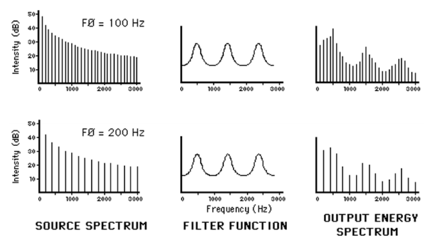
Introduction to Speech and Science

Lecture 4
Vowels and Filters

Review: Source-Filter Theory of Speech Production

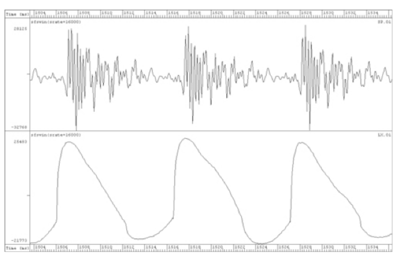


Sources and filters are relatively independent

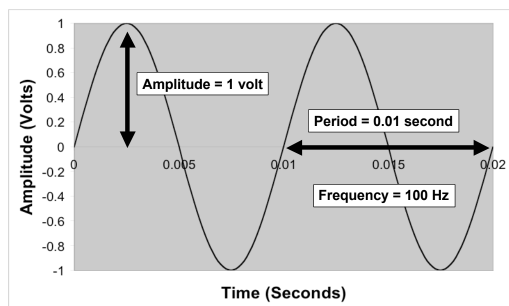
Last Week

Sound waveform

LX



Last Week: Waveform

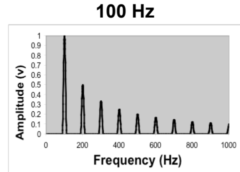


Last Week: Fourier Analysis and Synthesis

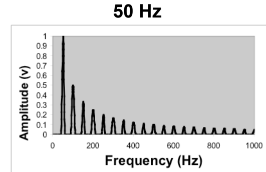
- *Fourier Analysis*
  - All sounds can be analyzed by breaking them down into sinusoids
- *Fourier Synthesis*
  - All sounds can be synthesized by adding sinusoids
  - Also called *Harmonic Synthesis* when making periodic sounds

Spectra: Different Pitches

Fundamental frequency: 100 Hz

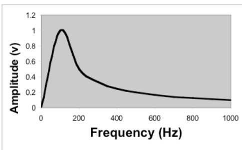


Fundamental frequency: 50 Hz

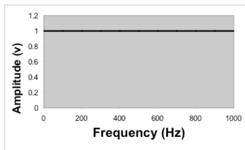


Spectra: Aperiodic Sounds

Sawtooth Impulse



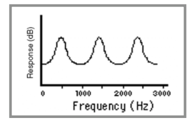
White Noise



This Week: Filters

- The vocal tract is a ***complex resonator*** (i.e., multiple resonances)
  - Can be thought of as a tube
    - One end closed (vocal folds)
    - One end open (mouth)

  - Multiple resonant frequencies
    - Resonances are called ***formants***
    - Resonant frequencies are called ***formant frequencies***



What is a filter?
Example: Simple Resonator

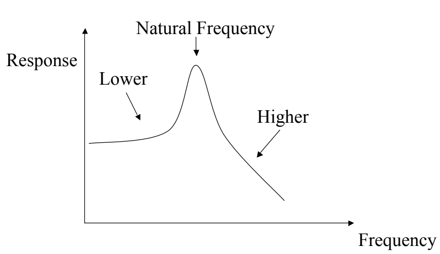
- Examples
  - a pendulum (***example)***
  - a mass on a spring
  - a tuning fork
- Each have a preferred frequency of vibration
  - 'natural' frequency
  - 'resonant' frequency

How to measure a resonator

- Frequency Response
  - How does the resonator change the amplitude of sinusoids with different frequencies
- Ratio Scale

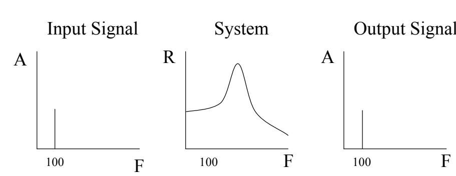
  Response = Output Amplitude ÷ Input Amplitude
- Usually expressed in decibels
  - dB = 20 log (Output ÷ Input)

Simple Resonator Response



Frequency Response Graph

Frequency Domain Description

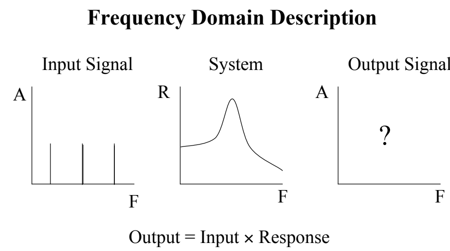


Output = Input × Response

Frequency Response Graph

- Shows how *response* of a system to a sinusoid varies as a function of frequency
- Axes of frequency (Hz) and response (dB)
- Can use to characterize how a system changes any signal
  - (since any signal can be considered a sum of sinusoids!)

Frequency Response Graph

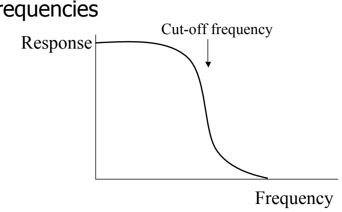


Complex Systems

- Like complex signals, can be analyzed as combination of simple systems
- But easier just to consider frequency response curve
- Calculate effect of system by multiplying input spectrum by frequency response
  - (remember this is *adding* values if we work in decibels)

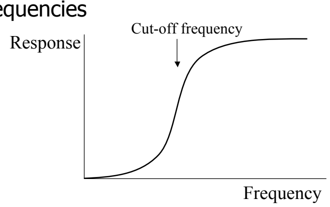
Example Complex Systems

- Low-pass filter
  - lets through low frequencies, attenuates high frequencies

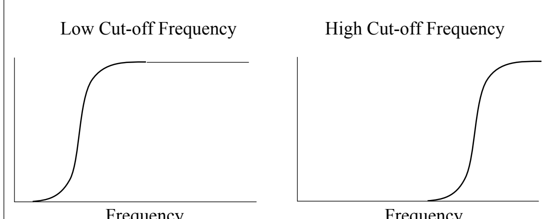


Example Complex Systems

- High-pass filter
  - lets through high frequencies, attenuates low frequencies

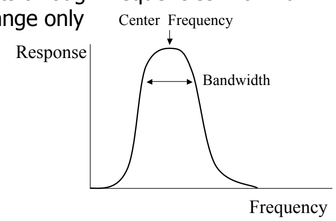


Example Complex Systems

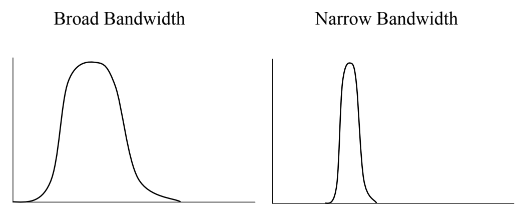


Example Complex Systems

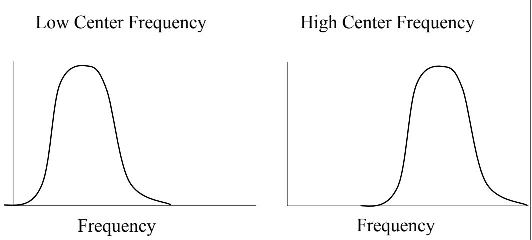
- Band-pass filter
  - lets through frequencies within a limited range only



Example Complex Systems



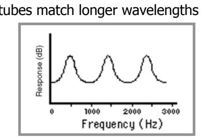
Example Complex Systems



Vocal tract is a complex resonator

- Can be thought of as a tube
  - One end closed (vocal folds)
  - One end open (mouth)

- Multiple resonant frequencies
  - Resonances are called ***formants***
  - Resonant frequencies are called ***formant frequencies***
- Resonant frequencies depend on length of the vocal tract
  - Longer tubes match longer wavelengths of sound (***deer example***)

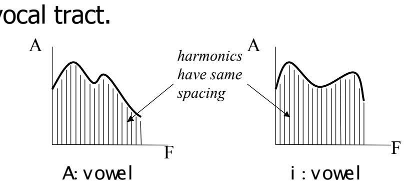


Voices of men, women, and children

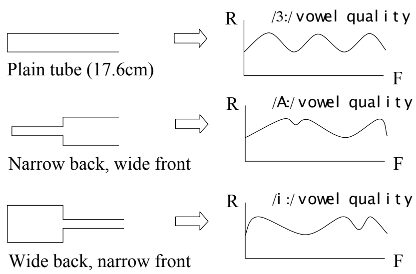
- Confusion: Pitch and formant frequencies are both lower for men than for women and children.
- However, pitch and formant frequencies are dependent on completely different factors
- Pitch of vowels depends on repetition frequency (=fundamental frequency). This is a property of the **source** (vocal fold vibration).
- Formant frequencies of vowels depend on the resonant frequencies of the vocal tract (**filter**).

Vowels

- Although formant frequencies depend on the ***length*** of the vocal tract, they can also be changed by the ***shape*** of the vocal tract.



Acoustic tube models

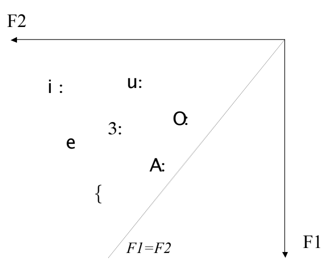


fMRI example

Acoustic tube models

- Summary
  - Even very simple models comprising two tubes of different cross-sectional areas show changes in frequency response very similar to changes we see with vocal tracts.
  - All of the interesting filter properties of the vocal tract arise from its tube shape, not from the physical nature of the articulators

F1-F2 Plane for Vowels



F1-F2 Plane for Vowels

- Summary
  - Surprisingly, most of the distinctive quality of vowels can be ascribed to changes in the first two formant frequencies
  - F1 seems to be related roughly to increasing open-ness
  - F2 seems to be related roughly to increasing front-ness

Variability

- The acoustic form of vowels varies a great deal because of:
  - Accents
  - Chosen speaker gestures
  - Vocal tract size
  - Prosodic context
  - Consonantal environment
  - Noise and channel effects

Summary

- The quality of vowels is controlled predominantly by the frequencies of the first two vocal tract resonances or formants
- Acoustic tube models show us that the response of the vocal tract is mainly due to its shape as a tube

Today's lab: Acoustic analysis of vowels