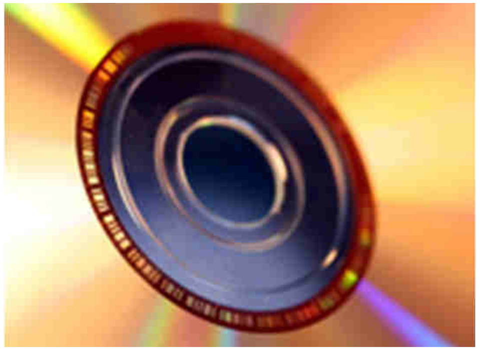

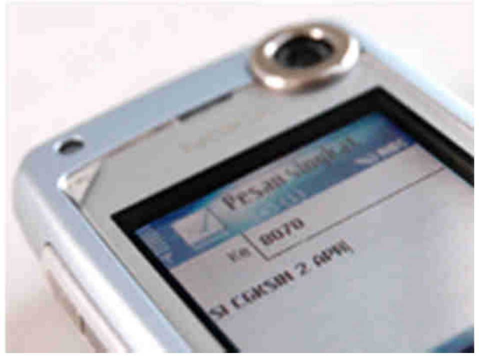

THE CHARACTERISTICS OF SOUNDS

ANALYSIS AND SYNTHESIS OF SOUNDS

Study aid for learning of Communication Acoustics

VIHIA 000

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Budapest

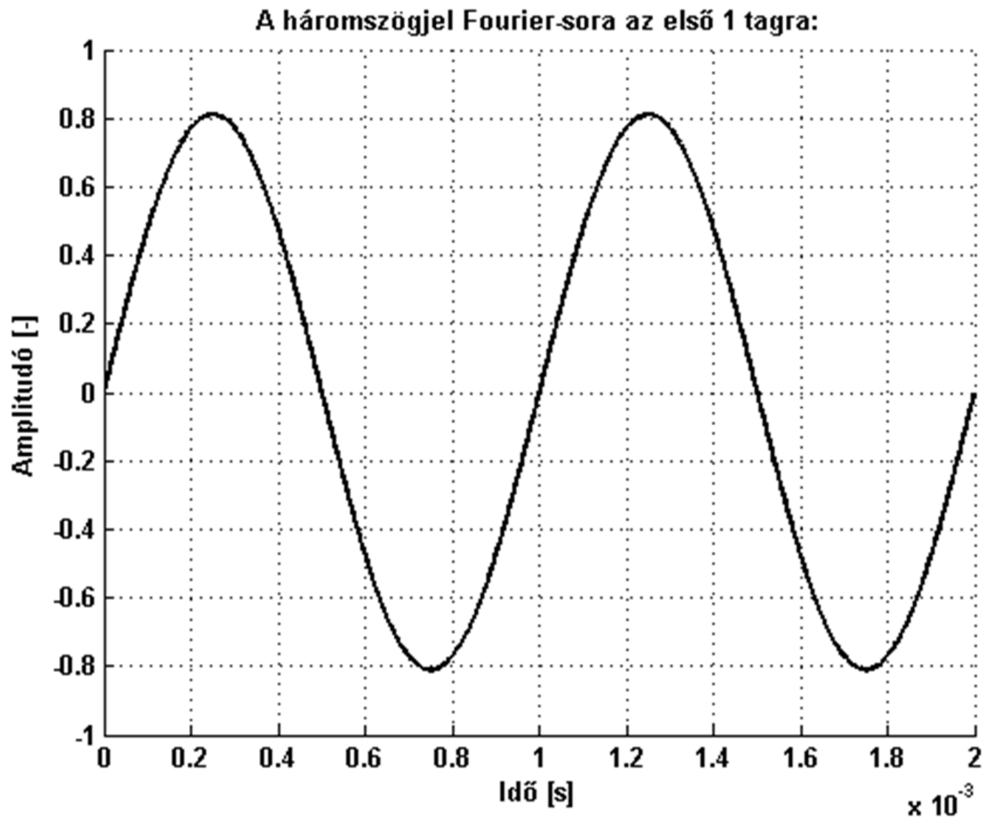
Classification of sounds

- According to origin
  - speech
  - music
  - noise

- On the basis of temporal variation
  - sinusoidal
  - periodic
  - transient (but still deterministic)
  - irregular, random
  - complex

Sinusoidal process

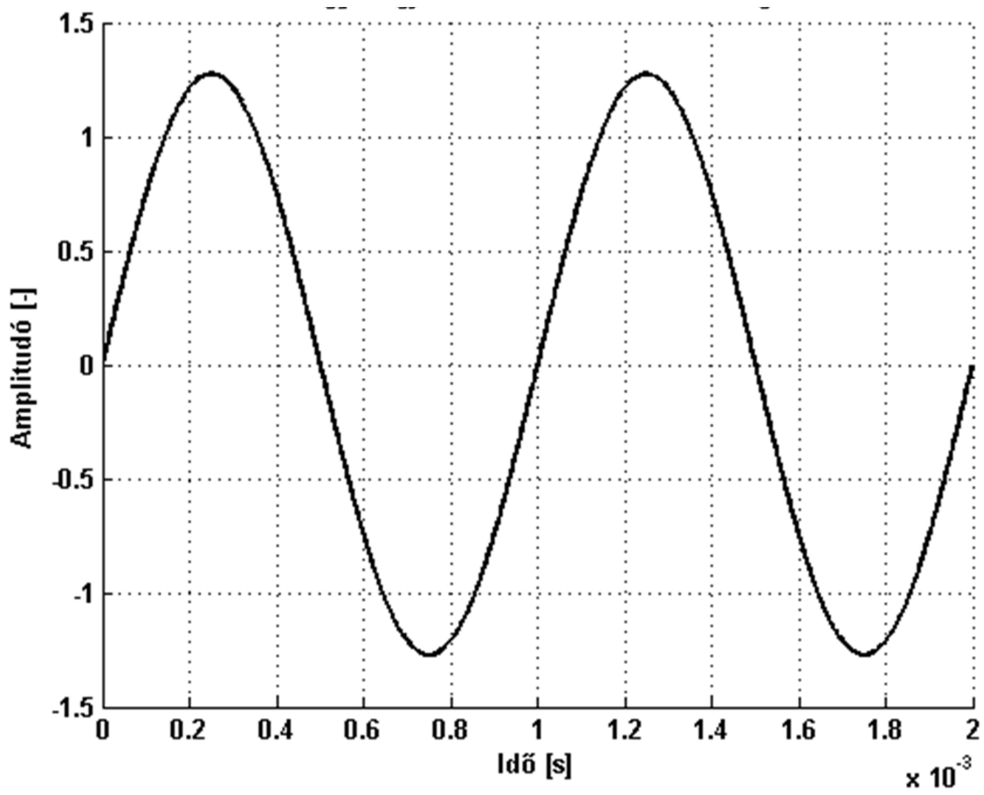
- A mechanical example: the swing



- Just one single frequency!

How are non-sinusoidal sounds generated?

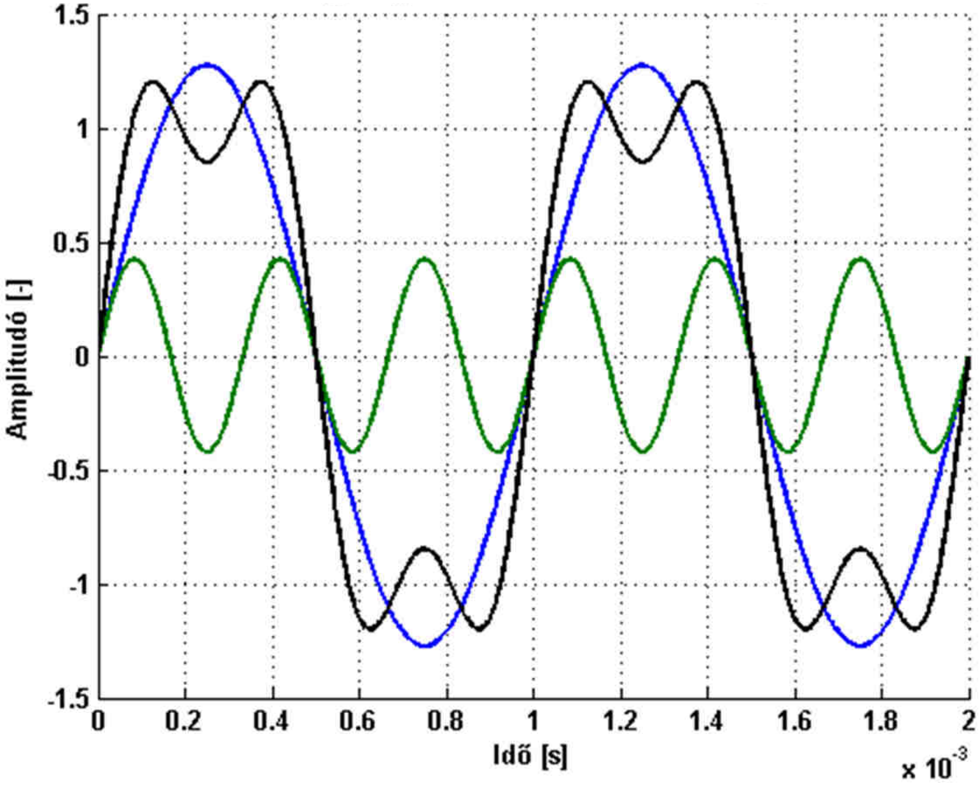
- Fundamental tone of a square wave



Wave Sound

Generation of non-sinusoidal vibration

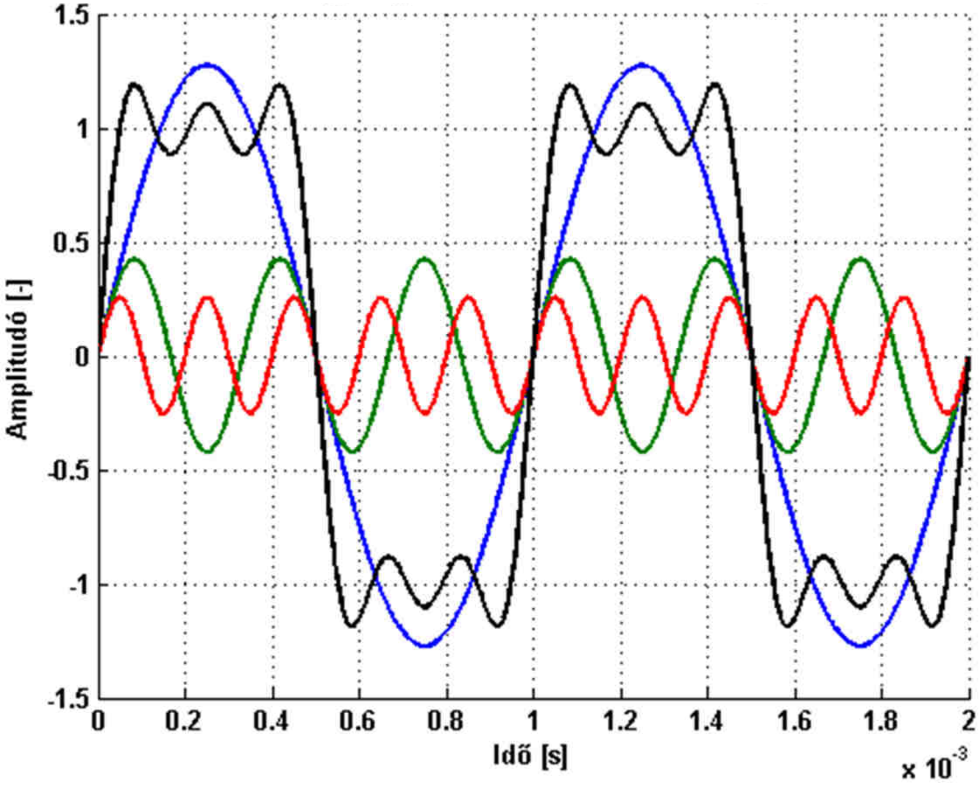
- The first two components



Wave Sound

Generation of non-sinusoidal vibration

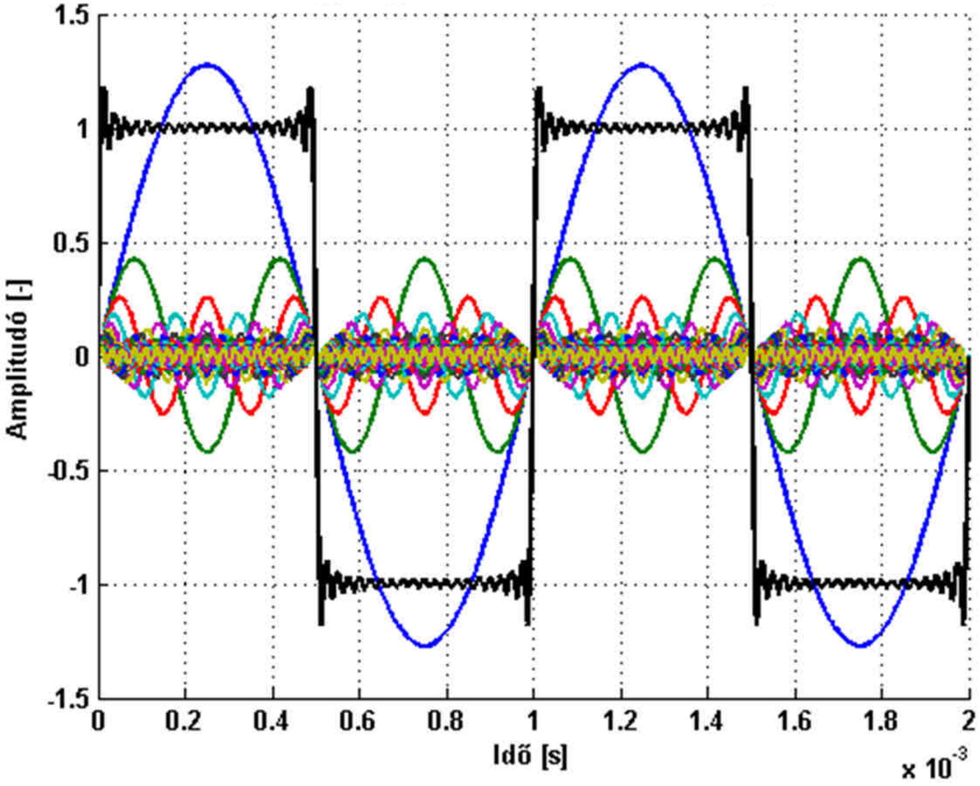
- The first three components



Wave Sound

Generation of non-sinusoidal vibration

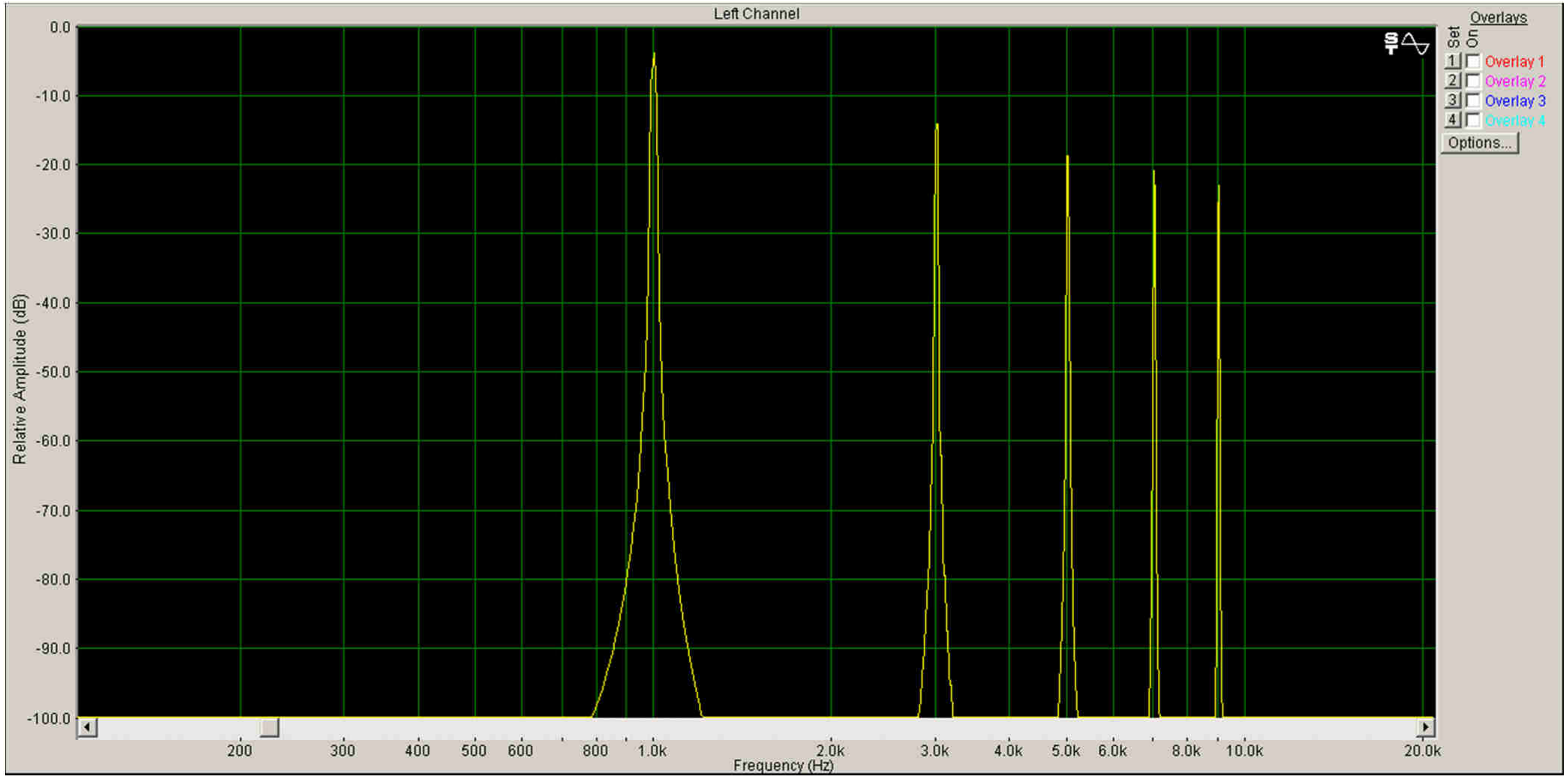
- The first ten components



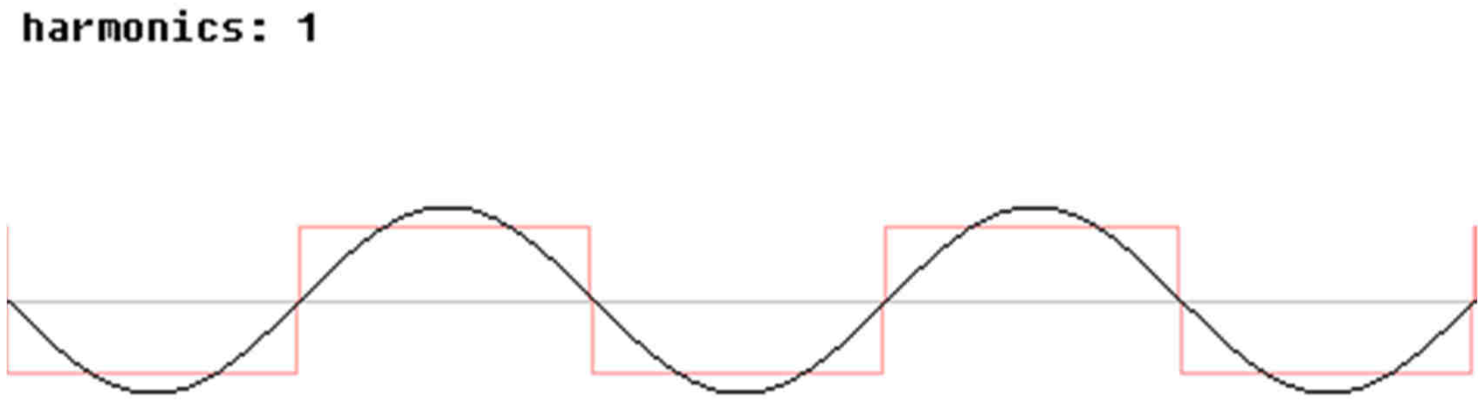
Wave Sound

Components in the frequency domain

- The first five components: **spectrum of the square wave**

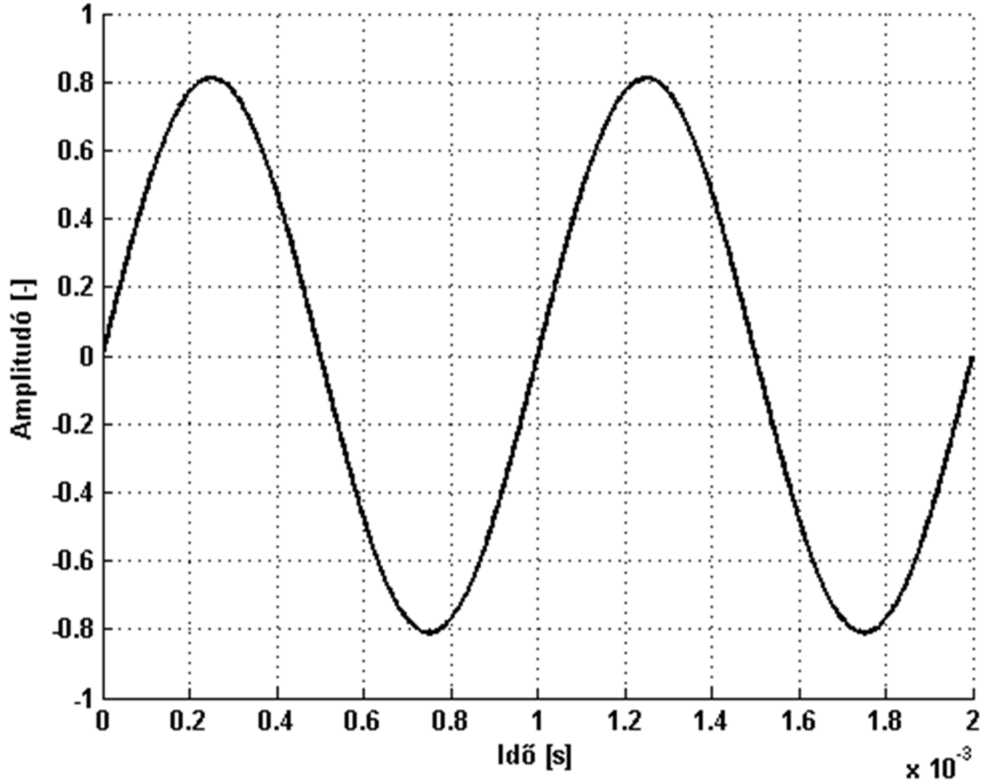


Synthesis of a square wave



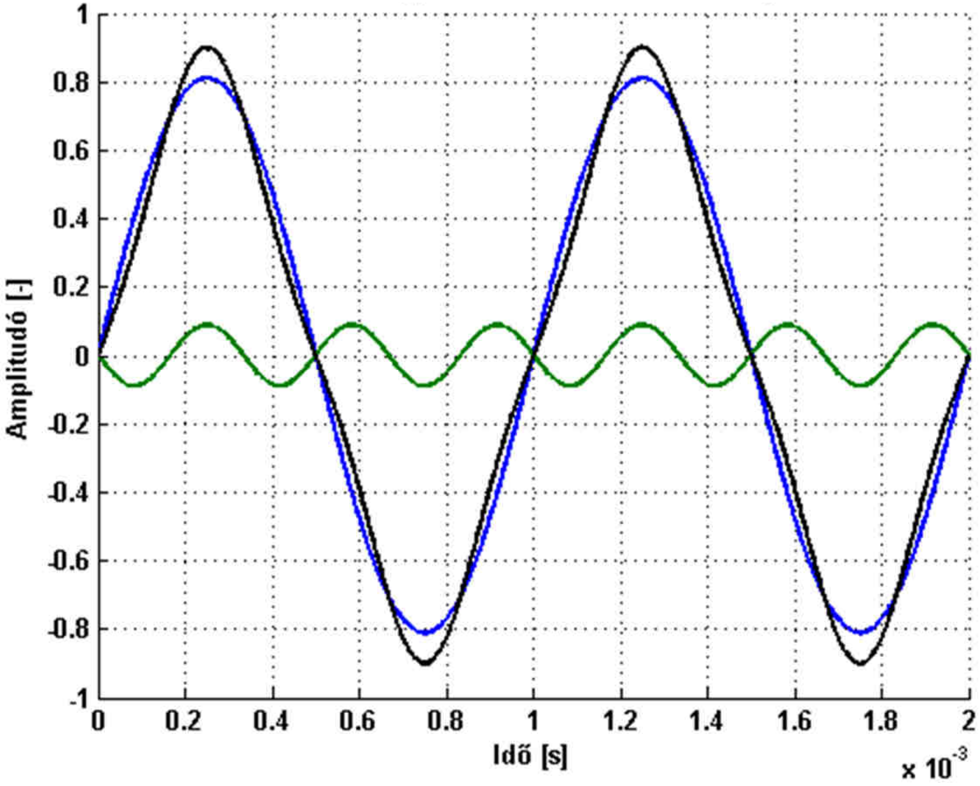
Another example: the sawtooth wave

- The fundamental



Another example: the sawtooth wave

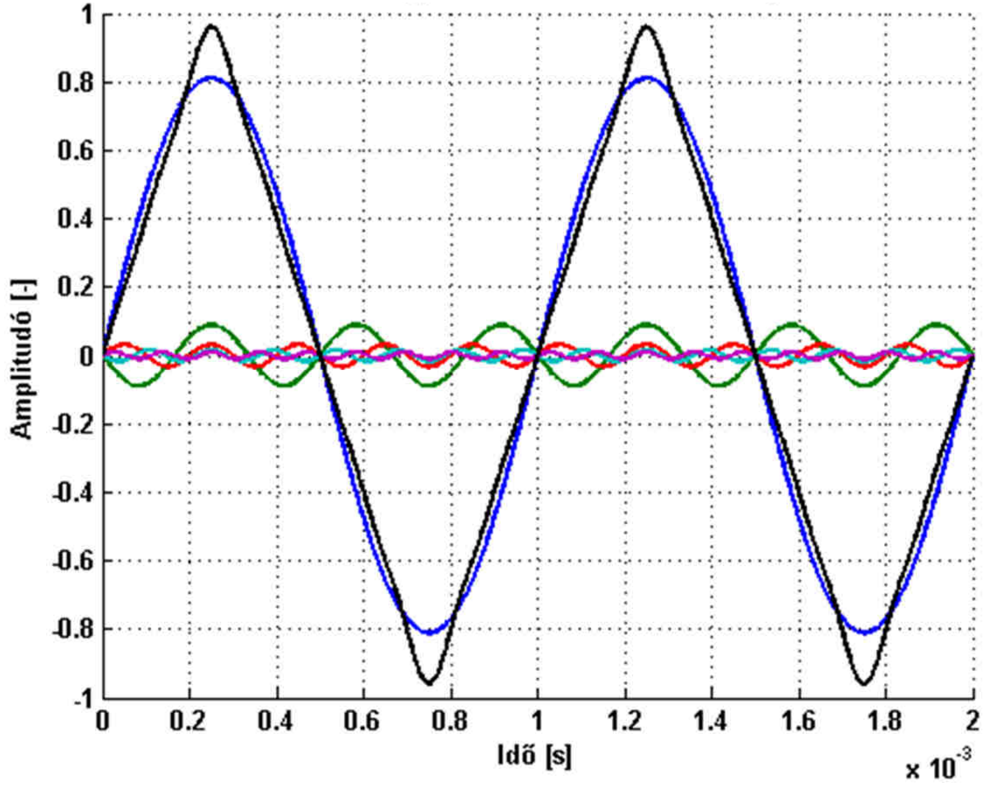
- The first two components

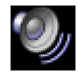


Wave Sound

Another example: the sawtooth wave

- The first five components





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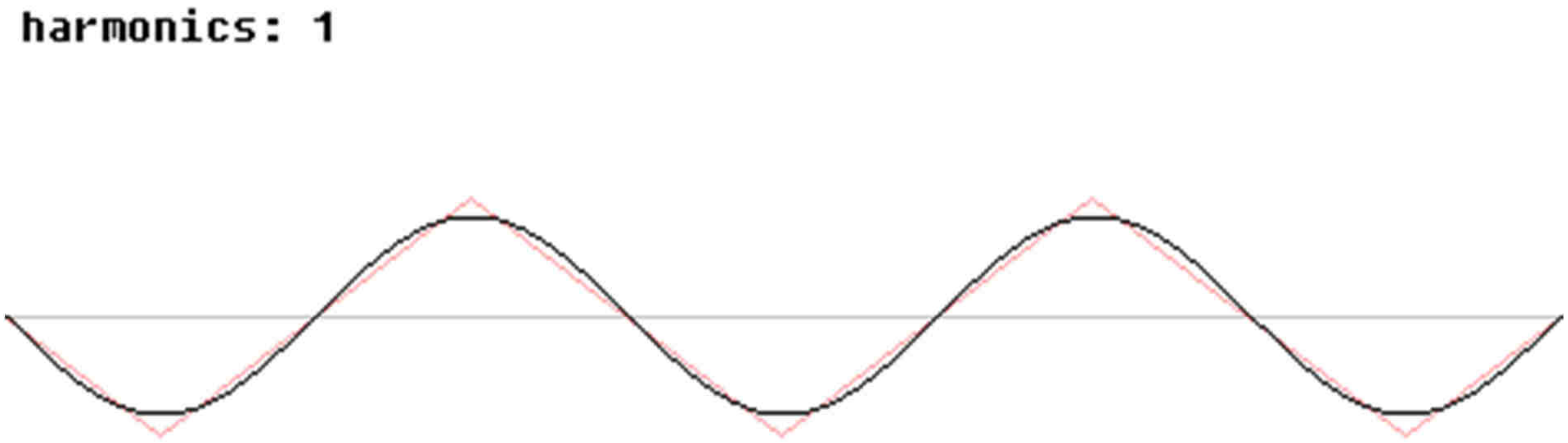
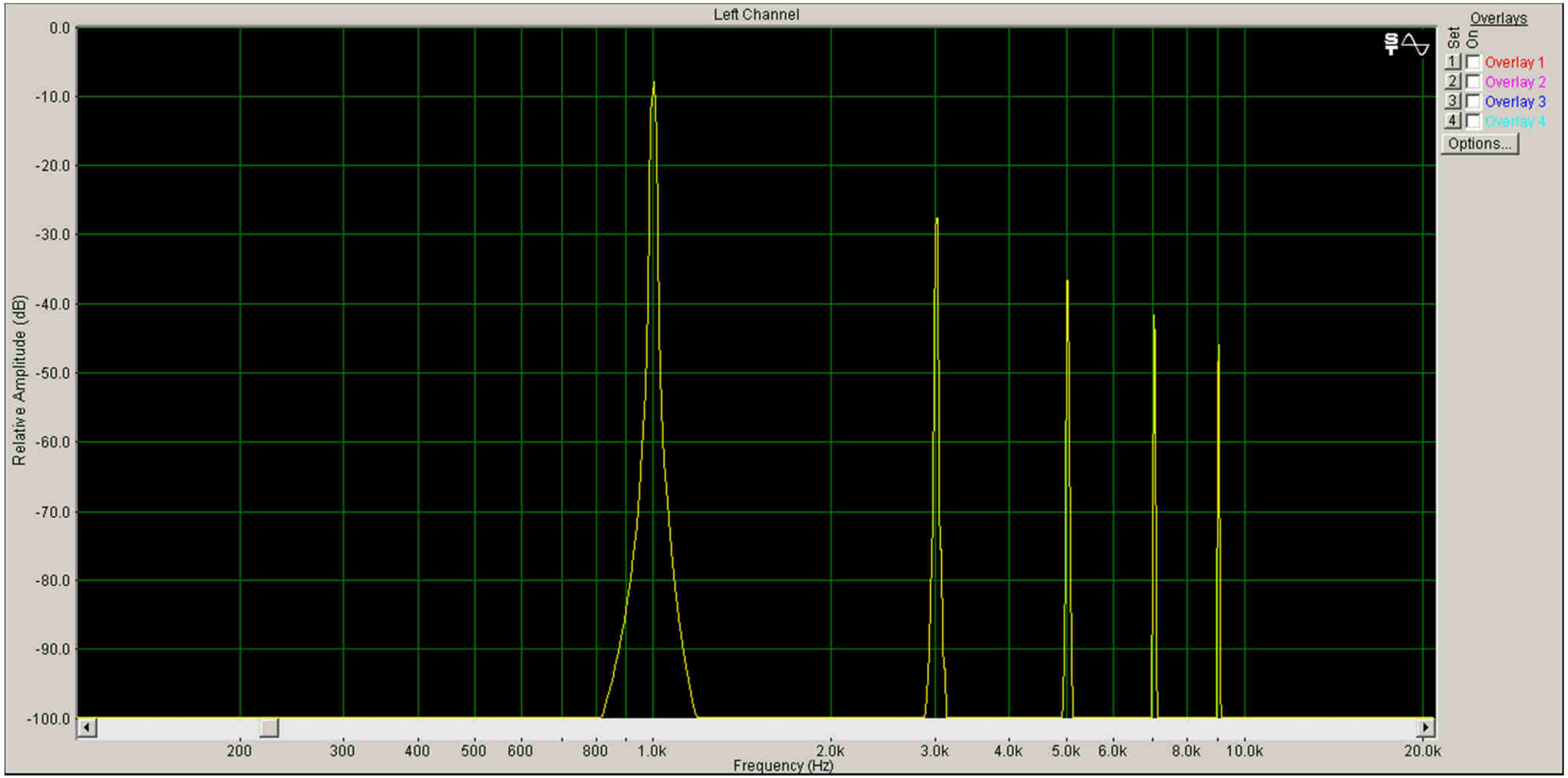


Frequency spectrum of the sawtooth wave

- Note: the same frequencies, but different phases and faster decrease of amplitudes

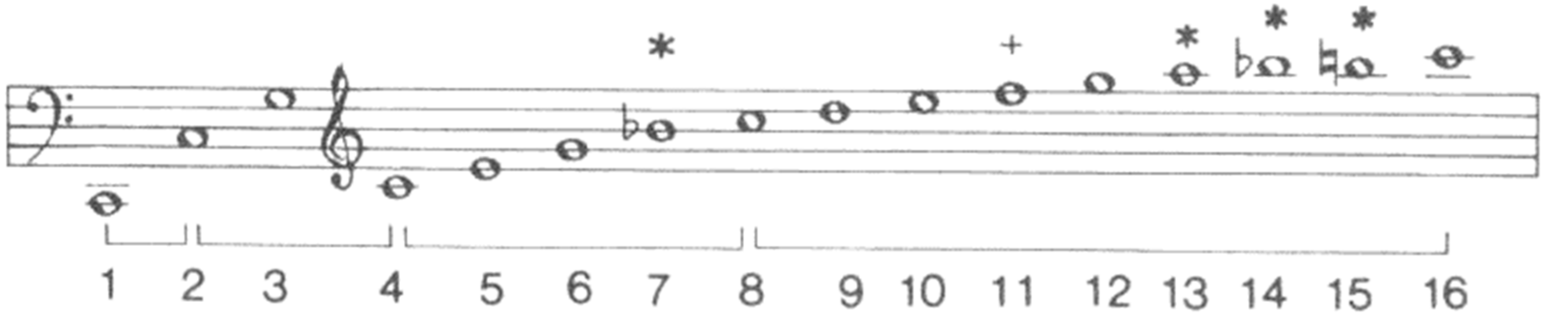


Harmonics

- Harmonics: multiples of the fundamental frequency

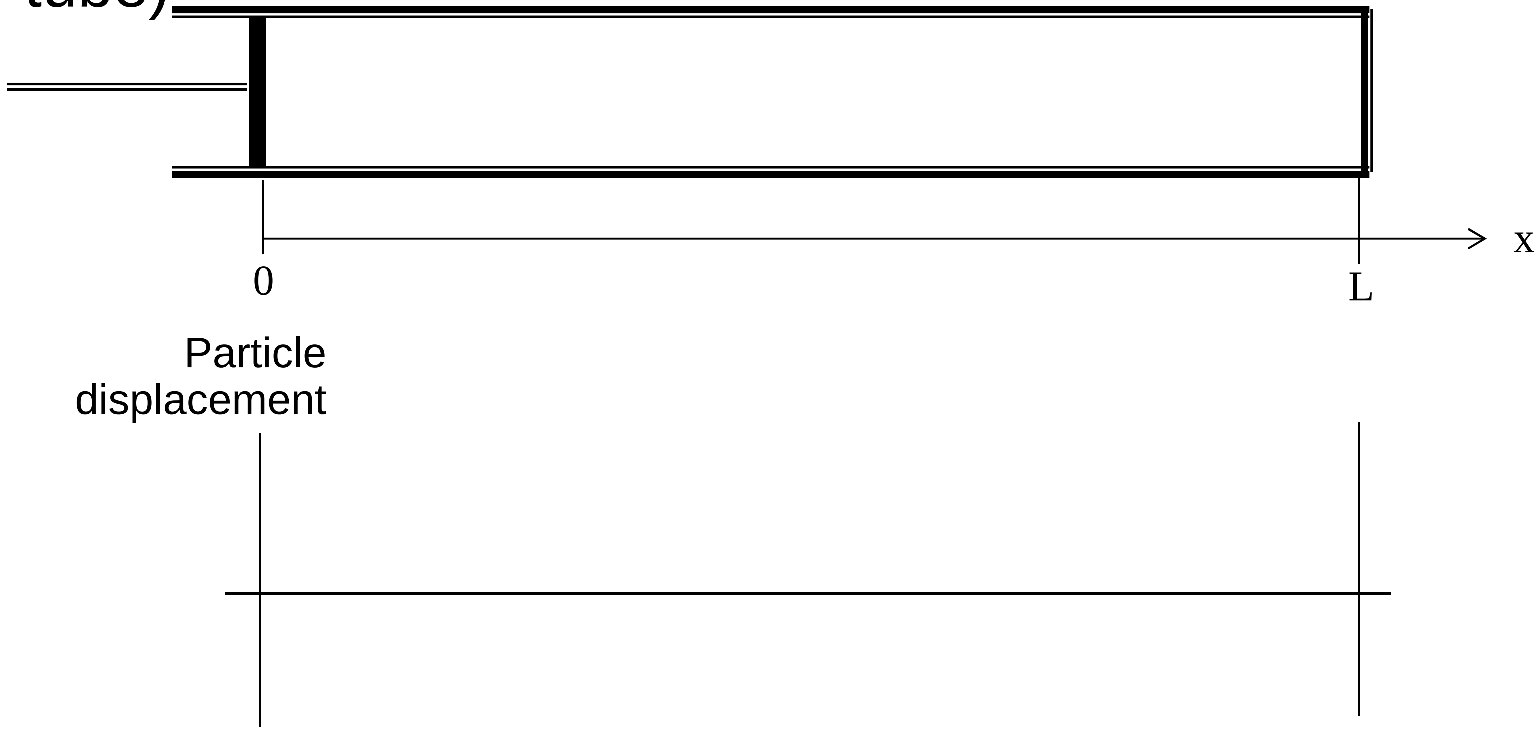
$$f_0,\ 2\times f_0,\ 3\times f_0,\qquad n\times f_0$$

- Musical notions: octave, third-octave



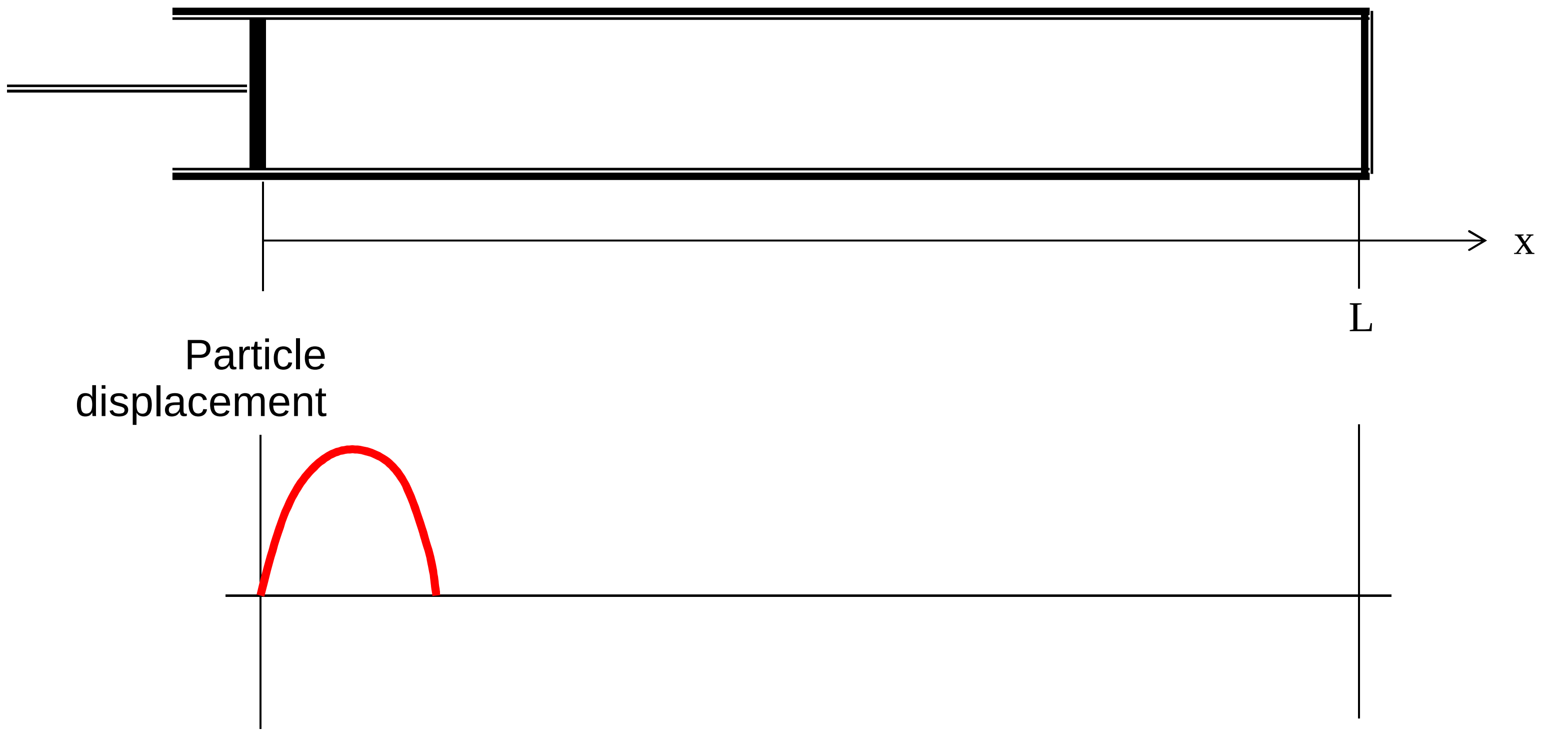
Generation of self-sustaining waves

- One-dimensional propagation and reflection (along a rigid tube)



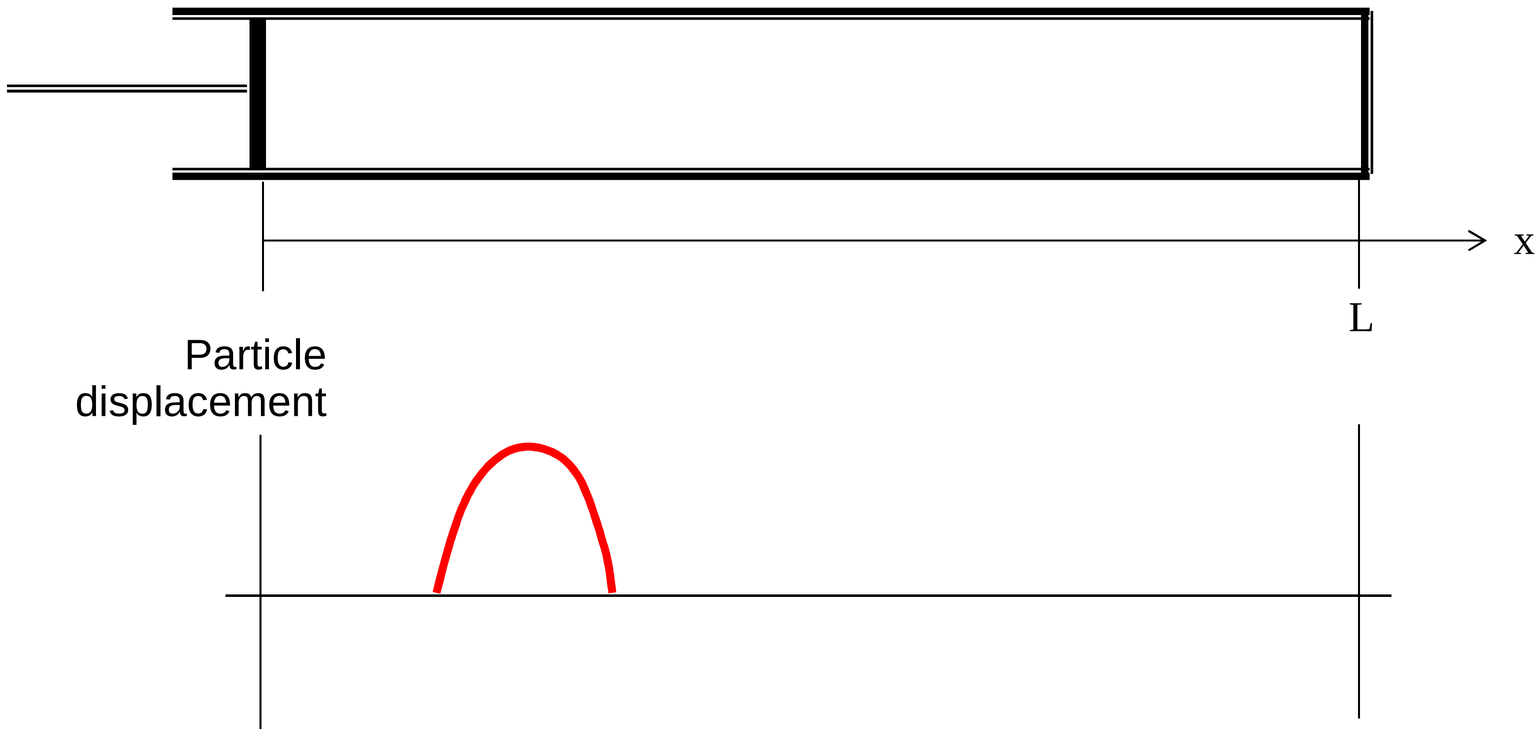
Generation of self-sustaining waves

- One-dimensional propagation and reflection



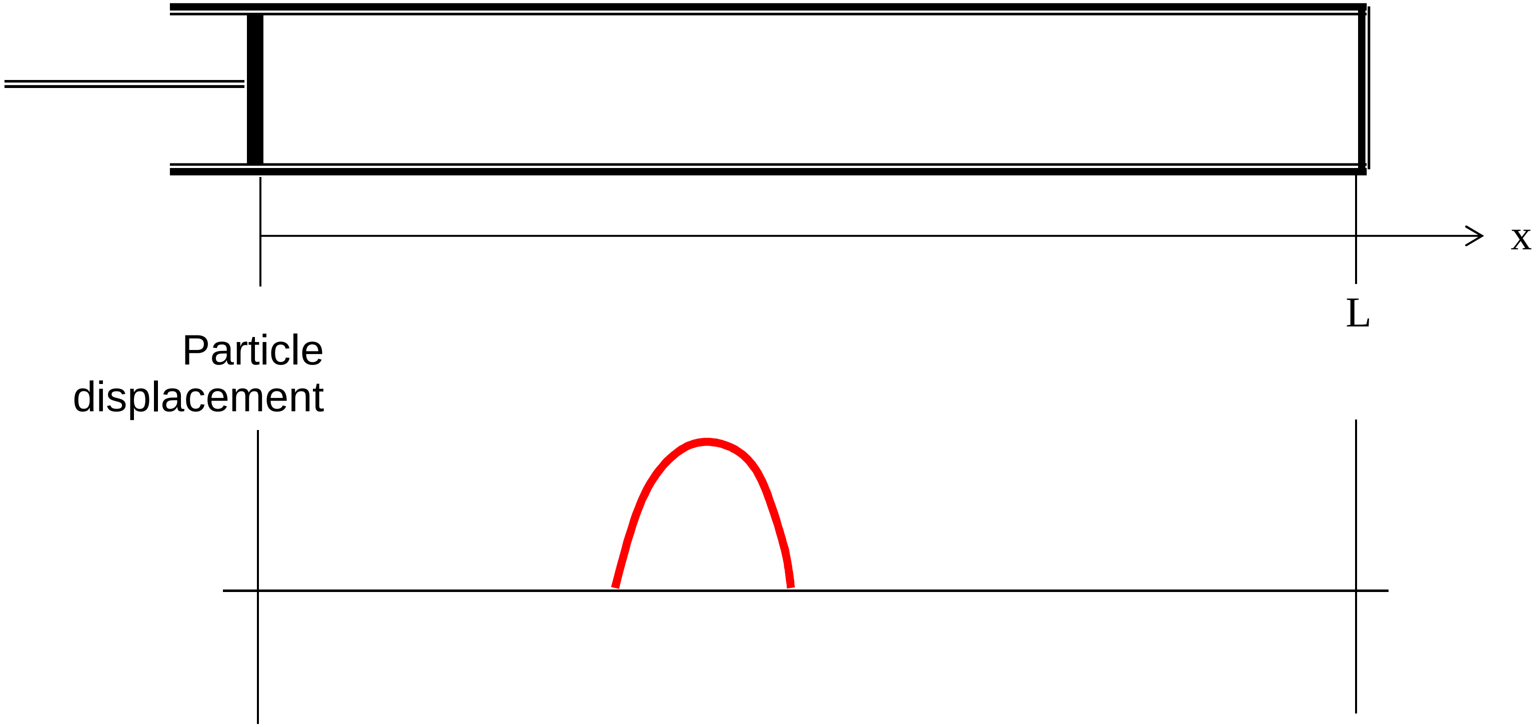
Generation of self-sustaining waves

- One-dimensional propagation and reflection



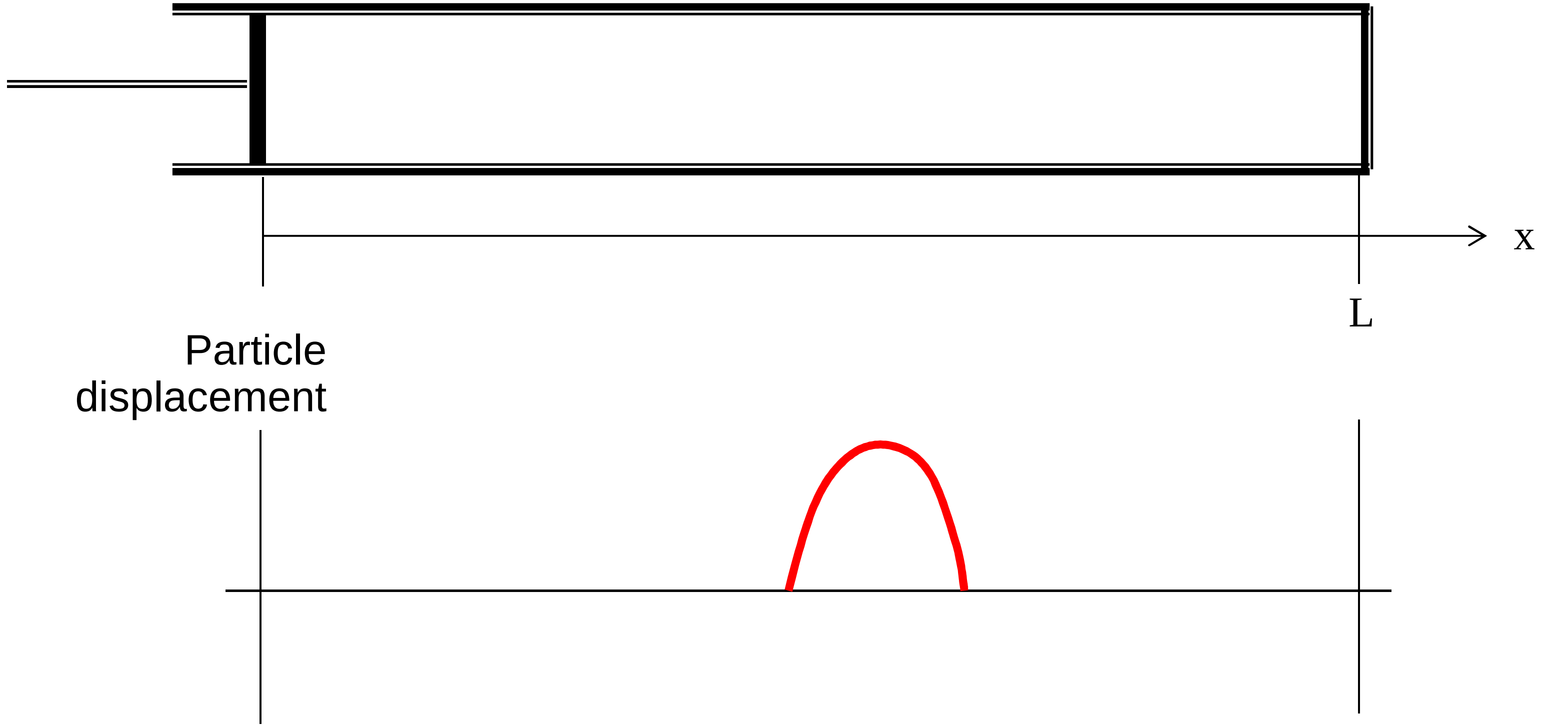
Generation of self-sustaining waves

- One-dimensional propagation and reflection



Generation of self-sustaining waves

- One-dimensional propagation and reflection



Generation of self-sustaining waves

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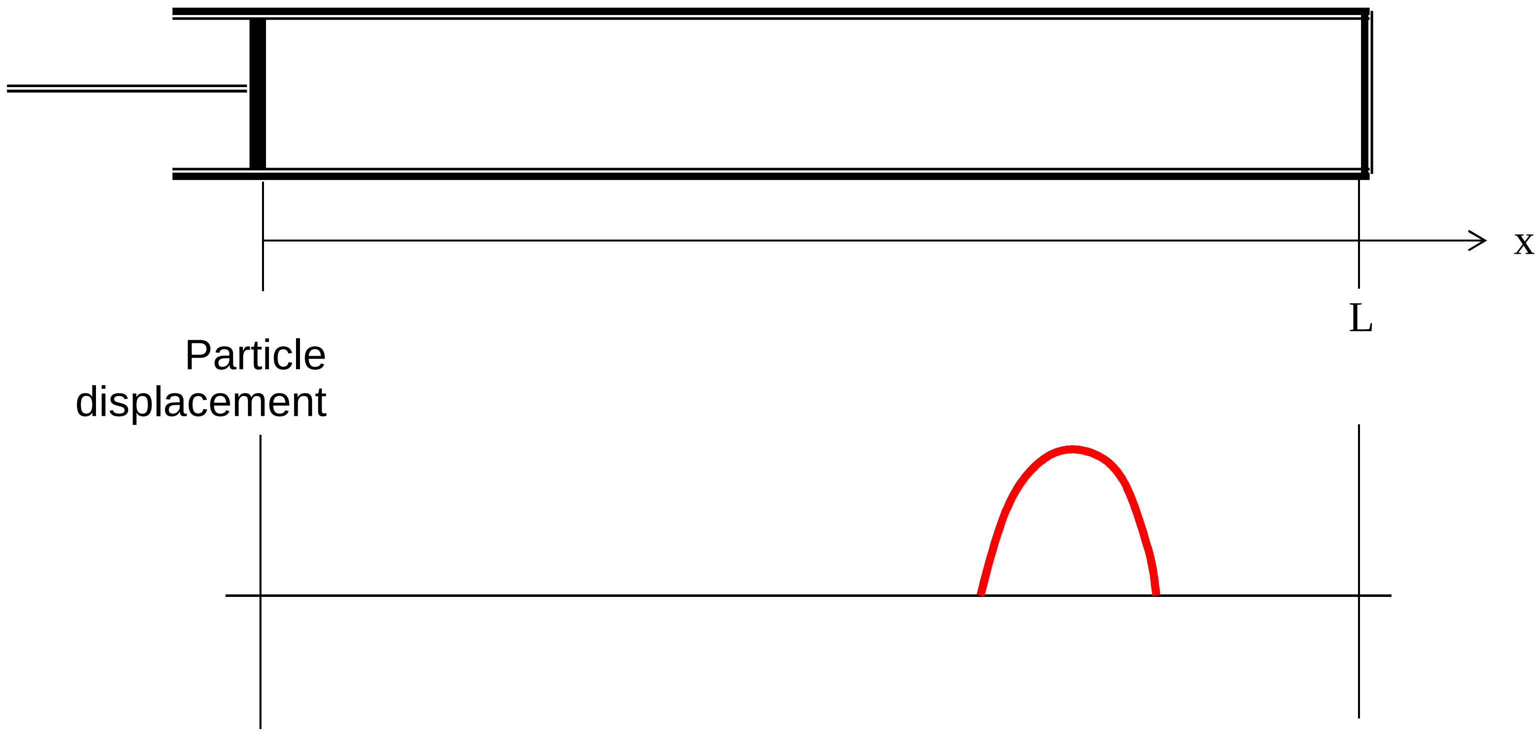
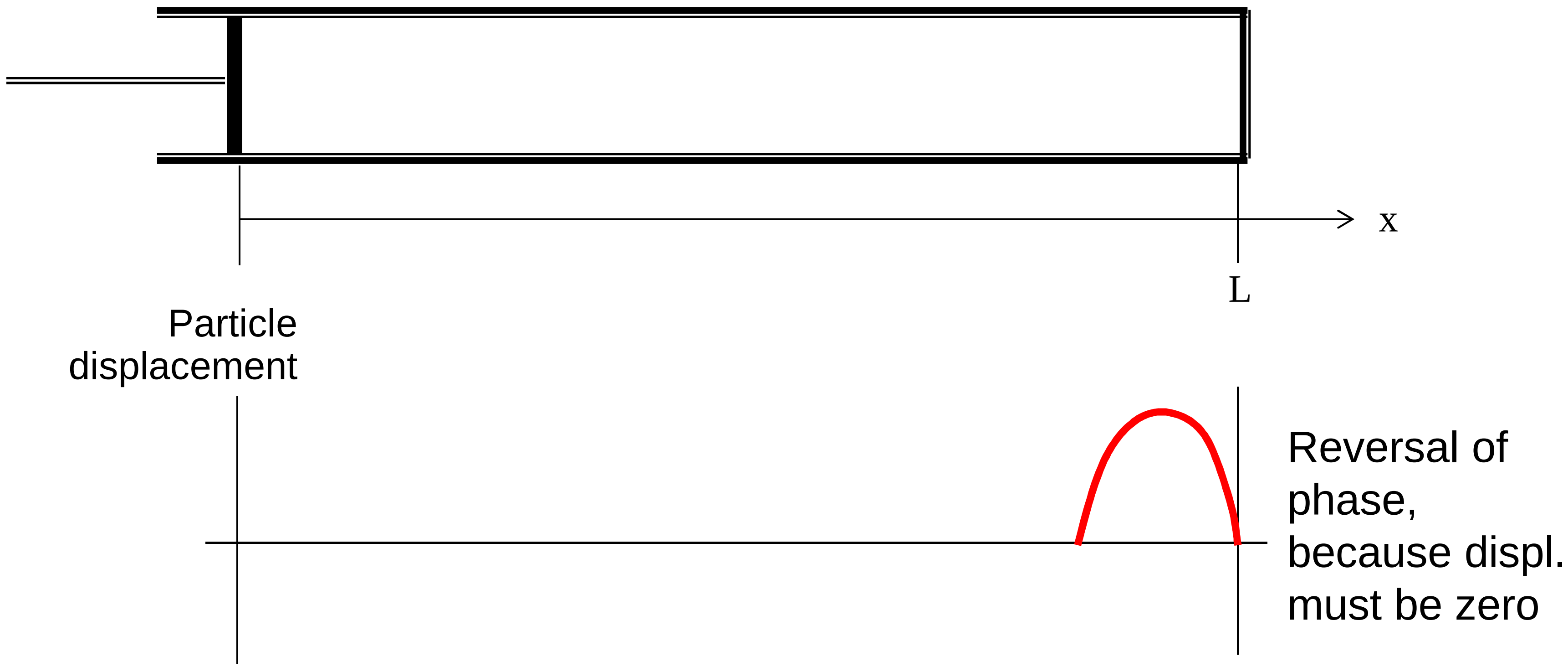


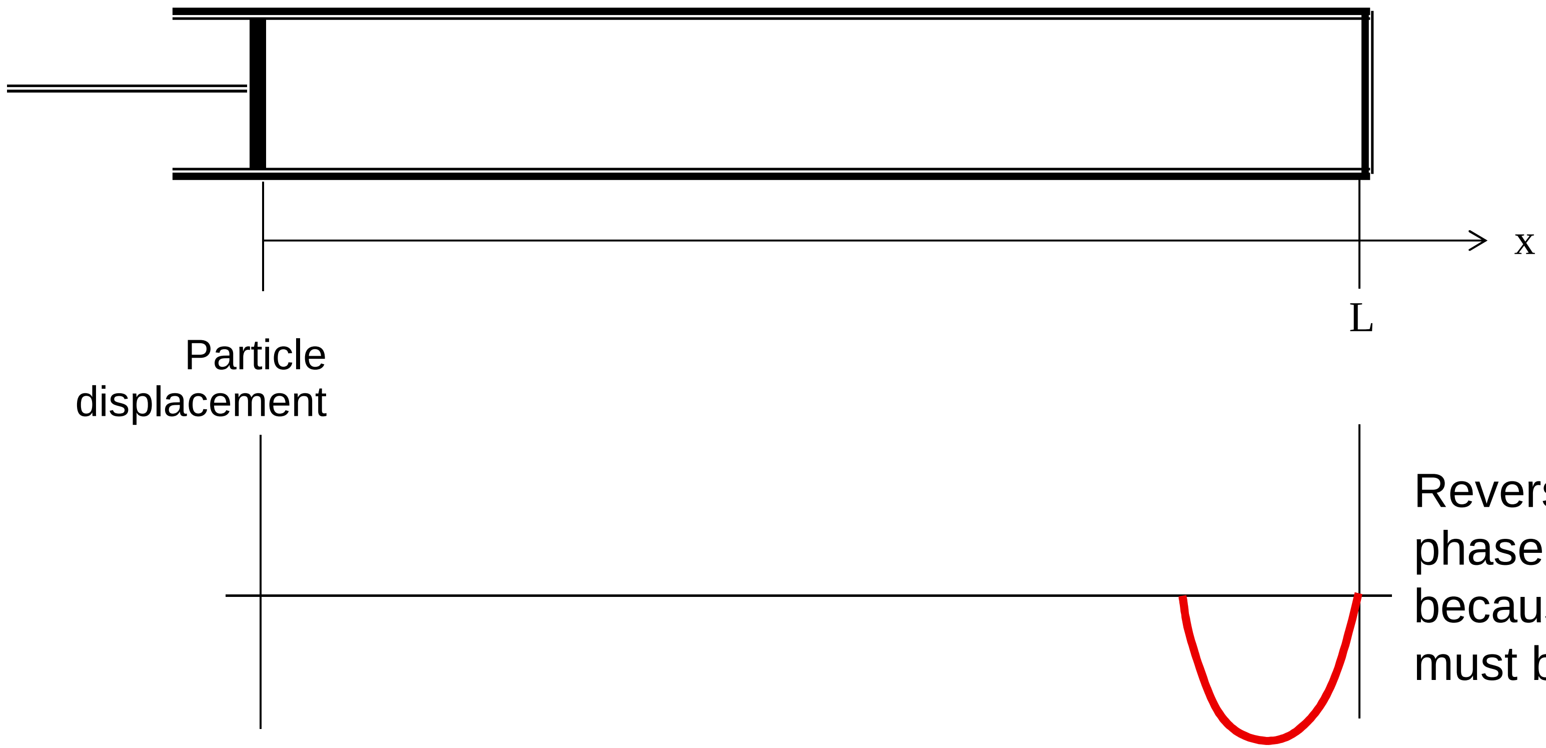
Generation of self-sustaining waves

- One-dimensional propagation and reflection



Generation of self-sustaining waves

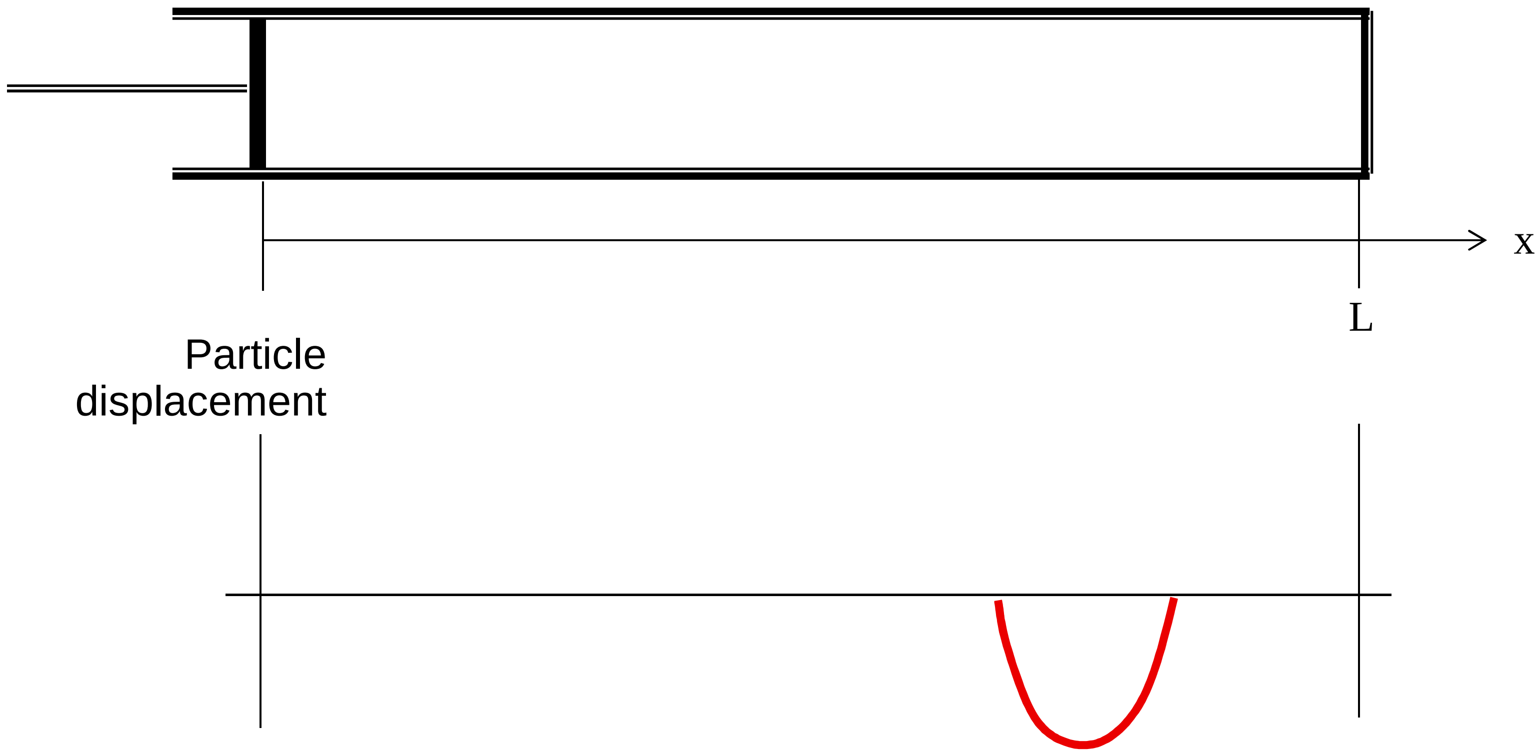
- One-dimensional propagation and reflection



Reversal of phase, because displ. must be zero

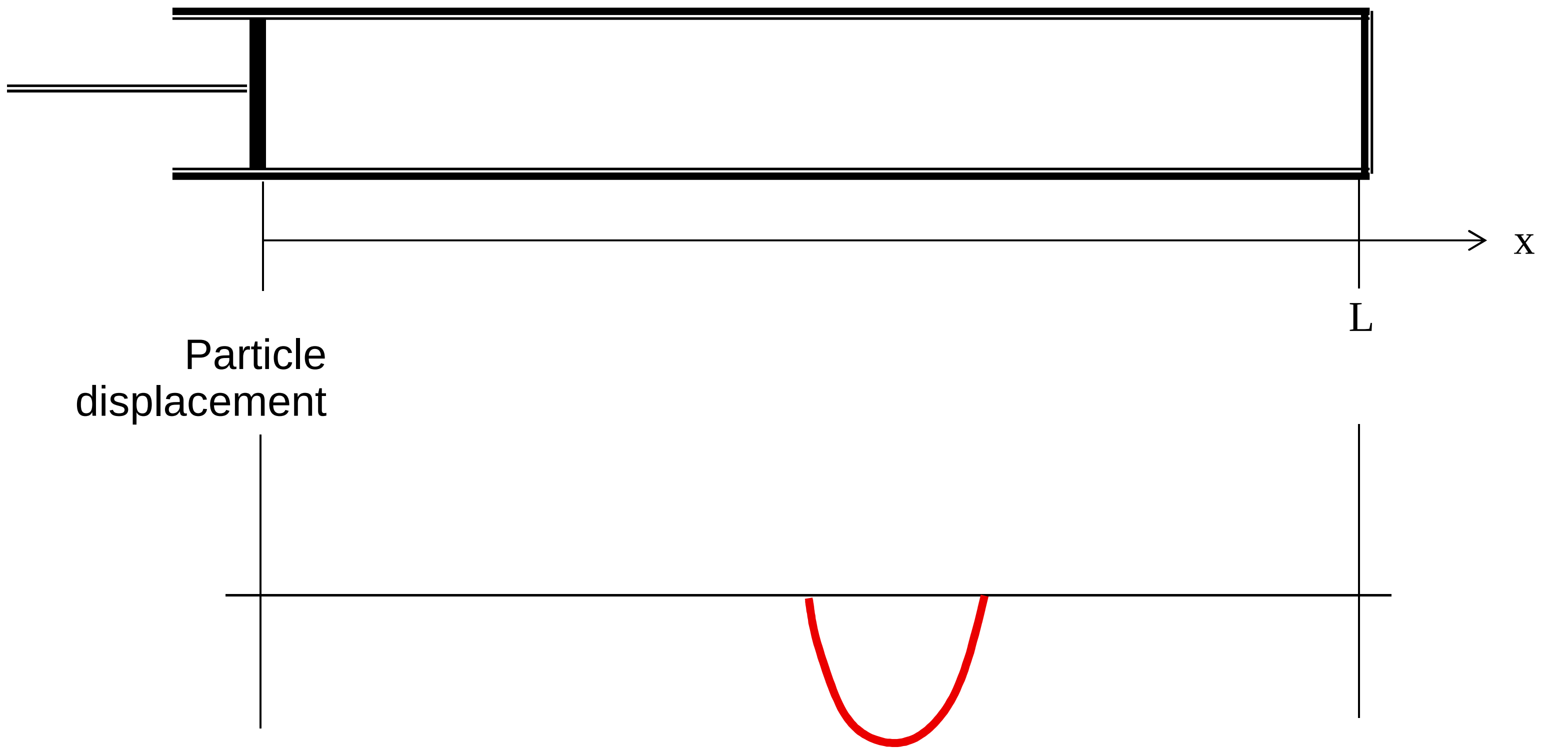
Generation of self-sustaining waves

- One-dimensional propagation and reflection



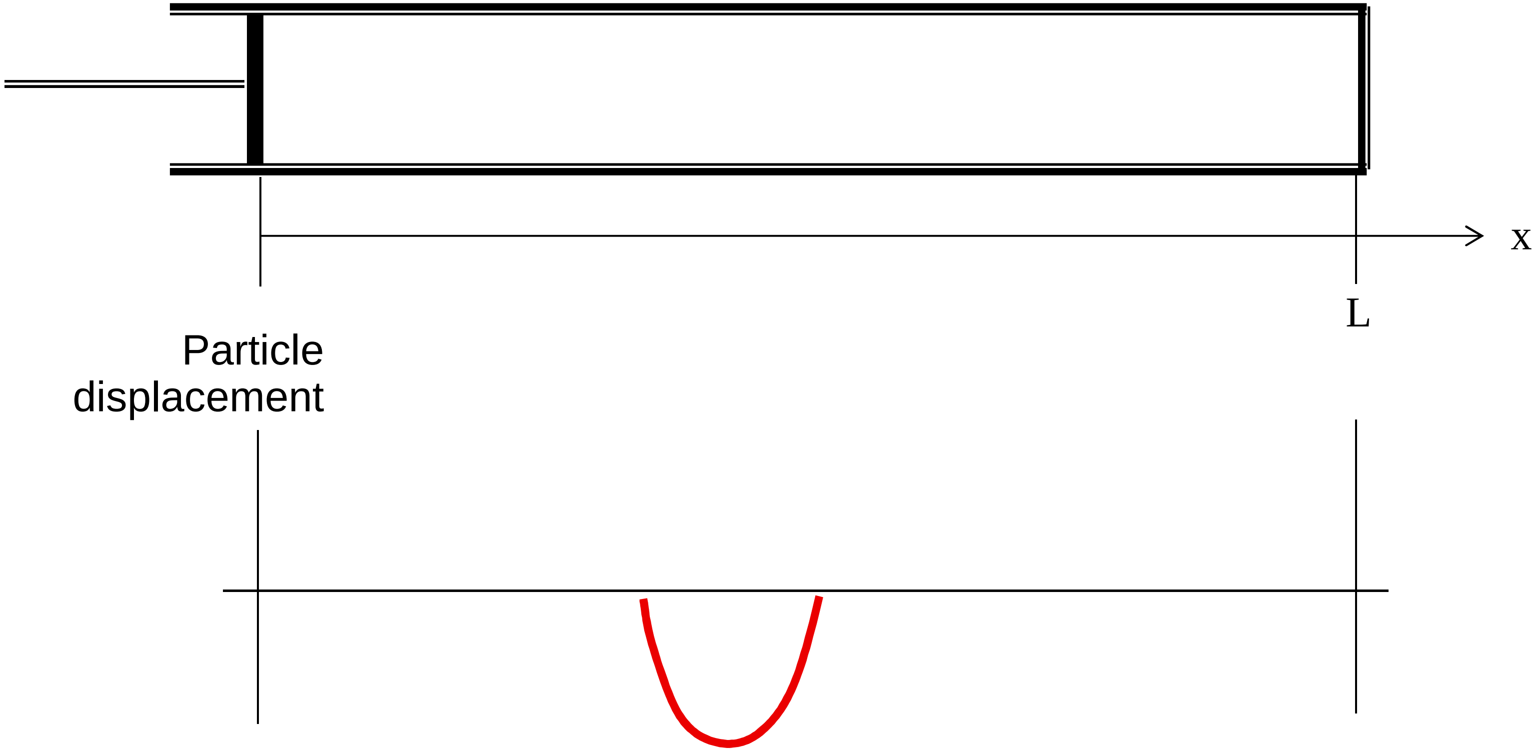
Generation of self-sustaining waves

- One-dimensional propagation and reflection



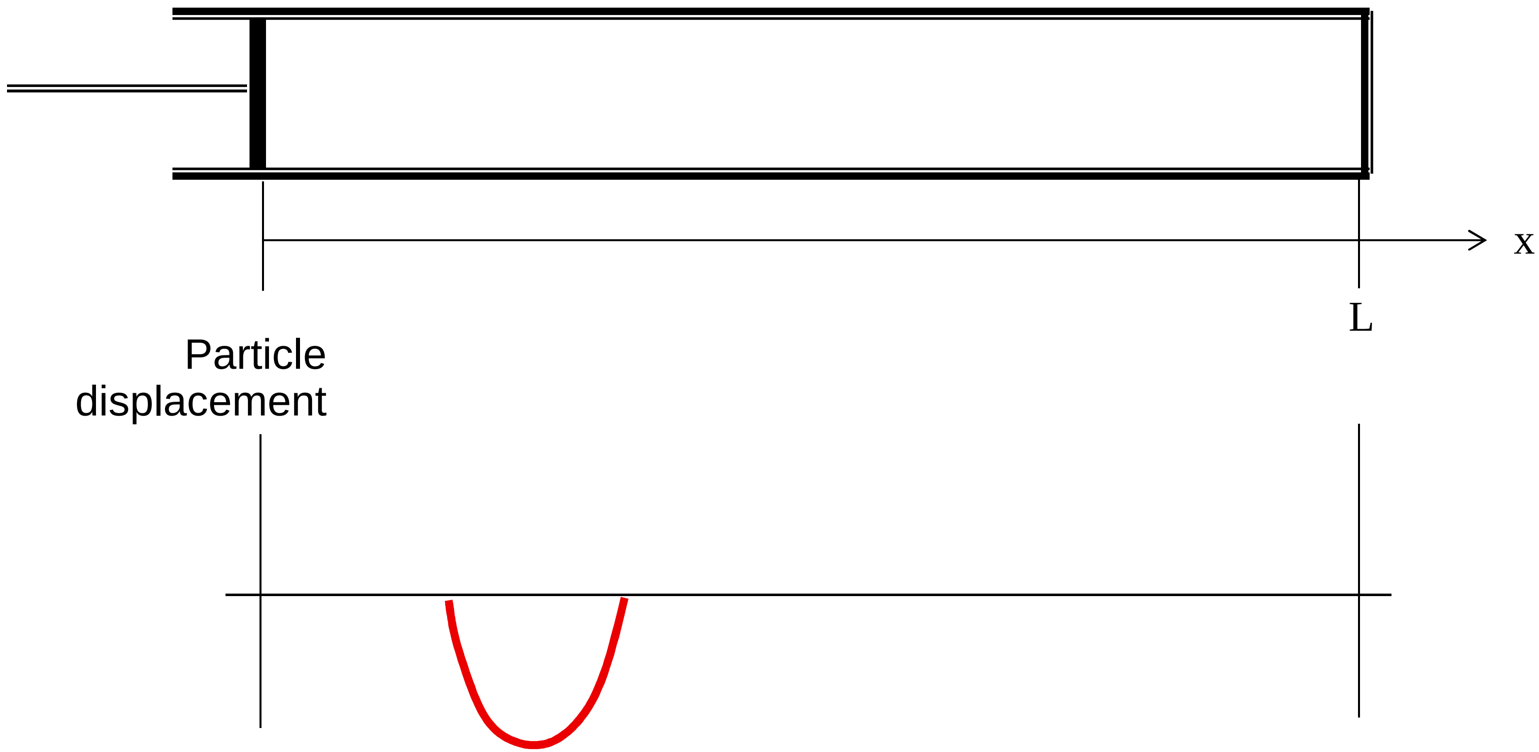
Generation of self-sustaining waves

- One-dimensional propagation and reflection



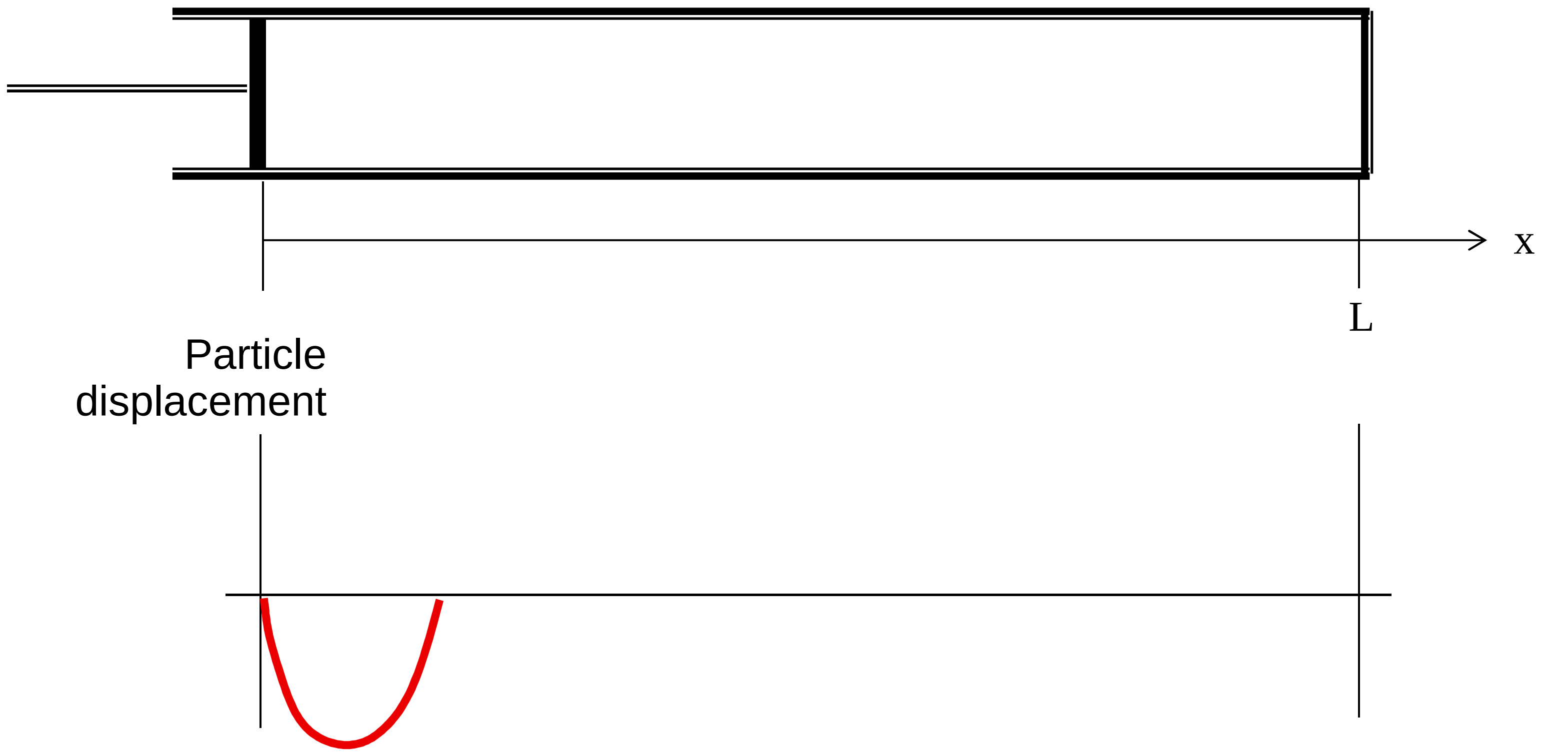
Generation of self-sustaining waves

- One-dimensional propagation and reflection



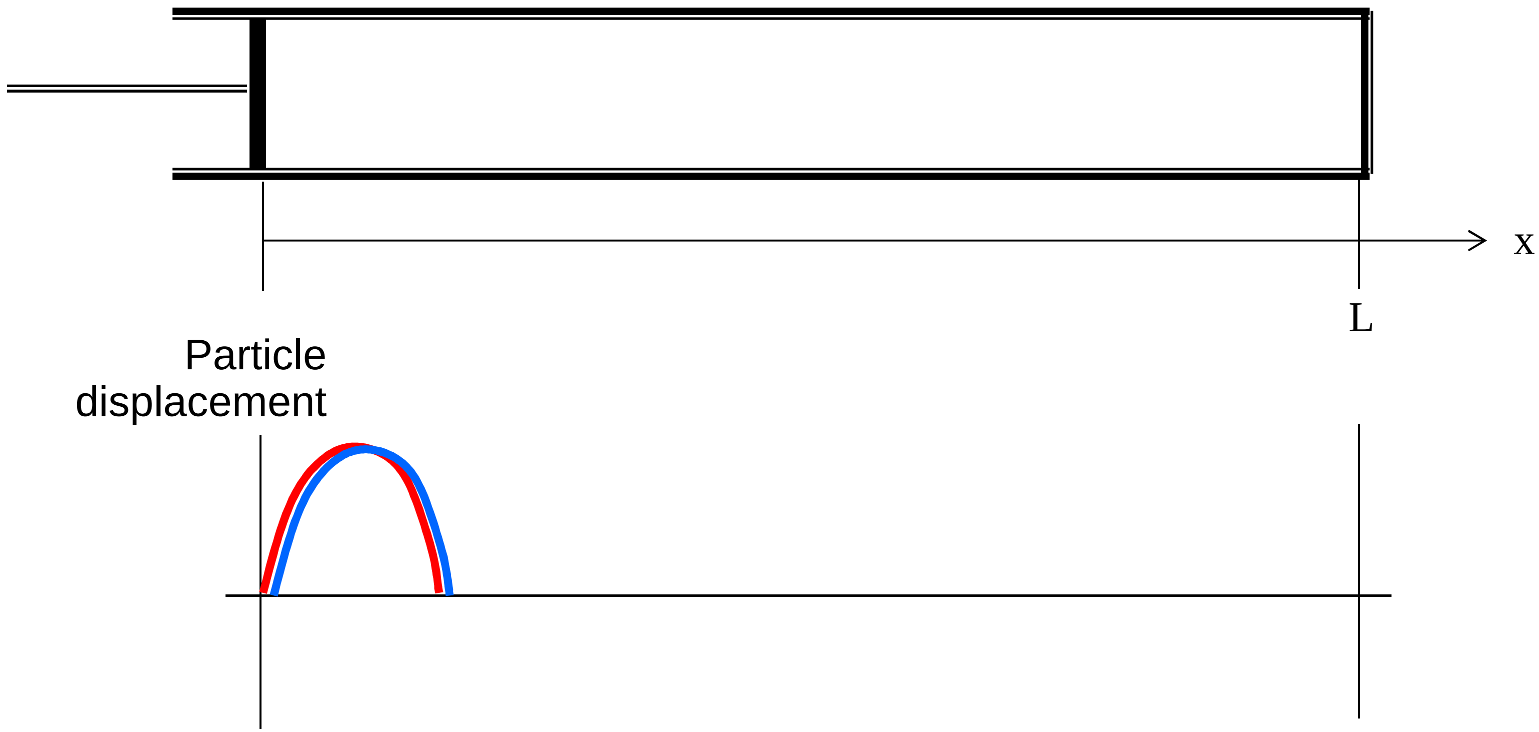
Generation of self-sustaining waves

- One-dimensional propagation and reflection



Generation of self-sustaining waves

- One-dimensional propagation and reflection



Relationship between L and f

- If the tube is closed on both ends:

$$2L = \lambda = \frac{c}{f}$$

$$f_0 = \frac{c}{2L}$$

- If one end is closed and the other is open:

$$2L = \frac{\lambda}{2} = \frac{c}{2f}$$

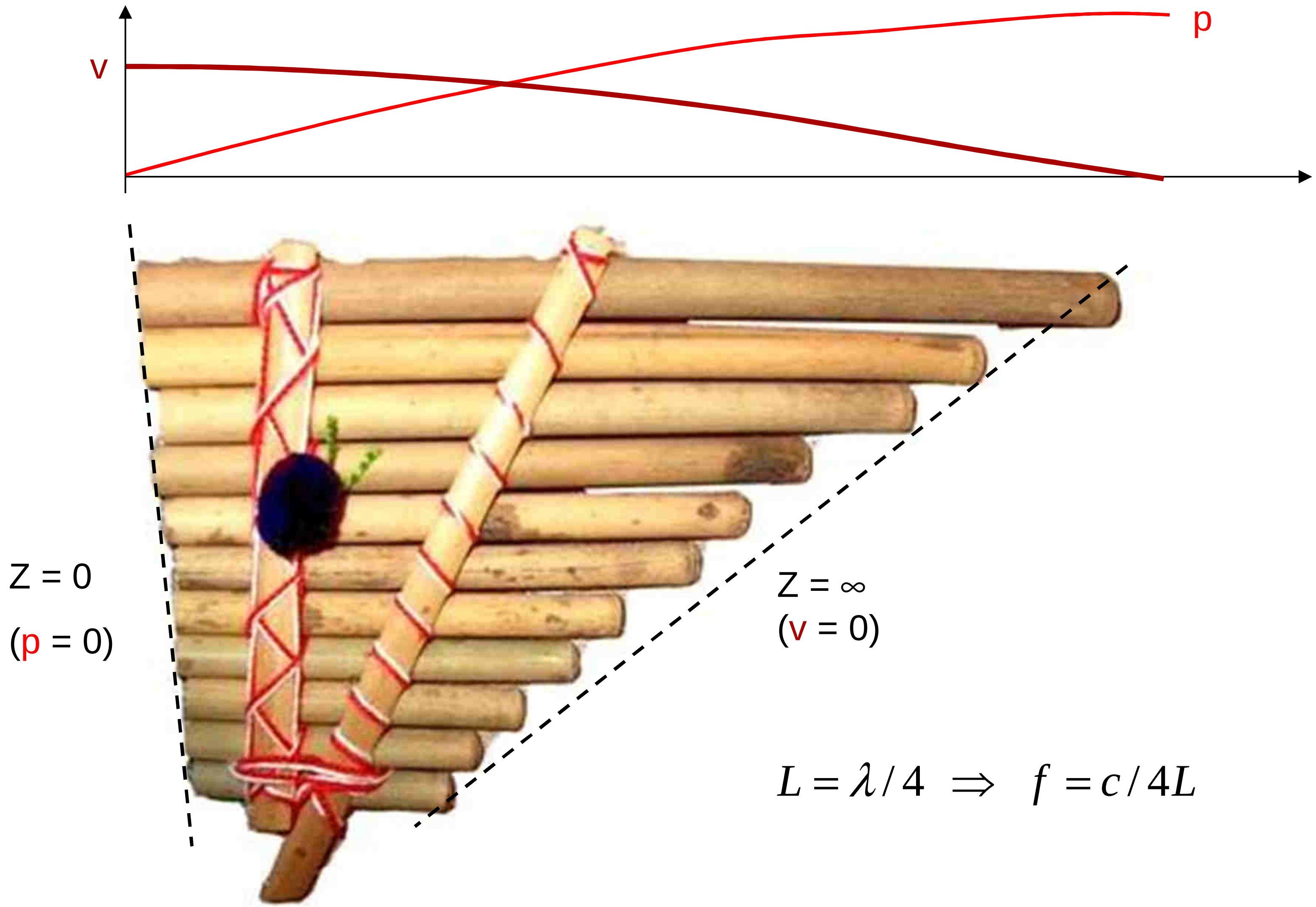
$$f_0 = \frac{c}{4L}$$

- The same thing happens, if more periods of wave correspond to the length of tube:

$$\textit{tube closed at both ends}: \; f_0, 2f_0, 3f_0, \ldots$$

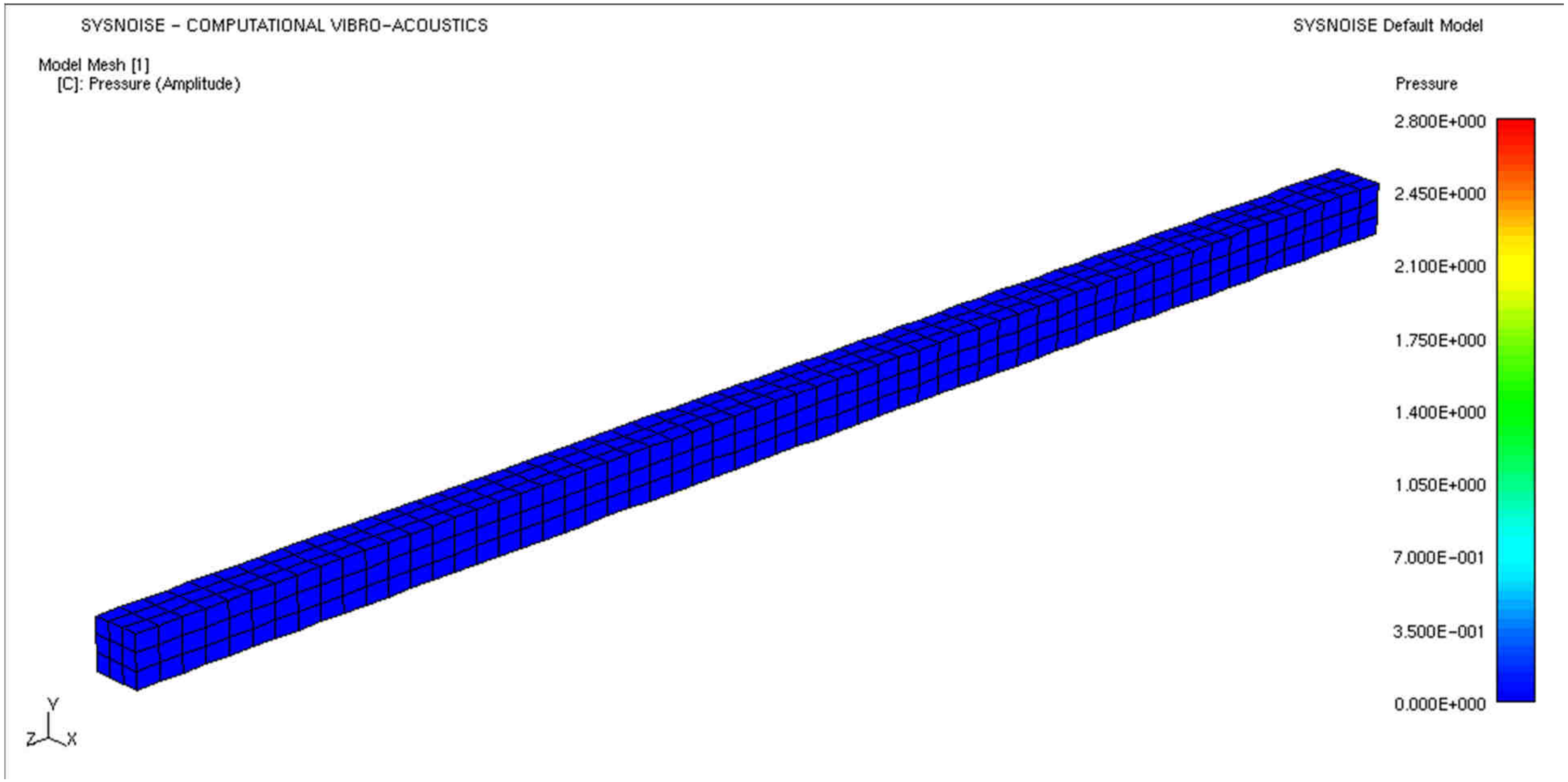
$$\textit{tube with one closed and one open end}: \; f_0, 3f_0, 5f_0, \ldots$$

A practical, very simple example: the pan's pipes

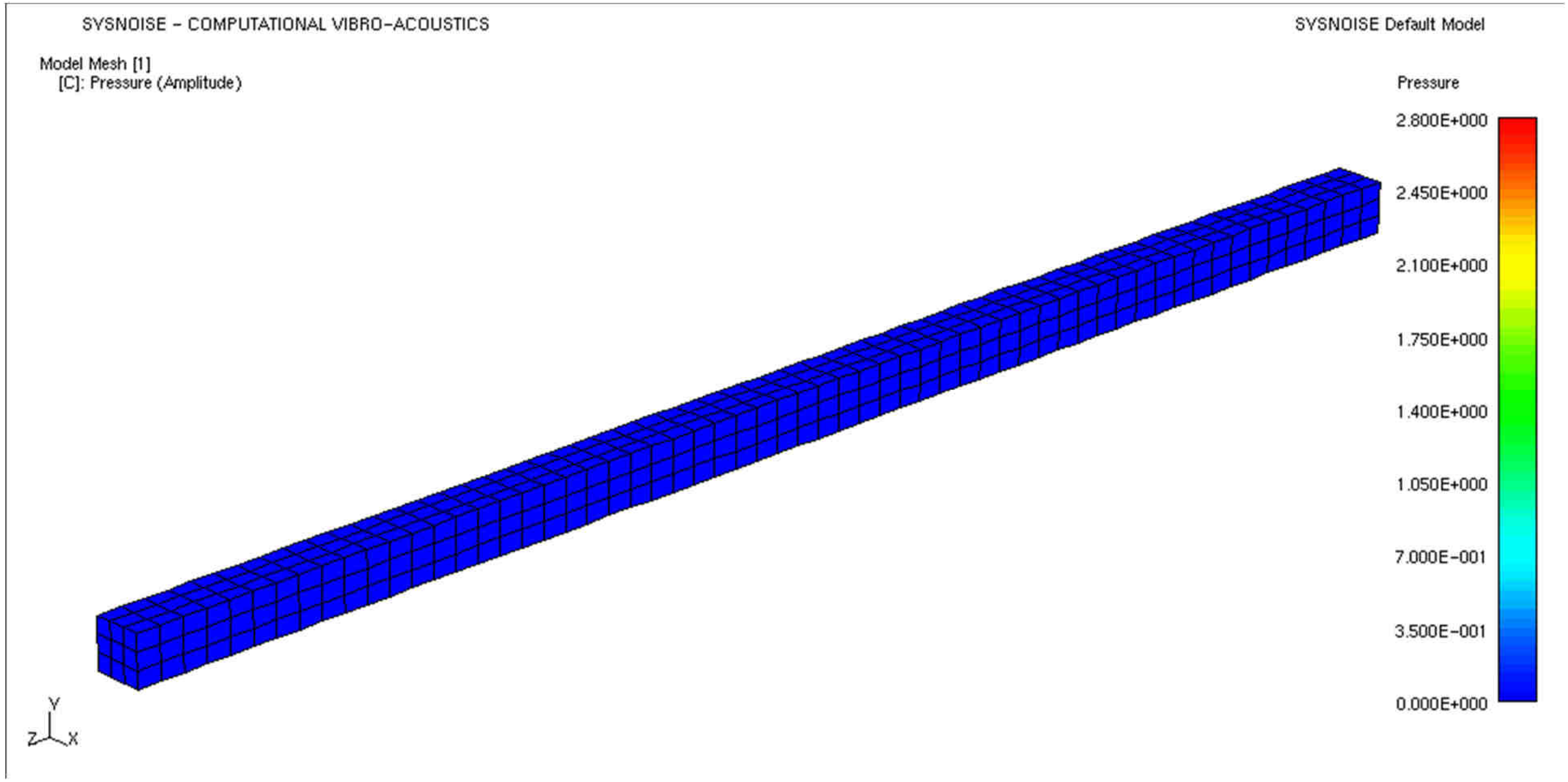


$$L = \lambda / 4 \;\Rightarrow\; f = c / 4L$$

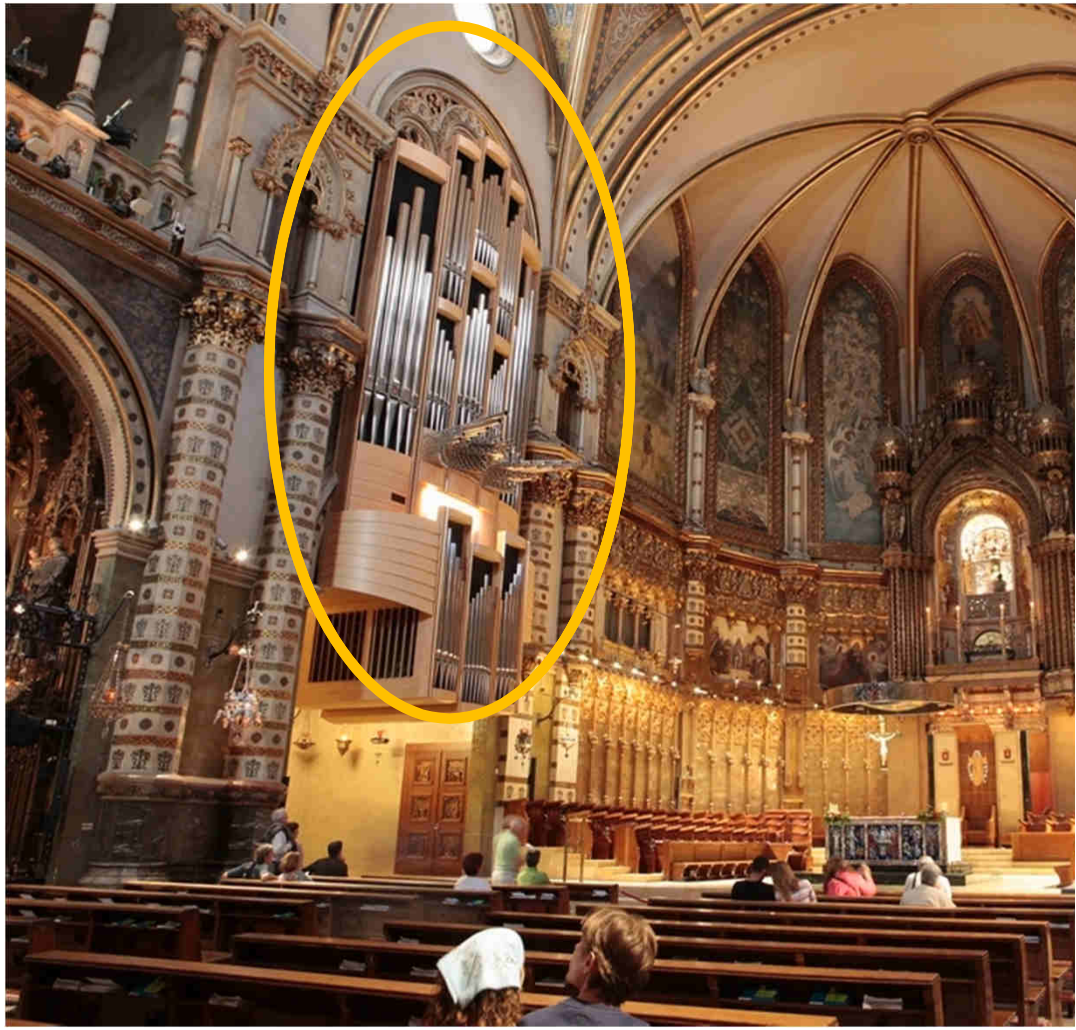
Model of a 1-D waveguide



Buildup of resonance in a closed waveguide

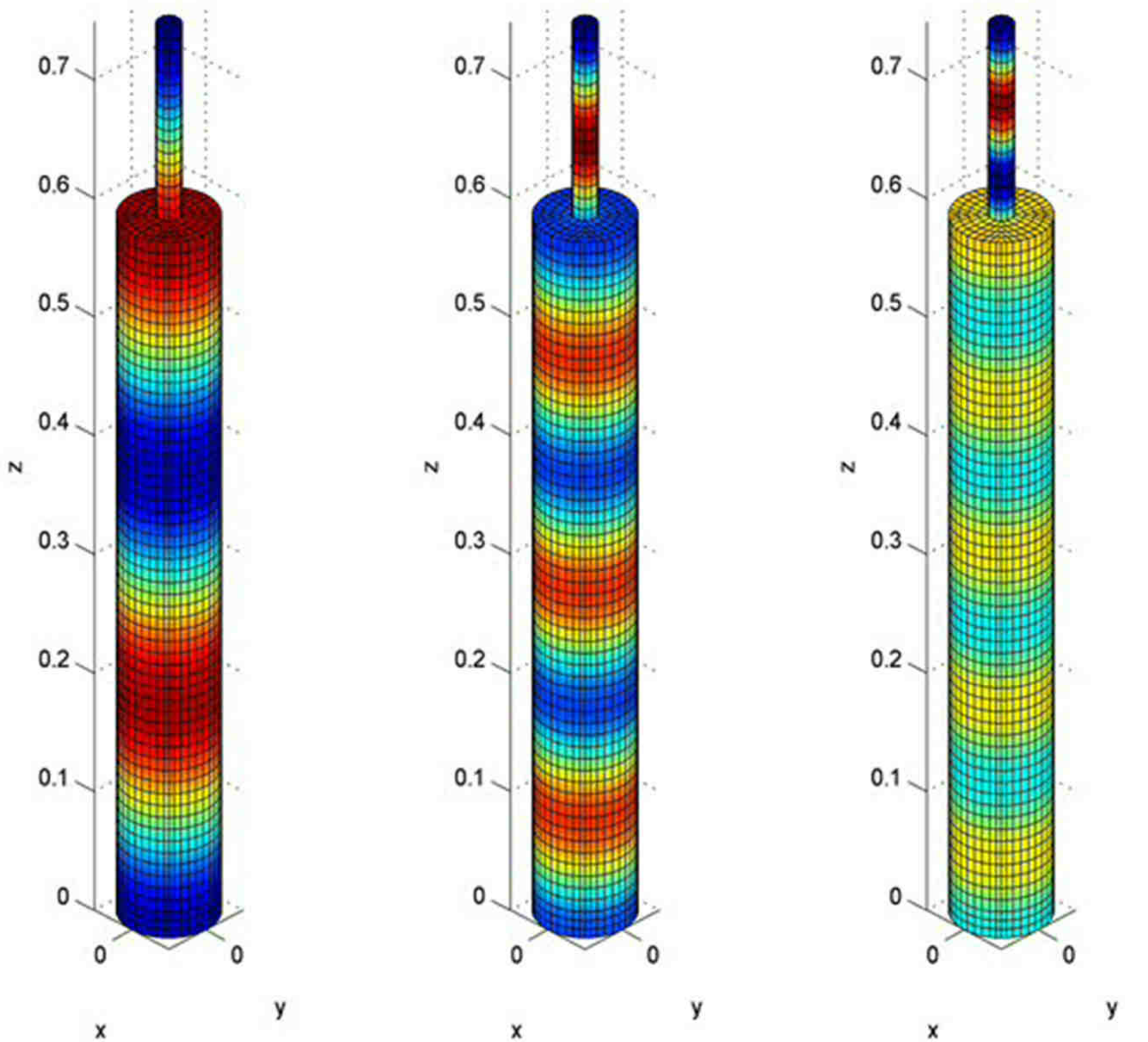


This is how the organ pipes work



Abbey of Montserrat and its organ builder

Operation of the chimney flute

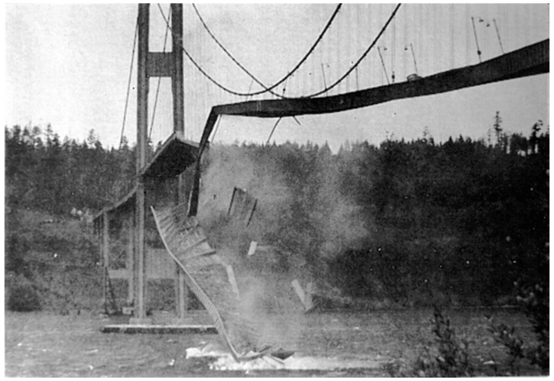


Formation of sounds in real-life systems

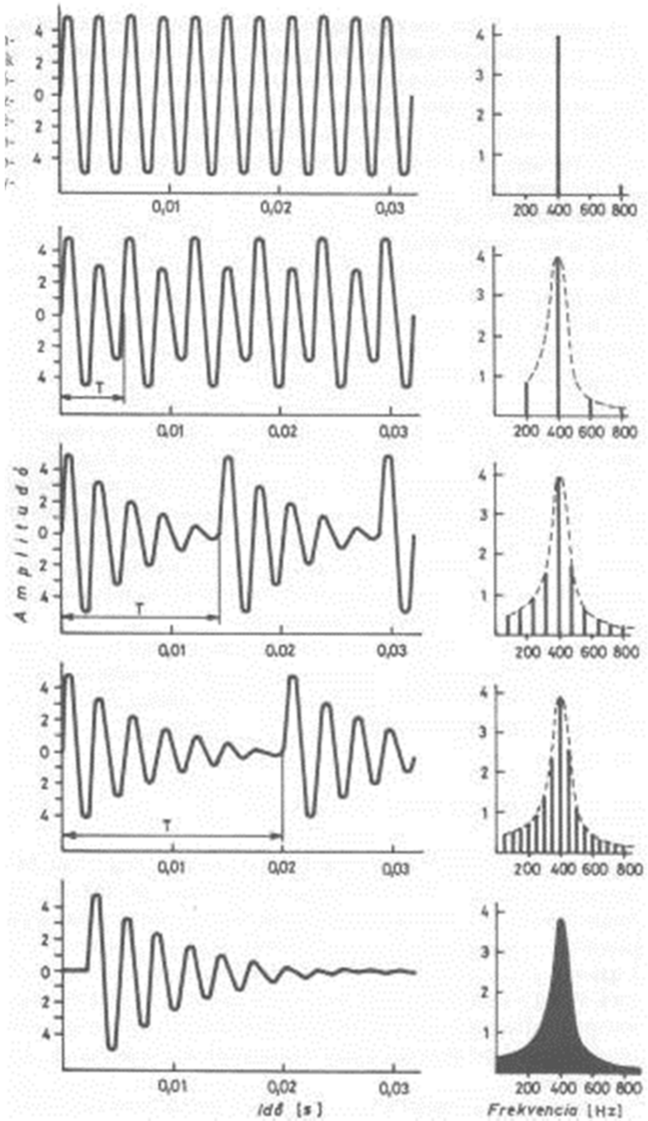
- The wave, propagating along a waveguide is reflected from both ends
- If the excitation appears in identical phase, amplification
- If he newly supplied energy is just enough to maintain the process: self-sustaining wave
- If it is too much: resonance
- A vey famous resonance: the collapse of the Tacoma bridge (US, November 7, 1940)

https://www.youtube.com/watch?v=j-zczJXSxnw

The real cause of the Tacoma catastrophy is not just resonance: it is aerodynamic flutter

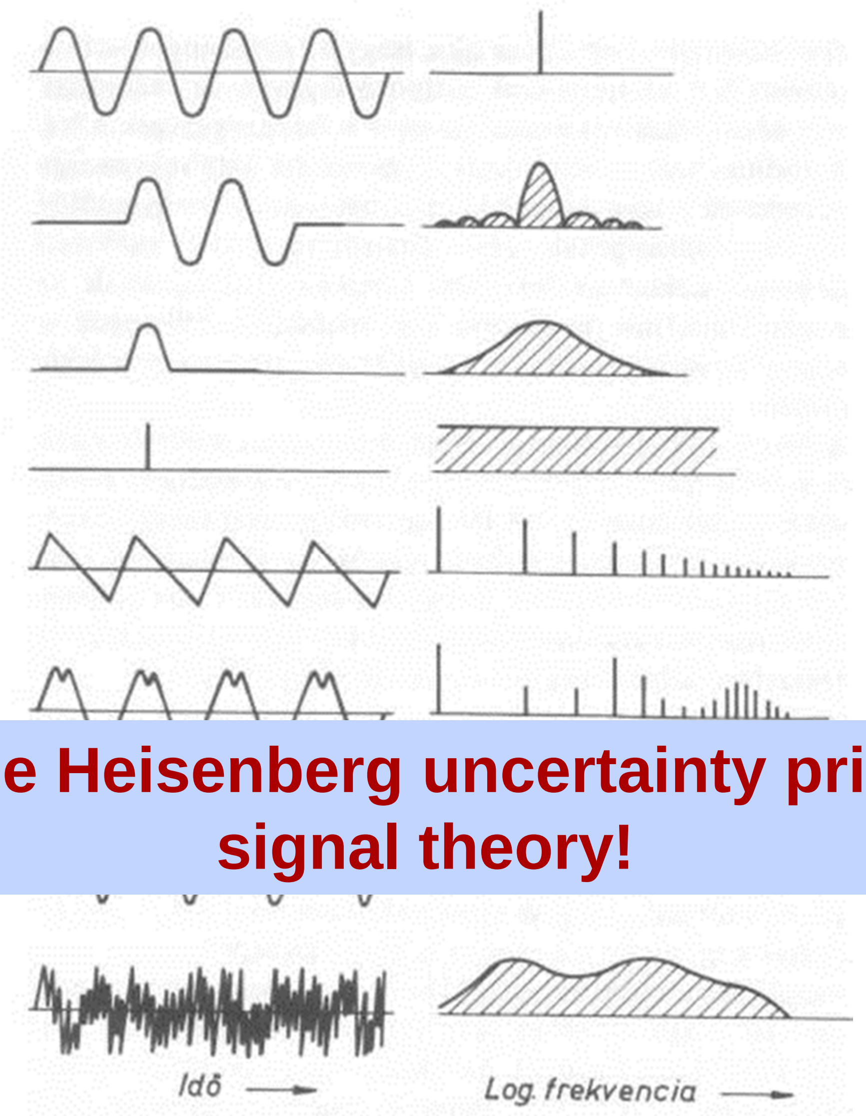


From sinusoids to transients



Relationship of frequency and time domain

Temporal variation



Frequency content

This is the Heisenberg uncertainty principle of signal theory!

And backwards (t ⇨ f): Fourier-analysis

Joseph Fourier (1768 – 1830)

A periodic function *x(t)* of period *T* can be transformed into an infinite series of sinusoids of amplitude *X:*

$$X_i = \frac{1}{T}\int_0^T x(t)\, e^{-j2\pi \frac{i}{T} t} \qquad x(t) = \sum_{i=-\infty}^{\infty} X_i e^{j2\pi \frac{i}{T} t}$$

This is the **Fourier-series** (expansion)

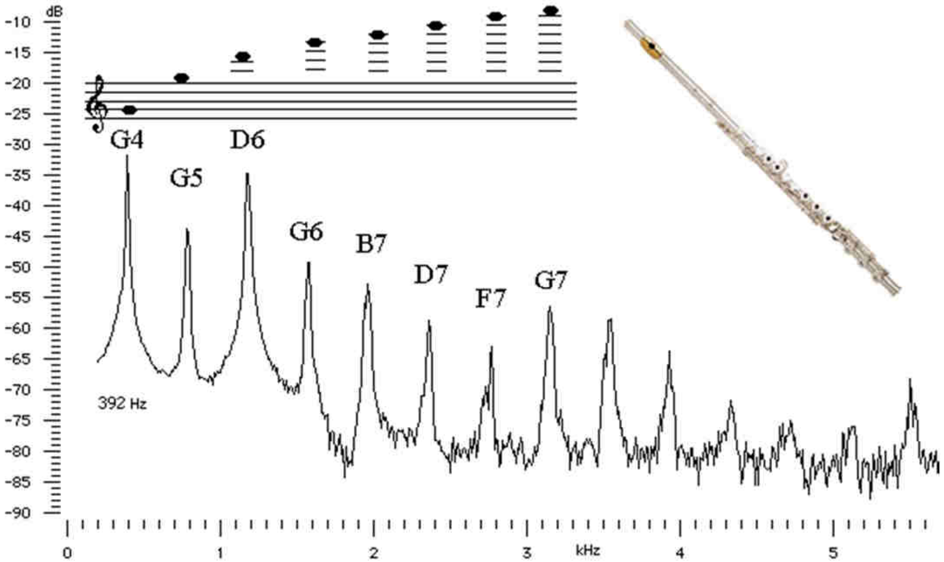
A nonperiodic function *x(t)* can be transformed into a continuous function, representing a continuous distribution *X(f)* of components in the frequency domain

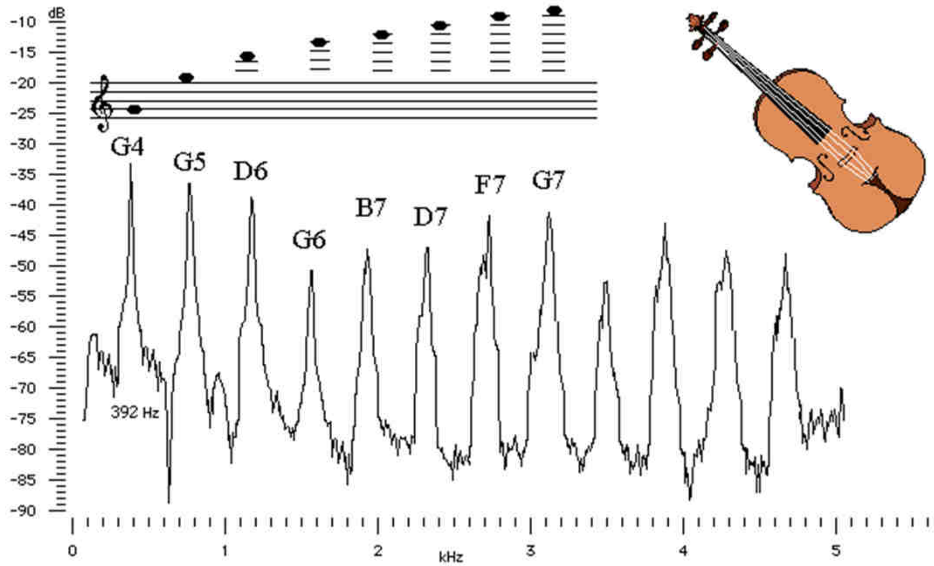
$$X(f) = \int_{-\infty}^{\infty} x(t)\, e^{-j2\pi ft}\, dt \qquad x(t) = \int_{-\infty}^{\infty} X(f)\, e^{j2\pi ft}\, df$$

This is the **Fourier-integral**

Harmonic content > tone/timbre

- Comparison of the sound of a flute and a violin



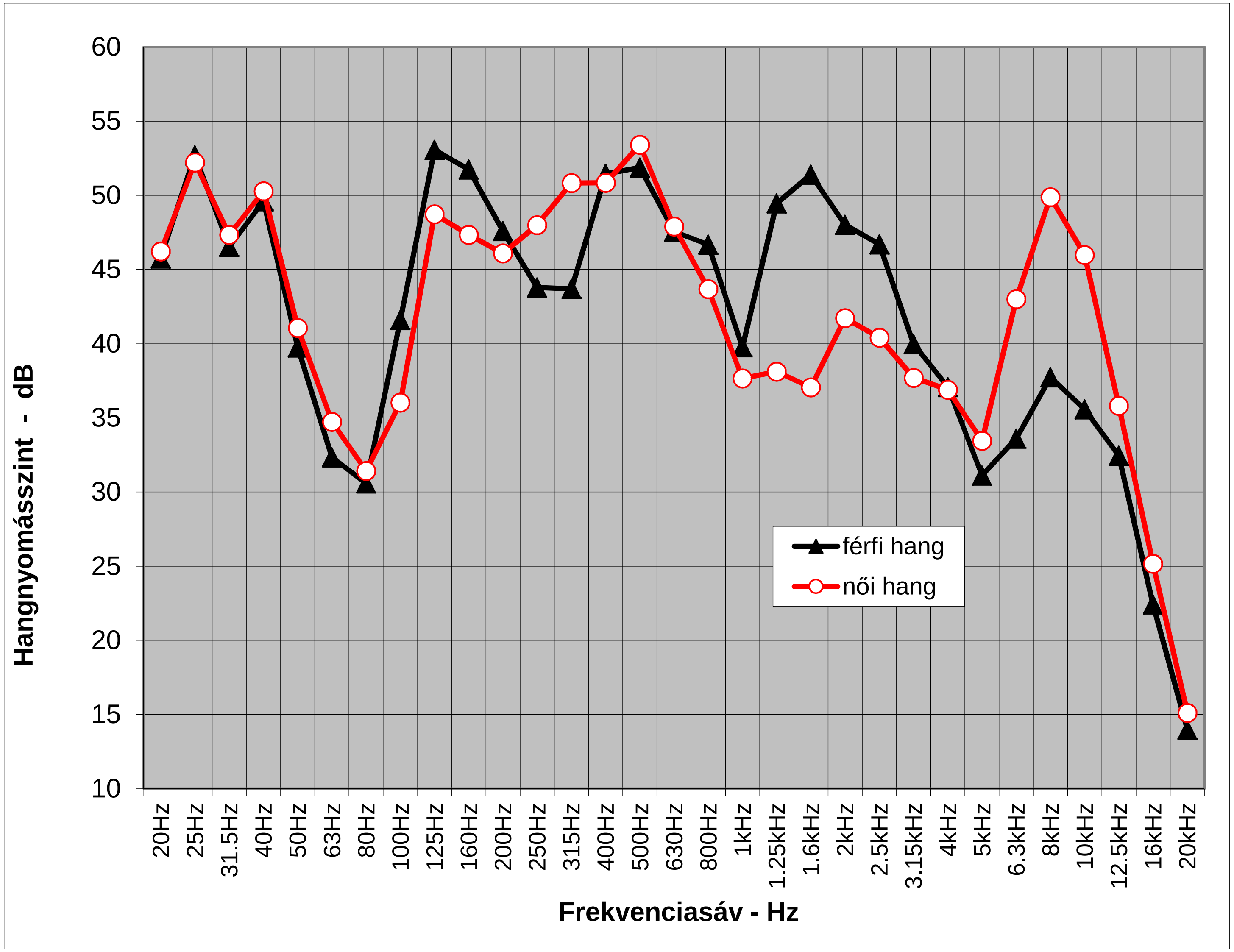


https://www.youtube.com/watch?v=c5o16fl0gqM

Frequency analysis - experimental

- Aim is to separate various frequency components by
  - decomposing into bands of constant ***absolute*** bandwidth
  - decomposing into bands of constant ***relative*** bandwidth
- Narrow-band frequency analysis is
  - aimed at exact identification of tonal frequencies
- Standard octave or third-octave band analysis is
  - aimed at modelling/imitating the human hearing system

Comparison of male and female voice by third-octave band analysis



Standard octave and third-octave bands

Oktávsávok			Tercsávok		
Közép-érték	Átfogás	Sáv-szélesség	Közép-érték	Átfogás	Sáv-szélesség
			20	18–22,5	4,5
			25	22,5–28	5,5
31,5	22,5–45	22,5	31,5	28–35,5	7,5
			40	35,5–45	9,5
			50	45–56	11
63	45–90	45	63	56–71	15
			80	71–90	19
			100	90–112	22
125	90–180	90	125	112–140	28
			160	140–180	40
			200	180–225	45
250	180–355	175	250	225–280	55
			315	280–355	75
			400	355–450	95
500	355–710	355	500	450–560	110
			630	560–710	150
			800	710–900	190
1000	710–1400	690	1000	900–1120	220
			1250	1120–1400	280
			1600	1400–1800	400
2000	1400–2800	1400	2000	1800–2250	450
			2500	2250–2800	550

Practical examples of frequency analysis

Narrow band and
third-.octave band
analyses of Organ pipes, speech and music