# Code for Programming Assignment - 1

January 28, 2020

EE2025 Independent Project Programming Assignment - 1

[1]:
```
# Setting the width of IPython Notebook

from IPython.display import HTML
display(HTML("<style>.container { width:100% !important; }</style>"))
```

```
<IPython.core.display.HTML object>
```

## 0.1 *Importing Libraries*

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
import scipy
from scipy import signal
from sklearn.metrics import mean_squared_error
```

## 0.2 *Functions*

Functions Coded for the given Task

Generates a Vector of Analog Signal Transmitted for the Bits Transmitted

[3]:
```
def Analog_Signal_Generator(a,b,i,samples,T,fc,fs,Sampling=False):
    # Generates s(t) for the given input of 2 bits with and without Sampling.
    if Sampling != True:
        # Without Sampling
        t = np.linspace((i-1)*T, i*T, samples,endpoint=False)
        c = np.cos(2*np.pi*fc*t)
        s = np.sin(2*np.pi*fc*t)
        output = a*c + b*s
    else:
        # With Sampling
        t = np.linspace((i-1)*T, i*T, int(T*fs),endpoint=False)
        """
        # to = np.arange((i-1)*T, i*T, 1/fs)
```

```
        np.arange has a "Stop Precision Issue so np.linspace is used."
        """
        c = np.cos(2*np.pi*fc*t)
        s = np.sin(2*np.pi*fc*t)
        output = a*c + b*s

    return output
```

Generates White Gaussian Noise

[4]:
```
def WGN(Variance,Nt,samples,T,fs,Sampling=False):
    # Generates White Gaussian Noise with and without Sampling

    if Sampling != True:
        # Without Sampling
        output = np.zeros((Nt,samples))
        mu = 0
        sigma = np.sqrt(Variance)
        for i in range(Nt):
            output[i] = np.random.normal(mu, sigma, samples)
    else:
        # With Sampling
        output = np.zeros((Nt,int(T*fs)))
        mu = 0
        sigma = np.sqrt(Variance)
        for i in range(Nt):
            output[i] = np.random.normal(mu, sigma, int(T*fs))

    return output
```

Generates a Matrix of Analog Signals that need to be Transmitted

[5]:
```
def Analog_Matrix(Digital_Signal,samples,T,fc,fs,Sampling=False):
    # Outputs a matrix of all Transmitted Signals
    s = int(Digital_Signal.shape[0]/2)
    if Sampling != True:
        # Without Sampling
        output = np.zeros((s,samples))
    else:
        # With Sampling
        output = np.zeros((s,int(T*fs)))

    for i in range(s):
        a = Digital_Signal[2*i]
        b = Digital_Signal[2*i + 1]
        output[i] = 
 ↪Analog_Signal_Generator(a,b,i+1,samples,T,fc,fs,Sampling=Sampling)
```

```
    Nt = s
    return output,Nt
```

To Calculate Energy of each Signal Transmitted

```
[6]: def Energy_Signal_Matrix(signal_matrix):
         # Total Energy Matrix
         s = signal_matrix.shape[1]
         output = np.multiply(signal_matrix,signal_matrix)
         output = np.sum(output,axis=1)
         output = output/s

         return output
```

For Fourier Transform of a Analog Signal Matrix

```
[7]: def FFT(Signal_Matrix,fs):
         # Gives Fourier Transform of Sampled Analog Noisy Signal Matrix
         FFT_Matrix = np.fft.fft(Signal_Matrix) # /int(Signal_Matrix.shape[-1]/2)
         freq = np.fft.fftfreq(Signal_Matrix.shape[-1])*fs

         return FFT_Matrix,freq
```

For Inverse Fourier Transform of Analog Signal Matrix

```
[8]: def IFFT(Signal_Matrix):
         # Gives Inverse Fourier Transform of Sampled Analog Noisy Signal Matrix
         IFFT_Matrix = np.fft.ifft(Signal_Matrix).real

         return IFFT_Matrix
```

Low Pass Filter for Matrix of Analog Signals

```
[9]: def Low_Pass_Filtered_Matrix(Matrix,Cutoff_Freq,fs,Order=2):
         # Applies Low Pass Filter to each Signal in Matrix
         Output = np.zeros(Matrix.shape)
         for i in range(Matrix.shape[0]):
             if (Cutoff_Freq*2 == fs):
                 w = 1 - 1e-9
             else:
                 w = Cutoff_Freq*2/fs

             b, a = signal.butter(8, w)
             x = np.array(list(Matrix[i]))
             Output[i] = signal.filtfilt(b,a, x)

         return Output
```

Total no.of Waveforms for Transmission

[10]:
```
def Waveforms(M,fs,T,fc):
    # Different Waveforms that are Transmitted by Transmitter
    Waveforms = np.zeros((M,int(fs*T)))
    a = np.array([0,0,1,1])
    b = np.array([0,1,0,1])
    t = np.linspace(0, T, int(fs*T),endpoint=False)
    c = np.cos(2*np.pi*fc*t)
    s = np.sin(2*np.pi*fc*t)
    i = 0

    Directory = {}

    for x,y in zip(a,b):
        Waveforms[i] = x*c +y*s
        Directory[i] = np.array([x,y])
        i = i+1

    return Waveforms,Directory
```

Decodes the Analog Signal Matrix and returns Bits

[11]:
```
def Decode(Signal_Matrix,Waveforms,Directory,M):
    # Returns Array of Bits decoded at the Reciever
    Index = np.zeros((Signal_Matrix.shape[0],2))
    Error = np.random.rand(M)

    for i in range(Signal_Matrix.shape[0]):

        for j in range(M):
            Error[j] = mean_squared_error(Signal_Matrix[i],Waveforms[j])

        x = np.argmin(Error)
        Index[i] = np.array(Directory[x])

    Output = Index.flatten()

    return Output.astype(int)
```

## 0.3 *Encode, Transmit, Receieve and Decode*

Function to Encode, Transmit and Decode Signals

Modulation Scheme:

Carrier Frequency = 2 MHz Symbol Duration T = 1 sec.

$s(t) = x_{2i-1}\cos(2\pi f_c t) + x_{2i}\sin(2\pi f_c t)$, for $(i-1)T \leq t < iT$

```
[12]: def Modulation(Digital_Signal,fc,T,M,fs,Ratio,Cutoff_Freq,samples=1000):

    # Different Waveforms Transmited and Corresponding Directory
    Waveforms_Transmitted,Directory = Waveforms(M,fs,T,fc)

    '''
    Examples of Non-Sampled Signals ("The Context Non-Sampled implies that they␣
↪are not samples with fs = 50MHz")
    '''
    Analog_Signal_Matrix,Nt =␣
↪Analog_Matrix(Digital_Signal,samples,T,fc,fs,Sampling=False)

    # Energy
    Energy = Energy_Signal_Matrix(Analog_Signal_Matrix)
    Average_Energy = np.mean(Energy)
    print ("Average Energy of Transmitted Signal",Average_Energy)
    Energy_per_Bit = Average_Energy/np.log2(M)
    print ("Energy per Bit of Transmitted Signal",Energy_per_Bit)

    # No Calculations
    No = Energy_per_Bit/pow(10,(Ratio/10))
    R = pow(10,(Ratio/10))
    print ("Eb/No Ratio in dB is", Ratio)
    print ("Eb/No Ratio is", R)


    # Variance of White Gaussian Noise/Channel
    Variance = No/2

    # Encoding and Transmitting Signal
    Analog_Sampled_Signal_Matrix =␣
↪Analog_Matrix(Digital_Signal,samples,T,fc,fs, Sampling = True)[0] +␣
↪WGN(Variance,Nt,samples,T,fs,Sampling=True)


    # Receving Signal
    Filtered_Signal_Matrix =␣
↪Low_Pass_Filtered_Matrix(Analog_Sampled_Signal_Matrix,Cutoff_Freq,fs)

    # Decoding the Signal
    Decoded_Array =␣
↪Decode(Filtered_Signal_Matrix,Waveforms_Transmitted,Directory,M)

    # Probability of Error
    Error_Bits = np.sum(np.abs(Decoded_Array - Digital_Signal))
    Percentage_of_Error = Error_Bits  * 100/(Decoded_Array.shape[0])
    print ("Percentage of Error is",Percentage_of_Error,"%")
```

```
Q = scipy.stats.norm(0, 1).cdf(-np.sqrt(2*R))
print ("Pe(Proballity of Error) <",Q)

#Plotting the Signal
Img = Decoded_Array.reshape(110,100)
plt.imshow(Img,'gray')
plt.show()
```

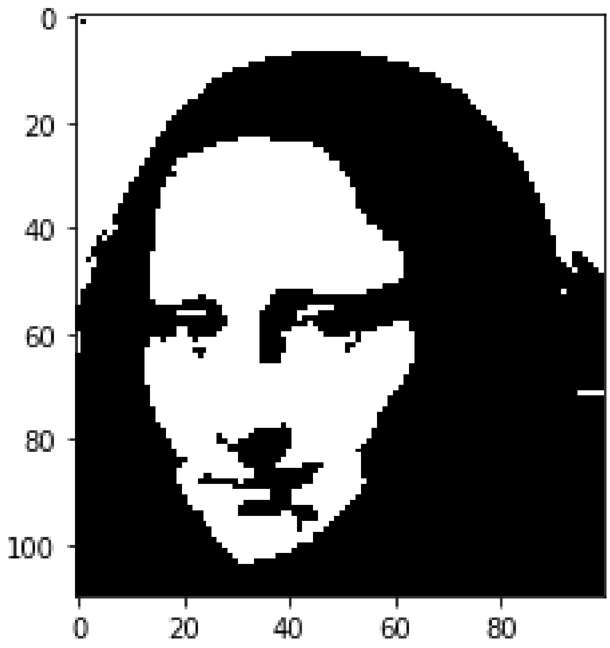
### 0.3.1 *Binary Image*

Importing Binary Image file

[13]:
```
MonaLisa = np.load('binary_image.npy')
```

Displaying Image

[14]:
```
plt.imshow(MonaLisa,'gray')
plt.show()
```



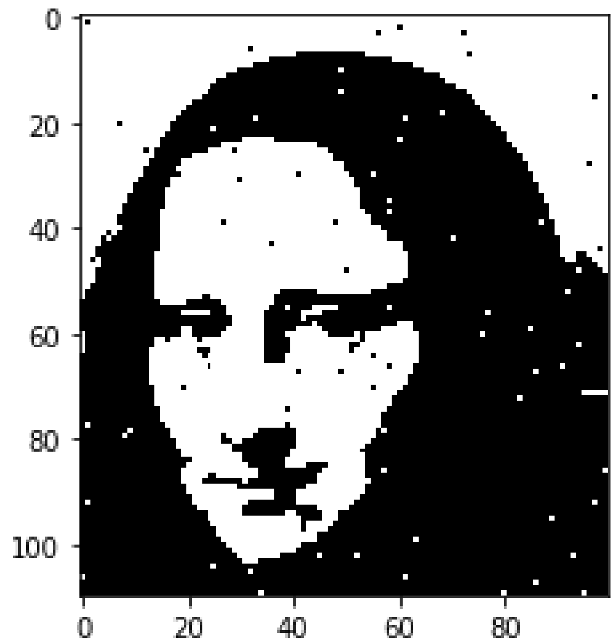

[15]:
```
Digital_Signal = MonaLisa.flatten()
```

## 0.4 *Results*

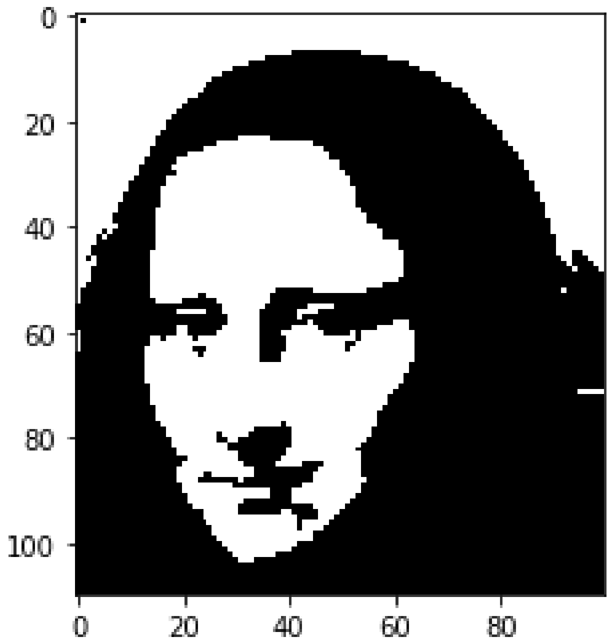
[16]:
```
fc = 2 * 1e6
T = 1e-6
M = 4
fs = 50 * 1e6
Cutoff_Freq = 25*pow(10,6)
Ratio = [-10,-5,0,5]

for r in Ratio:
    Modulation(Digital_Signal,fc,T,M,fs,r,Cutoff_Freq)
```

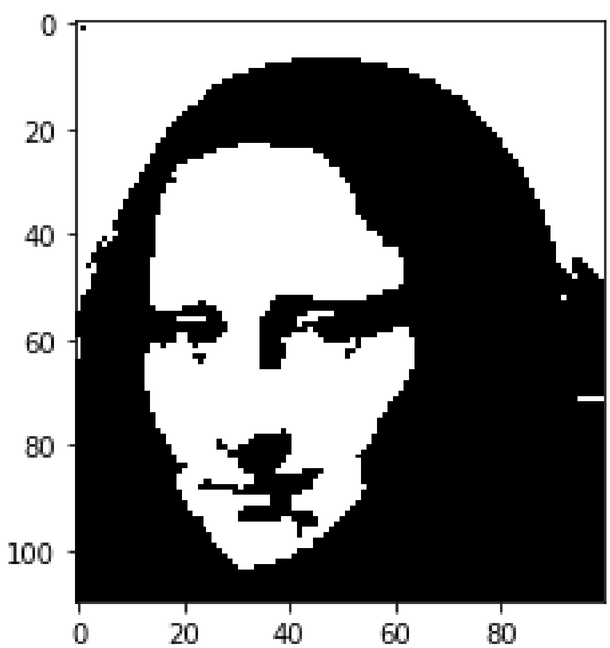
```
Average Energy of Transmitted Signal 0.42309090909090924
Energy per Bit of Transmitted Signal 0.21154545454545462
Eb/No Ratio in dB is -10
Eb/No Ratio is 0.1
Percentage of Error is 0.6454545454545455 %
Pe(Proballity of Error) < 0.32736042300928847
```




```
Average Energy of Transmitted Signal 0.42309090909090924
Energy per Bit of Transmitted Signal 0.21154545454545462
Eb/No Ratio in dB is -5
Eb/No Ratio is 0.31622776601683794
Percentage of Error is 0.0 %
Pe(Proballity of Error) < 0.2132280183576204
```




```
Average Energy of Transmitted Signal 0.42309090909090924
Energy per Bit of Transmitted Signal 0.21154545454545462
Eb/No Ratio in dB is 0
Eb/No Ratio is 1.0
Percentage of Error is 0.0 %
Pe(Proballity of Error) < 0.07864960352514251
```



```
Average Energy of Transmitted Signal 0.42309090909090924
Energy per Bit of Transmitted Signal 0.21154545454545462
Eb/No Ratio in dB is 5
Eb/No Ratio is 3.1622776601683795
Percentage of Error is 0.0 %
Pe(Proballity of Error) < 0.005953867147778654
```