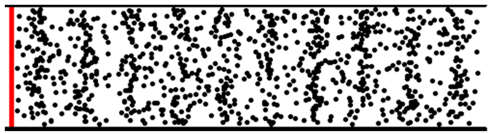
Signals & Systems for Speech & Hearing

Week 1

You may find this course demanding! How to get through it:

- Consult the Web site:
  www.phon.ucl.ac.uk/courses/spsci/sigsys
  (also accessible through Moodle)
- Essential to do the reading and suggested exercises
- Laboratory sessions go a long way to clarify the material presented
- Bring questions to the tutorial sessions
- Send questions to the staff through Moodle
- Keep up with the work
- If you have problems, *ask for help!*
- If you can do the course work and exercises, you will do well on the exam …
  - if you cannot, you will not!
- After today, you are responsible for bringing printed-out notes to class, if you want to.
  - Made available on the web site 5 days prior
  - Lab sheets will be provided, so you need not print them

What is sound?



Sound is oscillation of air pressure (pressure wave).

high pressure: air molecules bunched up
low pressure: air molecules spread out

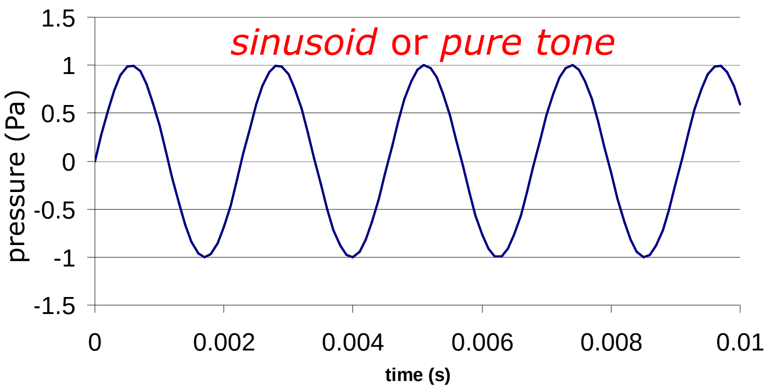
Air molecules do **not** travel through space to carry sound

Sound is a SIGNAL

Imagine measuring the instantaneous pressure at a single place

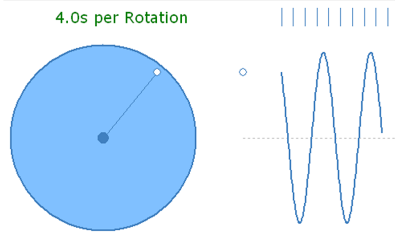
A microphone converts variations in sound pressure to electrical variations in voltage

A very simple signal



Essential characteristics of sinusoids

- Sinusoids are a *unique* shape
  - not just any vaguely regular form
  - are *periodic*
    - a basic *cycle* repeats over and over
  - can be constructed from *uniform circular motion*

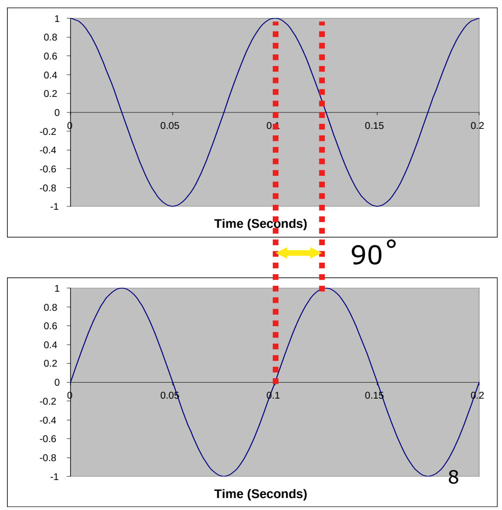


Sinusoids can only differ in three ways

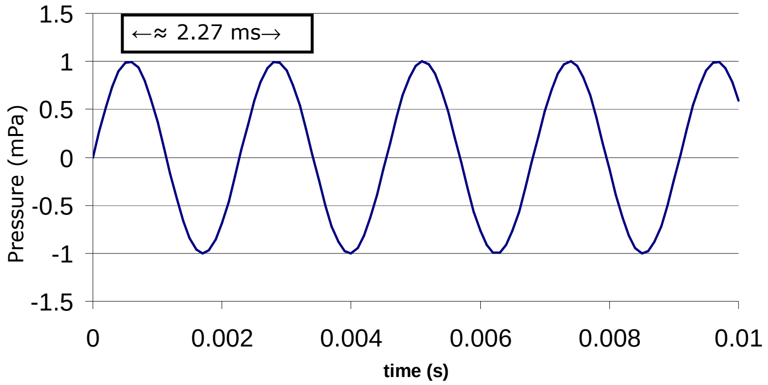
- In other words, once you know a wave is sinusoidal, there are only three things to know about it:
  - frequency
  - amplitude
  - phase (generally less important because phase changes are typically not perceived)

I: Phase

- Where a sinewave *starts* at some arbitrary time
- Measured in cycles or degrees (or radians)
  - 360° = 1 period
  - 180° = ½ period
  - 90° = ¼ period
- Equivalent to a shift in time
- Relatively little effect on perception but still important in many situations



II: Periodicity (frequency)



Specifying periodicity

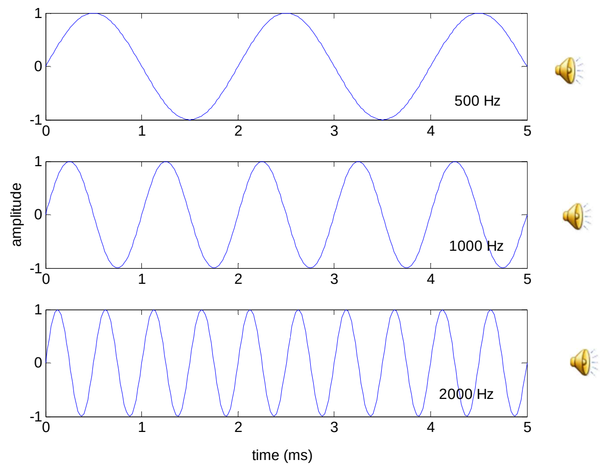
- The period (*p*) is the time to complete one *cycle* of the wave
- Alternatively, the number of cycles that are completed in one second, is the *frequency (f)*
- *f=1/p* and *p=1/f*
  - here =1/0.00227 sec = 440 cycles per second (cps)
- But a special unit name is used …
  - 1 Hz = 1 cycle per second

Keep your units consistent!

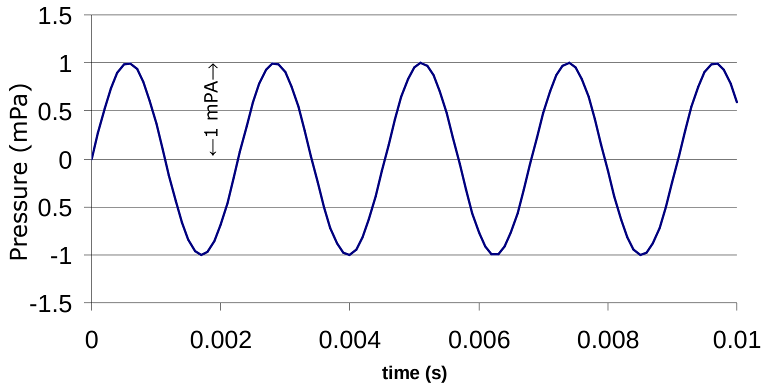
- period of 0.001 sec = 1 ms (millisecond)
  so:
- period in seconds: f (Hz)=1/p (s)
- period in ms: f (Hz)=1000/p (ms)
- period in ms: f (kHz) =1/p (ms)

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

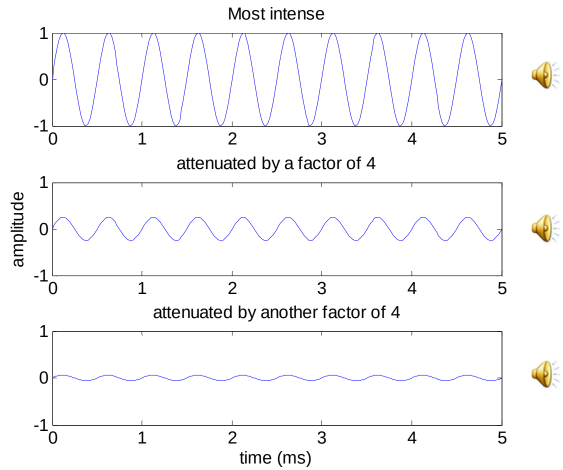
Increases in frequency (decreases in period) lead to increases in subjective pitch



III: Amplitude



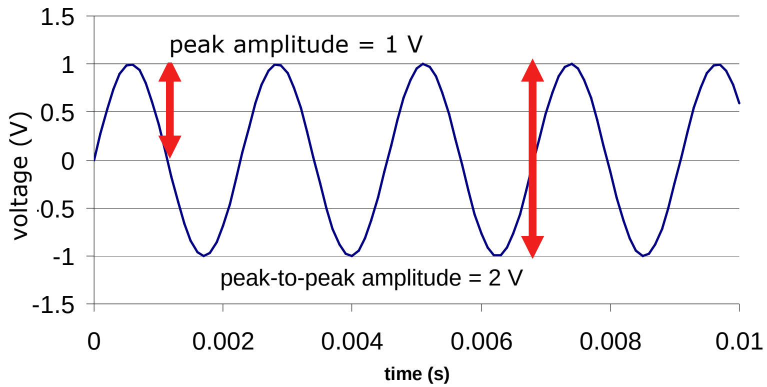
Increases in amplitude lead to increases in perceived loudness



Measures of amplitude

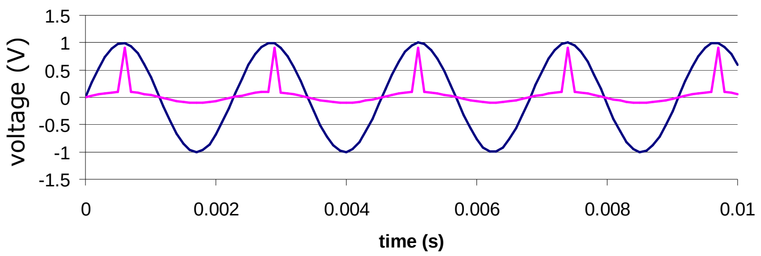
- It is crucial to distinguish instantaneous measures (as in a waveform) from some kind of average
- Instantaneous measures always linear (e.g., pressure in Pa, voltage in V, displacement in metres)
- But also want a single number to be a good summary of the 'size' of a wave
- Average measures can be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

Simple measures of amplitude



Drawback to peak measures

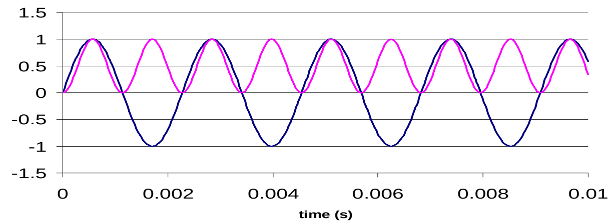
- Don't accurately reflect the energy in a waveform



root-mean-square (rms)

- Square all the values of the wave
- Take the average area under the curve
- Take the square root
- A measure of the *energy*, applicable to all waveforms
- Similar to calculating a standard deviation
- Still a *linear* measure (Pa, mm, V)

rms=.707



Scaling amplitude: The decibel Scale

Idea I:

Define a point of reference and rescale data in terms of that reference

Idea II:

Use a kind of warped scale that relates to perception

a) Find reference point and rescale:
- refer to threshold of hearing (0 dB SPL)

b) Warp the scale to reflect perception:
- e.g. 20 – 100 000 μPa more detailed
- e.g. 1 000 000 – 200 000 000 μPa less detailed
- Logarithmic scaling reflects human hearing

~~c) Handle big numbers:~~
- ~~20 - 200 000 000 μPa → 0 – 140 dB~~

How to rescale data? Logarithms!

- Logarithms are a way of saying
  - "Ten to the power of *what* is this number?"
- For example: $\log_{10}(100)$
  - Ten to the power of *what* is 100?
  - Ten to the power of **two** is 100
  - $10^2=100$
  - Therefore $\log_{10}(100)$ is 2.
- Logarithms convert numbers into powers of 10

Logarithms are simple!

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

rewrite 1000 as a power of 10

$10^?=1000$

$10^3=1000$

$\log_{10}(10^3)=??$

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

Examples of logarithms

- log(10) = ??
  log(10) = 1 because 10^1 =10
- log(0.1) = ??
  log(0.1) = -1 because 10^{-1} =0.1
- log(1) = ??
  log(1) = 0 because 10^0 =1
- So
  log of a number that is greater than 1 is positive
  log of a number that is less than 1 is negative
- not only integers
  log(50) = 1.699 makes sense!
- log(-1) = ??

Sound Pressure Level

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

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

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 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.

dB SPL Examples

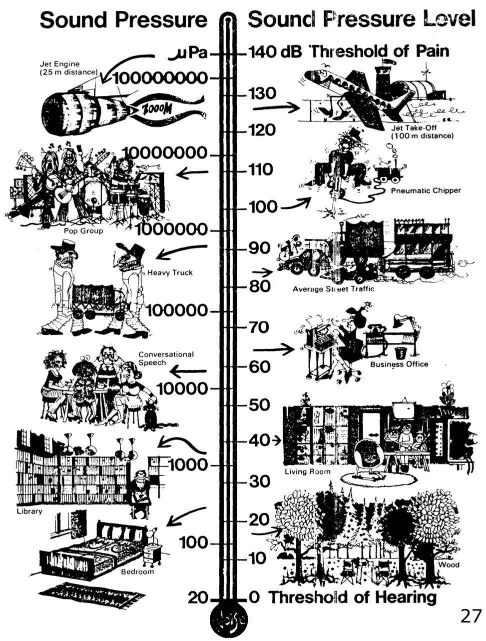
- Threshold of Hearing (20 μPa)

  $20 \times \log_{10}(20\ \mu Pa/20\ \mu Pa)$
  $= 20 \times \log_{10}(1) = 20 \times 0$
  $= 0$ dB SPL
- Threshold of 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)

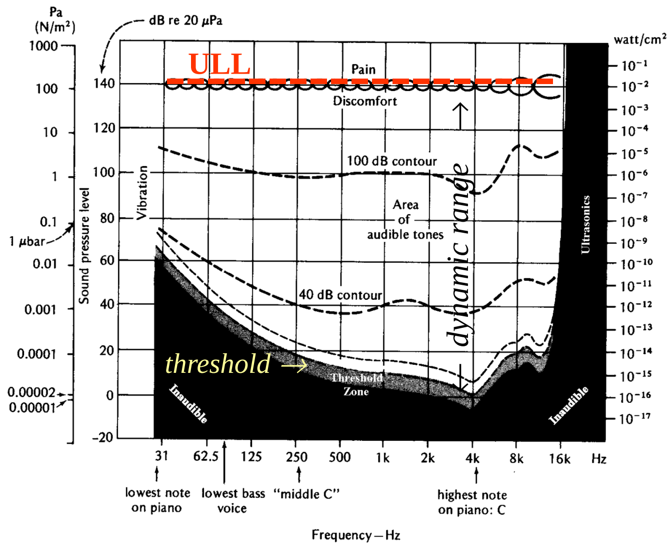
  $20 \times \log_{10}(2\ \mu Pa / 20\ \mu Pa)$
  $= 20 \times \log_{10}(0.1) = 20 \times -1$
  $= -20$ dB SPL

Getting a feel for decibels (dB SPL)

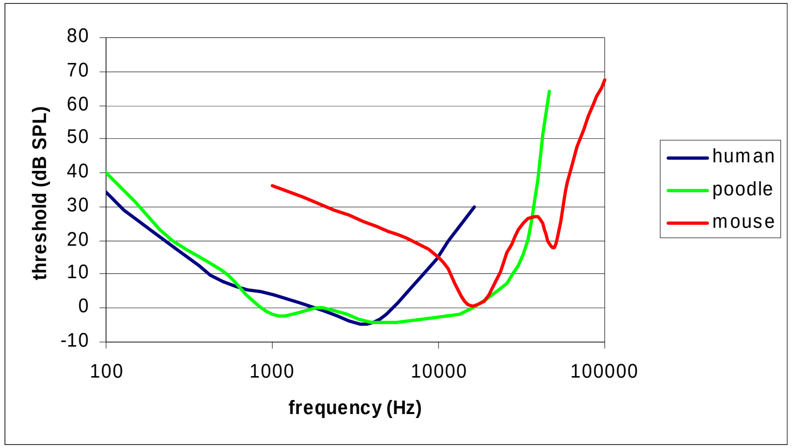


Human hearing for sinusoids

dB SPL



Thresholds for different mammals



Why use a logarithmic unit (dB)?

- Waveforms *can* be specified in linear rms units and often are,
- But our perception of changes in sound amplitude is more closely related to a logarithmic scale (based on ratios/proportions)
- Compare distinguishing a 1 kHz sinusoid of 50 μPa vs. 100 μPa (obvious change)
- And 1 Pa to (1 Pa + 50 μPa) = 1.00005 Pa (indistinguishable)
- Just-noticeable difference in intensity is about 1 dB

Amplitude and Intensity

- Strictly, dB SPL scale is a measure of relative **intensity**
  - (intensity = amount of energy delivered per unit area per unit time)
- However intensity turns out to be simply related to amplitude, and so we use **amplitude** in the dB SPL formula (also explains why the multiplier is 20 instead of 10, for 'deci-').
- dB can be used for any amplitude

l.

$$\text{Sound Pressure Level}\,(dBSPL) = 20\log_{10}\left(\frac{\text{Pressure}(Pa)}{20\mu Pa}\right)$$

dB scales are used widely

- dB can be used for any amplitude measure as long as a reference is defined.
- dB re 1 mV = 20 * $\log_{10}$(x mV/1 mV) where x is any number
- 1 V = 20 * $\log_{10}$(1000 mV/1 mV) = 60 dB re 1 mV
- 1 V = 20 * $\log_{10}$(1 V/1 V) = 0 dB re 1 V
- Can use dB for displacement (meters), current (amps), etc.
- Can use dB for sound pressure but a different reference in place of 20 μPa

What this is all for…

What’s the most commonly used piece of electronic equipment in the audiological clinic?

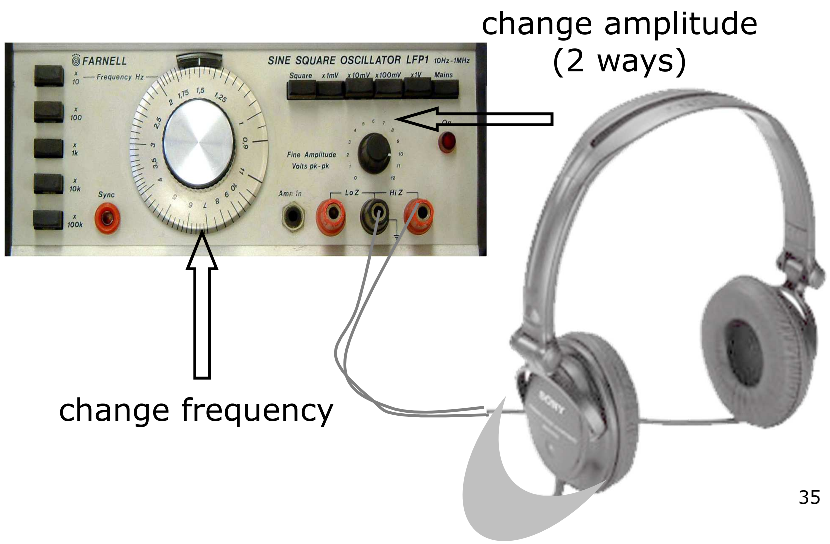
Audiometers are used to determine the lowest intensity sounds that people can hear

(for pure tones as a function of their frequency)

The minimalist audiometer needs …

- An oscillator to *generate* an electrical sinusoidal wave at the desired frequencies
- A calibrated volume control to *adjust* the intensity of the sound
- A headphone to convert the electrical wave to an acoustic one, so it can be presented to the listener

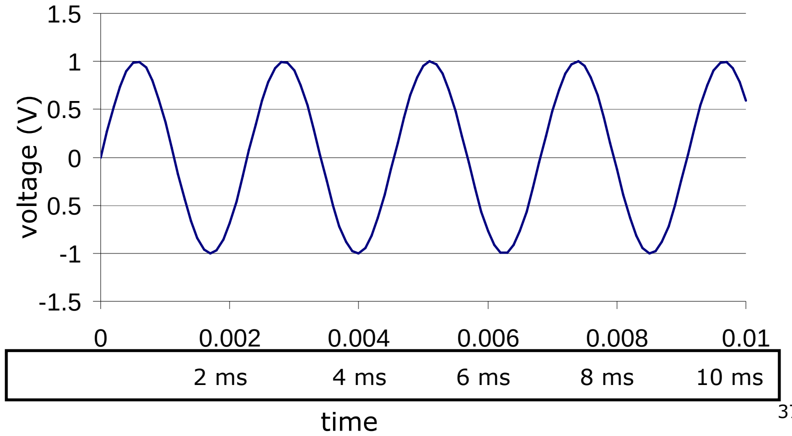
The minimal audiometer



What comes out of the oscillator?

- Electrical wave (to be graphed as a *waveform*)
  - A graph of the *instantaneous* value of the voltage (or current), across time
- Crucial for every waveform …
  - x-axis is always *time* (s, ms, µs)
  - y-axis always a *linear instantaneous* amplitude measure (V, mV, µV)
- But oscillators usually give a very special waveform, a *sinusoid*, also known as a *pure tone* (at least in reference to sounds)

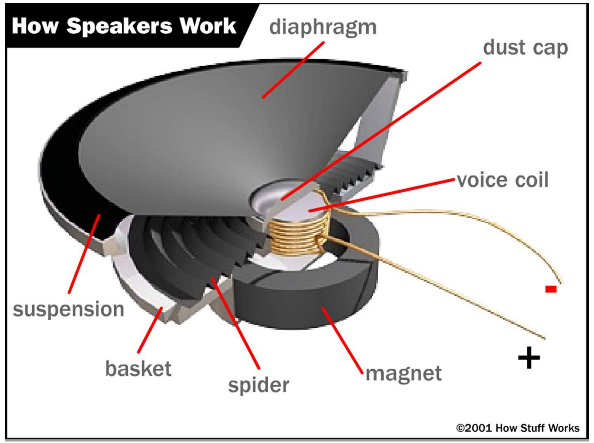
An electrical sinusoidal waveform from an oscillator



Transducing an electrical wave to an acoustic one

- We cannot hear an electrical wave directly, so need to convert it …
- by feeding to the headphones
- which *transduce* the variations in the electrical wave to a mechanical wave
  - the changes in voltage cause the headphone diaphragm to vibrate, which makes the sound

Just like a miniature loudspeaker



http://electronics.howstuffworks.com/speaker5.htm

Movement of the headphone diaphragm