Experiment No. 03

3.1 Experiment Name

3.1 s1 and s2 are two separate given signals. And s3=s1+s2, plot the Fast Fourier Transform (FFT) of s1, s2 and s3.

3.2 s4=s3+ random noise, write a python code to remove the random noise from s4 using FFT analysis.

3.3 denoise the signal s4 by designing a filter (Butter-worth filter) using python code

3.2 Objectives

- To get a better understanding of the Fast Fourier Transform (FFT) of the given signals
- To gain a deeper understanding of signal properties, relationships, and characteristics

3.3 Apparatus

- Jupyter Notebook

3.4 Python code & graph

3.4.1 s1 and s2 are two separate given signals. And s3=s1+s2, plot the Fast Fourier Transform (FFT) of s1, s2 and s3.

```
import numpy as np
import matplotlib.pyplot as plt

# Define the time axis
t = np.linspace(0, 1, 100)

# Define the frequency and amplitude of the sine signals
f1 = float(input("Enter frequency of s1: "))
A1 = float(input("Enter amplitude of s1: "))

f2 = float(input("Enter frequency of s2: "))
A2 = float(input("Enter amplitude of s2: "))

# Generate the sine signals
s1 = A1 * np.sin(2 * np.pi * f1 * t) + np.random.normal(size=len(t))
s2 = A2 * np.sin(2 * np.pi * f2 * t) #+ np.random.normal(size=len(t))
s3 = s1 + s2

# Compute the FFT of the signals
fft_s1 = np.fft.fft(s1)
fft_s2 = np.fft.fft(s2)
fft_s3 = np.fft.fft(s3)

# Compute the corresponding frequencies for the FFT bins
freqs = np.fft.fftfreq(len(t), t[1] - t[0])

# Plot the FFT results
plt.figure(figsize=(10, 10))
```

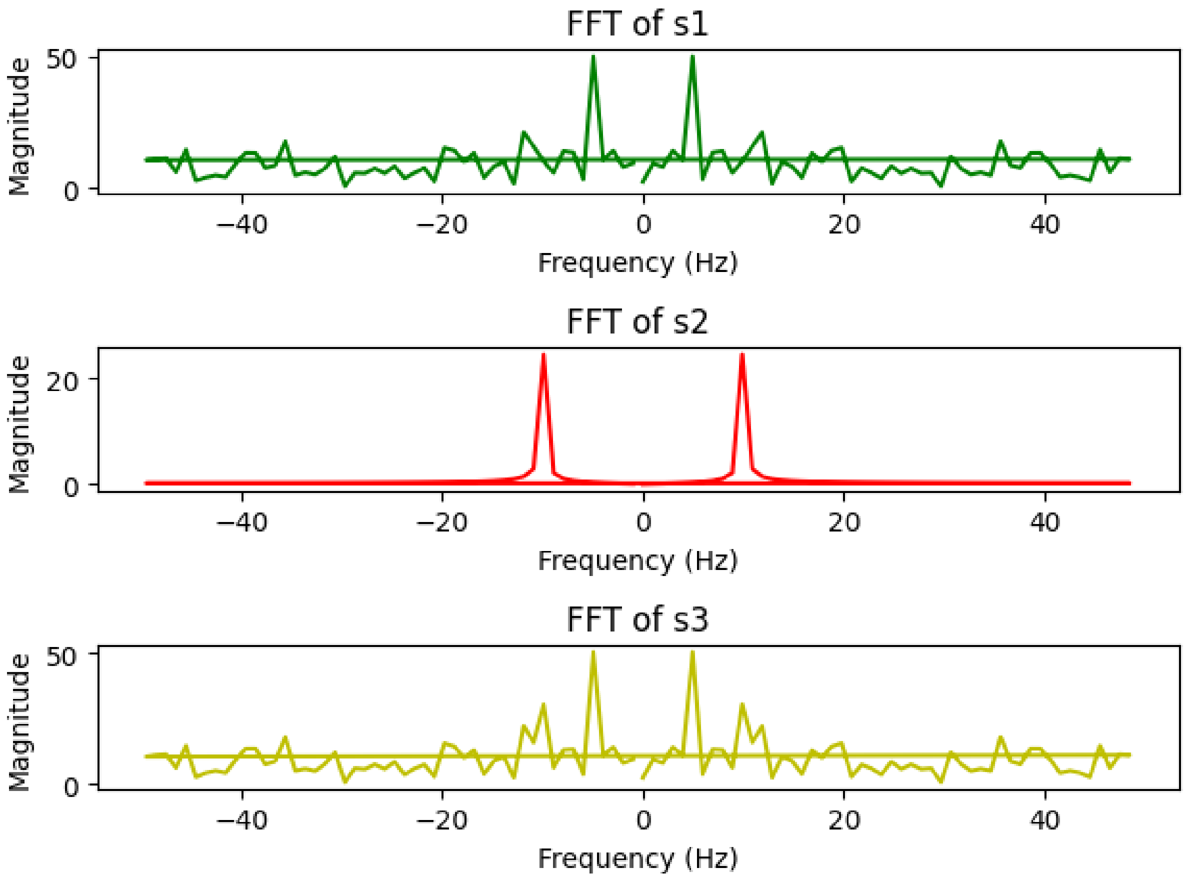
```
# Plot FFT of s1
plt.subplot(311)
plt.plot(freqs, np.abs(fft_s1),'g')
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s1')

# Plot FFT of s2
plt.subplot(312)
plt.plot(freqs, np.abs(fft_s2),'r')
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s2')

# Plot FFT of s3
plt.subplot(313)
plt.plot(freqs, np.abs(fft_s3),'y')
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s3')

plt.tight_layout()
plt.show()
```

```
Enter frequency of s1: 5
Enter amplitude of s1: 1
Enter frequency of s2: 10
Enter amplitude of s2: 0.5
```



3.4.2 s4=s3+ random noise, write a python code to remove the random noise from s4 using FFT analysis.

```python
import numpy as np
import matplotlib.pyplot as plt

# Define the time axis
t = np.linspace(0, 1, 1000)
# Define the frequency and amplitude of the signals
f1 = 5
f2 = 10
A1 = 1
A2 = 1
# Generate the signals
s1 = A1 * np.sin(2 * np.pi * f1 * t)
s2 = A2 * np.sin(2 * np.pi * f2 * t)
s3 = s1 + s2

# Compute the FFT of the signals
fft_s1 = np.fft.fft(s1)
fft_s2 = np.fft.fft(s2)
fft_s3 = np.fft.fft(s3)

# Add random noise to s3
np.random.seed(0)  # Set a seed for reproducibility
noise = np.random.normal(0, 0.2, len(t))
s4 = s3 + noise
# Compute the FFT of s4
fft_s4 = np.fft.fft(s4)
# Set a threshold for noise removal
threshold = 0.1 * np.max(np.abs(fft_s4))
# Filter the FFT coefficients below the threshold
filtered_fft_s4 = fft_s4.copy()
filtered_fft_s4[np.abs(fft_s4) < threshold] = 0
# Reconstruct the filtered signal
filtered_s4 = np.fft.ifft(filtered_fft_s4).real
```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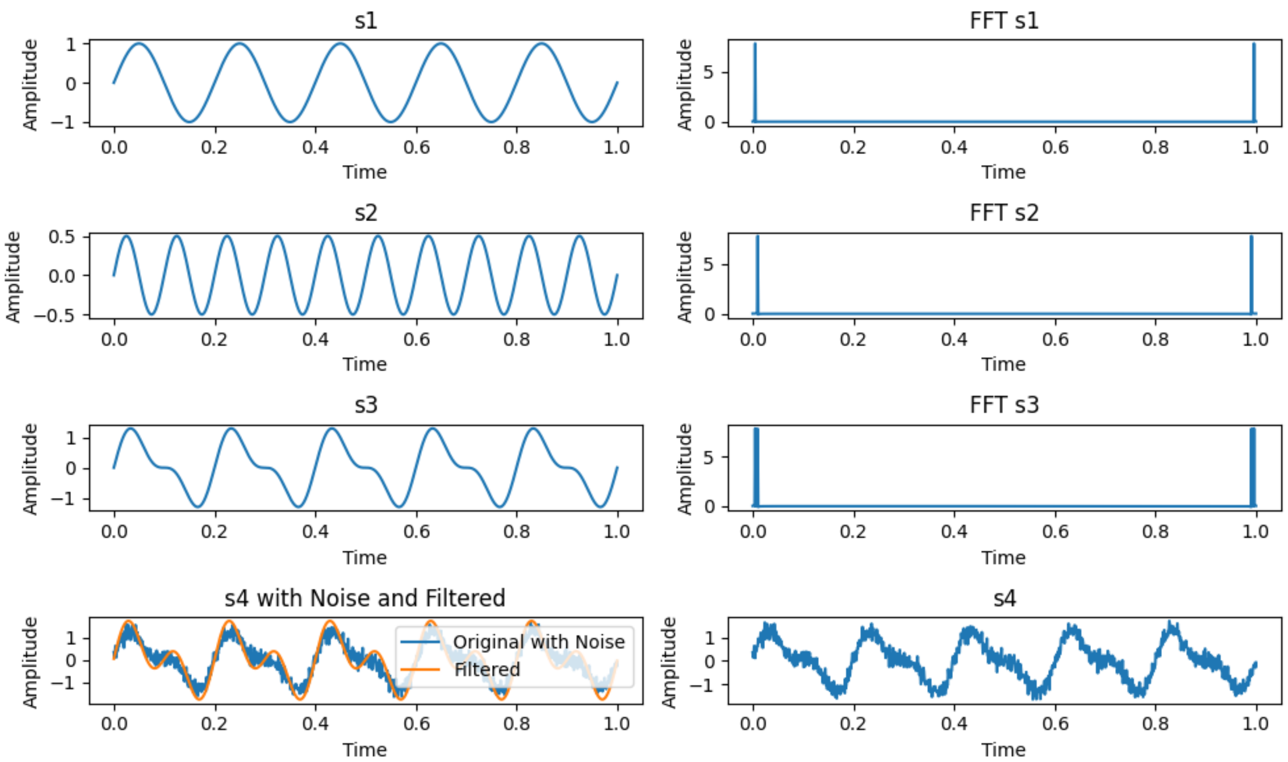
```python
# Plot the original and filtered signals
plt.figure(figsize=(10, 6))
plt.subplot(421)
plt.plot(t, s1)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s1')
plt.subplot(422)
plt.plot(t, fft_s1)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('FFT s1')
plt.subplot(423)
plt.plot(t, s2)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s2')
plt.subplot(424)
plt.plot(t, fft_s2)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('FFT s2')
plt.subplot(425)
plt.plot(t, s3)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s3')
plt.subplot(426)
plt.plot(t, fft_s3)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('FFT s3')
plt.subplot(428)
plt.plot(t, s4)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s4')
plt.subplot(427)
plt.plot(t, s4, label='Original with Noise')
plt.plot(t, filtered_s4, label='Filtered')
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s4 with Noise and Filtered')
plt.legend()

plt.tight_layout()
plt.show()
```



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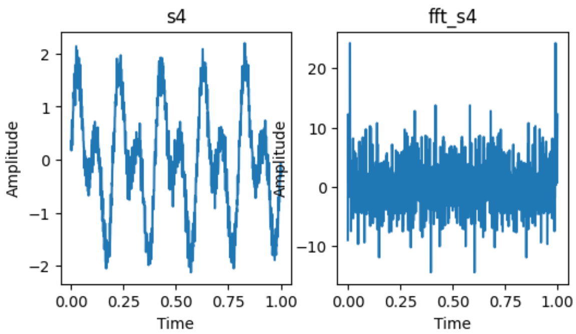
3.4.3 denoise the signal s4 by designing a filter (Butter-worth filter) using python code

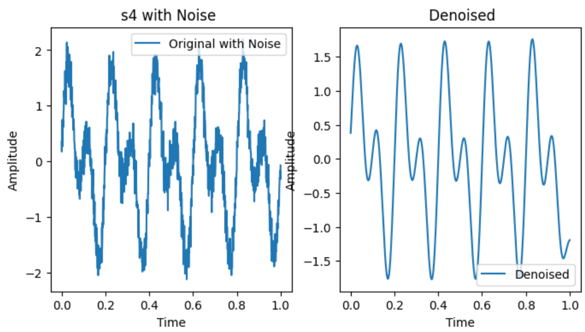
- **Butterworth filter**

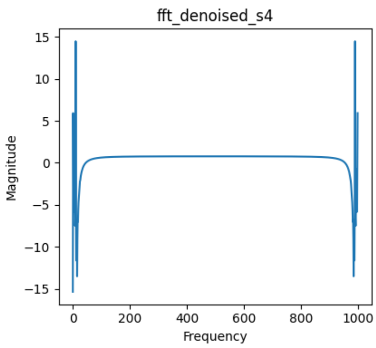
```
import numpy as np
import matplotlib.pyplot as plt
from scipy import signal

# Define the time axis
t = np.linspace(0, 1, 1000)

# Define the frequency and amplitude of the signals
f1 = 5
f2 = 10
A1 = 1
A2 = 1

# Generate the signals
s1 = A1 * np.sin(2 * np.pi * f1 * t)
s2 = A2 * np.sin(2 * np.pi * f2 * t)
s3 = s1 + s2

# Compute the FFT of the signals
fft_s1 = np.fft.fft(s1)
fft_s2 = np.fft.fft(s2)
fft_s3 = np.fft.fft(s3)

# Add random noise to s3
np.random.seed(0)  # Set a seed for reproducibility
noise = np.random.normal(0, 0.2, len(t))
fft_noise = np.fft.fft(noise)
s4 = s3 + noise

# Compute the FFT of s4
fft_s4 = np.fft.fft(s4)

# Set a threshold for noise removal
threshold = 0.1 * np.max(np.abs(fft_s4))
```

```
# Filter the FFT coefficients below the threshold
filtered_fft_s4 = fft_s4.copy()
filtered_fft_s4[np.abs(fft_s4) < threshold] = 0

# Reconstruct the filtered signal
filtered_s4 = np.fft.ifft(filtered_fft_s4).real

# Plot the original and filtered signals
plt.figure(figsize=(6, 3))
plt.subplot(121)
plt.plot(t, s4)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s4')
plt.subplot(122)
plt.plot(t, fft_s4)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('fft_s4')

# Plot the original and filtered signals
plt.figure(figsize=(6, 3))
plt.subplot(121)
plt.plot(t, noise)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('noise')
plt.subplot(122)
plt.plot(t, fft_noise)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('fft_noise')

# Define the Butterworth filter parameters
order = 4 # Filter order
cutoff_freq = 15 # Cutoff frequency in Hz

# Normalize the cutoff frequency
nyquist_freq = 0.5 * 1000 # Nyquist frequency (half of the sampling frequency)
normalized_cutoff_freq = cutoff_freq / nyquist_freq

# Design the Butterworth filter
b, a = signal.butter(order, normalized_cutoff_freq, btype='low', analog=False, output='ba')
```

```python
# Apply the filter to the noisy signal
denoised_s4 = signal.filtfilt(b, a, s4)
fft_denoised_s4 = np.fft.fft(denoised_s4)

plt.figure(figsize=(8, 4))
plt.subplot(121)
plt.plot(t, s4, label='Original with Noise')
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s4 with Noise ')
plt.legend()

plt.subplot(122)
plt.plot(t, denoised_s4, label='Denoised')
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title(' Denoised')
plt.legend()

plt.figure(figsize=(8, 4))
plt.subplot(121)
plt.plot(fft_denoised_s4)
plt.xlabel('Frequency')
plt.ylabel('Magnitude')
plt.title('fft_denoised_s4')

plt.tight_layout()
plt.show()
```







- **Chebyshev II filter**

```python
import numpy as np
import matplotlib.pyplot as plt
from scipy import signal

# Define the signals
t = np.linspace(0, 1, 1000)
s1 = np.sin(2 * np.pi * 10 * t)  # Signal 1
s2 = np.sin(2 * np.pi * 20 * t)  # Signal 2
s3 = s1 + s2  # Combined signal
noise = np.random.normal(0, 0.5, len(t))  # Random noise
s4 = s3 + noise  # Signal with noise

# Compute the FFT of the signals
fft_s1 = np.fft.fft(s1)
fft_s2 = np.fft.fft(s2)
fft_s3 = np.fft.fft(s3)
fft_s4 = np.fft.fft(s4)
```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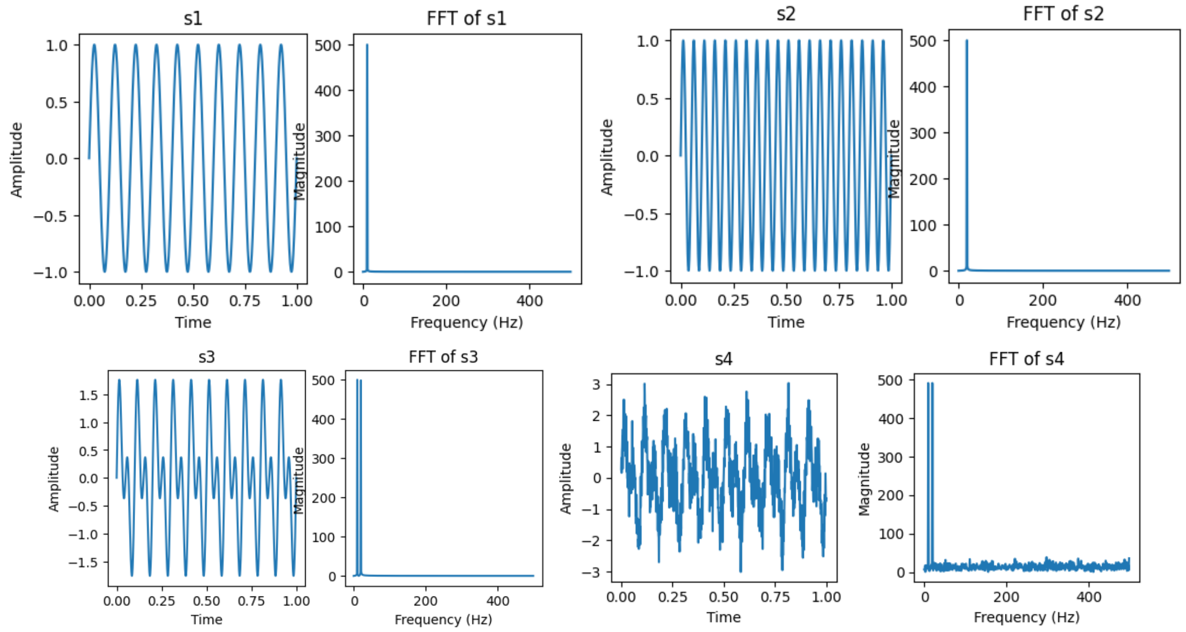
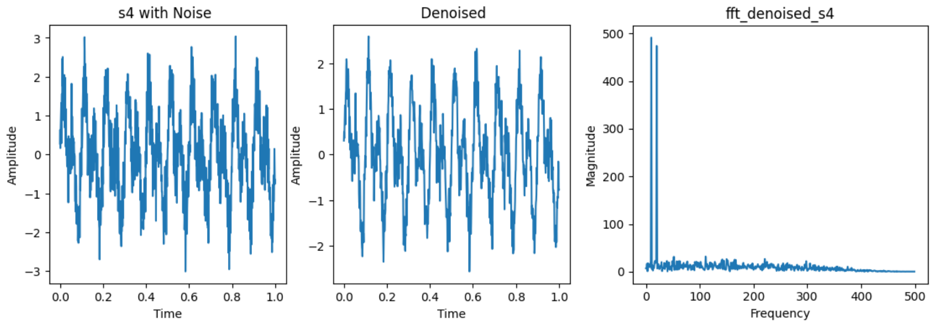
```python
positive_freqs = np.fft.fftfreq(len(t), t[1] - t[0])[:len(t)//2]

fft_s1_positive = fft_s1[:len(t)//2]
fft_s2_positive = fft_s2[:len(t)//2]
fft_s3_positive = fft_s3[:len(t)//2]
fft_s4_positive = fft_s4[:len(t)//2]

# Plot the time domain signals
plt.figure(figsize=(6, 3))

# Plot s1
plt.subplot(121)
plt.plot(t, s1)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s1')

# Plot FFT of s1
plt.subplot(122)
plt.plot(positive_freqs, np.abs(fft_s1_positive))
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s1')

# Plot the time domain signals
plt.figure(figsize=(6, 3))

# Plot s2
plt.subplot(121)
plt.plot(t, s2)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s2')

# Plot FFT of s2
plt.subplot(122)
plt.plot(positive_freqs, np.abs(fft_s2_positive))
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s2')

# Plot the time domain signals
plt.figure(figsize=(6, 3))
# Plot s3
plt.subplot(121)
plt.plot(t, s3)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s3')

# Plot FFT of s3
plt.subplot(122)
plt.plot(positive_freqs, np.abs(fft_s3_positive))
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s3')

# Plot the time domain signals
plt.figure(figsize=(6, 3))

# Plot s3
plt.subplot(121)
plt.plot(t, s4)
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s4')

# Plot FFT of s3
plt.subplot(122)
plt.plot(positive_freqs, np.abs(fft_s4_positive))
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.title('FFT of s4')

plt.tight_layout()
plt.show()
# Denoise the signal using a Chebyshev Type II filter
order = 5  # Filter order
ripple = 0.1  # Maximum ripple allowed in the stopband (in dB)
cutoff_freq = 15  # Cutoff frequency for the filter

# Design the filter
b, a = signal.cheby2(order, ripple, cutoff_freq, fs=1 / (t[1] - t[0]), output='ba')
```

```python
# Apply the filter to remove noise from s4
denoised_s4 = signal.filtfilt(b, a, s4)
fft_denoised_s4 = np.fft.fft(denoised_s4)
denoised_s4_positive=fft_denoised_s4[:len(t)//2]
plt.figure(figsize=(8, 4))

plt.subplot(121)
plt.plot(t, s4, label='Original with Noise')

plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title('s4 with Noise ')


plt.subplot(122)

plt.plot(t, denoised_s4, label='Denoised')
plt.xlabel('Time')
plt.ylabel('Amplitude')
plt.title(' Denoised')


plt.figure(figsize=(8, 4))
plt.subplot(121)
plt.plot(np.abs(denoised_s4_positive))
plt.xlabel('Frequency')
plt.ylabel('Magnitude')
plt.title('fft_denoised_s4')


plt.tight_layout()
plt.show()
```





3.5 Discussion & Conclusion

In this experiment, we used the python to analyze the Fast Fourier Transform (FFT) of the given signals. We may better grasp the behavior and properties of signals and make wise decisions in signal processing applications by studying the FFT signal.