Advanced Digital Signal Processing (ADSP) Lab - Python Lab Manual

> **Course Code:** EEE G613
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Experiment No. - 3

1. Generate the following discrete time signals x1(n) = cos(2*pi*1*n) and x2(n) = cos(2*pi*12*n). Assume a sampling frequency 100 Hz for both the signals. Consider the time t/n = 0 to 5 sec. Add these two signals i.e. x3(n) =x1(n)+x2(2). Perform filtering operation on x3(n) signal using an FIR filter; consider 20 filter coefficients i.e. b0 =1, b1=1…..b19 =1. Write your own MATLAB code/program using the built-in 'filter' MATLAB command/function.

   Hint: read section *3.6.3 Moving Average Processes* of Monson H. Hayes

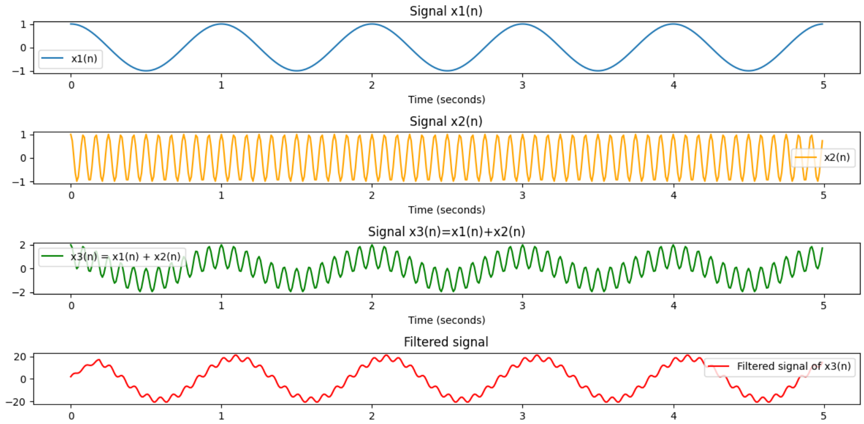
Python Code:

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

```
# Function to generate discrete time signal
def generate_signal(frequency, sampling_rate, duration):
  t = np.arange(0, duration, 1/sampling_rate)
  signal = np.cos(2 * np.pi * frequency * t)
  return t, signal
# Generate signals x1(n) and x2(n)
fs = 100 # Sampling frequency (Hz)
duration = 5 # Duration of the signal (seconds)
t1, x1 = generate_signal(1, fs, duration)
t2, x2 = generate_signal(12, fs, duration)
# Add the signals to create x3(n)
x3 = x1 + x2
# FIR filter coefficients
filter_coefficients = np.ones(20)
# Filter the signal x3(n)
filtered_signal = lfilter(filter_coefficients,1,x3)
```

```
# Plotting the original signals and the filtered signal
plt.figure(figsize=(12, 6))
plt.subplot(4, 1, 1)
plt.plot(t1, x1, label='x1(n)')
plt.title('Signal x1(n)')
plt.xlabel('Time (seconds)')
plt.legend()
plt.subplot(4, 1, 2)
plt.plot(t2, x2, label='x2(n)', color='orange')
plt.title('Signal x2(n)')
plt.xlabel('Time (seconds)')
plt.legend()
plt.subplot(4, 1, 3)
plt.plot(t1, x3, label='x3(n) = x1(n) + x2(n)', color='green')
plt.title('Signal x3(n)=x1(n)+x2(n)')
plt.xlabel('Time (seconds)')
plt.legend()
plt.subplot(4, 1, 4)
```

```
plt.plot(t1, filtered_signal, label='Filtered signal of x3(n)', color='red')
plt.title('Filtered signal')
plt.legend()
plt.tight_layout()
plt.show()
```



2. a) Generate a random sinusoidal signal x(k) of 100 samples. Calculate and plot the sample autocorrelation function $r_x(k)$ for lag < 100.

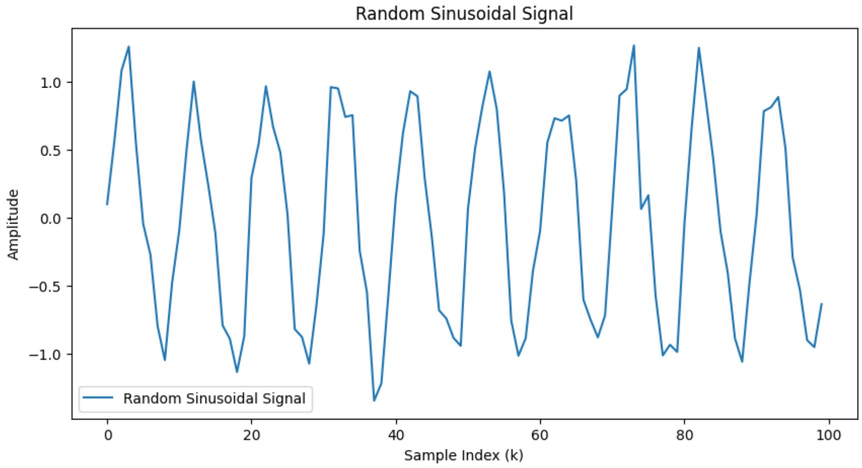
   b) Calculate and plot its power spectral density (PSD). Plot the magnitude of the PSD

   Hint: Use the Matlab function fft. Do not use inbuilt function psd

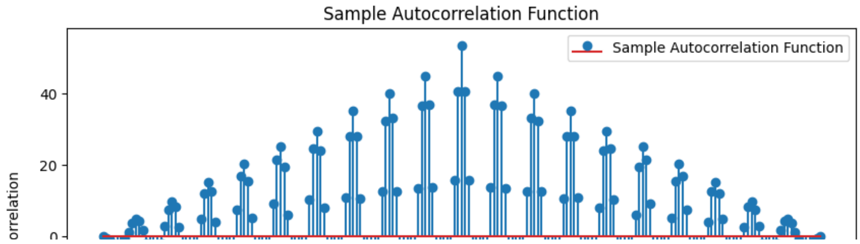
Python Code:

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

```
# Generate a random sinusoidal signal
np.random.seed(42) # Setting seed for reproducibility
k = np.arange(100)
x = np.sin(2 * np.pi * 0.1 * k) + 0.2 * np.random.randn(100)
# Plot the signal
plt.figure(figsize=(10, 5))
plt.plot(k, x, label='Random Sinusoidal Signal')
plt.title('Random Sinusoidal Signal')
plt.xlabel('Sample Index (k)')
plt.ylabel('Amplitude')
plt.legend()
plt.show()
# Calculate the sample autocorrelation function
rx = np.correlate(x, x, mode='full')
```




```
# Plot the autocorrelation function
lags = np.arange(-99, 100)
plt.figure(figsize=(10, 5))
plt.stem(lags, rx[:199], label='Sample Autocorrelation Function')
plt.title('Sample Autocorrelation Function')
plt.xlabel('Lag (k)')
plt.ylabel('Autocorrelation')
plt.legend()
plt.show()
# Calculate the power spectral density (PSD)
frequencies = np.fft.fftshift(np.fft.fftfreq(100))
X = np.fft.fftshift(np.fft.fft(x))
PSD = np.abs(X) ** 2
# Plot the magnitude of the PSD
plt.figure(figsize=(10, 5))
plt.plot(frequencies, PSD, label='Power Spectral Density (PSD)')
plt.title('Power Spectral Density (PSD)')
plt.xlabel('Frequency (Hz)')
plt.ylabel('Magnitude')
plt.legend()
plt.show()
```



3. For the given linear shift-invariant system having a Transfer function H(z)

$$H(z)=\frac{1-\frac{1}{2}z^{-1}}{1-\frac{1}{3}z^{-1}}$$

which is excited by zero mean exponential signal x(n) whose autocorrelation sequence is given by $r_x = (\frac{1}{2})^{|k|}$. Let y(n) be the output process y(n)=x(n)*h(n).

a) Derive the expression for power spectrum Px(z) in your observation book. Write a program to plot its power spectrum Px(jω).

b) Derive the expression for the autocorrelation sequence $r_y(k)$ in your observation book. Write a program to plot the $r_y(k)$ for the given k in the range of -10 to 10.

c) Derive the expression for power spectrum Py(z) in your observation book. Write a program to plot its power spectrum Py(jω).

Hint: read Example 3.6.2 of Monson H. Hayes

- **Use convolution theorem and find power spectrum using $P_y(z) = H(z)H(z^{-1})P_x(z)$**
- **Use convolution theorem and use**

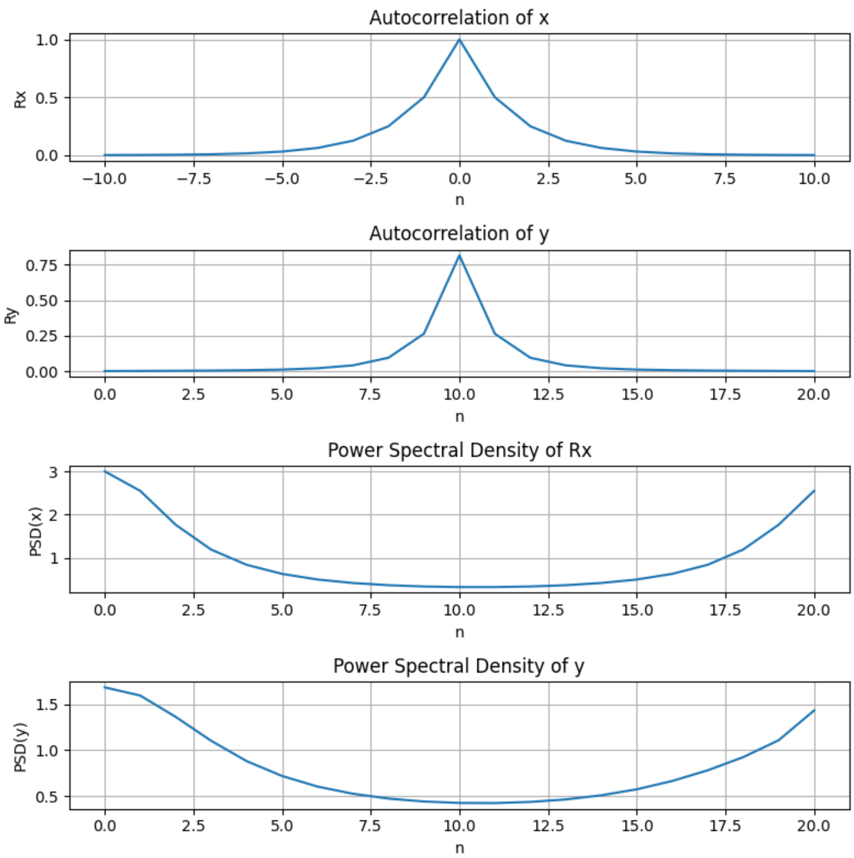
$$\alpha^{|k|} \longleftrightarrow \frac{1-\alpha^2}{(1-\alpha z^{-1})(1-\alpha z)}$$

Python Code:

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

```
# Constants
r = 1
w = np.arange(0, 2 * np.pi + np.pi / 10, np.pi / 10)
z = r * (np.exp(-1j * w))
H = (1 - 0.5 * (z ** -1)) / (1 - (1 / 3) * (z ** -1))
H_inv = (1 - 0.5 * z) / (1 - (1 / 3) * z)
k = np.arange(-10, 11)
Rx = 0.5 ** np.abs(k)
PSDx = np.fft.fft(Rx)
Py = PSDx * H * H_inv
Ry = np.abs(np.fft.ifft(Py))
```

```
# Plotting
plt.figure(figsize=(8, 8))
plt.subplot(4, 1, 1)
plt.plot(k, Rx)
plt.title('Autocorrelation of x')
plt.xlabel('n')
plt.ylabel('Rx')
plt.grid(True)
plt.subplot(4, 1, 2)
plt.plot(np.abs(Ry))
plt.title('Autocorrelation of y')
plt.xlabel('n')
plt.ylabel('Ry')
plt.grid(True)
plt.subplot(4, 1, 3)
plt.plot(np.abs(PSDx))
plt.title('Power Spectral Density of Rx')
plt.xlabel('n')
plt.ylabel('PSD(x)')
plt.grid(True)
plt.subplot(4, 1, 4)
plt.plot(np.abs(Py))
plt.title('Power Spectral Density of y')
plt.xlabel('n')
plt.ylabel('PSD(y)')
plt.grid(True)
plt.tight_layout()
plt.show()
```



4. Derive the autocorrelation sequence $r_x(k)$ corresponding to the given power spectral density function $P_x(e^{jw})$ given below

$$P_x(e^{jw}) = \frac{1}{5+3\cos(w)}$$

Write a program to plot the autocorrelation sequence $r_x(k)$ for the k = -3 to 3.

Hint: read section 3.6 special types of random processes of Monson H. Haye

- **Use $a^{|k|}$ for finding $r_x(k)$**

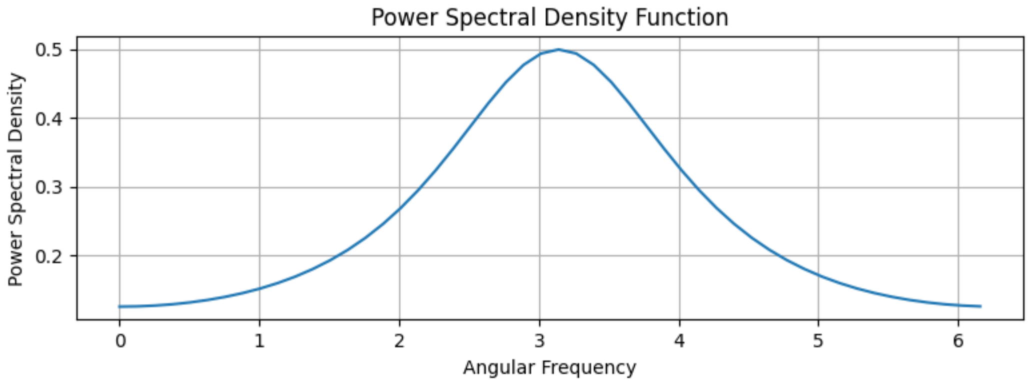
$$\alpha^{|k|} \longleftrightarrow \frac{1-\alpha^2}{(1-\alpha z^{-1})(1-\alpha z)}$$

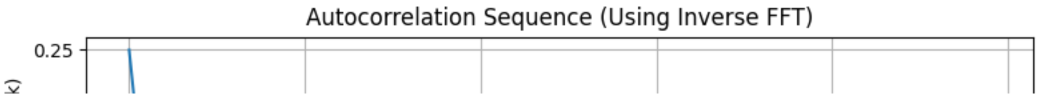
Python Code:

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

```
# Constants
fs = 50
k = np.arange(0, 1, 1/fs)
f = k * fs
w = 2 * np.pi * k
PSD = 1 / (5 + 3 * np.cos(w))
# Compute autocorrelation using inverse FFT
rx = np.abs(np.fft.ifft(PSD))
```

```
# Plotting
plt.figure(figsize=(8, 6))
plt.subplot(2, 1, 1)
plt.plot(w, PSD)
plt.xlabel('Angular Frequency')
plt.ylabel('Power Spectral Density')
plt.title('Power Spectral Density Function')
plt.grid(True)
plt.subplot(2, 1, 2)
plt.plot(k, rx)
plt.xlabel('k')
plt.ylabel('Autocorrelation r_x(k)')
plt.title('Autocorrelation Sequence (Using Inverse FFT)')
plt.grid(True)
plt.tight_layout()
plt.show()
```


Power Spectral Density Function
Power Spectral Density
Angular Frequency
0.5
0.4
0.3
0.2
0
1
2
3
4
5
6


Autocorrelation Sequence (Using Inverse FFT)
0.25