Digital Communication Lab

Laboratory report submitted for the partial fulfillment
of the requirements for the degree of

Bachelor of Technology
in
Electronics and Communication Engineering

by

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Chapter *5*

Experiment - 5

5.1 Name of the Experiment

Performance analysis of binary modulation schemes (BPSK / OOK) over AWGN channel

5.2 Software Used

- MATLAB
- Simulink

5.3 Theory

5.3.1 About AWGN channel :

Additive white Gaussian noise (AWGN) is a basic noise model used in information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics:

- Additive : it is added to any noise that might be intrinsic to the information system.
- White : refers to the idea that it has **uniform power** across the frequency band for the information system. It is an analogy to the color white which has **uniform emissions** at all frequencies in the **visible spectrum**.
- Gaussian : because it has a normal distribution in the time domain with an average time domain value of zero and variance σ^2.

Wideband noise comes from many natural noise sources, such as the thermal vibrations of atoms in conductors (referred to as thermal noise or Johnson–Nyquist noise), shot noise, black-body radiation from the earth and other warm objects, and from celestial sources such as the Sun. The **central limit theorem** of probability theory indicates that the summation of many random processes will tend to have distribution called **Gaussian** or **Normal**.

5.3.1.1 About Gaussian Random Variable:

Consider the Gaussian random variable of mean μ and variance σ^2. This is represented using the notation N(μ,σ^2). The probability density function $f_X(x)$ is given as :

$$f_X(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{5.1}$$

The **Standard Gaussian Random Variable** is a random variable with **mean** equal to **zero** and **variance** equal to **unity**. The standard Gaussian random variable is represented by N(0,1) and its probability density function $f_X(x)$ is given as :

$$f_X(x) = \frac{1}{\sqrt{(2\pi)}} e^{-\frac{x^2}{2}} \tag{5.2}$$

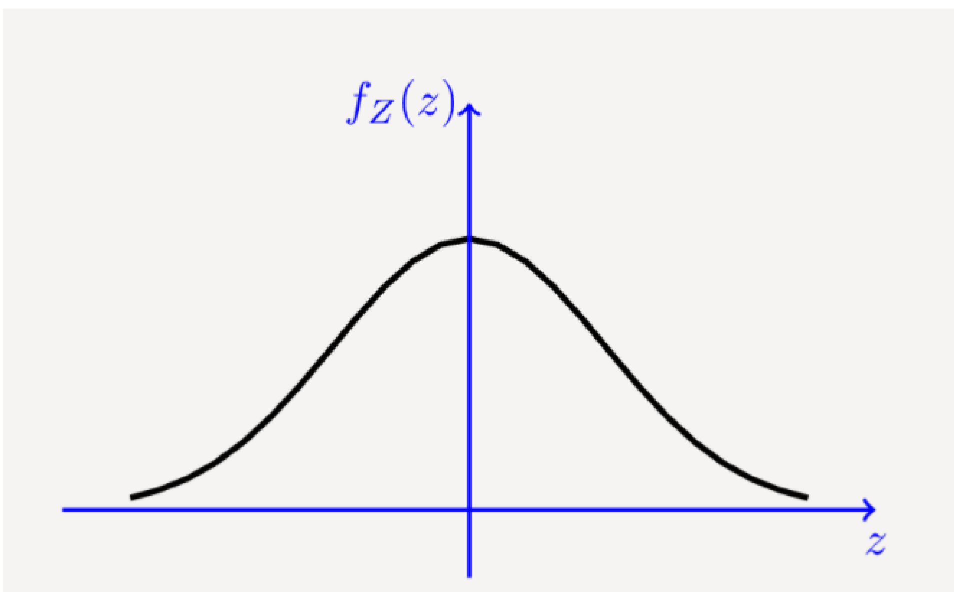

Figure 5.1 PDF of Gaussian Random Variable

Normal distributions are important in **statistics** and are often used in the **natural** and **social sciences** to represent real-valued random variables whose distributions are not known.Their importance is partly due to the **central limit theorem**. It states that, under some conditions, the average of many samples (observations) of a random variable with finite mean and variance is itself a random variable—whose distribution converges to a normal distribution as the number of samples increases. Therefore, physical quantities that are expected to be the sum of many **independent processes**, such as measurement errors, often have distributions that are nearly normal.

5.3.2 About Bit error rate of BPSK Modulation :

This is also called as **2-phase PSK** or **Phase Reversal Keying**. In this technique, the sine wave carrier takes two phase reversals such as 0° and 180°. The Pulse Energy is given by E_b and the transmitted symbols are given as $s_1(t)$ = $\sqrt{E_b}$ and $s_2(t)$ = -$\sqrt{E_b}$ for the information symbols 1 and 0 respectively. The **bit error** would refer to decoding a transmitted $\sqrt{E_b}$ (corresponding to bit 1) erroneously as the 0 bit and vice-versa. The corruption of the detected information symbol stream arises centrally due to presence of the white Gaussian noise at the receiver. Such a channel is called AWGN channel.

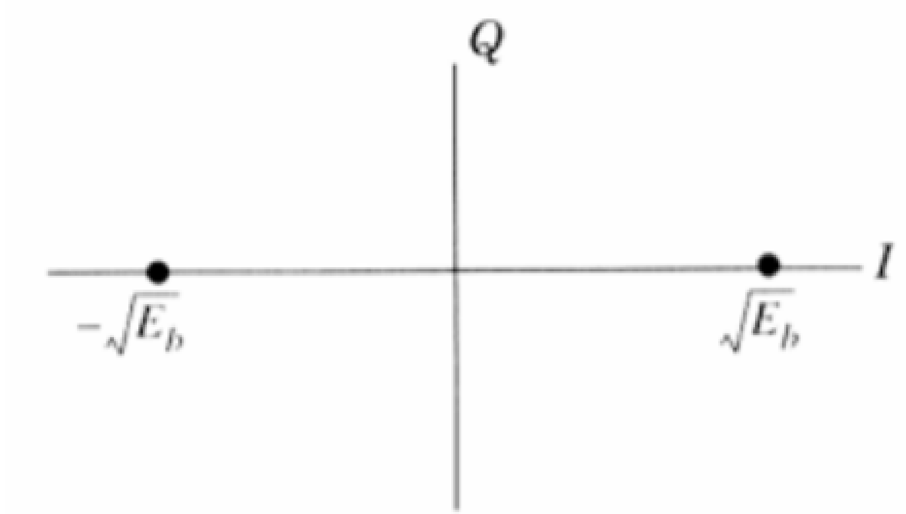

Figure 5.2 Constellation diagram of BPSK Modulation

The two signals are equally likely and let signal $s_1(t)$ is transmitted. Then, received signal from the matched filter (demodulator) is given as :

$$r = s_1 + n = \sqrt{E_b} + n \tag{5.3}$$

where n = N(0,σ^2) is the AWGN at receiver.

According to **ML detection rule** , if r¿=0 then decision is made that $s_1(t)$ is transmitted and if r¡0 then decision is made that $s_2(t)$ is transmitted. The **bit error probability** of BPSK signal for the AWGN channel is :

$$P_{e,BPSK} = Q(\sqrt{\frac{E_b}{\sigma^2}}) = Q(\sqrt{SNR}) \tag{5.4}$$

In the above equation , the term **SNR** = $\frac{E_b}{\sigma^2}$ is the **signal-to-noise ratio** of the AWGN channel.

5.3.3 About Bit error rate of OOK Modulation :

On–off keying (OOK) denotes the simplest form of **amplitude-shift keying (ASK)** modulation that represents digital data as the **presence** or **absence** of a carrier wave. In its simplest form, the **presence of a carrier** for a specific duration represents a **binary one**, while its **absence** for the same duration represents a **binary zero**. On–off keying is most commonly used to **transmit Morse code** over **radio frequencies** (referred to as CW (continuous wave) operation), although in principle any digital encoding scheme may be used. OOK has been used in the **ISM bands** to transfer data between computers. The **constellation diagram** of OOK Modulation is given as :

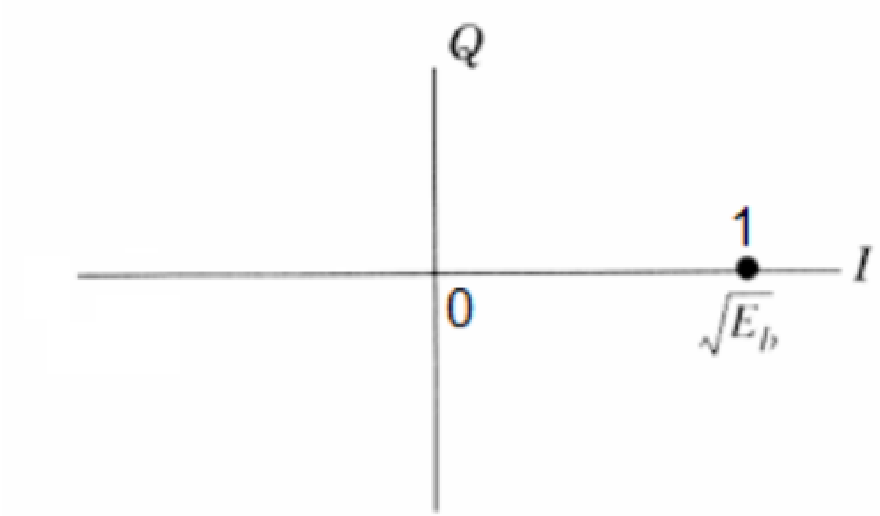

Figure 5.3 Constellation Diagram of OOK Modulation

According to **ML detection rule** , the decision is made that r = n if transmitted symbol is 0 and r = s_1 + n = $\sqrt{E_b}$ + n if transmitted symbol is 1.

The received signal is compared with threshold α = 1/2 and if r ¿= α then decision is made that 1 is transmitted otherwise decision is made that 0 is transmitted. The bit error rate of a OOK signal for the AWGN channel is :

$$P_{e,OOK} = Q(\sqrt{\frac{E_b}{2\sigma^2}}) = Q(\sqrt{SNR/2}) \tag{5.5}$$

5.4 Code and Results

5.4.1 Bit Error Rate of BPSK Modulation :

```
% 19ucc023
% Mohit Akhouri
% Observation 1 - Practical and Theoretical BER of BPSK Modulation

% This code will implement BPSK Modulation and compare the theoretical
 and
% analytical BER

% This code will also plot the graph between Theoretical and Practical
 BER
% vs. Signal to Noise Ratio ( SNR )

clc;
clear all;
close all;

size = 10000; % intializing the size for the random variable and input
 signal
BER_Practical = zeros(1,10); % Initializing the Array to store
 practical values of BER
BER_Theoretical = zeros(1,10); % Initializing the Array to store
 Theoretical values of BER

x=zeros(1,size); % Initializing the array to store the POLAR input
 signal x[n]

% ALGORITHM for initializing a POLAR SIGNALLING x[n]
for i=1:size
    rnd = rand();
    if(rnd>0.5)
        x(i)=1;  % +V in POLAR SIGNALLING
    else
        x(i)=-1; % -V in POLAR SIGNALLING
    end
end

SNR_dB = 0:9; % defining the range of Signal to Noise Ratio ( Measured
 in dB )

% Main loop algorithm for calculation of x[n],y[n], noise "n"
% and calculation of theoretical and practical BER
for i=1:length(SNR_dB)

    SNR=10^((i-1)/10);
    N = 1/SNR;
    M=sqrt(N/2);

    y=zeros(1,size); % to store the output signal y[n] = x[n] + n , n=
 AWGN noise
    n=zeros(1,size); % to store the AWGN noise

    % Loop for calculation of AWGN noise and storing in variable 'n'
```

Figure 5.4 Part 1 of the Code for calculation of BER of BPSK Modulation

```
    for j=1:size
        n(j)=M*randn(); % using randn function to randomly choose any
 integer
    end

    % Loop to calculate the output signal y[n] = x[n] + n, n = AWGN
 noise
    for j=1:size
        y(j)=x(j)+n(j);
    end

    % Main Loop algorithm for ML-Detection of BPSK modulation
    yn=zeros(1,size);
    for j=1:size
        if(y(j)>=0) % Based on decision rule , either +V(1) or -V(-1)
 is choosen
            yn(j)=1;
        else
            yn(j)=-1;
        end
    end

    % Comparing the transmitted and received message signal
    % and calculating the Practical BER
    for j=1:size
        if(x(j)~=yn(j))
            BER_Practical(i)=BER_Practical(i)+1;
        end
    end

    BER_Practical(i)=BER_Practical(i)/size; % Calculation of Practical
 BER
    BER_Theoretical(i)=qfunc(sqrt(2/N));  % Calculation of Theoretical
 BER using Q function

end

% Display of Theoretical and Practical BER
disp(sprintf('%-10s \t %-20s \t %-20s','index','Theoretical
 BER','Practical BER'));
for i=1:10
    disp(sprintf('%-10i %-20d \t
 %-20d',i,BER_Practical(i),BER_Theoretical(i)));
end

% Plots of Practical and Theoretical BER vs. Signal to Noise Ratio
 ( SNR )
% in dB
semilogy(SNR_dB,BER_Practical,'Color','blue'); % semilogy used for
 plotting on base-10 logarithmic scale on Y-axis
hold on;
semilogy(SNR_dB,BER_Theoretical,'Color','red'); % semilogy used for
 plotting on base-10 logarithmic scale on Y-axis
```

Figure 5.5 Part 2 of the Code for calculation of BER of BPSK Modulation

```
ylabel('Bit Error Rate (BER) ->');
xlabel('SNR(dB) ->');
legend('Practical BER','Theoretical BER');
title('19ucc023 - Mohit Akhouri','Plot of Theoretical and Practical
 BER vs. SNR(dB) for BPSK modulation');
grid on;

hold off;
```

Figure 5.6 Part 3 of the Code for calculation of BER of BPSK Modulation

Command Window

index	Theoretical BER	Practical BER
1	7.620000e-02	7.864960e-02
2	5.730000e-02	5.628195e-02
3	3.750000e-02	3.750613e-02
4	2.380000e-02	2.287841e-02
5	1.220000e-02	1.250082e-02
6	7.500000e-03	5.953867e-03
7	2.600000e-03	2.388291e-03
8	4.000000e-04	7.726748e-04
9	2.000000e-04	1.909078e-04
10	1.000000e-04	3.362723e-05

Figure 5.7 Table of Theoretical and Practical values of BER of BPSK Modulation

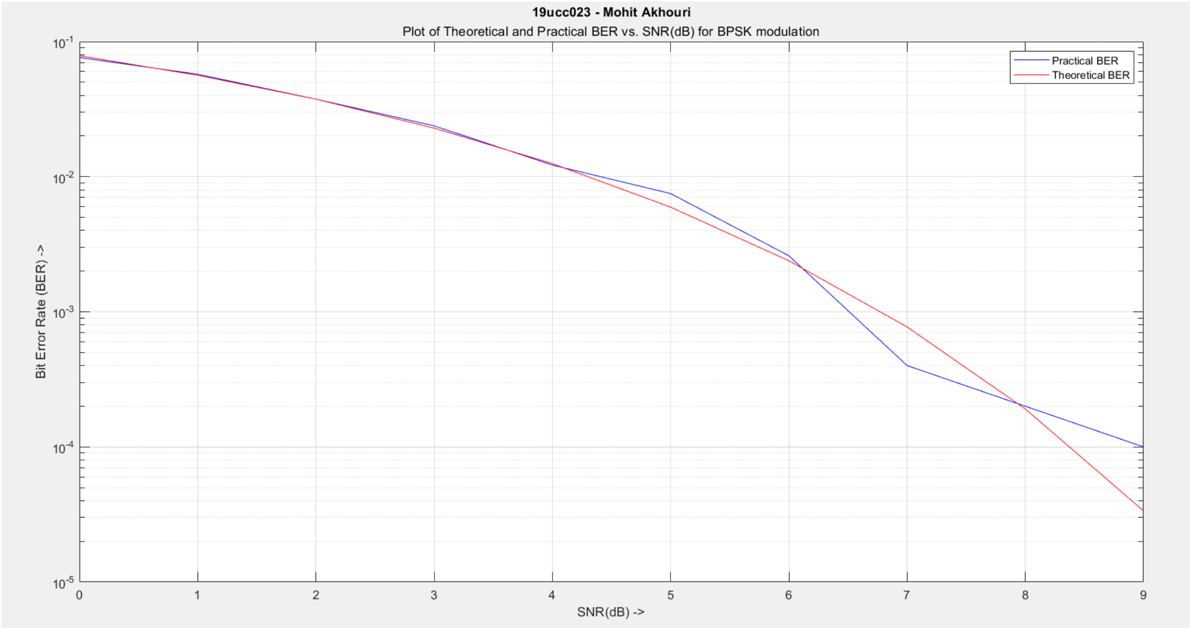

Figure 5.8 Plot of Theoretical and Practical BER vs. SNR (dB) for BPSK Modulation

5.4.1.1 Observation Table for BER of BPSK Modulation :

BER	Analytical BER	Simulated BER
1	0.0762	0.0786
2	0.0573	0.0562
3	0.0375	0.0375
4	0.0238	0.0228
5	0.0122	0.0125
6	0.0075	0.0059
7	0.0026	0.0023
8	0.0004	0.0007
9	0.0002	0.0001
10	0.0001	0.00003

Table 5.1 Analytical BER and Simulated BER for BPSK Modulation

5.4.2 Bit Error Rate of OOK Modulation :

```
% 19ucc023
% Mohit Akhouri
% Observation 2 - Practical and Theoretical BER of OOK Modulation

% This code will implement OOK Modulation and compare the theoretical
 and
% analytical BER

% This code will also plot the graph between Theoretical and Practical
 BER
% vs. Signal to Noise Ratio ( SNR )

clc;
clear all;
close all;

size = 10000; % intializing the size for the random variable and input
 signal
BER_Practical = zeros(1,10); % Initializing the Array to store
 practical values of BER
BER_Theoretical = zeros(1,10); % Initializing the Array to store
 Theoretical values of BER

x=zeros(1,size); % Initializing the array to store the POLAR input
 signal x[n]

% ALGORITHM for initializing a UNI-POLAR SIGNALLING x[n]
for i=1:size
    rnd = rand();
    if(rnd>0.5)
        x(i)=1;  % +V in UNI-POLAR SIGNALLING
    else
        x(i)=0; % 0 in UNI-POLAR SIGNALLING
    end
end

SNR_dB = 0:9; % defining the range of Signal to Noise Ratio ( Measured
 in dB )

% Main loop algorithm for calculation of x[n],y[n], noise "n"
% and calculation of theoretical and practical BER
for i=1:length(SNR_dB)

    SNR=10^((i-1)/10);
    N = 1/SNR;
    M=sqrt(N/2);

    y=zeros(1,size); % to store the output signal y[n] = x[n] + n , n=
 AWGN noise
    n=zeros(1,size); % to store the AWGN noise

    % Loop for calculation of AWGN noise and storing in variable 'n'
```

Figure 5.9 Part 1 of the Code for calculation of BER of OOK Modulation

```
    for j=1:size
        n(j)=sqrt(1/2)*M*randn(); % using randn function to randomly
 choose any integer
    end

    % Loop to calculate the output signal y[n] = x[n] + n, n = AWGN
 noise
    for j=1:size
        y(j)=x(j)+n(j);
    end

    % Main Loop algorithm for ML-Detection of OOK modulation
    yn=zeros(1,size);
    for j=1:size
        if(y(j)>=0.5) % Based on decision rule , either +V(1) or 0 is
 choosen
            yn(j)=1;
        else
            yn(j)=0;
        end
    end

    % Comparing the transmitted and received message signal
    % and calculating the Practical BER
    for j=1:size
        if(x(j)~=yn(j))
            BER_Practical(i)=BER_Practical(i)+1;
        end
    end

    BER_Practical(i)=BER_Practical(i)/size; % Calculation of Practical
 BER
    BER_Theoretical(i)=qfunc(sqrt(1/N));  % Calculation of Theoretical
 BER using Q function

end

% Display of Theoretical and Practical BER
disp(sprintf('%-10s \t %-20s \t %-20s','index','Theoretical
 BER','Practical BER'));
for i=1:10
    disp(sprintf('%-10i %-20d \t
 %-20d',i,BER_Practical(i),BER_Theoretical(i)));
end

% Plots of Practical and Theoretical BER vs. Signal to Noise Ratio
 ( SNR )
% in dB
semilogy(SNR_dB,BER_Practical,'Color','blue'); % semilogy used for
 plotting on base-10 logarithmic scale on Y-axis
hold on;
semilogy(SNR_dB,BER_Theoretical,'Color','red'); % semilogy used for
 plotting on base-10 logarithmic scale on Y-axis
```

Figure 5.10 Part 2 of the Code for calculation of BER of OOK Modulation

```
ylabel('Bit Error Rate (BER) ->');
xlabel('SNR(dB) ->');
legend('Practical BER','Theoretical BER');
title('19ucc023 - Mohit Akhouri','Plot of Theoretical and Practical
 BER vs. SNR(dB) for OOK modulation');
grid on;

hold off;
```

Figure 5.11 Part 3 of the Code for calculation of BER of OOK Modulation

index	Theoretical BER	Practical BER
1	1.565000e-01	1.586553e-01
2	1.282000e-01	1.309273e-01
3	1.030000e-01	1.040286e-01
4	7.780000e-02	7.889587e-02
5	5.390000e-02	5.649530e-02
6	3.420000e-02	3.767899e-02
7	2.290000e-02	2.300714e-02
8	1.420000e-02	1.258703e-02
9	5.700000e-03	6.004386e-03
10	3.100000e-03	2.413310e-03

Figure 5.12 Table of Theoretical and Practical values of BER of OOK Modulation

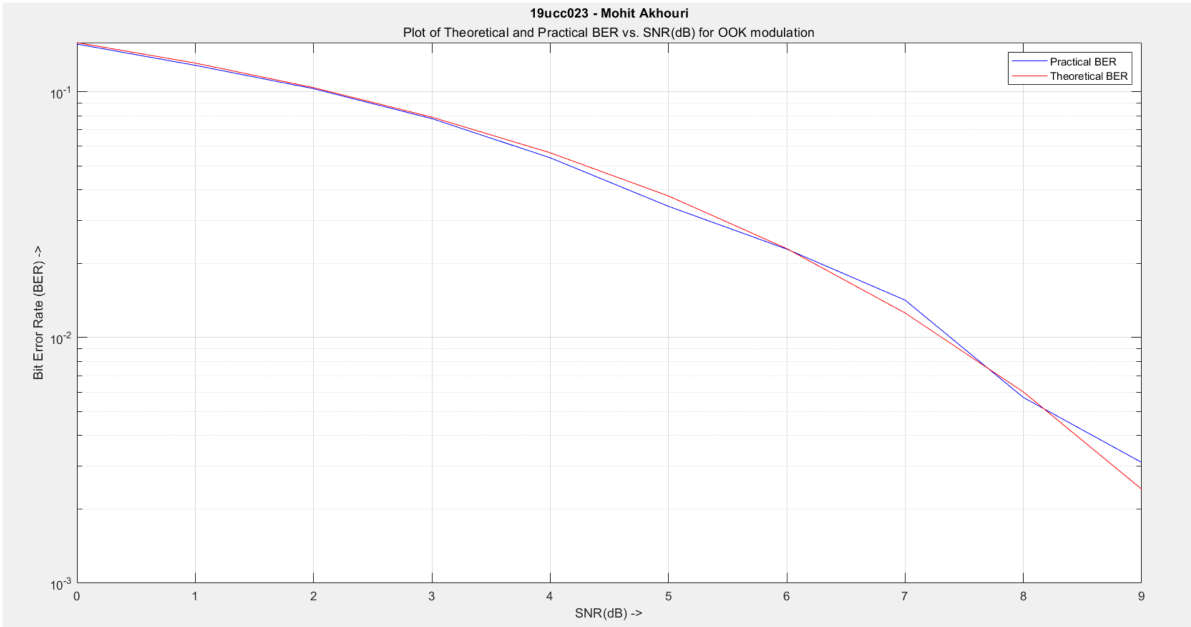

Figure 5.13 Plot of Theoretical and Practical BER vs. SNR (dB) for OOK Modulation

5.4.2.1 Observation Table for BER of OOK Modulation :

BER	Analytical BER	Simulated BER
1	0.1565	0.1586
2	0.1282	0.1309
3	0.1030	0.1040
4	0.0778	0.0788
5	0.0539	0.0564
6	0.0342	0.0376
7	0.0229	0.0230
8	0.0142	0.0125
9	0.0057	0.0060
10	0.0031	0.0024

Table 5.2 Analytical BER and Simulated BER for OOK Modulation

5.5 Conclusion

In this experiment , we learnt about two types of Modulation **BPSK Modulation** and **OOK Modulation**. We analysed how to generate the BPSK and OOK waveforms and calculate their Bit-Error rate. We learnt about important concepts like the **AWGN noise** and how it affects the Bit error rate. We also learnt about **Q-function** and how to calculate Theoretical BER of both BPSK and OOK Modulation. We implemented the codes in MATLAB and analysed the results. We also plotted the graph between BER and SNR (in dB) and verified the results.