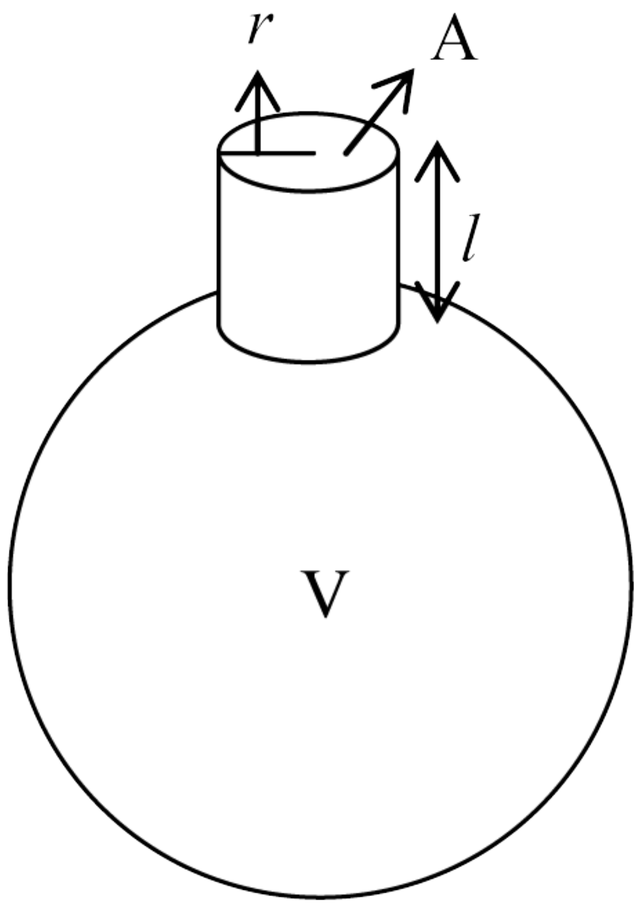
Helmholtz resonator



$$f = \frac{v}{2\pi}\sqrt{\frac{A}{l_{\text{eff}}V}}$$

- Example:

$r = 1\ \text{cm}\,,\ l = 2.7\ \text{cm}\,,\ V = 425\ \text{mL}\,,\ v = 346\ \text{m/s}$

$A = \pi r^2\,,\ 1\ \text{mL} = 10^{-6}\ \text{m}^3$

4. Fourier analysis & synthesis

Fourier's theorem

- **standing waves** are the **"building blocks"** for any complex vibration
- any complex periodic wave can be written as a **sum of harmonics**

$$y(t) = A_1 \sin(2\pi f_1 t + \phi_1) + A_2 \sin(2\pi f_2 t + \phi_2) + \cdots$$

$$f_N = N f_1, \qquad N = 1,2,\cdots$$

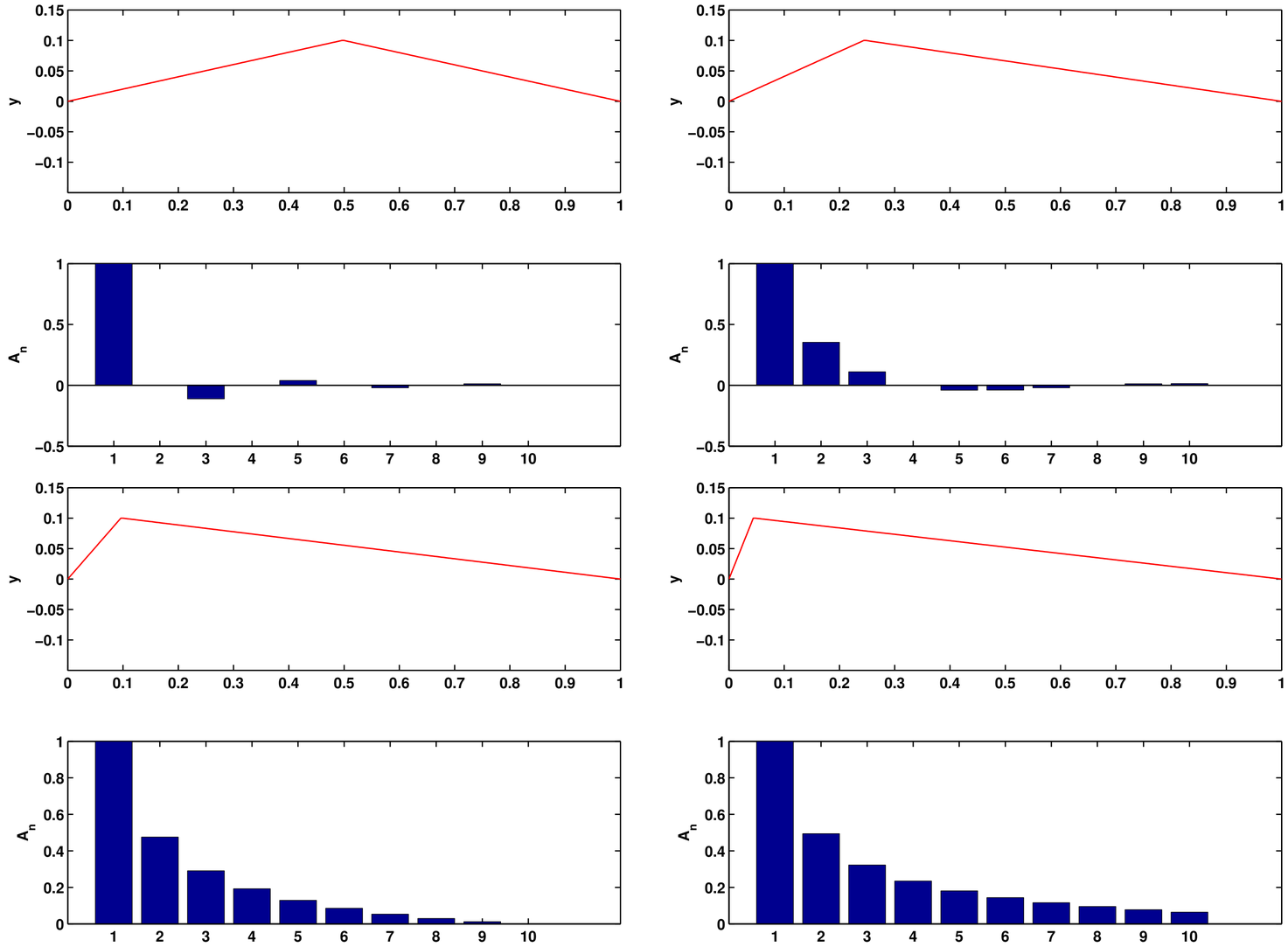
- **Ohm's law of hearing**: Phases have little effect on the timbre of the sound
- **Fourier analysis**: decomposing a complex periodic wave into its contributing harmonics
- **Fourier synthesis**: constructing a complex periodic wave by combining harmonics

5. String instruments

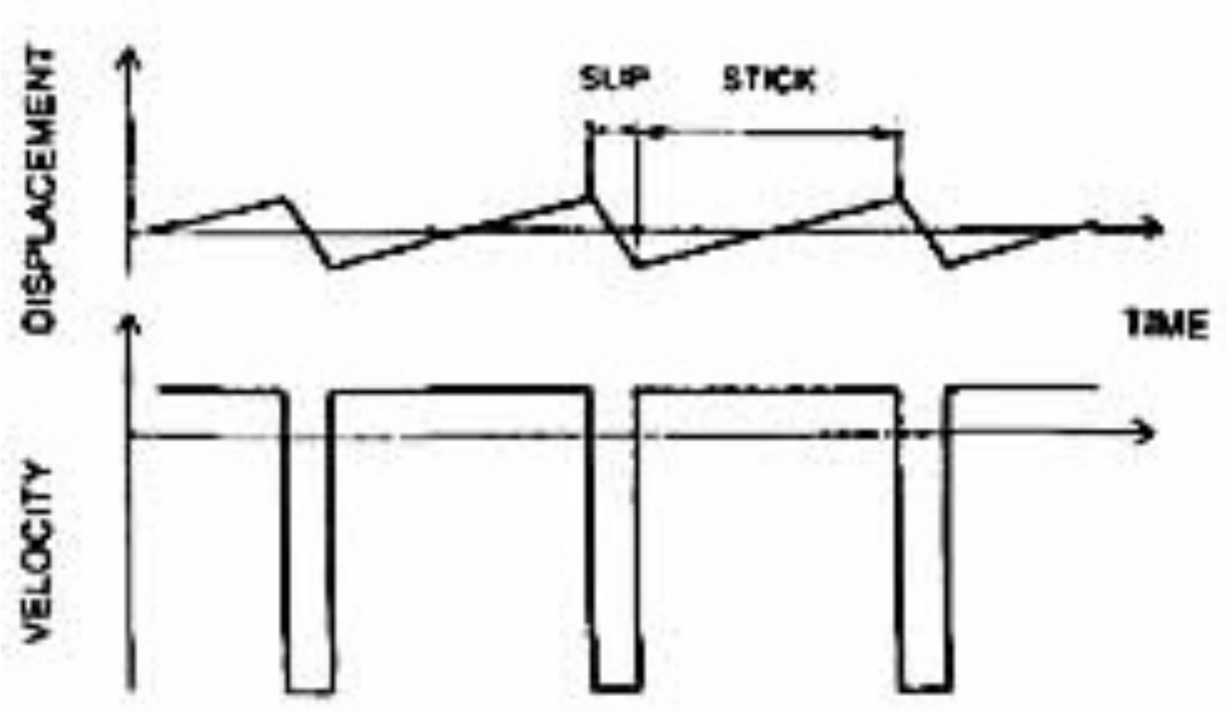
Plucked versus bowed strings

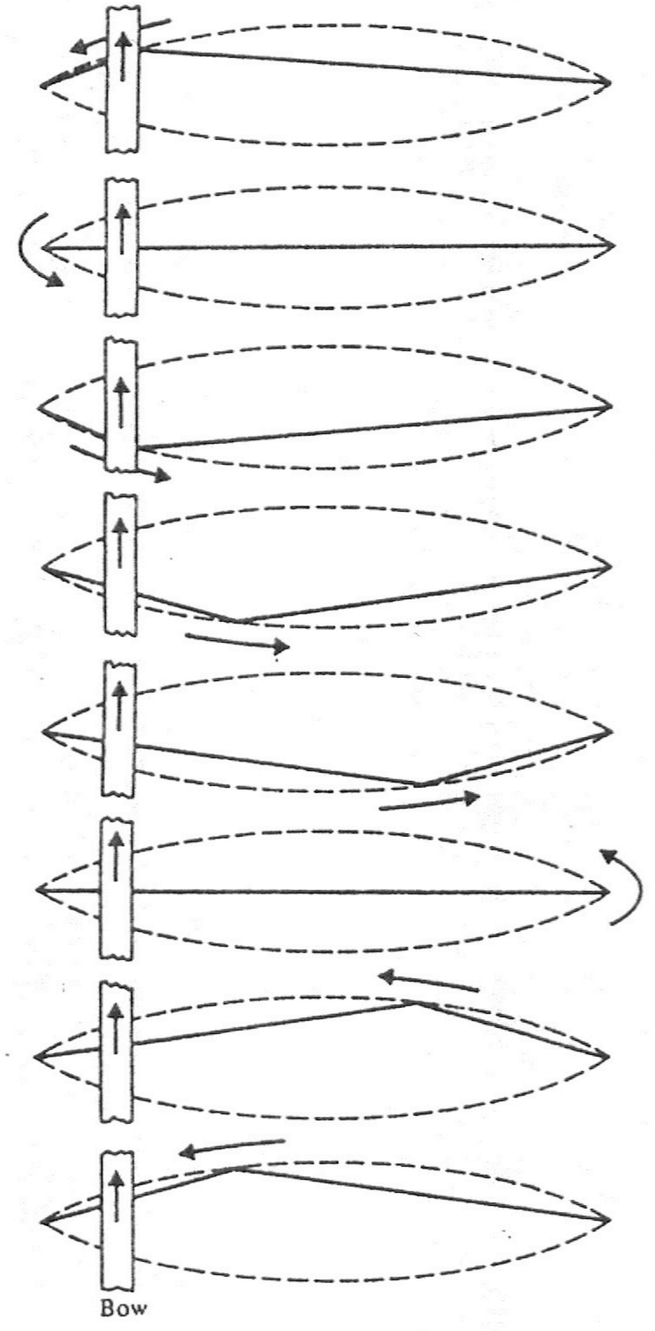
- Plucked string: https://www.youtube.com/watch?v=_X72on6CSL0
- Bowed string: https://www.youtube.com/watch?v=6JeyiM0YNo4
- iPhone guitar video: https://www.youtube.com/watch?v=TKF6nFzpHBU

Fourier coefficients of a plucked string



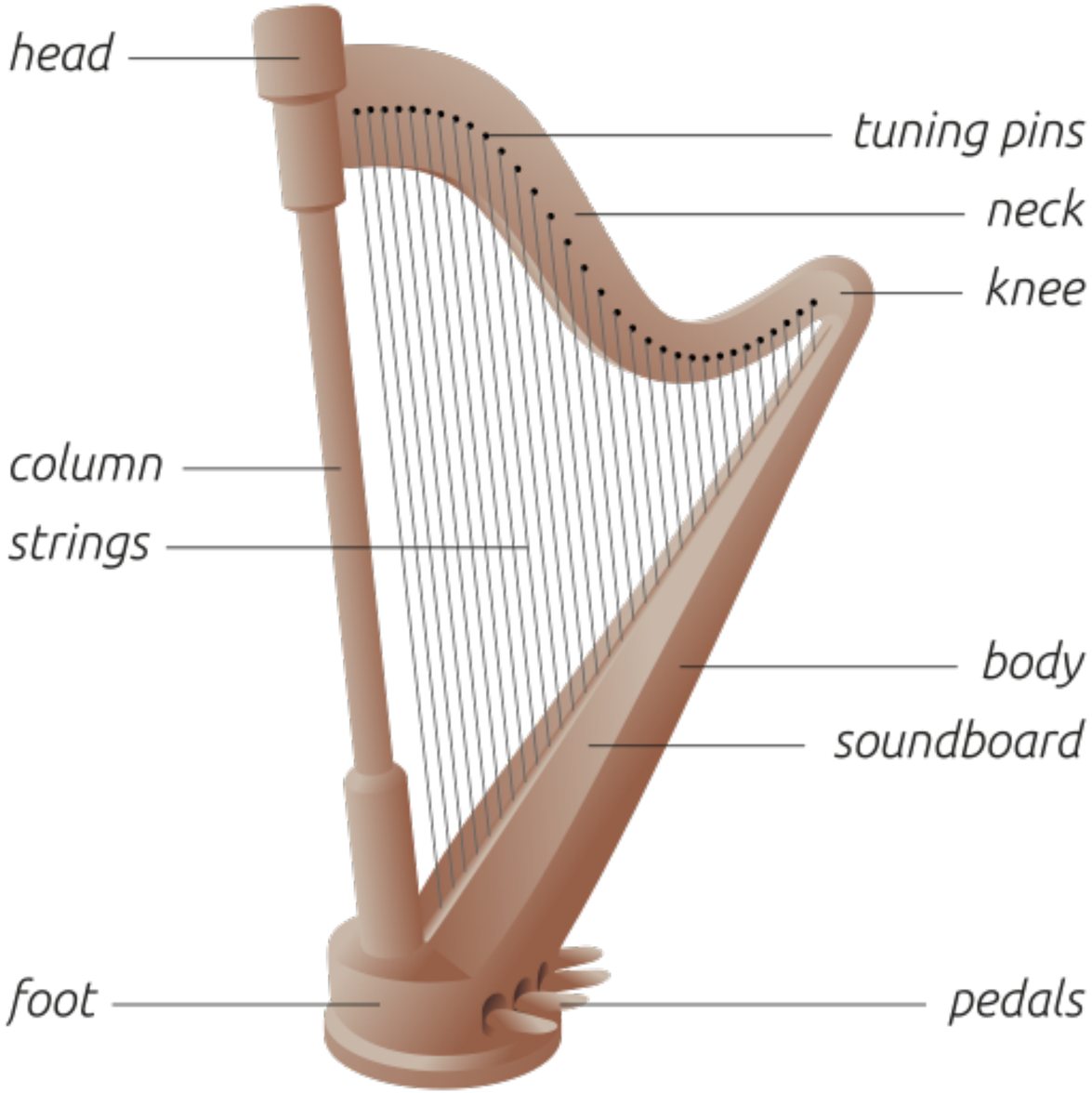
Stick-slip motion of a bowed string





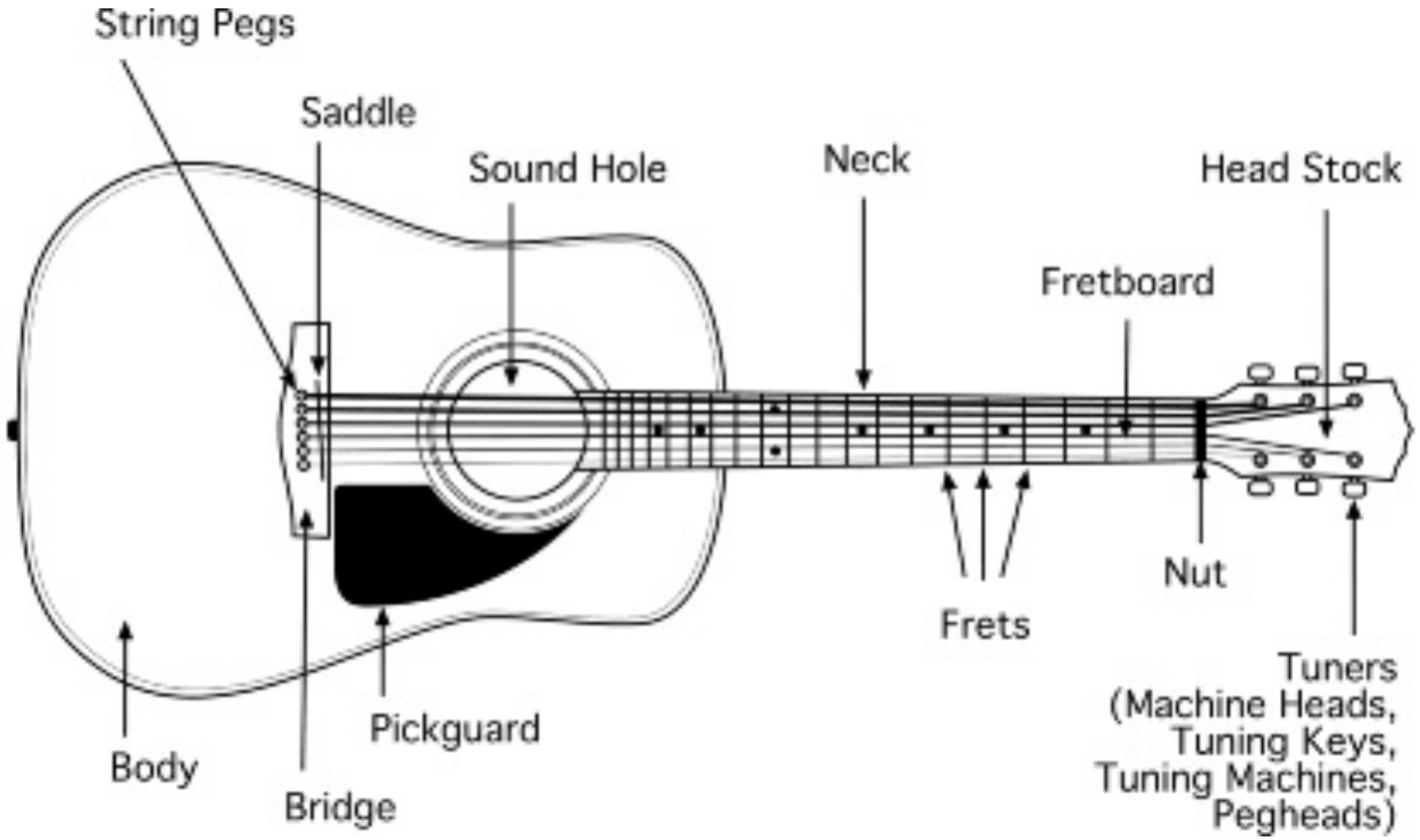
Harp

- the strings have different fixed lengths and are plucked
- each string produces just one note -> need lots of strings
- foot pedal can change the note but only by only a semitone



Guitar

- strings are all the same length, but are made of different materials and are under different tensions
- get multiple notes per string by pressing against a fret
- frets -> fixed notes (like a piano keyboard)



Violin

- strings have all the same length but are under different tensions
- get multiple notes per string by pressing against the neck
- no frets -> no fixed notes
- string vibrations are quickly damped if strings are plucked -> bowed instead
- can vary tone quality by adjusting the intensity of bowing