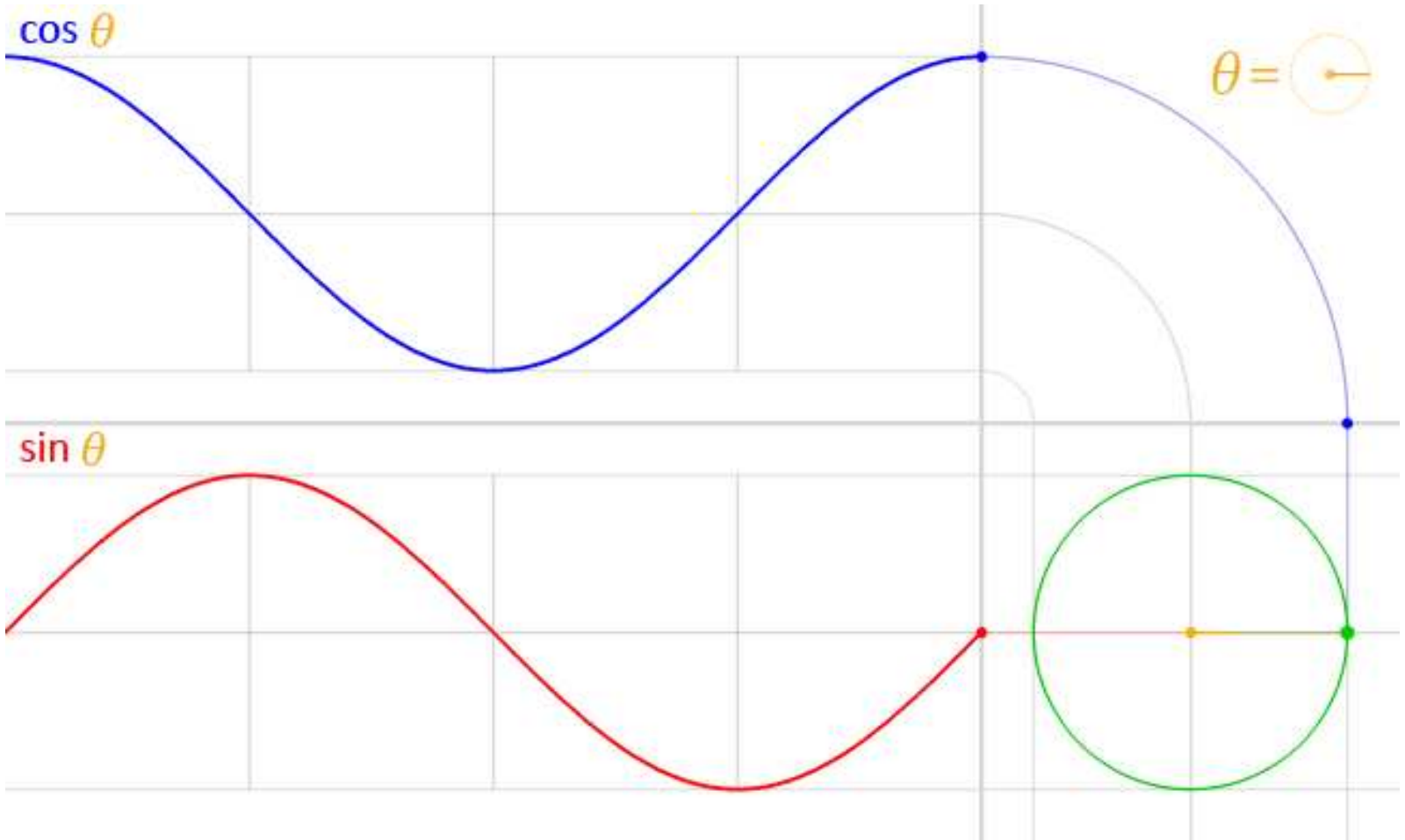
The angle of displacement at a specific point in time

Measured in cycles or degrees (or radians)

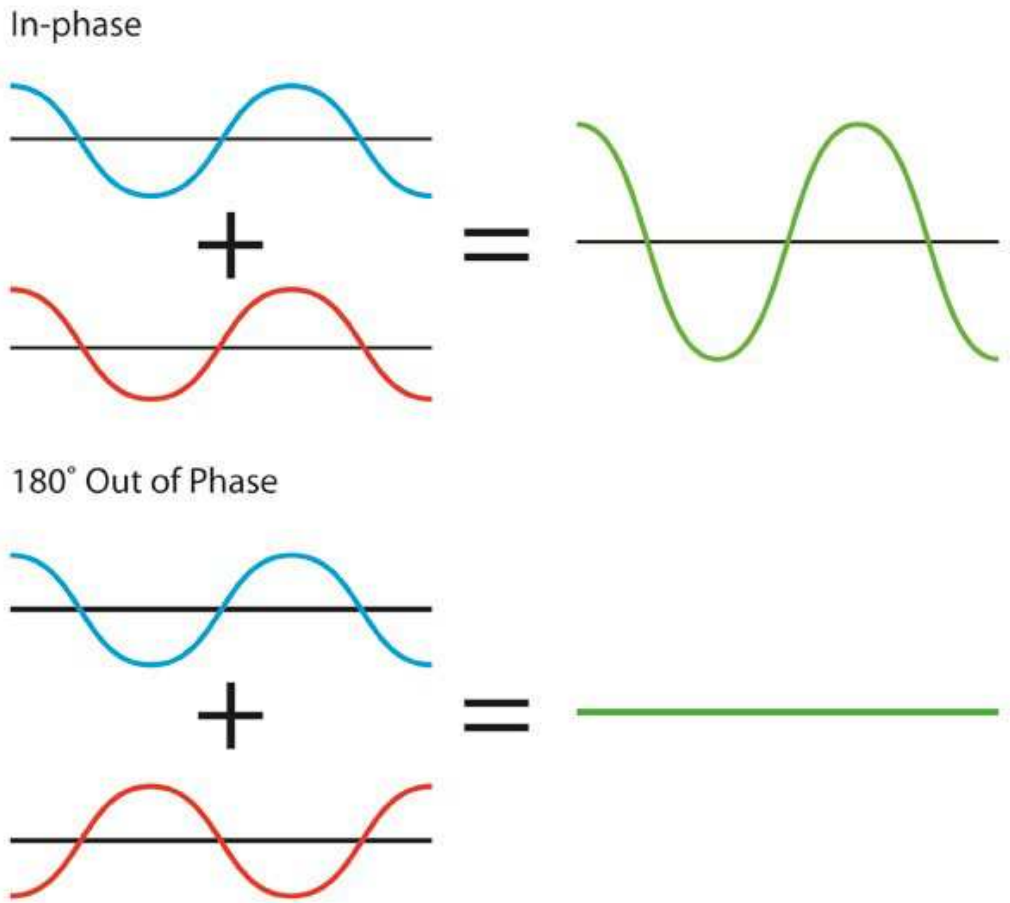
360˚ = 1 period = 2π rads
180˚ = ½ period = π rads
90˚ = ¼ period = π/2 rads

Relatively little effect on perception

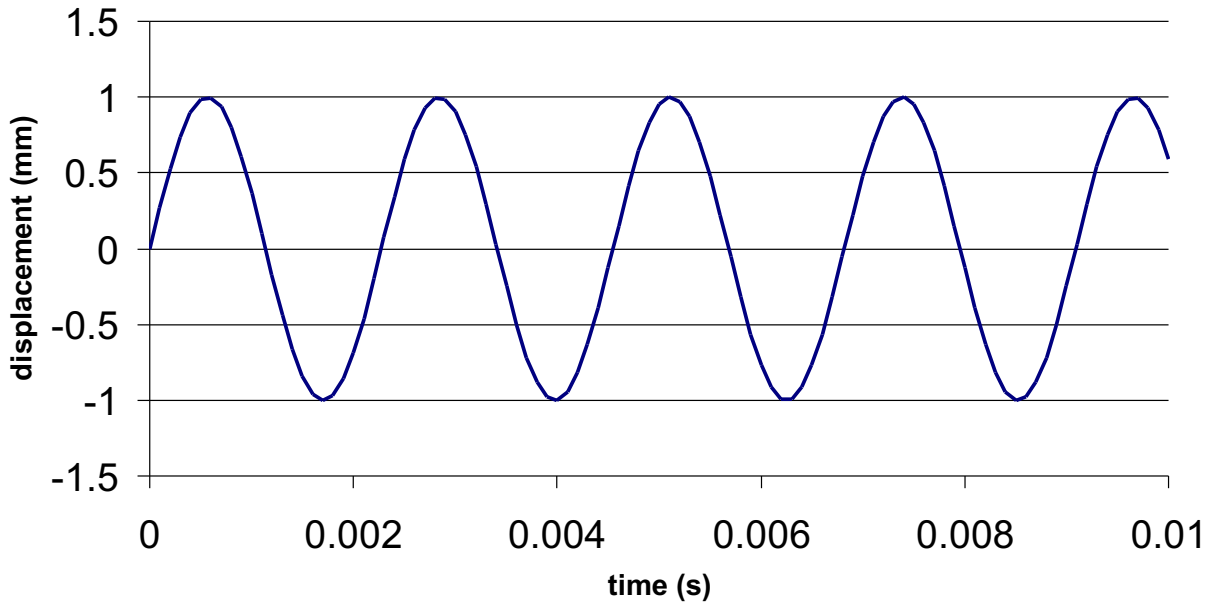



cos θ
θ =
sin θ

I: Phase



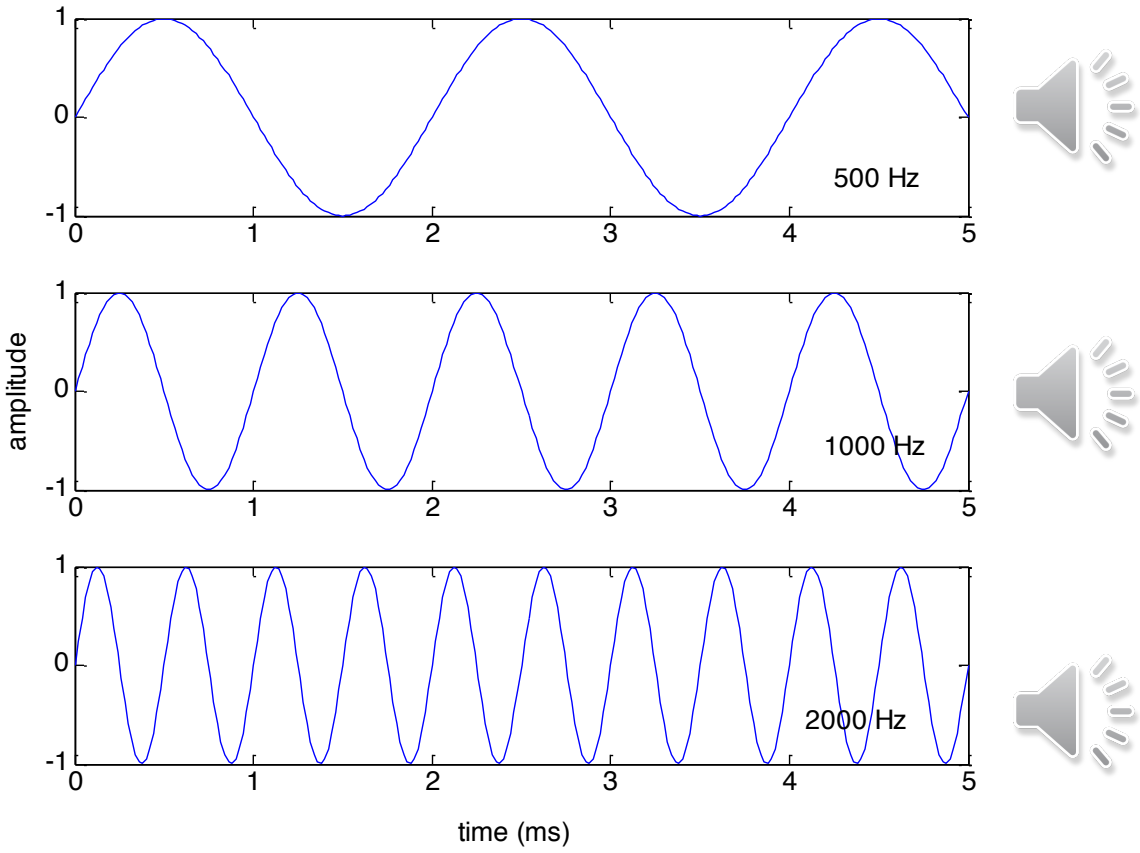
II: Periodicity (frequency)



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



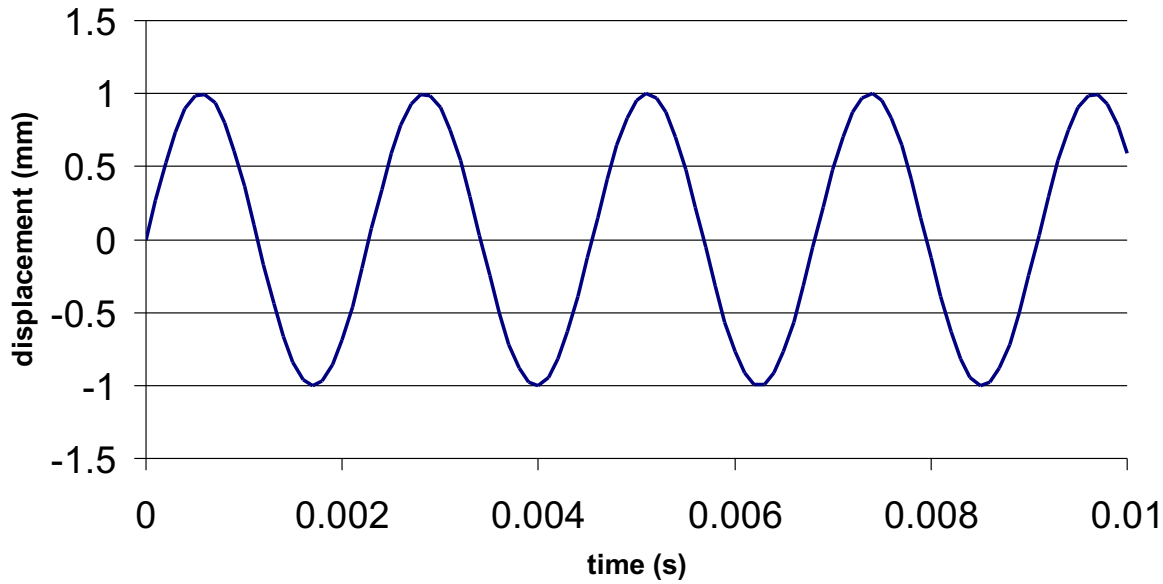
Keep your units consistent!

- 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

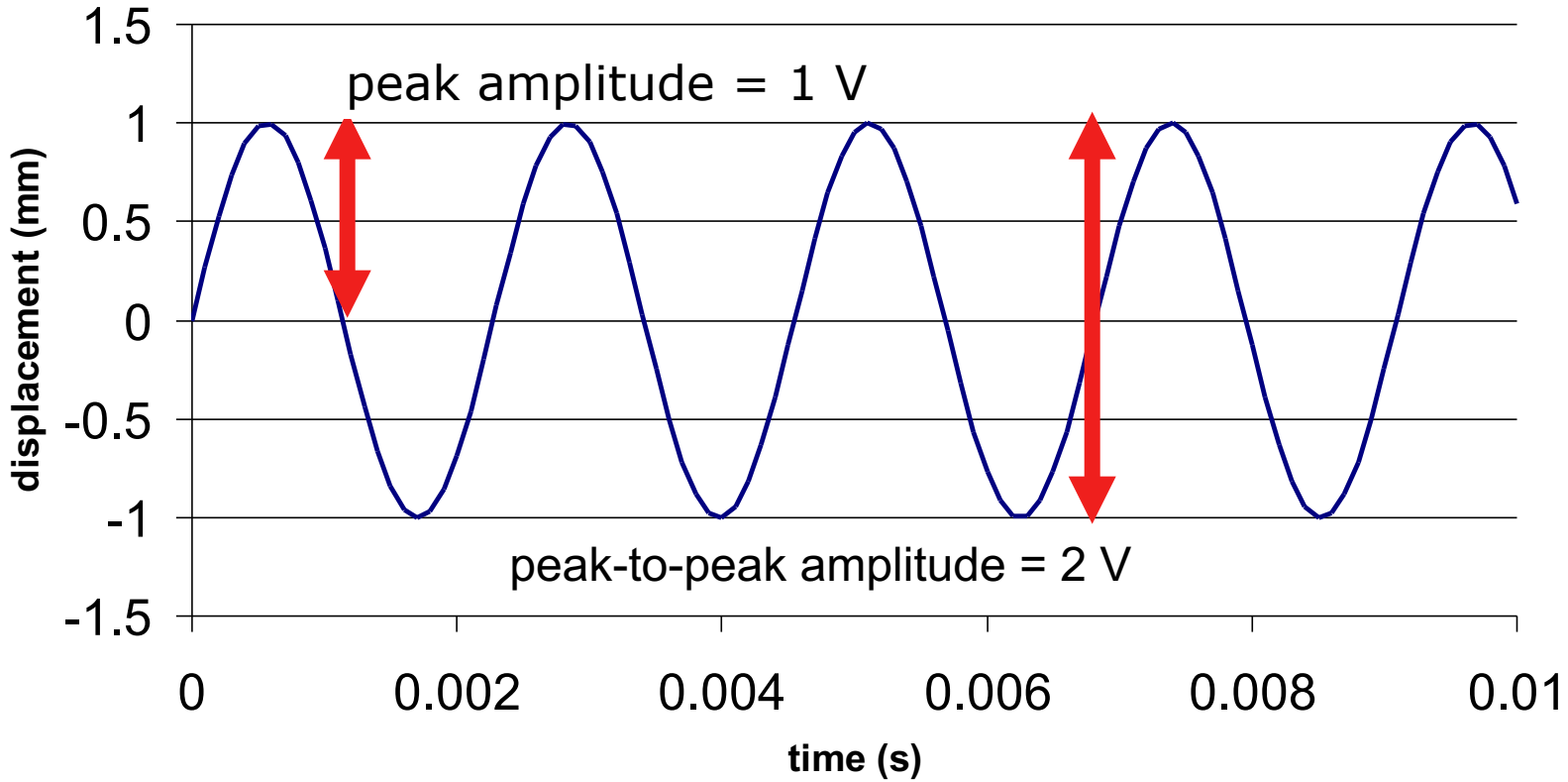
III: Amplitude



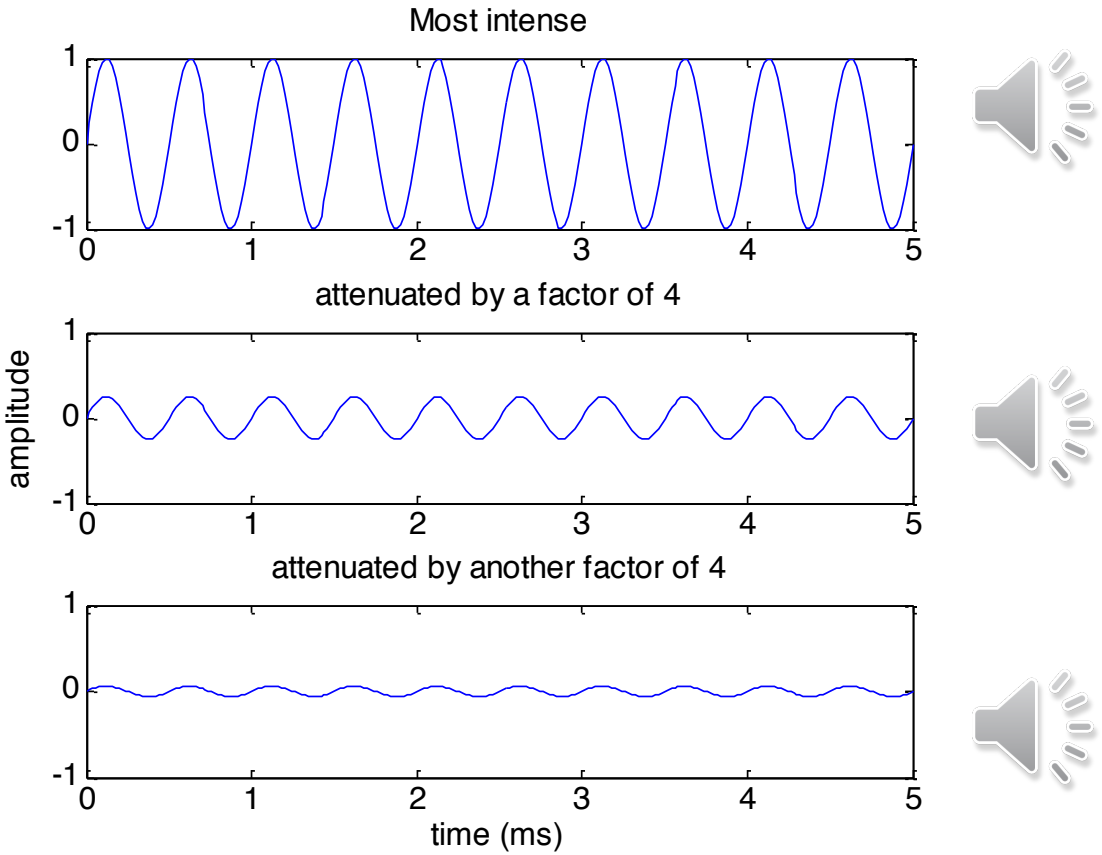
Measures of amplitude

- 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

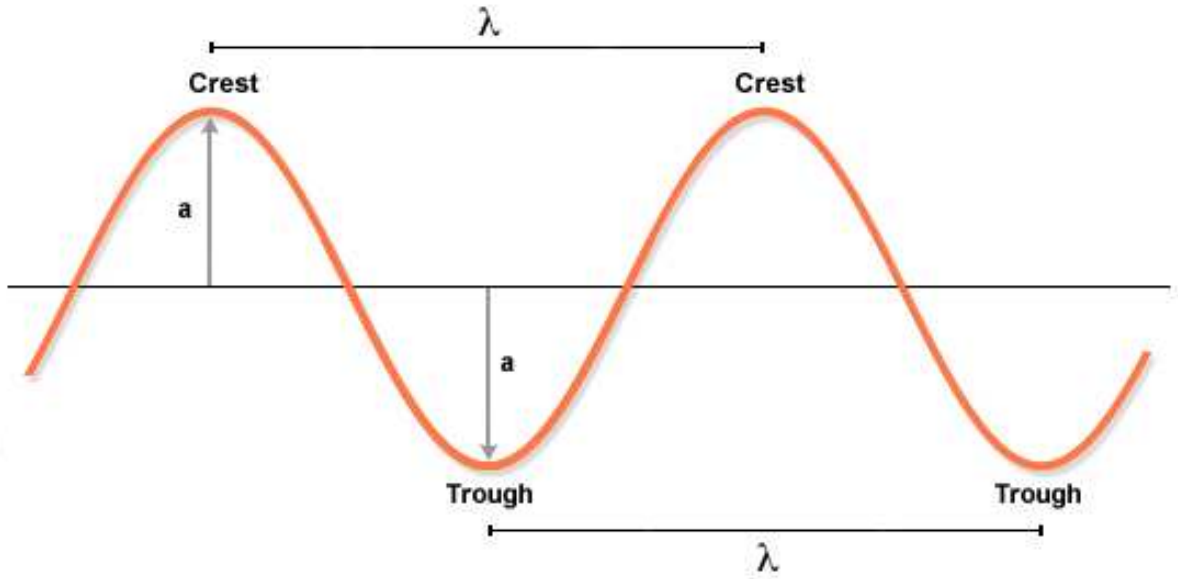


Increases in amplitude lead to increases in perceived loudness



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:

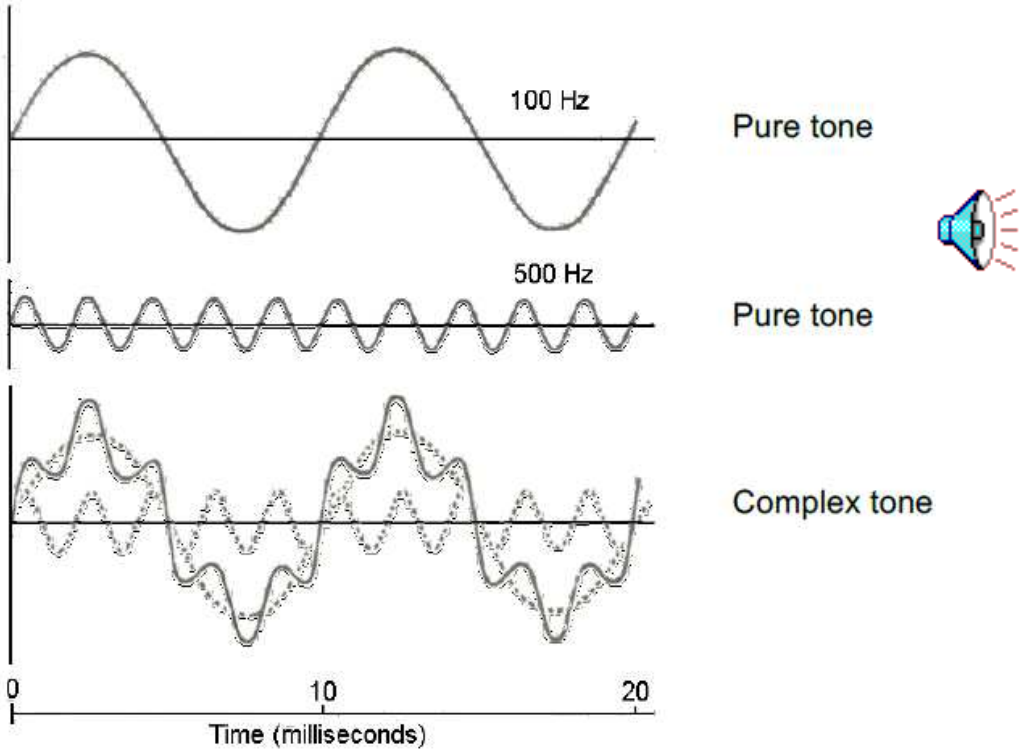
$$V = f * \lambda$$

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

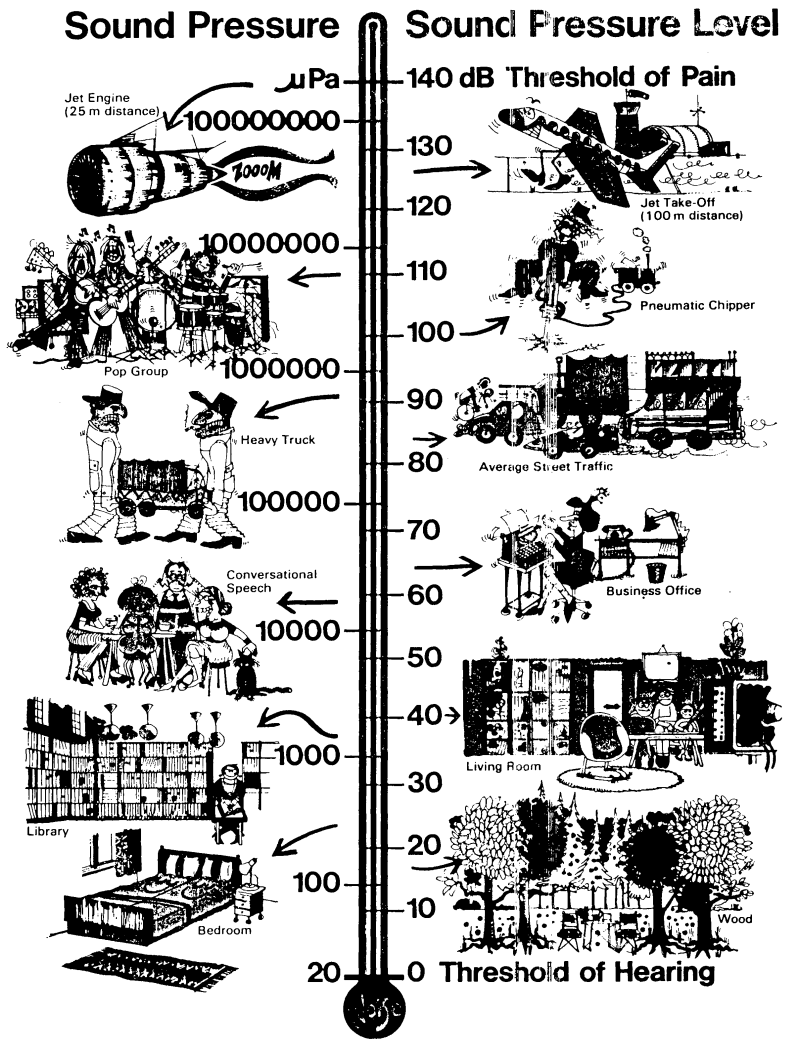
- An inaudible sound (2 µPa)

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

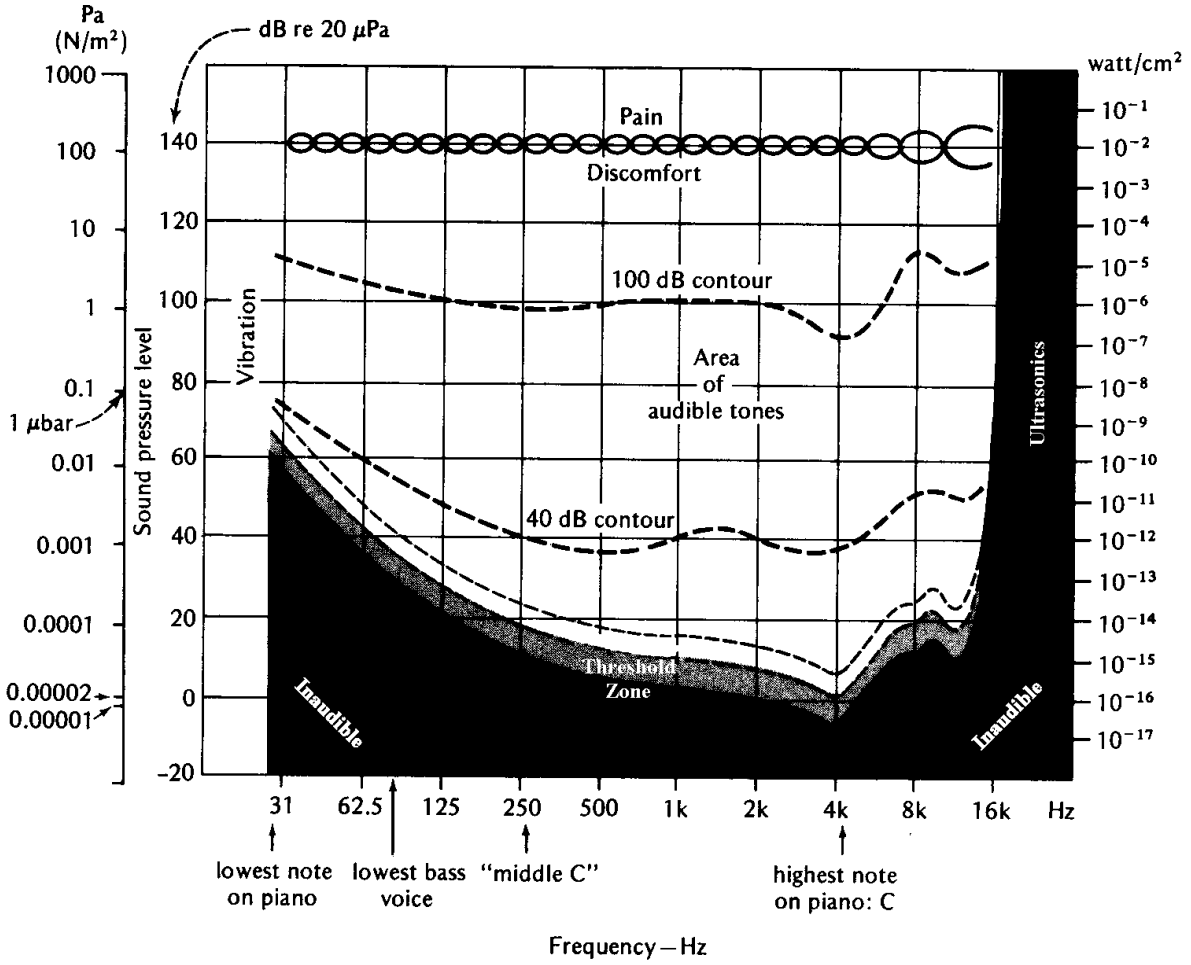
  $= 20 \times \log_{10}(0.1) = 20 \times -1$

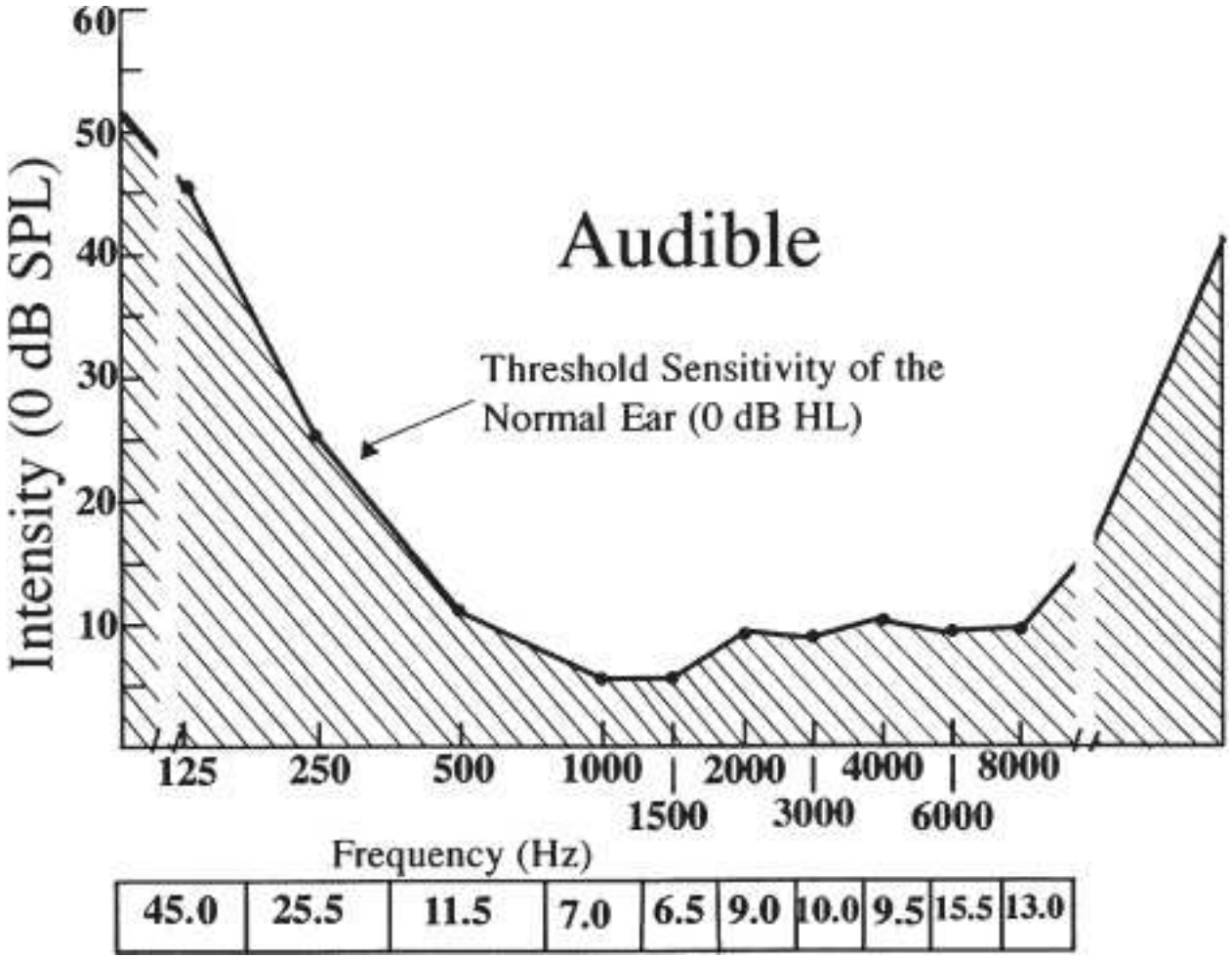
  = -20 dB SPL

Getting a feel for decibels (dB SPL)



Human hearing for sinusoids





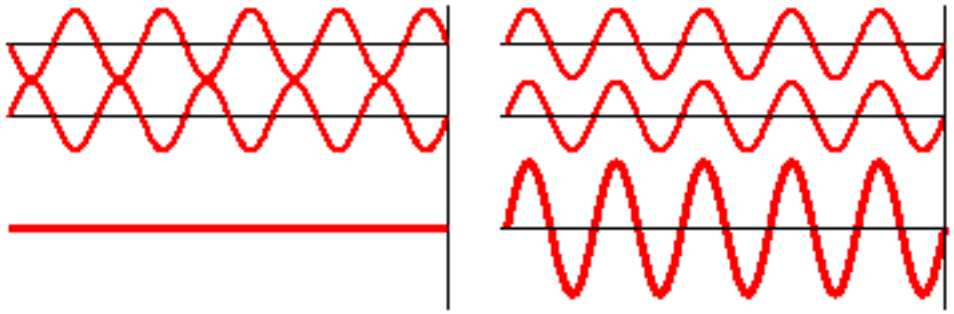
Here is the ANSI S3.6-1996 standard to convert dB SPL to dB HL.

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

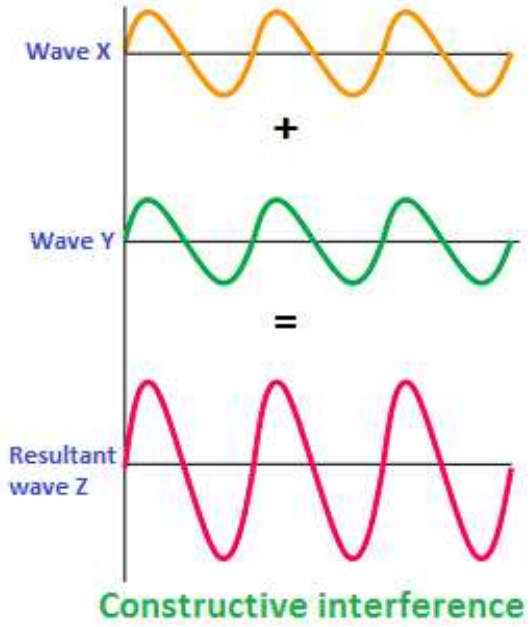
- Wave interference refers to the phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude.

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



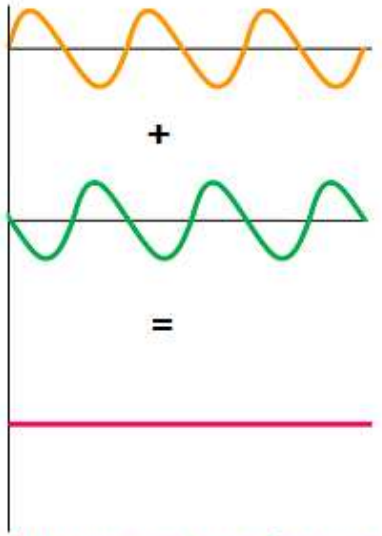
Constructive/ In-phase Interference

- 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.



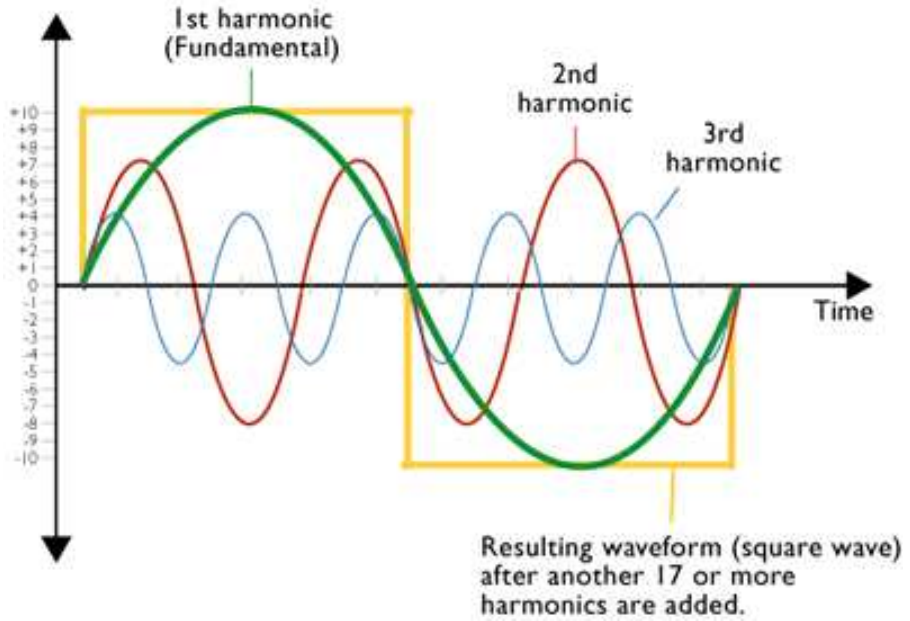
Destructive/ Out-of-phase Interference

- 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

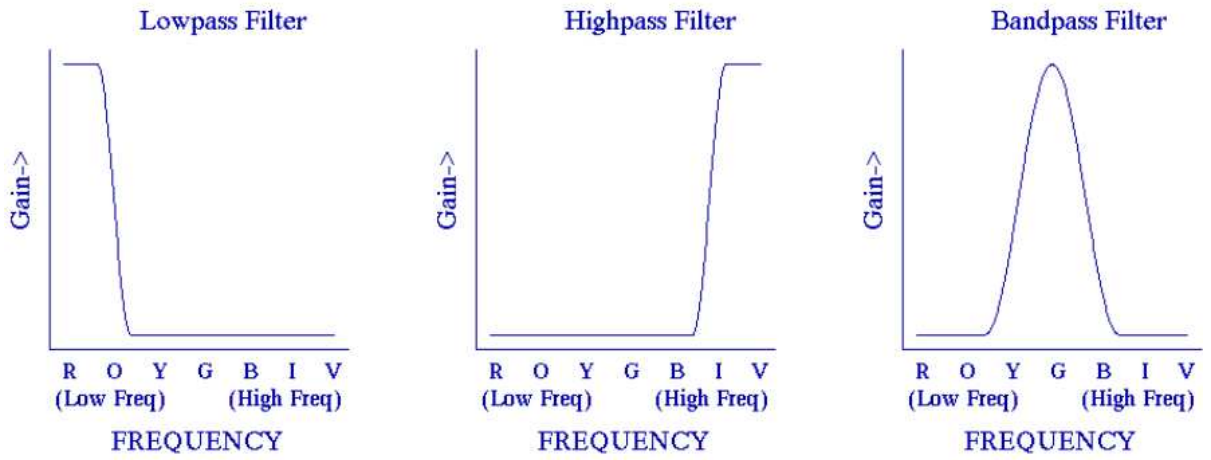
- An octave is a logarithmic unit for ratios between frequencies, with one octave corresponding to a **doubling of frequency**
- For example, the frequency one octave from (or above) 40Hz is 80Hz.

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

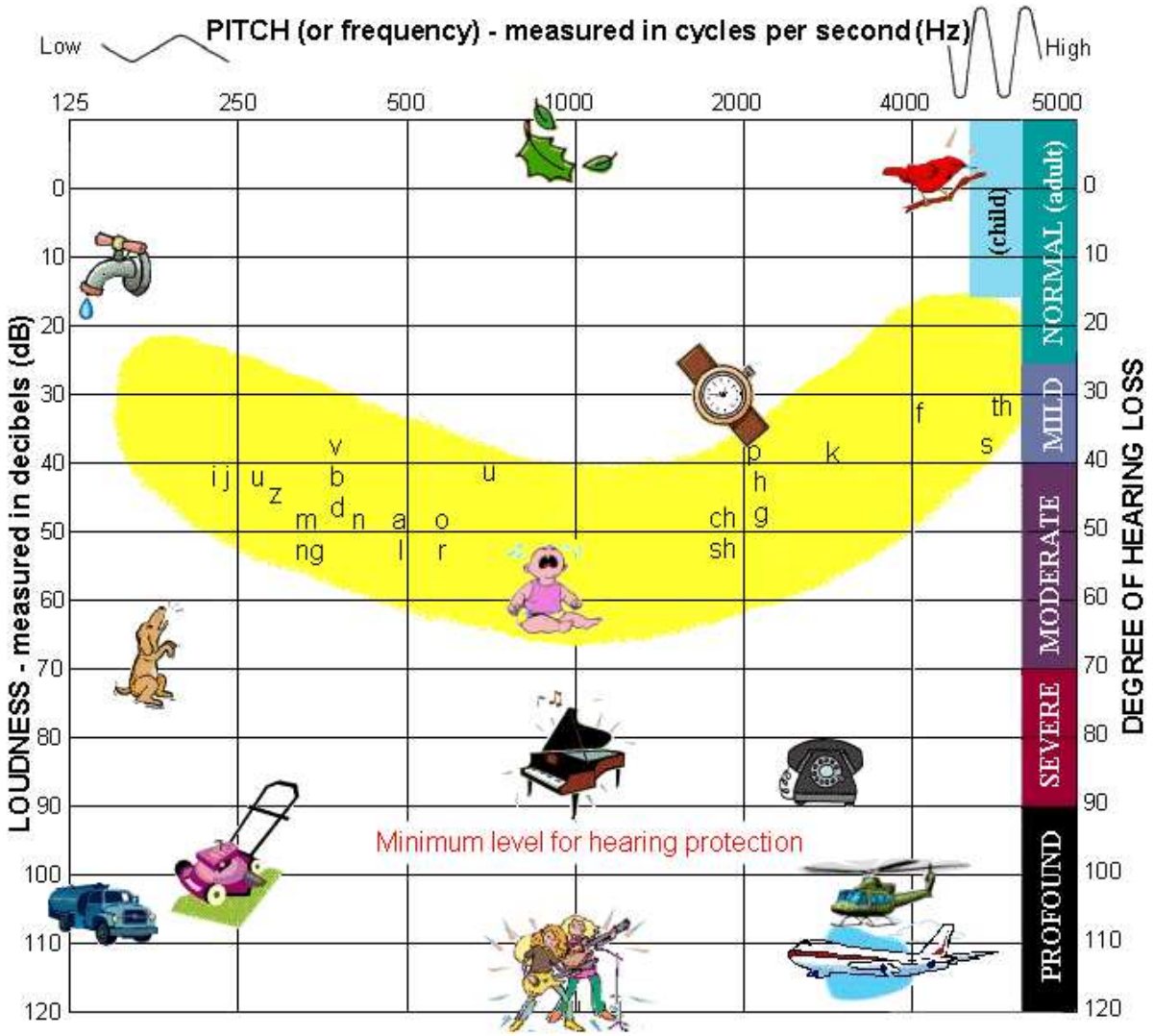
- High-pass filter: an acoustic filter that passes all frequencies above a specific frequency.
- Low-pass filter: passes all frequencies from a certain value up to some specified frequency.
- Band-pass filter: passes a more or less narrow frequency range b/w two specific frequencies.

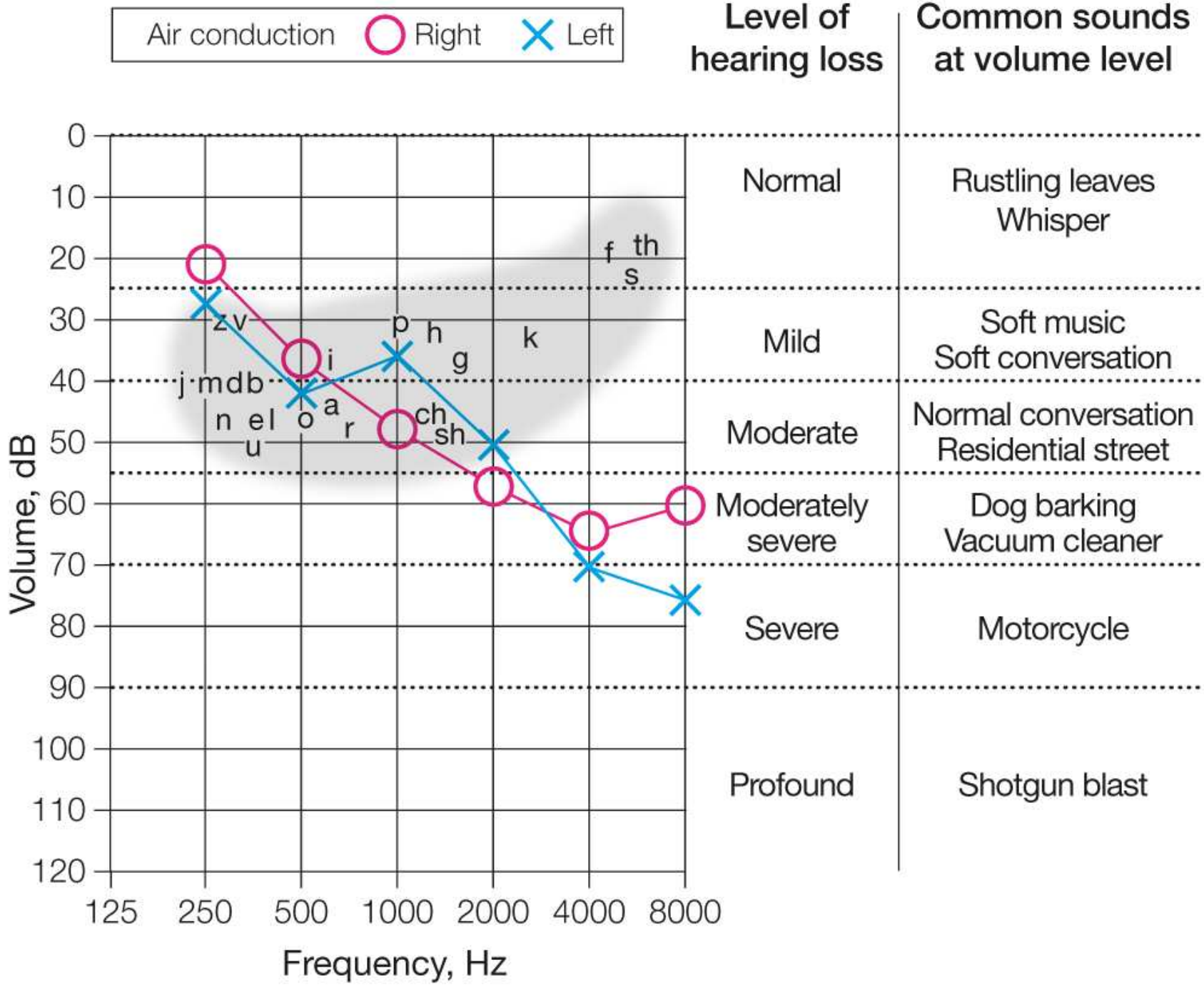


Acoustics of speech

- 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




Air conduction
Right
Left
Level of hearing loss
Common sounds at volume level
Normal
Rustling leaves
Whisper
Mild
Soft music
Soft conversation
Moderate
Normal conversation
Residential street
Moderately severe
Dog barking
Vacuum cleaner
Severe
Motorcycle
Profound
Shotgun blast
Volume, dB
0
10
20
30
40
50
60
70
80
90
100
110
120
125
250
500
1000
2000
4000
8000
Frequency, Hz
f th s
z v
p h g k
j m d b
i
n e l u
o a r
ch sh

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