# Resonance and resonators

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# Harmonics and Resonance

An example...

- Suppose you are pushing a child on a swing and you want the child to go progressively higher with each push.
- When do you push the child?

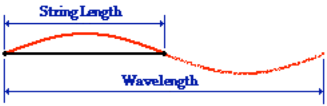
- If you push right as the child reaches the peak height, the amplitude of your push will be added to the momentum of the child on the swing and he/she will go higher.

- If you push before the child reaches the peak height, the same intensity push does not make the child go higher, but actually makes the child go lower.

- Why? When can you push a swing to make it go higher?

- A swing has the motion of a pendulum and it has a cycle.
- The length of time it takes for the swing to go forward and then come back is the period of the swing; it has a frequency.
- Pushing the swing out of *phase* with its period interrupts its cycle because it produces destructive interference.
- The natural cycle of the swing is called its *resonance*.
- Many objects which produce sound have a resonance, which is the *fundamental frequency*, F0, at which the object vibrates.

- When you pluck a guitar string, the fundamental frequency is the resonance frequency of the string. This frequency corresponds to the wavelength (and tension) of the string.
- In guitars, the resonance has exactly twice the wavelength of the string.
- Assuming that all strings are of the same tension, longer strings will have longer waves and lower frequencies than shorter strings, and vice-versa.

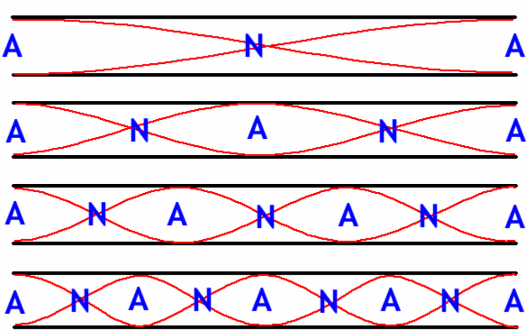



For the first harmonic of a guitar string, the length of the wave is twice the length of the string.

- When you pluck the string, you may be setting in motion a number of different frequency waves.
- However, only the resonance frequency (and harmonics) will stay in motion, just like how only pushing at the right moment keeps a swing in motion.
- Harmonics stay in motion since they are **in phase** with the fundamental frequency, which produces net constructive interference; the **nodes** of the waves correspond.
- Many objects have a resonance frequency, but in general, the larger the object, the lower the resonance frequency.

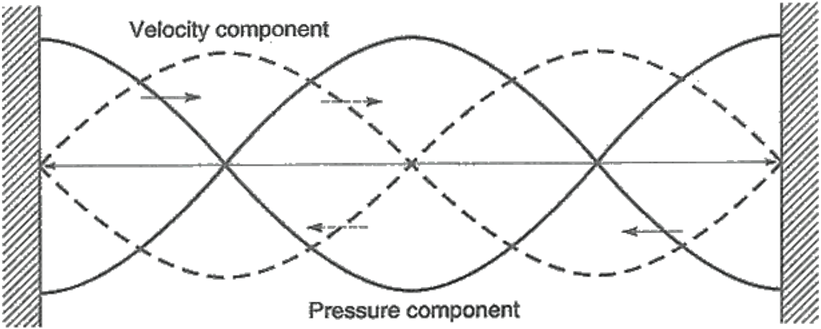
# Wave components

Locations of no displacement are called **nodes** while locations of maximal displacement are called **antinodes**.



# Pressure and velocity

There is inverse relation between velocity and pressure in sound waves. Locations of maximum displacement (pressure antinodes) are locations of minimum velocity (velocity nodes) and vice-versa.



# Sources and filters

- The production of sound involves a *source*, but the sounds coming from this source, including harmonics, may travel through another object before they travel through the air. This object is called a *filter* or *resonator*.
- A string from a guitar has an F0 and a number of harmonics. The string is the source. The box behind the strings is the resonator.
- Humans have vocal folds, which have an F0 and a number of harmonics. Your vocal folds are the source and your oral cavity is the resonator.

# Articulation of the Source

- The velocity of air coming through the vocal cords (in the larynx) causes the pressure to decrease and the muscles to come together briefly.
- Once the muscles come together, the flow is stopped, but then pressure builds up again and forces the muscles apart. The cycle repeats.
- These repetitions create a vibratory pattern of the vocal folds which is the fundamental frequency of the voice. If the vocal folds come together and apart 100 times per second, the F0 of the voice is 100 Hz.
- Called the *myoelastic aerodynamic theory of phonation*

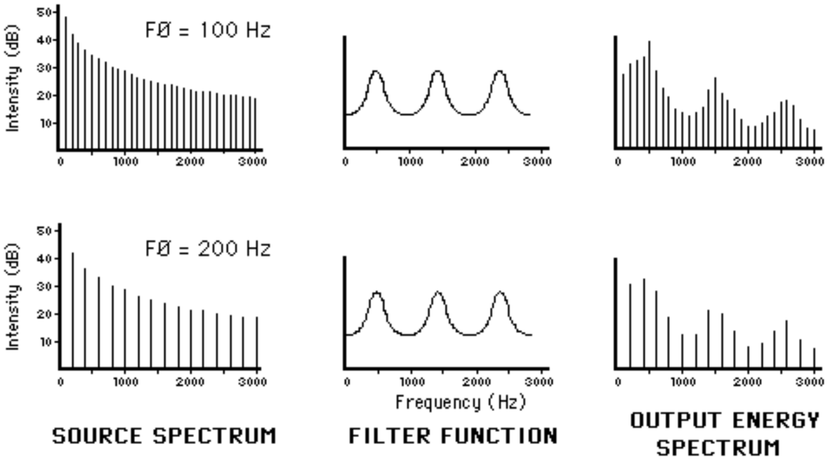
- The source produces the fundamental frequency and all the harmonics in mammals. However, the length of the oral cavity is a filter through which all the harmonics pass.

- The oral cavity is the *resonator* for the source. It has certain *resonance* frequencies which are based on its length.

- The longer the resonator, the lower its resonance frequency.

- Harmonics from the source which pass through the filter which match the resonance frequency of the cavity will be amplified while those which do not match the resonance of the cavity will be *damped* (opposite of amplification).

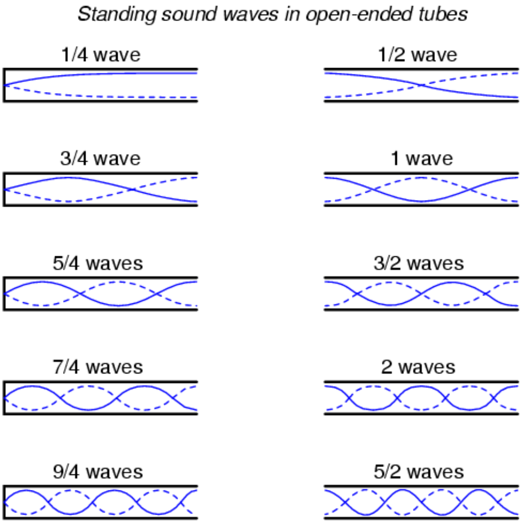
# Source and Filter in Human Speech



# Some properties of a resonating tube

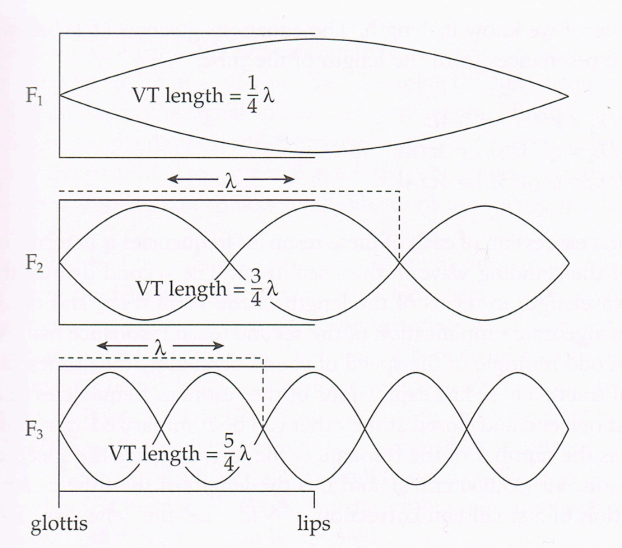
- Just as the source has multiple harmonics, the tube may have multiple resonances.
- Sound travels around curves, so a tube that is coiled up and a tube that is straight have similar acoustic properties.
- We can represent most oral cavities as uniform tubes with one closed end and one open end (the mouth).
- We do this because we can predict the resonances of uniform tubes rather well.

# Resonances in tubes



- The first resonance of a tube with one open end has a pressure node at the open end and a pressure antinode at the closed end.
- The first resonance of a tube with one open end has a velocity antinode at the open end and a velocity node at the closed end.
- The first resonance has a wavelength four times the length of tube.
- The second resonance has a wavelength $1\frac{1}{3}$ times the length of the tube.

- Frequency of the resonance in an tube with one open end is derived:
  - $F_n = \frac{c \times (2n-1)}{4 \times L}$
  - F = frequency, c = speed of sound, n = number of resonance, L = length of tube in cm.
  - If we have a 17 cm. tube and the speed of sound is 34000 cm/sec., what is the frequency of the first resonance?
- A **formant** is the frequency of the resonance in this tube. F1 = frequency of first resonance, F2 = frequency of second, etc.



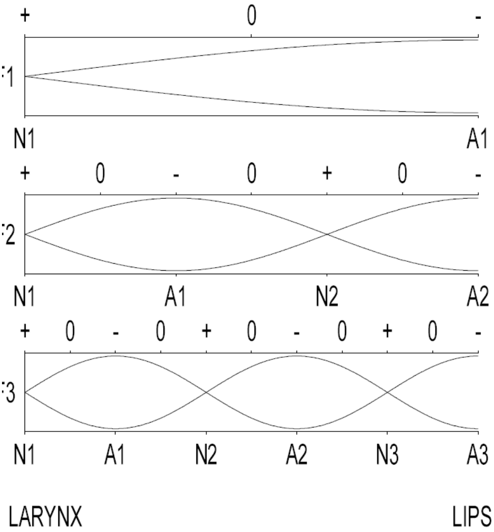

(Johnson 2012, p.43)

Why care about resonance of a tube?

- If we understand the resonance of a tube, we can predict how changing that tube will alter sounds.
- The "tube" in sound communication is the resonator above the source of sound production.
- To produce different vowels, we effectively constrict or expand areas corresponding to different pressure nodes and anti-nodes. The result of this is that vowels will have different formant values. These formants values are the main acoustic characteristics distinguishing vowels in human languages.

## Resonance in the Human Vocal Tract

- The lips are a velocity antinode, where the velocity of air is highest.
- The larynx is a velocity node, where the velocity of air is lowest and the pressure is the highest.
- By changing the width of the tube near nodes and antinodes, humans change the quality of the sound produced.
- Constriction at a velocity node will raise the resonance frequency of a sound while constriction at a velocity antinode will lower the resonance frequency.

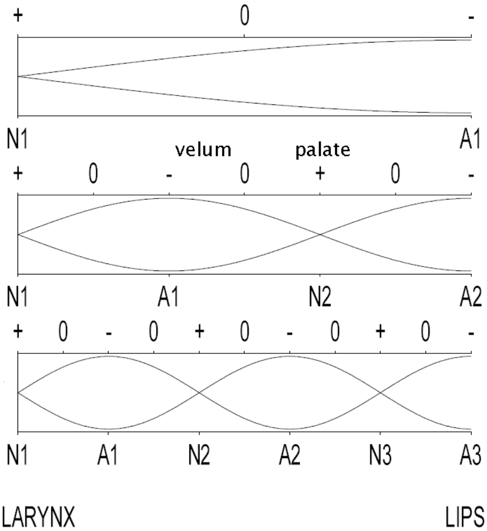

+
0
-
F1
N1
A1
+
0
-
0
+
0
-
F2
N1
A1
N2
A2
+
0
-
0
+
0
-
0
+
0
-
F3
N1
A1
N2
A2
N3
A3
LARYNX
LIPS

Example - Vowels in Human Speech

- The vocal tract is a uniform tube only when the jaw is in a resting position, neither completely open or closed, and when the tongue is in a resting position, being neither raised, lowered, advanced, nor retracted.
- Vowels which are advanced and closed will constrict the front part of the tube near the lips.
- Vowels which are advanced and retracted will constrict the back part of the tube.
- These two actions have different acoustic consequences.

- The constriction of the tongue at various places along the tube has the effect of changing the resonance frequencies of the tube. As a result, the sound [i] sounds different from the sound [u].

- When an velocity antinode is constricted, the resonance frequency of the tube is lowered. When a velocity node is constricted, the resonance frequency is raised.


+ 0 -
N1 A1
velum palate
+ 0 - 0 + 0 -
N1 A1 N2 A2
+ 0 - 0 + 0 - 0 + 0 -
N1 A1 N2 A2 N3 A3
LARYNX
LIPS

- In the case of [i], constriction occurs at the palate, so we expect a raising of the second resonance frequency in the tube.
- In the case of [u], constriction occurs at the velum, so we expect a lowering of the second resonance frequency of the tube.
- Careful manipulations of the tongue, lips, and the rest of the oral cavity allows humans to distinguish between many different vowels.

# Vowels

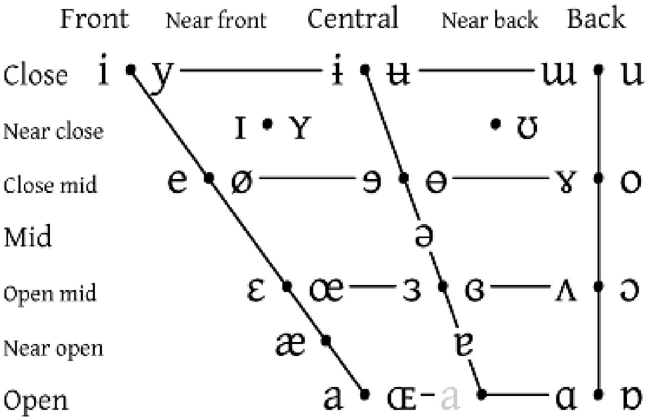
We distinguish vowels acoustically based on their **formant** frequencies, which are the resonances produced from the vocal tract as a consequence of constricting the tube at certain locations.

Our fundamental frequencies (and harmonics) can differ, but the constrictions we produce in our oral cavities have a consistent result across speakers.

This is why we still recognize the vowel [i] from different speakers, even if they have different $F_0$ ranges.

The formant differences between vowels are a topic for our next lecture.

VOWELS




Vowels at right & left of bullets are rounded & unrounded.

# Review

- harmonics vs. resonance
- wave components
- source vs. filter/resonator
- Myoelastic theory of phonation
- Pressure nodes and antinodes
- Constriction at nodes on different resonances.
- Formants