# Foundations of Language Science and Technology

## Acoustic Phonetics 2: Speech signals and waveforms

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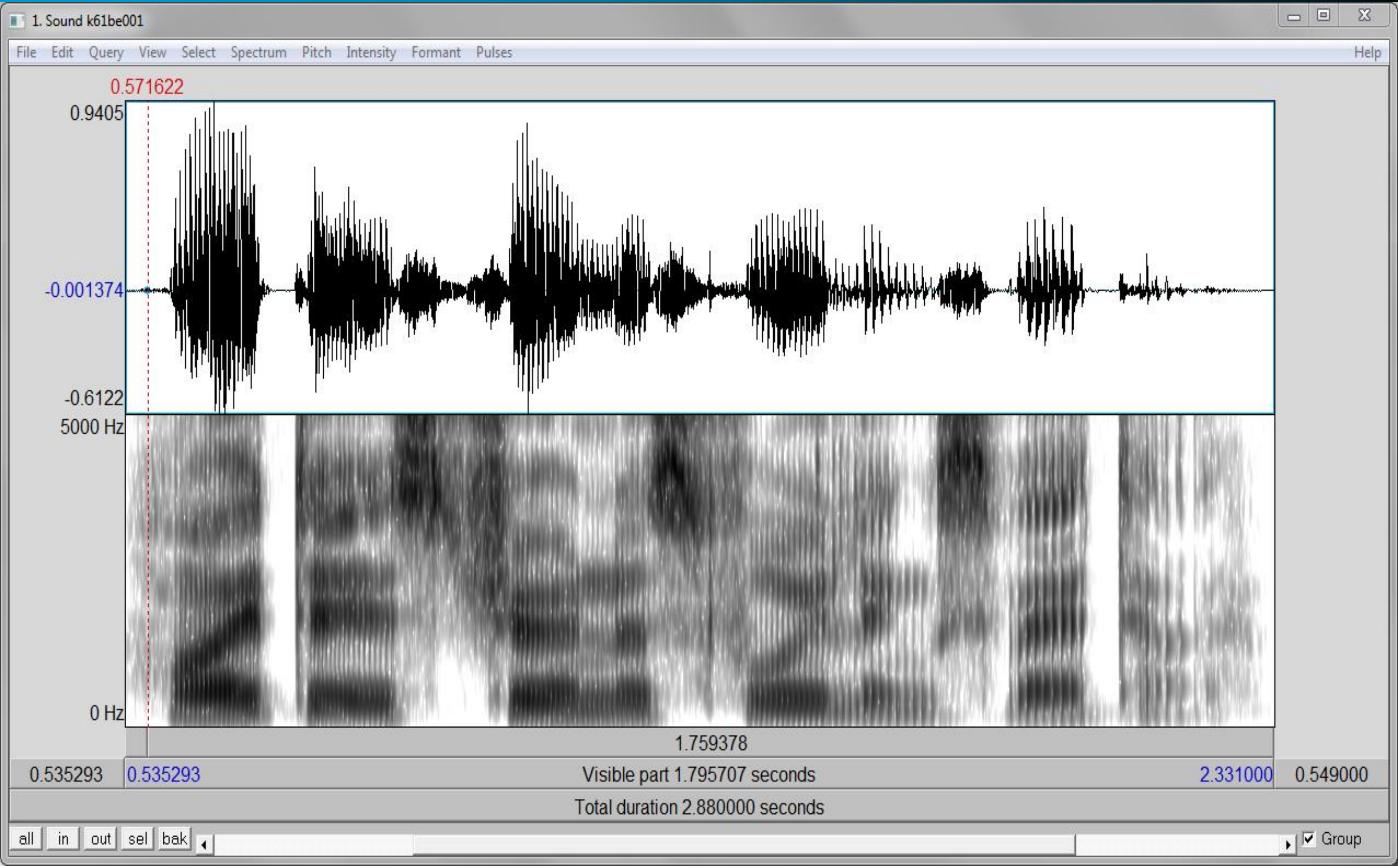
# Acoustic communication

- Prerequisites for acoustically based speech communication
  - sound production
  - sound perception
  - sound propagating medium
- Basic acoustic properties of speech sounds
  - frequencies within the range of human auditory perception (20 – 20,000 Hz)
  - amplitude: displacement of an oscillation → perceived loudness
  - duration: perceptible minimum duration; duration of units of speech
  - (timbre)

# Speech sounds and speech signals

- Basic types of speech signals
  - quasi-periodic signals: sonority
    - vowels
    - sonorants (approximants, glides, nasals, liquids)
  - stochastic signals: frication noise
    - fricatives
    - plosive aspirations
  - transient signals – impulse
    - plosive releases
  - mixed excitation – voiced frication noise
    - voiced fricatives

# Speech sounds and speech signals




"Heute ist schönes Frühlingswetter."

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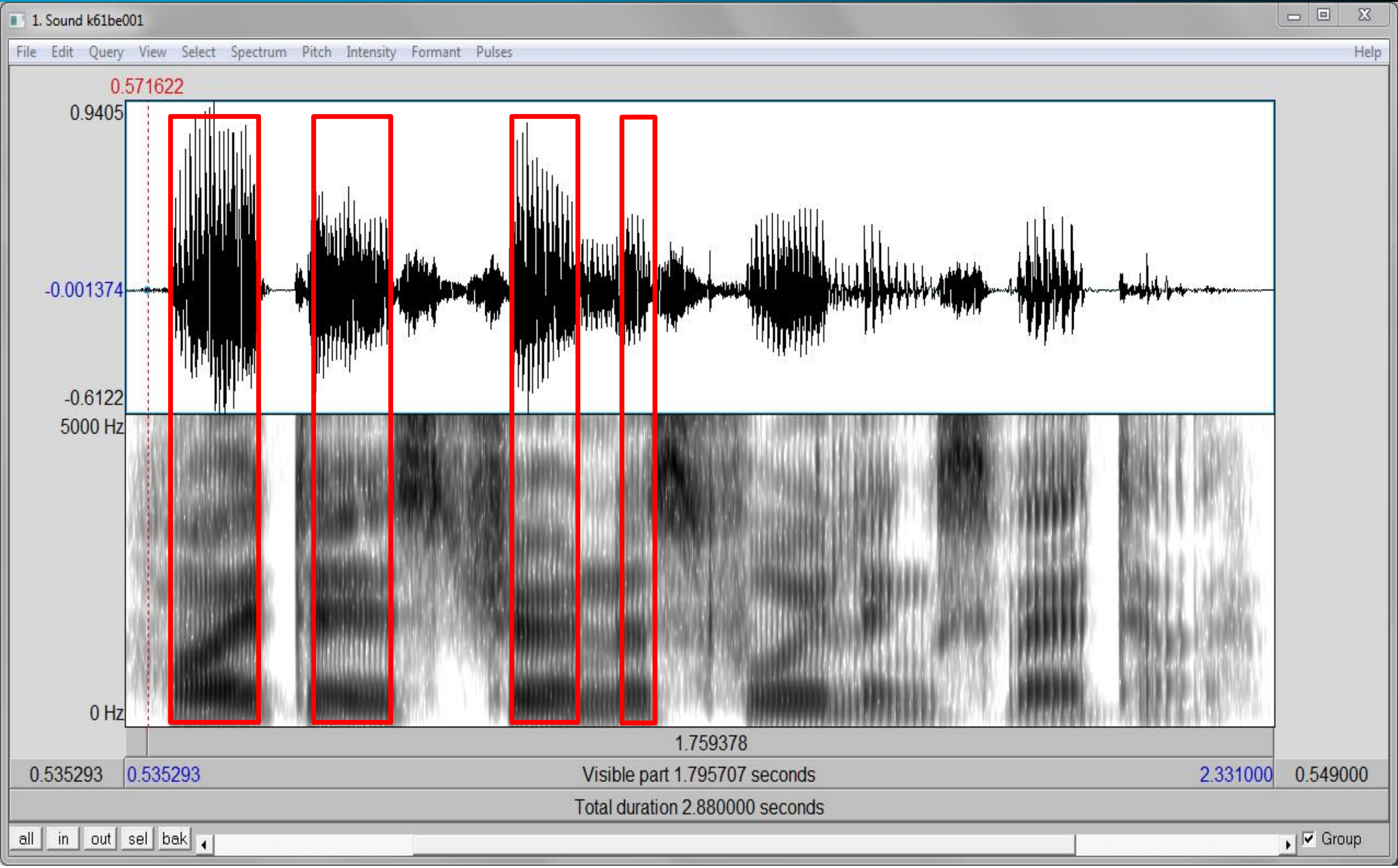
# Speech sounds and speech signals: vowels

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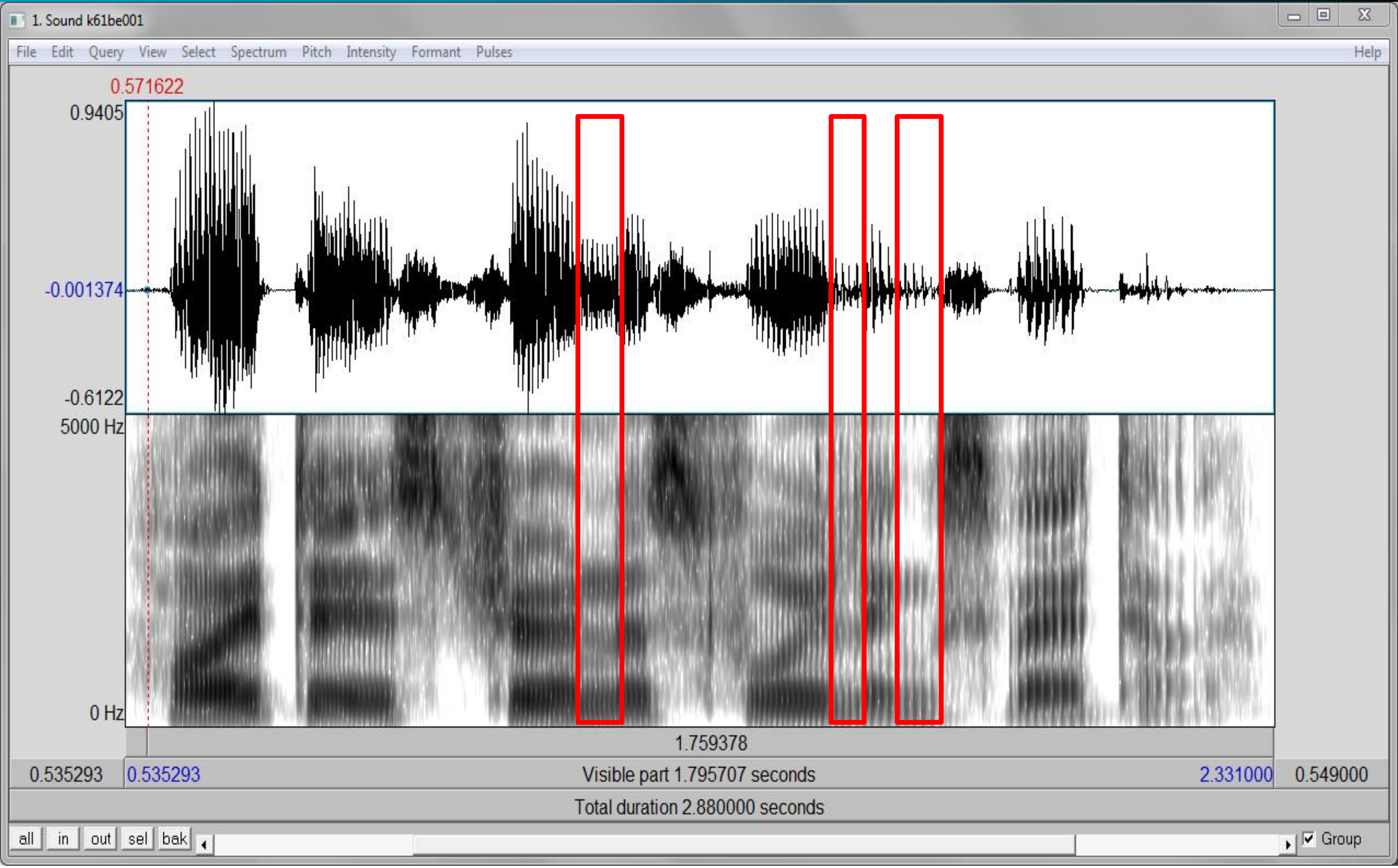
# Speech sounds and speech signals: sonorants

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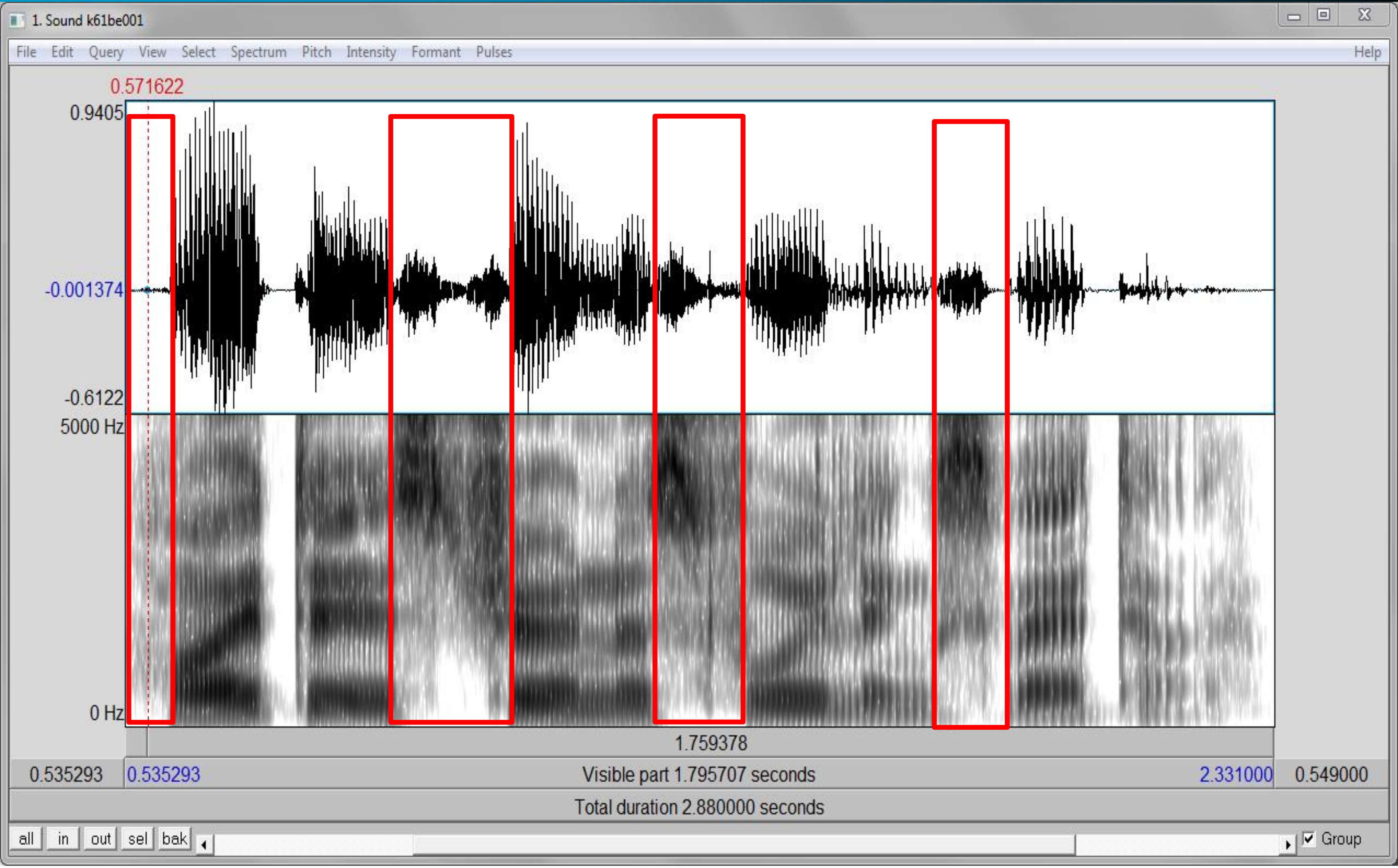
# Speech sounds and speech signals: fricatives

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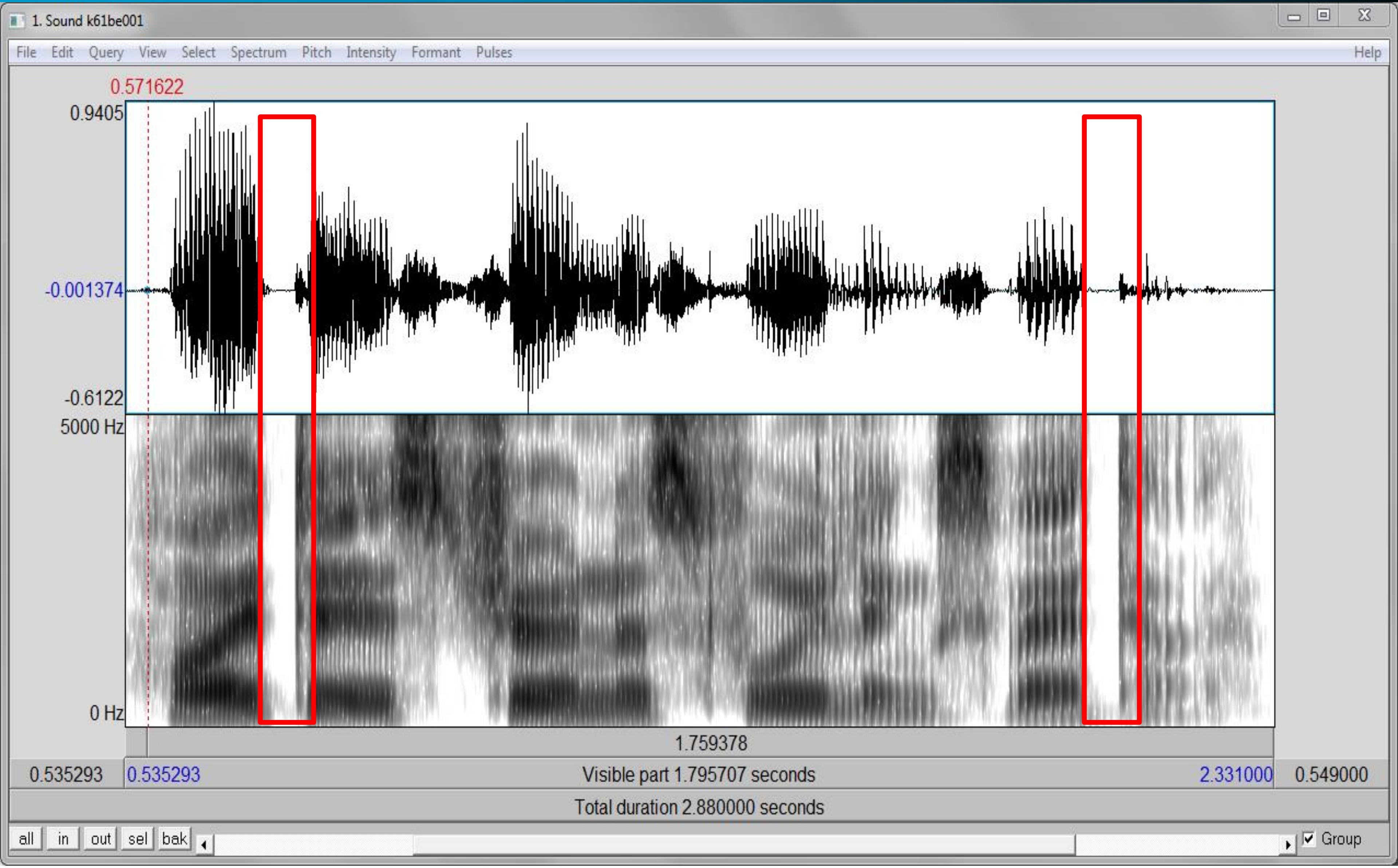
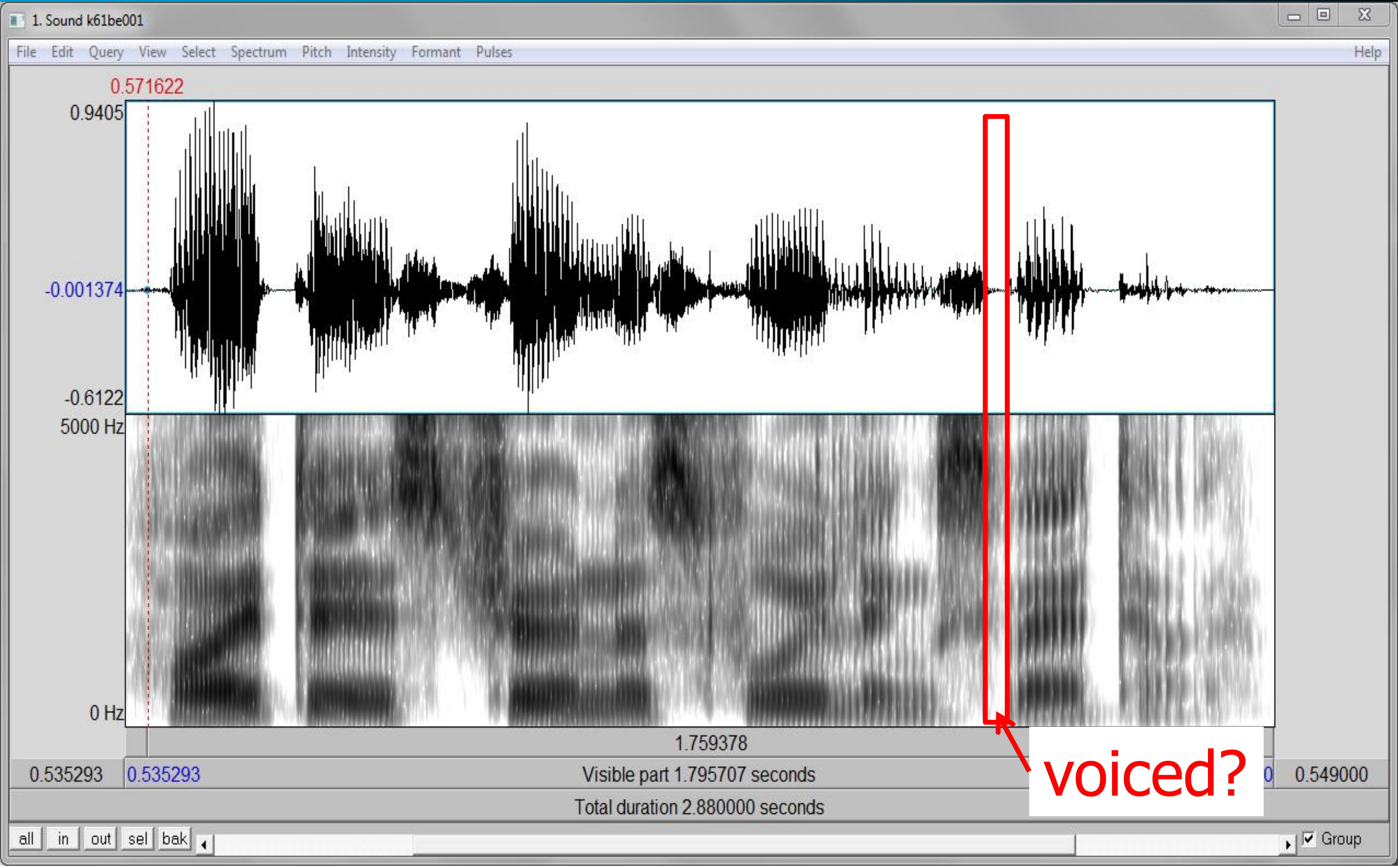
# Speech sounds and speech signals: plosives



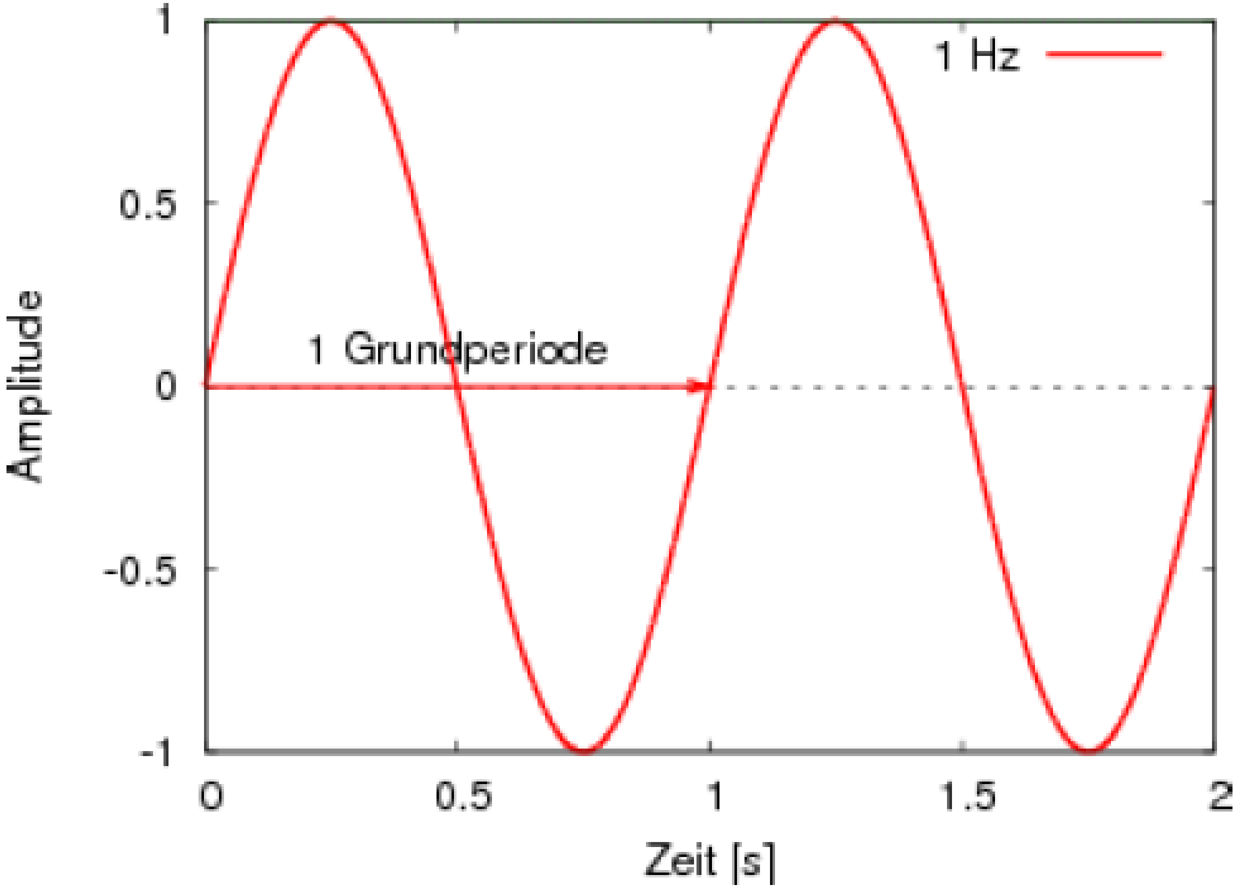

"Heute is(t) schönes Frühlingswetter."

# Speech sounds...: voiced fricatives




"Heute ist schönes Frühlingswetter."

# Simple waveforms



# Simple waveforms

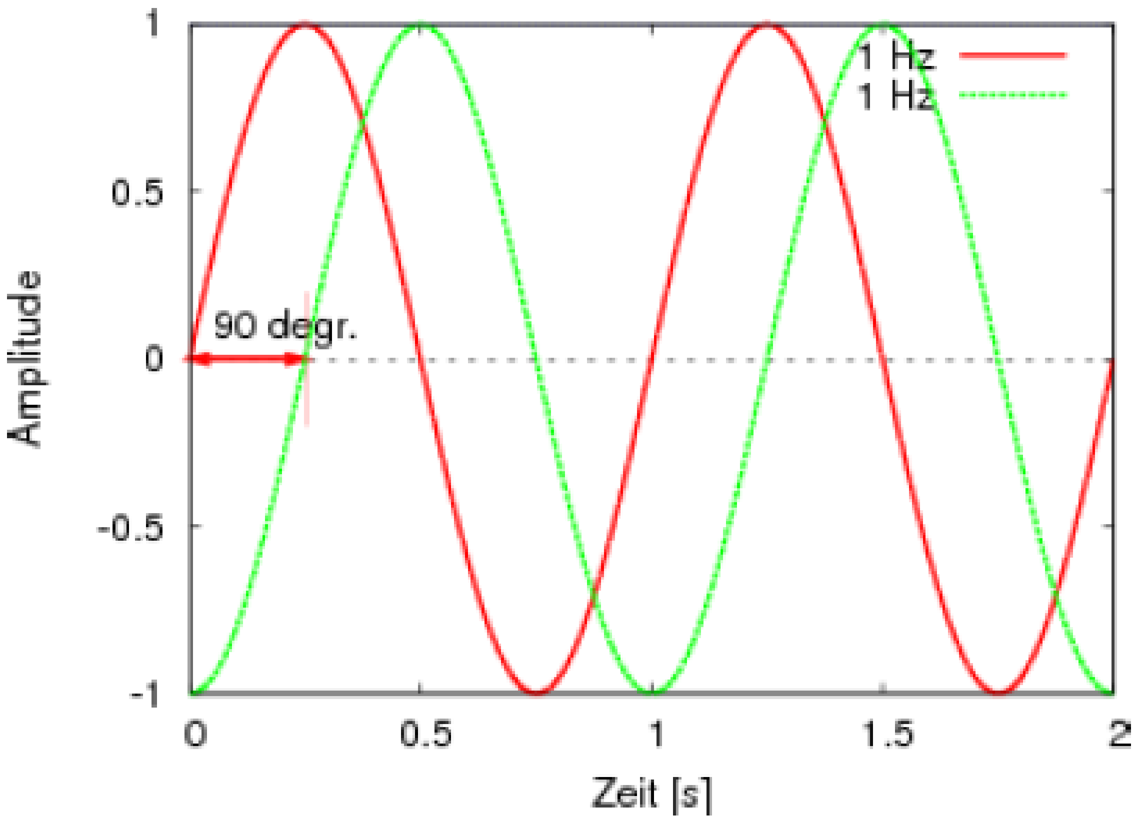
- Simple periodic oscillation: pure sine wave
  - cyclically recurring, simple oscillation pattern, determined by
    - fundamental period $T_0$
    - amplitude A
    - phase $\Phi$
- Fundamental frequency [Hz]: 1 / fundamental period [s]

  $F_0 = 1 / T_0$

# Simple waveforms

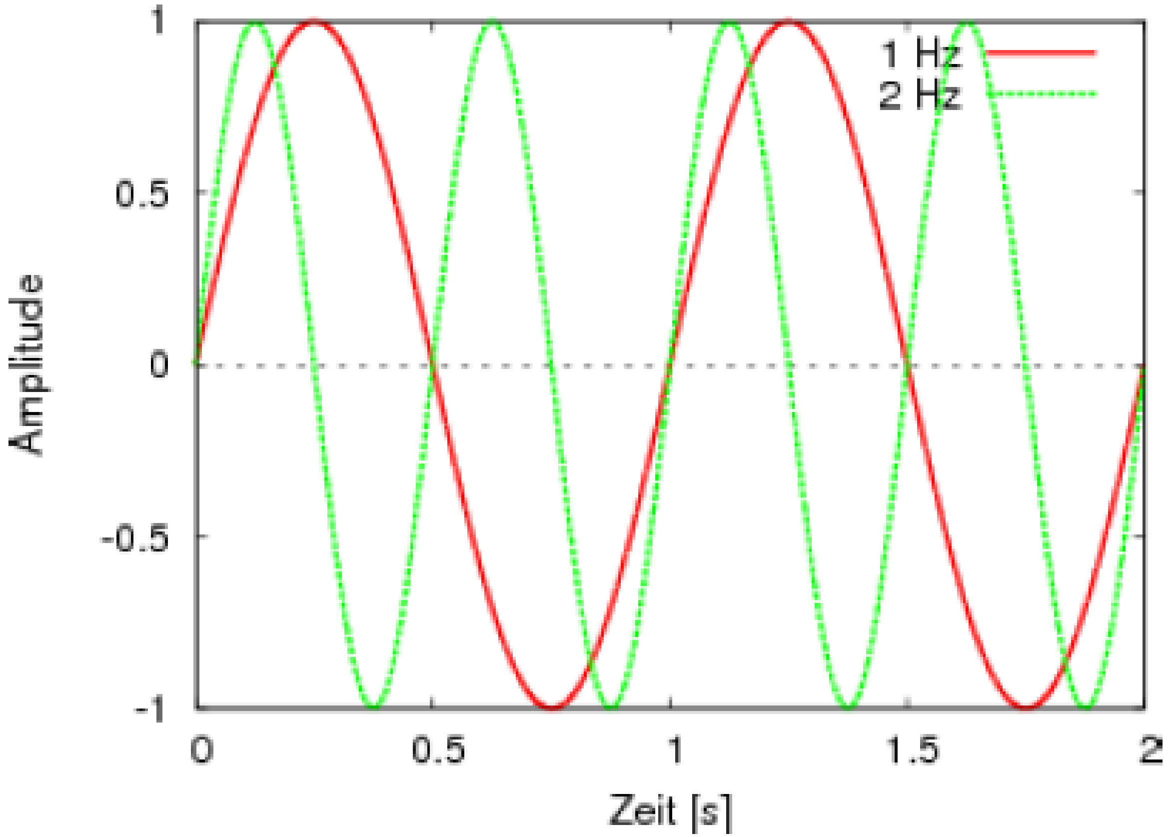
- Phase relation
  - two sine waves of same frequency and amplitude, but temporally displaced maxima, minima, and zero crossings

    → phase shift (here: angle 90º)



# Simple waveforms

- Frequency differences
  - two sine waves of same amplitude and phase, but different frequency (here: 1 vs. 2 Hz)

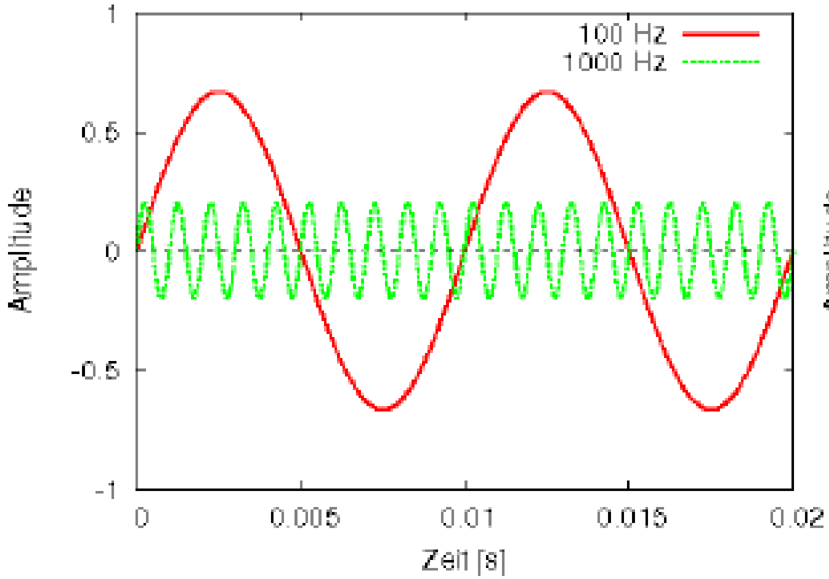


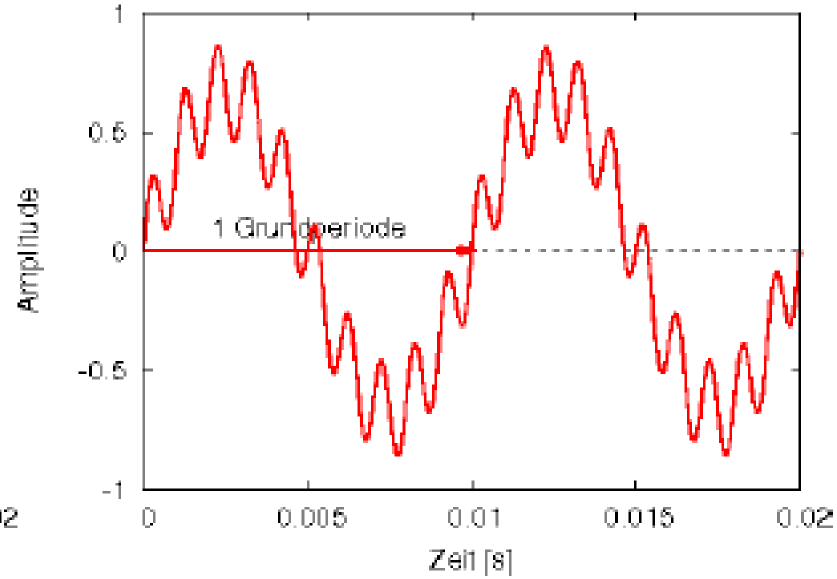
# Complex waveforms

- Complex periodic signals
  - cyclically recurring oscillation patterns
  - composed of at least two sine waves
  - fundamental frequency = 1 / complex fundamental period
- Form of resulting complex wave depends on frequency, amplitude and phase relations between component waves

# Complex waveforms

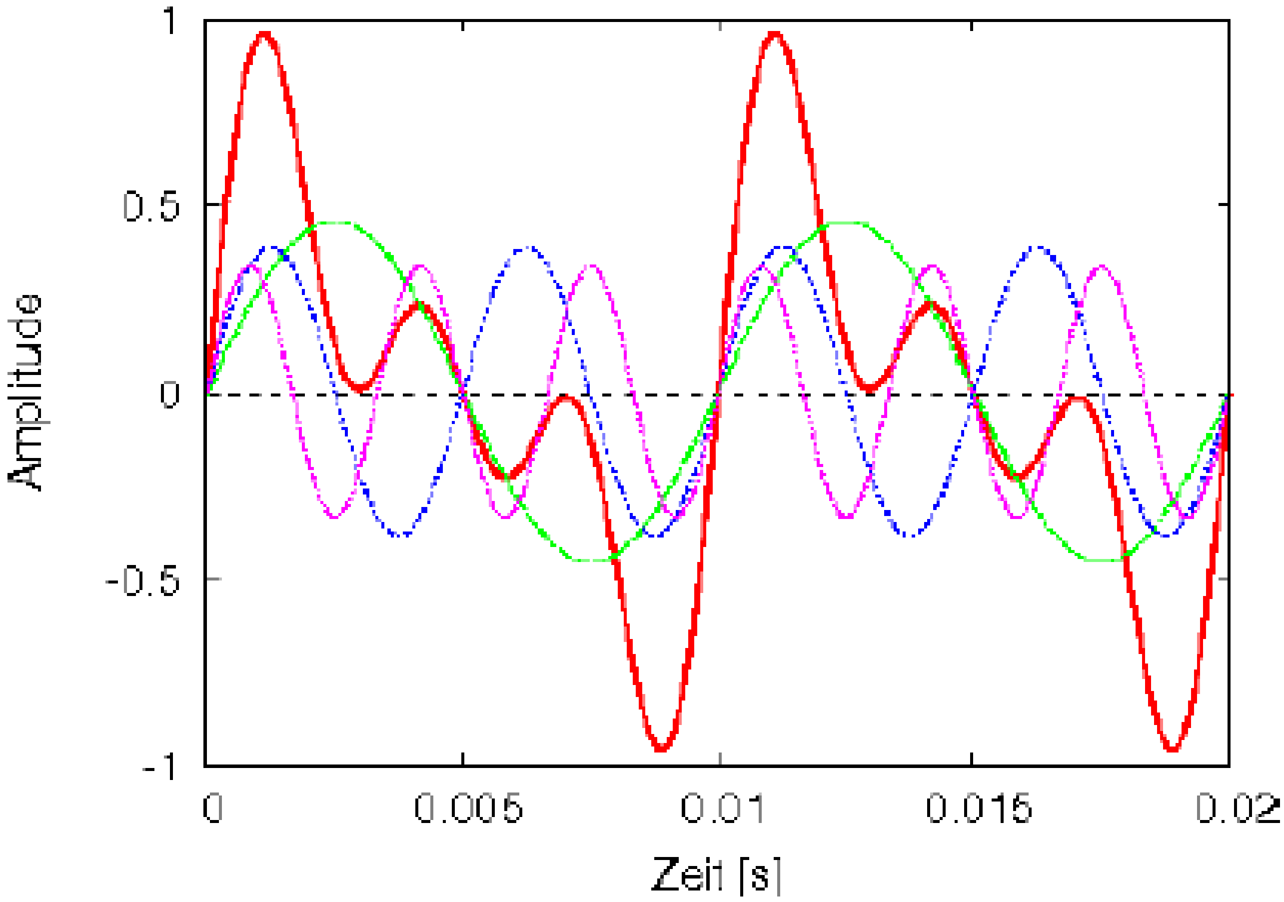
- Complex waveform: 2 components
  - two sine waves (100 Hz, 1000 Hz) with same phase and different amplitude (left)
  - complex wave (right) resulting from addition of the two components
  - $F_0$ = 100 Hz



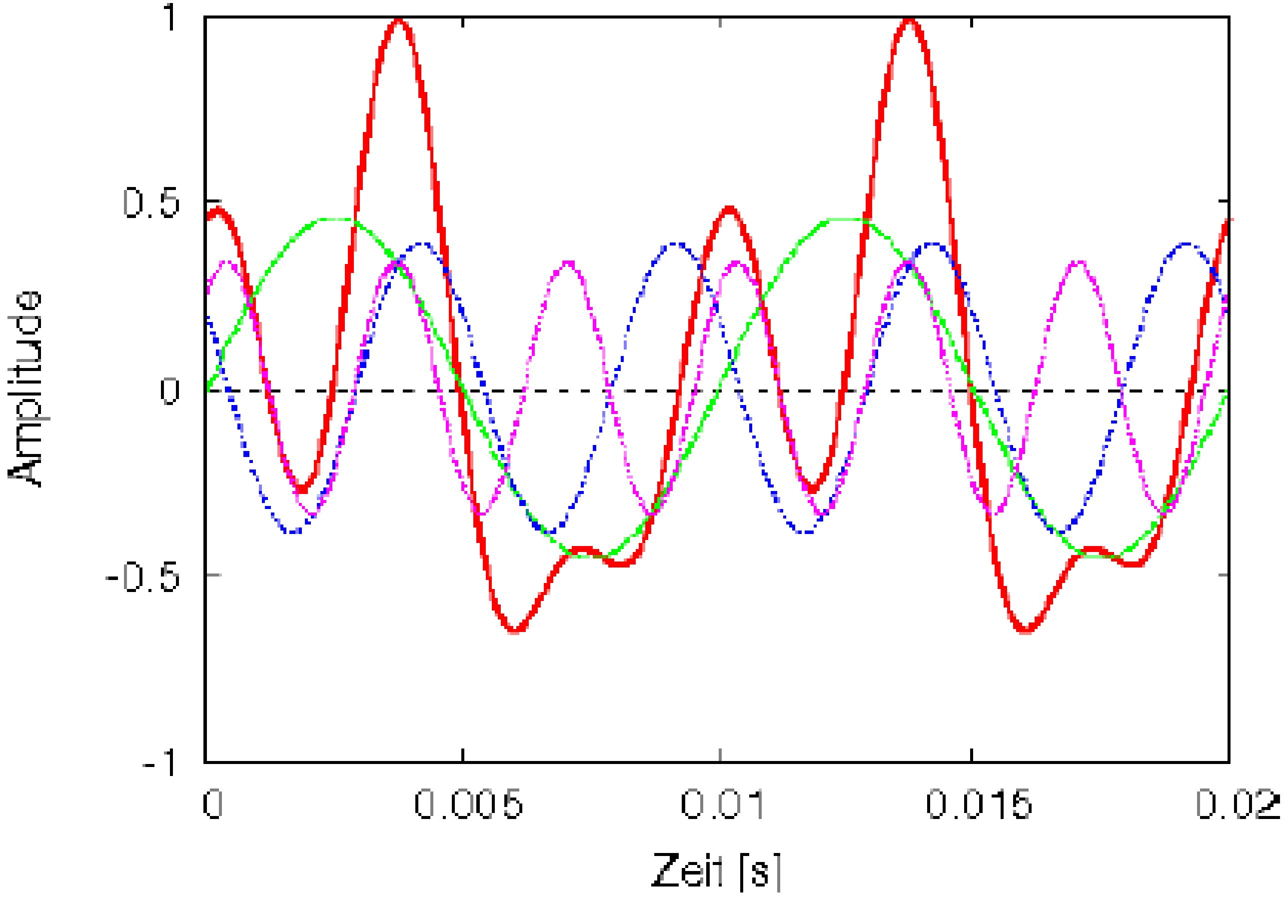
# Complex waveforms

- Complex waveform (red): 5 components
  - five sine waves (100, 200, 300, 400, 500 Hz) with same phase
  - only 3 lowest frequency components displayed



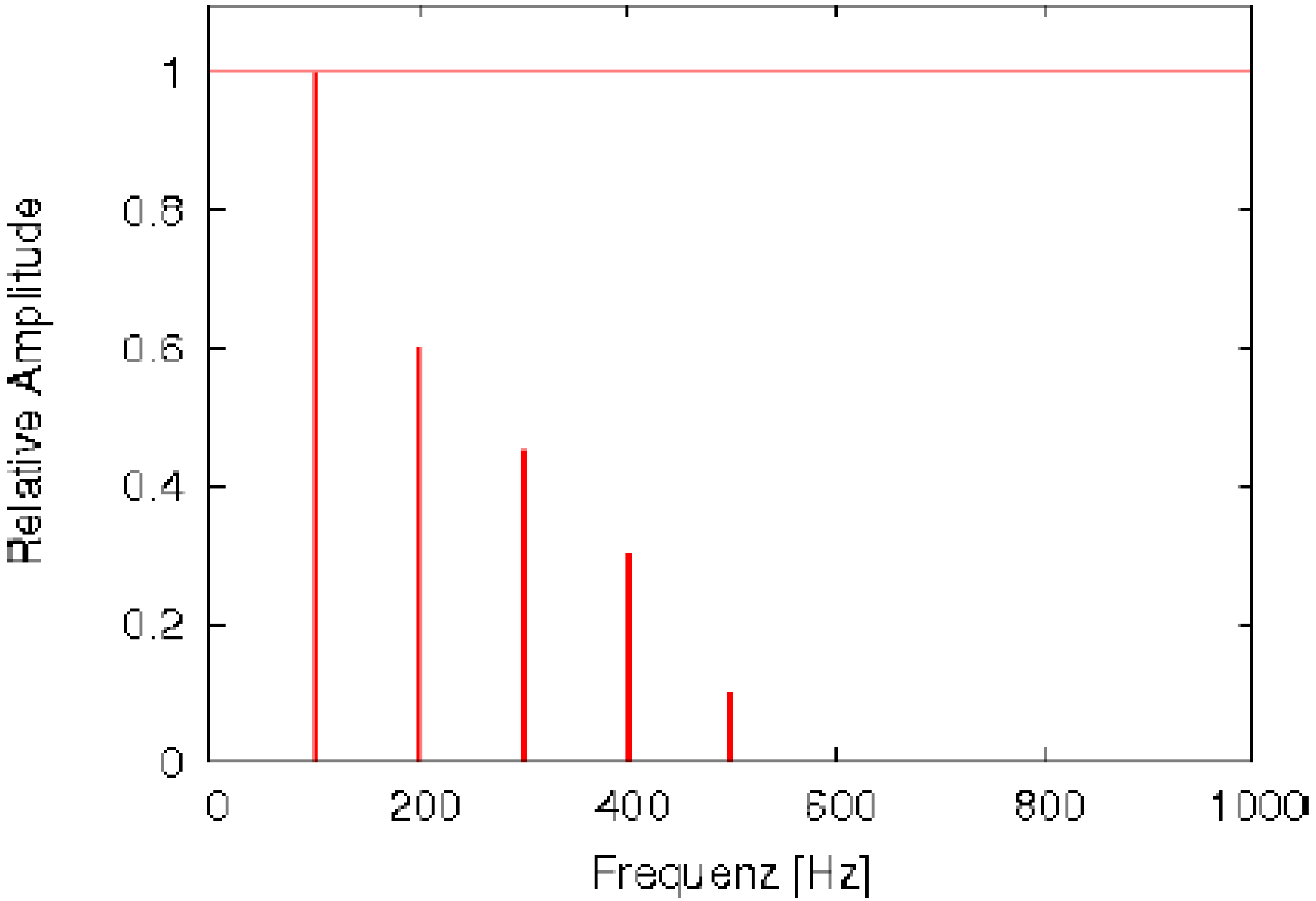
# Complex waveforms

- Complex waveform (red): 5 components
  - five sine waves (100, 200, 300, 400, 500 Hz) with phase shifts
  - only 3 lowest frequency components displayed



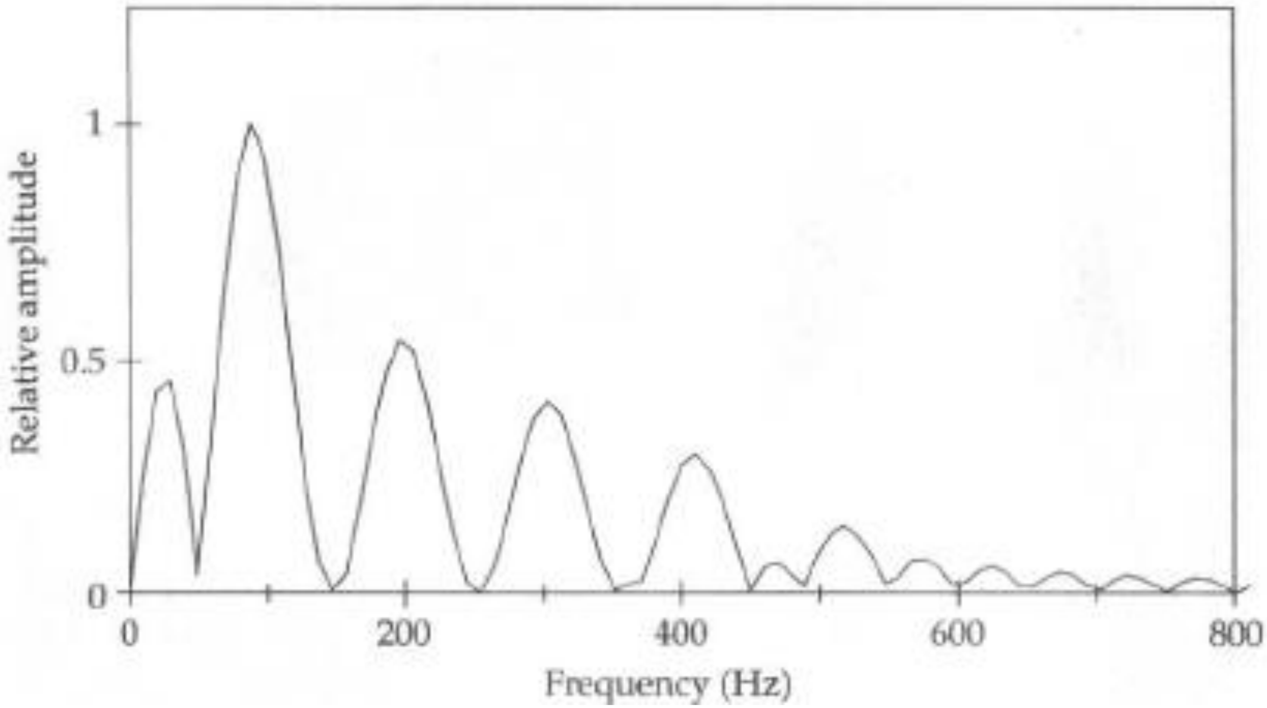
# Power spectrum

- Power spectrum (amplitude over frequencies) of the complex waveform composed of five components (see above)



# Fourier analysis

- Fourier analysis: power spectrum of 5 component wave (see above)




- Fourier's theorem
  - every complex wave can be analytically decomposed into a series of sine waves, each with a specific set of frequency, amplitude and phase values

# Fourier analysis and power spectrum

- Differences between result of Fourier analysis and idealized power spectrum (see above):
  - broader peaks
  - additional peaks
- Reasons for these differences:
  - Fourier analysis assumes infinitely long signal, whereas analysis is performed over 2 fundamental periods (quasi-periodic signal)
  - analog vs. digital signal representation

# Discrete Fourier Transform

- Discrete Fourier analysis (Discrete Fourier Transform, DFT)
  - digital Fourier analysis of complex signals, yielding a spectrum of sine wave components
  - transformation of data from time domain into frequency data
  - resolution parameters
    - sampling rate (e.g. 16000 Hz)
    - window size (length; e.g. 512 samples)
  - granularity of computed spectrum ca. 31 Hz (16000/512=31.25), with linear interpolation
  - trading relation (uncertainty principle)
    - good frequency resolution $\leftrightarrow$ poor time resolution
    - good time resolution $\leftrightarrow$ poor frequency resolution

# Spectrogram

- Analysis window size/length:
  - short temporal window : good time resolution
  - long temporal window: good frequency resolution
- Types of spectrograms:
  - narrow band spectrogram (e.g. 50 Hz): good frequency resolution
  - wide band spectrogram (e.g. 300 Hz): good temporal resolution

# From spectrum to spectrogram

- Power spectrum:
  - snapshot taken at a specific instant of time in the speech signal
- Spectrogram:
  - time as 3rd dimension (beside frequency and amplitude)
    - x-axis: time [s]
    - y-axis: frequency [Hz]
    - "z-axis": amplitude [dB] (gray-scale or color coding)

Let's go use Praat for further interactive demos...

(exercise session on Friday!)

Thanks!