POLITECNICO DI MILANO

Brass instruments simulation

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Wind instruments

According to their acoustical input characteristics, wind instruments can be roughly divided in two categories:

- Low input impedance instruments
- High input impedance instruments

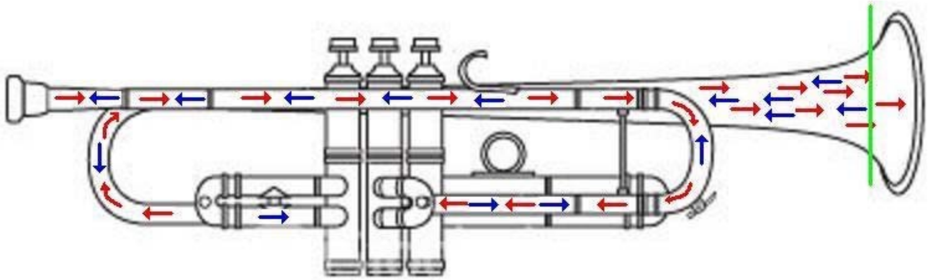
- Low input impedance instruments:
  - Flute, organ pipes, recorder
- High input impedance instruments:
  - Clarinet, saxophone, trumpet (both wood and brass)

Brass instruments

- Sound waves are generated in the air column inside the instruments
- Air vibration is caused by buzzing lips → lip-reed instruments
- Actually, not necessarily made of brass
- High input impedance instruments:
  - Impedance governs the sound generation
  - Interaction with player

Acoustic impedance is a measure of resistance to putting a pressure wave through the tube

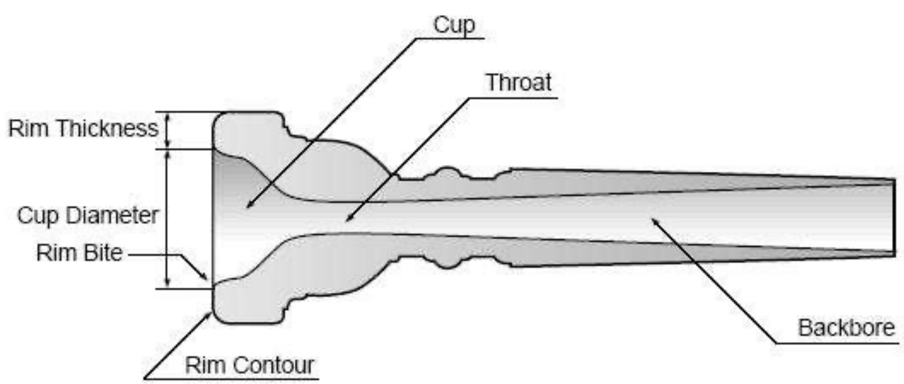
- Pressure wave is reflected at the bell
- Reflected pressure “informs” the player → easier note to play



Brass instruments: parts

- **Lips**: blowing through lips in tension causes oscillation of sound pressure injected into the instrument. Experienced players have a detailed control of the sound generation

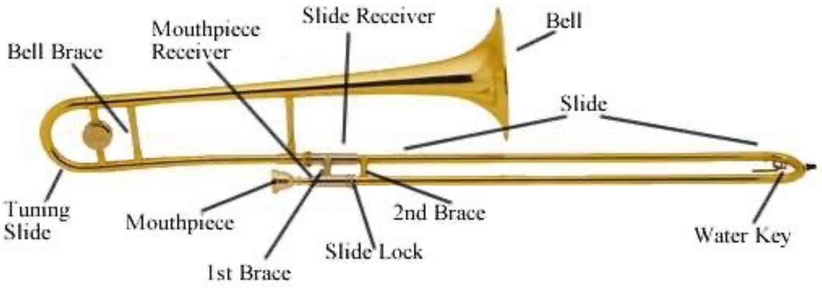
- **Mouthpiece**: composed of a cup and a narrow throat where high acoustic pressure is generated.
  - Comfortable sit for the lips
  - Modify the resonances of the instrument:
    - Louder sound (large cup and wider throat)
    - Easier to play and more high end (small cup and narrow throat)



Brass instruments: parts

- **Tube**:
  - It can produce only “fixed” tones i.e., the eigenfrequencies
  - Acts as a selector for the final produced sounds

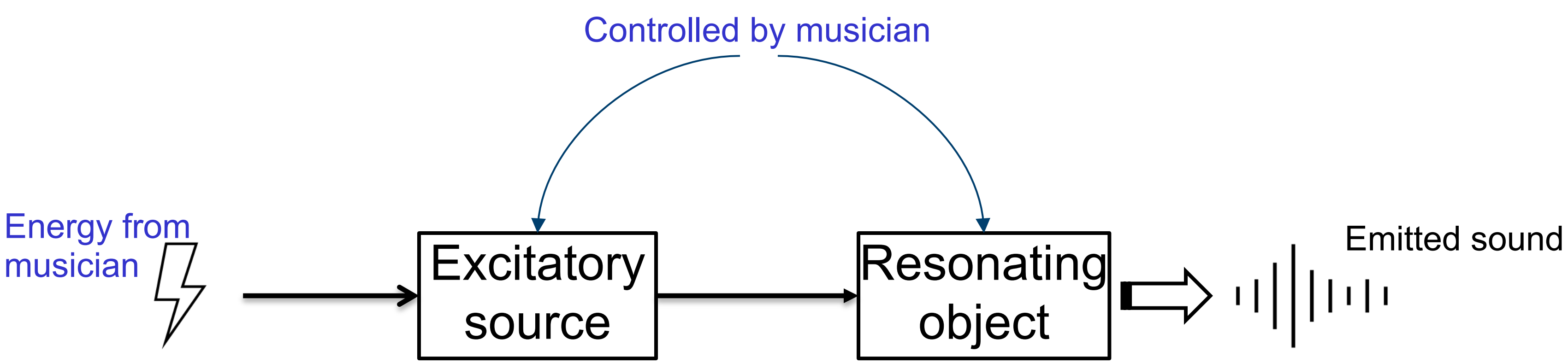
- **Bell**:
  - it modifies the tube with a conical section that varies the overtones
  - Improves radiation of higher frequencies → bright and louder sound



Source filter model

Simple free-vibration musical instrument model

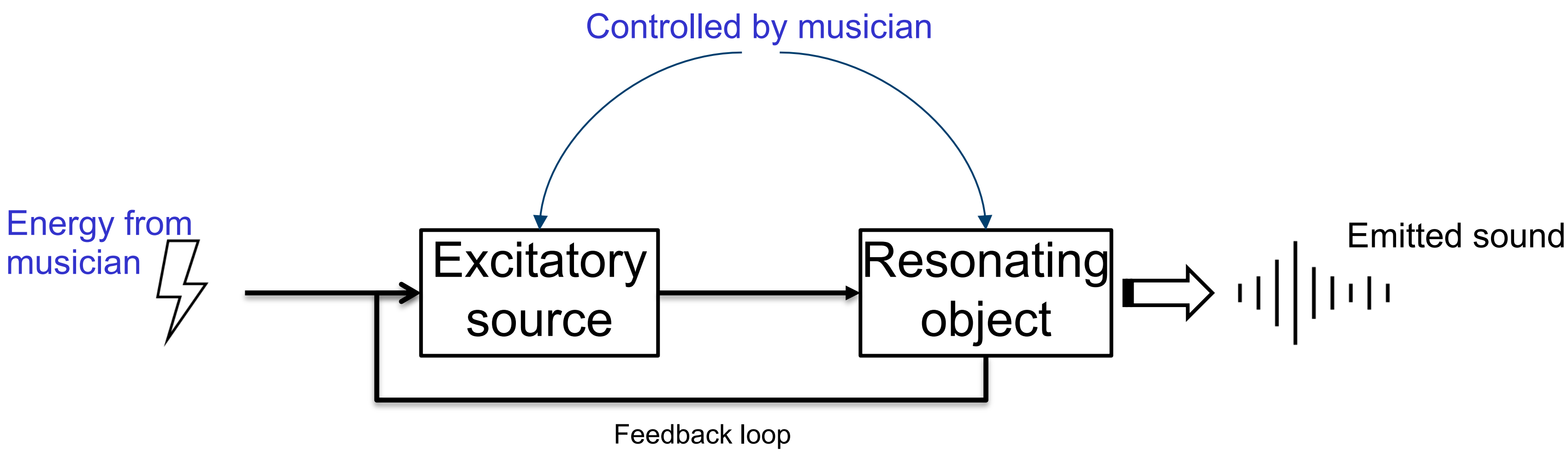
- Common model for percussive-like instruments
- Excitation is “impulsive” (hammer, finger, stick etc.)
- The resonator generates sound and then fades out



Source filter model: feedback

Closed-loop musical instrument model

- Valid for wind and bowed instrument
- Auto-oscillation given by retroaction
- Continuous excitation
  - Resonator acts on the excitator through feedback loop
- More difficult to control



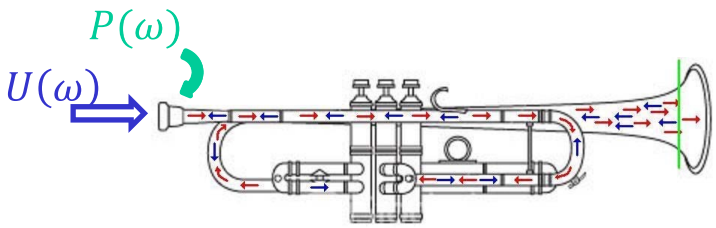
Source filter model:input impedance

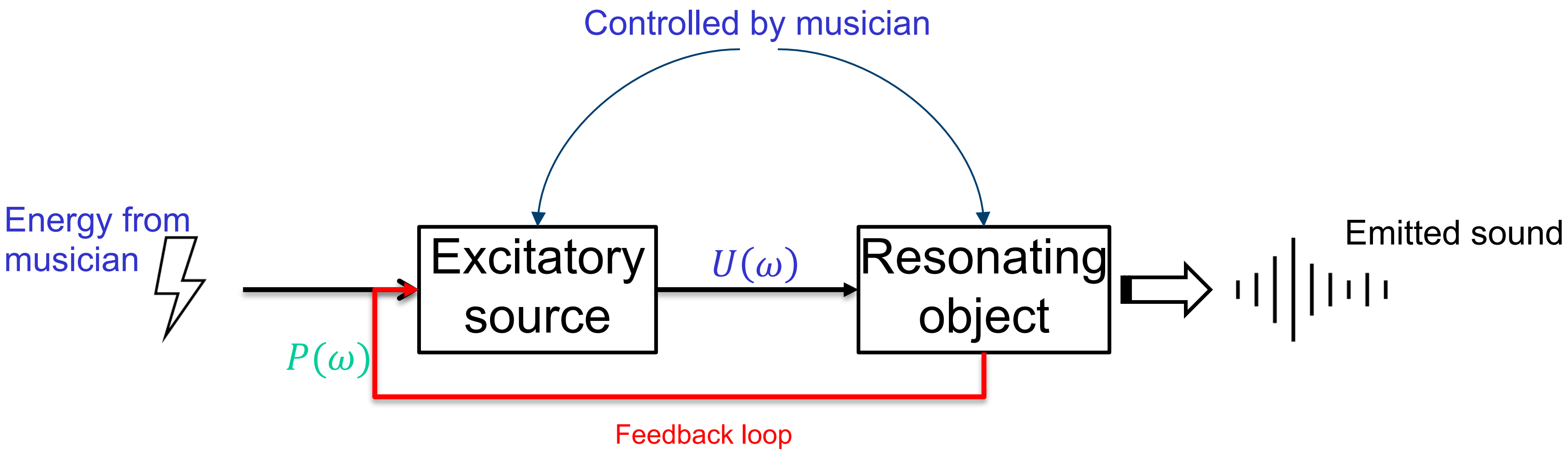
How can we quantify retroaction?

- Acoustic impedance:

$$Z(\omega) = \frac{P(\omega)}{U(\omega)}$$

  - Describes the effect of retroaction to the input
  - Represent a linear approximation of the resonator
  - Can be measured/simulated

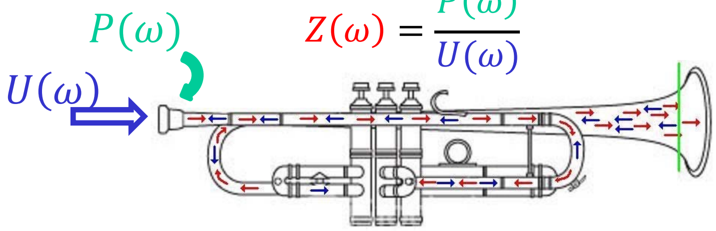


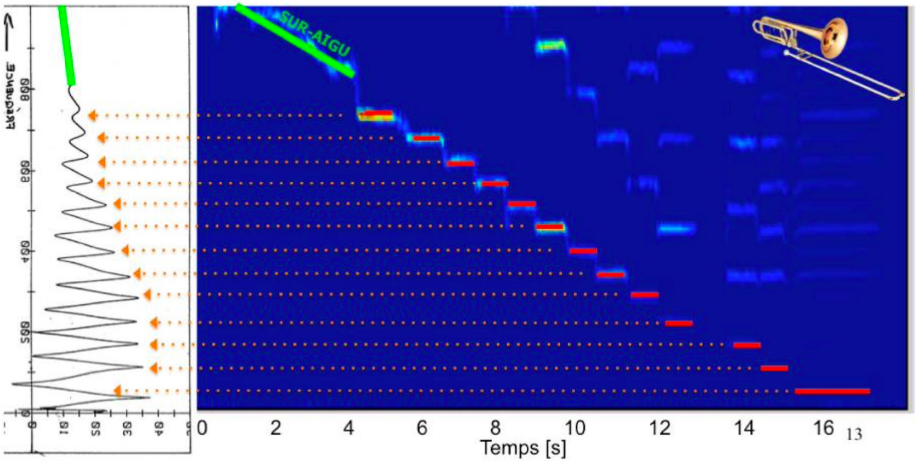


Source filter model:input impedance

- Resonator “works” at specific frequencies
  - Air column in the tube
- Inspecting input impedance we can find “playable” notes
  - Located at impedance peaks
  - Musician can play one of the available notes
- Important aspects:
  - Tuning: frequency location
  - Amplitude: playing difficulty

$$Z(\omega) = \frac{P(\omega)}{U(\omega)}$$





Source filter model:Resonator

- We have to model the resonator in order to obtain the desired behavior

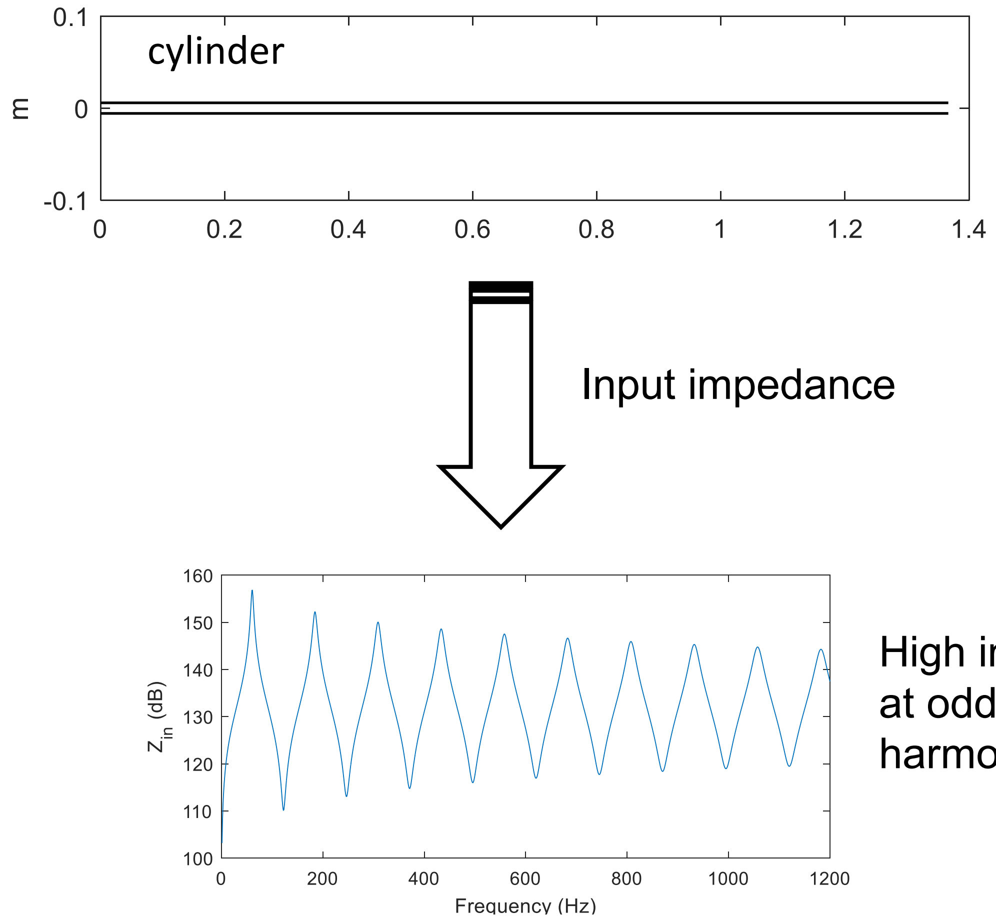
- Most important parameter: Geometry

- Long/short tube → low/high notes

- Shape influence:
  - Cylindrical instrument $f_1 \approx \frac{c}{4L}$, L is the tube length
  - Conical instruments $f_1 \approx \frac{c}{2L}$

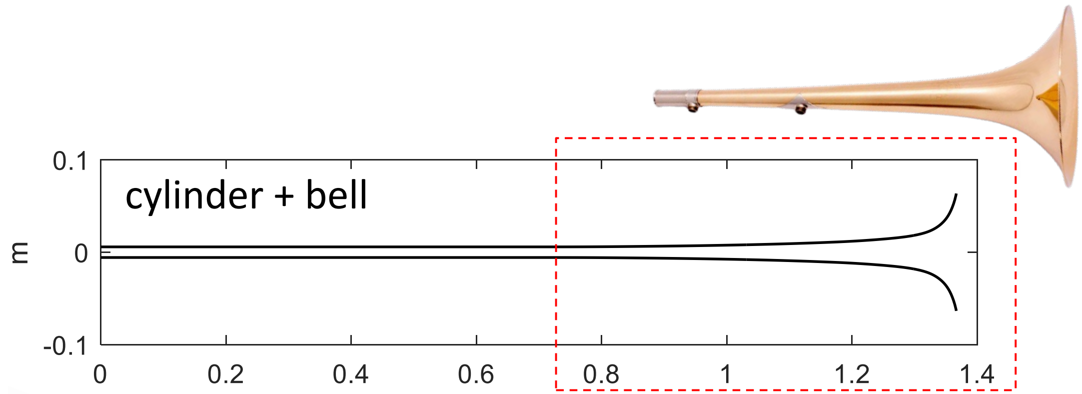
- Maker ability:
  - Find the optimal shape for well-tuned instrument

Source filter model: Design



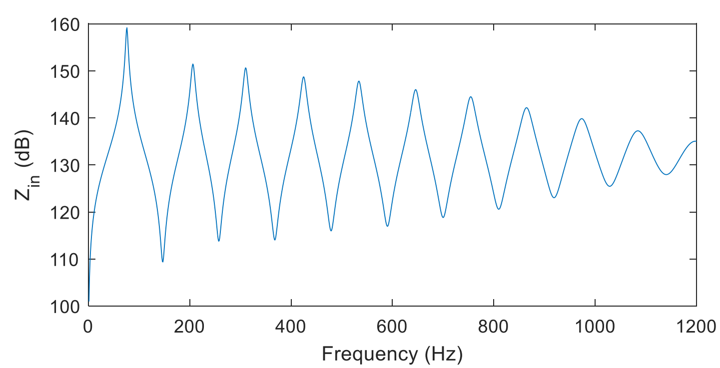
High impedance at odd harmonics

Source filter model: Design



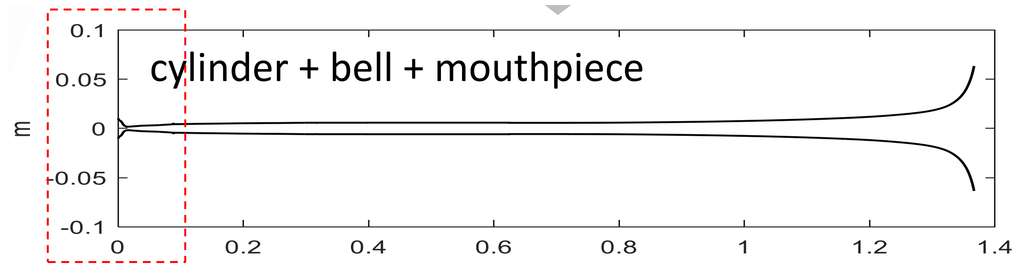
Input impedance

Raised resonance frequencies



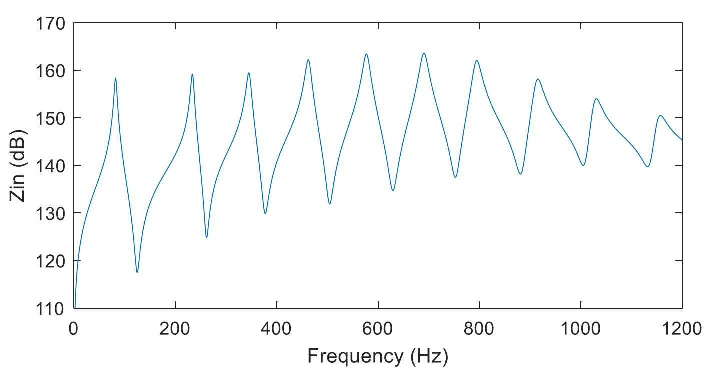
Improved radiation
Smoothed high frequencies impedance

Source filter model: Design



Input impedance

Added mouthpiece resonance



Improved impedance in the ”middle range”

Bibliography

Campbell, M., Gilbert, J. & Myers, A. “The Science of Brass Instruments” ISBN: 978-3-030-55684-6 (Springer-Verlag, 2021)

Freour, V. “Seminar on Brass instruments”, Musical Acoustics Course, 2020, available at: https://politecnicomilano.webex.com/politecnicomilano/ldr.php?RCID=7133bc0ff3f945e2a4e070ecd9a7a511

Comsol simulation

- We want to implement simulation of brass instrument (trumpet)

- Take advantage of 2D axisymmetric simulation
  - Reduced complexity
  - Reduced computation time

- The physics involves acoustic pressure

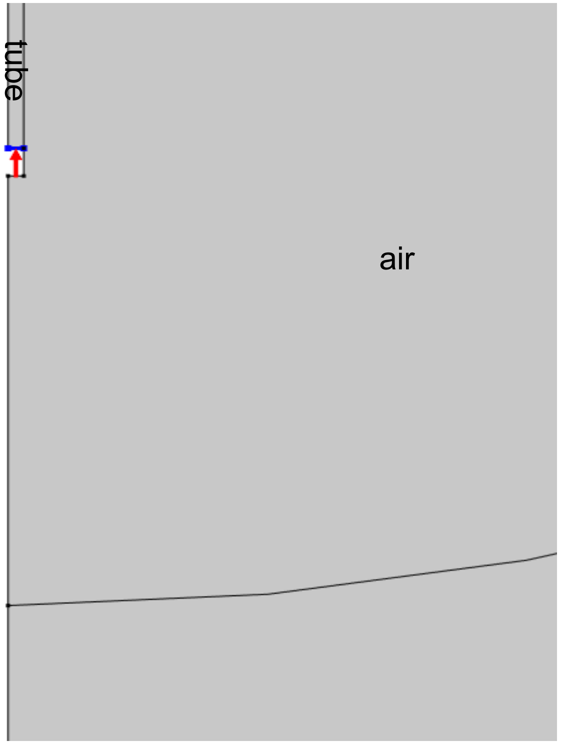
- We are interested in the input impedance: $Z(\omega) = \frac{P(\omega)}{U(\omega)}$
  - Hence a frequency domain study is used

- Start from simple geometry: tube

- Progressively add components (bell and mouthpiece)

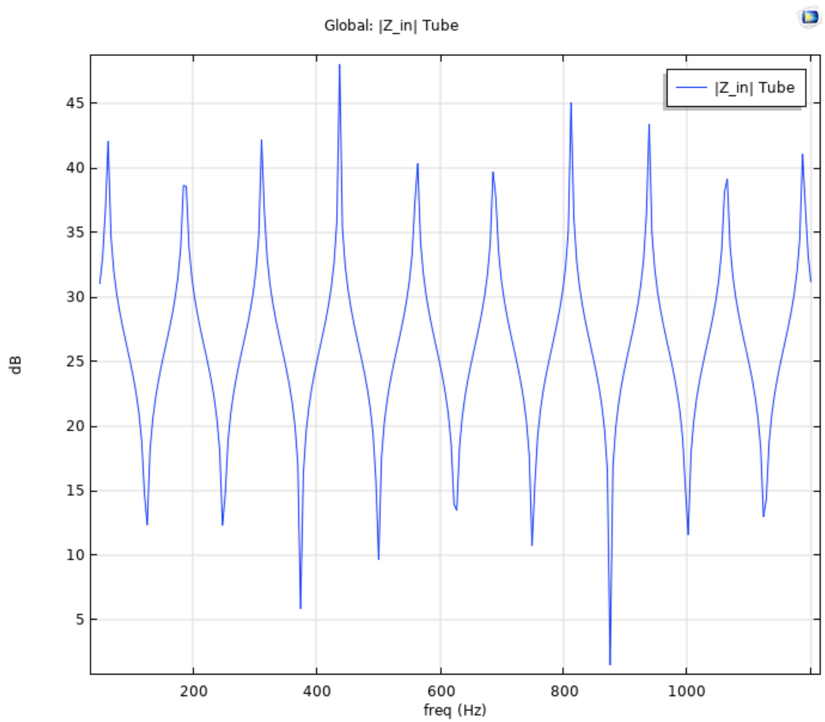
Simple tube model

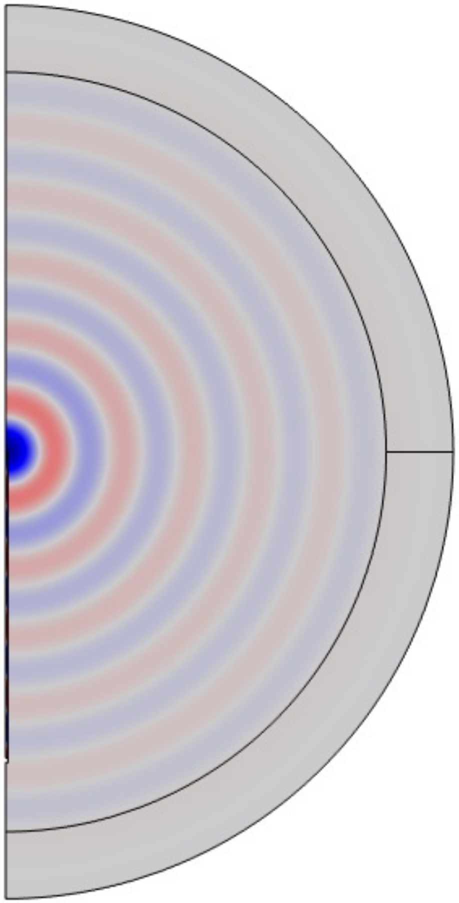
- Study the input impedance of a tube.
- Frequency study from minimum frequency f_{min} to maximum frequency f_{max}.
- Use a 2D axisymmetric geometry
- Tube is surrounded by air to simulate free field
- We impose a given pressure at the input



Simple tube model

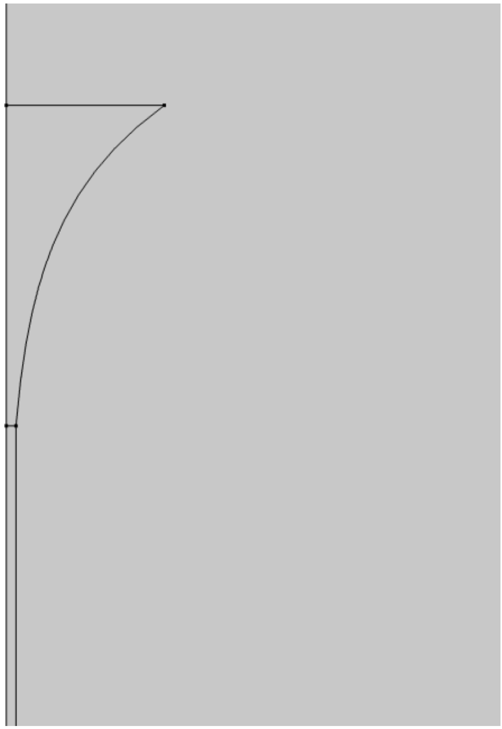
- Study the input impedance of a tube.
- Frequency study from minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$.
- Use a 2D axisymmetric geometry
- Tube is surrounded by air to simulate free field
- We impose a given pressure at the input

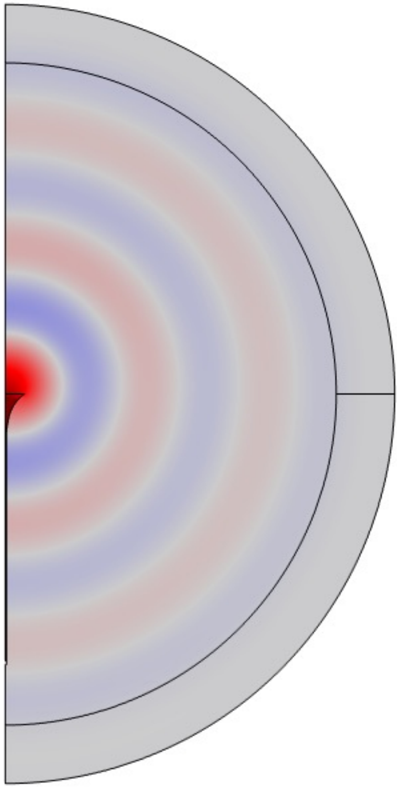




Tube with bell model

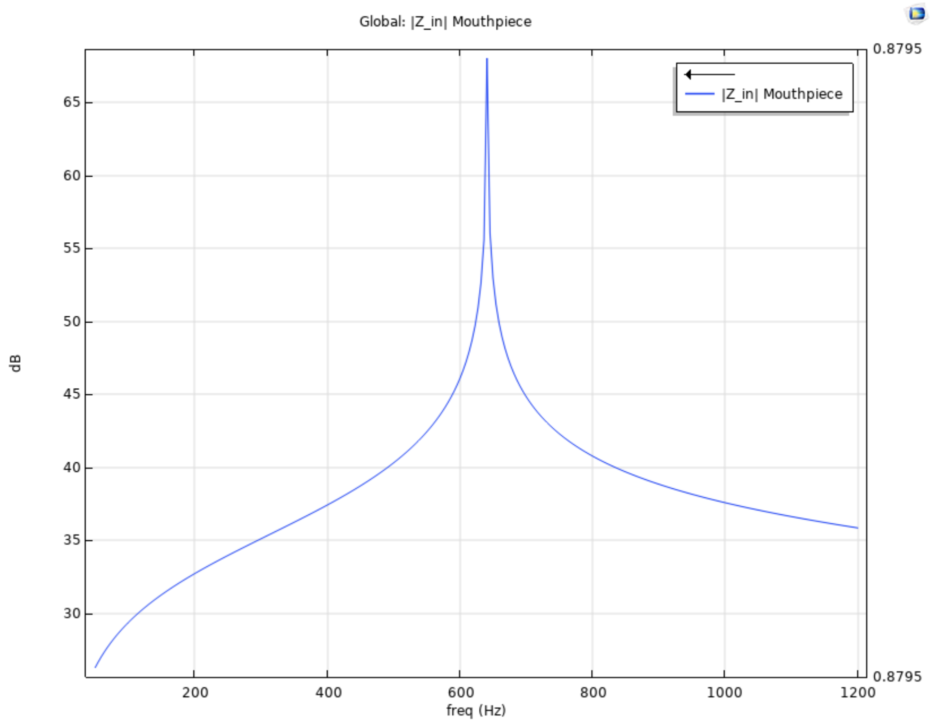
- Frequency study from minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$.
- Use a 2D axisymmetric geometry
- Modify the tube geometry with a bell at the end of the tube
- We impose a given pressure at the input

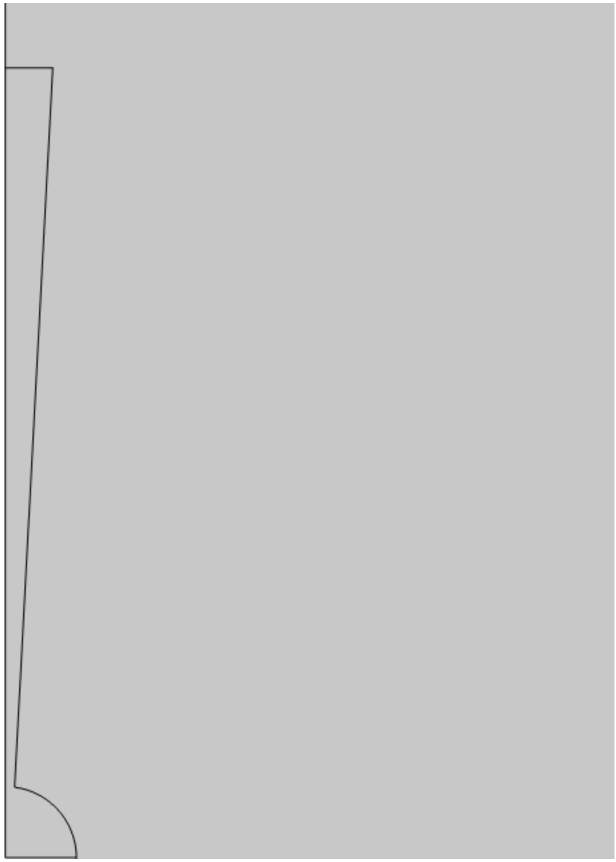




Mouthpiece

- Frequency study from minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$.
- Use a 2D axisymmetric geometry
- We impose a given pressure at the input





Complete trumpet model

- Frequency study from minimum frequency $f_{\min}$ to maximum frequency $f_{\max}$.
- Combine the previous geometries to get the model of the trumpet
- We impose a given pressure at the input