DOING PHYSICS WITH PYTHON

FOURIER METHODS

FOURIER TRANSFORMS

SOUND RECORDINGS

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DOWNLOAD DIRECTORIES FOR PYTHON CODE

Google drive

GitHub

simFM005.py

audio440.wav wav_S1000_1008.wav audioGuitar1.wav

audioClarient1.wav audioVoice1.wav audioTrain.wav

The Code are used to calculate the Fourier transform and the power spectral density functions by the direct integration of the Fourier integrals using Simpson's rule.

For a more in-depth discussion on the Fourier transform visit

FOURIER TRANSFORMS / GAUSSIAN FUNCTION

INTRODUCTION

Many physical processes can be described in the **time domain** by the values of a function $h(t)$ or else in the **frequency domain** $H(f)$. The function $H(f)$ is usually complex function specified by its amplitude and phase.

Fourier transform equations

(1) $$H(f) = \int_{-\infty}^{\infty} h(t) e^{i(2\pi f t)}\, dt$$

(2) $$h(t) = \int_{-\infty}^{\infty} H(f) e^{-i(2\pi f t)}\, df$$

Equation 1 is the **Fourier transform** and equation 2 gives the **inverse Fourier transform**. If t is measured in seconds, then the frequency f is measured in hertz and the angular frequency ω in radians.

SOUND RECORDINGS

Sounds, for example made by musical instruments can be recorded as **wav** files. These **wav** files can be loaded into Python from **scipy.io import wav file** and the data extracted. The extracted data becomes the time domain function h.

```
from scipy.io import wavfile
# Load audio file
def loadFile(name):
    sampleRate, data = wavfile.read(name)
    dt = 1/sampleRate
    return [sampleRate, data, dt]
```

At the end of the Code, the sound of the recording is played

```
import os
file = name
os.system(file)
```

Simulation 1 Pure tone recording at 440 Hz simFM005.py

flag = 1 name = 'audio440.wav'

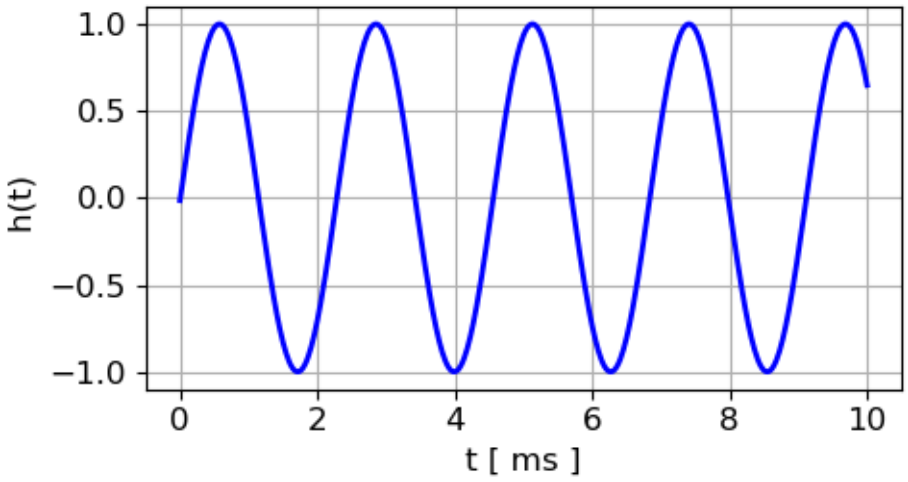


Fig. 1.1. Pure tone audio signal at 440 Hz

period T = 2.28 ms frequency f = 439 Hz

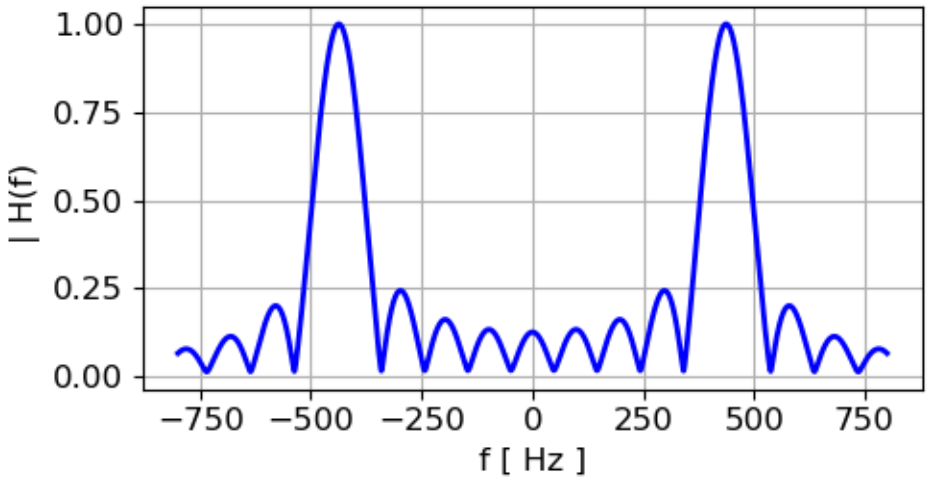


Fig. 1.2. Frequency spectrum f_{peak} = 437 Hz.

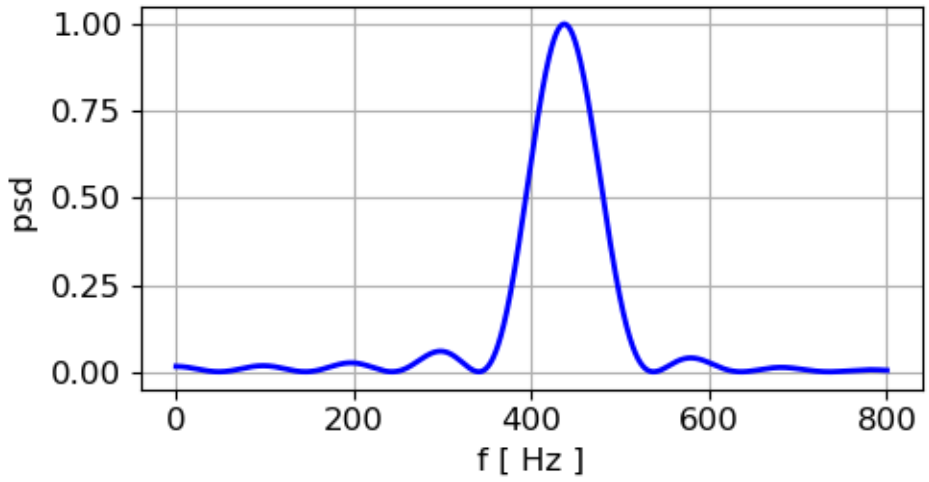


Fig. 1.3. One-sided power spectral density f_{peak} = 437 Hz.

Simulation 2 BEATS simFM005.py

flag = 2 name = 'wav_S1000_1008.wav'

In acoustics, a **beat** is an interference pattern between two sound waves of slightly different frequencies that causes a periodic variation in loudness. The **beat frequency** is the rate at which the volume swells or throbs. It equals the absolute difference between the frequencies of the two original sound waves

$$f_{beat} = |f_1 - f_2|$$

where f_1 and f_2 are the frequencies of the two individual sound waves, and the beat frequency f_{beat} is the resulting number of loud pulses per second.

BEATS

1. **Constructive Interference**: When the compressions (peaks) and rarefactions (troughs) of two waves line up in phase, they reinforce each other, making the sound **louder**.
2. **Destructive Interference**: As the waves drift out of phase because of their different frequencies, they cancel each other out, making the sound quieter.
3. **Result**: You hear a pulsing "wa-wa-wa" sound. As the two frequencies get closer together, the beats slow down; when the frequencies match completely, the beating stops.

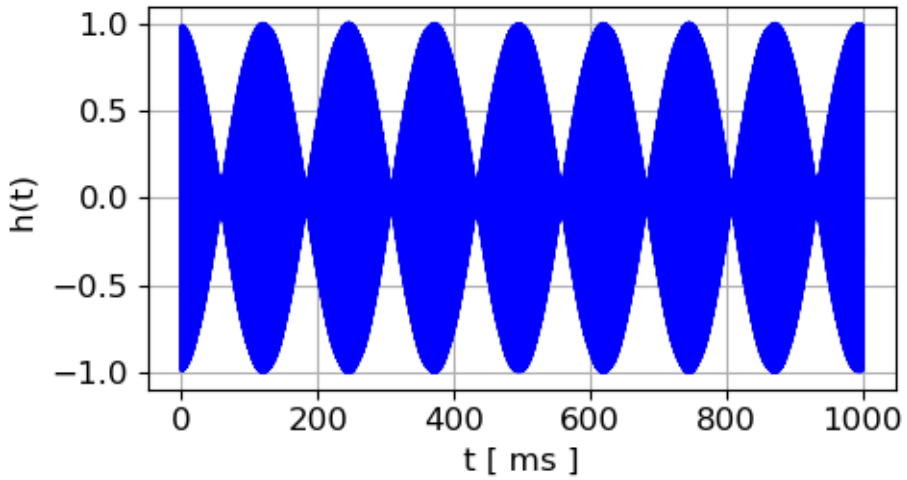


Fig. 2.1. The beat pattern for the superposition of two sinusoidal waves with frequencies **1000 Hz** and **1008 Hz**. The beat frequency is **8 Hz**. In **one second** there are **8** loud pulsations of the sound.

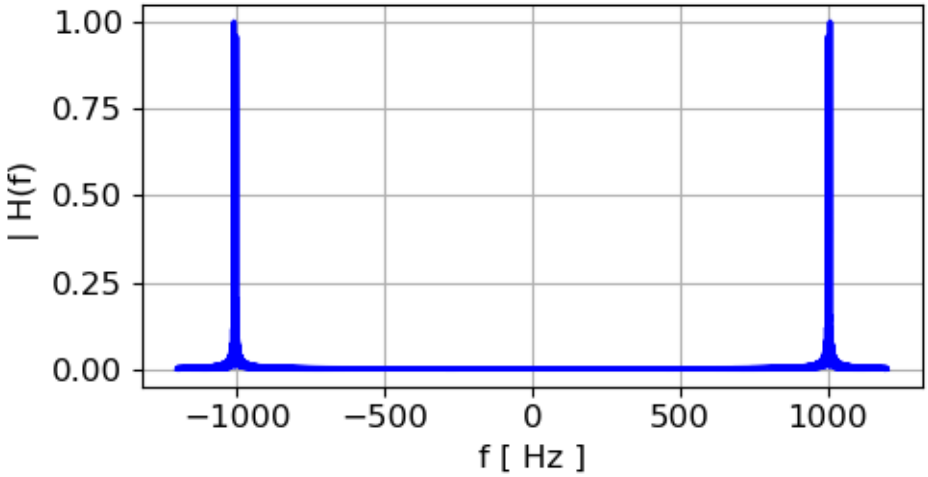


Fig. 2.2. The Fourier transform of the beat signal showing a major peak at a frequency near 1000 Hz.

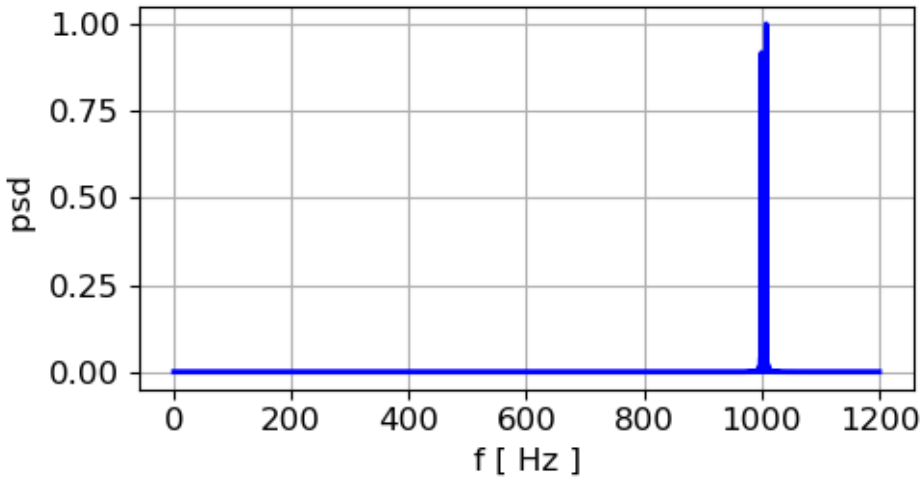


Fig. 2.3. The one-sided spectral power density which has a large peak at a frequency near 1000 Hz.

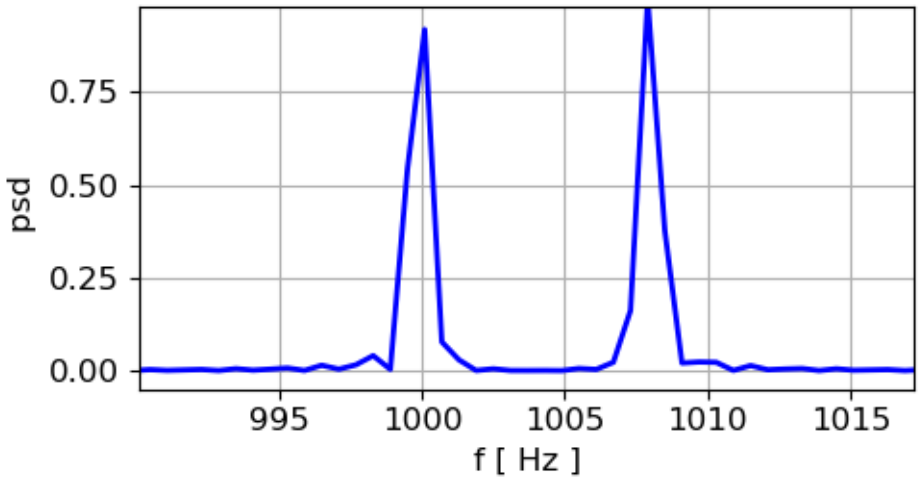


Fig. 2.4. The peak shown in figures 2.2 and 2.3 is actually a double peak at frequencies of **1000 Hz** and **1008 Hz**.

Simulation 3 GUITAR 220 Hz simFM005.py

flag = 3 name = 'audioGuitar1.wav'

We can compare three recording of a note at 220 Hz produced by a guitar, clarinet and by a voice.

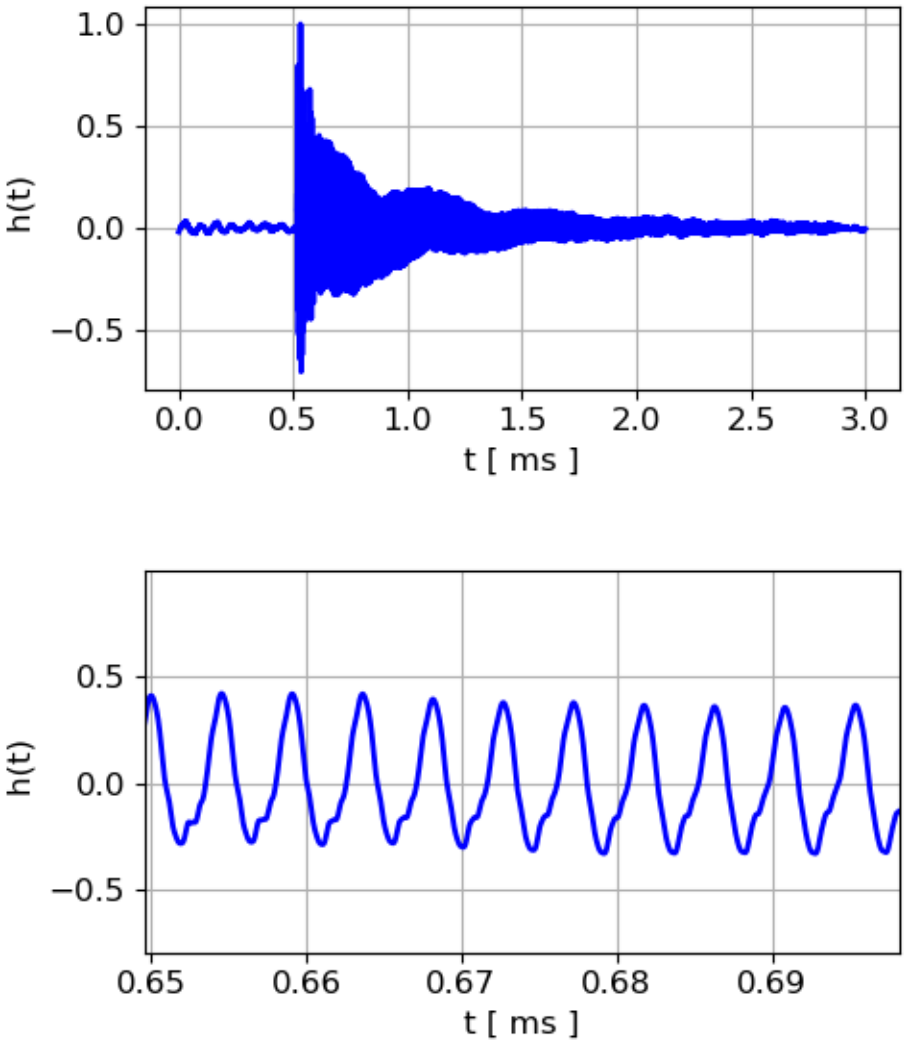


Fig. 3.1. The audio signal for the guitar.

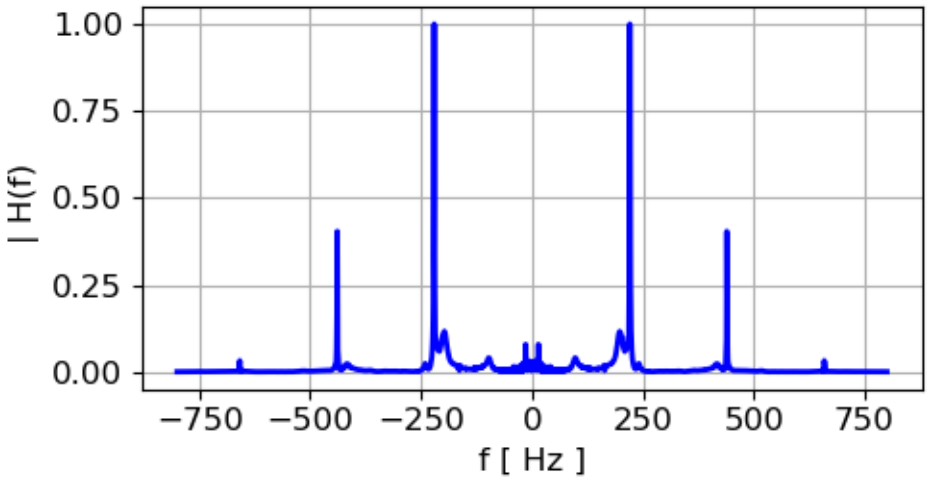


Fig. 3.2. The Fourier transform of the audio signal for the guitar. The two major frequency peaks are 221 Hz and 439 Hz and a very small peak at 659 Hz. The three peaks correspond to the first three harmonics (n = 1, 2, 3).



Fig. 3.3. Image of a guitar. A guitar produces sound by converting the mechanical energy of plucked strings into standing waves, which are then amplified either acoustically through air resonance or electromagnetically through pickups. Both the even and odd harmonics can be excited.

Simulation 4 CLARINET 220 Hz simFM005.py

flag = 4 name = 'audioClarinet1.wav'

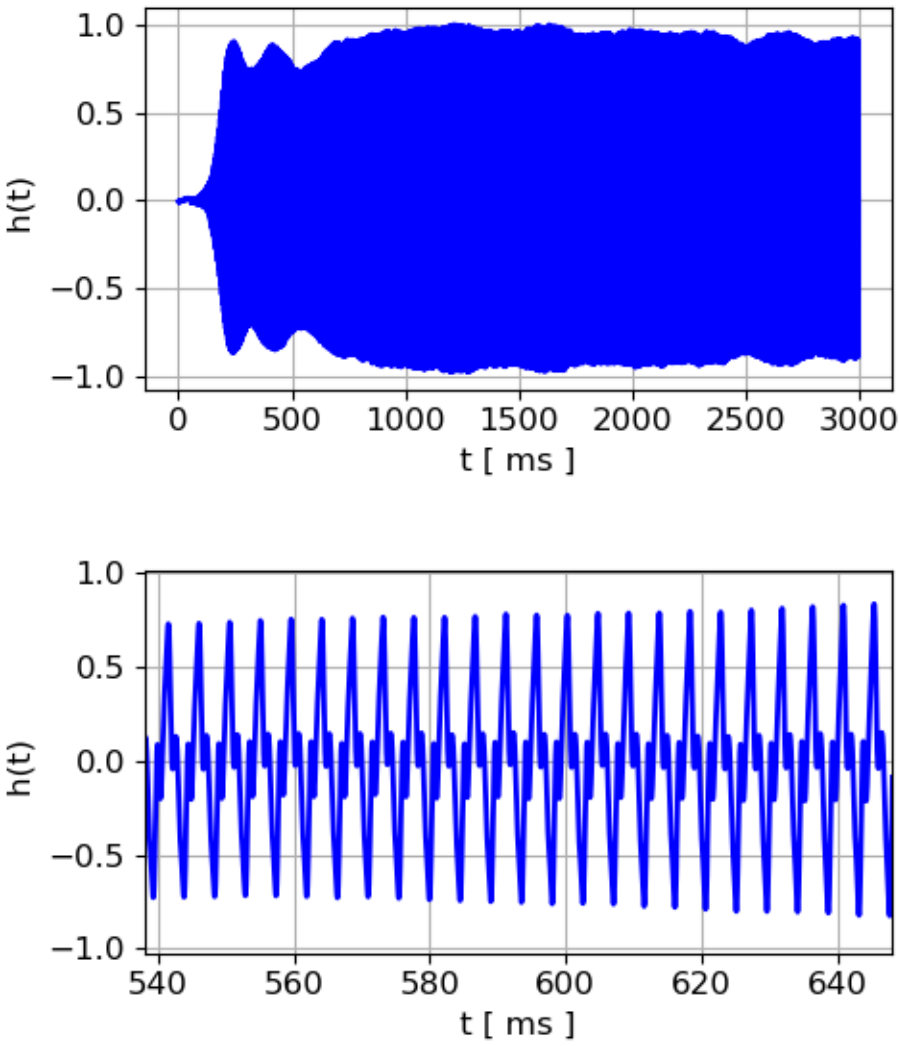


Fig. 4.1. The audio signal for the clarinet.

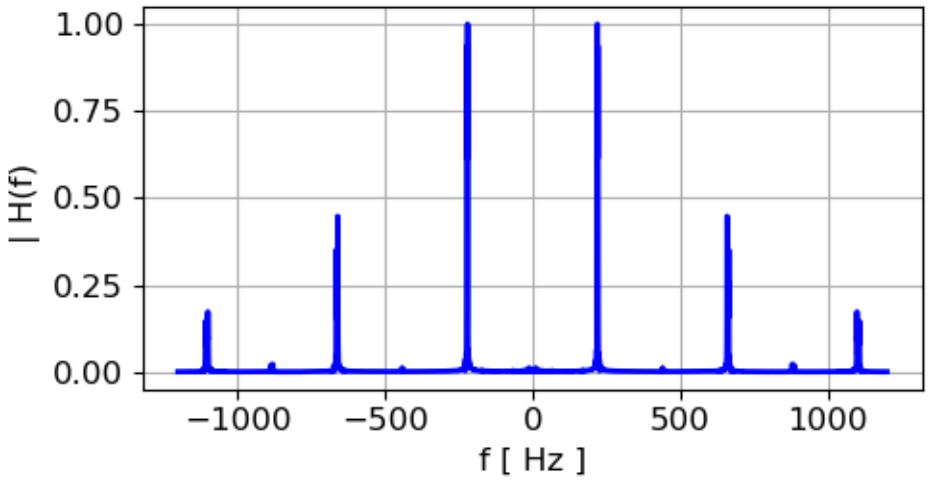


Fig. 4.2. The Fourier transform of the audio signal for the clarinet. The three major frequency peaks are 220 Hz, 660 Hz, and 1099 Hz. The first three peaks correspond to the first three odd harmonics (n = 1, 3, 5). The odd harmonics are excited when playing the clarinet since the boundary conditions are closed at one end and open at the other. The physics of a clarinet relies on a unique combination of a single-reed acoustic valve, a cylindrical bore closed at the mouthpiece end, and an open bell at the other.



Simulation 5 VOICE RECORDING 220 Hz simFM005.py

flag = 5 name = 'audioVoice1.wav'

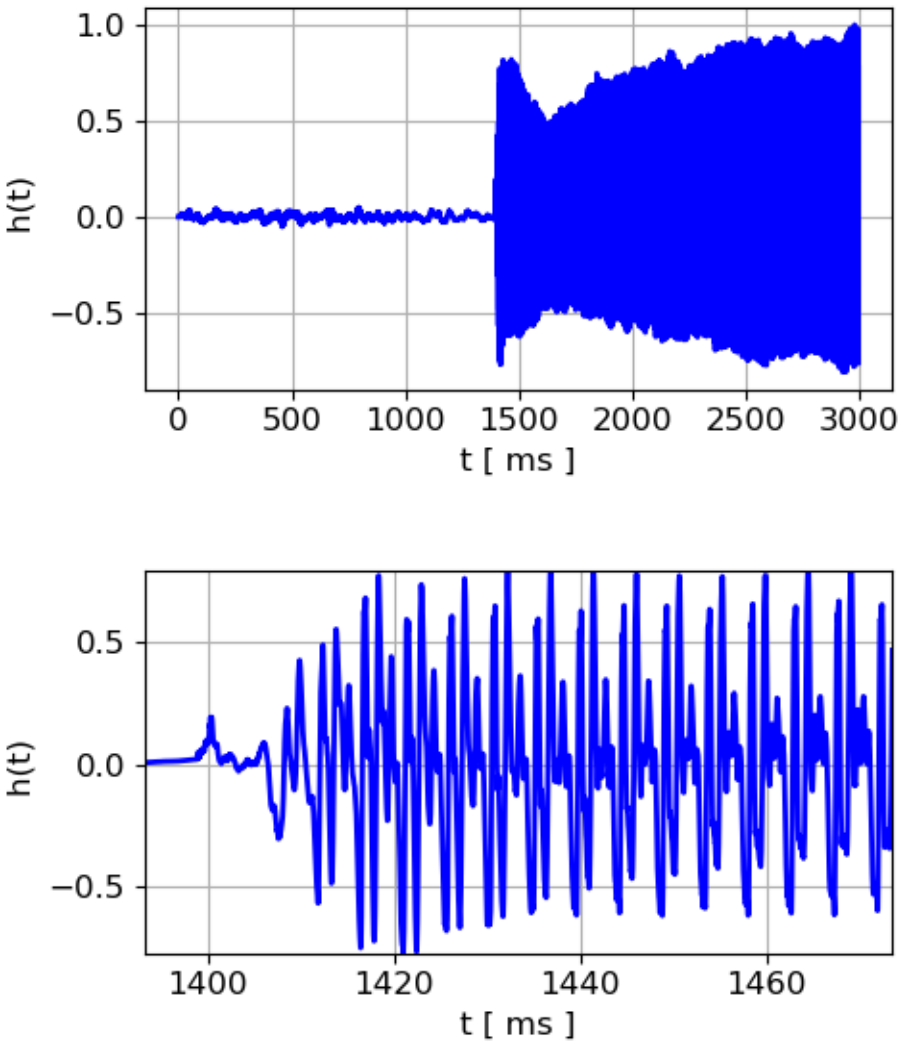


Fig. 5.1. The audio signal for a voice recording.

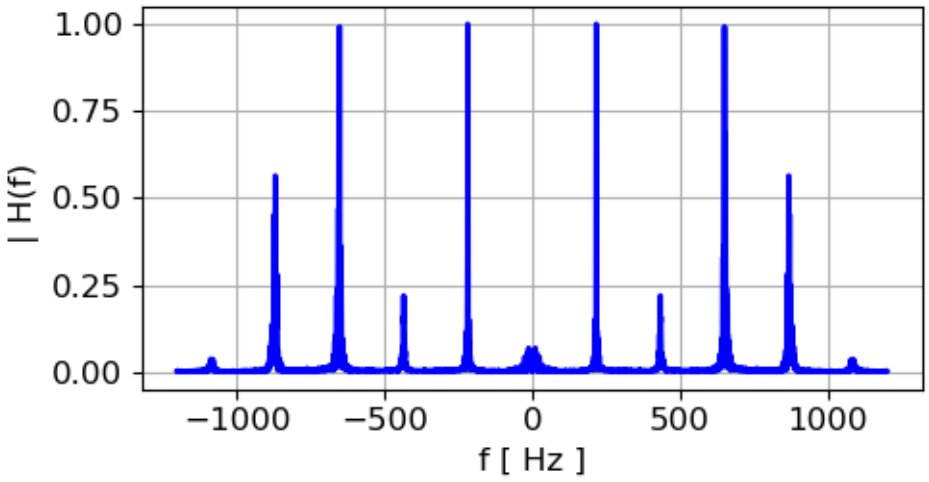


Fig. 5.2. The Fourier transform of the voice recording.

The fundamental frequency is 218 Hz. The harmonic series is:

$f_1 = 218 \quad f_2 = 436\ (434) \quad f_3 = 654\ (651) \quad f_4 = 872\ (868) \quad f_5 = 1090\,(1083)$

The values shown in brackets are the peak frequency shown in the plot. The amplitudes of the peaks are:

$A_1 = 1.00 \quad A_2 = 0.22 \quad A_3 = 0.99 \quad A_4 = 0.56 \quad A_5 = 0.04$

The first and third harmonics are the two most predominant peaks.

Simulation 6 TRAIN WHISTLE RECORDING simFM005.py

flag = 6 name = 'audioTrain.wav'

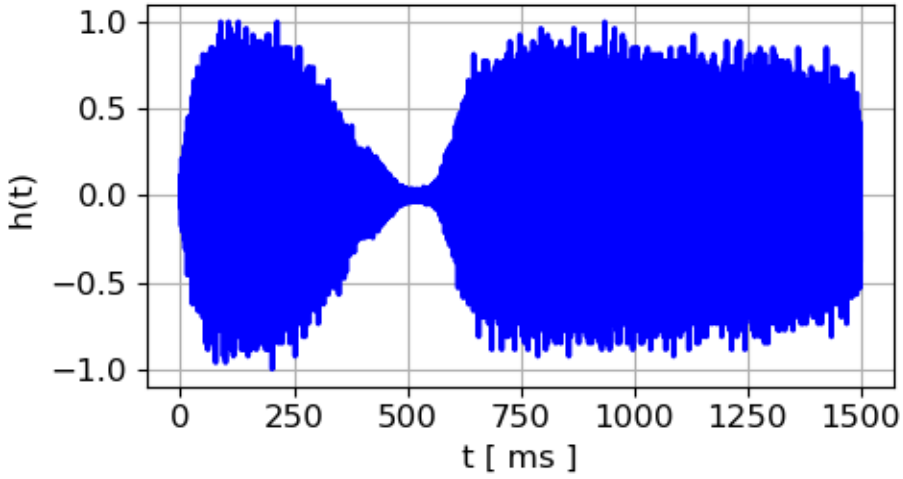


Fig. 6.1. The audio signal for a train whistle recording.

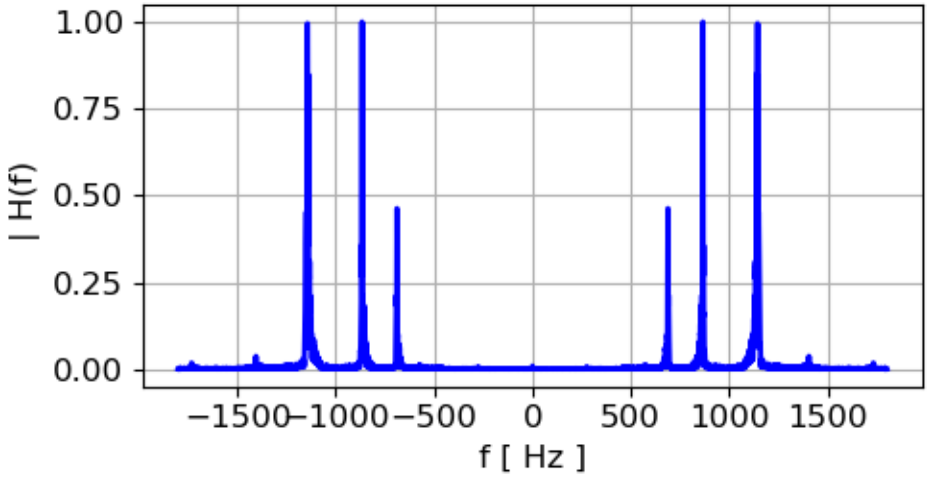


Fig. 6.2. The Fourier transform of the train whistle recording.

The peak frequencies and their amplitudes are:

(688 Hz, 0.46), (865 Hz, 1.00), (1143 Hz, 1.00). For the train whistle there is no harmonic series.