HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY

MINI-PROJECT REPORT

Digital modulation and demodulation techniques

NGUYEN TUAN HIEP
hiep.nt205151@sis.hust.edu.vn

NGUYEN MINH HUY
huy.nm205158@sis.hust.edu.vn

NGUYEN HOANG HAI
hai.nh200193@sis.hust.edu.vn

GROUP 9

Supervisor: Professor: Trinh Van Chien ______________

Signature

Department: Computer Engineering

School: School of Information and Communications Technology

HANOI, 02/2023

TABLE OF CONTENTS

CHAPTER 1. Introduction

1.1 Problem Statement

Digital modulation and demodulation is an important aspect of modern communication systems, but it also poses several challenges that need to be addressed. Some of the major problems associated with digital modulation and demodulation are:

Interference: In a communication system, the digital signal may be disturbed by various types of interference such as thermal noise, atmospheric noise, or electromagnetic interference. This can cause the digital signal to become corrupted, leading to errors in the demodulated signal.

Channel Distortion: The signal may also be distorted by the communication channel, leading to a reduction in signal quality. This can result in signal degradation, increased bit error rate (BER), and decreased system performance.

Bandwidth Requirements: Digital modulation schemes require a larger bandwidth compared to analog modulation schemes. This can be a problem for systems that have limited bandwidth resources, such as satellite communication systems or low-frequency radio communication systems.

Complexity: Digital modulation and demodulation require complex algorithms and signal processing techniques to be implemented in the communication system. This adds to the complexity of the system and increases the risk of errors and system failure.

Power Consumption: The complexity of digital modulation and demodulation algorithms increases the power consumption of the communication system, making it more challenging to design energy-efficient communication systems.

1.2 Organization of Report

In this report, we will discuss the three fundamental digital modulation techniques - Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Frequency Shift Keying (FSK). The purpose of this report is to provide a comprehensive overview of these digital modulation techniques and their applications in modern communication systems.

Chapter 2: Amplitude Shift Keying (ASK). In this chapter, we will discuss the basics of Amplitude Shift Keying (ASK), including its modulation, demodulation with and without noise. We will also study the performance evaluation metrics on the demodulation, e.g. Bit Error Rate (BER).

Chapter 3: Phase Shift Keying (PSK). In this chapter, we will discuss the principles of Phase Shift Keying (PSK), including its definition, key characteristics, and basic operation. We also explore the demodulation of PSK under the effect of Additive White Gaussian Noise.

Chapter 4: Frequency Shift Keying (FSK). In this chapter, we will discuss the basics of Frequency Shift Keying (FSK), including its definition, principle of operation, and key characteristics. We will also provide an overview of the different types of FSK, including Binary Frequency Shift Keying ($BFSK$) and Quadrature Frequency Shift Keying ($QFSK$). We also explore the effects of noise on the performance of FSK modulation.

2.1 Overview

Amplitude-shift keying (ASK) is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. In an ASK system, a symbol, representing one or more bits, is sent by transmitting a fixed-amplitude carrier wave at a fixed frequency for a specific time duration.

In this project, we will perform the ASK modulation and demodulation of a random binary signal and analyze the performance of the ASK system with and without the effects of additive white Gaussian noise ($AWGN$).

2.2 Perform ASK modulation

- We generate a random binary sequence with length is 500, and visualize as follows.

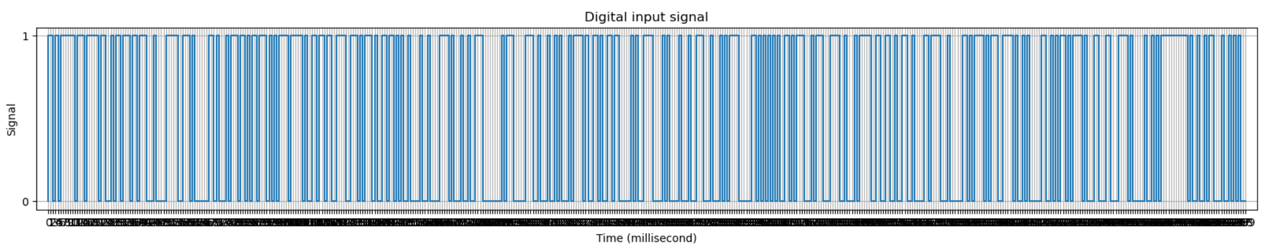


Figure 2.1: Binary sequence

- After generating random binary sequence, we choose carrier signal. We choose cosine wave $\cos(2\pi f_c t)$, where f_c is the frequency of carrier signal and t is the time, multiply with amplitude 1 for signal 0 and amplitude 1.5 for signal 1.

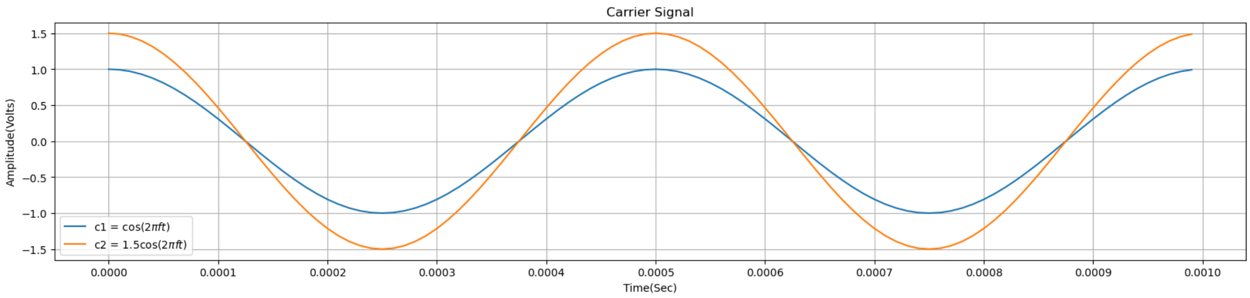


Figure 2.2: Carrier signal

- Performing ASK Modulation and Plotting the ASK Modulated Signal: The final step is to perform the ASK modulation of the binary data sequence using the carrier signals. The ASK modulated signal is generated by multiplying the binary data sequence with the carrier signals.

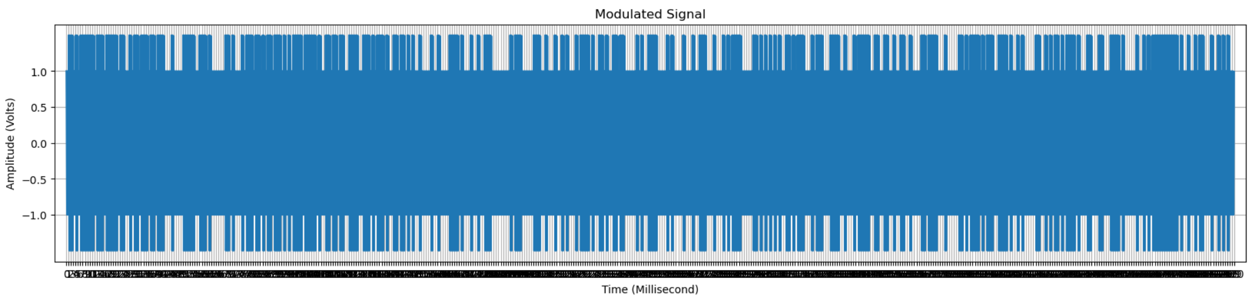


Figure 2.3: ASK modulated signal

2.3 Perform ASK demodulation

The method in ASK demodulation is to correlate the ASK modulated signal with the carrier signals. The purpose of correlation is to generate decision variables that will be used to determine the demodulated binary data. The correlation is performed using the Maximum Likelihood Criterion, which is a mathematical method that determines the most likely value of the demodulated binary data based on the ASK modulated signal and the carrier signals. This will define whether the demodulated binary data is 0 or 1.

In this figure, we haven't added the noise yet, so the demodulated signal is exactly the same as input signal.

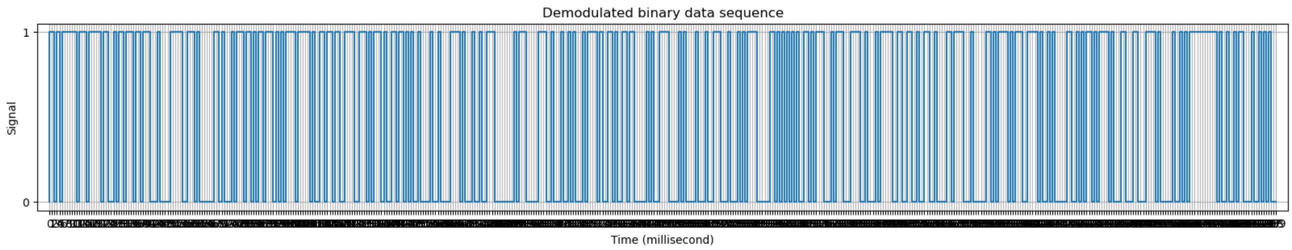


Figure 2.4: ASK demodulated signal

2.4 ASK modulation and demodulation under the effects of Gaussian noise

Gaussian noise is a type of random noise that is commonly present in communication systems. It is characterized by a zero mean and a variance of $N_0/2$. A low value of N_0 indicates a low level of noise, while a high value of N_0 indicates a high level of noise. The value of N_0 can be used in conjunction with the SNR to determine the error rate in the system, as well as to design and evaluate the performance of communication systems. The noise is added to the transmitted waveform as $r(t) = s(t) + n(t)$, where $s(t)$ is the transmitted waveform and $n(t)$ is the Gaussian noise.

For this part, we choose $N_0 = 2$, which makes the standard variation to be 1.

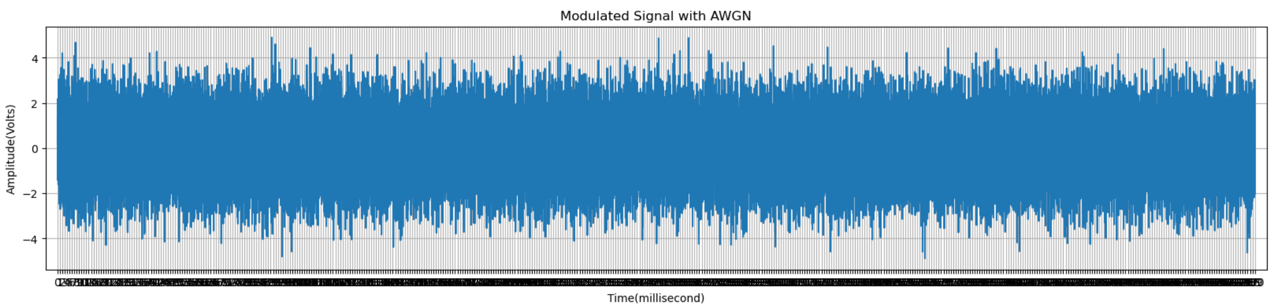


Figure 2.5: Modulated signal under the effect of $AWGN$

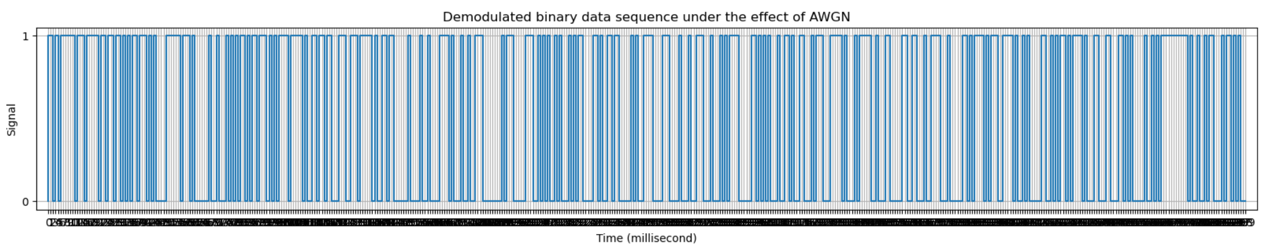


Figure 2.6: Demodulated signal under the effect of $AWGN$

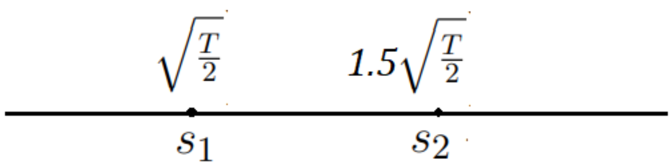
2.5 Compute the Error rate

The error probability is calculated by comparing the original binary data sequence with the demodulated binary data under the effect of noise. The number of difference bits between the input and output bits divided by the total number of input bits represent the bit error rate.

Bit error rate: $P(e) = P(u_R[i] \neq u_T[i])$

From the above experiment, it can be seen that there are 23 bits difference between the input binary sequence and the demodulated signal after adding the noise, therefore the $P(e) = \frac{23}{500} = 4.6\%$

2.6 Derive the BER of a Gaussian channel using the ASK modulation and demodulation



We have:

$$M = \{s_1(t) = A\cos(2\pi f_c t), s_2(t) = kA\cos(2\pi f_c t)\}$$
$$E_1 = \int_0^T A^2\cos^2(2\pi f_c t)\,dt = \frac{A^2T}{2}$$
$$E_2 = \frac{k^2A^2T}{2}$$
$$\Rightarrow E_S = \frac{E_1+E_2}{2} = \frac{k^2+1}{4}A^2T \Rightarrow E_b = \frac{k^2+1}{4}A^2T$$
$$\varphi_1(t) = \frac{s_1(t)}{\sqrt{E_1}} = \sqrt{\frac{2}{T}}\cos(2\pi f_c t)$$
$$s_{21} = \int_0^T kA\cos^2(2\pi f_c t) = kA\sqrt{\frac{T}{2}}$$
$$g_2 = s_2 - s_{21}\varphi_1(t) = kA\cos(2\pi f_c t) - kA\sqrt{\frac{T}{2}}\sqrt{\frac{2}{T}}\cos(2\pi f_c t) = 0 \Rightarrow \varphi_2 = 0$$
$$\Rightarrow \text{Orthogonal basis : } B = \left\{\varphi_1 = \sqrt{\frac{2}{T}}\cos(2\pi f_c t)\right\}$$
$$\Rightarrow \text{Constellation signal :} M = \left\{s_1\left(A\sqrt{\frac{T}{2}}\right), s_2\left(kA\sqrt{\frac{T}{2}}\right)\right\}$$
$$\text{In this project, } A = 1,\ k = 1.5,\ \text{ hence : } s_1\left(\sqrt{\frac{T}{2}}\right), s_2\left(1.5\sqrt{\frac{T}{2}}\right)$$
$$P(e|s_T = s_1) = P(\rho \in V(s_2)|s_T = s_1) = P\left(\rho > \frac{5}{4}\sqrt{\frac{T}{2}}\right)$$
$$= P\left(\sqrt{\frac{T}{2}} + n > \frac{5}{4}\sqrt{\frac{T}{2}}\right) = P\left(n > \frac{1}{4}\sqrt{\frac{T}{2}}\right) = \frac{1}{2}erfc\left(\frac{1}{4}\sqrt{\frac{T}{2N_0}}\right)$$
$$P(e|s_T = s_2) = P(\rho \in V(s_1)|s_T = s_2) = P\left(\rho < \frac{5}{4}\sqrt{\frac{T}{2}}\right)$$
$$= P\left(1.5\sqrt{\frac{T}{2}} + n < \frac{5}{4}\sqrt{\frac{T}{2}}\right) = P\left(n < -\frac{1}{4}\sqrt{\frac{T}{2}}\right) = P\left(n > \frac{1}{4}\sqrt{\frac{T}{2}}\right) = \frac{1}{2}erfc\left(\frac{1}{4}\sqrt{\frac{T}{2N_0}}\right)$$
$$\Rightarrow P(e) = \frac{1}{2}\Big[P(e|s_T = s_1) + P(e|s_T = s_2)\Big] = \frac{1}{2}erfc\left(\frac{1}{4}\sqrt{\frac{T}{2N_0}}\right) = \frac{1}{2}erfc\left(\sqrt{\frac{E_b}{26N_0}}\right)$$

2.7 Plot the Bit error rate between simulation and theory for ASK

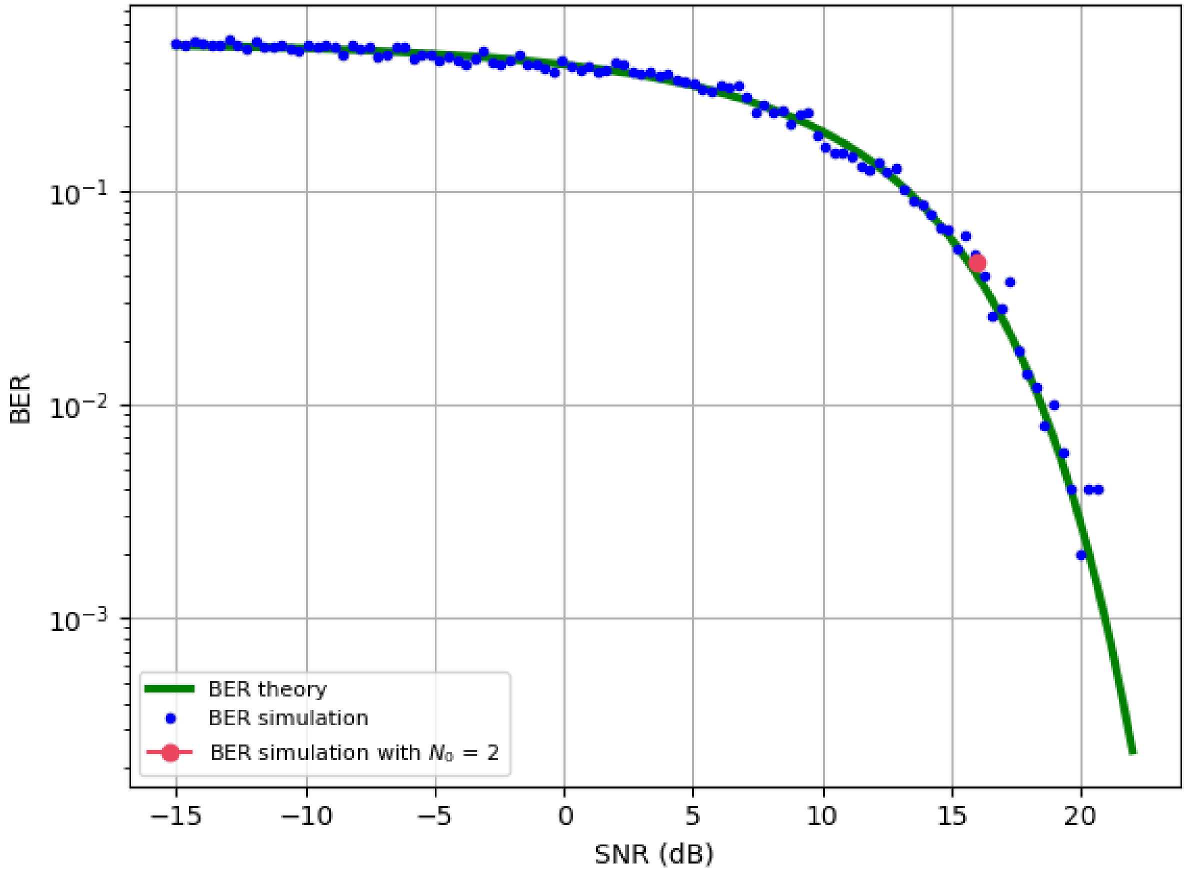


Figure 2.7: BER plot for $2-ASK$

3.1 Overview

Phase Shift Keying (PSK) is a digital modulation technique that transmits the data through changes in the phase of a carrier signal. It is a popular method of communication because of its robustness against noise and its ability to transmit data at high rates. PSK is used in various applications such as radio and satellite communication, wireless communication, and digital audio broadcasting. In this project, we will perform the PSK modulation and demodulation of a random binary signal and analyze the performance of the PSK system with and without the effects of additive white Gaussian noise.

3.2 Perform the PSK modulation

- Generating and Plotting the Carrier Signals: The first step in PSK modulation is to generate the carrier signals. The carrier signals are cosine waves with a phase usually of either 0 or π. If the binary data is 0, the carrier signal is $\cos(2\pi f_c t)$, and if the carrier signal is 1, the carrier signal is $\cos(2\pi f_c t + \pi)$, where f_c is the frequency of carrier signal and t is the time. These carrier signals are then plotted to visualize the waveform.

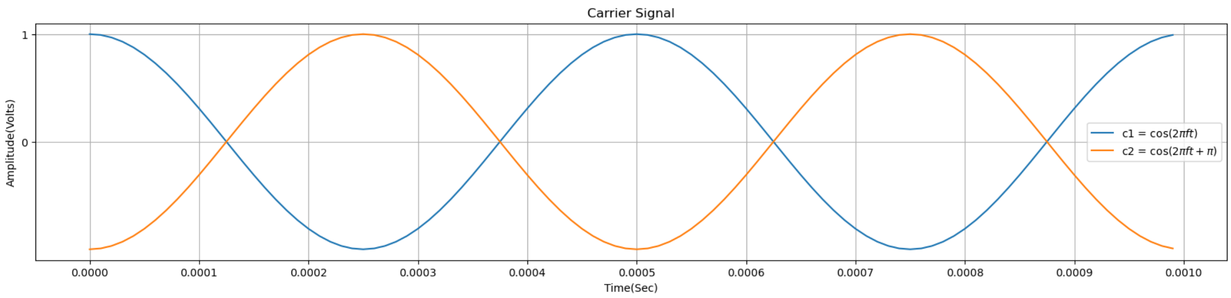


Figure 3.1: Carrier signal

- Generating and Plotting the Binary Data Sequence: The next step is to generate a random binary data sequence, which consist of $1s$ and $0s$. In this assignment, I use a stream bit with the length of 500. The binary data sequence is then plotted to visualize the pattern of data.

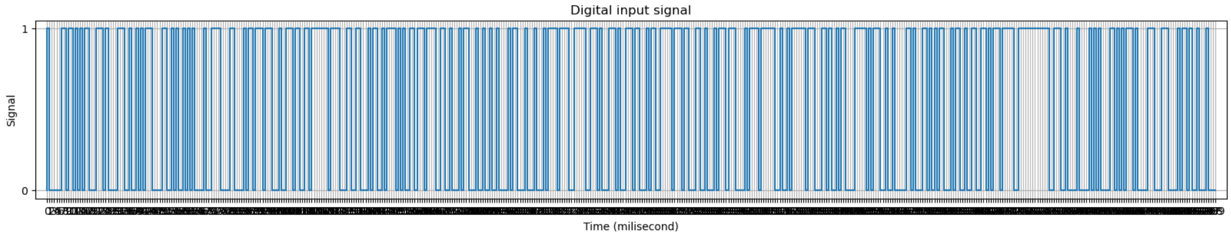


Figure 3.2: Binary data sequence

- Performing PSK Modulation and Plotting the PSK Modulated Signal: The final step is to perform the PSK modulation of the binary data sequence using the carrier signals. The PSK modulated signal is generated by multiplying the binary data sequence with the carrier signals. The PSK modulated signal is then plotted to visualize the waveform with the help of $matplotlib$ library.

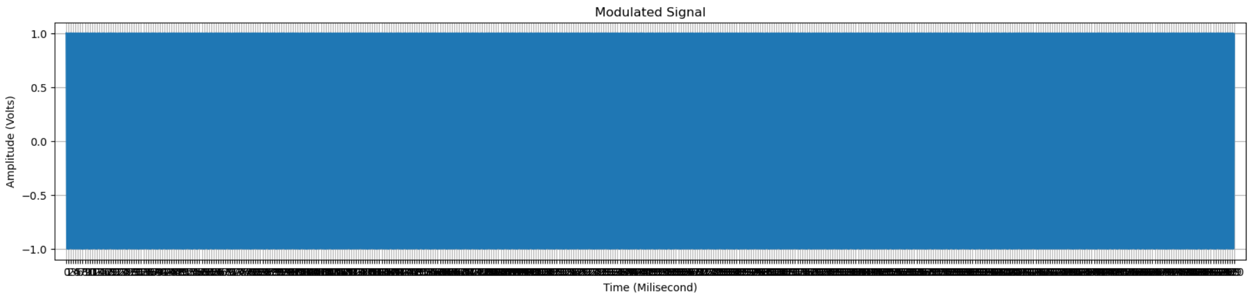


Figure 3.3: Modulated signal

3.3 Perform the PSK demodulation

The method in PSK demodulation is to correlate the PSK modulated signal with the carrier signals. The purpose of correlation is to generate decision variables that will be used to determine the demodulated binary data. The correlation is performed using the Maximum Likelihood Criterion, which is a mathematical method that determines the most likely value of the demodulated binary data based on the PSK modulated signal and the carrier signals. This will define whether the demodulated binary data is 0 or 1.

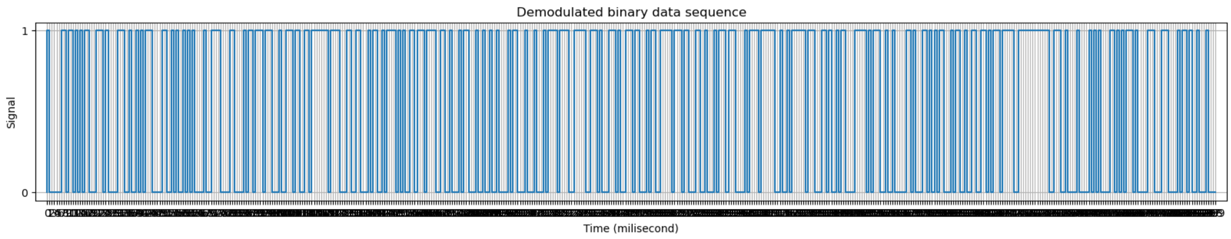


Figure 3.4: Demodulated signal

3.4 PSK modulation and demodulation under the effects of Gaussian noise

Gaussian noise is a type of random noise that is commonly present in communication systems. It is characterized by a zero mean and a variance of $N_0/2$. A low value of N_0 indicates a low level of noise, while a high value of N_0 indicates a high level of noise. The value of N_0 can be used in conjunction with the SNR to determine the error rate in the system, as well as to design and evaluate the performance of communication systems. The noise is added to the transmitted waveform as $r(t) = s(t) + n(t)$, where $s(t)$ is the transmitted waveform and $n(t)$ is the Gaussian noise. In the project, I choose $N_0 = 18$, which makes the standard variation to be 3.

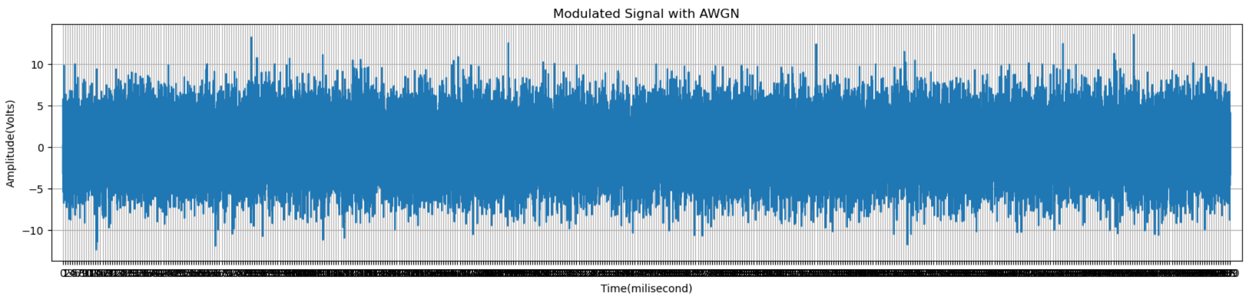


Figure 3.5: Modulated signal under the effect of $AWGN$

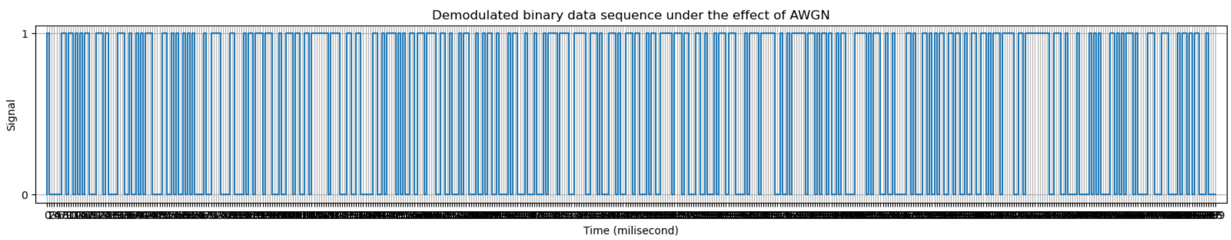


Figure 3.6: Demodulated signal under the effect of $AWGN$

3.5 Compute the Error rate

The error probability is calculated by comparing the original binary data sequence with the demodulated binary data under the effect of noise. The number of difference bits between the input and output bits divided by the total number of input bits represent the bit error rate. For $2-PSK$, one symbol (carrier phase) represents one bit and hence symbol rate equals bit rate.

Bit error rate: $P(e) = P(u_R[i] \neq u_T[i])$

From the above experiment, it can be seen that there is 6 bit difference between the input binary sequence and the demodulated signal after adding the noise, therefore the $P(e) = \frac{6}{500} = 1.2\%$

3.6 Derive the BER of a Gaussian channel using the PSK modulation and demodulation

We have:

$$
\begin{aligned}
M &= \Big\{ s_1(t) = \cos(2\pi f_c t),\ s_2(t) = \cos(2\pi f_c t + \pi) \Big\} \\
E_1 &= \int_{-\infty}^{\infty} s_1^2(t)\,dt = \int_0^{T_b} \cos^2(2\pi f_c t)\,dt = \frac{1}{2}\int_0^{T_b} \Big[1 + cos(4\pi f_c t)\Big]\,dt \\
&= \frac{1}{2}T_b + \frac{1}{2}\int_0^{T_b} \cos(4\pi f_c t)\,\frac{d(4\pi f_c t)}{4\pi f_c} = \frac{T_b}{2} + \frac{1}{8\pi f_c}\sin(4\pi f_c t)\Big|_0^{T_b} \\
&= \frac{T_b}{2} + \frac{\sin(4\pi f_c T_b)}{8\pi f_c}
\end{aligned}
$$

In this project, I choose f_c = $2\times$ bit rate = $\frac{2}{T_b}$, therefore $E_1 = \frac{T_b}{2}$. Similarly:

$$
\begin{aligned}
E_2 &= \int_{-\infty}^{\infty} s_2^2(t)\,dt = \int_0^{T_b} \cos^2(2\pi f_c t + \pi)\,dt = \int_0^{T_b} (-\cos(2\pi f_c t))^2\,dt \\
&= \int_0^{T_b} \cos^2(2\pi f_c t)\,dt = \frac{T_b}{2} \\
E_s &= \frac{E_1 + E_2}{2} = \frac{T_b}{2} \Rightarrow E_b = \frac{E_b}{k} = \frac{T_b}{2} \\
\varphi_1(t) &= \frac{s_1(t)}{\sqrt{E_1}} = \sqrt{\frac{2}{T_b}}\cos\left(\frac{4\pi t}{T_b}\right) \Rightarrow s_{21} = \int_0^{T_b} s_2(t)\varphi_1(t)\,dt = -\sqrt{\frac{T_b}{2}} \\
g_2(t) &= s_2(t) - s_{21}(t).\varphi_1(t) = -\cos\left(\frac{4\pi t}{T_b}\right) - \left[-\cos\left(\frac{4\pi t}{T_b}\right)\right] = 0 \Rightarrow \varphi_2(t) = 0
\end{aligned}
$$

Then we have $B = \left\{\varphi_1(t) = \sqrt{\frac{2}{T_b}} \cos\left(\frac{4\pi t}{T_b}\right)\right\}$ is the orthonormal basis. M can be written as below with respect to B:

$$M = \left\{s_1\left(\sqrt{E_b}\right),\ s_2\left(-\sqrt{E_b}\right)\right\}$$

According to the BER computation:

$$P\left(e|s_T = s_1\right) = P\left(\sqrt{E_b} + n < 0\right) = P\left(n < -\sqrt{E_b}\right) = P\left(n > \sqrt{E_b}\right)$$
$$P\left(e|s_T = s_2\right) = P\left(n > \sqrt{E_b}\right)$$
$$P(e) = \frac{P\left(e|s_T = s_1\right) + P\left(e|s_T = s_2\right)}{2} = P\left(n > \sqrt{E_b}\right) = \frac{1}{2}erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$

3.7 Plot the Bit error rate between simulation and theory for PSK

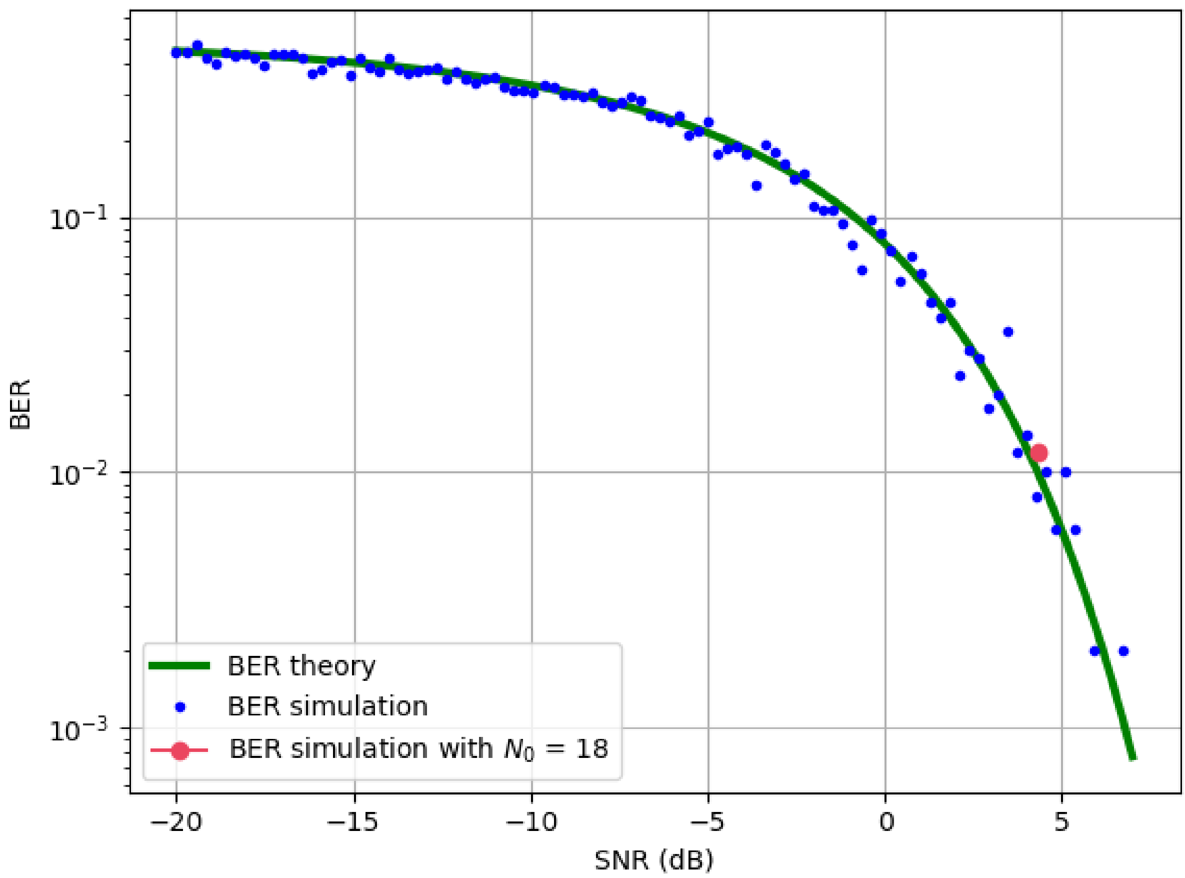


Figure 3.7: BER plot for $2-PSK$

4.1 Overview

Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is encoded on a carrier signal by periodically shifting the frequency of the carrier between several discrete frequencies. The technology is used for communication systems such as telemetry, weather balloon radiosondes, caller ID, garage door openers, and low frequency radio transmission in the VLF and ELF bands. The simplest FSK is $binary\ FSK$ ($BFSK$), in which the carrier is shifted between two discrete frequencies to transmit binary (0s and 1s) information.

4.2 Perform the FSK modulation

- Generating and Plotting the Carrier Signals: The first step in FSK modulation is to generate the carrier signals. The carrier signals are 2 cosine waves with same amplitude and phase but different frequencies. $0s$ are represented by $\cos(2\pi f_1 t)$ and $1s$ are represented by $\cos(2\pi f_2 t)$ and $f_2 = 2 \times f_1$

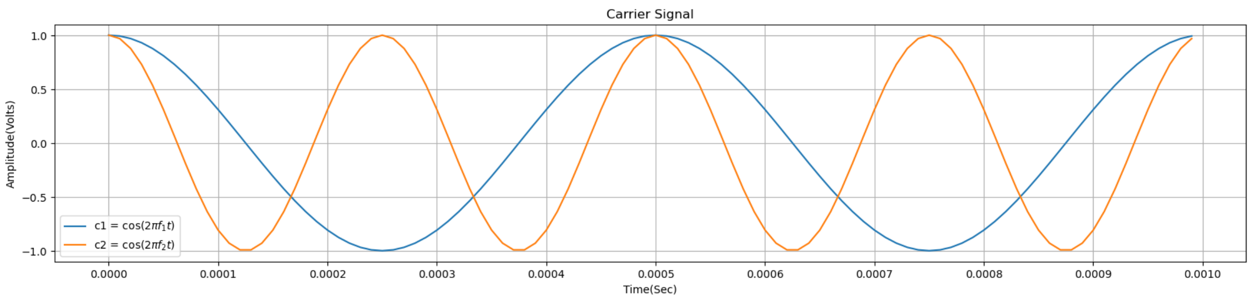


Figure 4.1: Carrier signal

- Generating and Plotting the Binary Data Sequence: The next step is to generate a random binary data sequence, which consist of $1s$ and $0s$. In this assignment, I use a stream bit with the length of 500. The binary data sequence is then plotted to visualize the pattern of data.

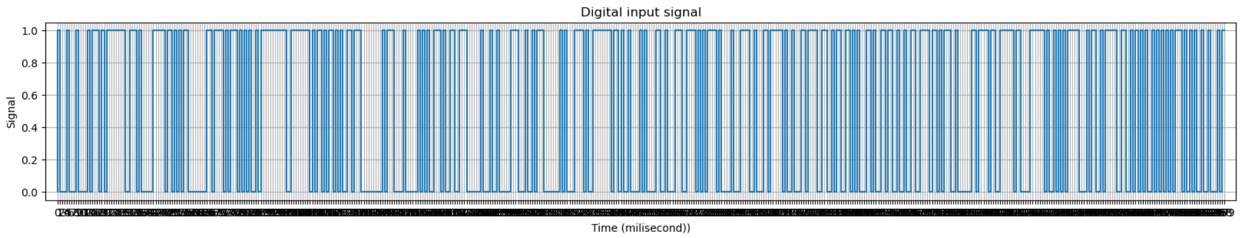


Figure 4.2: Binary data sequence

- Performing FSK Modulation and Plotting the FSK Modulated Signal: The final step is to perform the FSK modulation of the binary data sequence using the carrier signals. The FSK modulated signal is generated by multiplying the binary data sequence with the carrier signals. The FSK modulated signal is then plotted to visualize the waveform with the help of $matplotlib$ library.

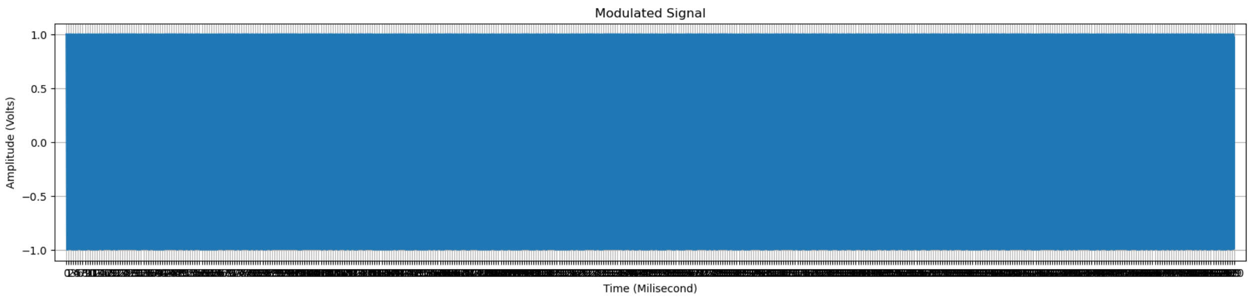


Figure 4.3: Modulated signal

4.3 Perform the FSK demodulation

The method in FSK demodulation is to correlate the FSK modulated signal with the carrier signals. The purpose of correlation is to generate decision variables that will be used to determine the demodulated binary data. The correlation is performed using the Maximum Likelihood Criterion, which is a mathematical method that determines the most likely value of the demodulated binary data based on the FSK modulated signal and the carrier signals. This will define whether the demodulated binary data is 0 or 1.

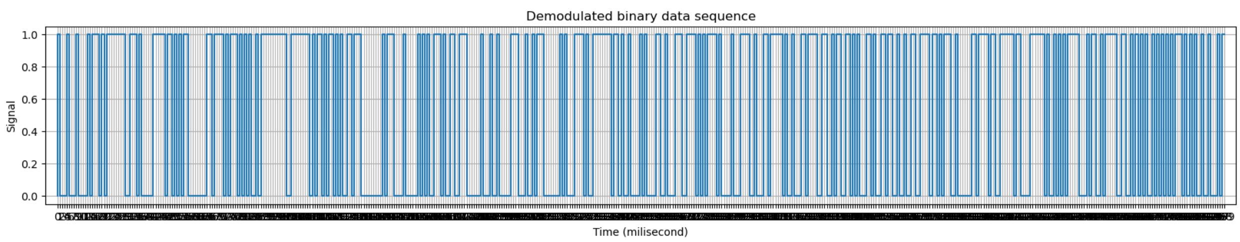


Figure 4.4: Demodulated signal

4.4 FSK modulation/demodulation under the effects of Gaussian noise

Gaussian noise is a type of random noise that is commonly present in communication systems. It is characterized by a zero mean and a variance of $N_0/2$. A low value of N_0 indicates a low level of noise, while a high value of N_0 indicates a high level of noise. The value of N_0 can be used in conjunction with the SNR to determine the error rate in the system, as well as to design and evaluate the performance of communication systems. The noise is added to the transmitted waveform as $r(t) = s(t) + n(t)$, where $s(t)$ is the transmitted waveform and $n(t)$ is the Gaussian noise. In the project, I choose $N_0 = 18$, which makes the standard variation to be 3.

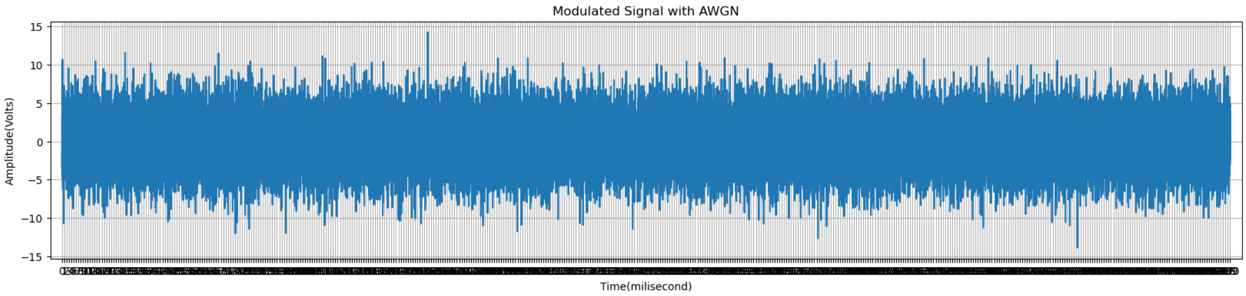


Figure 4.5: Modulated signal under the effect of $AWGN$

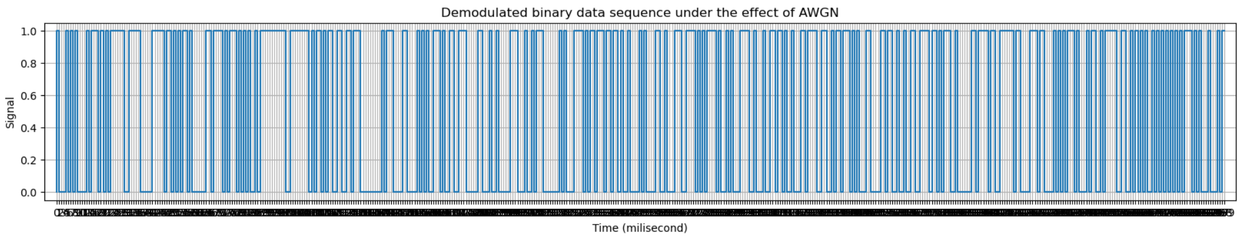


Figure 4.6: Demodulated signal under the effect of $AWGN$

4.5 Compute the Error rate

The error probability is calculated by comparing the original binary data sequence with the demodulated binary data under the effect of noise. The number of difference bits between the input and output bits divided by the total number of input bits represent the bit error rate.

Bit error rate: $P(e) = P(u_R[i] \neq u_T[i])$

From the above experiment, it can be seen that there are 32 bits difference between the input binary sequence and the demodulated signal after adding the noise, therefore the $P(e) = \frac{32}{500} = 6.4\%$

4.6 Derive the BER of a Gaussian channel using the FSK modulation and demodulation

We have:

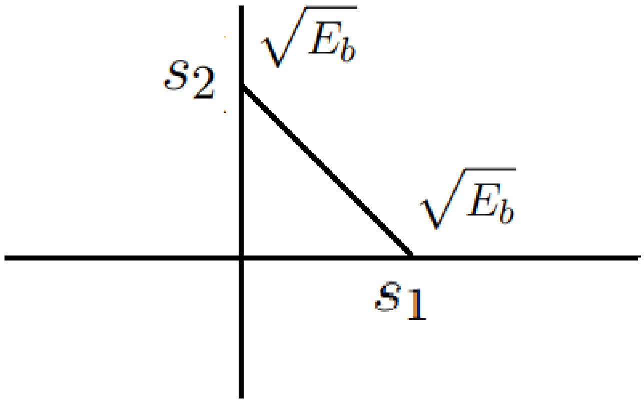
$$\begin{aligned}
M &= \Big\{s_1(t) = \cos(2\pi f_1 t),\ s_2(t) = \cos(2\pi f_2 t)\Big\} \\
E_1 &= \int_{-\infty}^{\infty} s_1^2(t)\,dt = \int_0^{T_b} \cos^2(2\pi f_1 t)\,dt = \frac{1}{2}\int_0^{T_b} \big[1 + cos(4\pi f_1 t)\big]\,dt \\
&= \frac{1}{2}T_b + \frac{1}{2}\int_0^{T_b} \cos(4\pi f_1 t)\,\frac{d(4\pi f_1 t)}{4\pi f_1} = \frac{T_b}{2} + \frac{1}{8\pi f_1}\sin(4\pi f_1 t)\Big|_0^{T_b} \\
&= \frac{T_b}{2} + \frac{\sin(4\pi f_1 T_b)}{8\pi f_1}
\end{aligned}$$

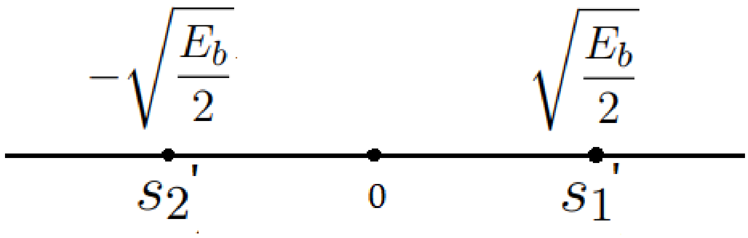
In this project, I choose f_1 = $2\times$ bit rate = $\frac{2}{T_b}$ and f_2 = $4\times$ bit rate = $\frac{4}{T_b}$, therefore $E_1 = \frac{T_b}{2}$.

$$\begin{aligned}
E_2 &= \int_{-\infty}^{\infty} s_2^2(t)\,dt = \int_0^{T_b} \cos^2(2\pi f_2 t)\,dt = \frac{T_b}{2} \\
E_s &= \frac{E_1 + E_2}{2} = \frac{T_b}{2} \Rightarrow E_b = \frac{E_b}{k} = \frac{T_b}{2}\ (k = 1) \\
\varphi_1(t) &= \frac{s_1(t)}{\sqrt{E_1}} = \sqrt{\frac{2}{T_b}}\cos\left(\frac{4\pi t}{T_b}\right) \\
s_{21}(t) &= \int_0^{T_b} s_2(t)\varphi_1(t)\,dt \\
&= \sqrt{\frac{2}{T_b}}\int_0^{T_b} \cos\left(\frac{8\pi t}{T_b}\right)\cos\left(\frac{4\pi t}{T_b}\right)dt \\
&= \sqrt{\frac{1}{2T_b}}\int_0^{T_b}\left(\cos\left(\frac{12\pi t}{T_b}\right) + \cos\left(\frac{4\pi t}{T_b}\right)\right)dt = 0 \\
g_2(t) &= s_2(t) - s_{21}(t).\varphi_1(t) = \cos\left(\frac{8\pi t}{T_b}\right) \Rightarrow \varphi_2(t) = \frac{g_2}{\sqrt{E_2}} = \sqrt{\frac{2}{T_b}}\cos\left(\frac{8\pi t}{T_b}\right)
\end{aligned}$$

Then we have $B = \Big\{\varphi_1(t) = \sqrt{\frac{2}{T_b}}\cos\left(\frac{4\pi t}{T_b}\right), \varphi_2(t) = \sqrt{\frac{2}{T_b}}\cos\left(\frac{8\pi t}{T_b}\right)\Big\}$ is the orthonormal basis.

$$\Rightarrow s_1\Big(\sqrt{E_b}, 0\Big),\ s_2\Big(0, \sqrt{E_b}\Big)$$





According to the BER computation:

$$P\big(e|s_T = s_1\big) = P\big(s_1' + n < 0\big) = P\left(n < -\sqrt{\frac{E_b}{2}}\right) = P\left(n > \sqrt{\frac{E_b}{2}}\right) = \frac{1}{2}erfc\left(\sqrt{\frac{E_b}{2N_0}}\right)$$

$$P\big(e|s_T = s_2\big) = P\left(s_2' + n > \sqrt{\frac{E_b}{2}}\right) = P\left(-\sqrt{\frac{E_b}{2}} + n > 0\right) = P\left(n > \sqrt{\frac{E_b}{2}}\right) = \frac{1}{2}erfc\left(\sqrt{\frac{E_b}{2N_0}}\right)$$

$$P(e) = \frac{P\big(e|s_T = s_1\big) + P\big(e|s_T = s_2\big)}{2} = \frac{1}{2}erfc\left(\sqrt{\frac{E_b}{2N_0}}\right)$$

4.7 Plot the Bit error rate between simulation and theory for FSK

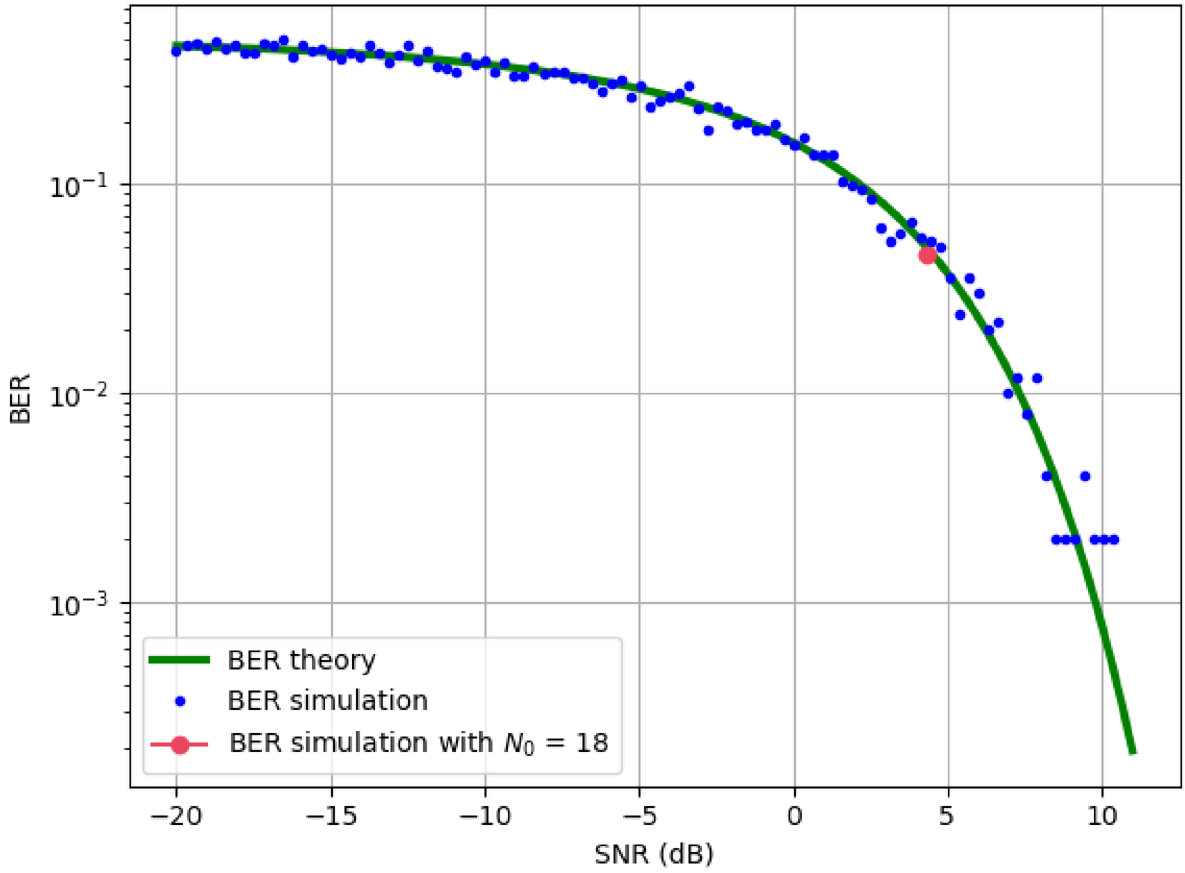


Figure 4.7: BER plot for $2 - FSK$

CHAPTER 5. CONCLUSIONS

In conclusion, digital modulation and demodulation techniques, such as Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Frequency Shift Keying (FSK), play a crucial role in the field of communication systems. Each of these techniques has its own advantages and disadvantages, and the choice of a particular technique depends on the requirements of the communication system.

ASK is a simple and low-cost modulation technique, but it is sensitive to noise and interference. PSK is more robust against noise and interference compared to ASK, but it requires a higher bandwidth for the same data rate. FSK is used for low-data rate applications and is also robust against interference, but it requires a larger bandwidth compared to PSK. On the other hand, the wider bandwidth of FSK may result in a lower signal-to-noise ratio, which can produce errors in the transmitted data.

In summary, digital modulation and demodulation techniques provide a convenient way to transmit digital information over a communication channel with the help of the modulation and demodulation process. The selection of the appropriate technique depends on the specific requirements of the communication system and the trade-off between its performance and complexity.