Code of Assignment - 2

February 11, 2020

EE2025 Independent Project Programming Assignment - 2

This Assignment is done by D.Krishna Srikar – EE18BTECH11014 and V.Narasimha Reddy – EE18BTECH11046

The image(M.S.SubbaLakshmi), in all, contains $400 \times 300 = 120000$ information bits. We will encode,modulate,transmit,demodulate and decode them using 4-QAM modulation scheme with carrier frequency 2 MHz and symbol duration 1 micro sec, i.e., 2 bits are transmitted per micro second. The receiver will use the optimal demodulator, i.e., the maximum-likelihood detector or the minimum distance detector. We will use and different Channel Encoding Techniques to Encode the bits and Minimum Hamming Distance Decoder to decode it.

The Simulation Results are at the end of pdf/ipynb file.

[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*

[0]:
```
import numpy as np
import matplotlib.pyplot as plt
import scipy
from scipy import signal
from sklearn.metrics import mean_squared_error
from numba import jit,cuda
```

0.2 *Functions*

Functions Coded for the given Task

Generates Constellation to encode for 4-QAM

```
[0]: def Encode_4QAM(Digital_Signal):

    output = np.zeros(Digital_Signal.shape)

    for i in range(Digital_Signal.shape[0]):
        if (Digital_Signal[i] == 0):
            output[i] = 1
        else:
            output[i] = -1

    return output
```

Decodes bits from 4-QAM Constellation

```
[0]: def Decode_4QAM(Signal):

    output = np.zeros(Signal.shape)

    for i in range(Signal.shape[0]):
        if (Signal[i] == 1):
            output[i] = 0
        else:
            output[i] = 1

    return output.astype(int)
```

Generates a Vector of Analog Signal Transmitted for the Bits Transmitted

```
[0]: 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

```
[0]: 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

```
[0]: 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

```
[0]: def Energy_Signal_Matrix(signal_matrix):
         # Total Energy Matrix
         output = np.multiply(signal_matrix,signal_matrix)
```

```
    output = np.mean(output,axis=1)

    return output
```

For Fourier Transform of a Analog Signal Matrix

```
[0]: 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

```
[0]: 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

```
[0]: def Low_Pass_Filtered_Matrix(Matrix,Cutoff_Freq,fs,T,Nt,Order=8):
         # Applies Low Pass Filter to each Signal in Matrix
         Output = np.zeros((Nt,int(fs*T)))

         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(Order, w)
             x = np.array(list(Matrix[i]))
             output = signal.filtfilt(b,a, x)

             # Decimating or Downsampling Signal
             Output[i] = signal.decimate(output,1)


         return Output
```

Total no.of Waveforms for Transmission

```
[0]: 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])
    a_encoded = Encode_4QAM(a)
    b_encoded = Encode_4QAM(b)
    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_encoded,b_encoded):
        Waveforms[i] = x*c +y*s
        Directory[i] = np.array([x,y])
        i = i+1

    return Waveforms,Directory
```

Total no.of Distint Possibilites of Encoded bits sent

```
[0]: def Bit_Possibilities_Encoded(Signal,Channel_No):
    BitPoss = {}
    Bits_8 = np.array([])
    Bits_4 = np.array([])
    t = 4

    if Channel_No == 1:
        M = np.matrix('1 1 1 1 0 0 0 0; 1 1 0 0 1 1 0 0; 1 0 1 0 1 0 1 0; 0 1 1␣
 ↪0 1 0 0 1')
    elif Channel_No == 3:
        M = np.matrix('1 0 0 0 0 1 1 1 1 0 1 0; 0 1 0 0 1 0 1 1 0 1 1 0; 0 0 1␣
 ↪0 1 1 1 0 1 1 1 1; 0 0 0 1 0 0 0 1 1 1 1 1')

    for i in range(0,Signal.shape[0],t):
        x = np.dot(Signal[i:i+t],M)%2
        x = np.squeeze(np.asarray(x))
        c = x.shape[0]
        BitPoss[np.array_str(x)] = 1

    r = len(list(BitPoss.keys()))

    for i in range(0,Signal.shape[0],t):
        x = np.dot(Signal[i:i+t],M)%2
        x = np.squeeze(np.asarray(x))
        y = np.array_str(x)
```

```
        if y in BitPoss.keys():
            del BitPoss[y]
            Bits_8 = np.concatenate([Bits_8,x])
            Bits_4 = np.concatenate([Bits_4,Signal[i:i+t]])


    Bits_8 = np.reshape(Bits_8,(r,c))
    Bits_4 = np.reshape(Bits_4,(r,t))

    return Bits_8,Bits_4
```

Decodes the Analog Signal Matrix and returns Bits

[0]:
```
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.zeros((Signal_Matrix.shape[0],Waveforms.shape[0]))

    for i in range(M):
        Error[:,i] = np.mean(np.multiply((Signal_Matrix -␣
↪Waveforms[i]),(Signal_Matrix - Waveforms[i])),axis=1)

    x = np.argmin(Error,axis=1)

    for i in range(x.shape[0]):
        Index[i] = np.array(Directory[x[i]])

    Output = Index.flatten()

    return Output.astype(int)
```

Plot BER vs $\frac{E_b}{N_0}$

[0]:
```
def Plot_BERGraph(Eb_per_No_dB,BER,label):
    plt.plot(Eb_per_No_dB,BER)
    plt.ylabel('BER')
    plt.xlabel(r'$\frac{E_{\mathrm{b}}}{N_{0}}$')
    plt.title(r'BER vs $\frac{E_{\mathrm{b}}}{N_{0}}$ Simulation Results for␣
↪'+label)
    plt.scatter(Eb_per_No_dB,BER)
    plt.grid()
    plt.show()
```

Plotting Image

```
[0]: def Plot_Image(Decoded_Array,shape):
    #Plotting the Signal
    Img = Decoded_Array.reshape(shape)
    plt.imshow(Img,'gray')
    plt.show()
    print␣
 ↪("---------------------------------------------------------------------------------------")
```

Bit Error Rate

```
[0]: def Bit_Error_Rate(Decoded_Array,Digital_Signal):
    Error_Bits = np.sum(np.abs(Decoded_Array - Digital_Signal))
    Fraction_of_Error = Error_Bits /(Decoded_Array.shape[0])

    return Fraction_of_Error
```

0.3 *Encode, Transmit, Receieve and Decode*

Function to Encode, Transmit and Decode Signals

0.3.1 *Channel Encoding Techniques*

```
[0]: def Channel_EncodeTech1(Signal):
    G1 = np.matrix('1 1 1 1 0 0 0 0; 1 1 0 0 1 1 0 0; 1 0 1 0 1 0 1 0; 0 1 1 0␣
 ↪1 0 0 1')

    S = np.transpose(np.reshape(Signal,(-1,4)))
    X = np.transpose(np.dot(G1.T,S))%2

    output = X.flatten()

    return np.squeeze(np.asarray(output))
```

```
[0]: def Channel_EncodeTech2(Signal):

    output = np.transpose(np.reshape(np.
 ↪concatenate([Signal,Signal,Signal]),(3,-1))).flatten()

    return output
```

```
[0]: def Channel_EncodeTech3(Signal):
    G3 = np.matrix('1 0 0 0 0 1 1 1 1 0 1 0; 0 1 0 0 1 0 1 1 0 1 1 0; 0 0 1 0 1␣
 ↪1 1 0 1 1 1 1; 0 0 0 1 0 0 0 1 1 1 1 1')

    S = np.transpose(np.reshape(Signal,(-1,4)))
```

```
    X = np.transpose(np.dot(G3.T,S))%2

    output = X.flatten()

    return np.squeeze(np.asarray(output))
```

0.3.2 *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 $(i-1)T \leq t < iT$

[0]:
```
def␣
↪Modulation(Digital_Signal,fc,T,M,fs,n,k,Cutoff_Freq,Ratio=0,Variance=0,samples=1000,Varianc
↪

    # 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")
    '''

    # Encoding Signal
    Digital_Signal_Encoded = Encode_4QAM(Digital_Signal)
    Analog_Signal_Matrix,Nt =␣
↪Analog_Matrix(Digital_Signal_Encoded,samples,T,fc,fs,Sampling=True)
    print (Analog_Signal_Matrix.shape)

    # Energy for Waveforms_Transmitted
    Average_Energy = T*n # By Integrating Analog Signal
    print ("Average Energy of Transmitted Signal",Average_Energy)
    Energy_per_Bit = Average_Energy/k
    print ("Energy per Bit of Transmitted Signal",Energy_per_Bit)

    if VarianceTruth != True:
        # 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)*(2*Cutoff_Freq)
        print ("Variance of WGN",Variance)
```

```
    else:
        Variance = Variance
        print ("Variance of WGN",Variance)
        No = Variance/Cutoff_Freq
        R = Energy_per_Bit/No
        print ("Eb/No Ratio is", R)
        Ratio = 10*np.log10(R)
        print ("Eb/No Ratio in dB is", Ratio)

    # Transmitting Signal
    Analog_Sampled_Signal_Matrix = Analog_Signal_Matrix +␣
↪WGN(Variance,Nt,samples,T,fs,Sampling=True)

    # Receving Signal
    Filtered_Signal_Matrix =  Analog_Sampled_Signal_Matrix␣
↪#Low_Pass_Filtered_Matrix(Analog_Sampled_Signal_Matrix,Cutoff_Freq,fs,T,Nt)␣
↪# Commented the Line as the Signal Frequency Components are in Low Pass␣
↪Filter Range

    # Decoding Signal
    Decoded_Array =␣
↪Decode_4QAM(Decode(Filtered_Signal_Matrix,Waveforms_Transmitted,Directory,M))

    """
    # Probability of Error
    Error_Bits = np.sum(np.abs(Decoded_Array - Digital_Signal))
    print ("No.of Wrong Bits",Error_Bits)
    Fraction_of_Error = Error_Bits /(Decoded_Array.shape[0])
    print ("Fraction of Error is",Fraction_of_Error)
    Q = scipy.stats.norm(0, 1).cdf(-np.sqrt(2*R/1))
    print ("Pe(Proballity of Error) =",Q)
    """

    return Decoded_Array,Ratio
```

0.3.3 *Channel Decoding Techniques*

[0]:
```
def Channel_DecodeTech1(Signal,Ref_8,Ref_4):

    Output = np.array([])
    for i in range(0,Signal.shape[0],8):
        s = Signal[i:i+8]
        m = np.argmin(np.sum(np.add(Ref_8,s)%2,axis=1))

        Output = np.concatenate([Output,Ref_4[m]])
```

```
    return Output.astype(int)
```

[0]:
```
def Channel_DecodeTech2(Signal):

    output = np.floor(np.sum(np.reshape(Signal,(-1,3)),axis=1)/2)

    return output.astype(int)
```

[0]:
```
def Channel_DecodeTech3(Signal,Ref_12,Ref_4):

    Output = np.array([])
    for i in range(0,Signal.shape[0],12):
        s = Signal[i:i+12]
        m = np.argmin(np.sum(np.add(Ref_12,s)%2,axis=1))
        Output = np.concatenate([Output,Ref_4[m]])

    return Output.astype(int)
```

0.3.4 *Binary Image*

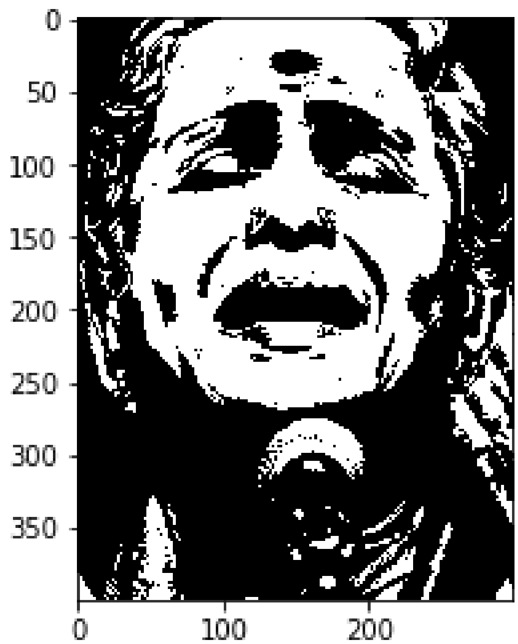
Importing Binary Image file

[25]:
```
MSS = np.load('mss.npy')
shape = MSS.shape
print (shape)
```

```
(400, 300)
```

Displaying Image

[26]:
```
plt.imshow(MSS,'gray')
plt.show()
```



```
[27]: Digital_Signal = MSS.flatten()
      print (Digital_Signal.shape)
```

(120000,)

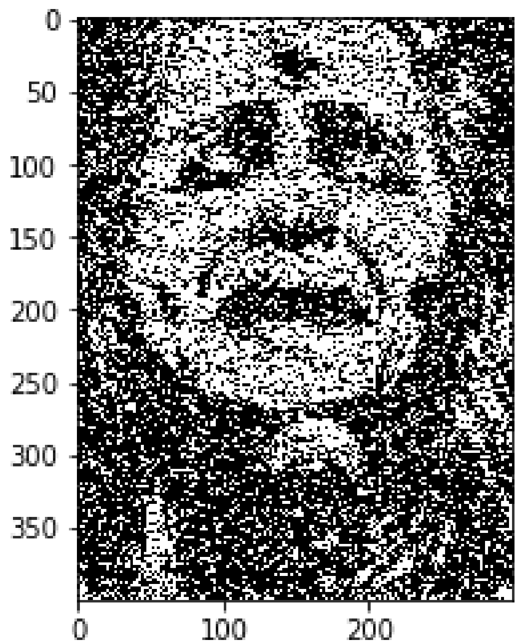
0.4 *Results*

```
[0]: fc = 2 * 1e6
     T = 1e-6
     M = 4
     fs = 50 * 1e6
     Cutoff_Freq = 25*pow(10,6)
     Variance = np.array([20,12,7,5]).astype(int)
     Ratio = np.array([-2,0,2,4,6]).astype(int)
```

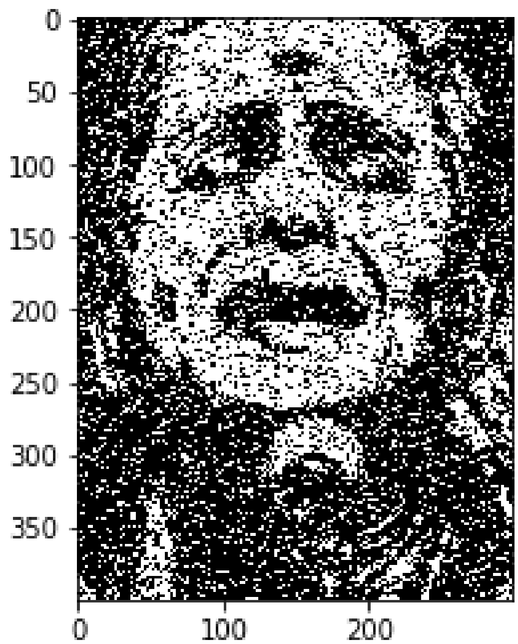
```
[29]: Variance = np.array([20,12,7,5]).astype(int)
      Ratio = np.array([-2,0,2,4,6]).astype(int)

      BER = []
      Eb_per_No_dB = []

      for r in Ratio:
          Encoded_Signal = Channel_EncodeTech1(Digital_Signal)
          Received_Signal,Ratio =␣
       ↪Modulation(Encoded_Signal,fc,T,M,fs,8,4,Cutoff_Freq=Cutoff_Freq,Ratio=r)
```

```
    Bits_8,Bits_4 = Bit_Possibilities_Encoded(Digital_Signal,1)
    Decoded_Signal = Channel_DecodeTech1(Received_Signal,Bits_8,Bits_4)

    BER.append(Bit_Error_Rate(Decoded_Signal,Digital_Signal))
    Eb_per_No_dB.append(Ratio)

    Plot_Image(Decoded_Signal,shape)

Plot_BERGraph(Eb_per_No_dB,BER,r'Channel Encoding-1 given␣
 ↪$\frac{E_{\mathrm{b}}}{N_{0}}$')


BER = []
Eb_per_No_dB = []

for v in Variance:
    Encoded_Signal = Channel_EncodeTech1(Digital_Signal)
    Received_Signal,Ratio =␣
 ↪Modulation(Encoded_Signal,fc,T,M,fs,8,4,Cutoff_Freq=Cutoff_Freq,Variance=v,VarianceTruth=Tr
    Bits_8,Bits_4 = Bit_Possibilities_Encoded(Digital_Signal,1)
    Decoded_Signal = Channel_DecodeTech1(Received_Signal,Bits_8,Bits_4)

    BER.append(Bit_Error_Rate(Decoded_Signal,Digital_Signal))
    Eb_per_No_dB.append(Ratio)

    Plot_Image(Decoded_Signal,shape)

Plot_BERGraph(Eb_per_No_dB,BER,'Channel Encoding-1 given Variance')
```

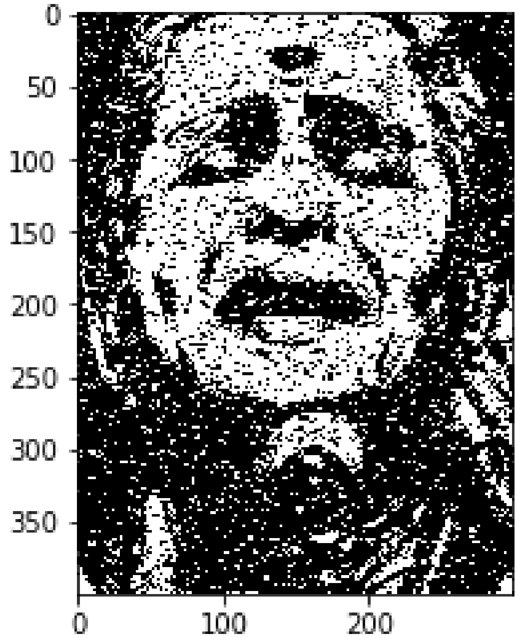
```
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Eb/No Ratio in dB is -2
Eb/No Ratio is 0.6309573444801932
Variance of WGN 79.24465962305567
```



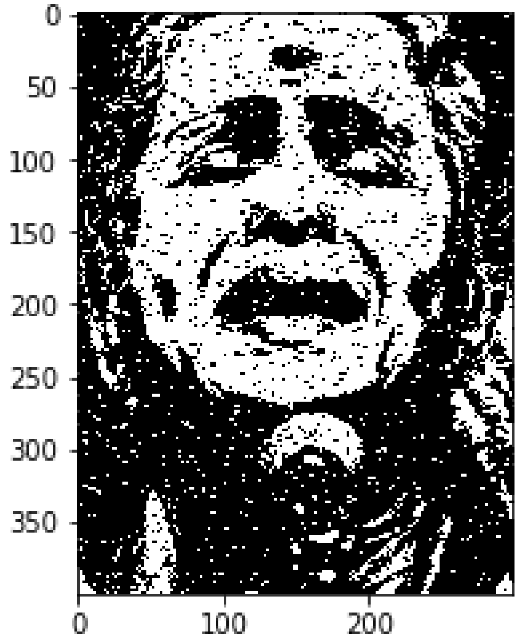

```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Eb/No Ratio in dB is 0
Eb/No Ratio is 1.0
Variance of WGN 50.0
```



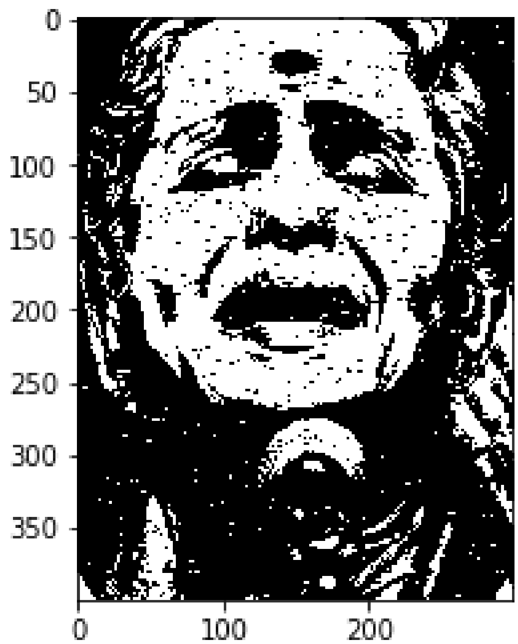

```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Eb/No Ratio in dB is 2
Eb/No Ratio is 1.5848931924611136
Variance of WGN 31.547867224009657
```

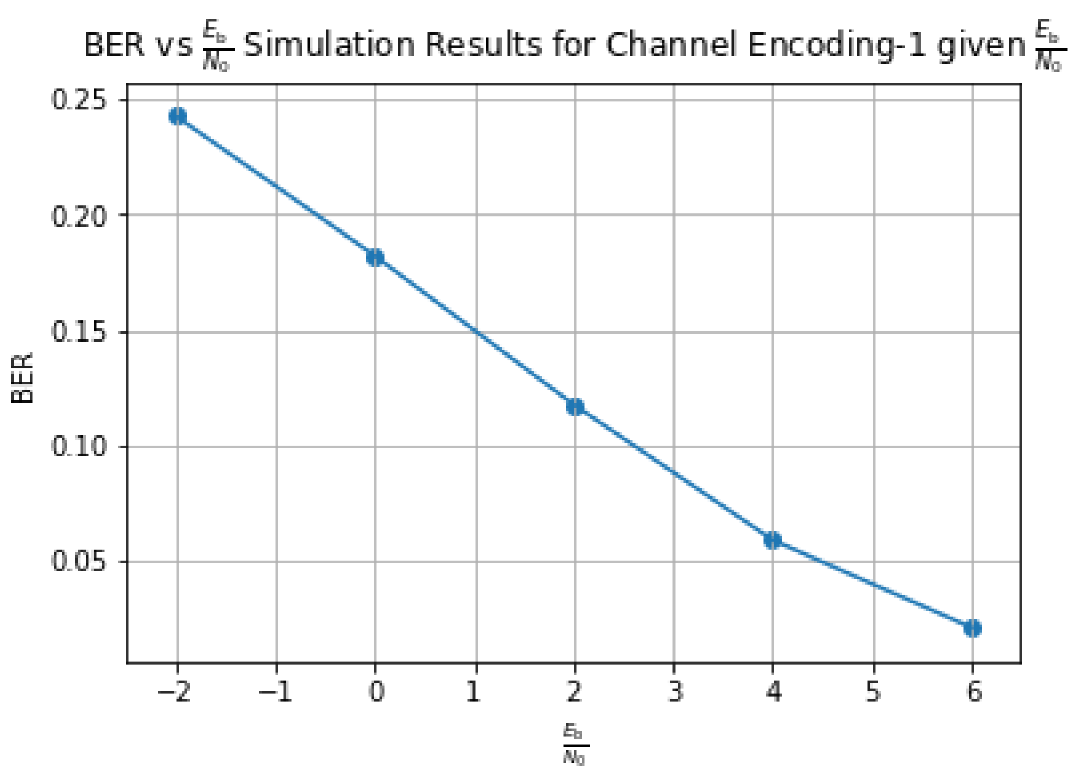



```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Eb/No Ratio in dB is 4
Eb/No Ratio is 2.51188643150958
Variance of WGN 19.905358527674863
```

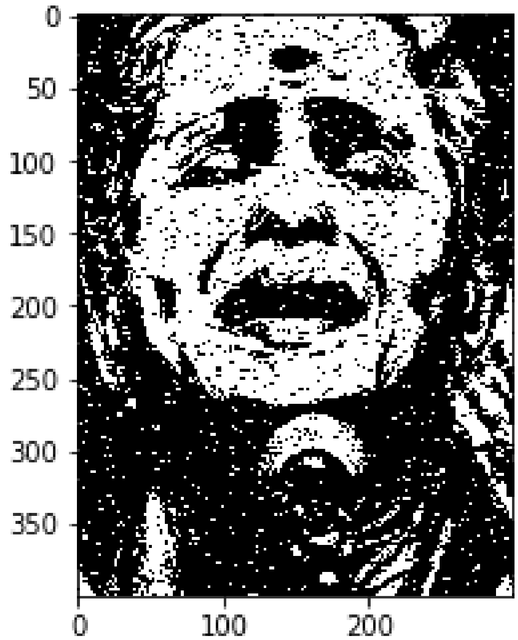



```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Eb/No Ratio in dB is 6
Eb/No Ratio is 3.9810717055349722
Variance of WGN 12.559432157547901
```

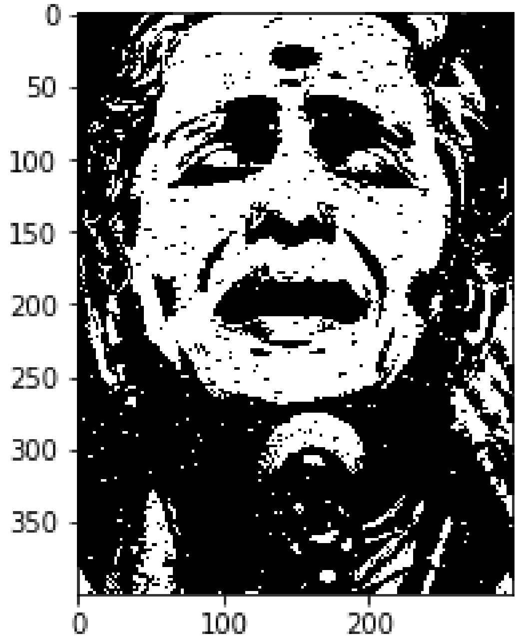

0
50
100
150
200
250
300
350
0
100
200


BER vs $\frac{E_b}{N_0}$ Simulation Results for Channel Encoding-1 given $\frac{E_b}{N_0}$
BER
0.25
0.20
0.15
0.10
0.05
−2
−1
0
1
2
3
4
5
6
$\frac{E_b}{N_0}$

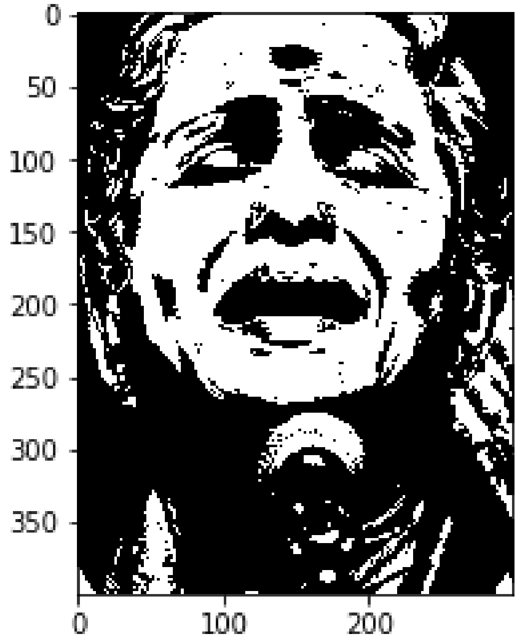
```
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Variance of WGN 20
Eb/No Ratio is 2.5
Eb/No Ratio in dB is 3.979400086720376
```



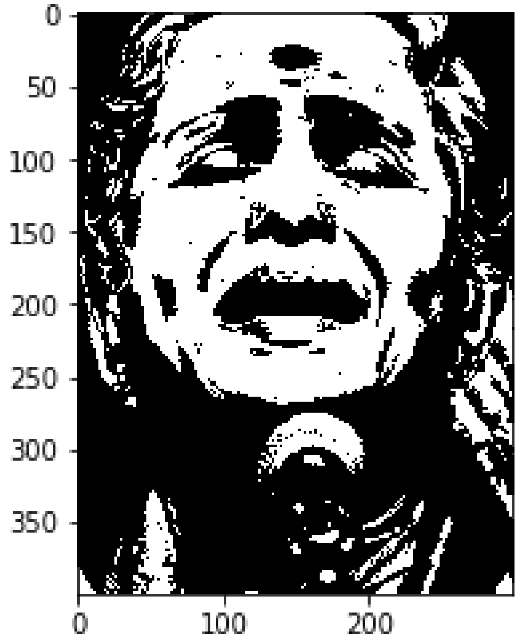

```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Variance of WGN 12
Eb/No Ratio is 4.166666666666667
Eb/No Ratio in dB is 6.19788758288394
```

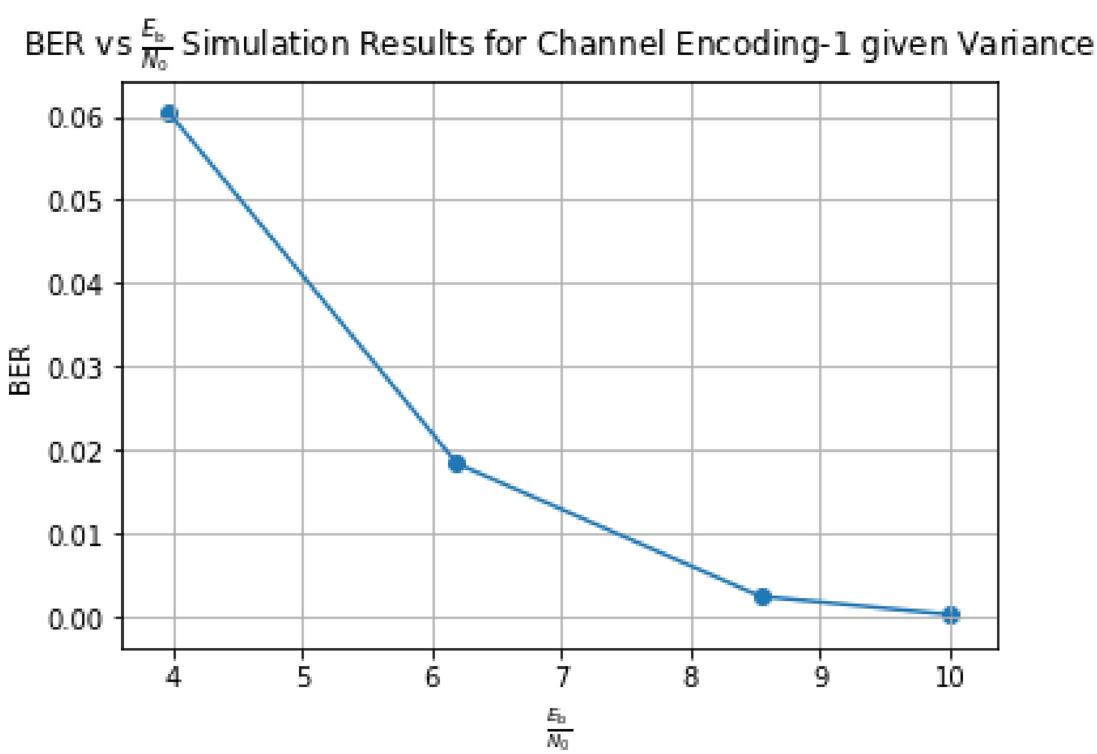



```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Variance of WGN 7
Eb/No Ratio is 7.142857142857142
Eb/No Ratio in dB is 8.53871964321762
```



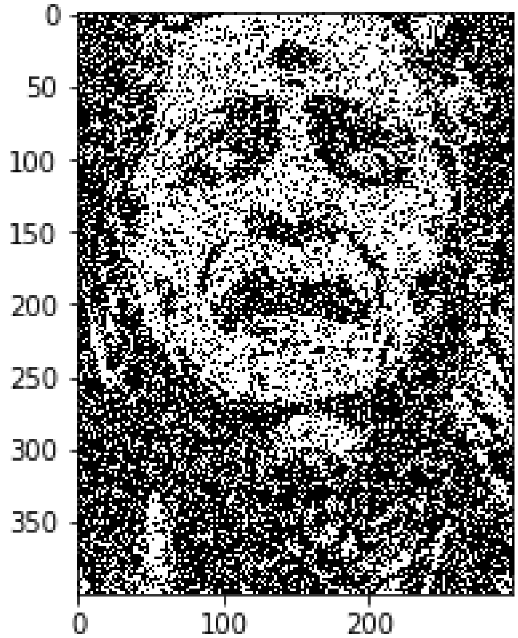

```
--------------------------------------------------------------------------------
-------
(120000, 50)
Average Energy of Transmitted Signal 8e-06
Energy per Bit of Transmitted Signal 2e-06
Variance of WGN 5
Eb/No Ratio is 10.0
Eb/No Ratio in dB is 10.0
```


0
50
100
150
200
250
300
350
0
100
200

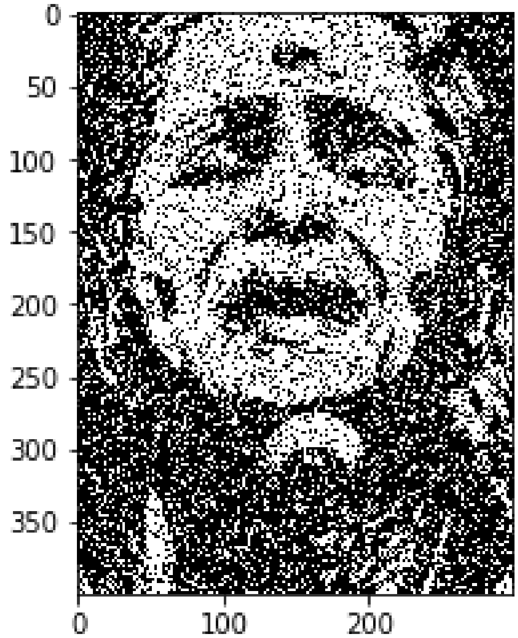

BER vs $\frac{E_b}{N_0}$ Simulation Results for Channel Encoding-1 given Variance
BER
0.06
0.05
0.04
0.03
0.02
0.01
0.00
4
5
6
7
8
9
10
$\frac{E_b}{N_0}$

[30]:
```
Variance = np.array([20,12,7,5]).astype(int)
Ratio = np.array([-2,0,2,4,6]).astype(int)

BER = []
Eb_per_No_dB = []
for r in Ratio:
    Encoded_Signal = Channel_EncodeTech2(Digital_Signal)
    Received_Signal,Ratio =␣
 ↪Modulation(Encoded_Signal,fc,T,M,fs,3,1,Cutoff_Freq=Cutoff_Freq,Ratio=r)
    Decoded_Signal = Channel_DecodeTech2(Received_Signal)

    BER.append(Bit_Error_Rate(Decoded_Signal,Digital_Signal))
    Eb_per_No_dB.append(Ratio)

    Plot_Image(Decoded_Signal,shape)

Plot_BERGraph(Eb_per_No_dB,BER,r'Channel Encoding-2 given␣
 ↪$\frac{E_{\mathrm{b}}}{N_{0}}$')


BER = []
Eb_per_No_dB = []

for v in Variance:
    Encoded_Signal = Channel_EncodeTech2(Digital_Signal)
    Received_Signal,Ratio =␣
 ↪Modulation(Encoded_Signal,fc,T,M,fs,3,1,Cutoff_Freq=Cutoff_Freq,Variance=v,VarianceTruth=Tr
    Decoded_Signal = Channel_DecodeTech2(Received_Signal)

    BER.append(Bit_Error_Rate(Decoded_Signal,Digital_Signal))
    Eb_per_No_dB.append(Ratio)

    Plot_Image(Decoded_Signal,shape)

Plot_BERGraph(Eb_per_No_dB,BER,'Channel Encoding-2 given Variance')
```

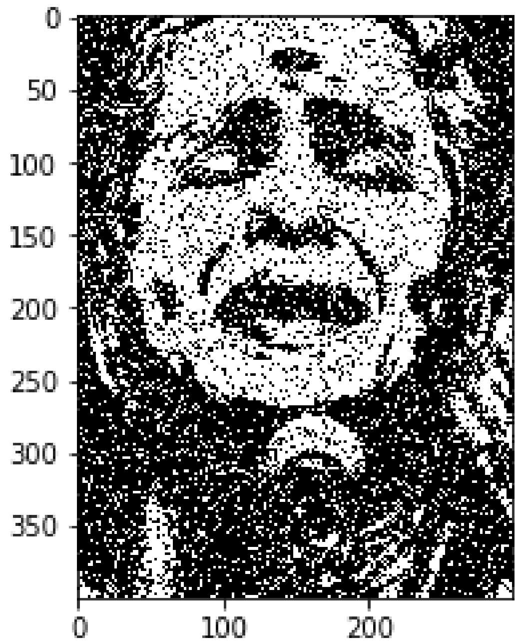
```
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is -2
Eb/No Ratio is 0.6309573444801932
Variance of WGN 118.8669894345835
```



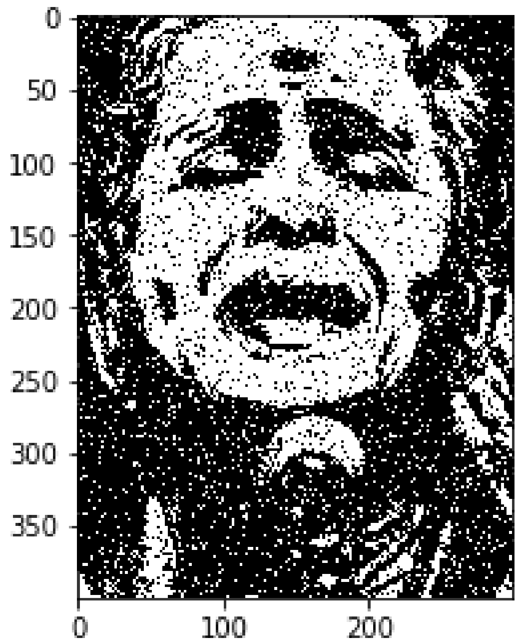
```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 0
Eb/No Ratio is 1.0
Variance of WGN 75.0
```



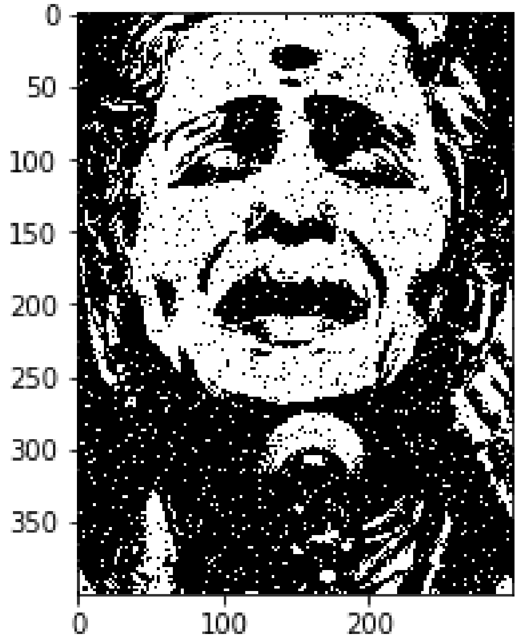

```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 2
Eb/No Ratio is 1.5848931924611136
Variance of WGN 47.321800836014496
```

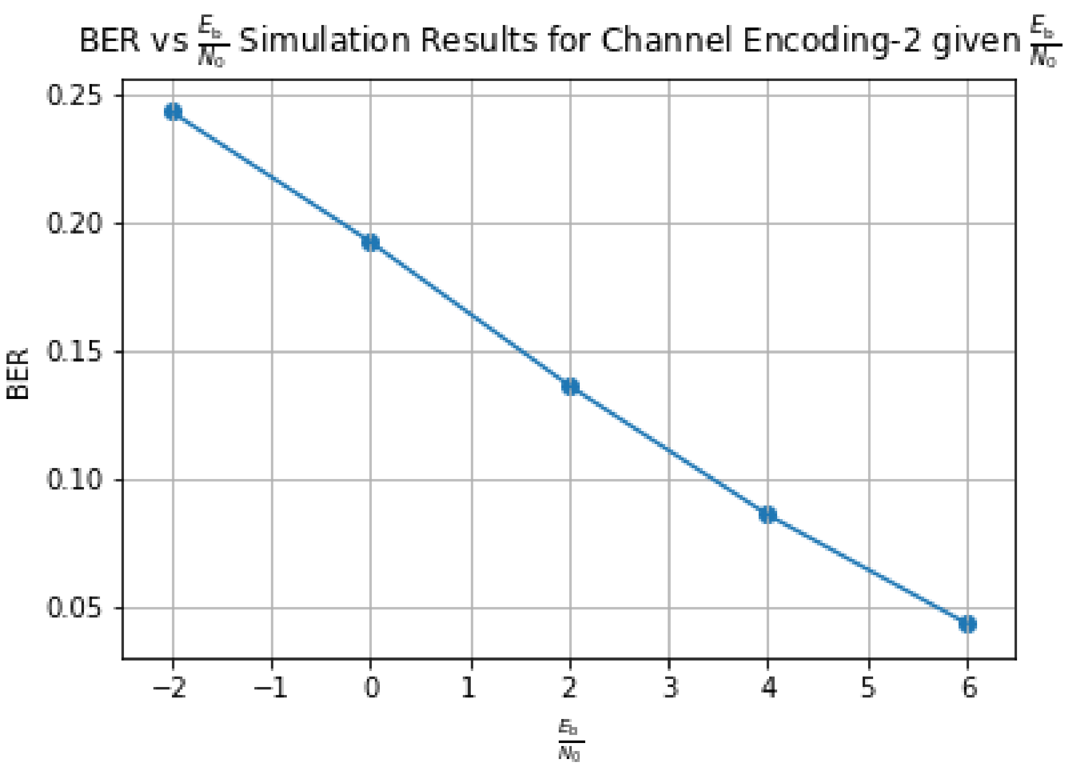



```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 4
Eb/No Ratio is 2.51188643150958
Variance of WGN 29.85803779151229
```

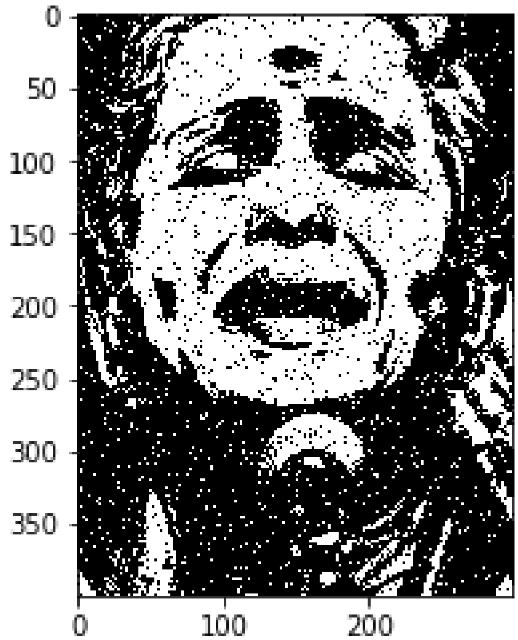



```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 6
Eb/No Ratio is 3.9810717055349722
Variance of WGN 18.839148236321854
```

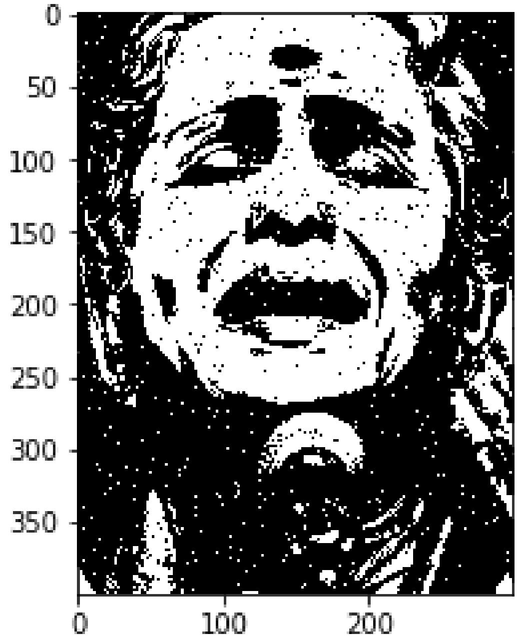

0
50
100
150
200
250
300
350
0
100
200


BER vs $\frac{E_b}{N_0}$ Simulation Results for Channel Encoding-2 given $\frac{E_b}{N_0}$
BER
0.25
0.20
0.15
0.10
0.05
−2
−1
0
1
2
3
4
5
6
$\frac{E_b}{N_0}$

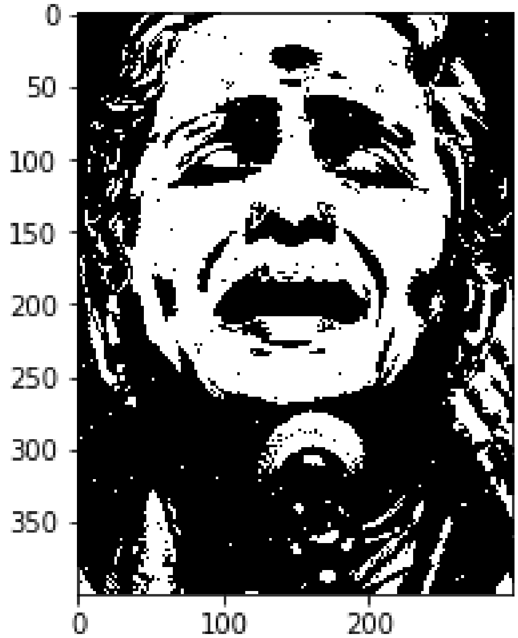
```
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 20
Eb/No Ratio is 3.7500000000000004
Eb/No Ratio in dB is 5.740312677277188
```



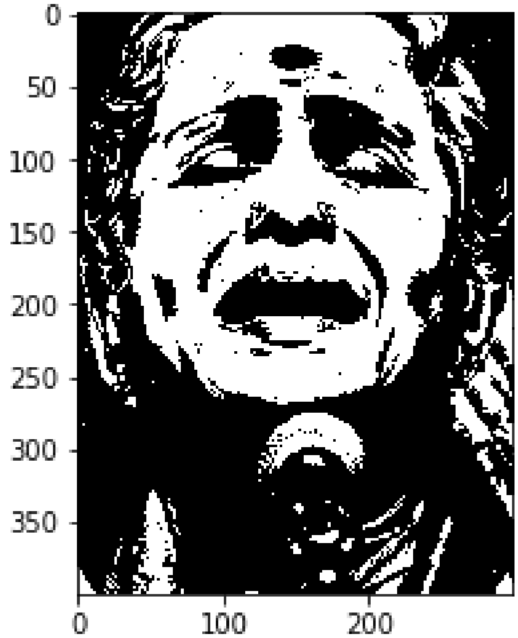

```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 12
Eb/No Ratio is 6.250000000000001
Eb/No Ratio in dB is 7.958800173440752
```

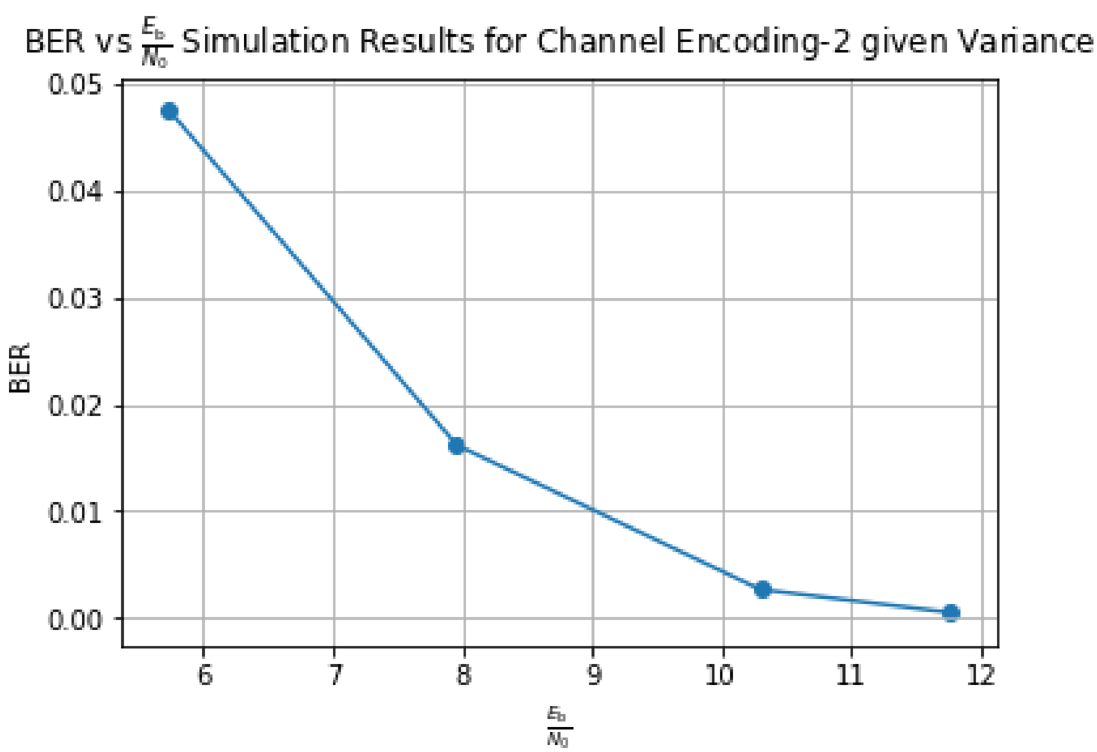



```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 7
Eb/No Ratio is 10.714285714285714
Eb/No Ratio in dB is 10.299632233774432
```




```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 3e-06
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 5
Eb/No Ratio is 15.000000000000002
Eb/No Ratio in dB is 11.760912590556813
```

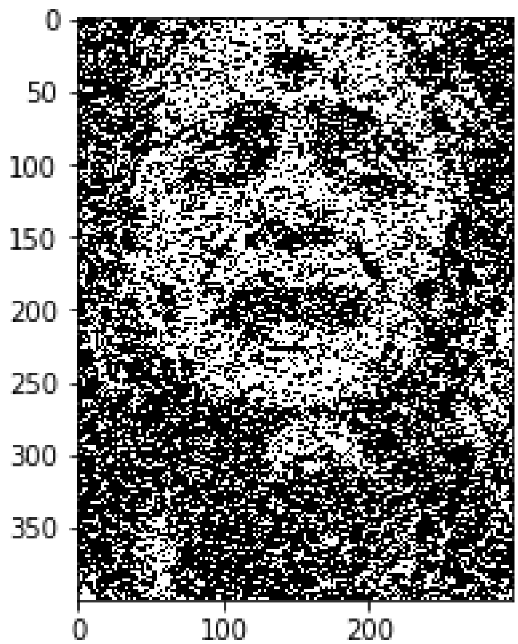

0
50
100
150
200
250
300
350
0
100
200


BER vs $\frac{E_b}{N_0}$ Simulation Results for Channel Encoding-2 given Variance
BER
$\frac{E_b}{N_0}$
0.05
0.04
0.03
0.02
0.01
0.00
6
7
8
9
10
11
12

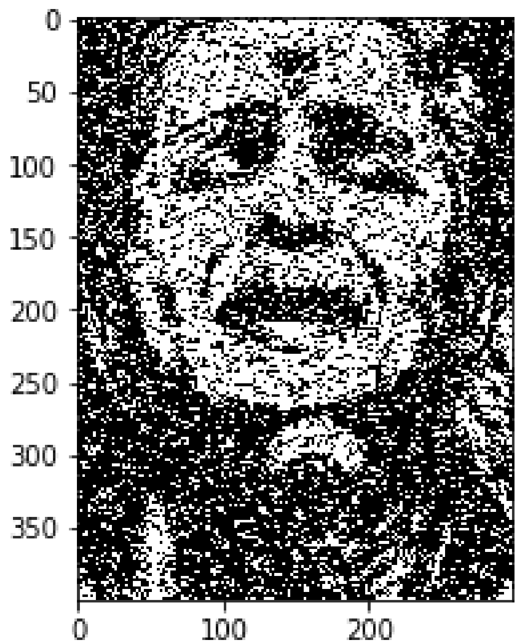
[31]:

```
Variance = np.array([20,12,7,5]).astype(int)
Ratio = np.array([-2,0,2,4,6]).astype(int)

BER = []
Eb_per_No_dB = []
for r in Ratio:
    Encoded_Signal = Channel_EncodeTech3(Digital_Signal)
    Received_Signal,Ratio =␣
 ↪Modulation(Encoded_Signal,fc,T,M,fs,12,4,Cutoff_Freq=Cutoff_Freq,Ratio=r)
    Bits_12,Bits_4 = Bit_Possibilities_Encoded(Digital_Signal,3)
    Decoded_Signal = Channel_DecodeTech3(Received_Signal,Bits_12,Bits_4)

    BER.append(Bit_Error_Rate(Decoded_Signal,Digital_Signal))
    Eb_per_No_dB.append(Ratio)

    Plot_Image(Decoded_Signal,shape)

Plot_BERGraph(Eb_per_No_dB,BER,r'Channel Encoding-3 given␣
 ↪$\frac{E_{\mathrm{b}}}{N_{0}}$')


BER = []
Eb_per_No_dB = []

for v in Variance:
    Encoded_Signal = Channel_EncodeTech3(Digital_Signal)
    Received_Signal,Ratio =␣
 ↪Modulation(Encoded_Signal,fc,T,M,fs,12,4,Cutoff_Freq=Cutoff_Freq,Variance=v,VarianceTruth=T
    Bits_12,Bits_4 = Bit_Possibilities_Encoded(Digital_Signal,3)
    Decoded_Signal = Channel_DecodeTech3(Received_Signal,Bits_12,Bits_4)

    BER.append(Bit_Error_Rate(Decoded_Signal,Digital_Signal))
    Eb_per_No_dB.append(Ratio)

    Plot_Image(Decoded_Signal,shape)

Plot_BERGraph(Eb_per_No_dB,BER,'Channel Encoding-3 given Variance')
```

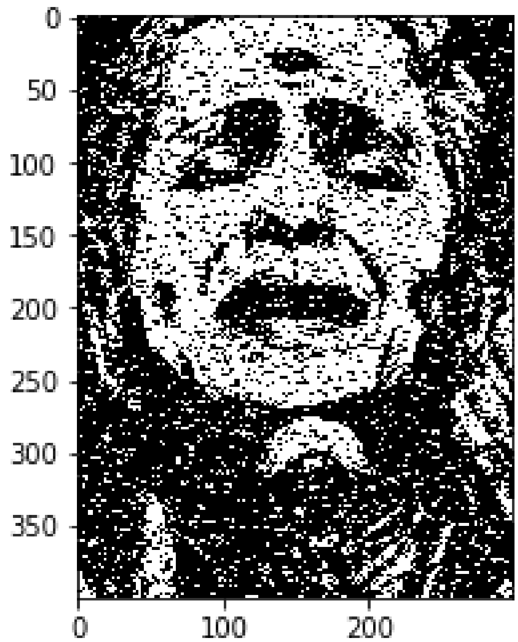
```
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is -2
Eb/No Ratio is 0.6309573444801932
Variance of WGN 118.8669894345835
```



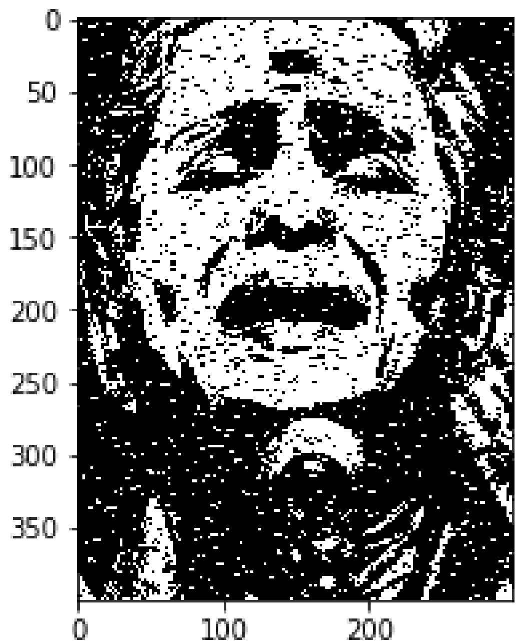

```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 0
Eb/No Ratio is 1.0
Variance of WGN 75.0
```



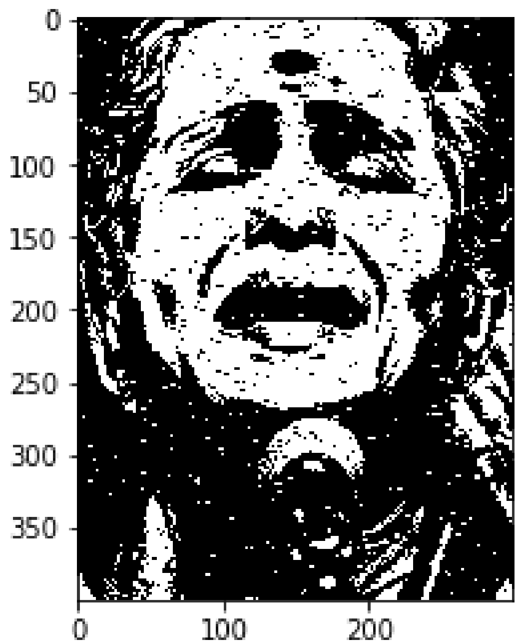

```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 2
Eb/No Ratio is 1.5848931924611136
Variance of WGN 47.321800836014496
```



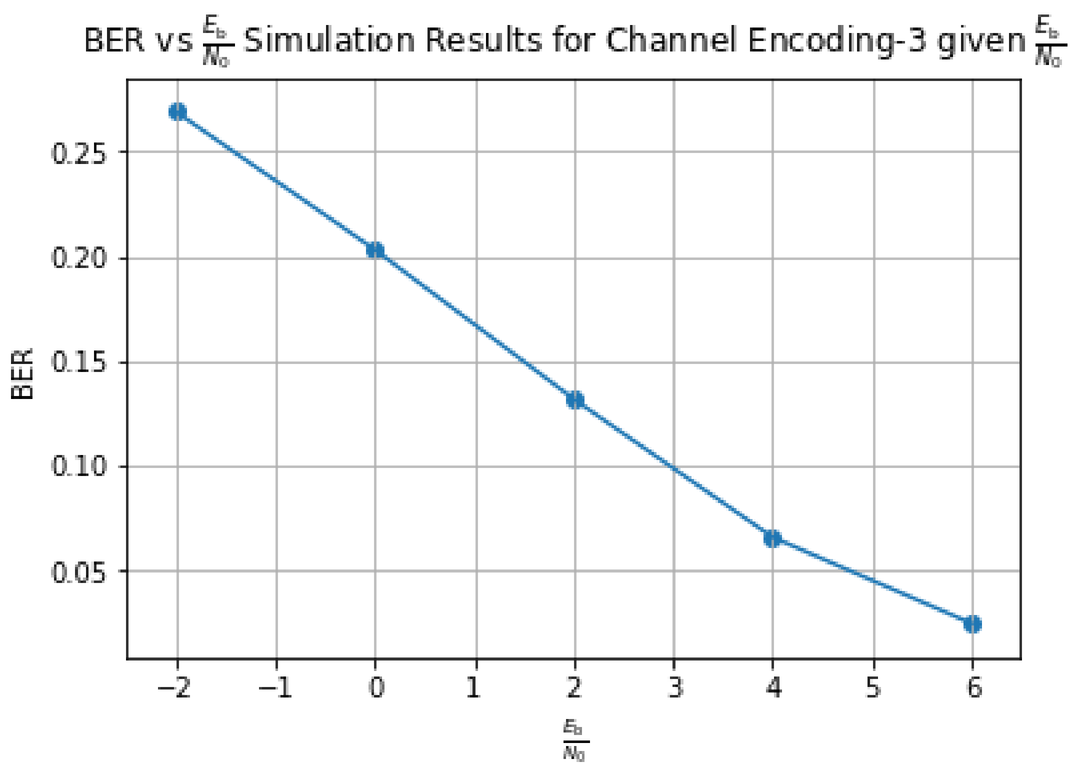

```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 4
Eb/No Ratio is 2.51188643150958
Variance of WGN 29.85803779151229
```



```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Eb/No Ratio in dB is 6
Eb/No Ratio is 3.9810717055349722
Variance of WGN 18.839148236321854
```

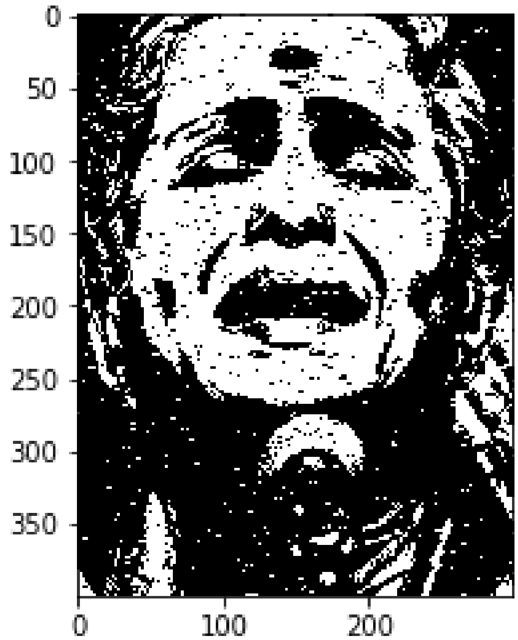


0
50
100
150
200
250
300
350
0
100
200

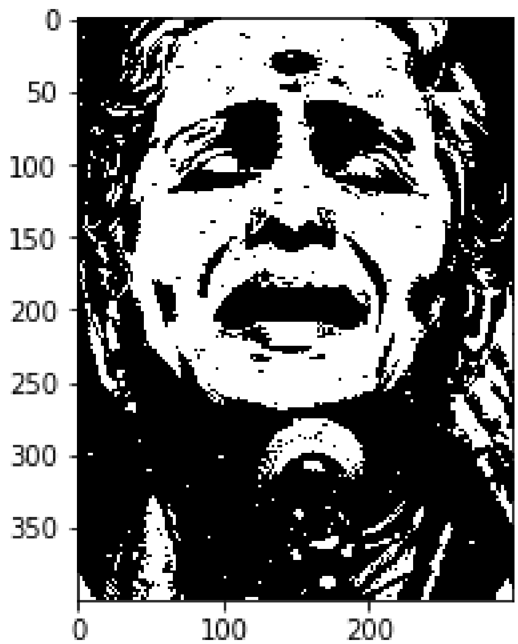


BER vs $\frac{E_b}{N_0}$ Simulation Results for Channel Encoding-3 given $\frac{E_b}{N_0}$
0.25
0.20
0.15
0.10
0.05
BER
−2
−1
0
1
2
3
4
5
6
$\frac{E_b}{N_0}$

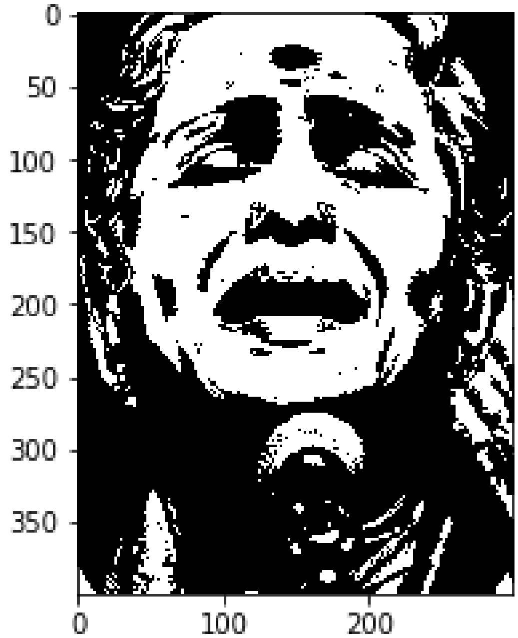
```
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 20
Eb/No Ratio is 3.7500000000000004
Eb/No Ratio in dB is 5.740312677277188
```



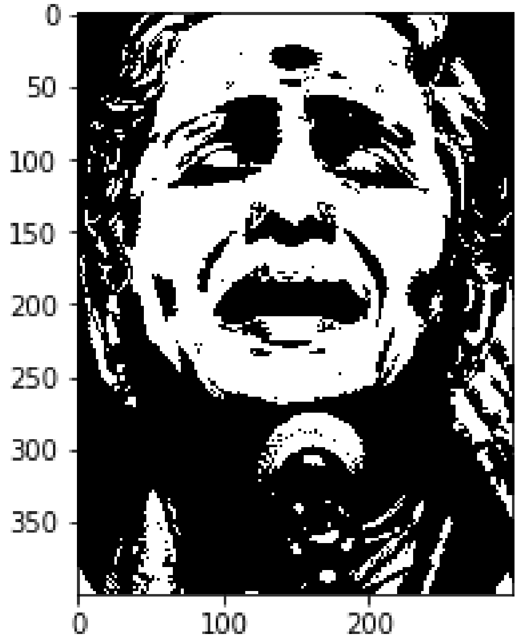

```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 12
Eb/No Ratio is 6.250000000000001
Eb/No Ratio in dB is 7.958800173440752
```

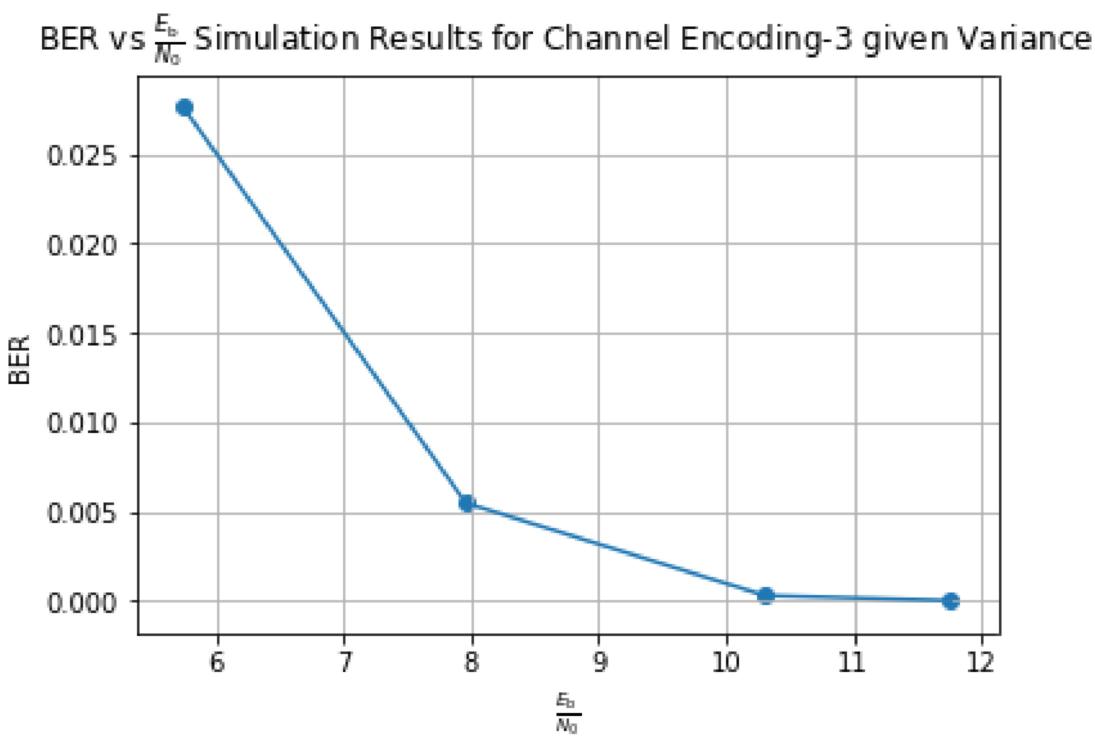


```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 7
Eb/No Ratio is 10.714285714285714
Eb/No Ratio in dB is 10.299632233774432
```




```
--------------------------------------------------------------------------------
-------
(180000, 50)
Average Energy of Transmitted Signal 1.2e-05
Energy per Bit of Transmitted Signal 3e-06
Variance of WGN 5
Eb/No Ratio is 15.000000000000002
Eb/No Ratio in dB is 11.760912590556813
```


0
50
100
150
200
250
300
350
0
100
200


BER vs $\frac{E_b}{N_0}$ Simulation Results for Channel Encoding-3 given Variance
BER
0.025
0.020
0.015
0.010
0.005
0.000
6
7
8
9
10
11
12
$\frac{E_b}{N_0}$

The Graphs shows us the results of Simulations. X-axis has $\frac{E_b}{N_0}$ in decibal scale and Y-axis as BER(Bit Error Rate). We can observe that as $\frac{E_b}{N_0}$ increases BER decreases.