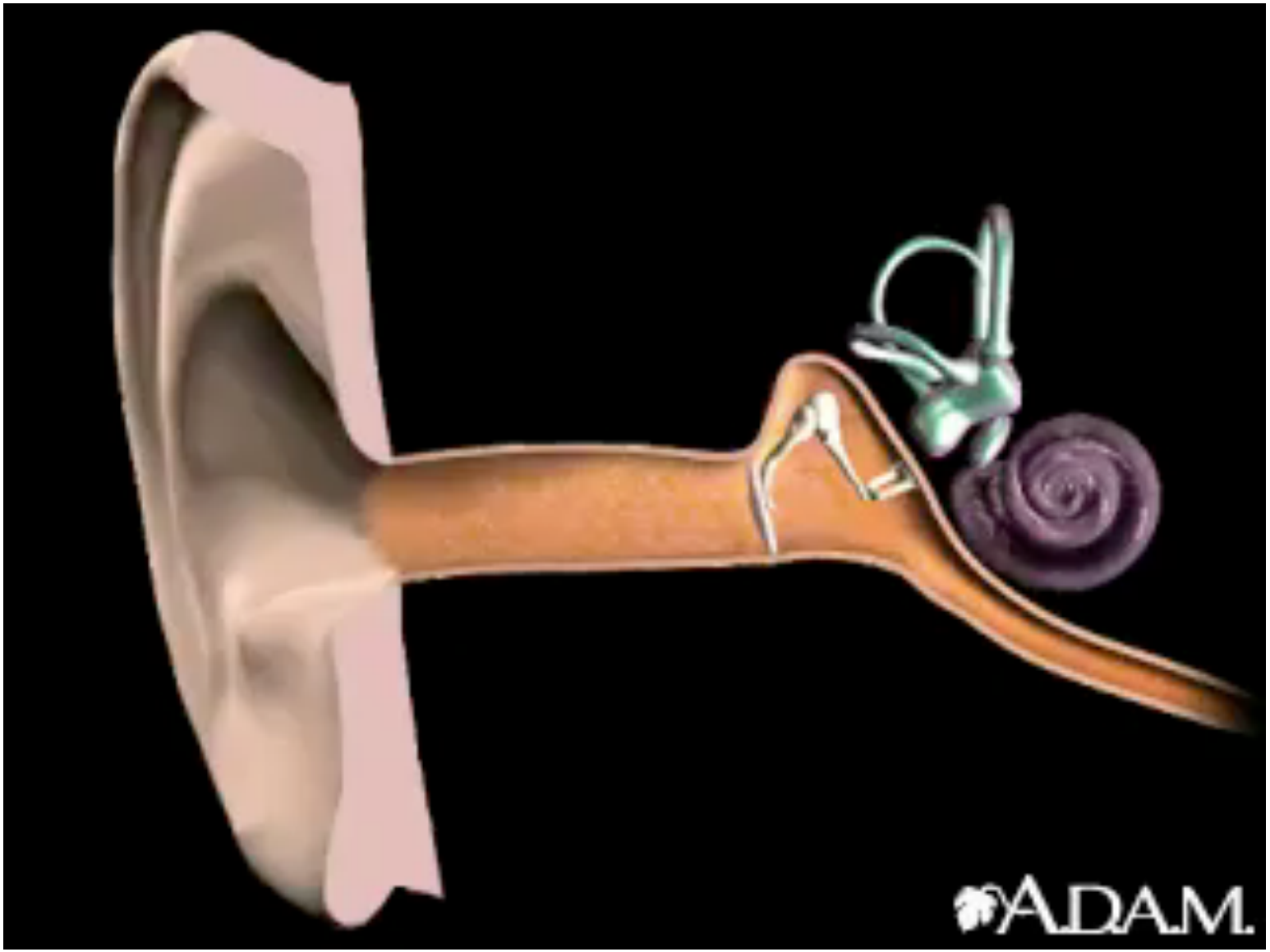
Introduction to Acoustics


A.D.A.M.

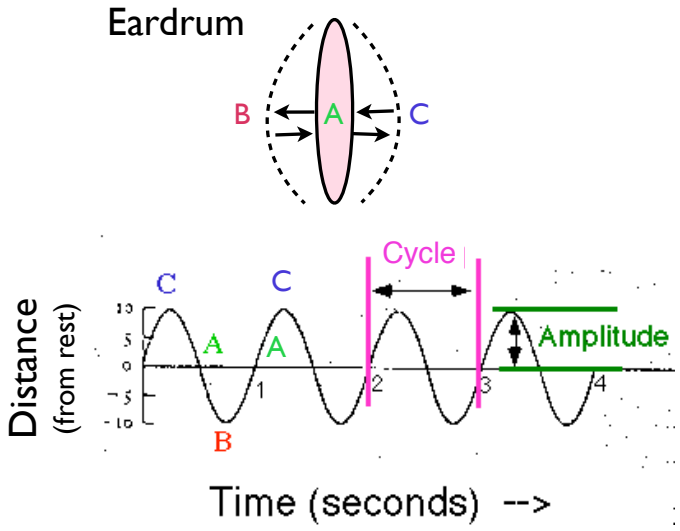
Sound

- Vibration of air molecules.
- Sound is a vibration of air molecules that can cause the ear drum to vibrate, producing an auditory sensation.
- To analyze sound, we need to characterize patterns of vibration.
- Most basic type of vibration is simple harmonic motion (SHM)
  - Period and frequency
  - Amplitude

Frequency and Amplitude

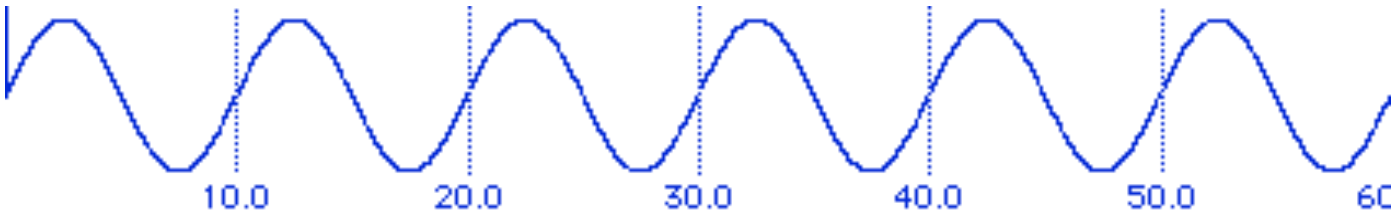
- Frequency: How many times per second the ear drum vibrates in and out, and is measured in Hz (number of round trips per second).
  Period is the amount of time required for each round trip, and for speech is usually measured in milliseconds (1/1000 of a second).

- Amplitude: The extent to which the ear goes in and out, i.e. how far in and how far out, is the amplitude or energy of vibration. Usually measured in decibels in speech (db).



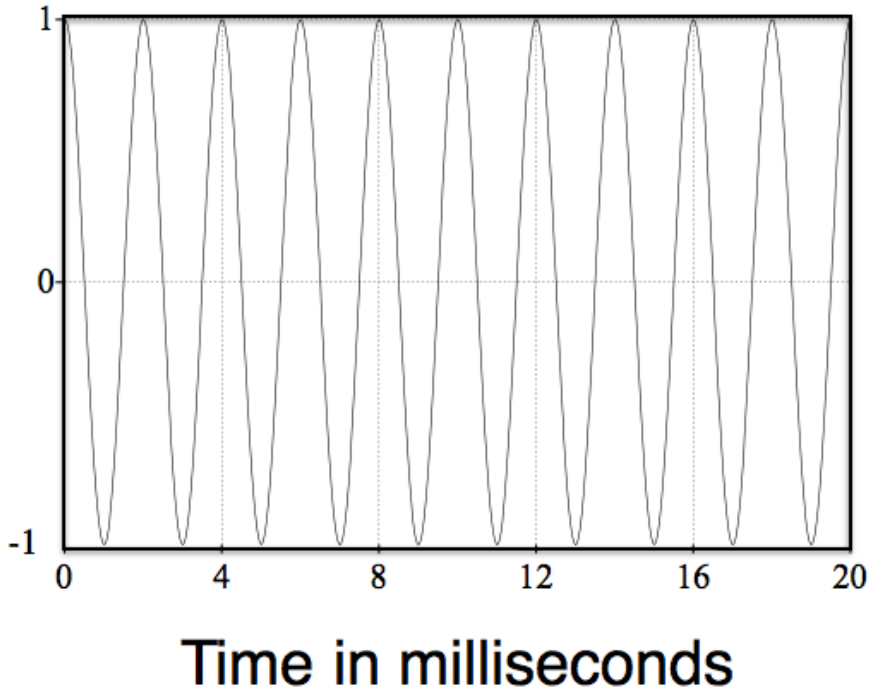
A more realistic example: 100 Hz

- 100 cycles in one second
- How many seconds does each cycle take?
- 1 sec = 1000 milliseconds
- How many milliseconds does each cycle take?



Visualizing sound: Waveform

- 500 Hz = 500 cycles in one second
- How many milliseconds in each cycle?



Period and amplitude are unrelated in SHM

- Period
- determined by the physical properties of the vibrating system
  - length of pendulum bob
  - stiffness of spring
  - size, stiffness of tuning fork tine (hair cells in ear)
- Amplitude
- depends on initial conditions: how the object was set into motion
  - how far from equilibrium position it it displaced
  - how hard it is pushed

Tuning forks

- Period (frequency) is determined by the size and stiffness of the fork.
  - Frequency is perceived as pitch.
  - Example
- Amplitude is determined by how hard you strike it to set it into motion.
  - Amplitude perceived as loudness.
  - Example

Complex Vibrations

- Very few of the sounds in the world exhibit SHM. These are pure tones .
- How do we characterize other patterns?
- Fundamental Frequency (f0)
  - 1/period of repetition of complex pattern
  - example of complex waves with different f0
  - Fundamental frequency in speech: Each fundamental period corresponds to one open and closing of the vocal folds
  - The fundamental frequency is a property of the sound source.
- Fourier Analysis (spectrum)

Fourier Analysis (spectrum)

- Any pattern of vibration can be analyzed as the sum of SHMs each with its characteristic amplitude and frequency.

- For a periodic sound (with an observable fundamental frequency), simple harmonic (pure tone) components always occur at integer multiples of the fundamental frequency, and are referred to as harmonics .

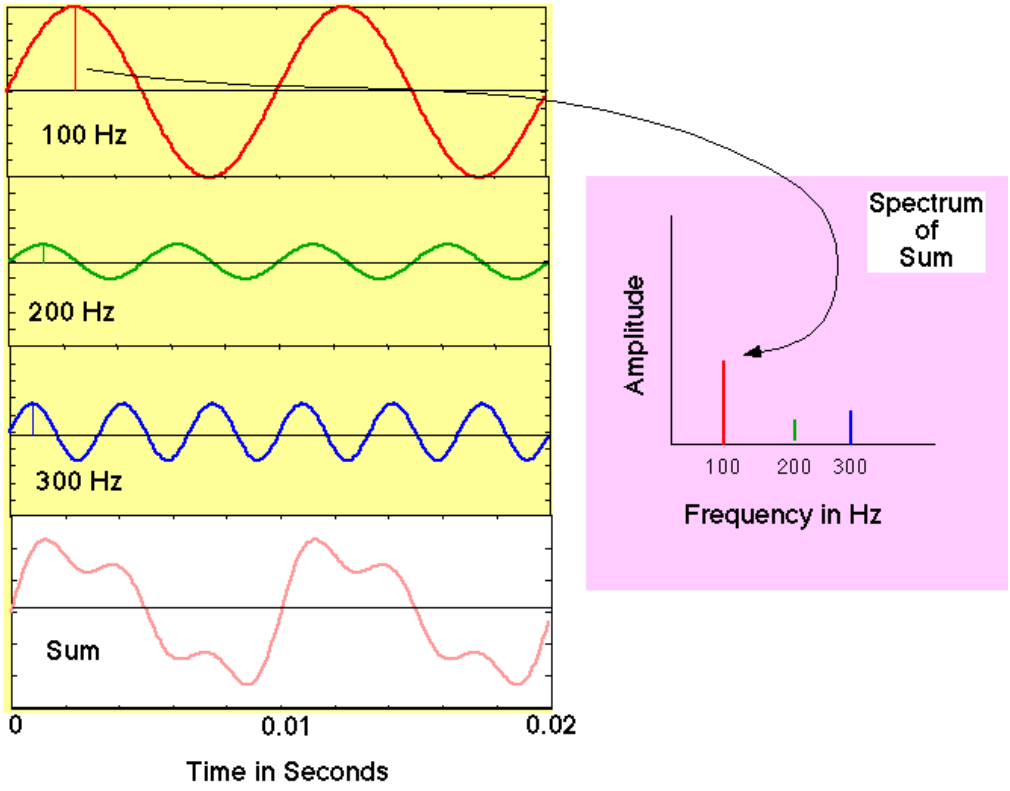
- 2nd harmonic frequency = 2f0.
  3rd harmonic frequency = 3f0.

- example of complex waves with same f0, different harmonic amplitudes

- Harmonic amplitudes are a properties of the sound filtering produced by the vocal tract.

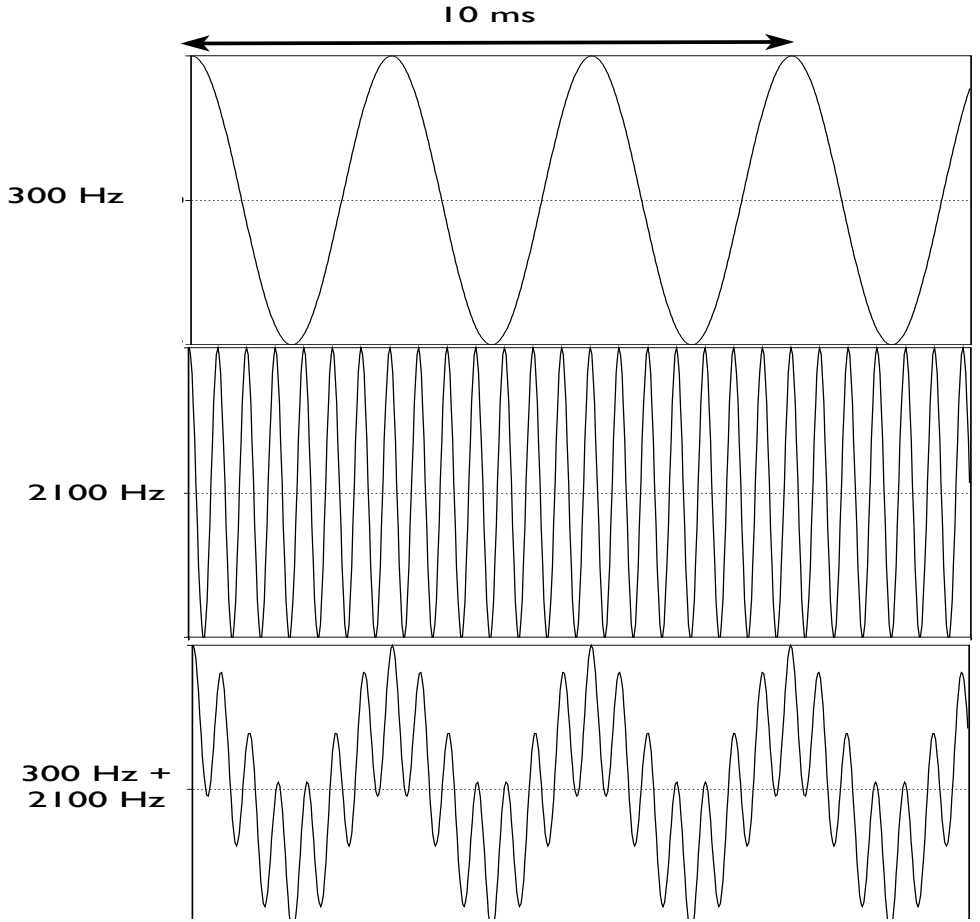
Complex Sounds: Spectrum

- Complex periodic sounds can be represented as the sum of a number of pure tone components.
- The pure tone components are found at integer multiples of the fundamental frequency of the sound and are called harmonics.
- The harmonic content of a complex sound can be represented in a graph called a spectrum.
  - The horizontal axis of a spectrum corresponds to frequency.
  - The vertical axis corresponds to amplitude of the harmonic component in the complex wave.

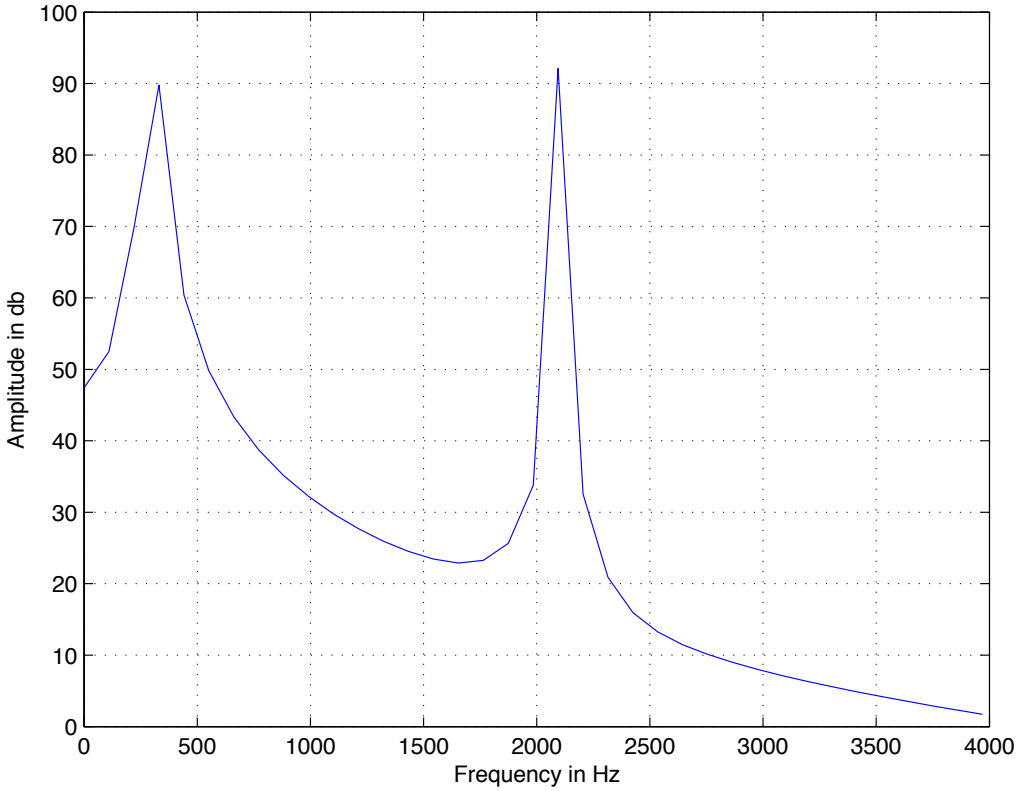


Auditory system:
performs Fourier Analysis on Basilar membrane

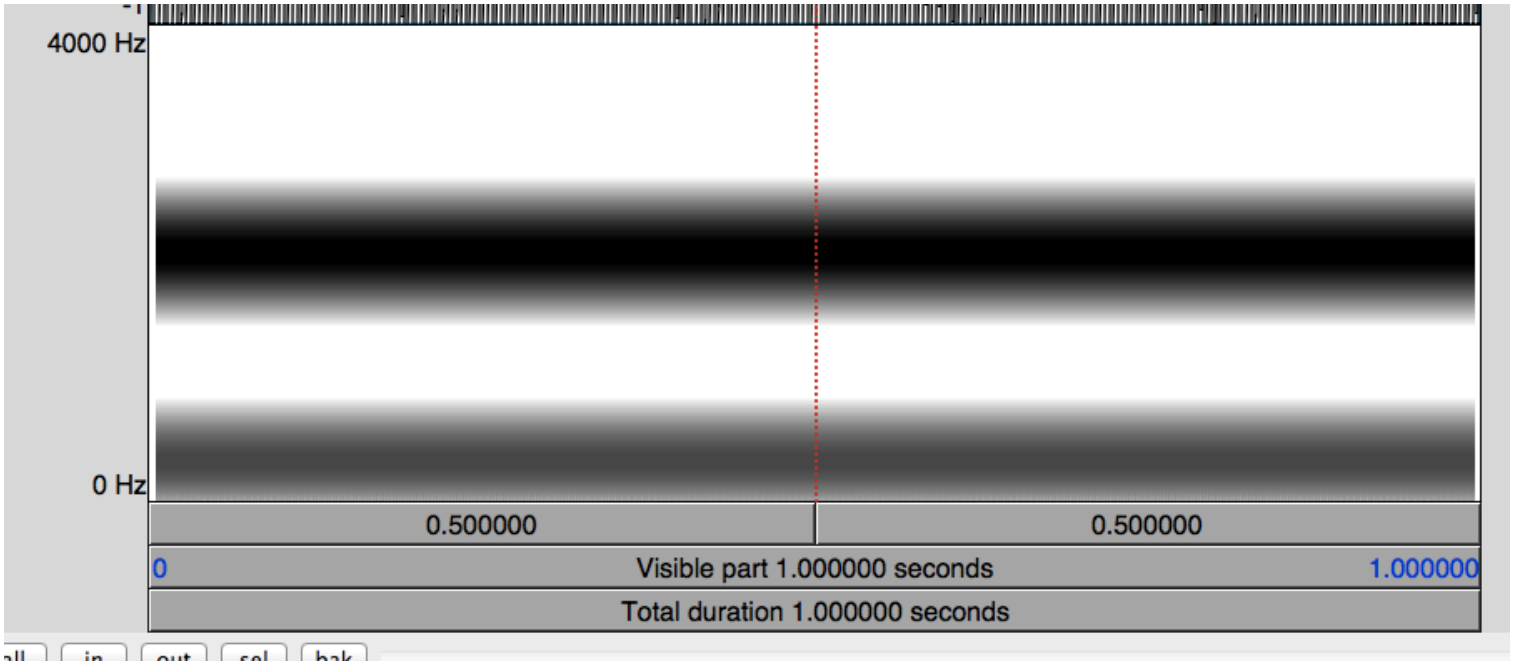
Two simultaneous vibrations: waveform



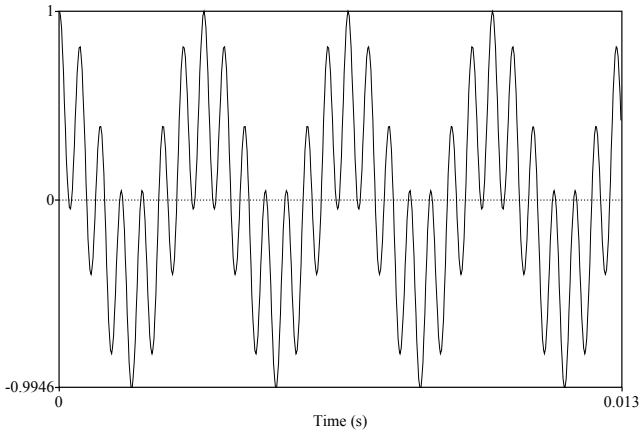
Two simultaneous vibrations: spectrum

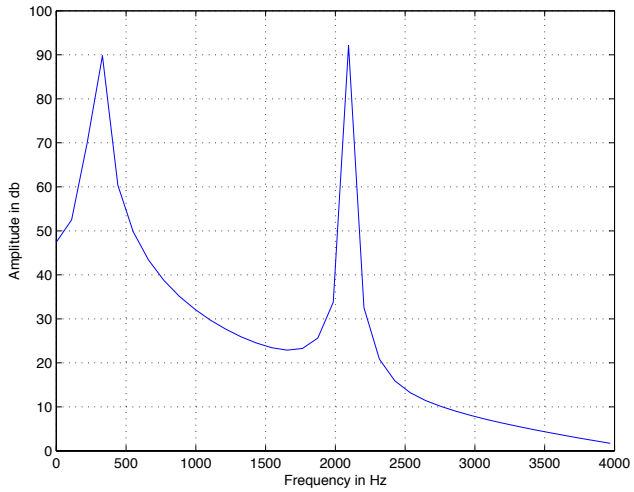


Two simultaneous vibrations: spectrogram

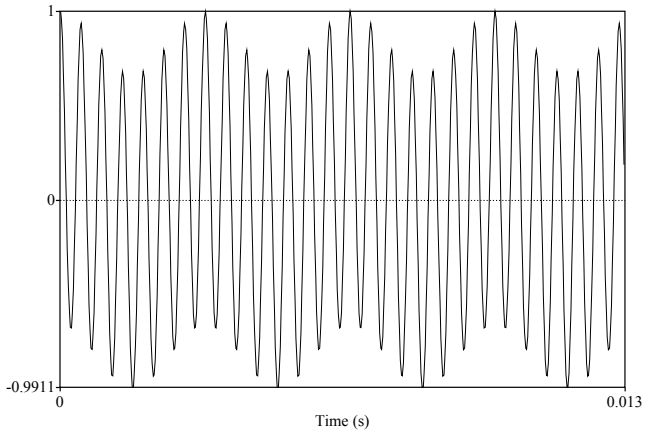


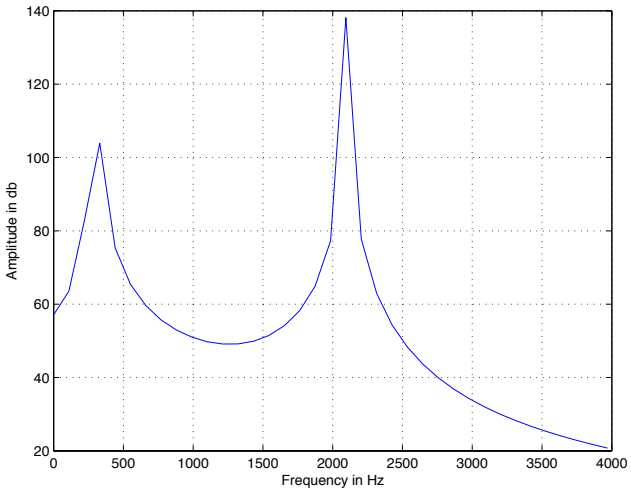
amp(2100) = amp (300)





amp(2100) > amp (300)

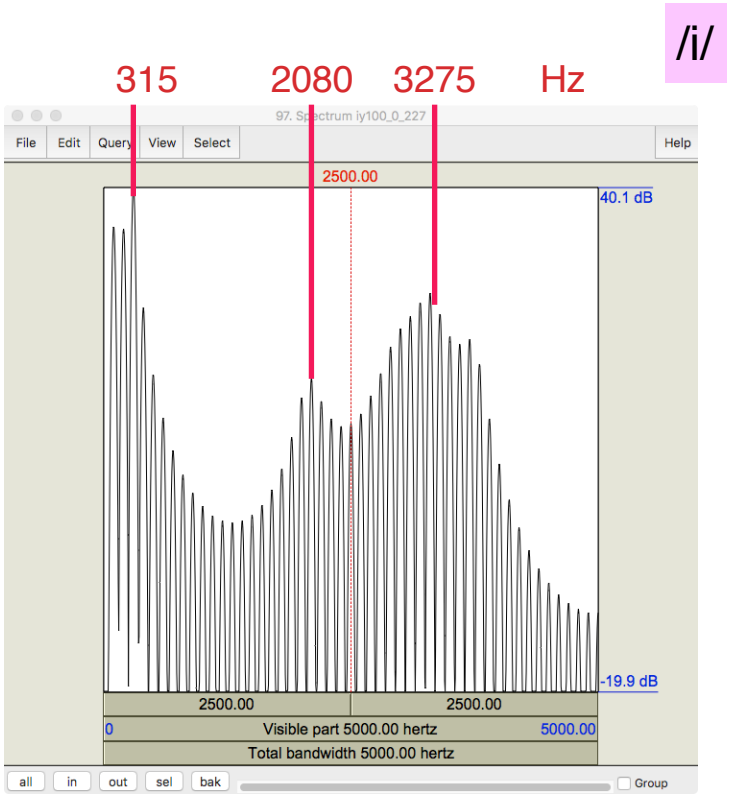


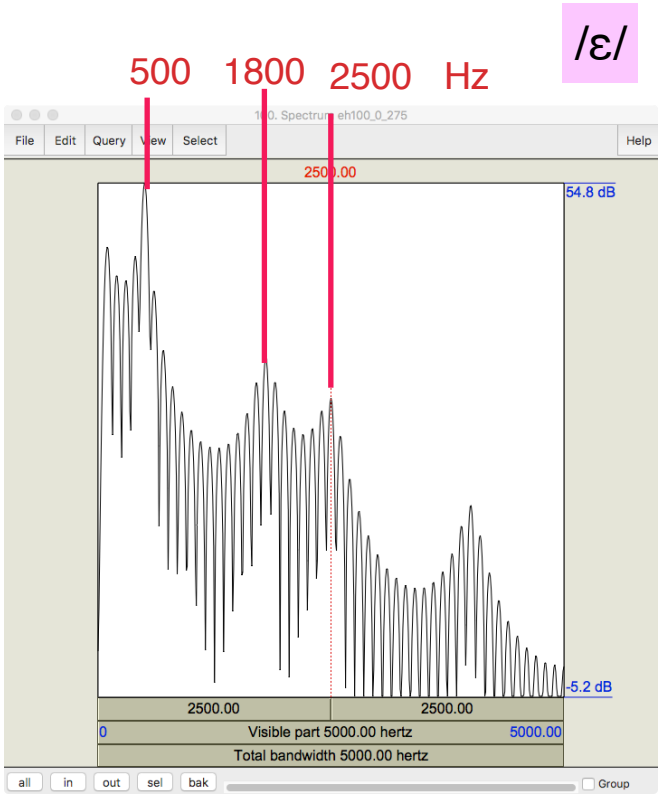


Formant Frequencies and Vowels

- Vowels can be distinguished by the regions of the spectrum that have high amplitude.

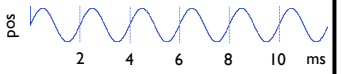
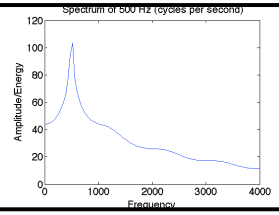
- These regions are called formants, and they are lawfully related to the shape of the supralaryngeal vocal tract and reflect its filtering action.





F0=100

Visualizations of sound

Type	*time*	*frequency*	*amplitude*	Example
Waveform	*x-axis*		*y-axis*	
Spectrum		*x-axis*	*y-axis*	
Spectrogram	*x-axis*	*y-axis*	*darkness, color*