Question 1 of Assignment 3

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1 Introduction

This section provides an analysis and observation of two signals: a chirp signal with increasing frequency and a signal based on the cumulative sum of a linear frequency function $\phi_i[n]$. Both time-domain waveforms and their respective 2D and 3D spectrograms have been generated and analyzed. The **Short-Time Fourier Transform (STFT)** is used to generate the spectrograms.

2 STFT: Short-Time Fourier Transform

The **Short-Time Fourier Transform (STFT)** is a time-frequency analysis technique used to understand the frequency content of a signal over time. The STFT of a signal $x[n]$ is defined as:

$$\text{STFT}\{x[n]\}(m,\omega) = X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]w[n-m]e^{-j\omega n}$$

where:

- $x[n]$ is the discrete-time signal.
- $w[n-m]$ is the window function centered at time m.
- ω is the angular frequency.

The **magnitude spectrogram** is computed as the squared magnitude of the STFT:

$$S(m,\omega) = |X(m,\omega)|^2$$

The STFT helps in analyzing how the frequency content of a signal changes over time, and is used to generate both 2D and 3D spectrograms in this report.

3 Problem 1: Chirp Signal Analysis

The chirp signal is characterized by a frequency that increases linearly over time, starting at 0.1 Hz and ending at 0.25 Hz. The signal is generated using MATLAB's `chirp` function. The time-domain waveform, as well as the 2D and 3D spectrograms, are plotted for further analysis.

3.1 Time-Domain Waveform

The time-domain waveform shows how the amplitude of the signal varies over time. The waveform exhibits oscillations that increase in frequency as time progresses.

3.2 Frequency vs Time

The frequency of the chirp signal increases linearly from 0.1 Hz to 0.25 Hz. This gradual increase in frequency is also captured in the spectrograms.

3.3 Spectrogram Analysis

The spectrogram for the chirp signal is generated using the STFT, where a window function is applied to successive segments of the signal to analyze its frequency content over time.

3.3.1 2D Spectrogram

The 2D spectrogram shows the power distribution of the chirp signal over time and frequency. The gradual increase in frequency is clearly observed, as the frequency components shift upward with time. This is expected in a chirp signal where the frequency is designed to increase linearly.

3.3.2 3D Spectrogram

The 3D spectrogram provides a detailed view of how power varies across time and frequency. The z-axis shows the power or energy concentration of the signal. The increasing frequency components are shown as peaks in the z-dimension, and the gradual frequency increase is evident.

3.4 Observations

- The chirp signal shows a clear linear increase in frequency from 0.1 Hz to 0.25 Hz.
- The 2D and 3D spectrograms both capture the gradual frequency shift very effectively, with the 3D plot providing additional detail on power distribution over time.
- The spectrograms confirm that the energy is concentrated along the increasing frequency components, which aligns with the characteristics of a chirp signal.

4 Problem 2: Signal Based on $\phi_i[n]$

In this part, the signal is generated based on a cumulative sum of a linear frequency function $\phi_i[n]$. The generated signal is expressed as:

$$s[n] = A\cos(2\pi\phi_i[n])$$

where $\phi_i[n]$ is the cumulative sum of a linearly increasing frequency function. This produces a non-linear variation in frequency.

4.1 Time-Domain Waveform

The time-domain waveform of the signal is more complex due to the rapid changes in frequency caused by the cumulative summation.

4.2 Spectrogram Analysis

The spectrogram is generated using the STFT, as described in the previous section. The non-linear frequency variation in this signal is clearly observed in both 2D and 3D spectrograms.

4.2.1 2D Spectrogram

The 2D spectrogram shows a much more rapid shift in frequency over time. This is expected because $\phi_i[n]$ is a cumulative function, causing frequency changes to accelerate.

4.2.2 3D Spectrogram

The 3D spectrogram provides additional insight into the power distribution of the signal. It shows the increasing complexity in frequency content as time progresses.

4.3 Observations

- The signal generated using $\phi_i[n]$ shows a more complex behavior compared to the chirp signal due to the cumulative nature of the frequency changes.
- The spectrograms (both 2D and 3D) capture the increasing complexity in frequency variation, with rapid shifts in frequency as expected.
- The 3D spectrogram highlights the non-linear frequency variation and its effect on the power distribution over time.

5 Conclusion

In conclusion, the analysis of both the chirp signal and the signal based on $\phi_i[n]$ shows distinct behaviors in terms of frequency variation. The chirp signal exhibits a smooth, linear frequency increase, while the signal based on $\phi_i[n]$ shows more complex frequency variations. Spectrograms (both 2D and 3D) effectively capture these differences, offering insights into the time-frequency characteristics of each signal.

Question 2: Analysis and Observations

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October 3, 2024

1 Introduction

This section analyses a MATLAB program designed to load various signal types, plot their time-domain waveforms, and compute and display their 2D and 3D spectrograms. The signals range from audio files to biomedical signals (ECG and EEG). Additionally, the report explains the conversion of EEG data stored in '.set' files using the EEGLAB library.

2 Key Points of the MATLAB Code

2.1 Signal Loading and Processing

The script processes eight different types of signals, each with unique file formats:

- `Gravitational-Wave.hdf5` (HDF5 format)
- `Speech-Female.wav`, `Speech-Male.mp3` (Audio files)
- `dog-bark-1.wav`, `dog-bark-2.wav` (Audio files)
- `Perfect-Violin.wav` (Audio file)
- `ecg.mat` (MAT file containing ECG data)
- `eeg.set` (EEG data in the EEGLAB format)

The sampling frequencies for some of the files (such as '.wav' and '.mp3') are loaded automatically, while others (like '.hdf5' and '.mat') require predefined values, such as 4096 Hz for the gravitational wave signal and 500 Hz for the ECG signal.

2.2 Waveform Plotting

For each signal, the time-domain waveform is plotted using:

$$t = \frac{0 : \text{length(signal)} - 1}{\text{fs}}$$

where t represents the time in seconds and fs is the sampling frequency. This plot provides a visual representation of how the signal amplitude changes over time. Each waveform is crucial in understanding the general behavior of the signal before performing spectral analysis.

2.3 Spectrogram Computation (STFT)

The spectrogram is computed using the **Short-Time Fourier Transform (STFT)**, where the signal is divided into short, overlapping segments (defined by the window length and overlap), and the Fourier Transform is applied to each segment.

The STFT is given by the equation:

$$\text{STFT}\{x[n]\}(m,\omega) = X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]w[n-m]e^{-j\omega n}$$

Here, $x[n]$ is the signal, $w[n-m]$ is the window function, and $e^{-j\omega n}$ applies the Fourier transform to each segment. The 2D and 3D spectrograms provide a visualization of how the signal's frequency content varies over time.

2.4 2D and 3D Spectrograms

The 2D spectrogram plots power as a function of both time and frequency. The magnitude of the Fourier Transform is converted to decibels using $10\log_{10}(S)$, where S represents the squared magnitude of the Fourier coefficients. The 3D spectrogram provides a three-dimensional visualization, where the Z-axis represents the magnitude of the power (in dB).

3 EEGLAB and .set File Conversion

The EEG data is stored in '.set' files, which are a standard format used in the **EEGLAB** toolbox. **EEGLAB** is a MATLAB toolbox used for processing electrophysiological data (primarily EEG data).

To load '.set' files, the following code snippet is used:

```
EEG = pop_loadset('filename', 'eeg.set');
```

This command loads the EEG data into the 'EEG' structure, from which the data is extracted. The sampling frequency is typically stored in 'EEG.srate', and the EEG signal data itself is stored in 'EEG.data'.

3.1 EEGLAB Library

EEGLAB is essential for working with '.set' files because it provides specific functions to handle the complex structure of EEG datasets, including:

- **pop_loadset**: Loads the EEG data from the '.set' file.
- **EEG.data**: Contains the EEG signal (usually multi-channel).
- **EEG.srate**: Stores the sampling frequency.

EEGLAB handles additional EEG-specific information such as events, epochs, and channel locations, making it a comprehensive tool for EEG analysis.

4 Analysis of Each Signal

4.1 Gravitational Wave (HDF5)

The gravitational wave signal is sampled at 4096 Hz, and its waveform shows the characteristic oscillations detected during an event. The 2D and 3D spectrograms provide insight into the frequency components of this low-frequency signal over time.

4.2 Speech Signals (Female and Male)

The speech signals are sampled at rates typical for audio (e.g., 16 kHz for '.wav' files). The spectrograms reveal the formant structures and harmonics characteristic of human speech. The female and male voices may exhibit different frequency ranges and energy distributions.

4.3 Dog Barks

The dog bark signals, also sampled at typical audio rates, show sharp transients in their waveforms. The 2D spectrograms reveal the high-frequency content during each bark, while the 3D spectrogram provides additional depth in visualizing the transient nature of the sound.

4.4 Violin Sound

The violin signal is expected to show strong harmonic content in its spectrogram, with clear frequency bands representing the fundamental frequency and its harmonics. The 3D spectrogram further emphasizes the energy concentrated in these harmonics over time.

4.5 ECG Signal

The ECG signal, sampled at 500 Hz, exhibits periodic peaks corresponding to heartbeats. The spectrogram provides a visual representation of the periodicity and any possible variations in the frequency content of the signal (such as arrhythmias).

4.6 EEG Signal

EEG signals, typically sampled at around 250 Hz, show lower-frequency oscillations that represent brain activity. The spectrograms provide insights into the frequency bands (such as alpha, beta, delta, and theta waves) that dominate the EEG during different states of the brain.

5 Observations

- Each signal type exhibits distinct frequency characteristics in both the 2D and 3D spectrograms, reflecting the nature of the source (e.g., speech, EEG, ECG, or environmental sounds).
- The use of appropriate window length and overlap ensures a good balance between time and frequency resolution in the spectrograms.
- The EEG data requires special handling through the EEGLAB library, which provides robust tools for loading and processing '.set' files.
- The 3D spectrogram adds a layer of visualization, making it easier to interpret changes in frequency content over time, especially for signals like speech and music.

6 Conclusion

This report provides a detailed analysis of the waveform and spectrograms generated for various signals using MATLAB. The script effectively demonstrates time-frequency analysis using STFT for a range of signal types, including audio, biomedical, and environmental data. Special consideration is given to EEG data, which requires conversion using the EEGLAB library.

Question 3: Analysis and Observations

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October 3, 2024

1 Introduction

This section analyses a MATLAB program that generates 3D narrowband and wideband spectrograms for various signals. The spectrograms offer insights into how the frequency content of each signal evolves, with narrowband spectrograms offering higher frequency resolution and wideband spectrograms offering better time resolution. Also, we'd like to discuss window length recommendations for each signal processed.

2 Code Analysis

The MATLAB code processes eight different signal types, generating both narrowband and wideband spectrograms for each. Here's a breakdown of the key steps and functionality:

2.1 Spectrogram Computation

The script computes **narrowband** and **wideband** spectrograms for each signal using a custom `custom_spectrogram` function. The parameters for each type of spectrogram are:

- **Narrowband Spectrogram**: Uses a large window size (1024 samples) to provide better frequency resolution.
- **Wideband Spectrogram**: Uses a smaller window size (32 samples) for better time resolution.

The Short-Time Fourier Transform (STFT) is applied to each signal segment. The power spectrum is plotted in both 2D and 3D, with the Z-axis in the 3D plot representing the magnitude in decibels (dB).

2.2 3D Plotting

The 'surf' function is used to plot 3D spectrograms. Both narrowband and wideband spectrograms are visualized with different window lengths to show how frequency resolution affects the analysis of each signal. The view angle is adjusted to enhance the 3D perspective.

3 Window Length Analysis for Different Signals

To determine the range of window lengths and the best window size for each of the 8 different signals, we must balance time and frequency resolution. Shorter windows provide better time resolution, while longer windows offer better frequency resolution.

3.0.1 General Guidelines for Window Length

- **Speech Signals** (e.g., Speech-Female, Speech-Male): Recommended window length is 20–40 ms. For a 16 kHz sampling rate, a window size of 320–640 samples is ideal.

- **Music Signals** (e.g., Violin): Recommended window length is 30–50 ms. For a 44.1 kHz sampling rate, the window size should be around 1323–2205 samples.
- **Transient Signals** (e.g., Dog Barks): Recommended window length is 5–20 ms. For a 16 kHz sampling rate, a window size of around 80–320 samples is appropriate.
- **Gravitational Wave Signals**: Recommended window length is 500 ms or more. For a 4096 Hz sampling rate, the window size should be around 2048–4096 samples.
- **ECG/EEG Signals**: Recommended window length is 100–500 ms. For ECG sampled at 500 Hz, this corresponds to 50–250 samples. For EEG sampled at 250 Hz, 100–500 samples are recommended.

3.0.2 Proposed Window Lengths for Each Signal

- **Gravitational Wave**:
  - Sampling Rate: 4096 Hz
  - Best Window Length: 2048–4096 samples (500–1000 ms)
  - Range: 1000–4096 samples
- **Speech-Female (WAV)**:
  - Sampling Rate: 16 kHz
  - Best Window Length: 320–640 samples (20–40 ms)
  - Range: 256–1024 samples
- **Speech-Male (MP3)**:
  - Sampling Rate: 16 kHz
  - Best Window Length: 320–640 samples (20–40 ms)
  - Range: 256–1024 samples
- **Dog-Bark-1 (WAV)**:
  - Sampling Rate: 16 kHz
  - Best Window Length: 80–320 samples (5–20 ms)
  - Range: 64–512 samples
- **Dog-Bark-2 (WAV)**:
  - Sampling Rate: 16 kHz
  - Best Window Length: 80–320 samples (5–20 ms)
  - Range: 64–512 samples
- **Violin (WAV)**:
  - Sampling Rate: 44.1 kHz
  - Best Window Length: 1323–2205 samples (30–50 ms)
  - Range: 1000–4000 samples
- **ECG (MAT)**:
  - Sampling Rate: 500 Hz
  - Best Window Length: 125–250 samples (250–500 ms)
  - Range: 50–500 samples
- **EEG (SET)**:
  - Sampling Rate: 250 Hz
  - Best Window Length: 125–250 samples (500–1000 ms)
  - Range: 100–500 samples

3.0.3 Summary of Suggested Window Lengths

Signal	Sampling Rate	Best Window Size (Samples)	Range (Samples)
Gravitational Wave	4096 Hz	2048–4096 samples	1000–4096 samples
Speech-Female	16 kHz	320–640 samples	256–1024 samples
Speech-Male	16 kHz	320–640 samples	256–1024 samples
Dog-Bark-1	16 kHz	80–320 samples	64–512 samples
Dog-Bark-2	16 kHz	80–320 samples	64–512 samples
Violin	44.1 kHz	1323–2205 samples	1000–4000 samples
ECG	500 Hz	125–250 samples	50–500 samples
EEG	250 Hz	125–250 samples	100–500 samples

Table 1: Window Size Recommendations for Different Signals

4 Conclusion

This report provides an analysis of narrowband and wideband spectrograms for various signals. The narrowband spectrogram is more effective for signals where frequency resolution is key, while the wideband spectrogram excels at capturing rapid transients. Additionally, window length recommendations have been provided for each signal type, balancing time and frequency resolution for optimal analysis.

Assignment 3: Spectrogram Plots

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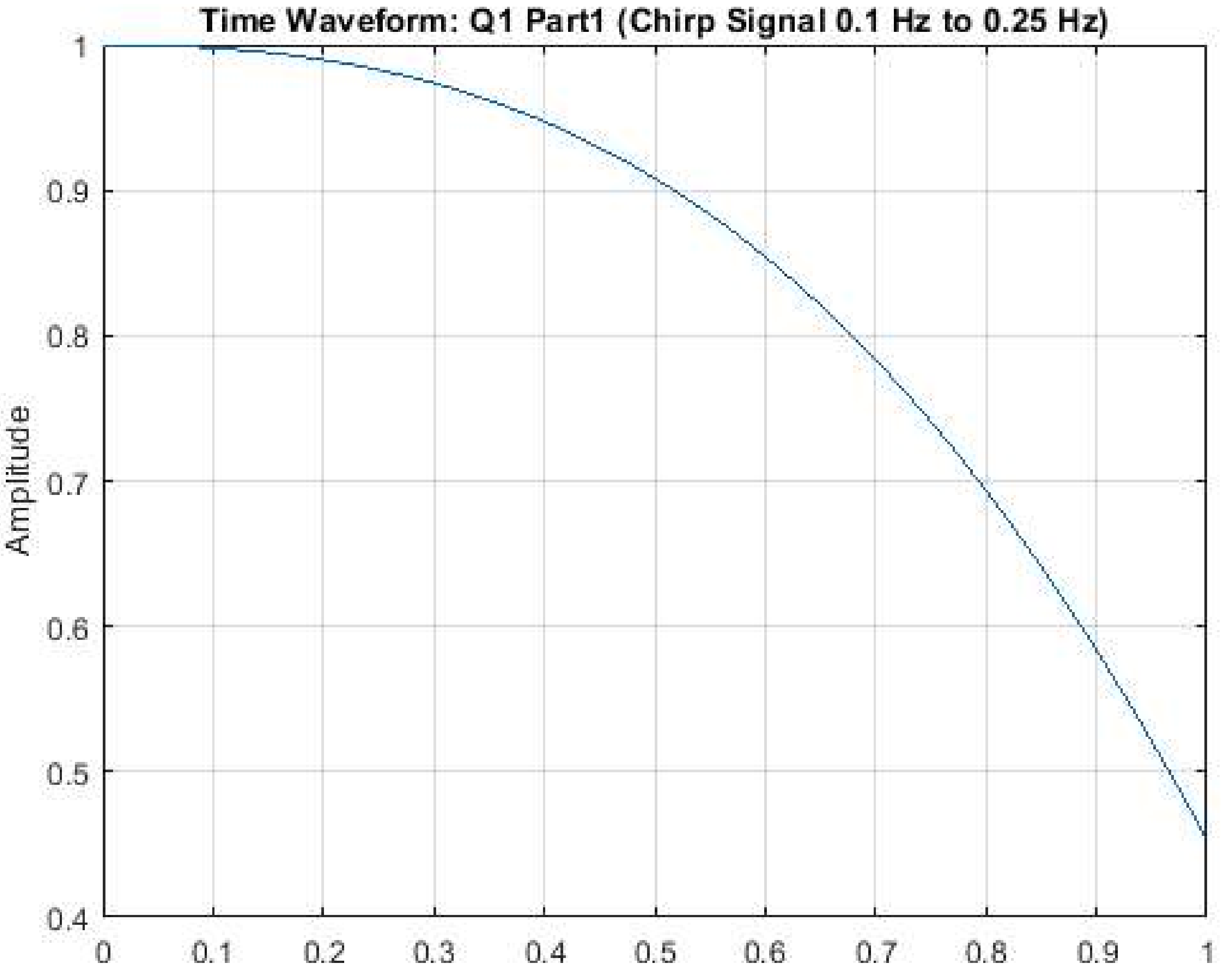
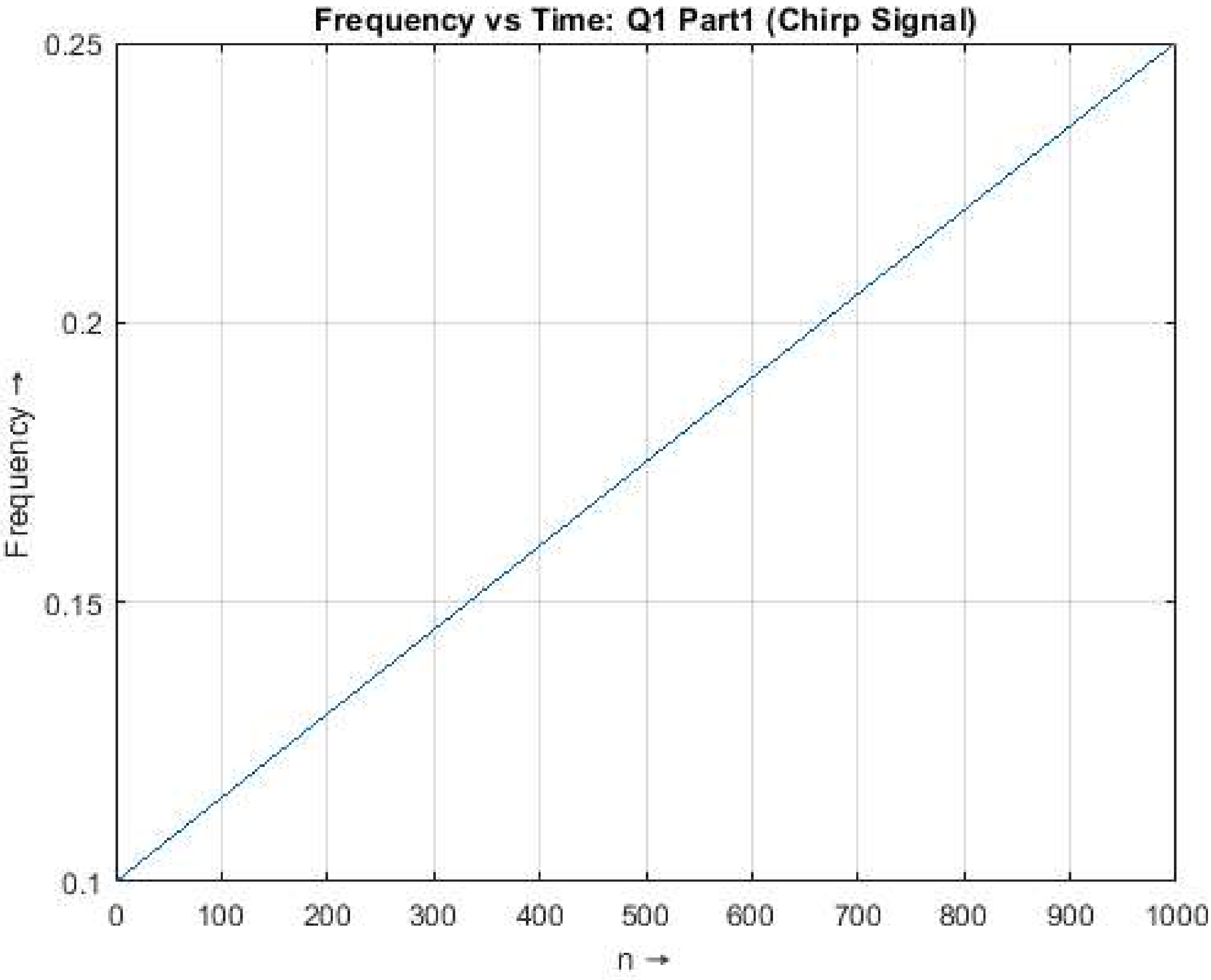
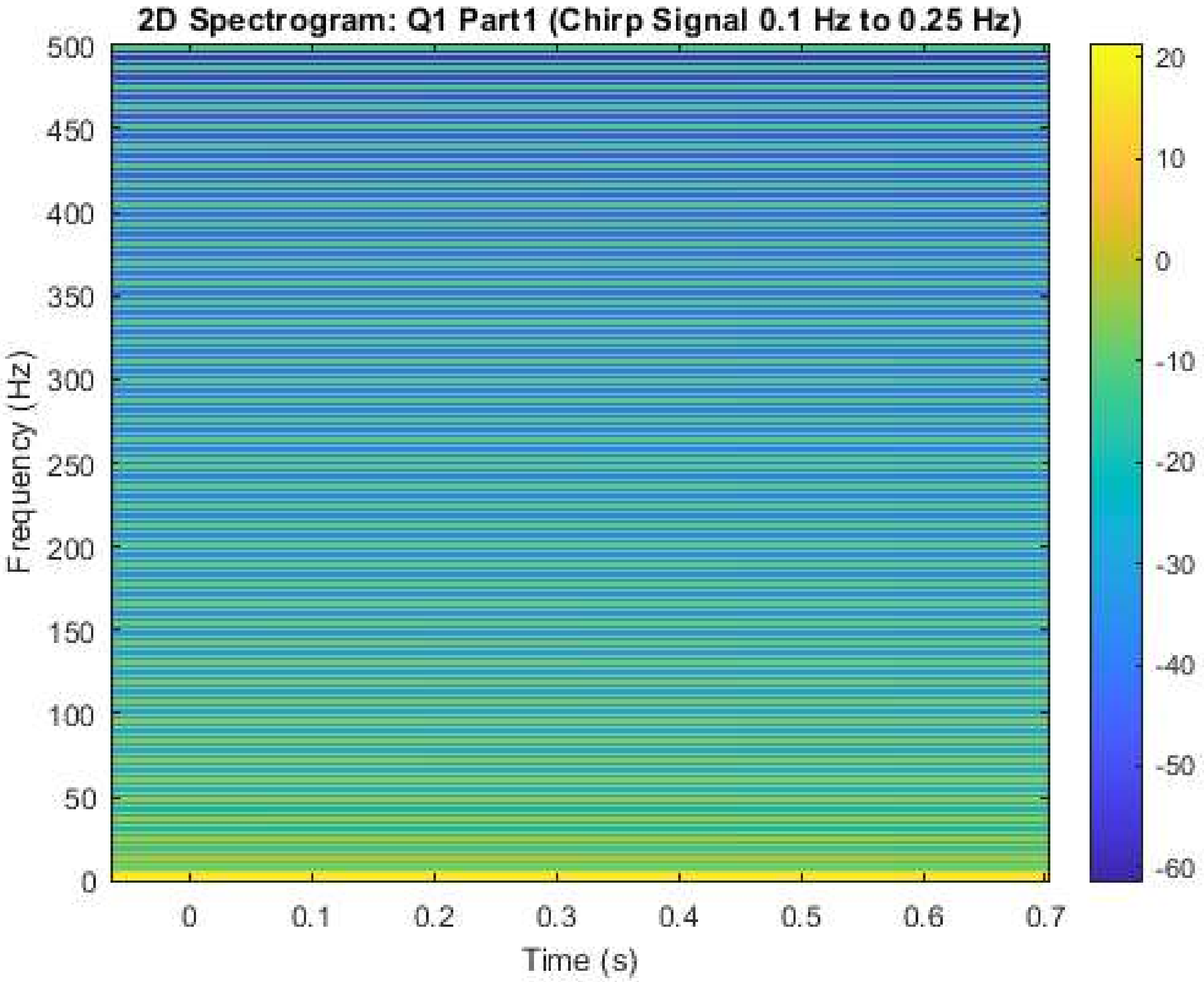
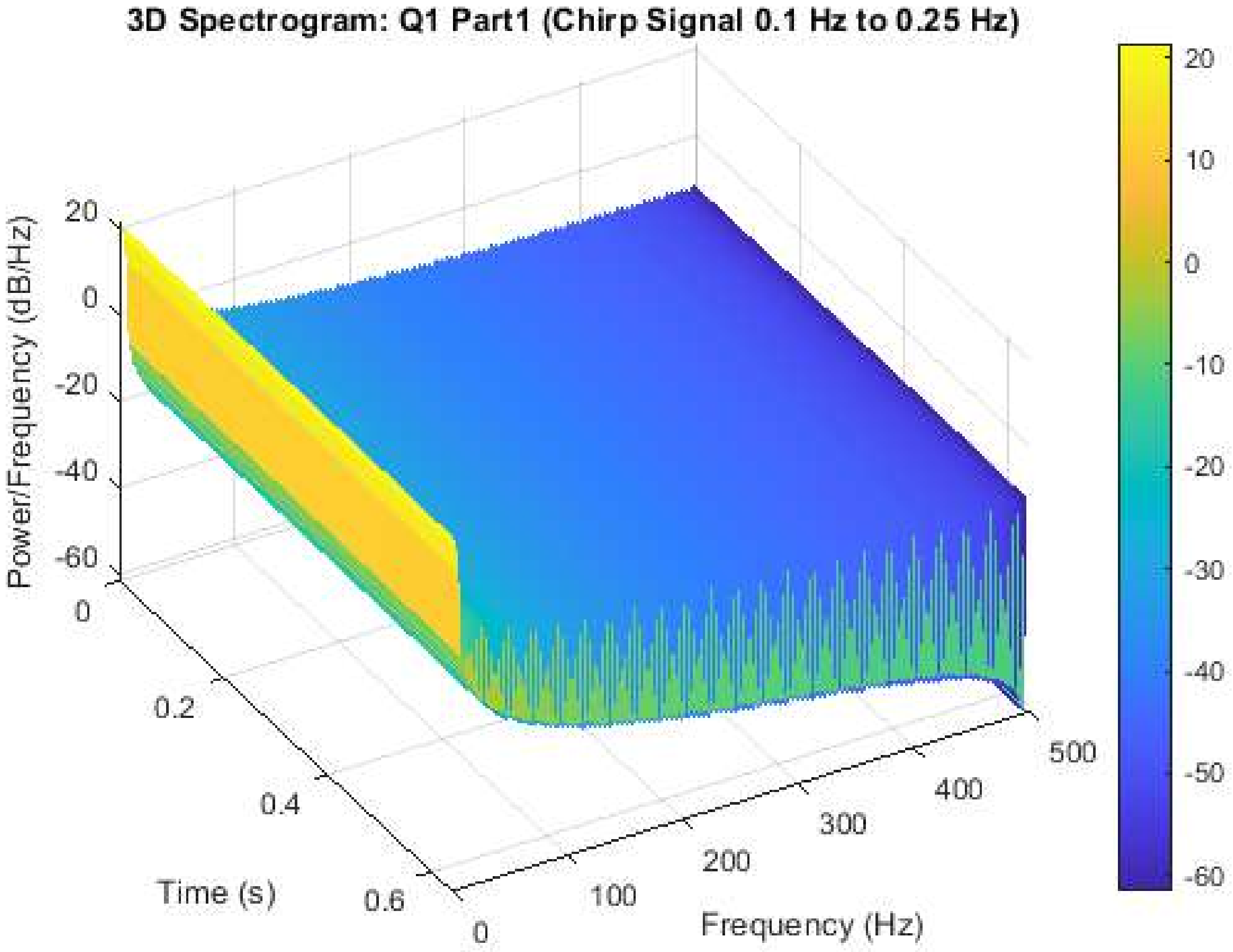
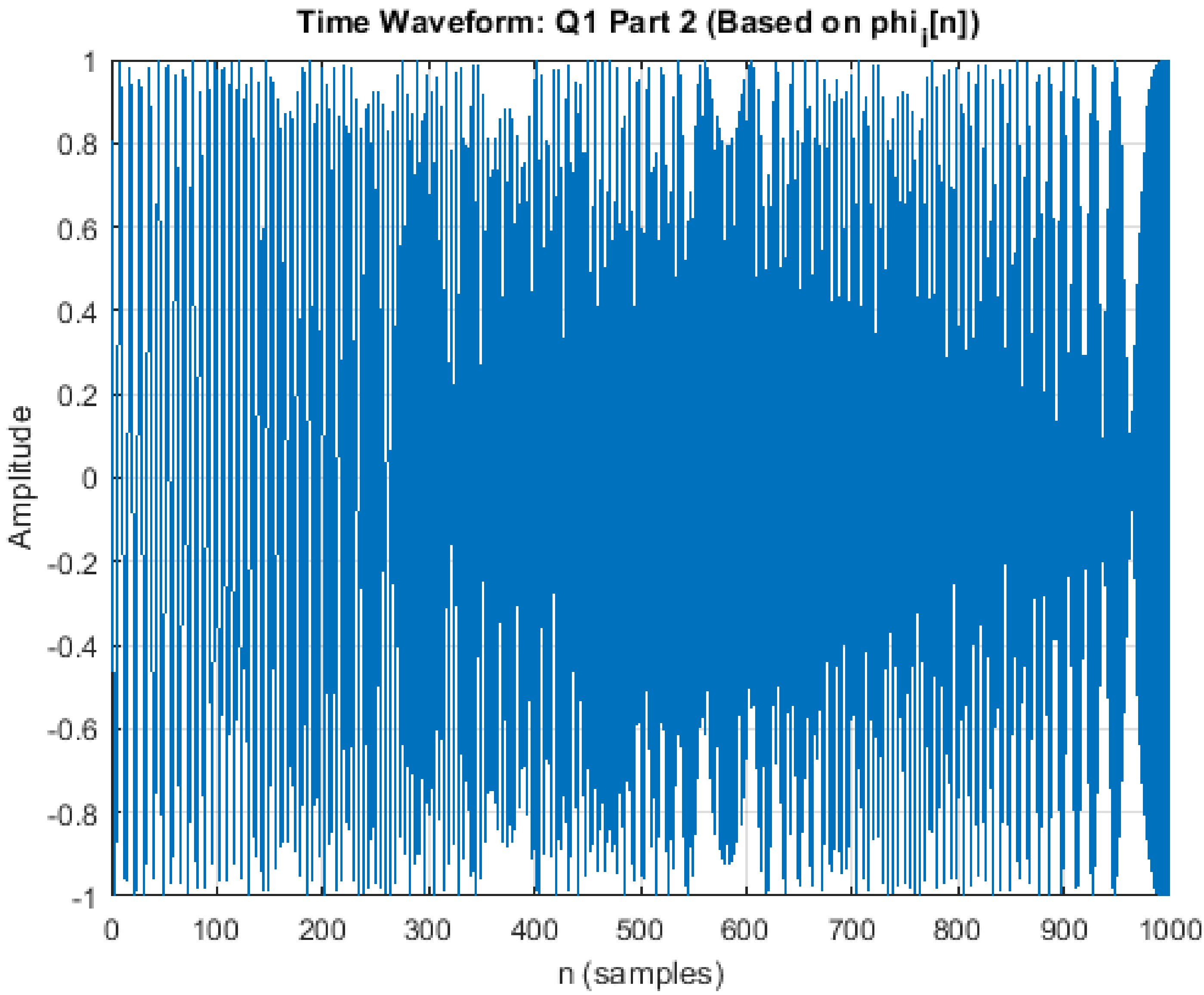
October 3, 2024

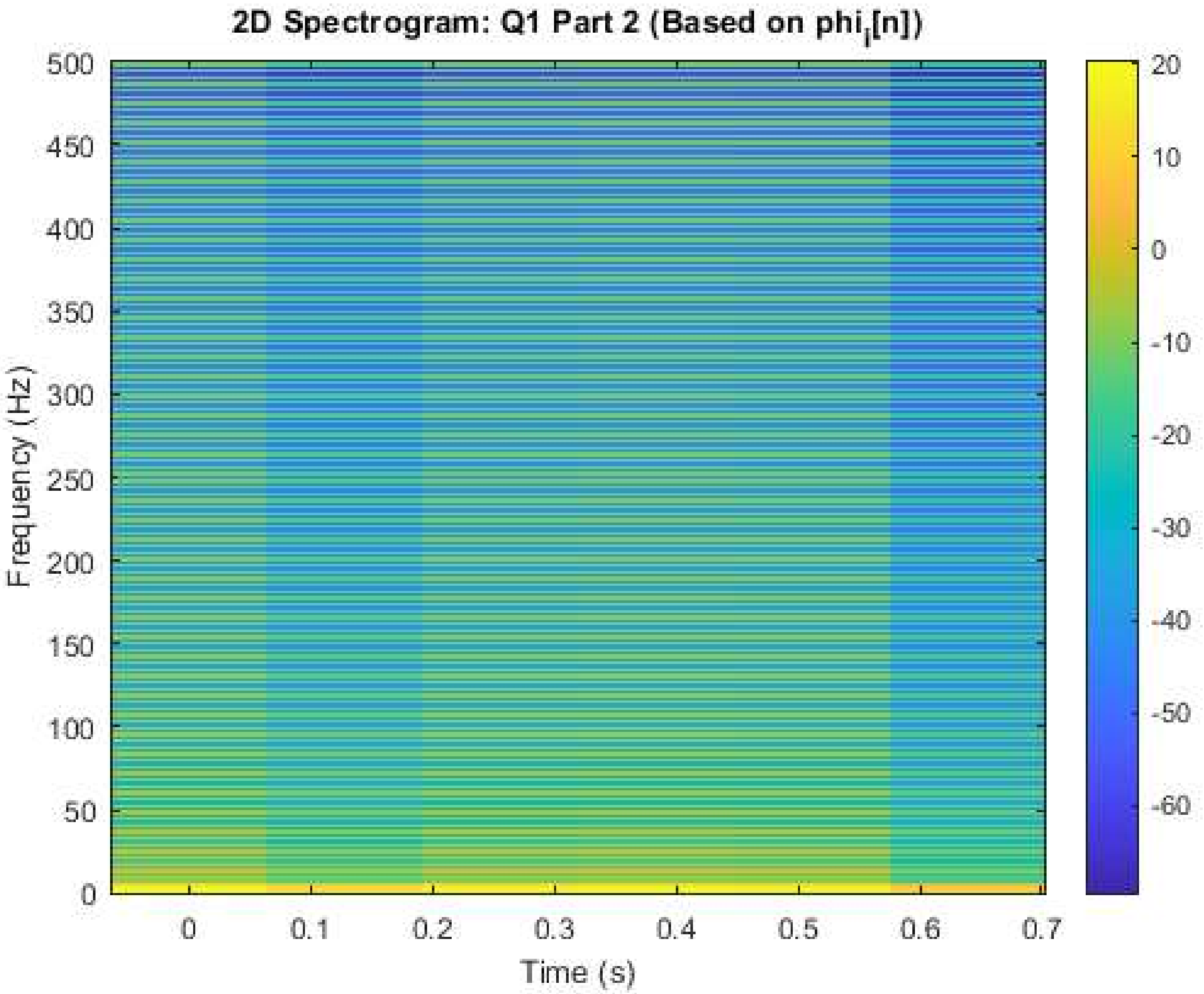

Time Waveform: Q1 Part1 (Chirp Signal 0.1 Hz to 0.25 Hz)
Amplitude
Time (s)
1
0.9
0.8
0.7
0.6
0.5
0.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

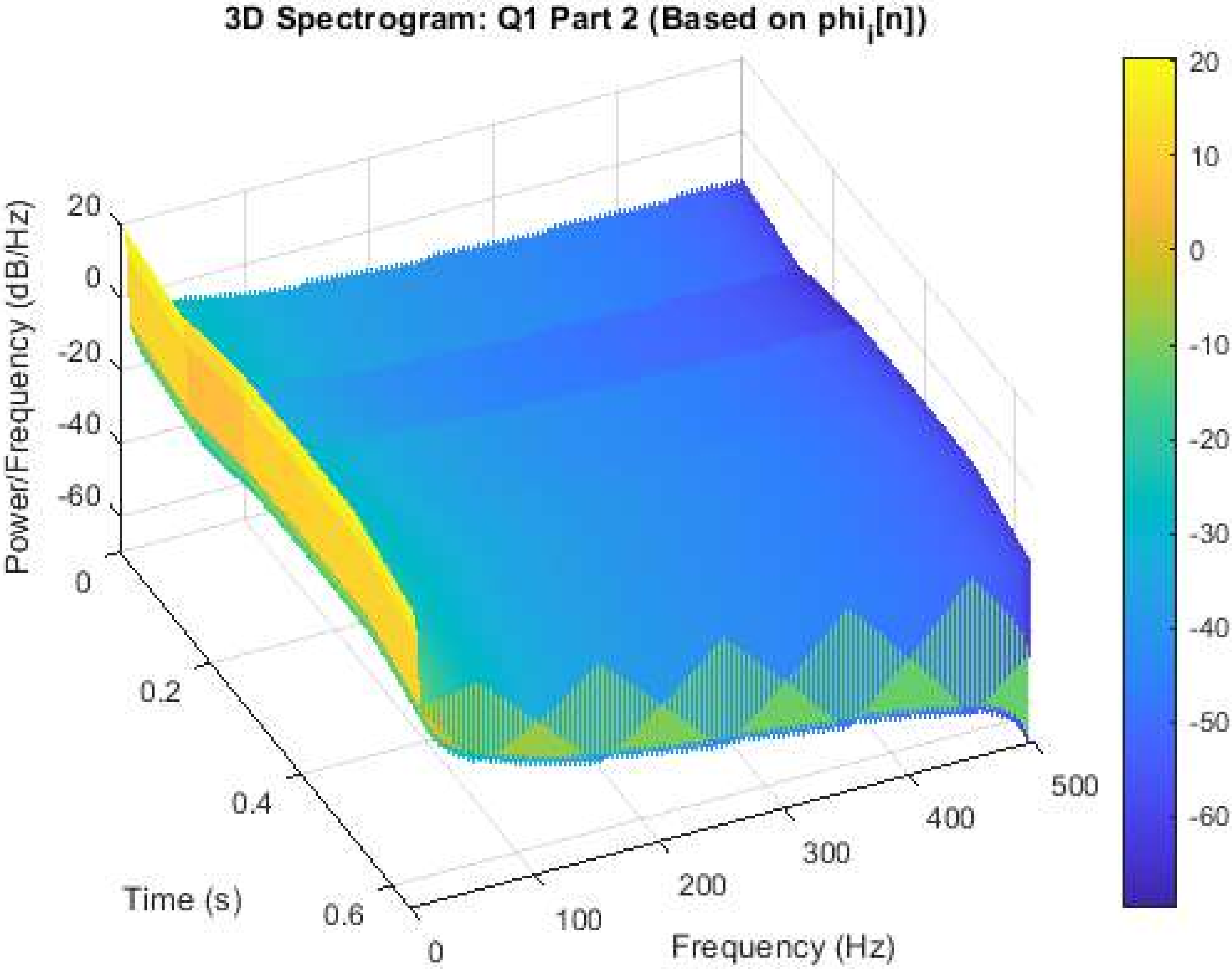

Frequency vs Time: Q1 Part1 (Chirp Signal)
0.25
0.2
0.15
0.1
Frequency →
0
100
200
300
400
500
600
700
800
900
1000
n →


2D Spectrogram: Q1 Part1 (Chirp Signal 0.1 Hz to 0.25 Hz)
Frequency (Hz)
Time (s)
0
50
100
150
200
250
300
350
400
450
500
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
20
10
0
-10
-20
-30
-40
-50
-60

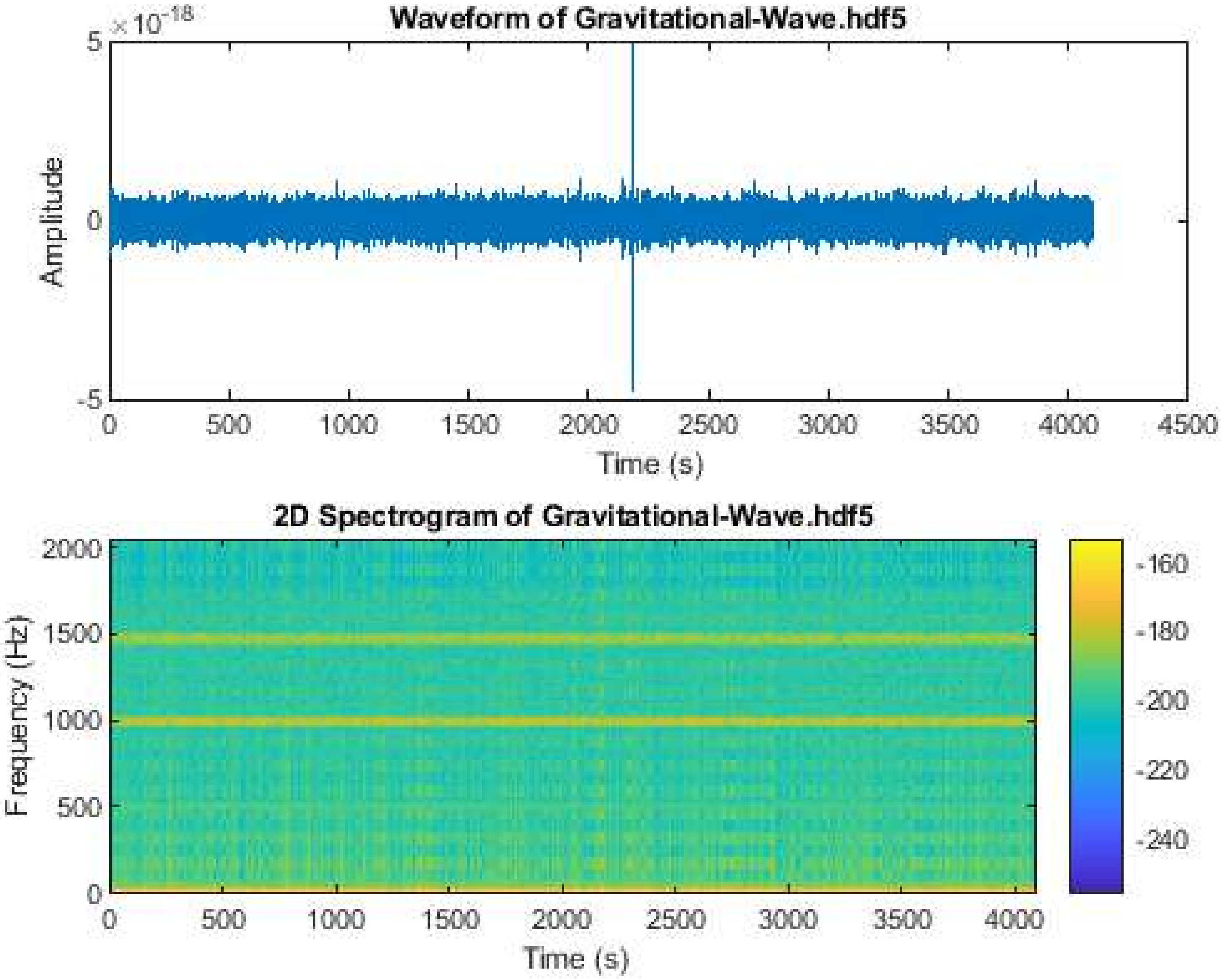

3D Spectrogram: Q1 Part1 (Chirp Signal 0.1 Hz to 0.25 Hz)
Power/Frequency (dB/Hz)
20
0
-20
-40
-60
Time (s)
0
0.2
0.4
0.6
Frequency (Hz)
0
100
200
300
400
500
20
10
0
-10
-20
-30
-40
-50
-60


Time Waveform: Q1 Part 2 (Based on phi_i[n])
Amplitude
n (samples)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
100
200
300
400
500
600
700
800
900
1000

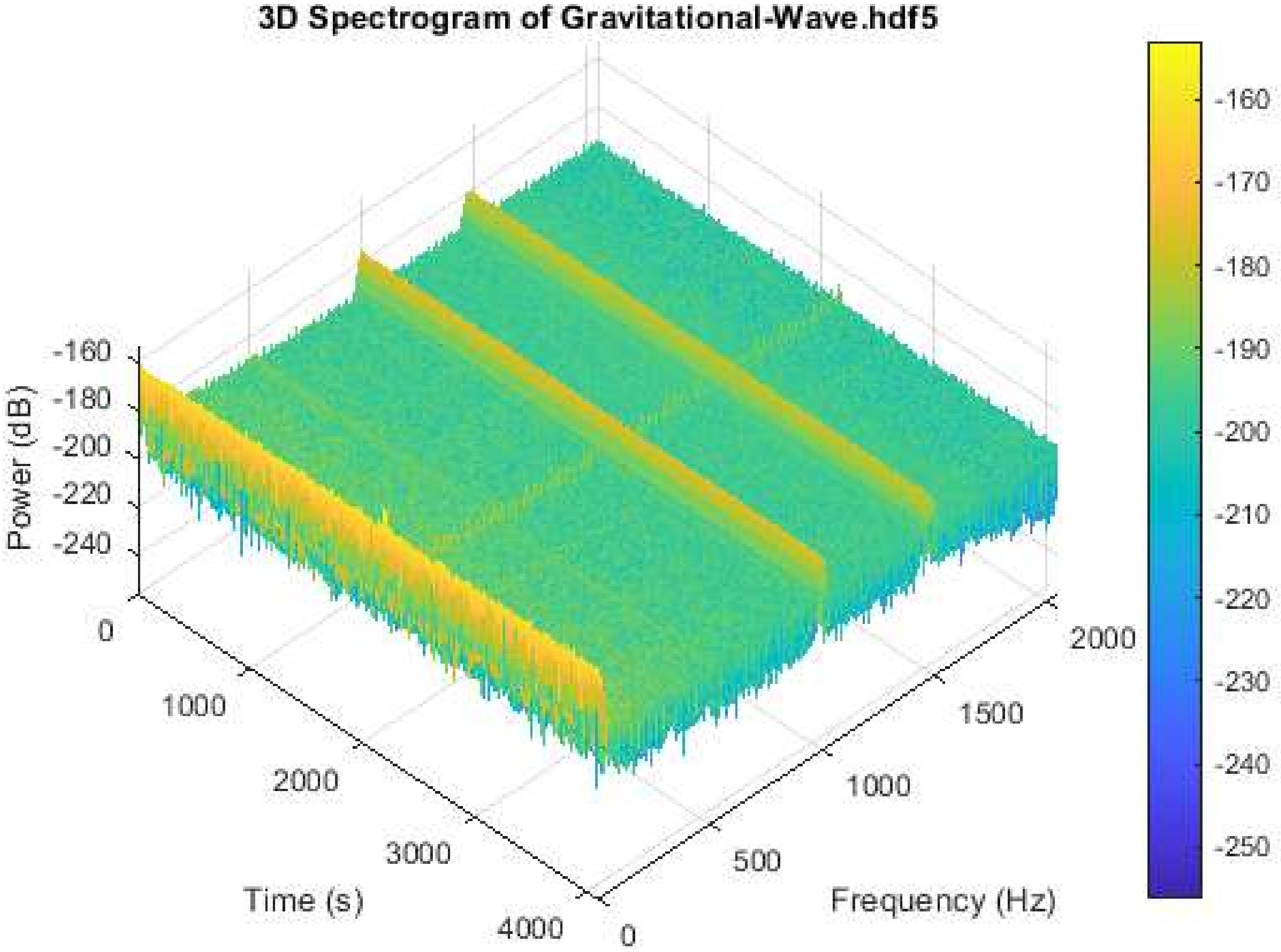

2D Spectrogram: Q1 Part 2 (Based on phi_i[n])
Frequency (Hz)
0
50
100
150
200
250
300
350
400
450
500
Time (s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
20
10
0
-10
-20
-30
-40
-50
-60

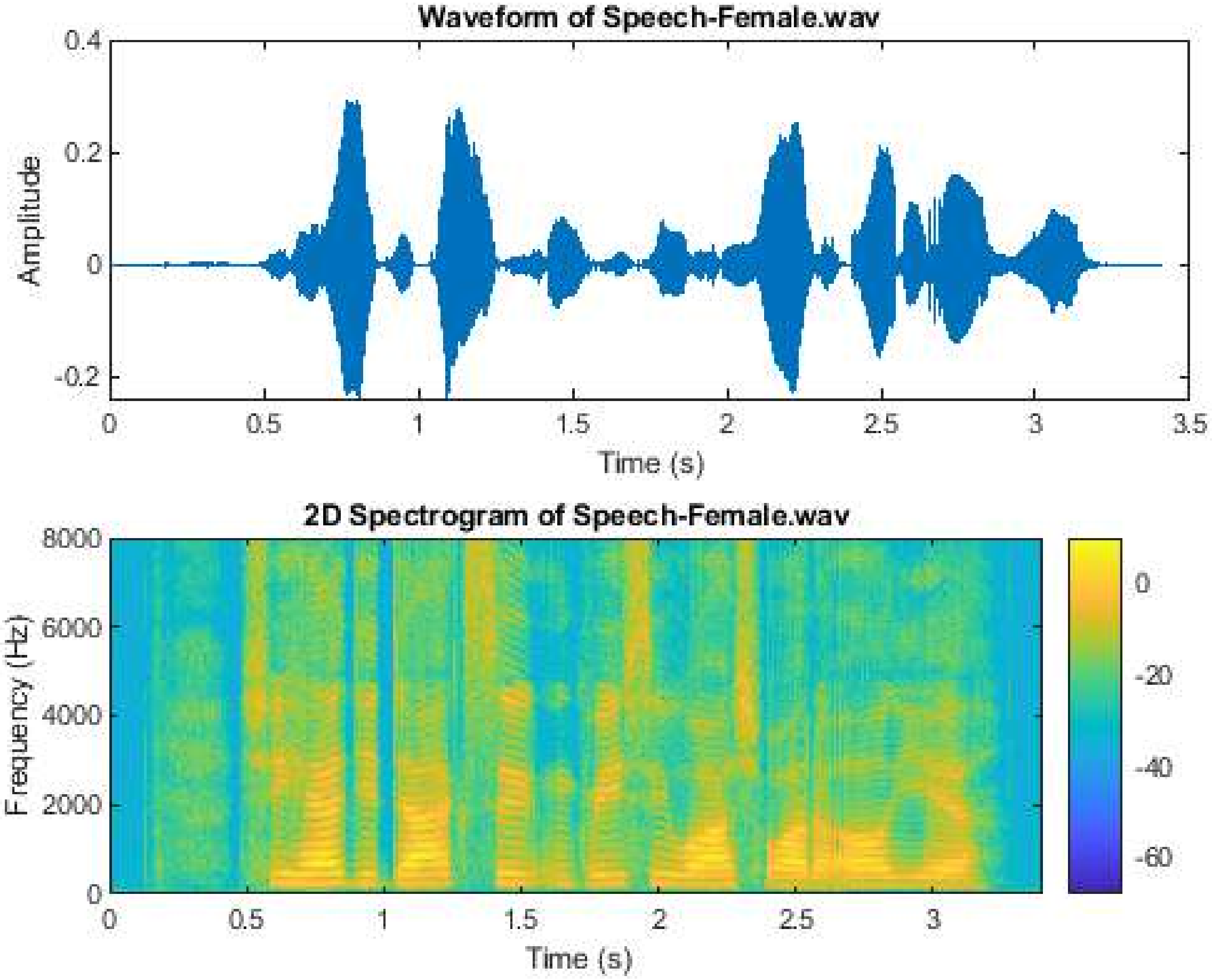


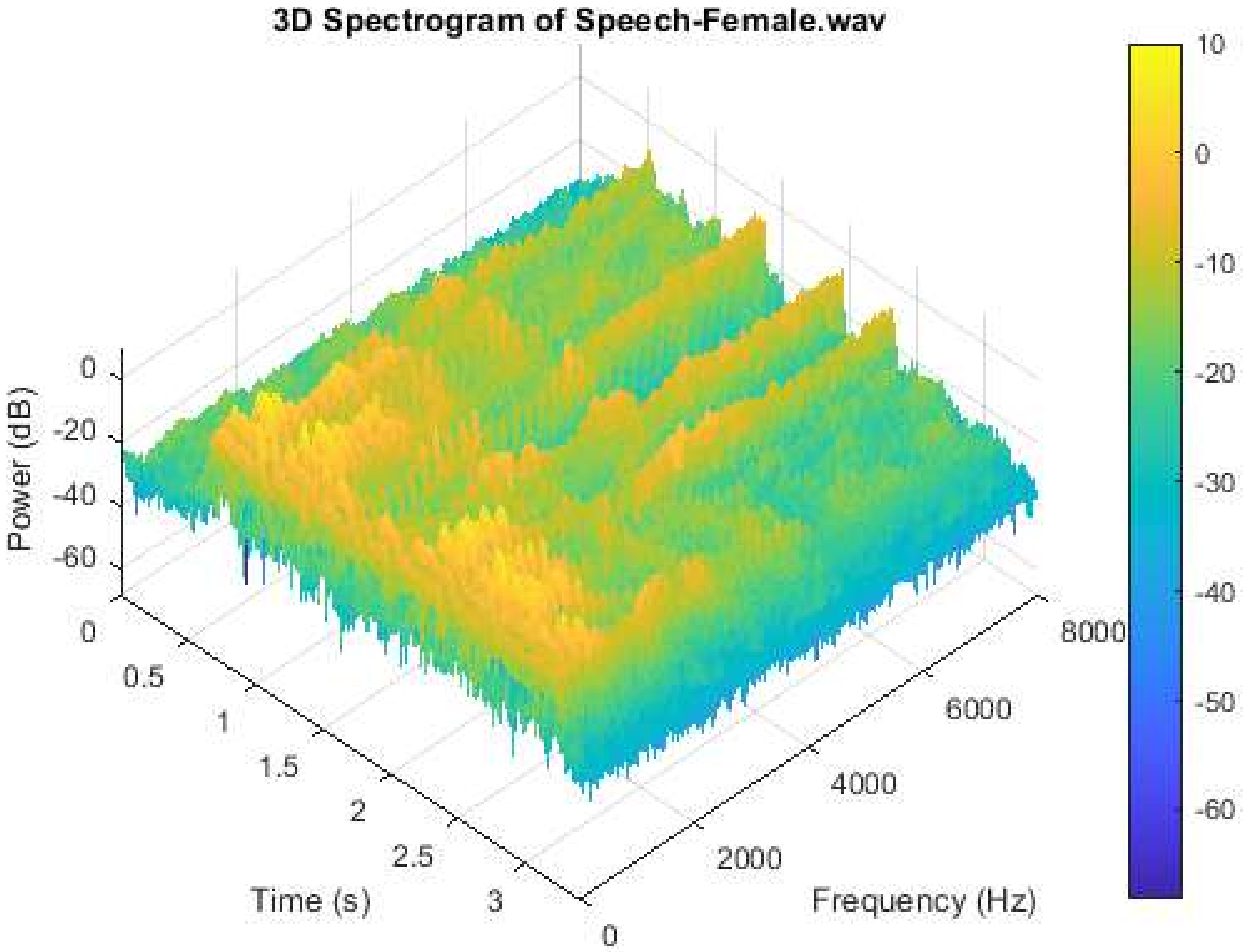
3D Spectrogram: Q1 Part 2 (Based on $phi_i[n]$)
Power/Frequency (dB/Hz)
20
0
-20
-40
-60
Time (s)
0
0.2
0.4
0.6
Frequency (Hz)
0
100
200
300
400
500
20
10
0
-10
-20
-30
-40
-50
-60

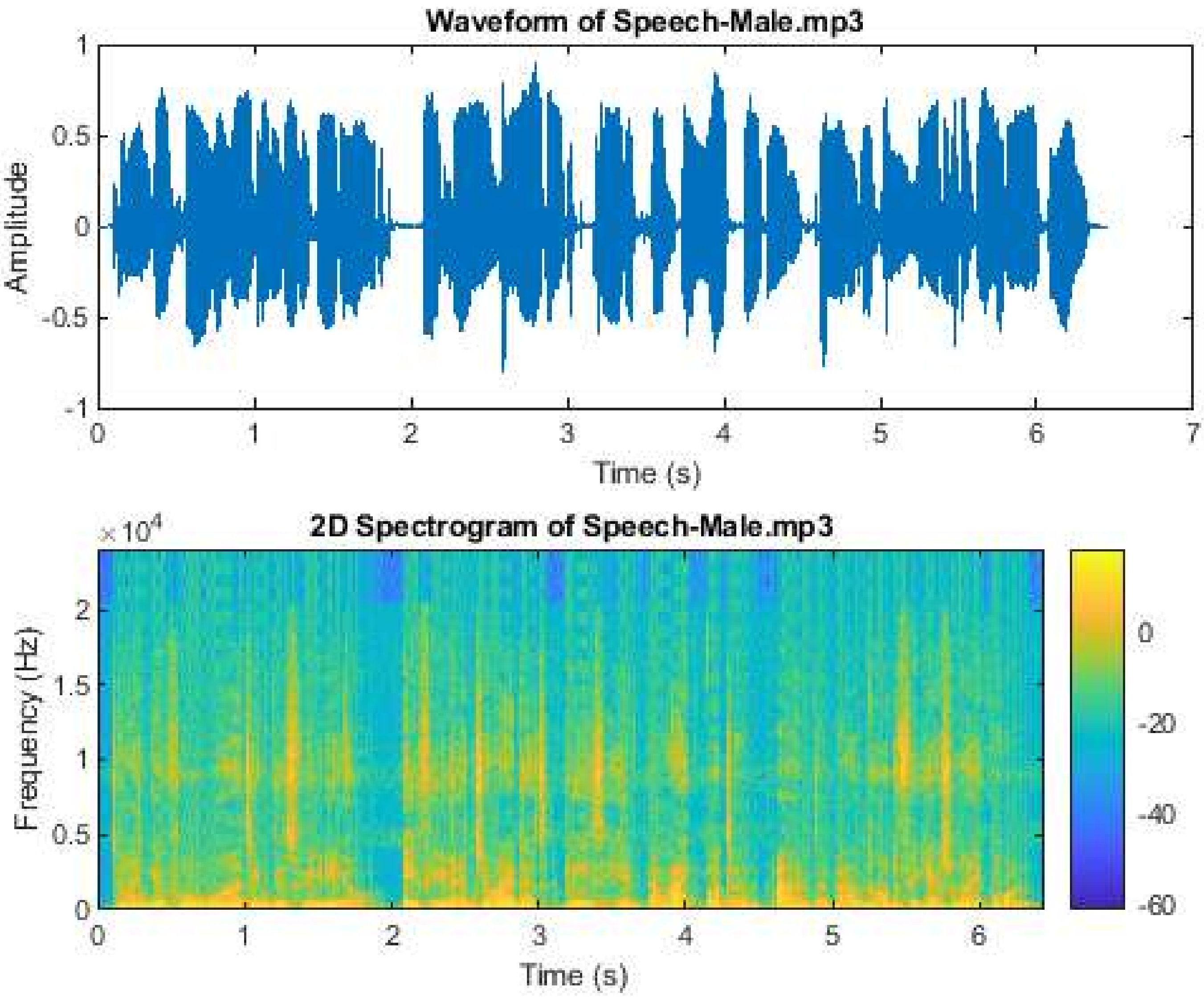


Waveform of Gravitational-Wave.hdf5
Amplitude
Time (s)
2D Spectrogram of Gravitational-Wave.hdf5
Frequency (Hz)
Time (s)

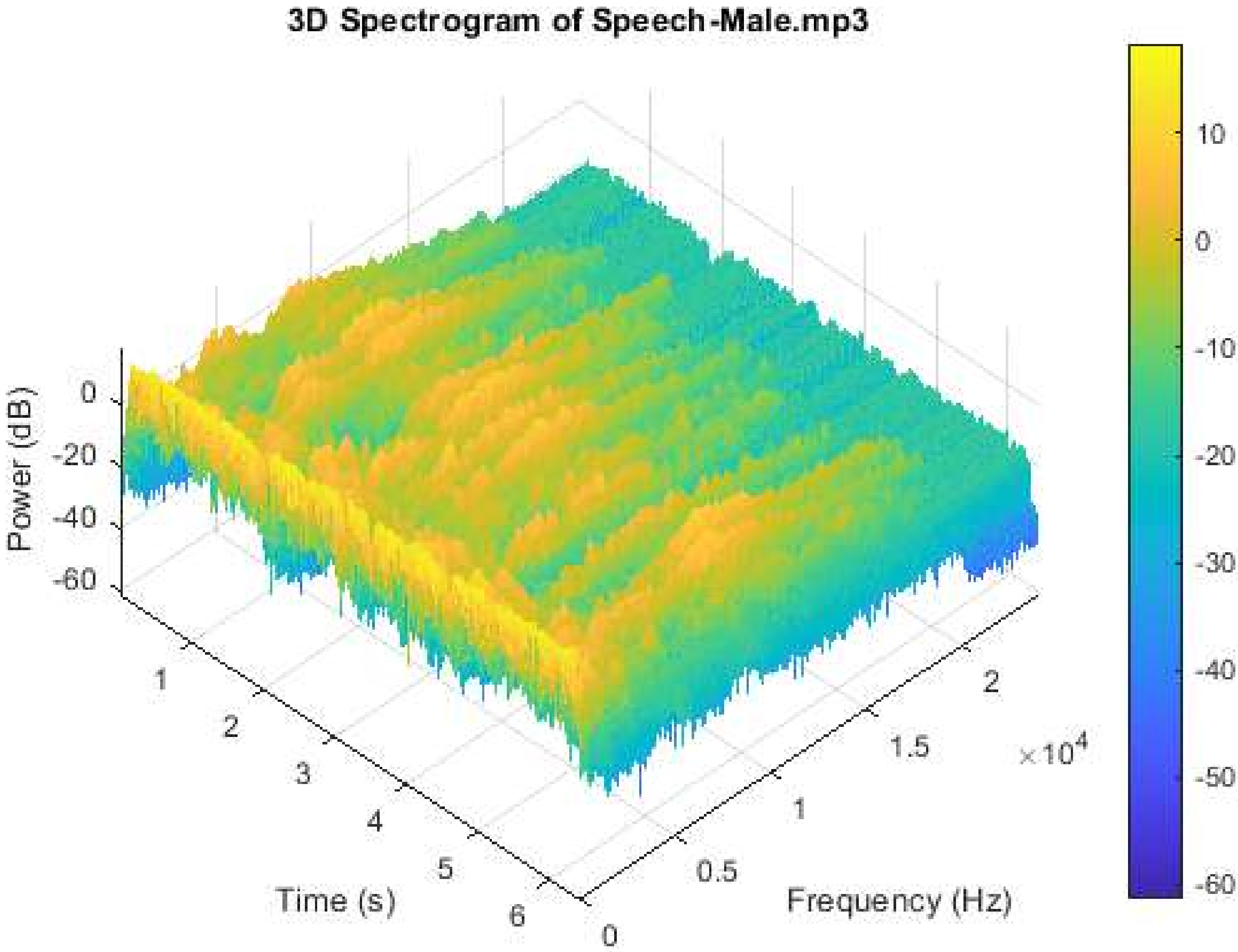

3D Spectrogram of Gravitational-Wave.hdf5
Power (dB)
-160
-180
-200
-220
-240
0
1000
2000
3000
4000
Time (s)
0
500
1000
1500
2000
Frequency (Hz)
-160
-170
-180
-190
-200
-210
-220
-230
-240
-250

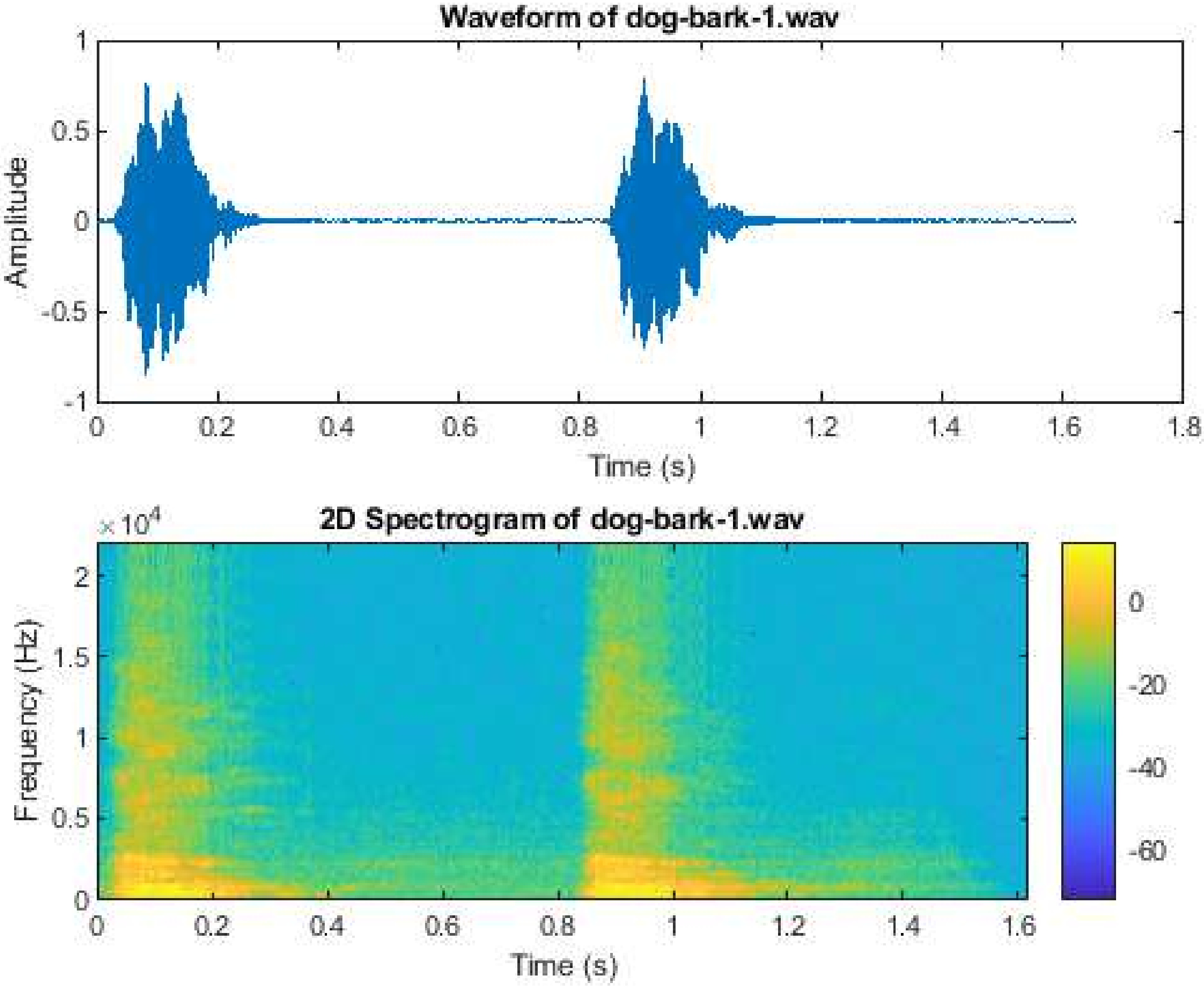

Waveform of Speech-Female.wav
0.4
0.2
0
-0.2
Amplitude
0
0.5
1
1.5
2
2.5
3
3.5
Time (s)
2D Spectrogram of Speech-Female.wav
8000
6000
4000
2000
0
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
Time (s)
0
-20
-40
-60

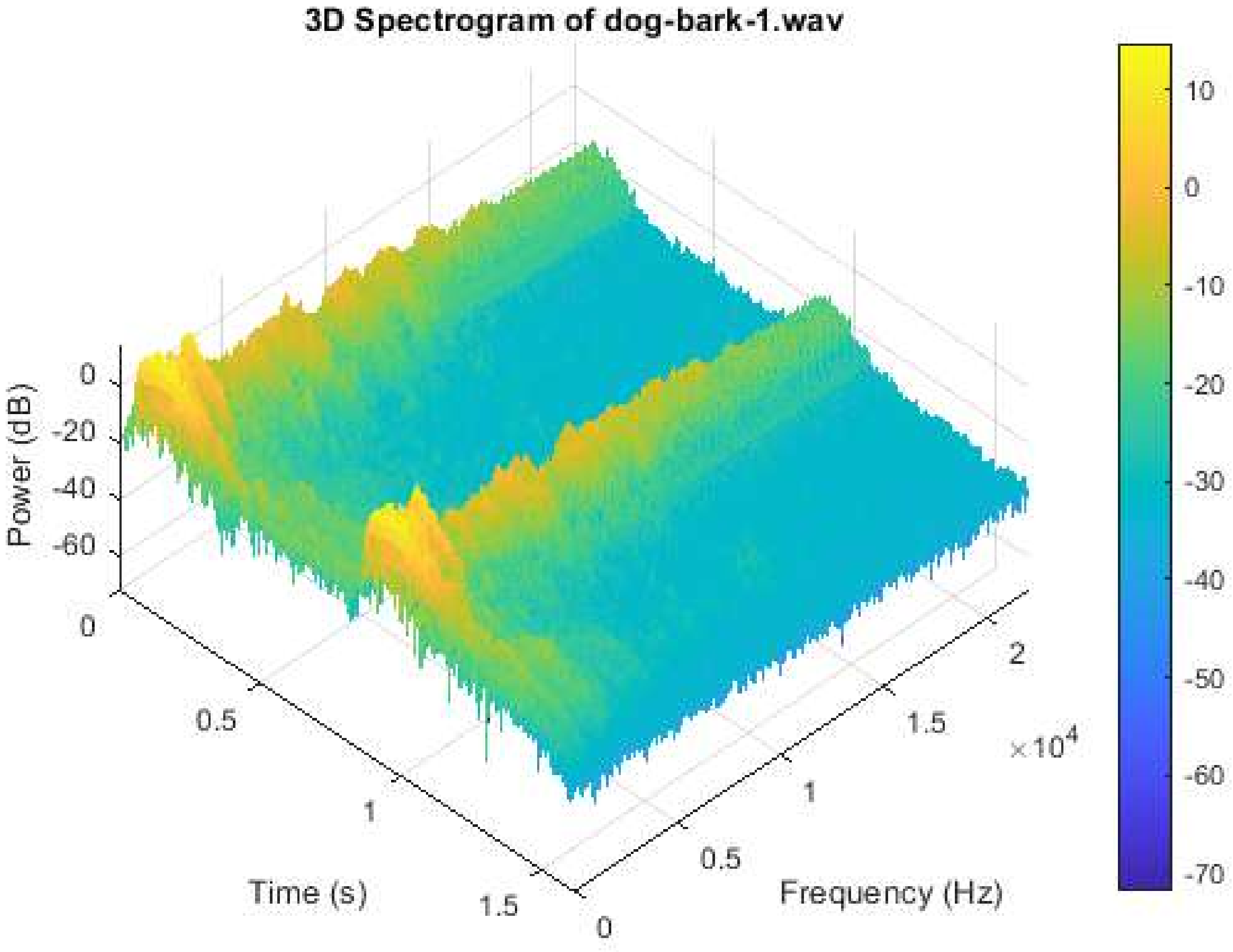

3D Spectrogram of Speech-Female.wav
Power (dB)
0
-20
-40
-60
Time (s)
0
0.5
1
1.5
2
2.5
3
Frequency (Hz)
0
2000
4000
6000
8000
10
0
-10
-20
-30
-40
-50
-60

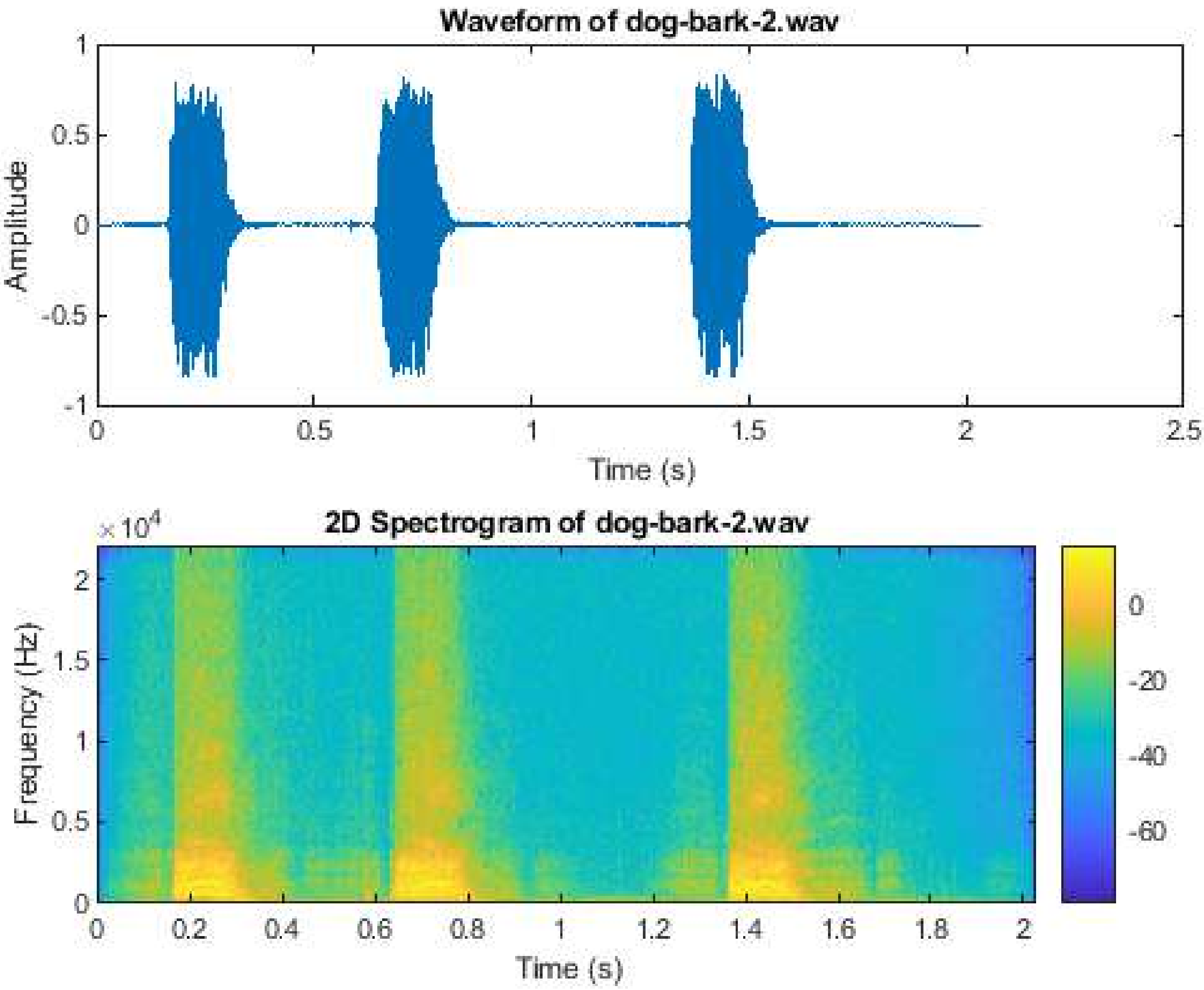


Waveform of Speech-Male.mp3
Amplitude
Time (s)
2D Spectrogram of Speech-Male.mp3
×10^4
Frequency (Hz)
Time (s)

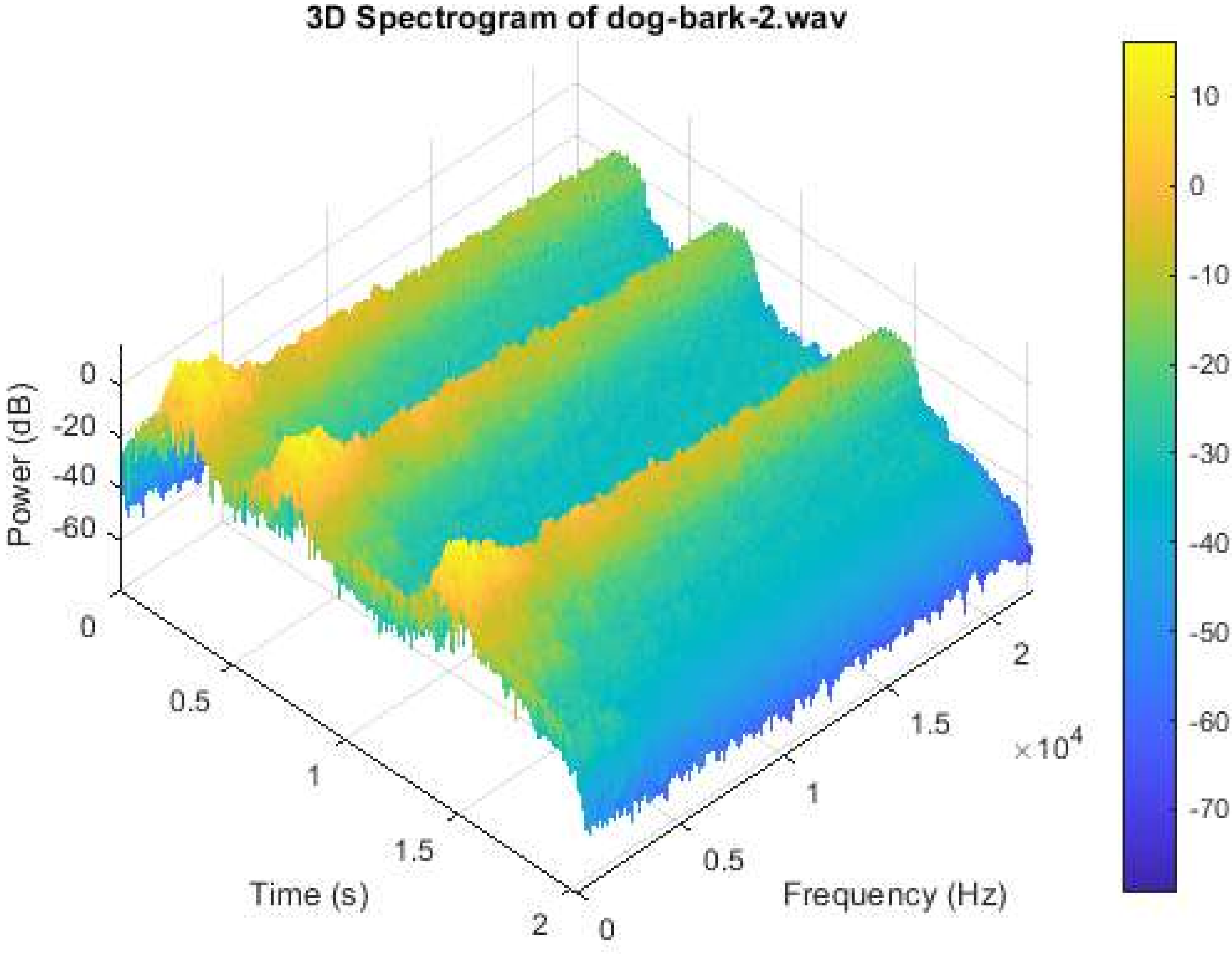

3D Spectrogram of Speech-Male.mp3
Power (dB)
0
-20
-40
-60
1
2
3
4
5
6
Time (s)
0
0.5
1
1.5
2
×10^4
Frequency (Hz)
10
0
-10
-20
-30
-40
-50
-60

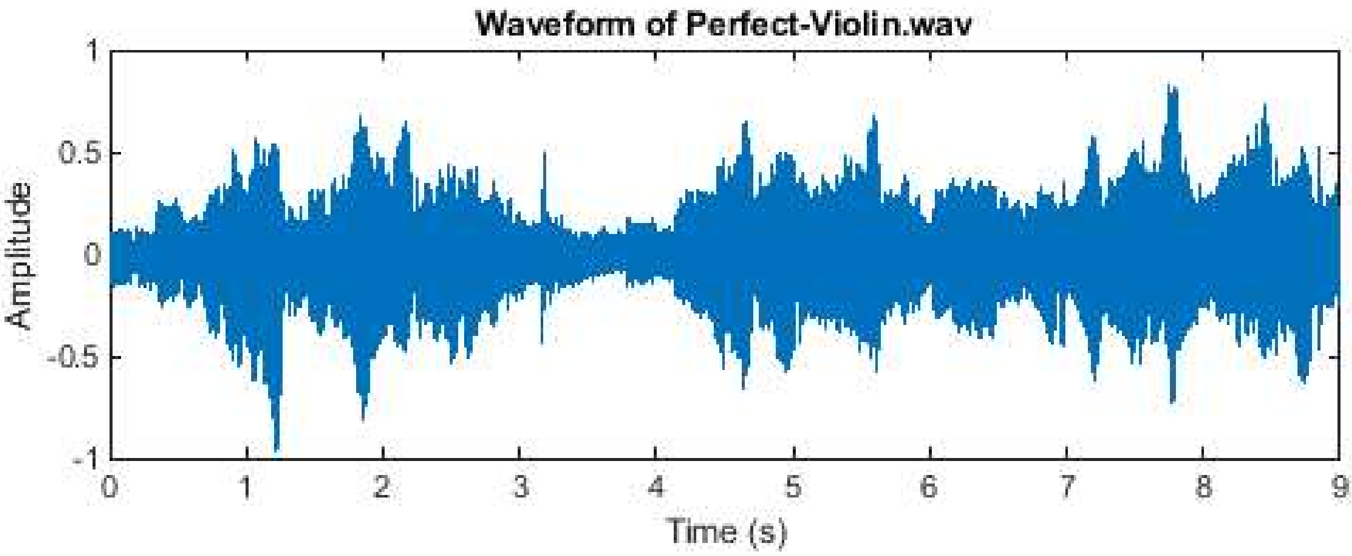

Waveform of dog-bark-1.wav
Amplitude
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Time (s)
2D Spectrogram of dog-bark-1.wav
$\times 10^4$
Frequency (Hz)
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Time (s)
0
-20
-40
-60


3D Spectrogram of dog-bark-1.wav
Power (dB)
0
-20
-40
-60
0
0.5
1
1.5
Time (s)
0
0.5
1
1.5
2
×10^4
Frequency (Hz)
10
0
-10
-20
-30
-40
-50
-60
-70

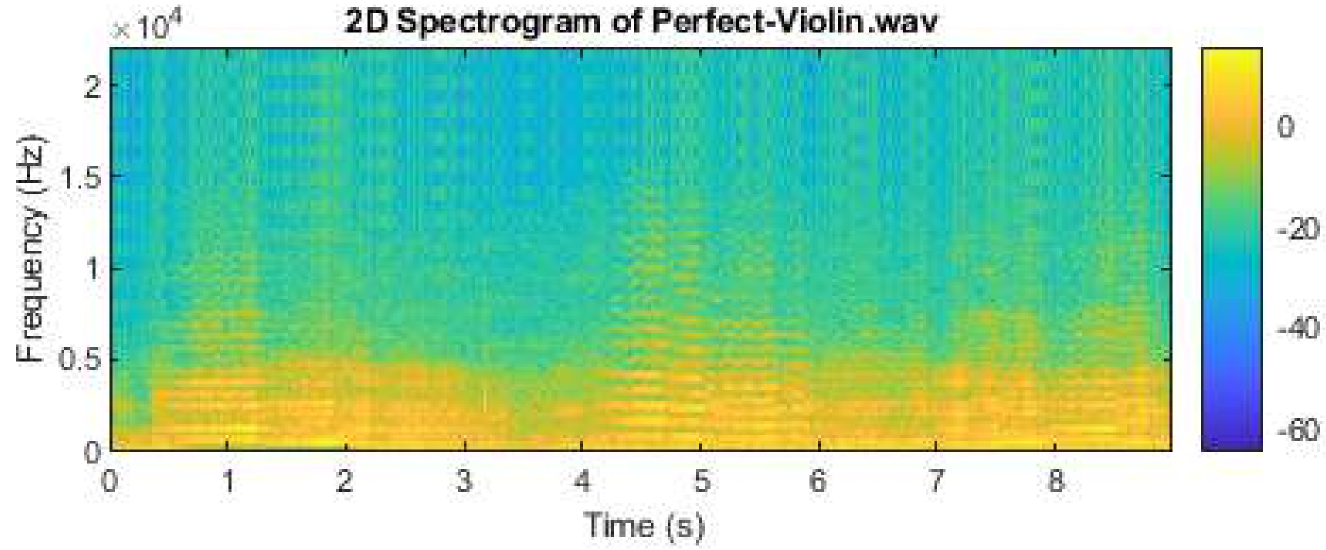


Waveform of dog-bark-2.wav
Amplitude
Time (s)
2D Spectrogram of dog-bark-2.wav
×10^4
Frequency (Hz)
Time (s)

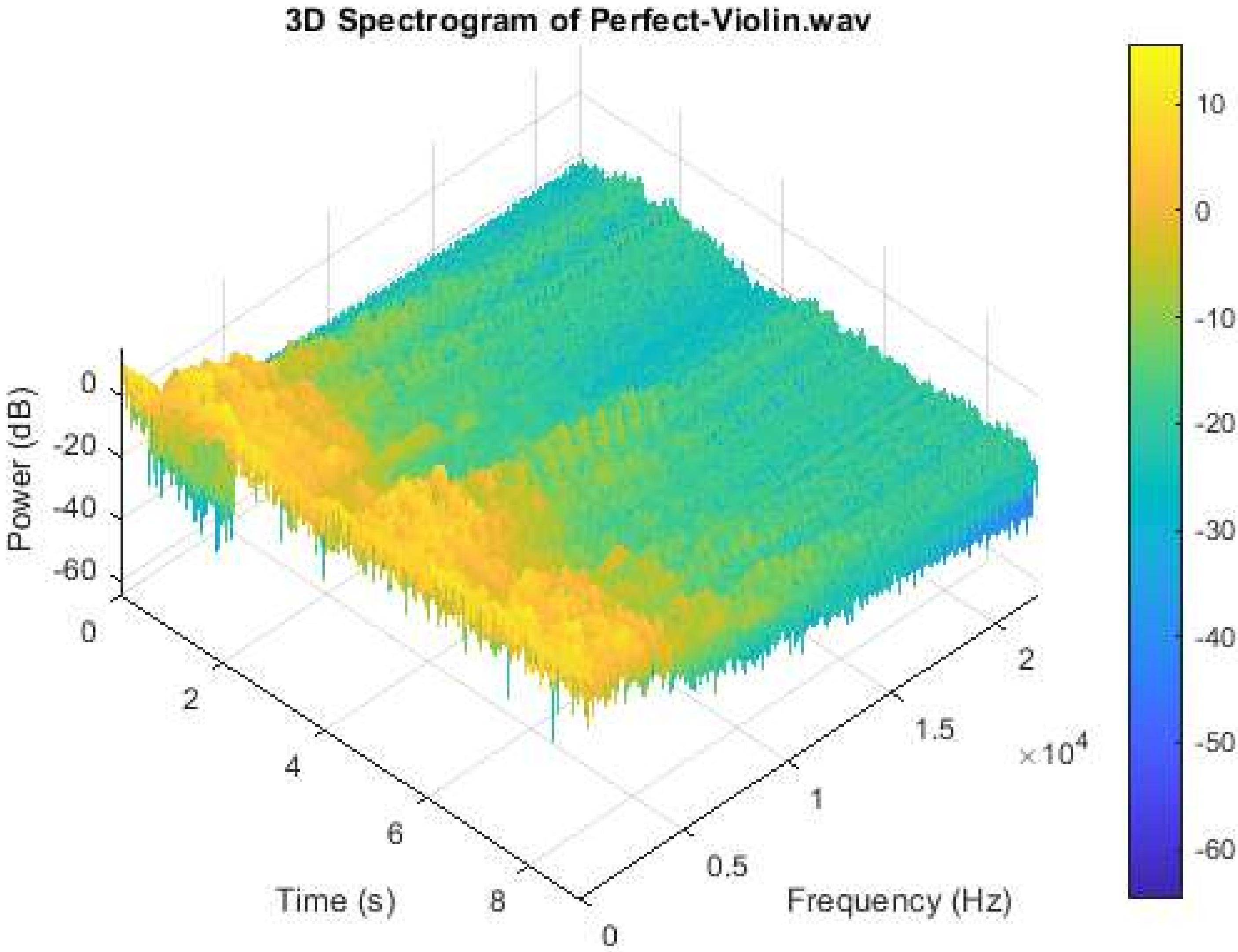

3D Spectrogram of dog-bark-2.wav
Power (dB)
0
-20
-40
-60
0
0.5
1
1.5
2
Time (s)
0
0.5
1
1.5
2
×10^4
Frequency (Hz)
10
0
-10
-20
-30
-40
-50
-60
-70

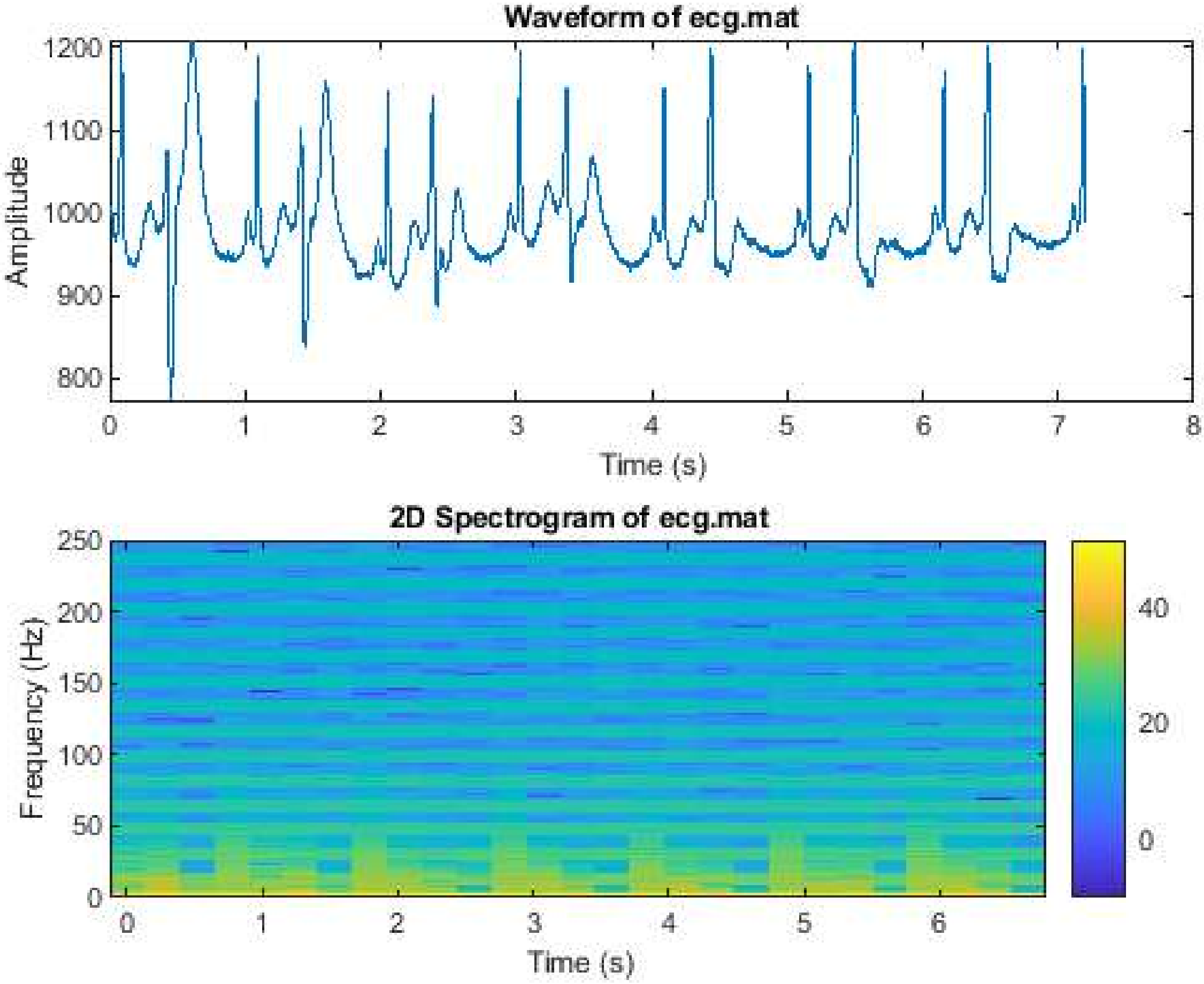


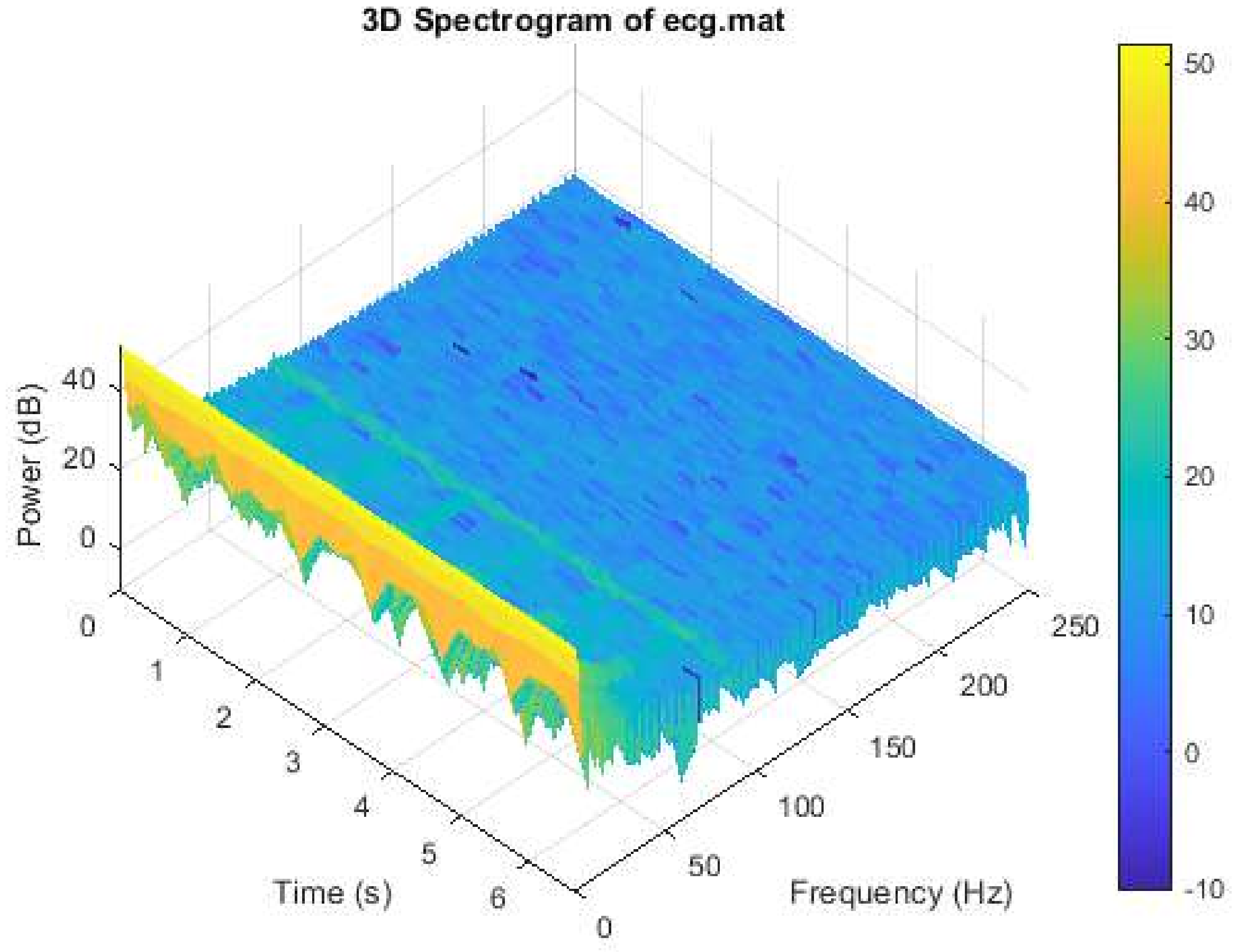
Waveform of Perfect-Violin.wav
Amplitude
Time (s)

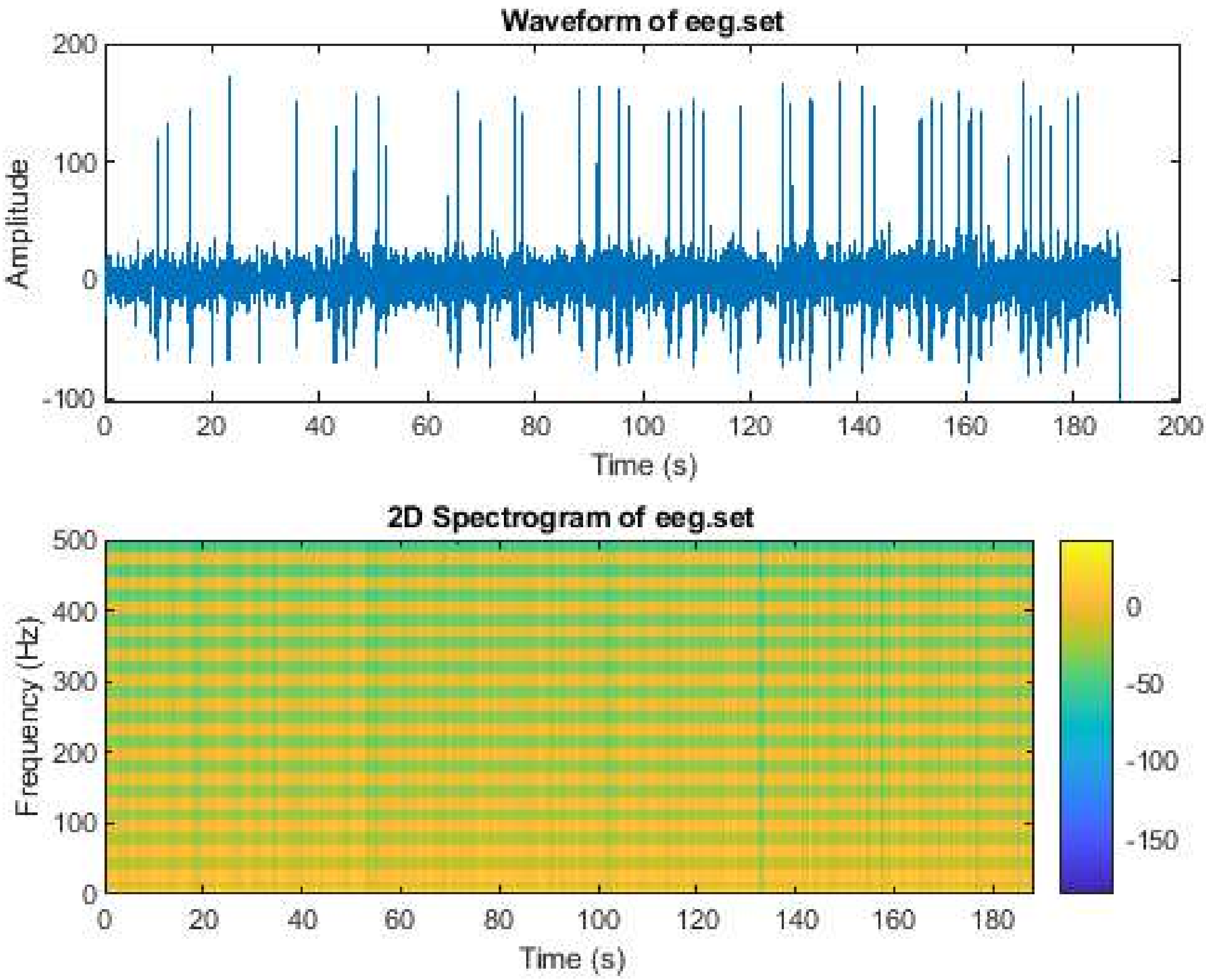


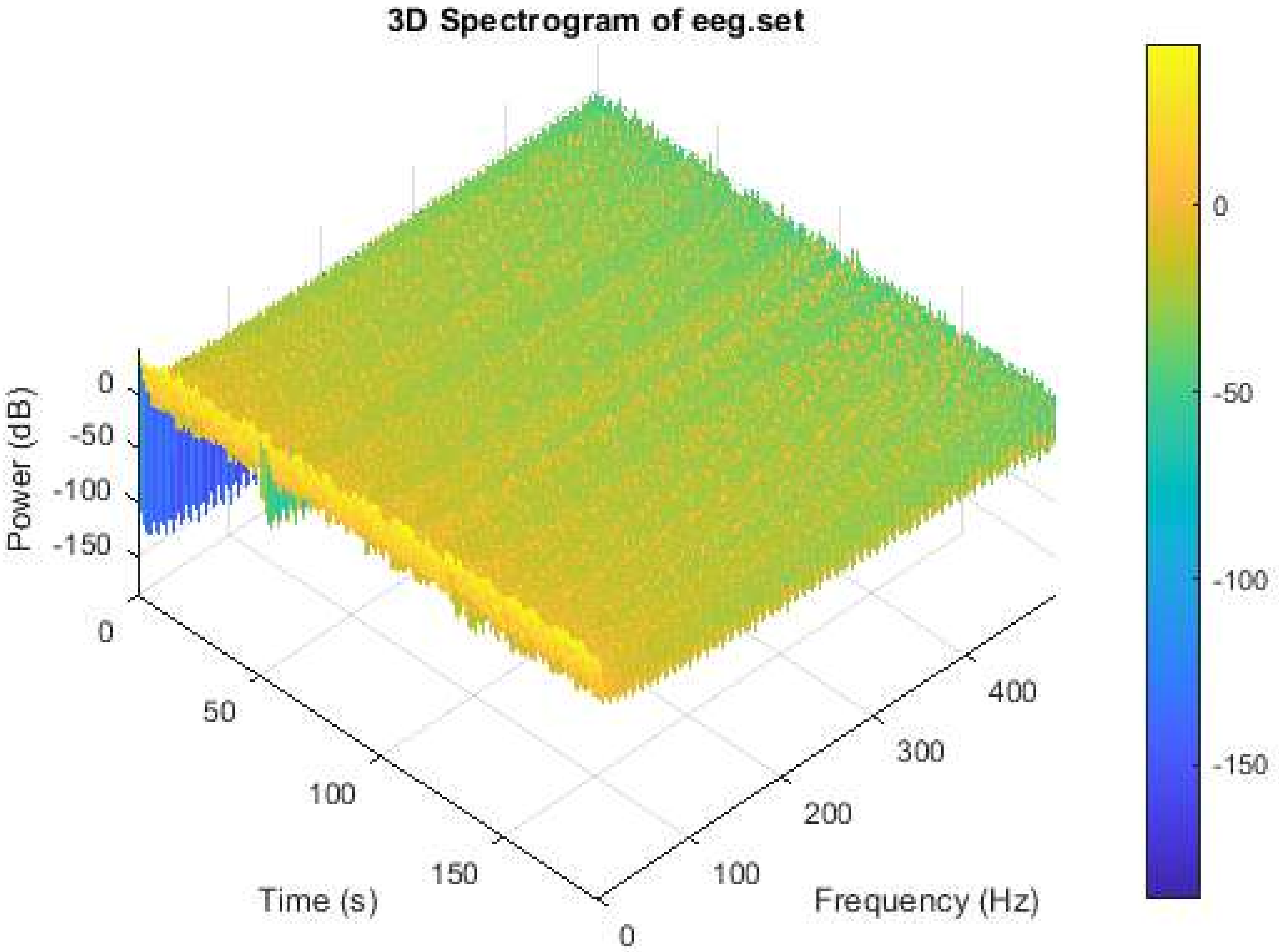
2D Spectrogram of Perfect-Violin.wav
×10^4
Frequency (Hz)
Time (s)

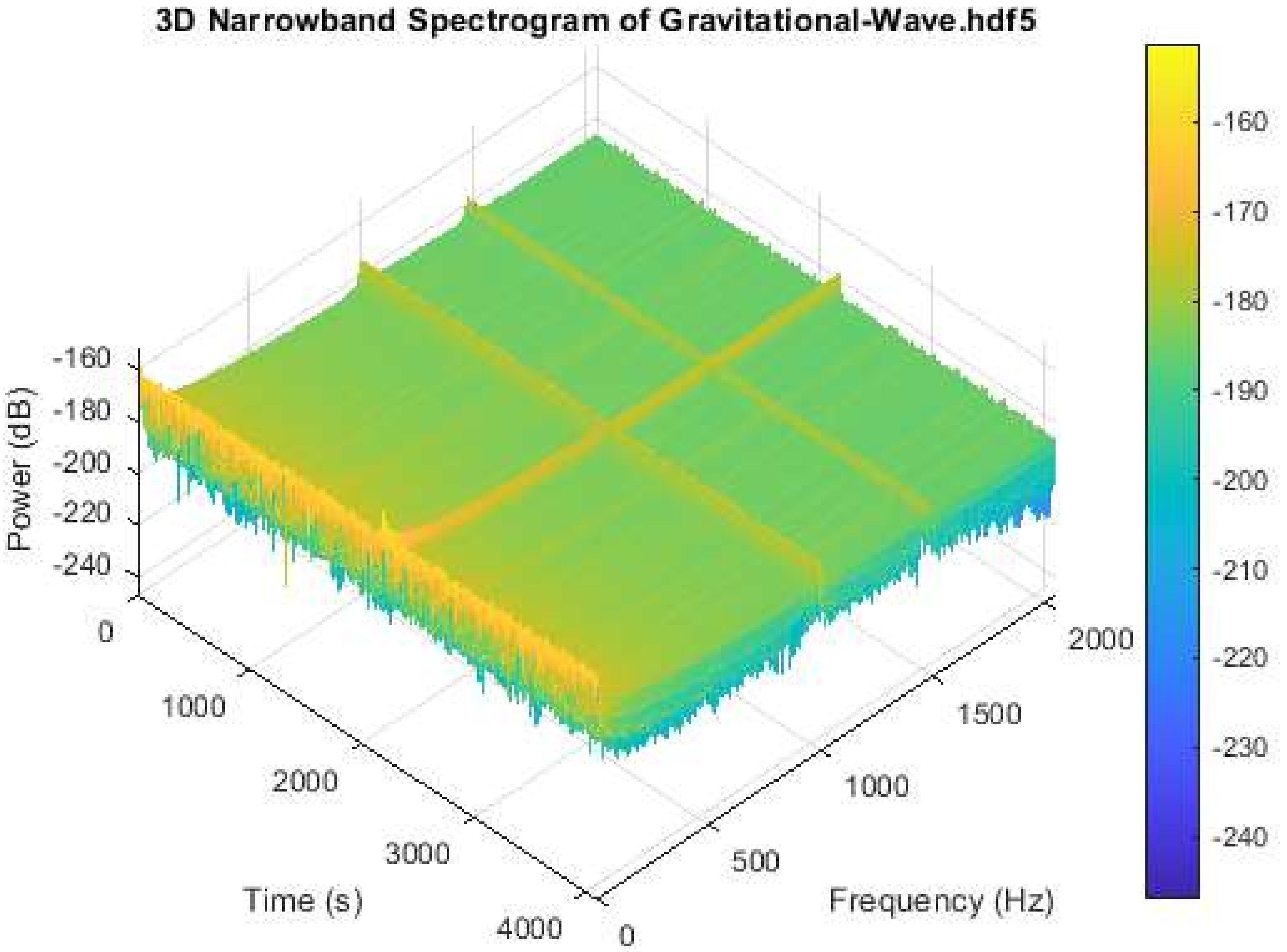

3D Spectrogram of Perfect-Violin.wav
Power (dB)
0
-20
-40
-60
0
2
4
6
8
Time (s)
0
0.5
1
1.5
2
$\times 10^4$
Frequency (Hz)
10
0
-10
-20
-30
-40
-50
-60

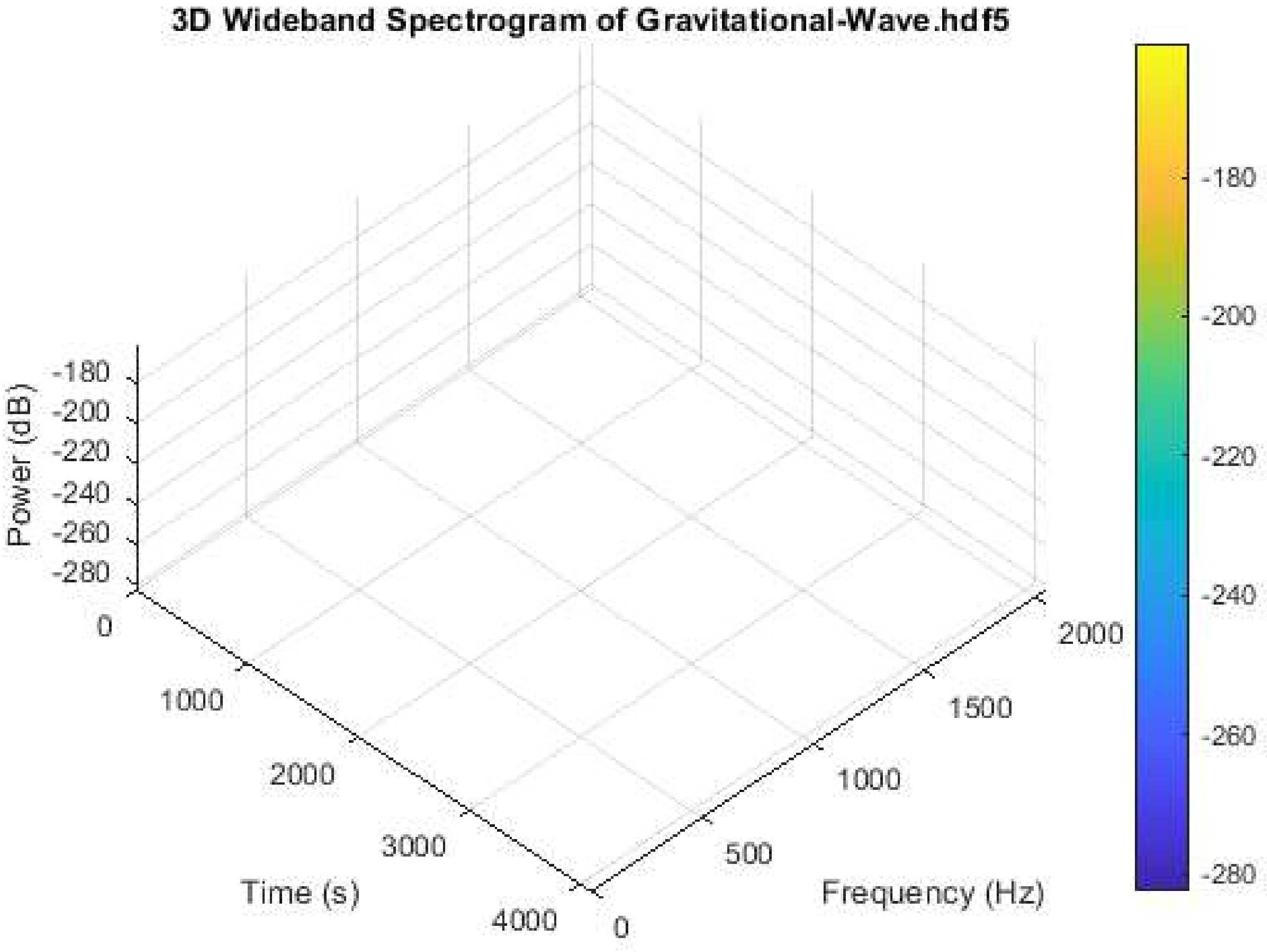

Waveform of ecg.mat
Amplitude
1200
1100
1000
900
800
0
1
2
3
4
5
6
7
8
Time (s)
2D Spectrogram of ecg.mat
Frequency (Hz)
250
200
150
100
50
0
0
1
2
3
4
5
6
Time (s)
40
20
0

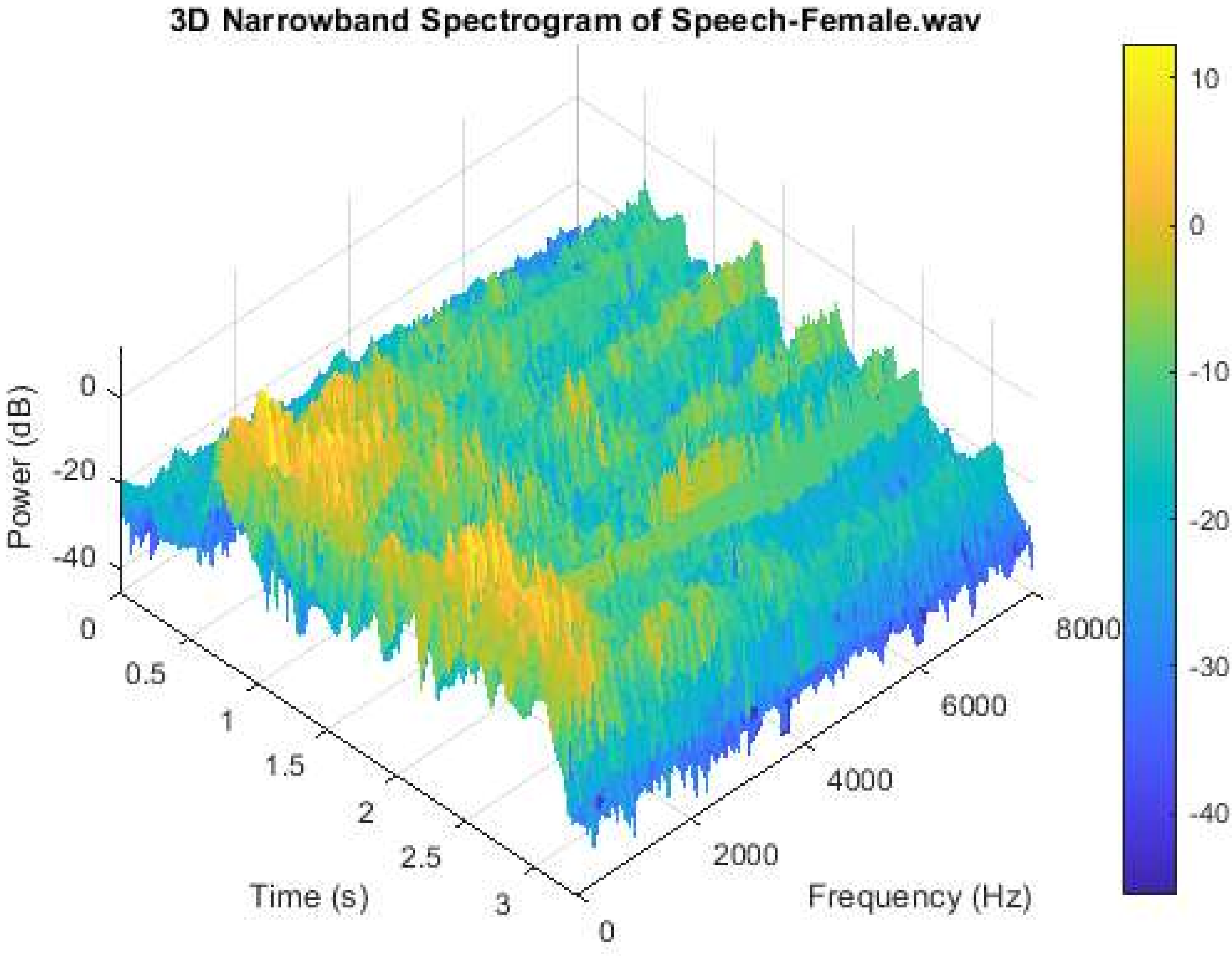

3D Spectrogram of ecg.mat
Power (dB)
40
20
0
Time (s)
0
1
2
3
4
5
6
Frequency (Hz)
0
50
100
150
200
250
50
40
30
20
10
0
-10

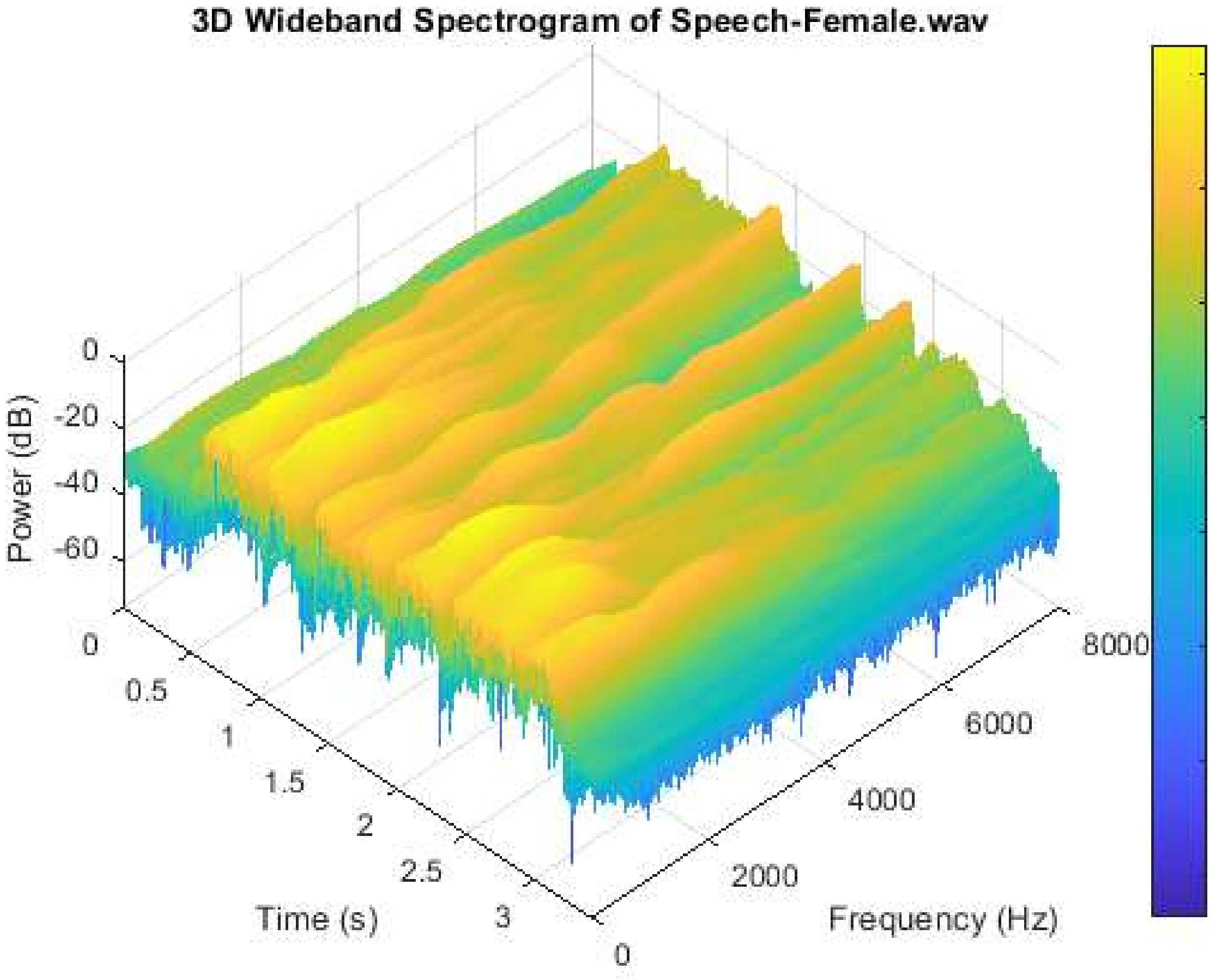

Waveform of eeg.set
Amplitude
200
100
0
-100
0
20
40
60
80
100
120
140
160
180
200
Time (s)
2D Spectrogram of eeg.set
Frequency (Hz)
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
180
Time (s)
0
-50
-100
-150

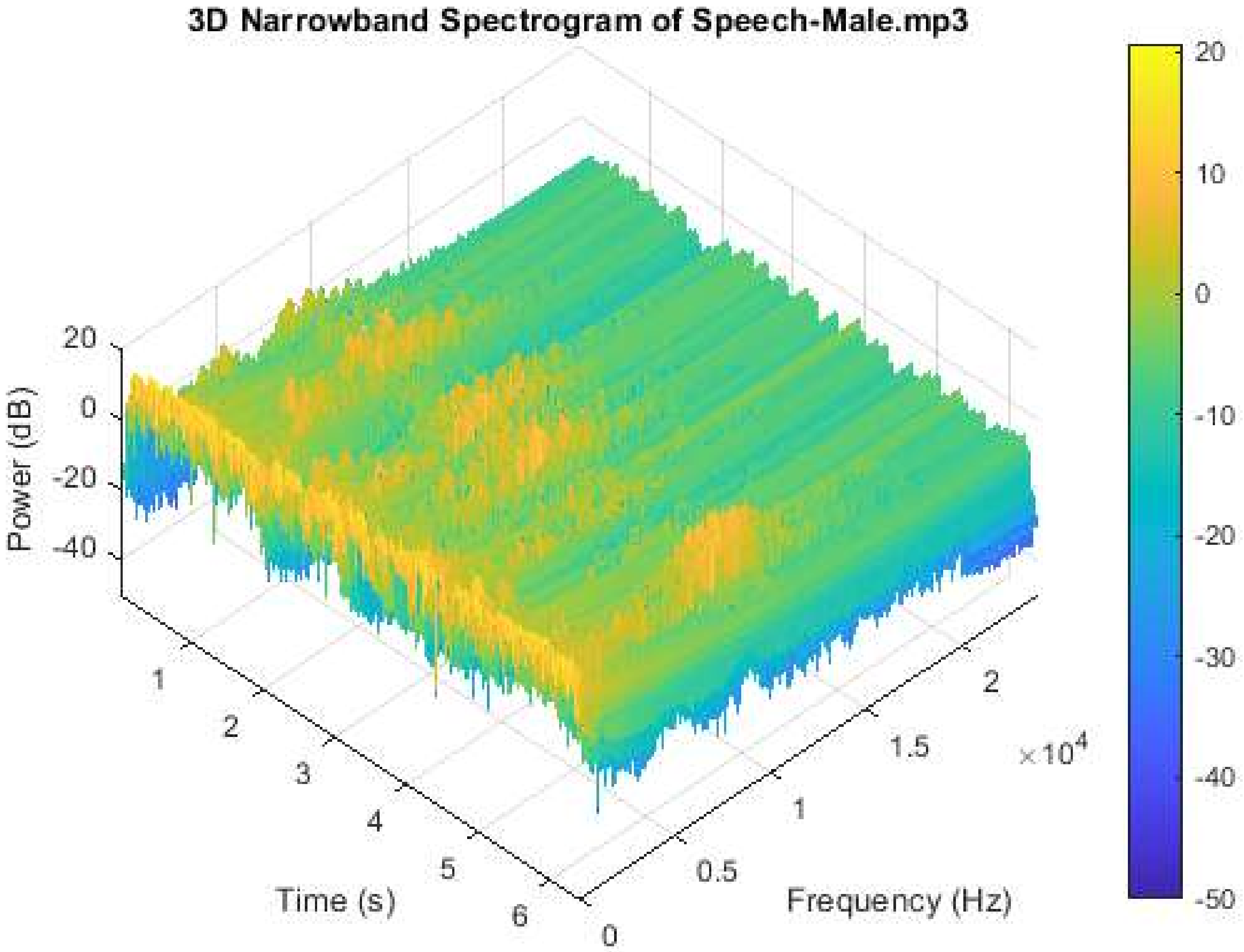

3D Spectrogram of eeg.set
Power (dB)
0
-50
-100
-150
0
50
100
150
Time (s)
0
100
200
300
400
Frequency (Hz)
0
-50
-100
-150


3D Narrowband Spectrogram of Gravitational-Wave.hdf5
Power (dB)
-160
-180
-200
-220
-240
Time (s)
0
1000
2000
3000
4000
Frequency (Hz)
0
500
1000
1500
2000
-160
-170
-180
-190
-200
-210
-220
-230
-240

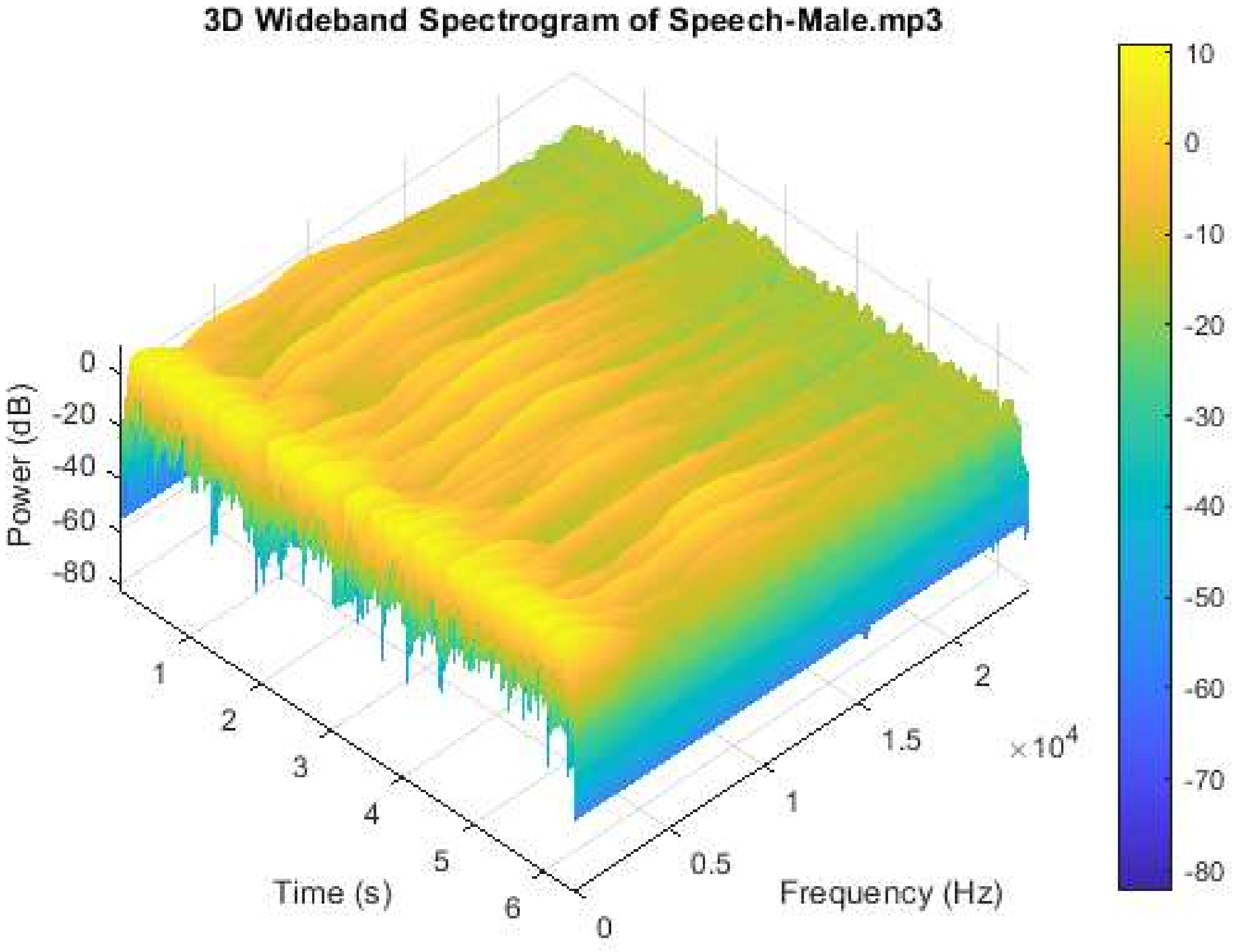

3D Wideband Spectrogram of Gravitational-Wave.hdf5
Power (dB)
-180
-200
-220
-240
-260
-280
Time (s)
0
1000
2000
3000
4000
Frequency (Hz)
0
500
1000
1500
2000
-180
-200
-220
-240
-260
-280

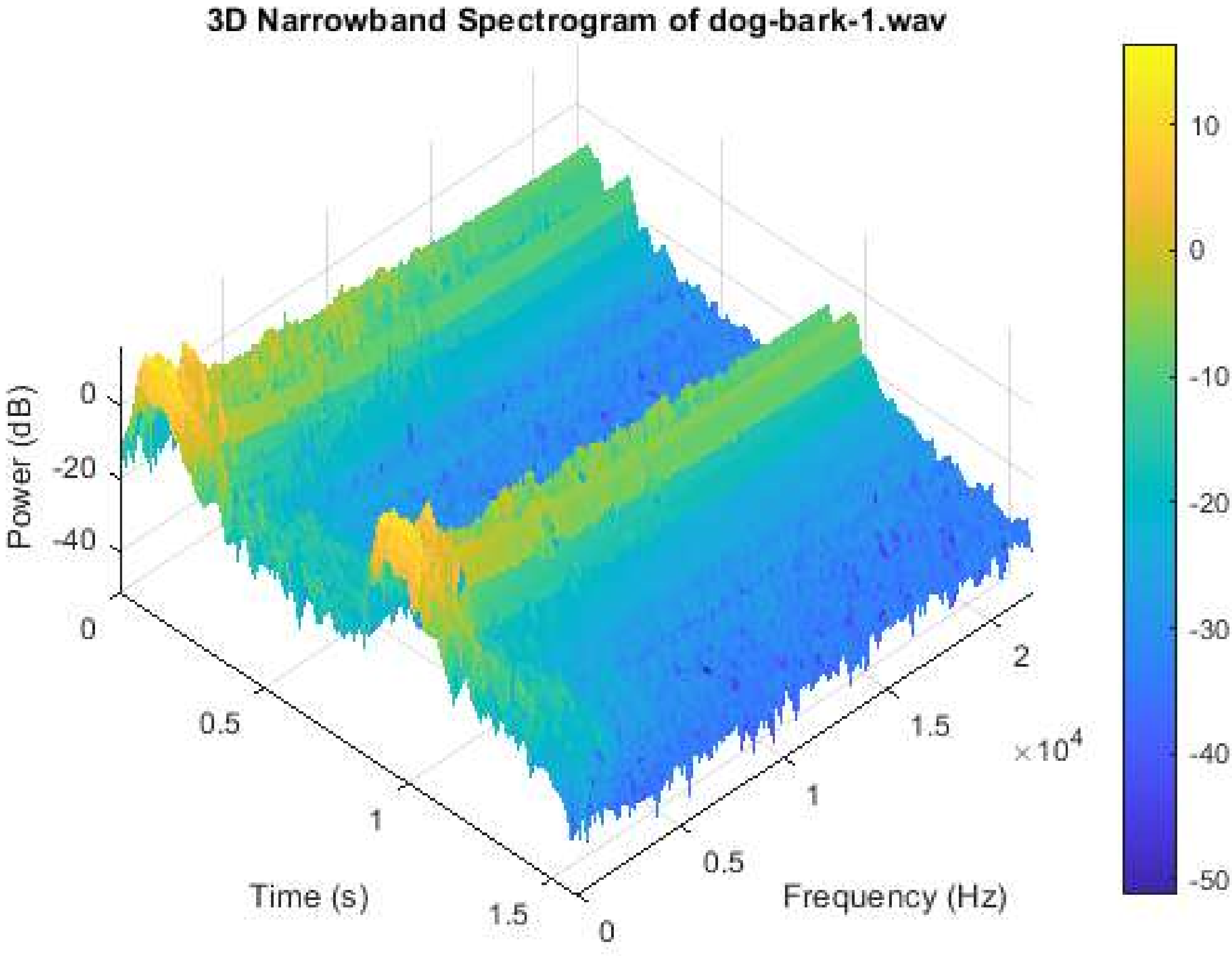

3D Narrowband Spectrogram of Speech-Female.wav
Power (dB)
0
-20
-40
Time (s)
0
0.5
1
1.5
2
2.5
3
Frequency (Hz)
0
2000
4000
6000
8000
10
0
-10
-20
-30
-40


3D Wideband Spectrogram of Speech-Female.wav
Power (dB)
0
-20
-40
-60
Time (s)
0
0.5
1
1.5
2
2.5
3
Frequency (Hz)
0
2000
4000
6000
8000
0
-10
-20
-30
-40
-50
-60
-70

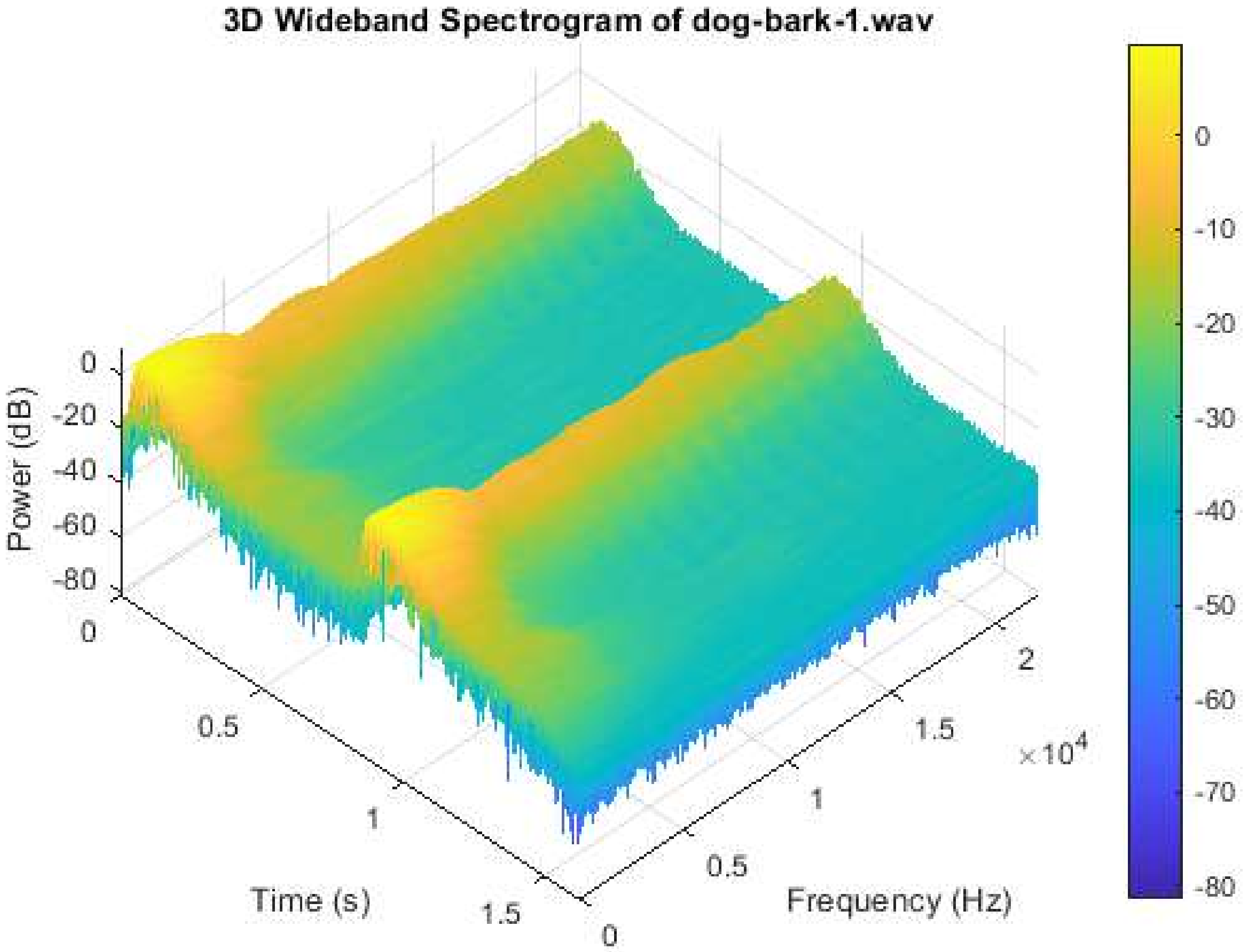


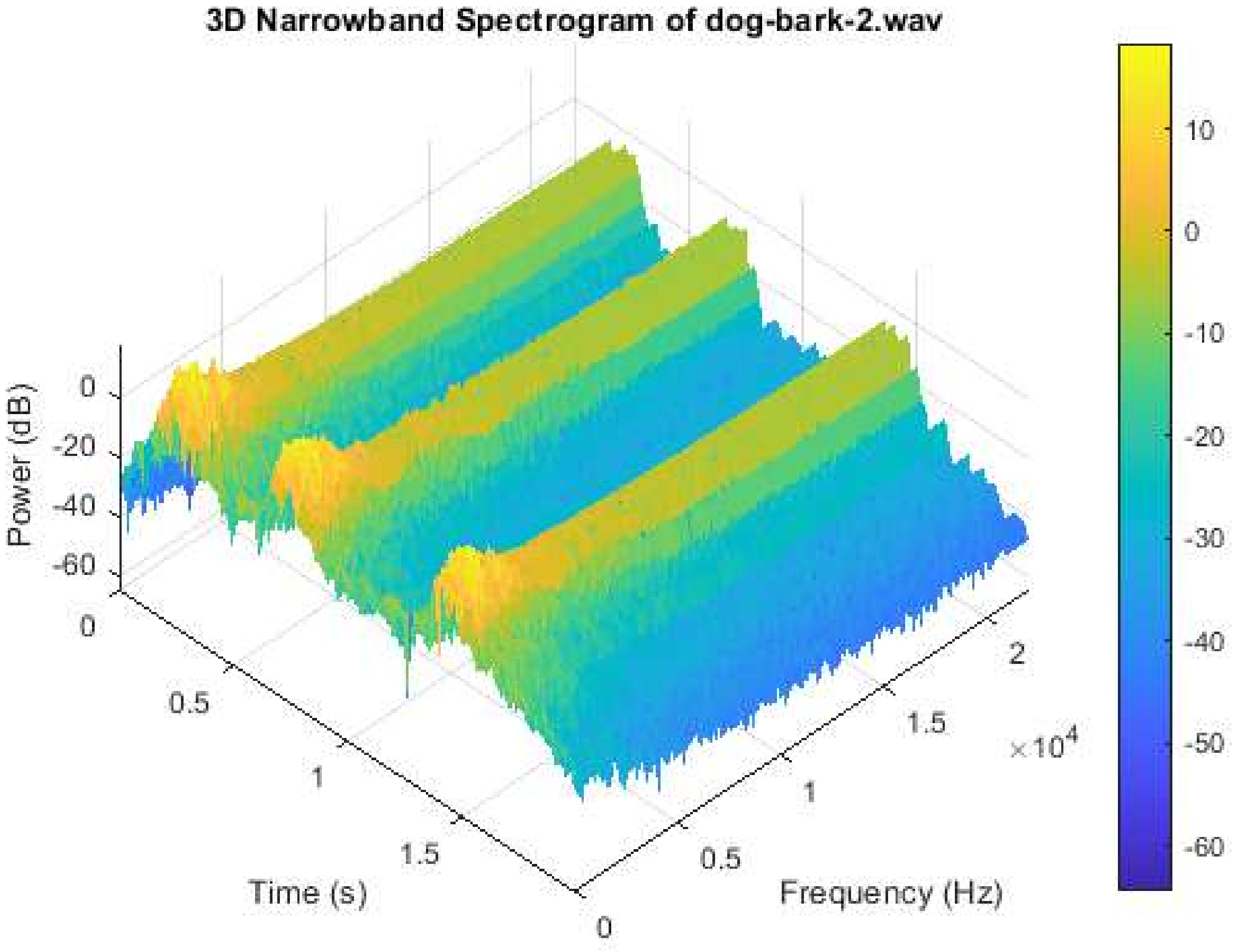
3D Narrowband Spectrogram of Speech-Male.mp3
Power (dB)
20
0
-20
-40
Time (s)
1
2
3
4
5
6
Frequency (Hz)
0
0.5
1
1.5
2
×10^4
20
10
0
-10
-20
-30
-40
-50


3D Wideband Spectrogram of Speech-Male.mp3
Power (dB)
0
-20
-40
-60
-80
Time (s)
1
2
3
4
5
6
Frequency (Hz)
0
0.5
1
1.5
2
×10^4
10
0
-10
-20
-30
-40
-50
-60
-70
-80

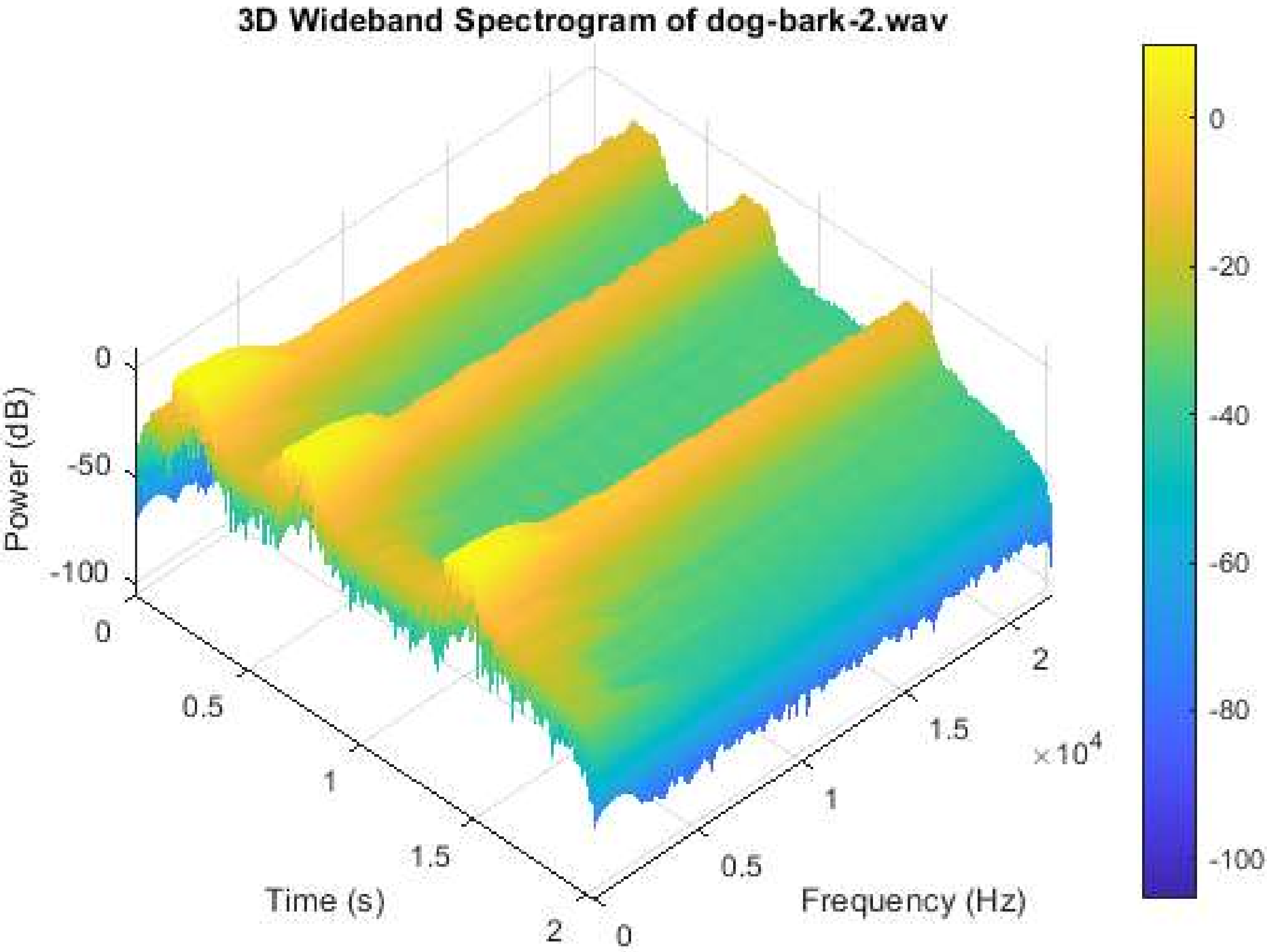


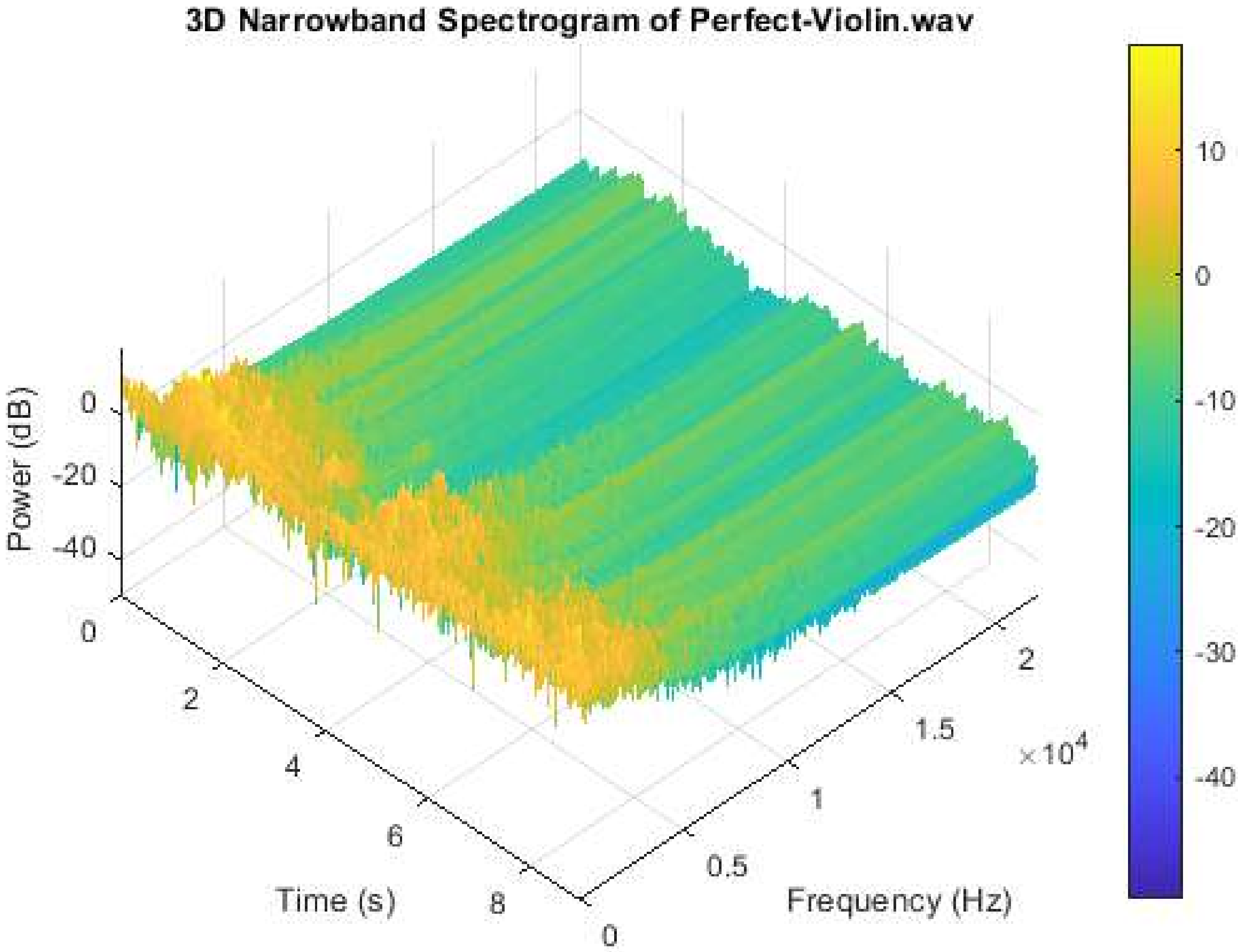
3D Narrowband Spectrogram of dog-bark-1.wav
Power (dB)
0
-20
-40
Time (s)
0
0.5
1
1.5
Frequency (Hz)
0
0.5
1
1.5
2
×10^4
10
0
-10
-20
-30
-40
-50


3D Wideband Spectrogram of dog-bark-1.wav
Power (dB)
0
-20
-40
-60
-80
0
0.5
1
1.5
Time (s)
0
0.5
1
1.5
2
×10^4
Frequency (Hz)
0
-10
-20
-30
-40
-50
-60
-70
-80

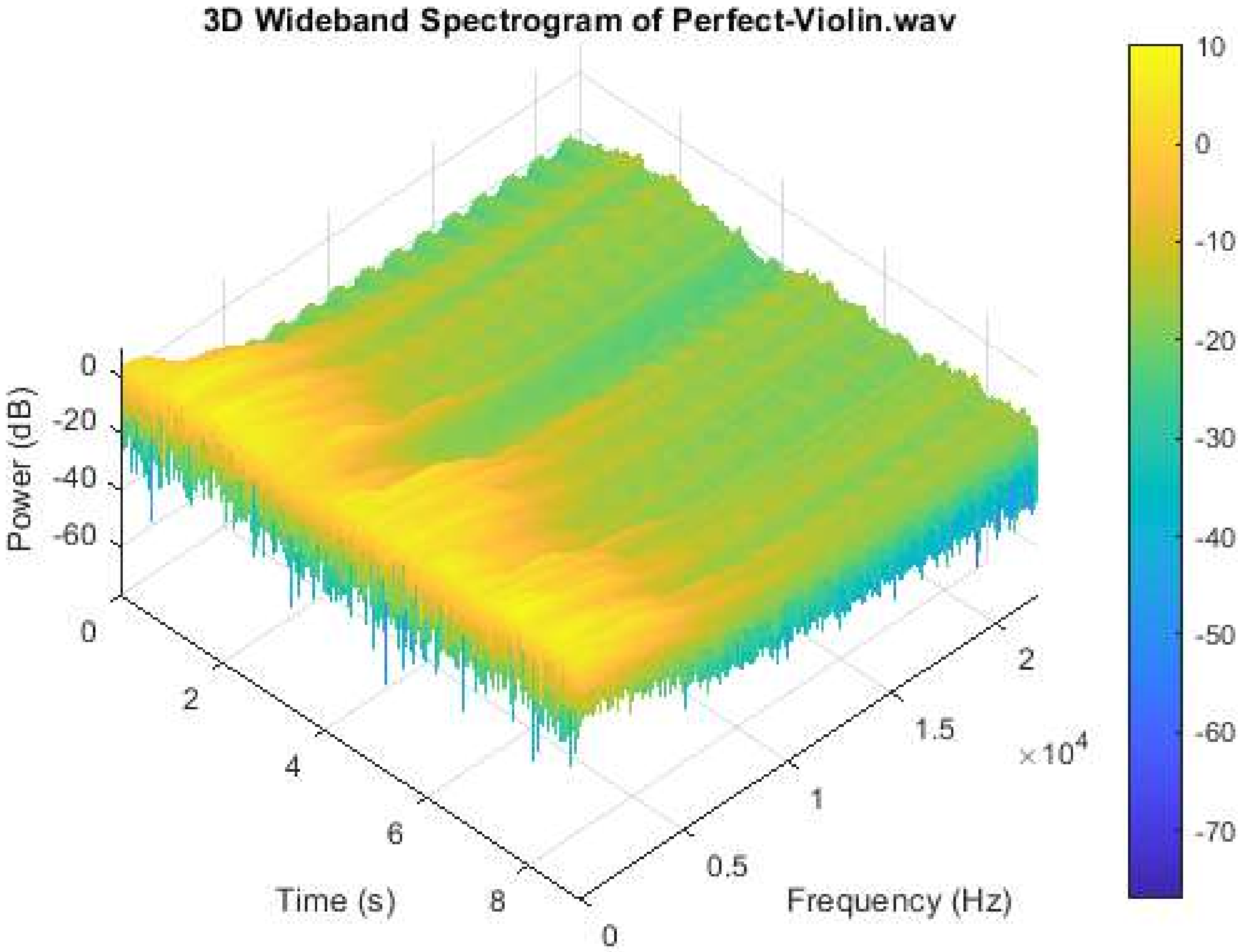


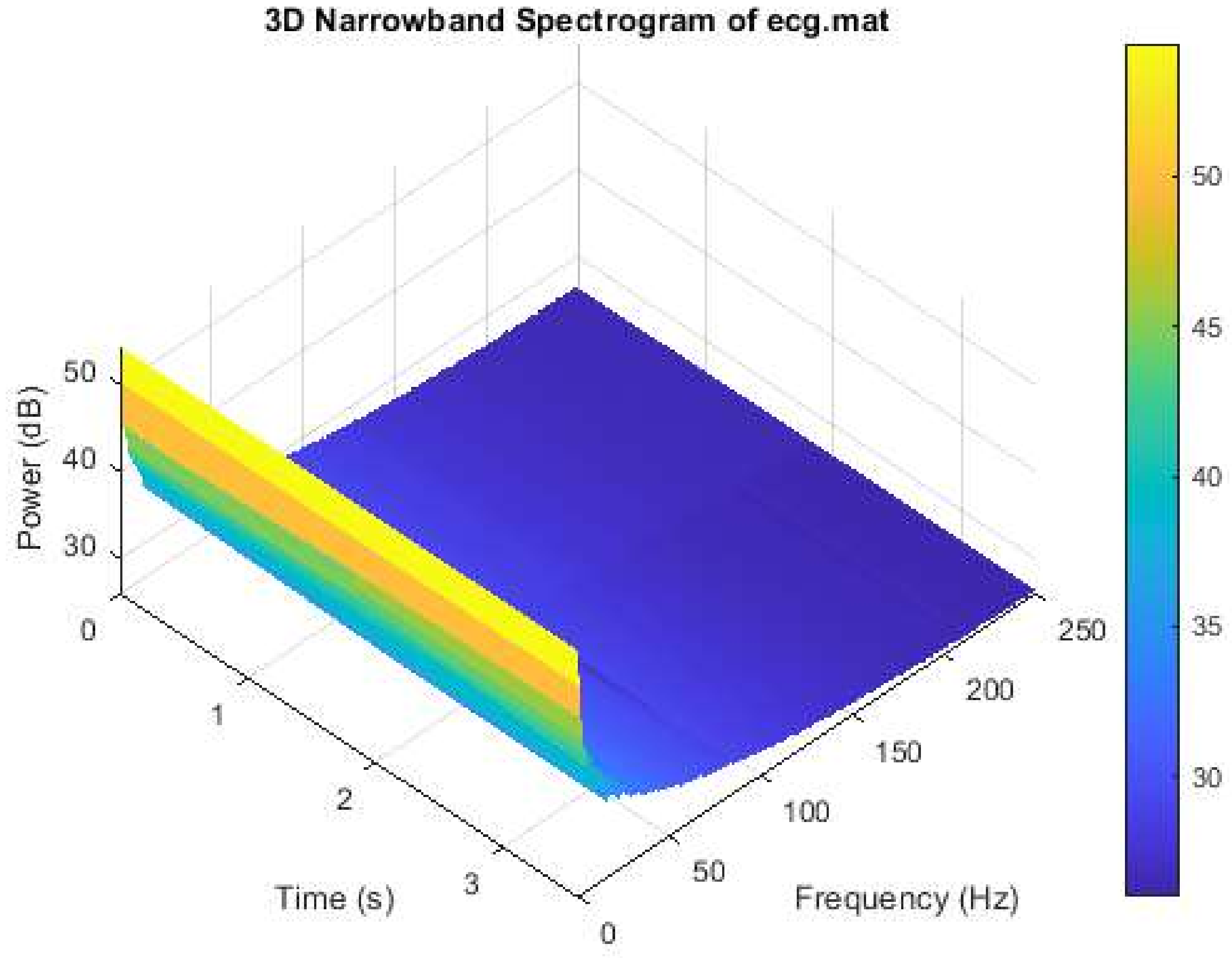
3D Narrowband Spectrogram of dog-bark-2.wav
Power (dB)
0
-20
-40
-60
0
0.5
1
1.5
Time (s)
0
0.5
1
1.5
2
×10^4
Frequency (Hz)
10
0
-10
-20
-30
-40
-50
-60

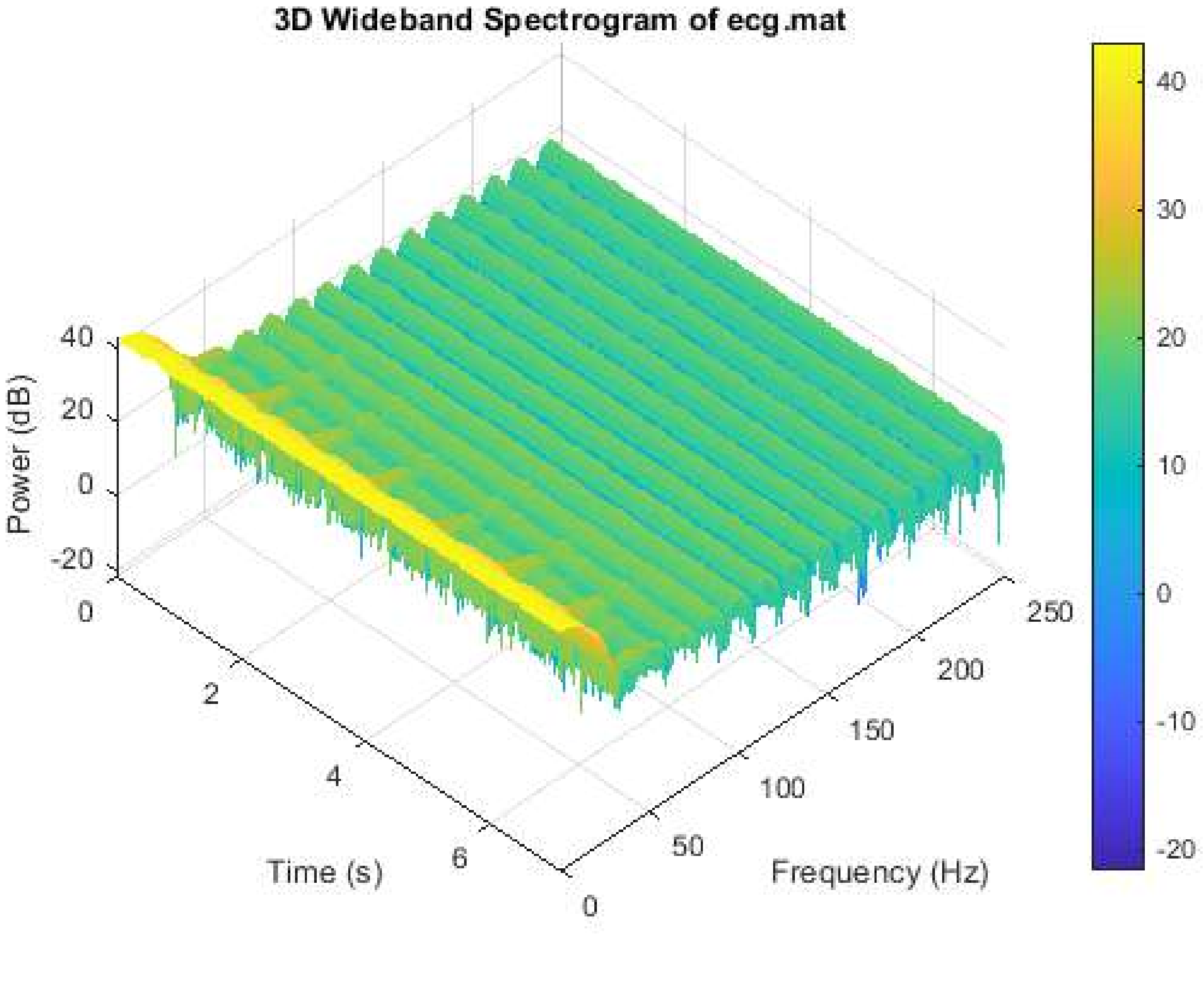

3D Wideband Spectrogram of dog-bark-2.wav
Power (dB)
0
-50
-100
Time (s)
0
0.5
1
1.5
2
Frequency (Hz)
0
0.5
1
1.5
2
×10^4
0
-20
-40
-60
-80
-100



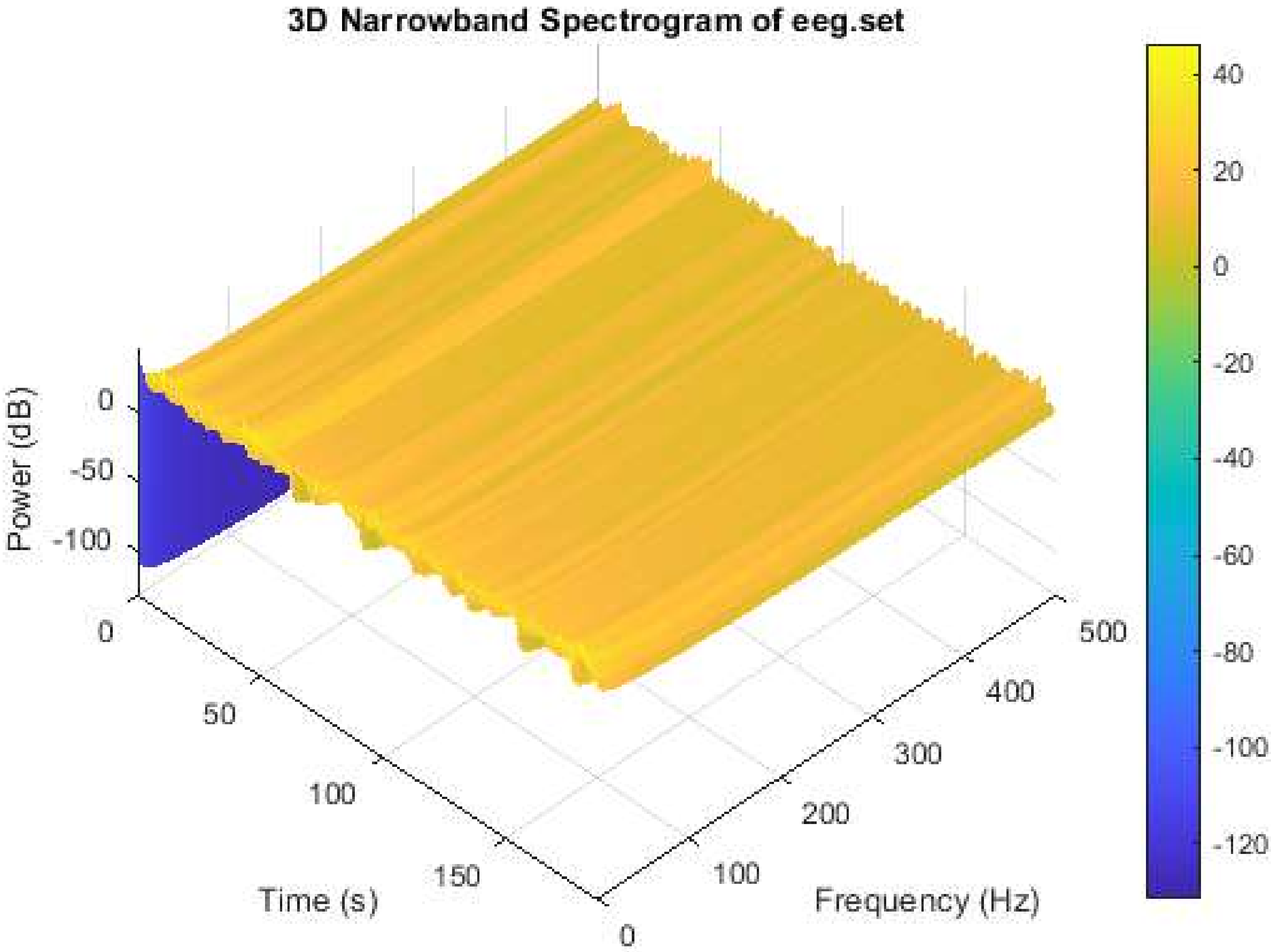
3D Narrowband Spectrogram of Perfect-Violin.wav
Power (dB)
0
-20
-40
Time (s)
0
2
4
6
8
Frequency (Hz)
0
0.5
1
1.5
2
$\times 10^4$
10
0
-10
-20
-30
-40

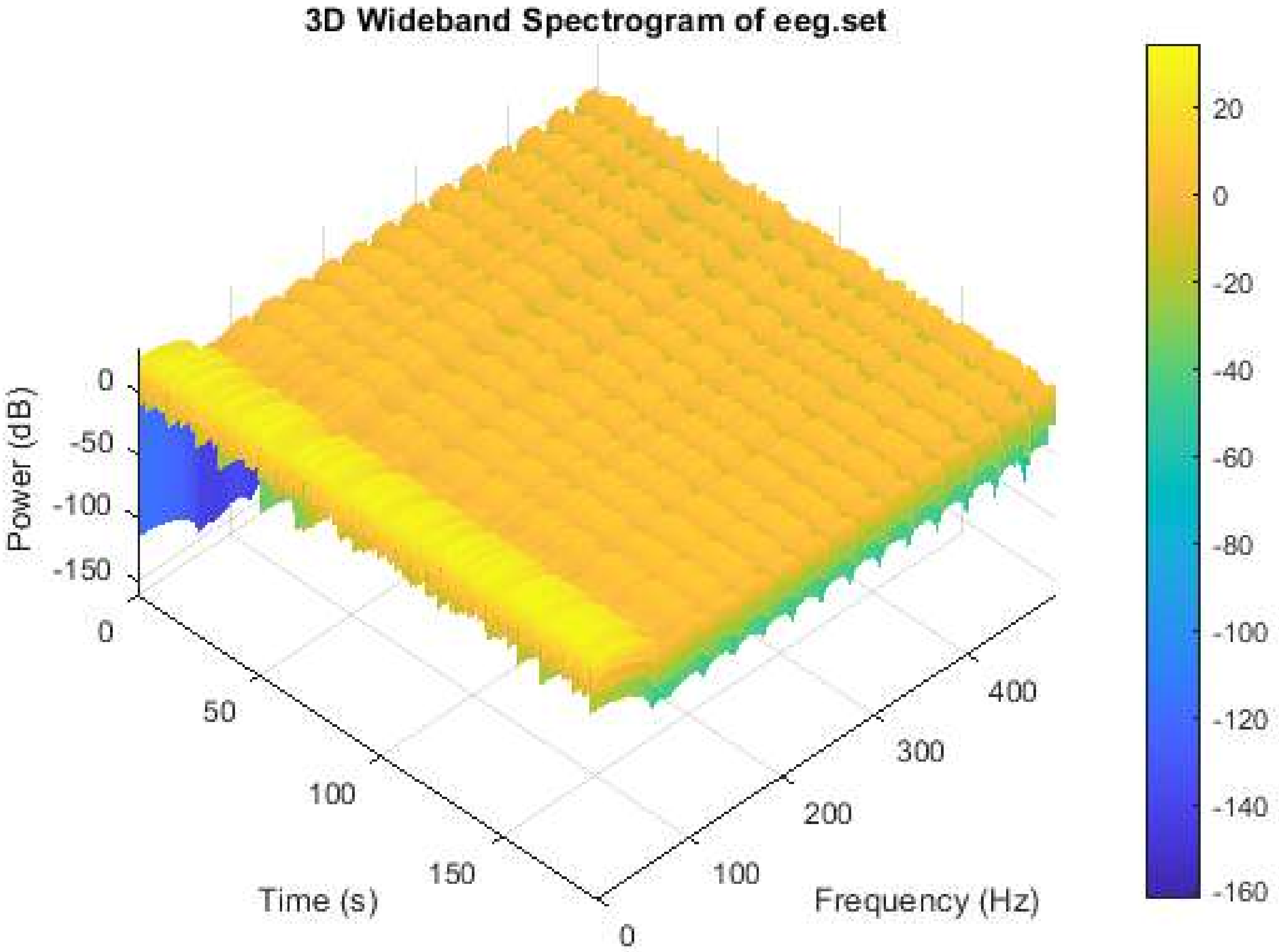

3D Wideband Spectrogram of Perfect-Violin.wav
Power (dB)
0
-20
-40
-60
Time (s)
0
2
4
6
8
Frequency (Hz)
0
0.5
1
1.5
2
×10^4
10
0
-10
-20
-30
-40
-50
-60
-70


3D Narrowband Spectrogram of ecg.mat
Power (dB)
50
40
30
0
1
2
3
Time (s)
0
50
100
150
200
250
Frequency (Hz)
50
45
40
35
30



3D Wideband Spectrogram of ecg.mat
Power (dB)
40
20
0
-20
0
2
4
6
Time (s)
0
50
100
150
200
250
Frequency (Hz)
40
30
20
10
0
-10
-20


3D Narrowband Spectrogram of eeg.set
Power (dB)
0
-50
-100
Time (s)
0
50
100
150
Frequency (Hz)
0
100
200
300
400
500
40
20
0
-20
-40
-60
-80
-100
-120


3D Wideband Spectrogram of eeg.set
Power (dB)
0
-50
-100
-150
0
50
100
150
Time (s)
0
100
200
300
400
Frequency (Hz)
20
0
-20
-40
-60
-80
-100
-120
-140
-160