Assignment 4

Alma Sehic s274208 – Group 6

Applied Signal Processing Laboratory 2023

Introduction

- The main topic of this assignment is Audio Processing.
- Three exercises will be covered and a new concept on the use of spectrograms will be introduced.

- The exercises of the assignment are the following:

1. Voice recording
2. Spectrogram applied to two tones
3. Spectrogram applied to a music audio

Exercise 4.1 – Fourier Transform of your own voice

- A MATLAB code is used to record and play back a three-second-long voice recording made as the code is run.

- Variables used are the following:

Sampling frequency: $\boxed{f_s = 44100\ Hz}$

Number of samples: $\boxed{N = 132300}$

Sampling period: $\boxed{T_s = \frac{1}{f_s} = 2.3 * 10^{-5}\ s}$

Recording duration: $\boxed{T = 3\ s}$

Exercise 4.1 – Plot in time and frequency domain

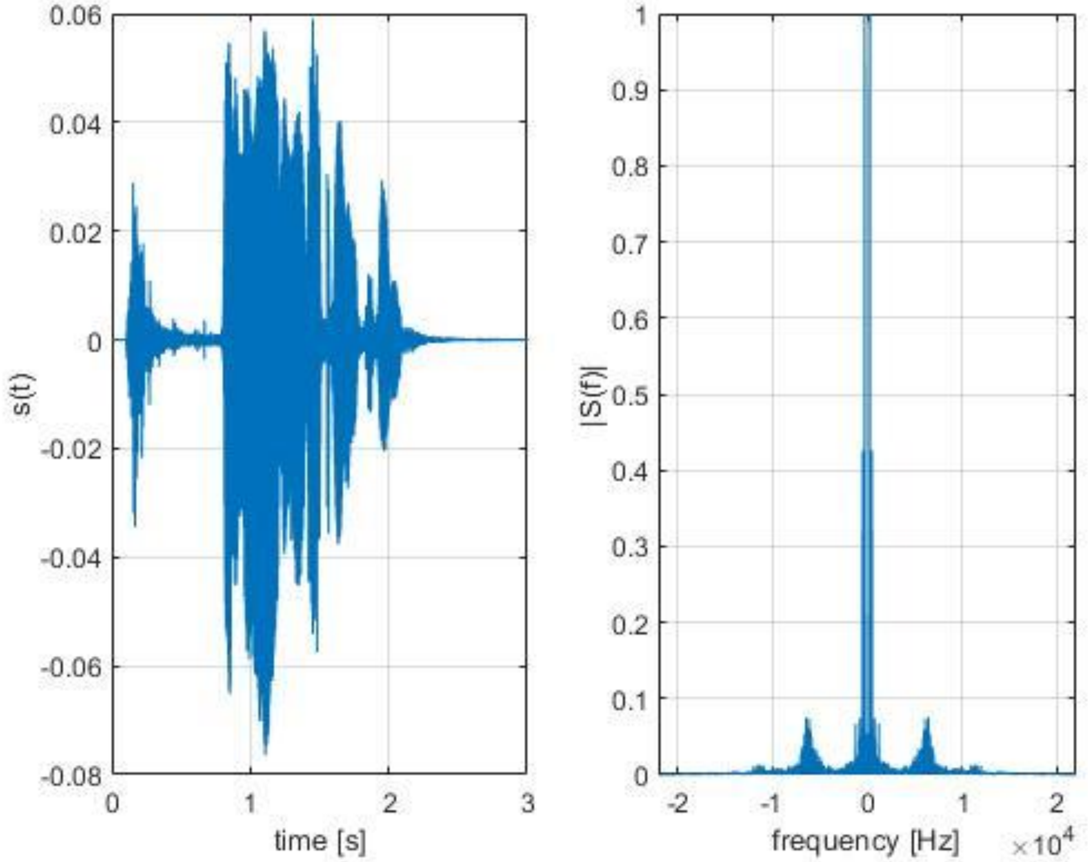


Figure 1.1: Plot of the signal of the recorded audio $s(t)$ wrt the time axis and the absolute value of the signal in frequency domain $|S(f)|$ wrt the symmetric frequency axis

As it can be seen in Figure 1.1, in the plot of the time domain, the high peaks in amplitude correspond to the louder sounds. Following that trend, the presence of high amplitudes will correspond to higher magnitudes in the frequency domain as well. Furthermore, in time domain, the sudden changes of the waveform present itself as sharp peaks at specific frequencies, meaning they contain bursts/peaks of energy compared to other lower energy content frequencies. The first mentioned are mainly concentrated around the lower frequencies, whereas in the higher frequencies, they seem insignificant.

Exercise 4.2 – Introduction to STFT and Spectrogram

- When a signal is not stationary, with a frequency content that changes in time, the FFT can provide a first view of the signal components that are present, but it is not able to highlight the true frequency structure of the signal.

- In this case, the STFT (Shirt-Time Fourier Transform) approach can be used. It consists of applying the FFT to a window of $N_{FFT} < N$ samples (where N is the total number of samples), then moving forward the window from left to right until all the N samples have been processed.

Exercise 4.2 – Introduction to STFT and Spectrogram

- In this was a matrix of N_{FFT} rows and N_c columns is obtained, where N_c is the number of times the FFT is applied. Each matrix element (i, j) contains the value of the Fourier Transform $S_j(f_i)$, e.g., the value at the frequency f_i computed by the FFT number j.

- Given this matrix, an image (a Spectrogram) can be plotted, where the horizontal axis is the time, the vertical axis is the frequency, and the color represents the magnitude of $S_j(f_i)$.

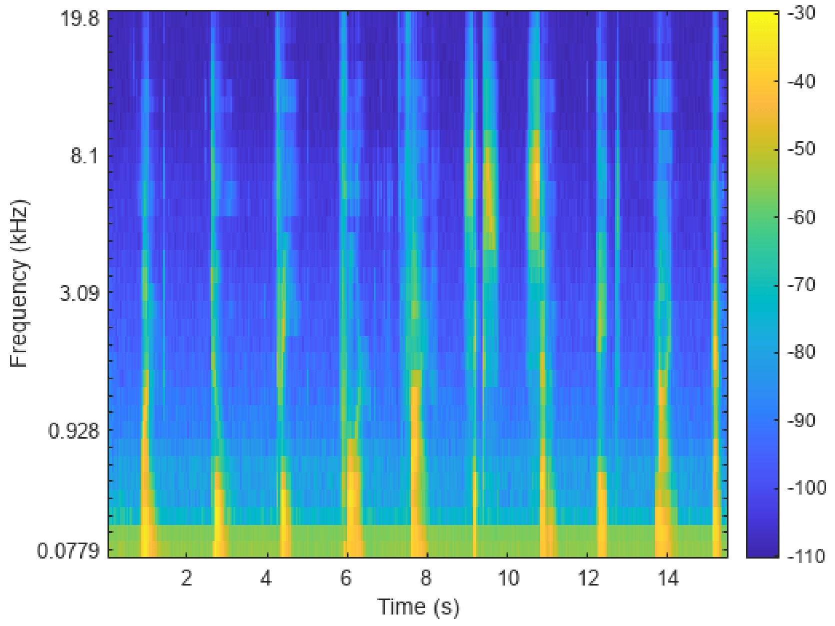


Figure 2.1: An example plot of a Spectrogram

Exercise 4.2 – Introduction to Overlapping and Windowing

- Very often it is not known where the characteristics of the non-stationary signal change, an *overlapping* is applied between the computation of consecutive FFTs

- When a partition in consecutive blocks of N_{FFT} samples is applied, it is like multiplying by a rectangular window. In frequency domain, there is the convolution with a sinc that induces some distortion. To limit the distortion, the N_{FFT} samples can be multiplied by a window, that is not a rectangular pulse but has a different shape. Some used are: Hamming, Hanning, Kaiser…

Exercise 4.2 – Defining signals and variables

- In this exercise section, the usefulness of the spectrogram approach is shown, highlighting the spectral structure of a non-stationary signal.

- Two sinusoidal signals and variables are defined as:

$$\boxed{s_1(t) = A_1 \cos(2\pi f_1 t + \varphi_1)}$$

$$\boxed{s_2(t) = A_2 \cos(2\pi f_2 t + \varphi_2)}$$

$$\boxed{f_s = 100\ Hz}$$

$$\boxed{T = 100\ s}$$

where:

$$A_1 = 1 \qquad f_1 = 1$$

$$A_2 = 2 \qquad f_2 = 4$$

$f_s = sampling\ frequency$

$T = time\ window$

$\varphi = random\ phase\ shift$

Exercise 4.2 – Plot of the sum of the signals

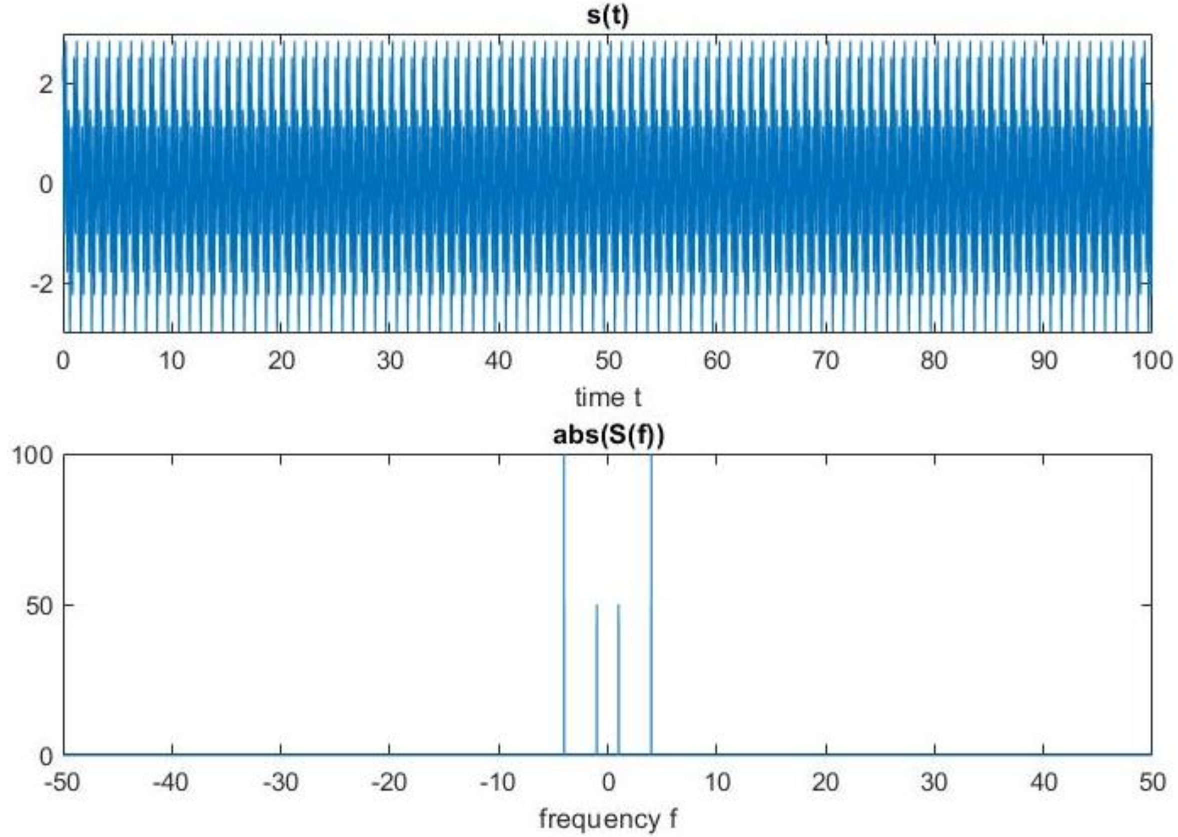


Figure 2.2.1: Plot of the sum of the two signals in time domain

Figure 2.2.2: Plot of the sum of the two signals in frequency domain

- In Figure 2.2.1 a plot of the sum of the signals in time domain can be seen, with a non-constant amplitude, unlike the individual signals. The plot in Figure 2.2.2 with the sum of the signals plotted in the frequency domain clearly shows the frequency components of the sum of the two signals. It can be seen that the magnitude of the frequency component at $f_2 = 4$ is higher than the magnitude of the frequency component at $f_1 = 1$, allowing us to conclude that the frequency at $f_1 = 4$ has greater strength relative to the other component.

Exercise 4.2 – Defining $s'(t)$

- In the next step, the signal $s'(t)$ is defined as the sum of the first part of $s_1(t)$ and the second part of $s_2(t)$ as:

$$s'(t) = P_{T/2}(t)\, s_1(t) + P_{T/2}(t - T/2)\, s_2(t)$$

- In MATLAB this has been done by using two rectangular pulses as such:

```
s_prime = rectangularPulse(0,T/2,t).*s1 + rectangularPulse(T/2,T,t).*s2;
```

Exercise 4.2 – Plot of the signal $s'(t)$

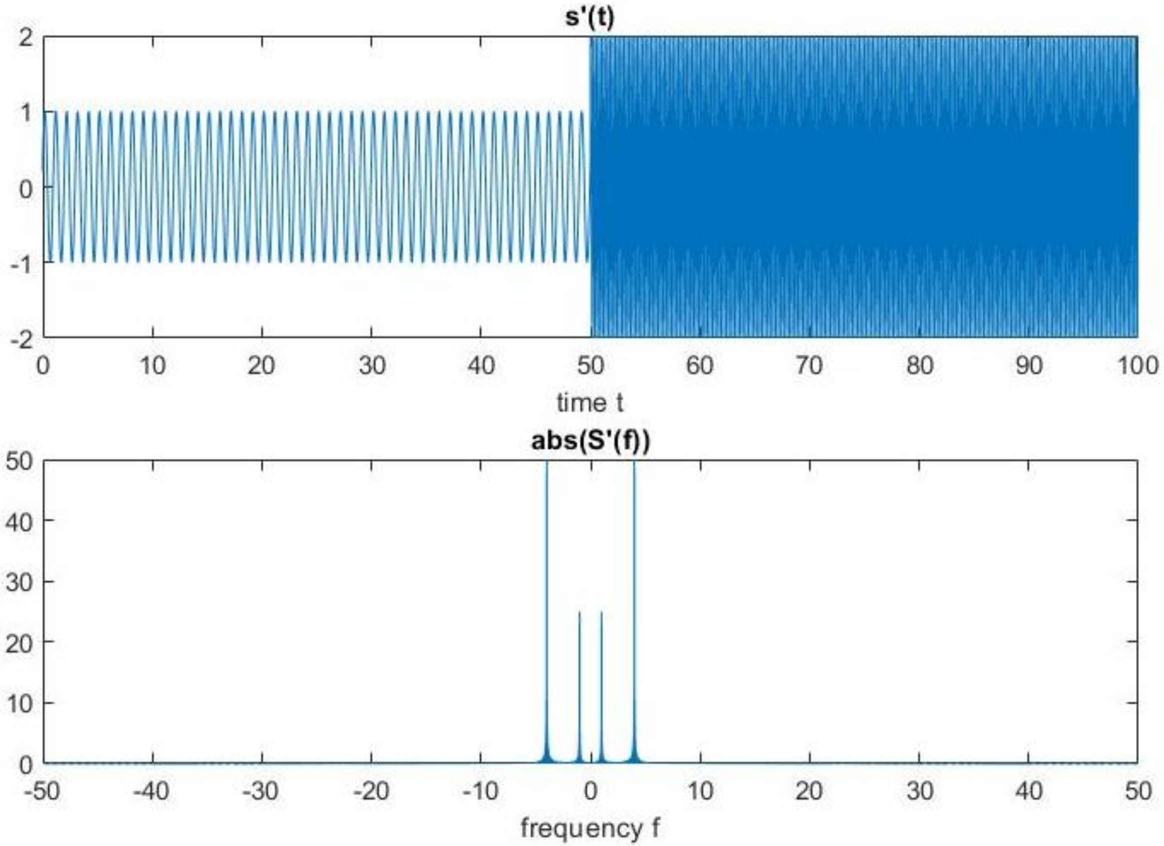


Figure 2.3.1: Plot of the sum of the two parts of the two signals in time domain

Figure 2.3.2: Plot of the sum of the two parts of the two signals in frequency domain

The first plot of the sum of two parts of the signals in time domain shows us the clear distinction between the beginning and end of each signal. Furthermore, in Figure 2.3.2 we can observe the frequency components of the said signal $s'(t)$. As expected, the plot of the spectrum of $s'(t)$ is the same as the spectrum of the signal $s(t)$ from Figure 2.2.2. Apart from the magnitude and the spurious components (due to the transition), the spectral components are overall the same as before.

Exercise 4.2 – Spectrogram of $s'(t)$ and $s(t)$

- To have a clearer distinction between $s'(t)$ and $s(t)$ we will use MATLAB to plot their respective spectrograms.

- The MATLAB code used to define and calculate necessary variables is:

```
N_fft = N/2;
N_overlap = 0;
window = ones(1,N_fft);
[S2,f2,t2] = spectrogram(s,window,N_overlap,N_fft,f_s,'centered','yaxis');
```

Exercise 4.2 – Plot of the spectrogram of $s(t)$

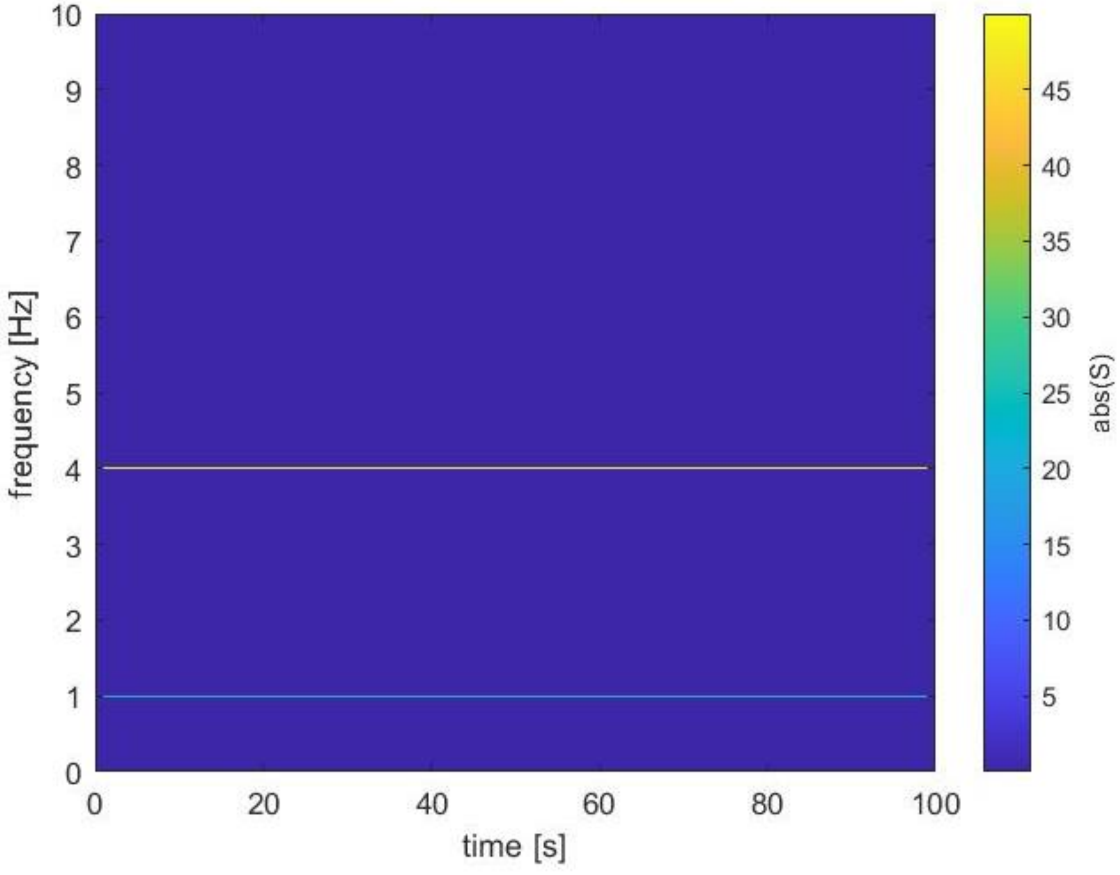


Figure 2.4: Plot of the spectrogram of the sum of the two signals $s(t)$

- In the first spectrogram plot in Figure 2.4, it can be seen from which point in time on the time axis which frequency component is present, alongside their magnitudes represented by the colors in the colorbar on the right of the plot. As expected, on the first plot of the sum of the two signals $s(t)$, a blue and a yellow line can be seen at frequencies equal to $f_1 = 1$ and $f_2 = 4$ respectively along the whole time axis. This shows us that those two frequency components are present over the whole time axis.

Exercise 4.2 – Plot of the spectrogram of $s'(t)$

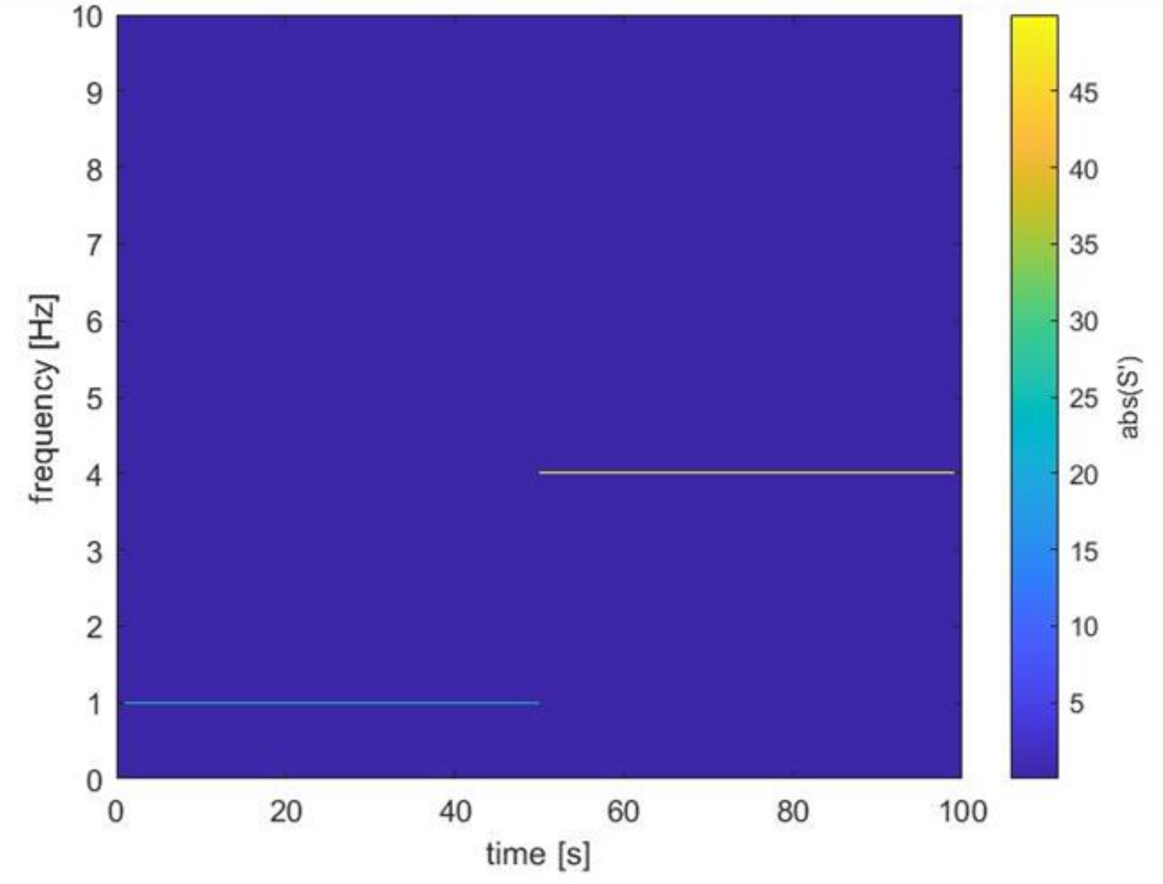


Figure 2.5: Plot of the spectrogram of two parts of the two signals $s'(t)$

- On the other hand, in the second spectrogram plot seen in Figure 2.5 it is clear that the frequency at $f_1 = 1$ is only present until $\mathrm{t} = 50s$ and the frequency at $f_2 = 4$ is present only from $\mathrm{t} = 50s$ until $\mathrm{t} = 100s$, in blue and yellow respectively. This was of course the expected behavior since the signal $s'(t)$ is composed of the sum of the first half of the signal $s_1(t)$ and the second half of the signal $s_2(t)$, with their respective frequencies of $f_1 = 1$ and $f_2 = 4$.

Exercise 4.2 – Plot of the two spectrograms

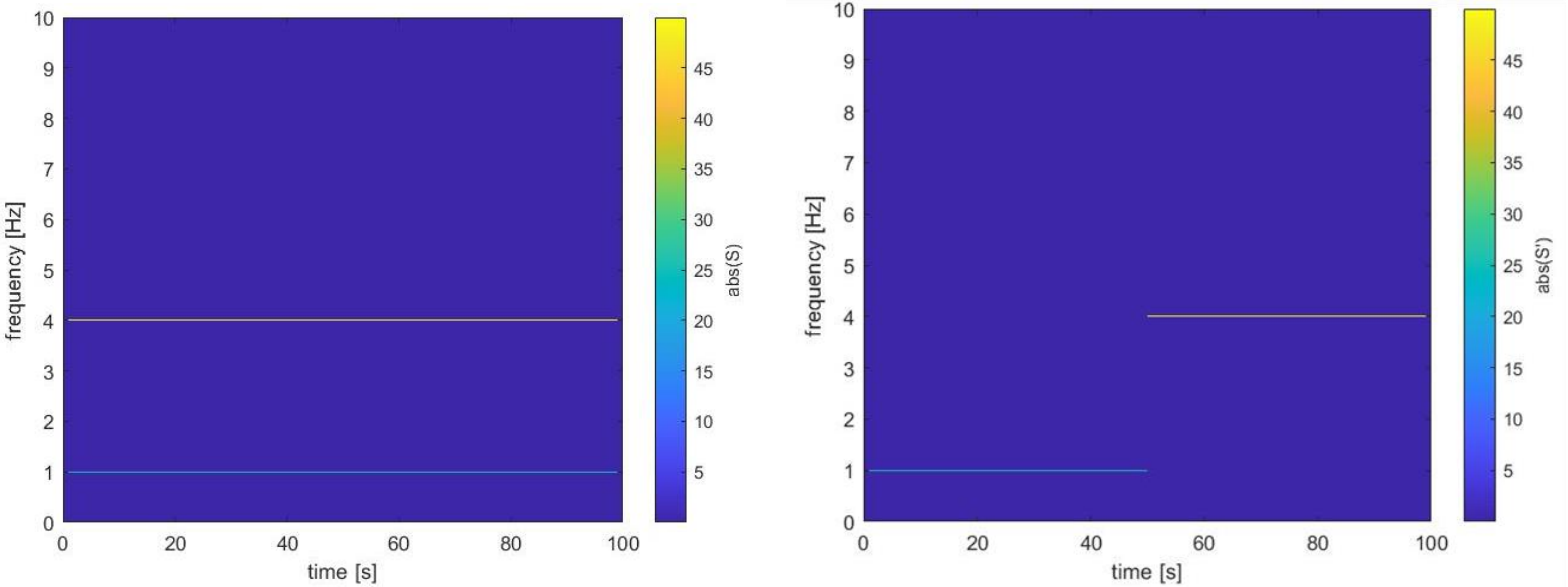


Figure 2.6: Spectrogram of $s(t)$ and $s'(t)$ side by side

Exercise 4.3 – Spectrogram on a musical signal

- In this next exercise, the spectrogram technique will once again be applied. This time a musical signal, an A major guitar scale will be analyzed.
- Firstly, a wav file containing the audio is read in matlab and the corresponding audio signal and the sampling frequency are saved.
- The variables are then the following:

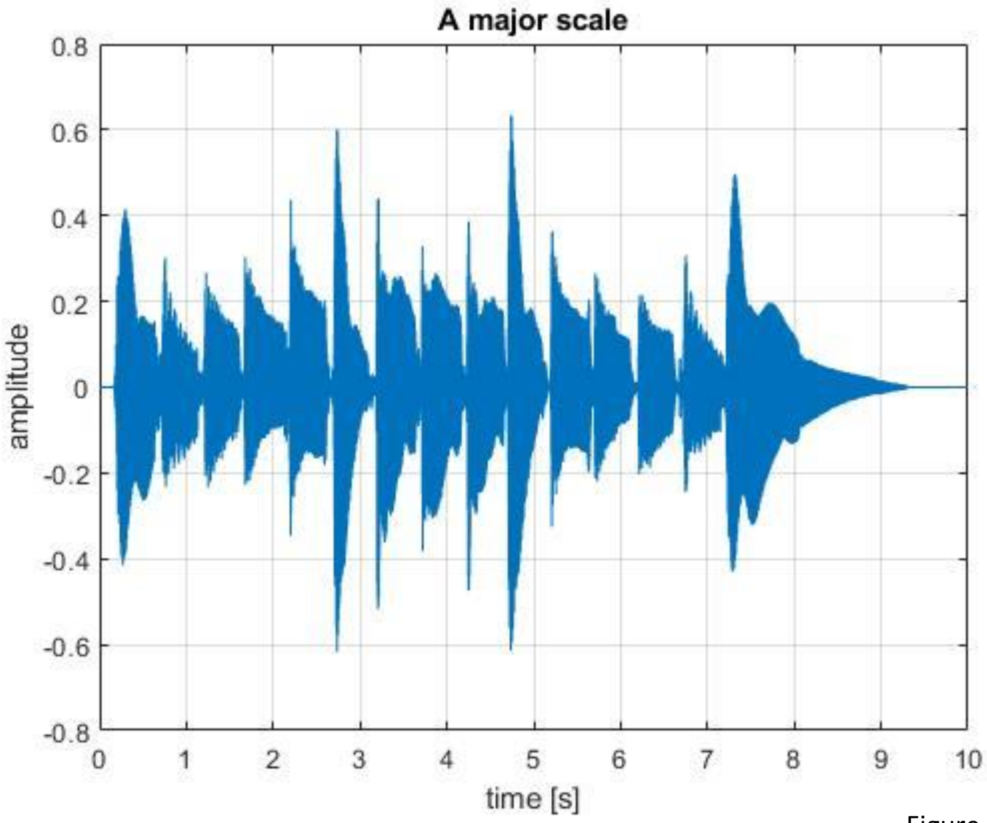
Sampling frequency: $\boxed{f_s = 100\ Hz}$

Sampling period: $\boxed{T_s = 0.01\ s}$

Number of samples: $\boxed{N = 441000}$

Exercise 4.3 – Plot of the signal in time and frequency domain

- In Figure 3.1, plots of the audio recording signal $s(t)$ in time domain and the plot of the same signal transformed into frequency domain $|S(f)|$ using FFT can be seen below



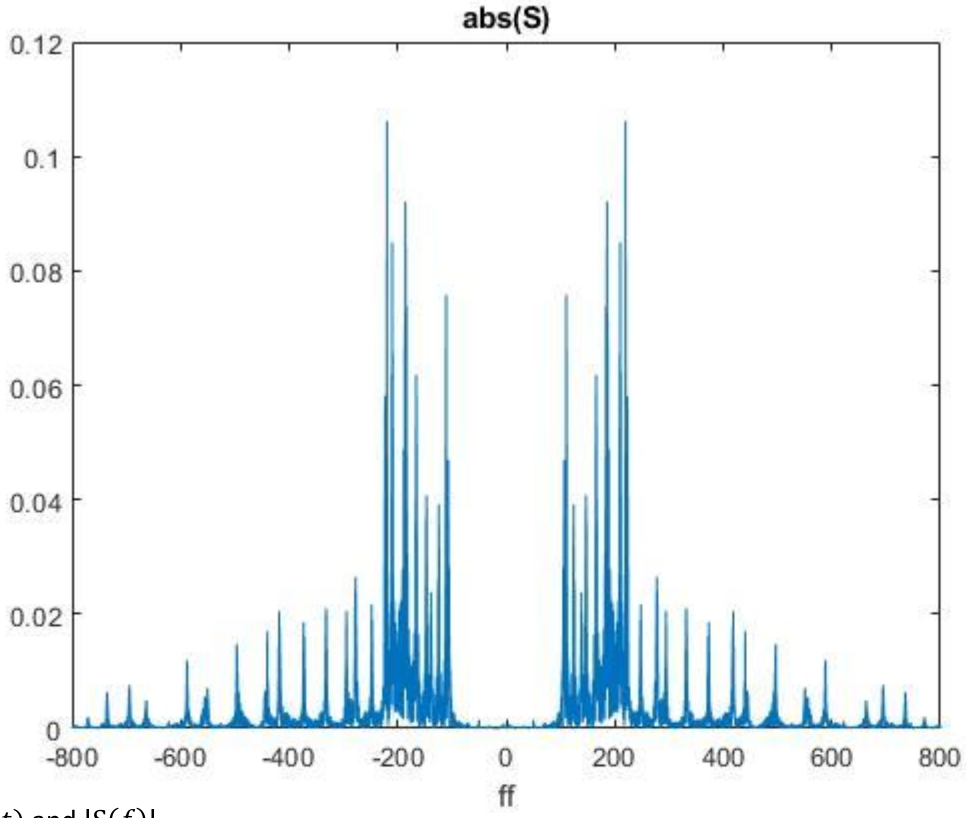


Figure 3.1: Plot of $s(t)$ and $|S(f)|$

Exercise 4.3 – Spectrogram of the audio recording

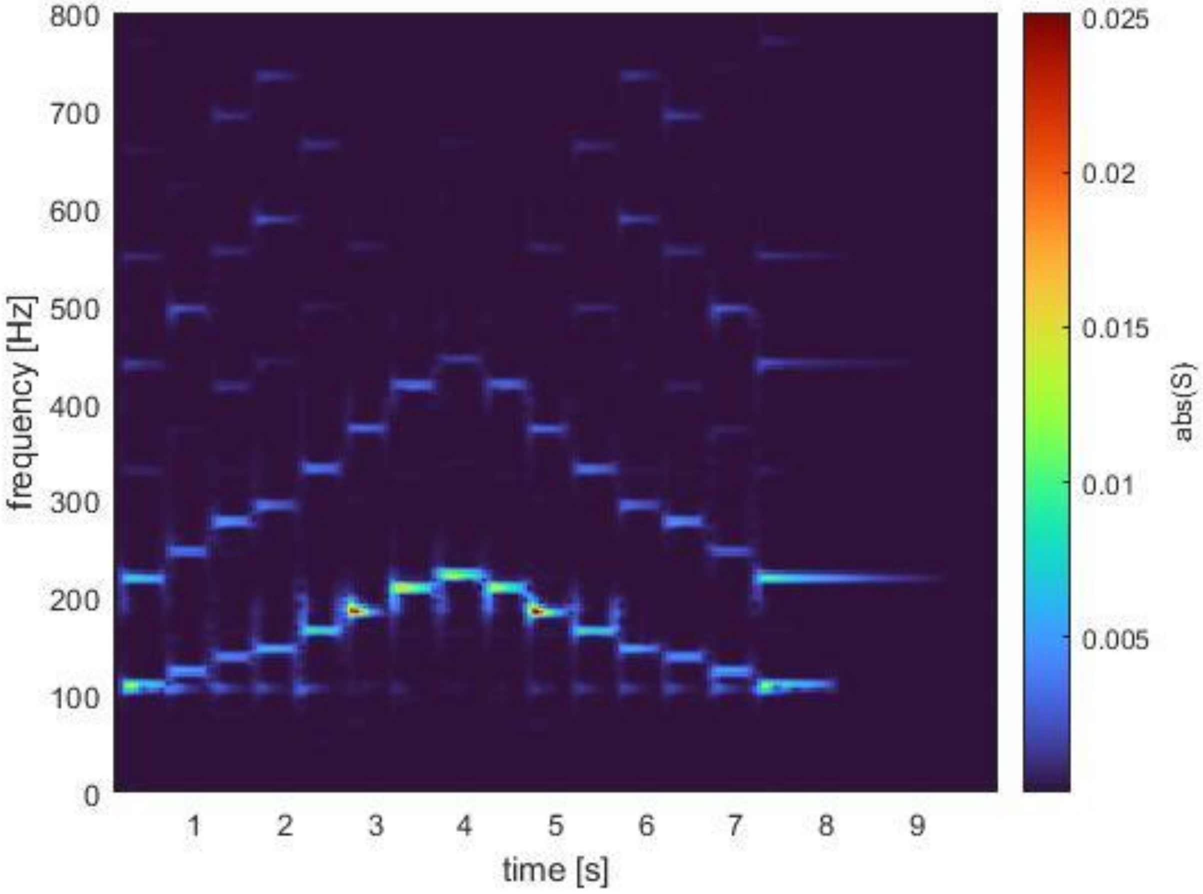


Figure 3.2: Spectrogram of the audio recording

- In the Figure 3.2 the spectrogram of the recorded audio can be seen. The light green and light blue colors imply that the frequency components at which those colors can be seen, are the strongest in those moments in time. Because the audio recording is of a major A scale played on a guitar, those high intensity color frequencies will be seen as a sequence of lines corresponding to the fundamental frequencies of each of the notes in the scale. The additional higher frequencies with a noticeable, but smaller intensity can be observed due to the presence of harmonics and overtones.

Exercise 4.3 – Spectrogram of the audio recording with a shifted pitch

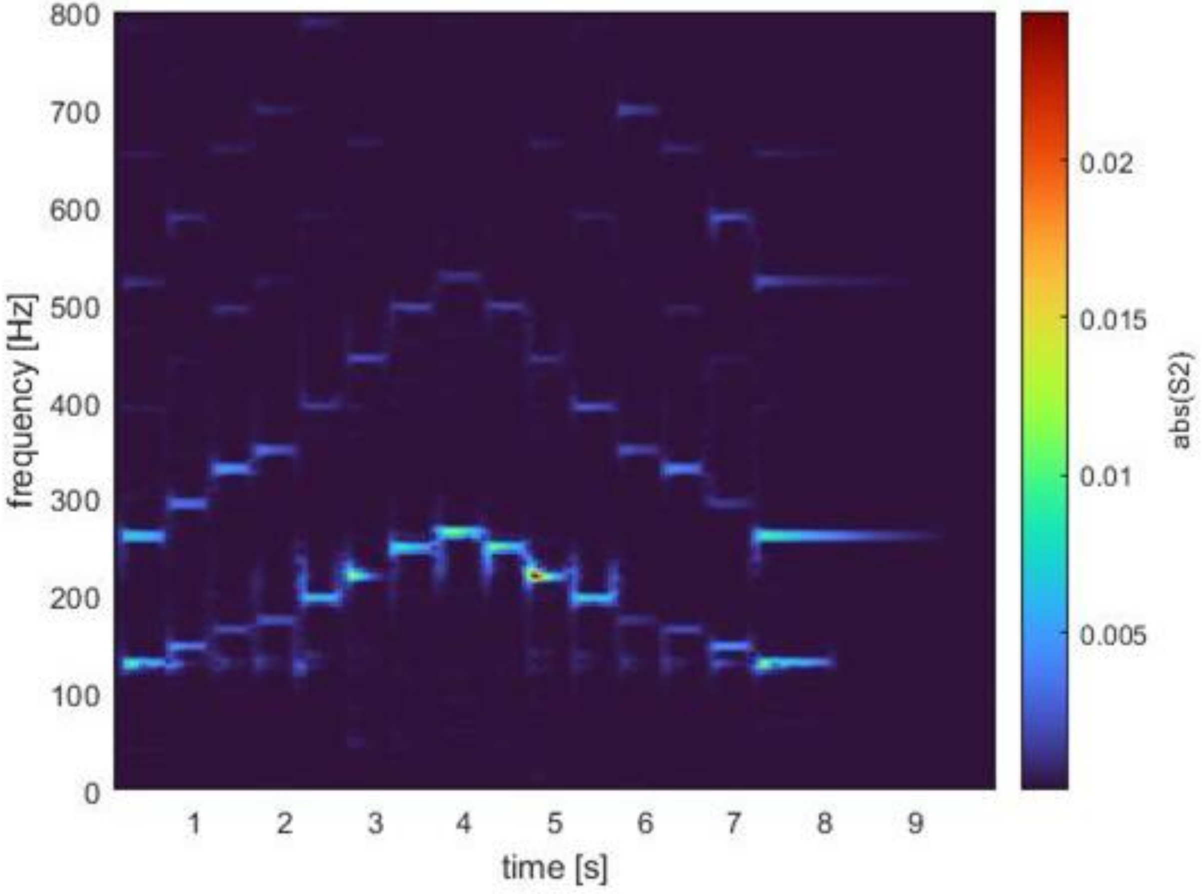


Figure 3.3: Spectrogram of the audio recording after shifting the pitch by 3 semitones

- To see how changing the pitch of the audio affects the original spectrogram, the function `shiftPitch(s,3)` is used to shift the pitch of the audio s by 3 semitones. This corresponds to multiplying the frequency components of the audio by a certain factor greater than 1, since we are increasing the pitch. The spectrogram plot in Figure 3.3 looks almost identical to the one before adjusting the pitch, with a very important difference: all the frequency components high in magnitude have been shifted upward by about 40Hz. This clearly shows that increasing the pitch of an audio file will correspond to higher frequency components.