HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY

PROJECT REPORT

INTRODUCTION TO COMMUNICATION ENGINEERING

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ABSTRACT

Electronic and communication engineering is a branch that uses advanced electronic technologies and techniques to create electronic equipment such as satellites, signal transmission equipment, television receivers, telephones, and computers. personal computers, tablets, etc., in order to build a communication network that helps the exchange of information between people take place smoothly in different space and time conditions. In the current digital technology era, the role of electronics and communication engineering is irreplaceable.

In the Introduction to Communication Engineering course, to better understand the basic knowledge of communication systems: the main elements of communication systems, problems of the information transmission process, and modulation/demodulation techniques.

We use MATLAB to plot the waveform for modulating and demodulating signals from a random binary sequence and then derive the bit error probability of a Gaussian channel. From there, we can better understand modulation, demodulation, and digital signal processing in communication.

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CHAPTER 1. INTRODUCTION

Nowadays, communication plays a critical role and wireless technologies are rapidly advancing it. The efficiency of transmitting and receiving systems is crucial for successful communication. To maintain high performance, it is important to minimize signal attenuation, distortion, and noise during transmission. Therefore, digital modulation techniques are used to improve the transmission quality and accuracy of the communication system.

Digital modulation involves converting continuous signals into discrete symbols to modulate a carrier wave, which is transmitted over long distances through communication media like radio channels. One of the benefits of digital modulation is that noise in the channel does not have a detrimental effect on the received, demodulated signal, unlike in analog signals where even a small amount of noise can corrupt the demodulated signal.

In this work, we analyzed only binary modulation schemas of ASK, PSK, and FSK. In the case of binary modulation schemes, the alphabet has two values “0” and “1.” In ASK, a “0” is mapped to one amplitude value and a “1” is mapped to another amplitude value. In FSK, a “0” is mapped to one frequency value and a “1” is mapped to another frequency value. In PSK, a “0” is mapped to one phase value and a “1” is mapped to another phase value. Also in this work, each modulation technique’s performance is evaluated by measuring its probability of error considering AWGN as a channel.

Modulate and demodulate binary amplitude shift keying (BASK or 2-ASK) signal from a random binary sequence.

2.1 Modulation

File ASK_Modulation.m in *CEProject20221*

2.1.1 Theory

ASK was one of the foremost digital modulation techniques, which is used in radiotelegraphy. Here carrier amplitude is varied with respect to the baseband digital input signal. The ASK is used in point-to-point military communication applications, etc. The advantage of using BASK is that it does not require more bandwidth when transmitting. This Linear modulation scheme carries the message bits in the envelope of the transmitted signal, which is more sensitive to noise and needs linear amplifiers, which are costly and less power efficient. For these reasons, the use of high-valued M-ASK may not be suitable for wireless applications. In this task, we only implement the BASK (2-ASK) modulation by two models, one is BASK unipolar modulation and the other is BASK modulation at 50% depth.

2.1.2 Matlab program

First, we generate a sequence of 10 bits randomly. This sequence represents the digital input signal. In the 2-ASK unipolar modulation, $A_1 = A$ and $A_2 = 0$, we refer to the modulation scheme as having 100% depth. In the 2-ASK modulation 50% depth, $A_1 = A$ and $A_2 = \frac{A}{2}$. In both cases, carrier 1 represents bit ’1’, and carrier 2 represents bit ’0’.

2.1.3 Observation

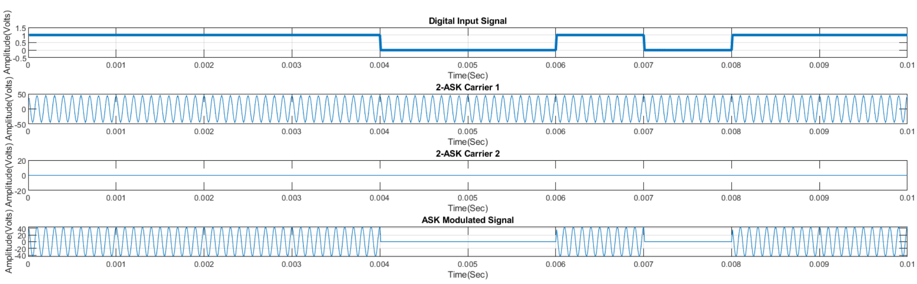

Figure 2.1: BASK unipolar modulation with $n = 10$ bits

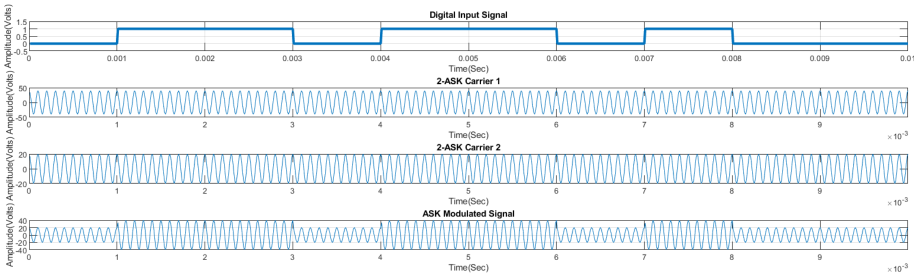

Figure 2.2: BASK modulation 50% depth with $n = 10$ bits

2.2 Demodulation Without Noise

File ASK_Demodulation.m in CEProject20221

2.2.1 Theory

After receiving the transmitted signal, the receiver has to demodulate it to a sequence of bit data. There are some demodulation methods, and in this report, we correlate the BASK modulated signal with the carrier signal to generate decision variables.

2.2.2 Matlab program

The modulated signal will be transmitted, then demodulated. In this step, we will correlate it with the carrier signal, then apply the decision theory to recover the original sequence of bits.

2.2.3 Observation

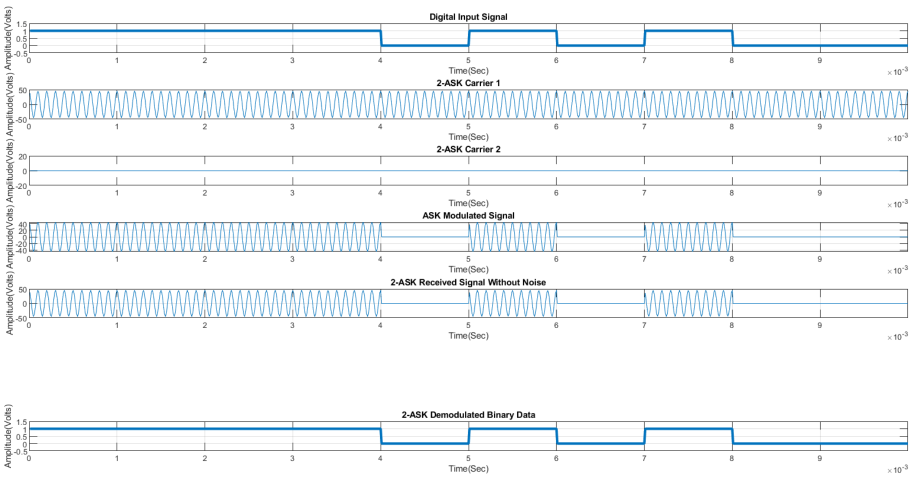

Figure 2.3: BASK unipolar demodulation with $n = 10$ bits

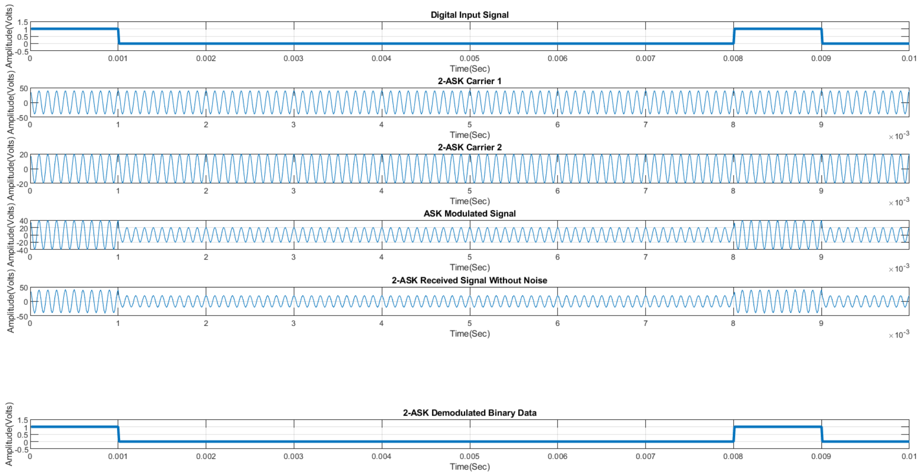

Figure 2.4: BASK demodulation 50% depth with $n = 10$ bits

2.3 Demodulation With Noise

File ASK_Demodulation_With_Noise.m in CEProject20221

2.3.1 Theory

Gaussian noise with zero mean and variance $\frac{N0}{2}$ is added to the transmitted waveform $s_i(t)$ as

$$r(t) = s_i(t) + n(t), \quad 0 \leq t \leq Ts, \quad i = 1, 2, 3...M$$

We apply the same method as one without noise, however, the noise effect will make some errors.

2.3.2 Matlab program

The difference in this section from the previous one is that we add AWGN before demodulating the signal. In MATLAB, we use $randn()$ function to add noise to the modulated signal.

2.3.3 Observation

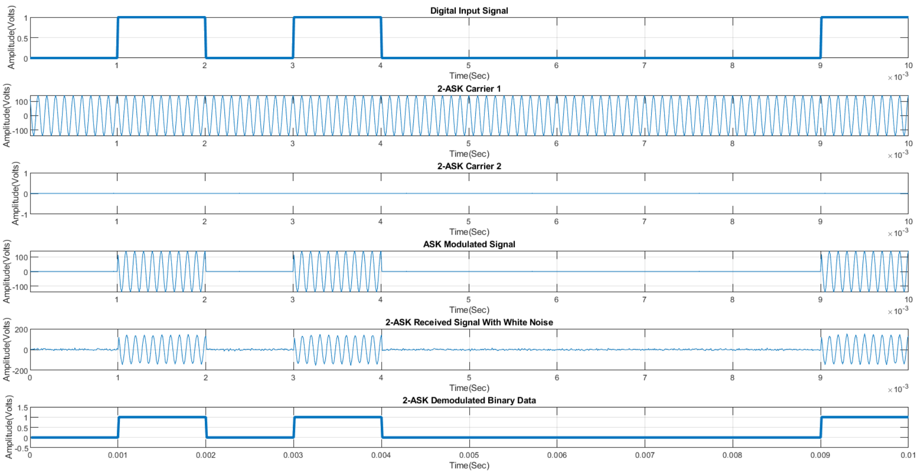

Figure 2.5: BASK unipolar demodulation with SNR= $-10dB$

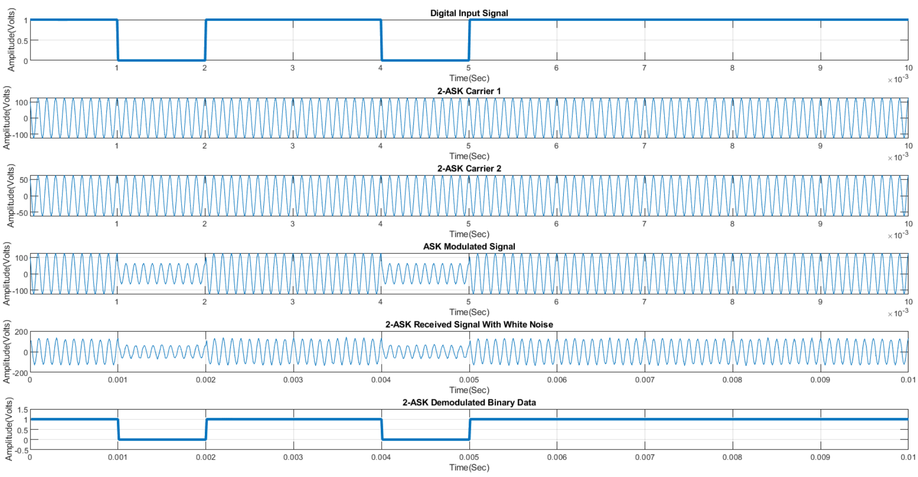

Figure 2.6: BASK demodulation 50% depth with SNR= $-10dB$

2.3.4 Numerically compute the error probability

In order to test the numerical error, we will increase the number of bits to 10000 and run the program three times. The results are below, for $SNR = -40dB$ and $E_b = 10V^2$.

For the BASK unipolar modulation:

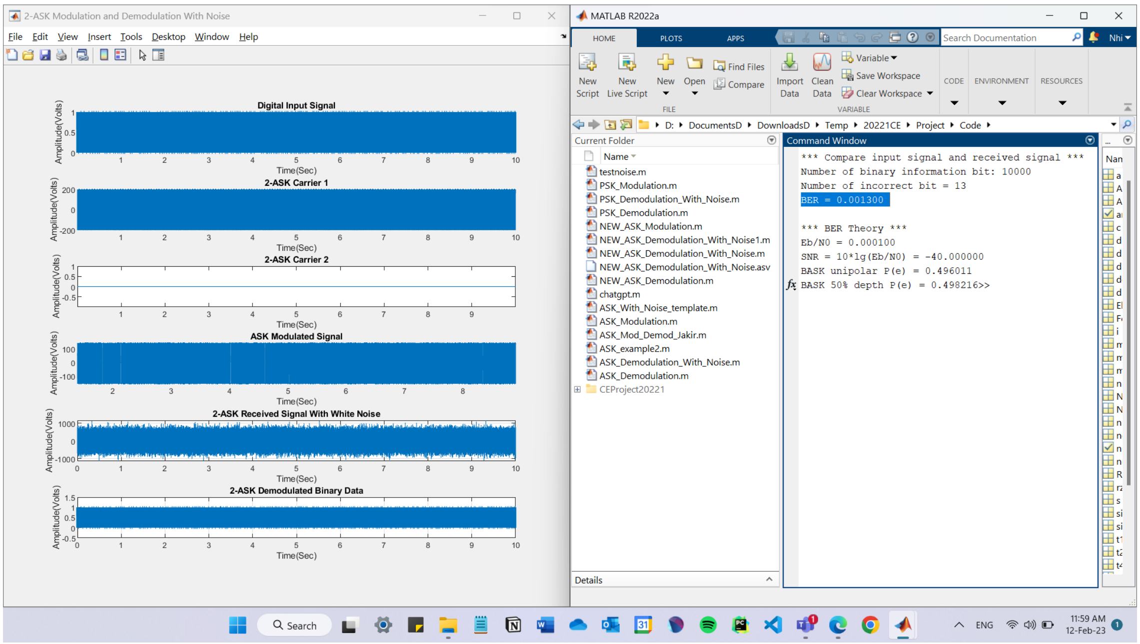

Figure 2.7: BASK unipolar BER = 0.0013%

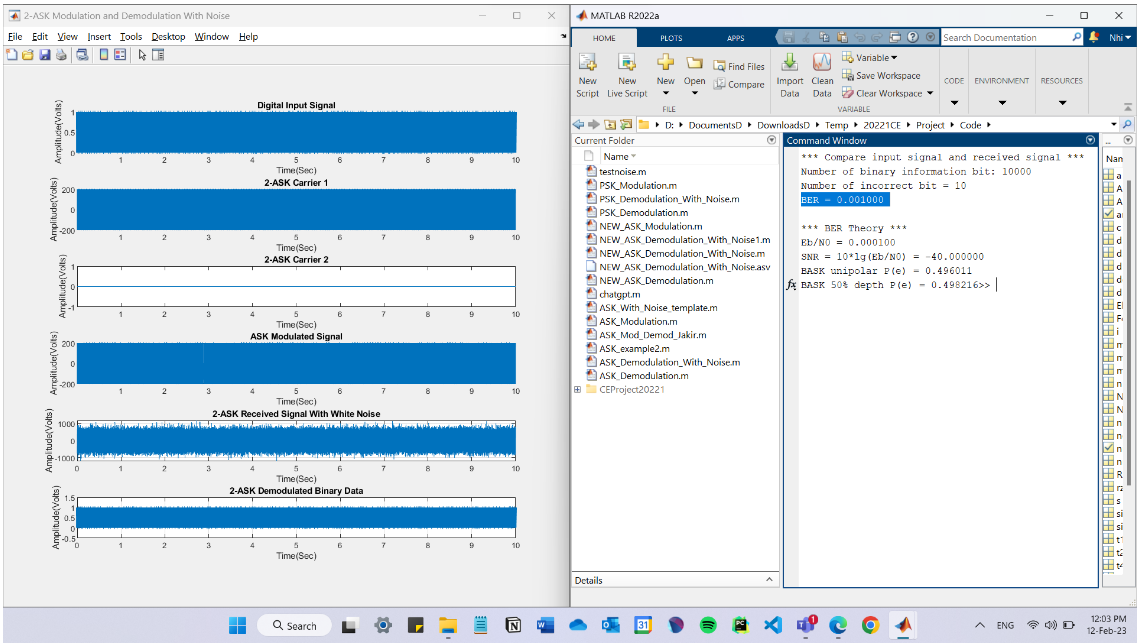

Figure 2.8: BASK unipolar BER = 0.001%

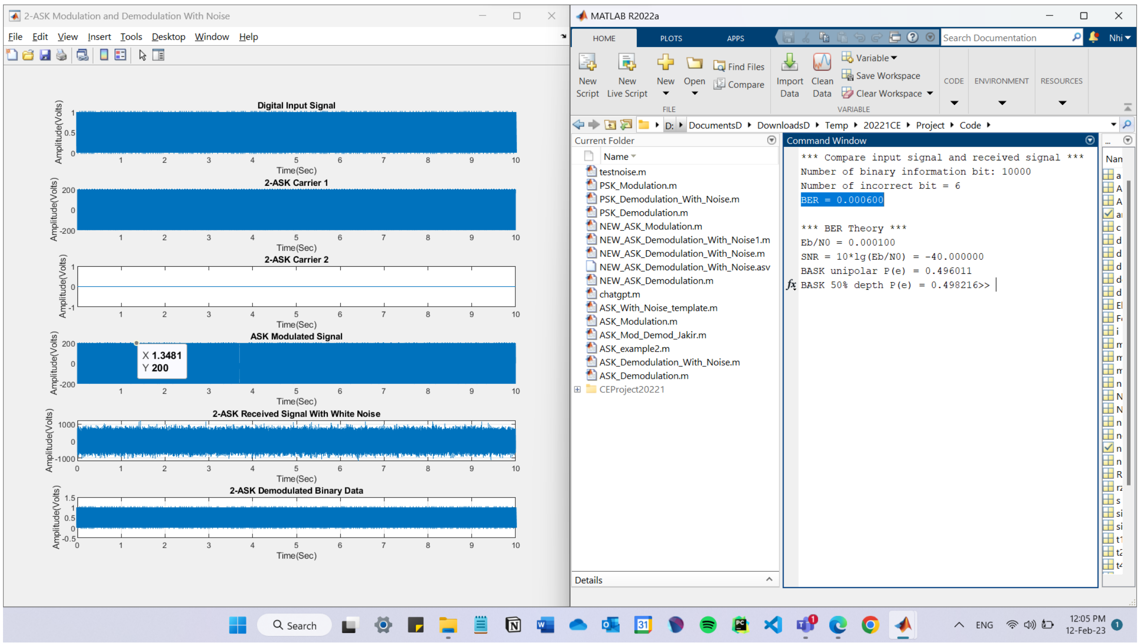

Figure 2.9: BASK unipolar BER = 0.0006%

For the BASK modulation 50% depth:

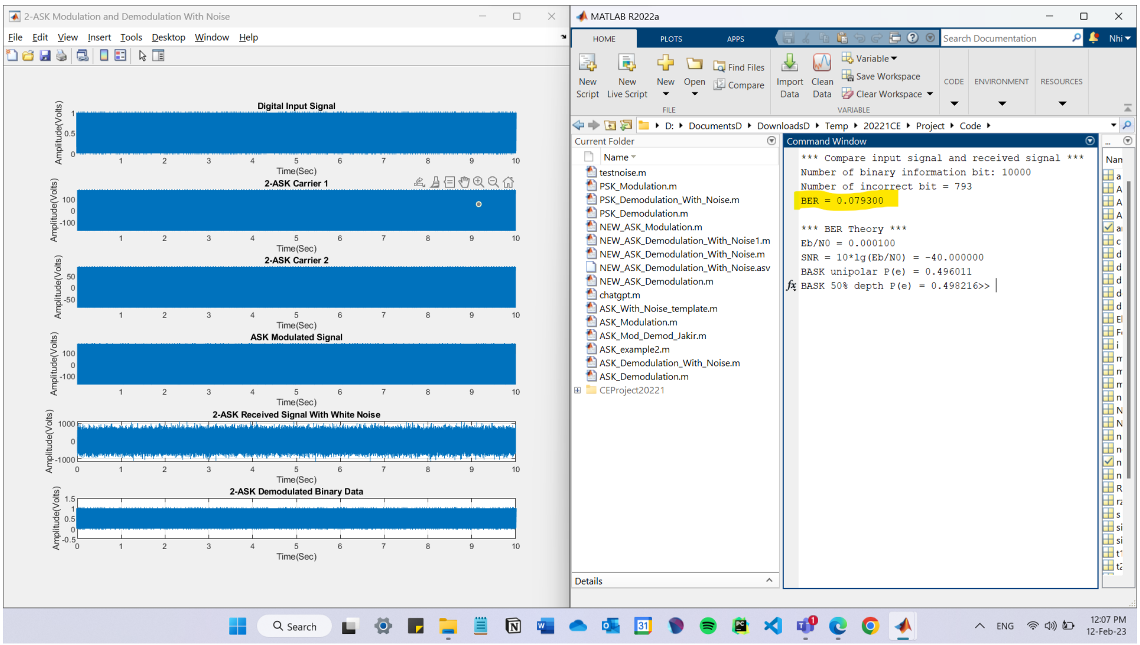

Figure 2.10: BASK modulation 50% depth BER = 0.07930%

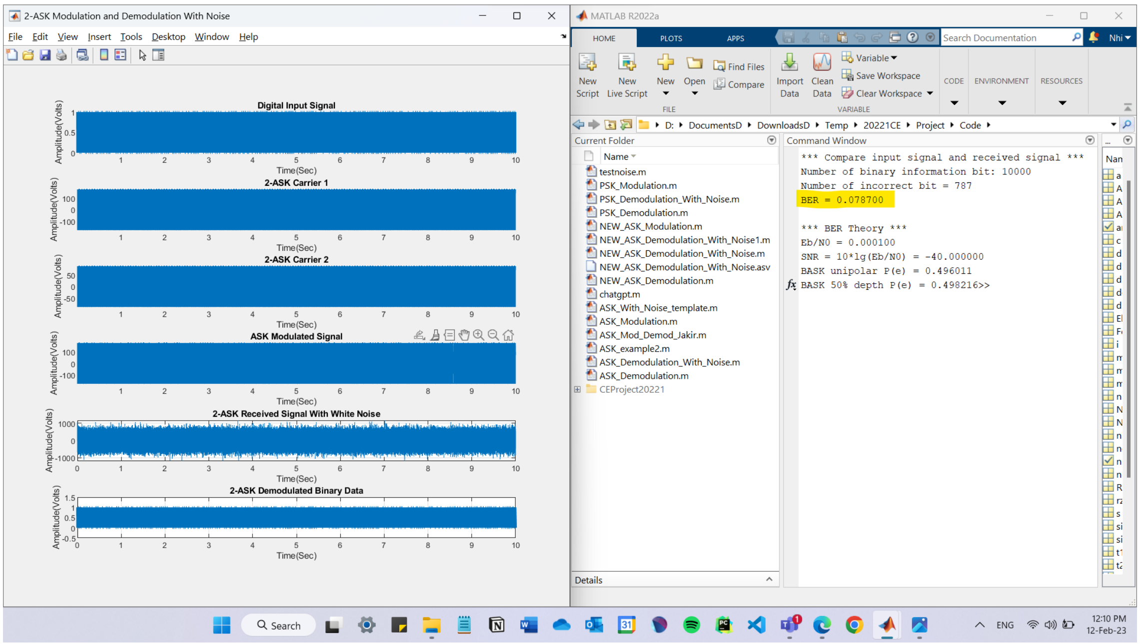

Figure 2.11: BASK modulation 50% depth BER = 0.0787%

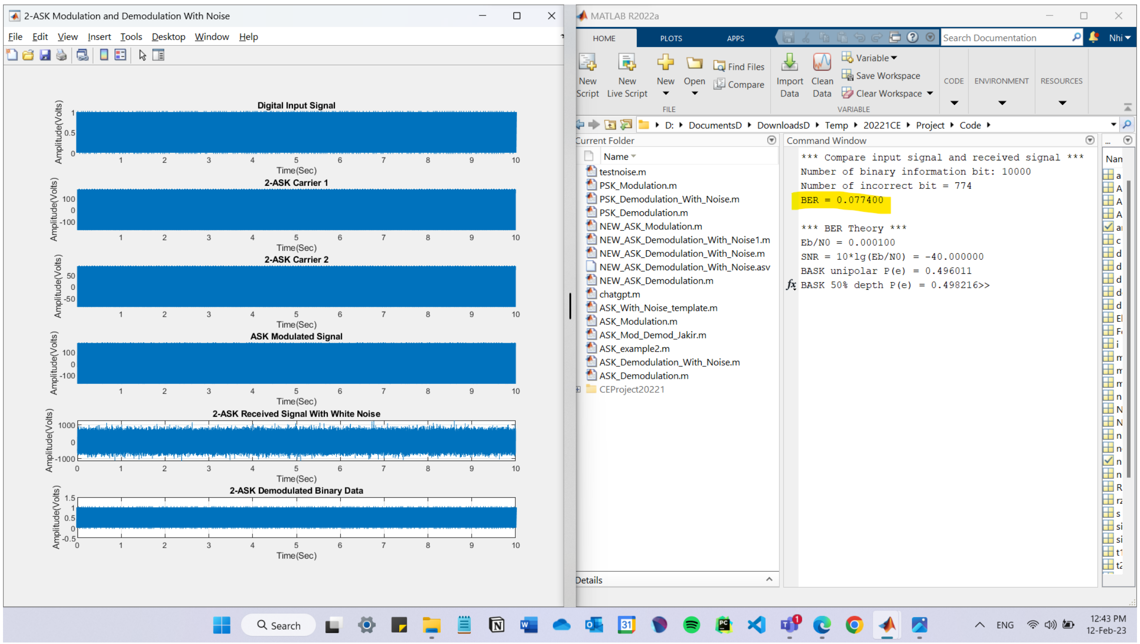

Figure 2.12: BASK modulation 50% depth BER = 0.0774%

Comments:

In both BASK modulations, we observed that the BASK modulation 50% depth had a higher BER rate than the BASK unipolar modulation.

2.4 Derive the bit error probability of a Gaussian channel using the ASK demodulation

2.4.1 BASK unipolar modulation

We choose $M = \{s_1(t) = A\cos(2\pi f_c t), \quad s_2(t) = 0\}$ where $k = 1, m = 2$

We have

$$E_1 = \int_{-\infty}^{\infty} s_1^2(t)dt \quad = \int_0^T A^2\cos^2(2\pi f_c t)dt \quad \approx \frac{A^2}{2}T_b$$

and

$$E_2 = 0$$

Thus

$$E_{s,avg} = \frac{(E_1 + E_2)}{2} = \frac{A^2}{4}T_b$$

Since $k = 1 \quad \rightarrow \quad \mathrm{E}_b = \frac{E_s}{k} = \frac{A^2}{4}T_b$ Let $A = 2\sqrt{\frac{E_b}{T_s}}$, choose $b_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t)$. Then we have

$$M = \{s_1(\sqrt{2E_b}), \quad s_2(0) = 0\}$$

According to the total error probability formula, we have:

$$P(e) = \frac{1}{2}\Big(P(e|s_T = s_1) + P(e|s_T = s_2)\Big)$$

Since:

$$P(e|s_T = s_1) = P\Big(\sqrt{2E_b} + n < \frac{\sqrt{2E_b}}{2}\Big)$$

$$= P\Big(n < \frac{-\sqrt{2E_b}}{2}\Big) = P\Big(n > \frac{\sqrt{2E_b}}{2}\Big) = \frac{1}{2}erfc\Big(\sqrt{\frac{E_b}{2N_0}}\Big)$$

and similarly,

$$P(e|s_T = s_2) = P\Big(n > \frac{\sqrt{2E_b}}{2}\Big) = \frac{1}{2}erfc\Big(\sqrt{\frac{E_b}{2N_0}}\Big)$$

Thus,

$$P(e) = \frac{1}{2} erfc\Big(\sqrt{\frac{E_b}{2N_0}}\Big)$$

2.4.2 BASK modulation 50% depth

We choose $M = \{s_1(t) = A\cos{(2\pi f_c t)}, \quad s_2(t) = \frac{A}{2}\cos{(2\pi f_c t)}\}$ where $k = 1, m = 2$

We have

$$E_1 = \int_{-\infty}^{\infty} s_1^2(t)dt \quad = \int_0^T A^2\cos^2{(2\pi f_c t)}dt \quad \approx \frac{A^2}{2}T_b$$

and similarly, we have

$$E_2 = \int_{-\infty}^{\infty} s_2^2(t)dt \quad \approx \frac{A^2}{8}T_b$$

Thus

$$E_{s,avg} = \frac{(E_1 + E_2)}{2} = \frac{5A^2}{16}T_b$$

Since $k = 1 \quad \rightarrow \quad$ E$_b = \frac{E_s}{k} = \frac{5A^2}{16}T_b$

Let $A = 4\sqrt{\frac{E_b}{5T_s}}$, $\quad$ choose $b_1(t) = \sqrt{\frac{2}{T_s}}\cos{(2\pi f_c t)}$. Then we have

$$M = \{s_1(\sqrt{\frac{8E_b}{5}}), \quad s_2(\sqrt{\frac{2E_b}{5}}) = 0\}$$

According to total error probability formula, we have:

$$P(e) = \frac{1}{2}\Big(P(e|s_T = s_1) + P(e|s_T = s_2)\Big)$$

Let $s_0 = \frac{\sqrt{\frac{8E_b}{5}}+\sqrt{\frac{2E_b}{5}}}{2}$

Since:

$$P(e|s_T = s_1) = P\Big(\sqrt{\frac{8E_b}{5}} + n < s_0\Big) = P\Big(n > \frac{\sqrt{10E_b}}{10}\Big) = \frac{1}{2}erfc\Big(\sqrt{\frac{E_b}{10N_0}}\Big)$$

and similarly,

$$P(e|s_T = s_2) = P\Big(n > \frac{\sqrt{10E_b}}{10}\Big) = \frac{1}{2}erfc\Big(\sqrt{\frac{E_b}{10N_0}}\Big)$$

Thus,

$$P(e) = \frac{1}{2}erfc\Big(\sqrt{\frac{E_b}{10N_0}}\Big)$$

Comments:

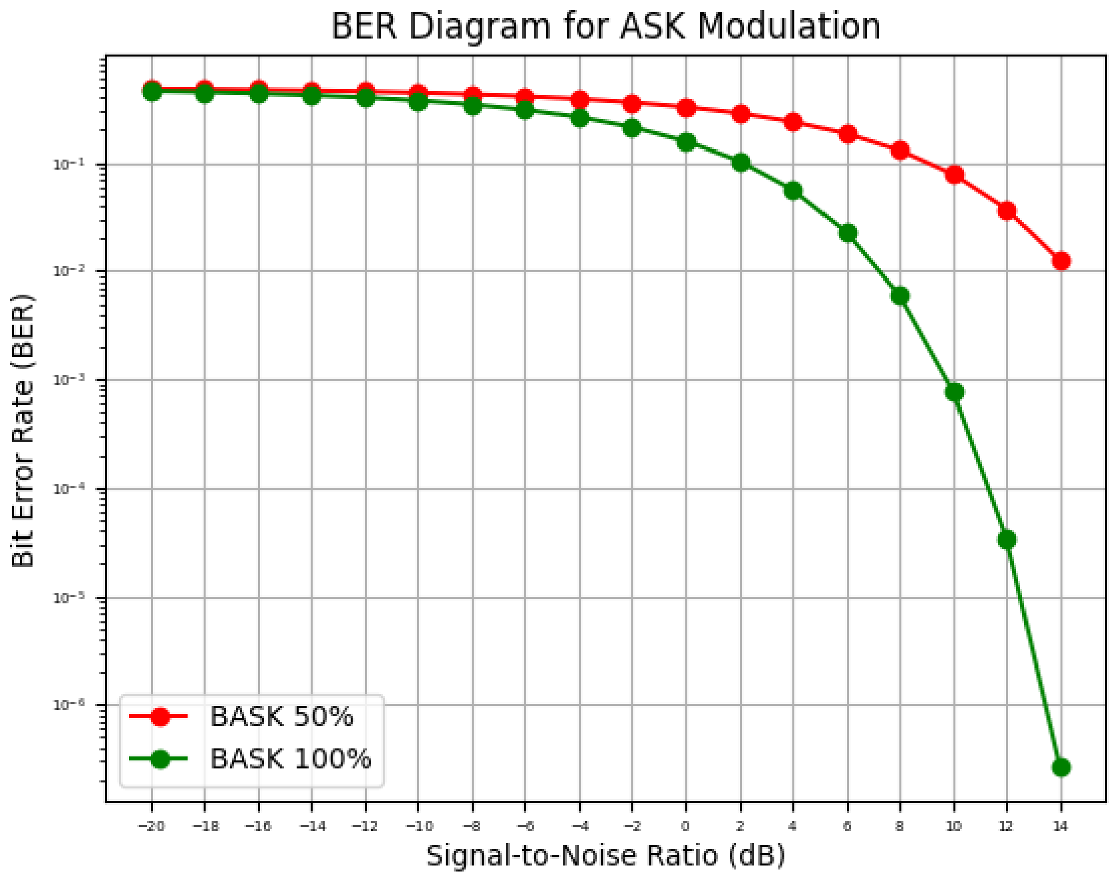

Figure 2.13: BER diagram for ASK modulation

Since $erfc(x)$ is decreasing, the higher $\frac{E_b}{N0}$ is, the smaller the BER is. For a bit error rate of 10^{-1}, BASK(100%) needs an $\frac{E_b}{N0}$ of approximately $2dB$, while BASK (50%) needs an $\frac{E_b}{N0}$ of $9dB$ (this is $7dB$ larger). The reason for this is BASK (50%) expends energy in both symbols used for transmission, while the BASK unipolar expends energy only to one symbol. Moreover, the distance distance between signals in signal space in BASK (50%) is smaller than those in BASK unipolar, meaning that the BASK (50%) is more sensitive to noise.

However, we observed a different result between code implementing and theory calculation. It is because we have just carried out the experiment several time and might not observe the big picture of the BER.

Phase-shift keying (PSK) is a phase modulation scheme in which digital information is encoded on a carrier signal by periodically shifting the frequency of the carrier between several discrete frequencies.

Using MATLAB, we plot the waveform for modulating and demodulating phase shift keying (PSK) signals from a random binary sequence. Then we derive the bit error probability of a Gaussian channel using the PSK demodulation.

3.1 Modulation

File PSK_Modulation in *CEProject20221*

3.1.1 Theory

In this kind of modulation, the sine carrier takes 2 or more phase values, directly determined by the binary data signal (2-phase modulation) or by the combination of a certain number of bits of the same data signal (N-phase modulation).

In 2-phase PSK modulation, called 2-PSK, or Binary PSK (BPSK), the sine carrier takes 2 phase values, determined by the binary data signal (fig.1). A modulation technique is the one using a balanced modulator. The output sine-wave of the modulator is the direct or inverted (i.e.shifted of 180°) input carrier, as a function of the data signal.

3.1.2 Matlab program

Firstly, the program will generate a random sequence of bits as input data, then it will be modulated by the BPSK method. Finally, the program will plot input data, the carrier signal, and modulated signals.

3.1.3 Observation

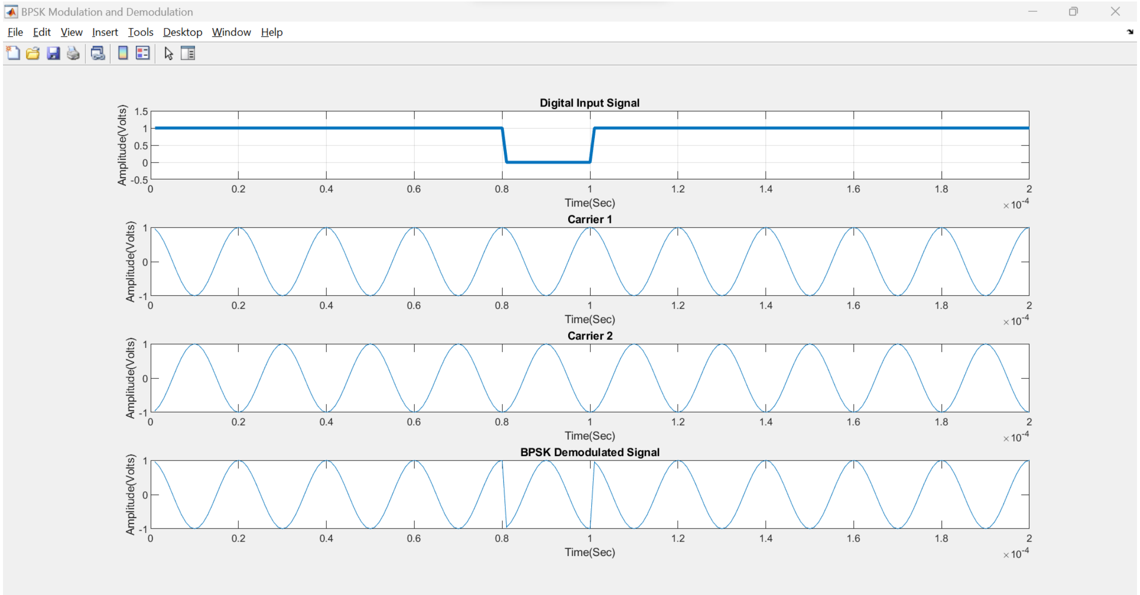

Figure 3.1: PSK modulation when n = 10

3.2 Demodulation Without Noise

3.2.1 Theory

After receiving the transmitted signal, the receiver has to demodulate it to a sequence of bit data. There are some demodulation methods, and in this report, we correlate the BPSK modulated signal with the carrier signal to generate decision variables.

3.2.2 Matlab program

The modulated signal will be transmitted, then demodulated. In this step, we will correlate it with the carrier signal, then apply the decision theory to recover the original sequence of bits.

3.2.3 Observation

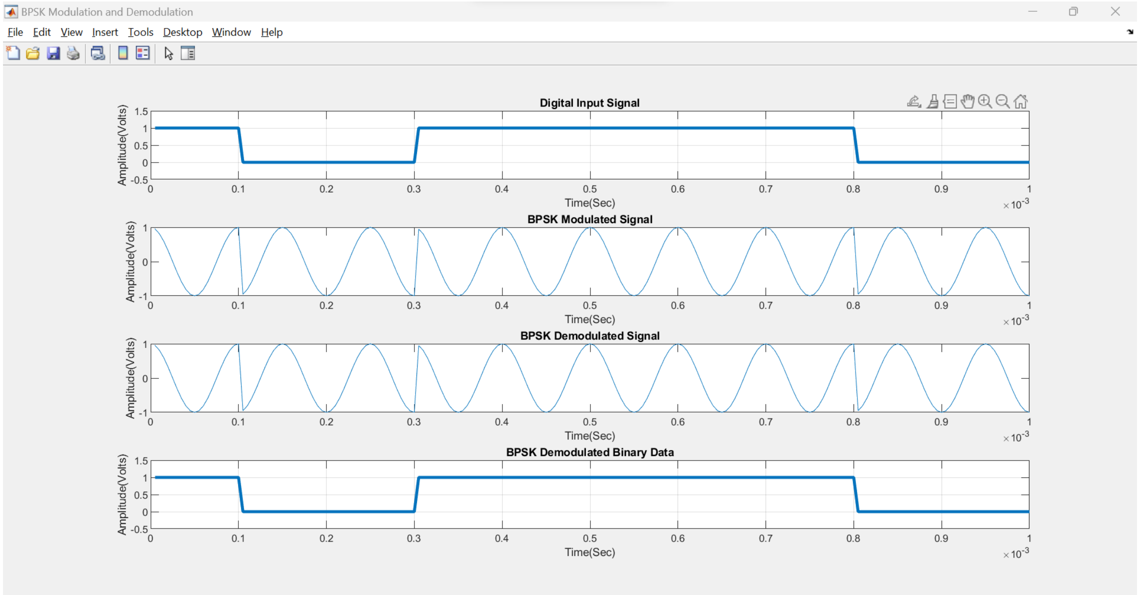

Figure 3.2: PSK demodulation without noise when n = 10

3.3 Demodulation With Noise

3.3.1 Theory

Gaussian noise with zero mean and variance $N0$ /2 is added to the transmitted waveform as $r(t) = s(t) + n(t)$ We apply the same method as one without noise, however, the noise effect will make some errors.

3.3.2 Matlab program

The difference in this section from the previous one is that we add AWGN before demodulating the signal. In MATLAB, we use the $randn()$ function to add noise to the modulated signal.

3.3.3 Observation

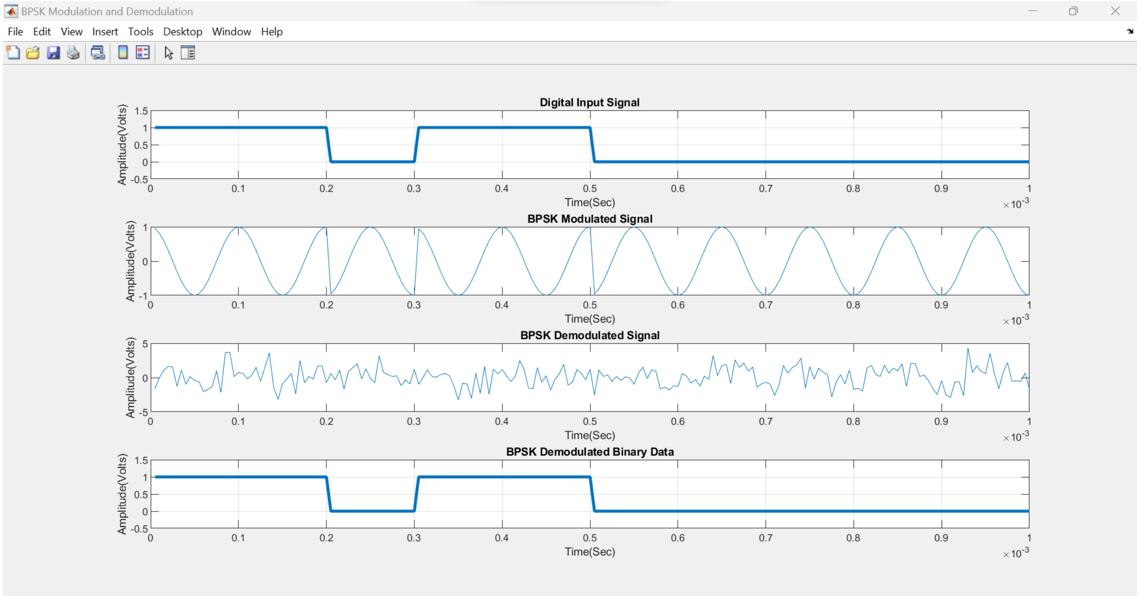

Figure 3.3: PSK demodulation with noise when $n = 10$

3.3.4 Numerically compute the error probability

In order to test the numerical error, we will increase the number of bits to 1000 and run the program three times. The results are below, for $Ac = 1$, $N0 = 3$.

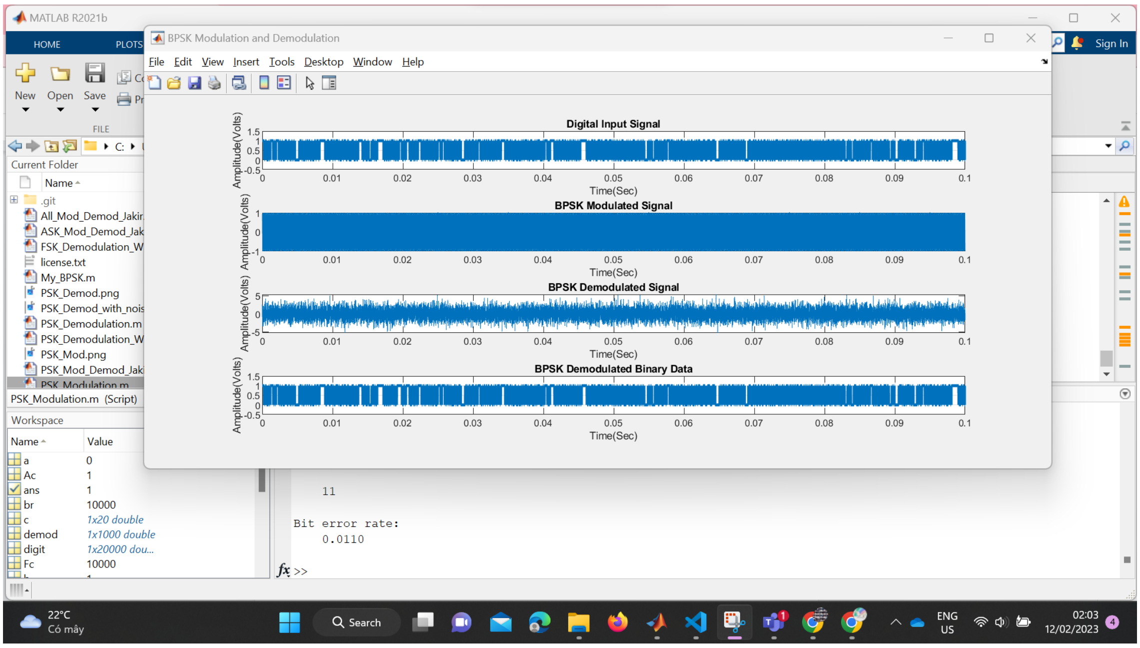

Figure 3.4: BER = 0.011

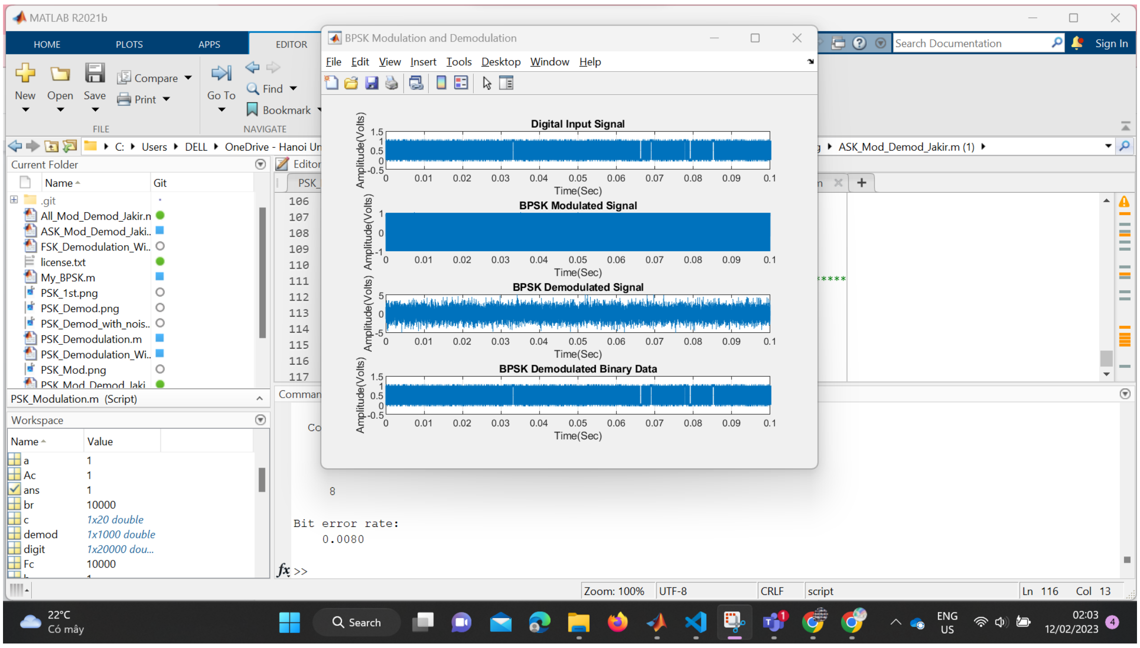

Figure 3.5: BER = 0.008

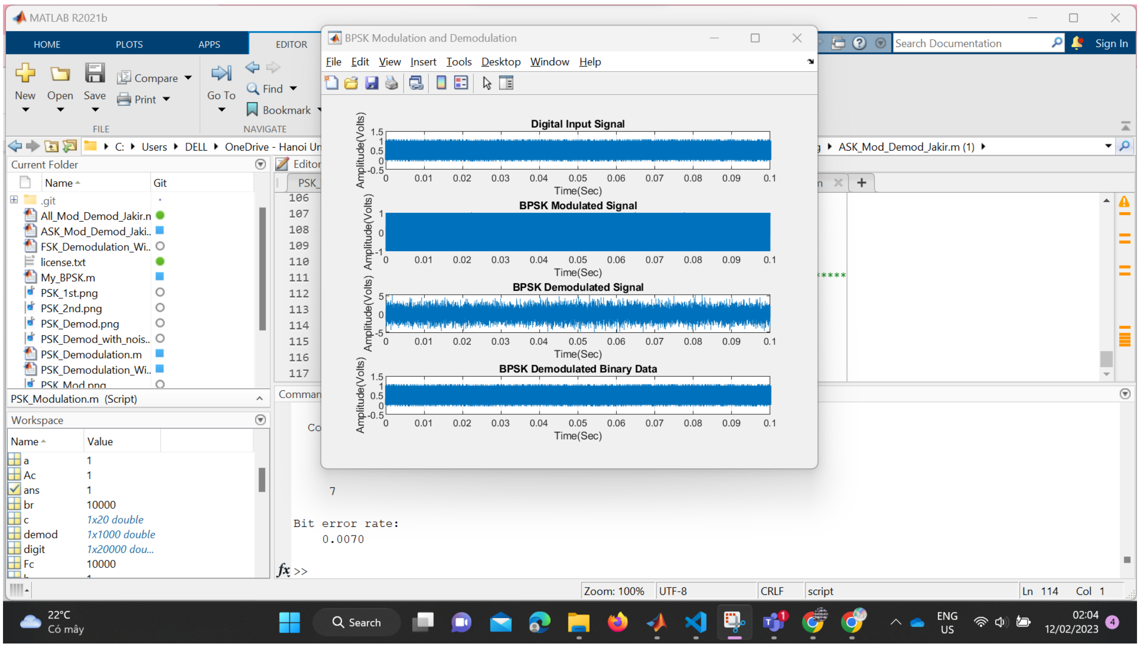

Figure 3.6: BER = 0.007

3.4 Derive the bit error probability of a Gaussian channel using the PSK demodulation

We choose $M = \{s_1(t) = A\cos(2\pi f_c t),\quad s_2(t) = A\cos(2\pi f_c t) + \pi\}$ where $k = 1, m = 2$

$$E_1 = \int_{-\infty}^{\infty} s_1^2(t)dt \quad = \int_0^T A^2\cos^2(2\pi f_c t)dt \quad \approx \frac{A^2}{2}T_b$$

Similarly,

$$E_2 = \frac{A^2}{2} T_b$$

Thus

$$E_{s,avg} = \frac{(E_1 + E_2)}{2} = \frac{A^2}{2} T_b$$

We have Let $A = \sqrt{\frac{2E_b}{T_s}}$, choose $b_1(t) = \sqrt{\frac{2}{T_s}} \cos{(2\pi f_c t)}$. Then we have

$$M = \{s_1 = \sqrt{E_b}, \quad s_2 = -\sqrt{E_b}\}$$

According to the total error probability formula, we have:

$$P(e) = \frac{1}{2}\Big(P(e|s_T = s_1) + P(e|s_T = s_2)\Big)$$

Since:

$$P(e|s_T = s_1) = P\Big(\sqrt{E_b} + n < 0\Big)$$

$$= P\Big(n < -\sqrt{E_b}\Big) = P\Big(n > -\sqrt{E_b}\Big) = \frac{1}{2} erfc\Big(\sqrt{\frac{E_b}{N_0}}\Big)$$

and similarly,

$$P(e|s_T = s_2) = P\Big(n > \sqrt{E_b}\Big) = \frac{1}{2} erfc\Big(\sqrt{\frac{E_b}{N_0}}\Big)$$

Thus,

$$P(e) = \frac{1}{2} erfc\Big(\sqrt{\frac{E_b}{N_0}}\Big)$$

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.

We plot the waveform for modulating and demodulating frequency shift keying (FSK) signals using MATLAB from a random binary sequence. Then we derive the bit error probability of a Gaussian channel using the FSK demodulation.

4.1 Modulation

4.1.1 Theory

Modulation is the process of encoding information in a transmitted signal. FSK is a scheme of frequency modulation. The output of an FSK-modulated wave is high in frequency for high binary input and low in frequency for binary low input.

4.1.2 Matlab program

File FSK/FSK_Modulation in *CEProject20221*

Firstly, we generate and plot the binary data sequence randomly with $randi()$ function in Matlab. Then we generate and plot two carrier signals with different frequency numbers. Finally, we assigned signals with suitable bits and plot the FSK-modulated signals.

4.1.3 Observation

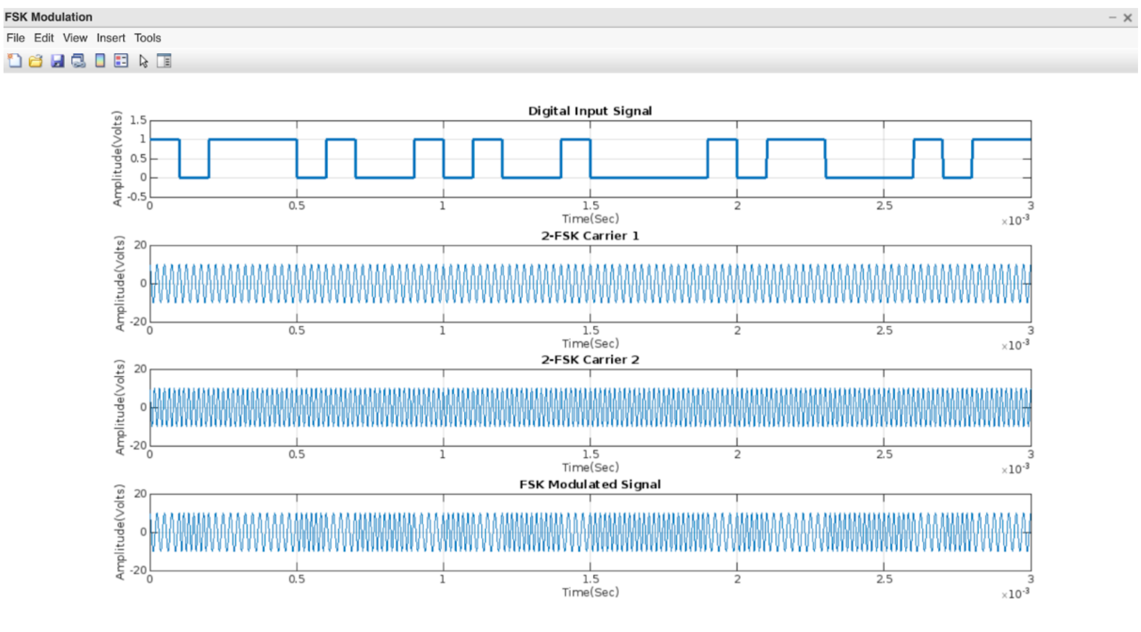

Figure 4.1: FSK Modulation

4.2 Demodulation Without Noise

4.2.1 Theory

Demodulation is the process of extracting information from the transmitted signal. Many factors influence how faithfully the extracted information replicates the original input information.

4.2.2 Matlab program

File FSK/FSK_Demodulation in *CEProject20221*

Firstly, we generate and plot the binary data sequence randomly and FSK-modulated signals. Then, we correlate the FSK- modulated signal with the carrier signal to generate decision variables. Finally, we obtain the demodulated binary data based on the decision variables.

4.2.3 Observation

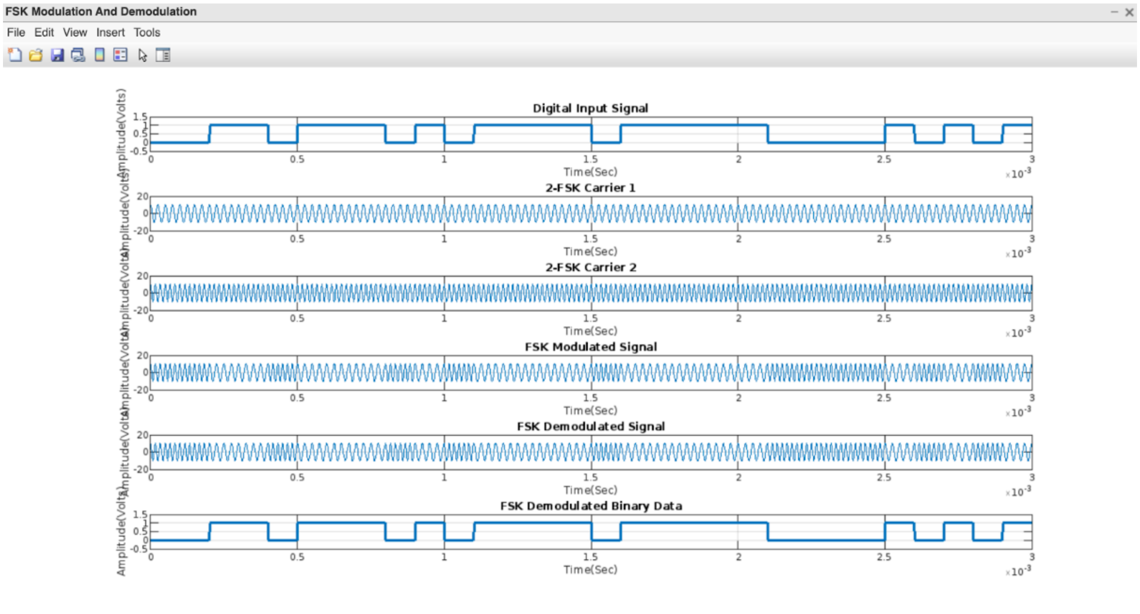

Figure 4.2: FSK Demodulation Without Noise

4.3 Demodulation With Noise

4.3.1 Theory

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 because 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.

4.3.2 Matlab program

File FSK/FSK_Demodulation_With_Noise in *CEProject20221*

We generate and plot the binary data sequence randomly and FSK-modulated signals. Then, we correlate the FSK- modulated signal with the carrier signal to generate decision variables. Finally, we obtain the demodulated binary data based on the decision variables.

Gaussian noise with zero mean and variance $N/2$ is added to the transmitted waveform as $r(t) = s(t) + n(t)$.

4.3.3 Observation

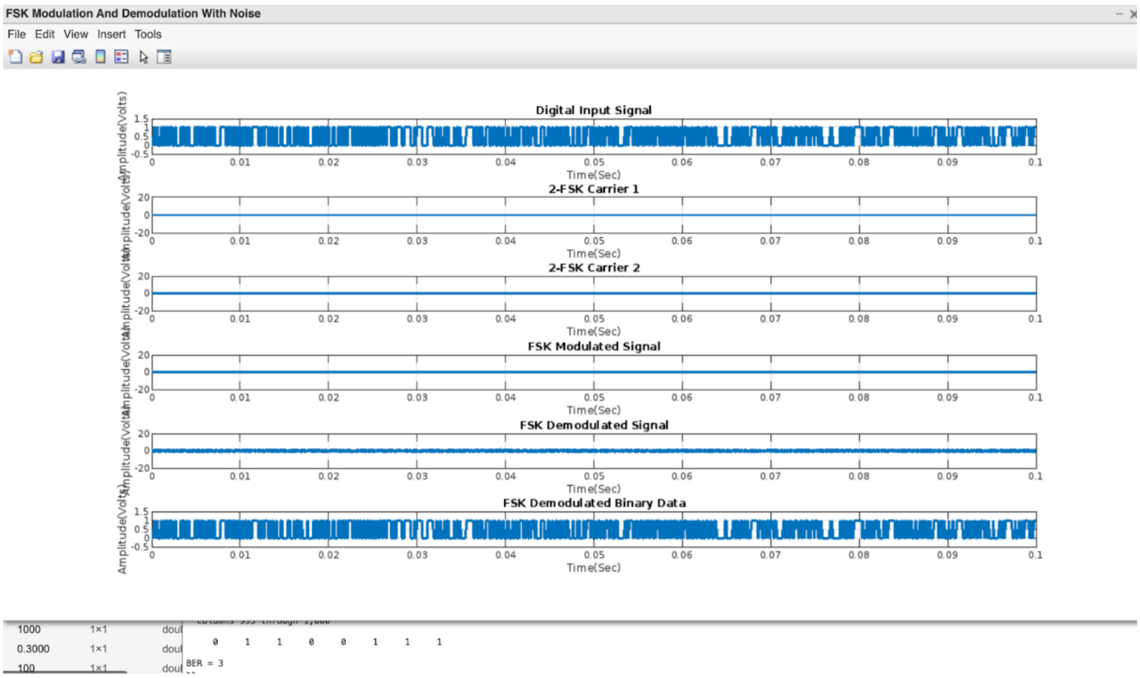

Figure 4.3: FSK Demodulation With Noise

4.3.4 Numerically compute the error probability

Bit error rate (BER) is defined as the rate at which errors occur in a transmission system.

In order to test the numerical error, we will increase the number of bits to 1000 and run the program three times. The results are below:

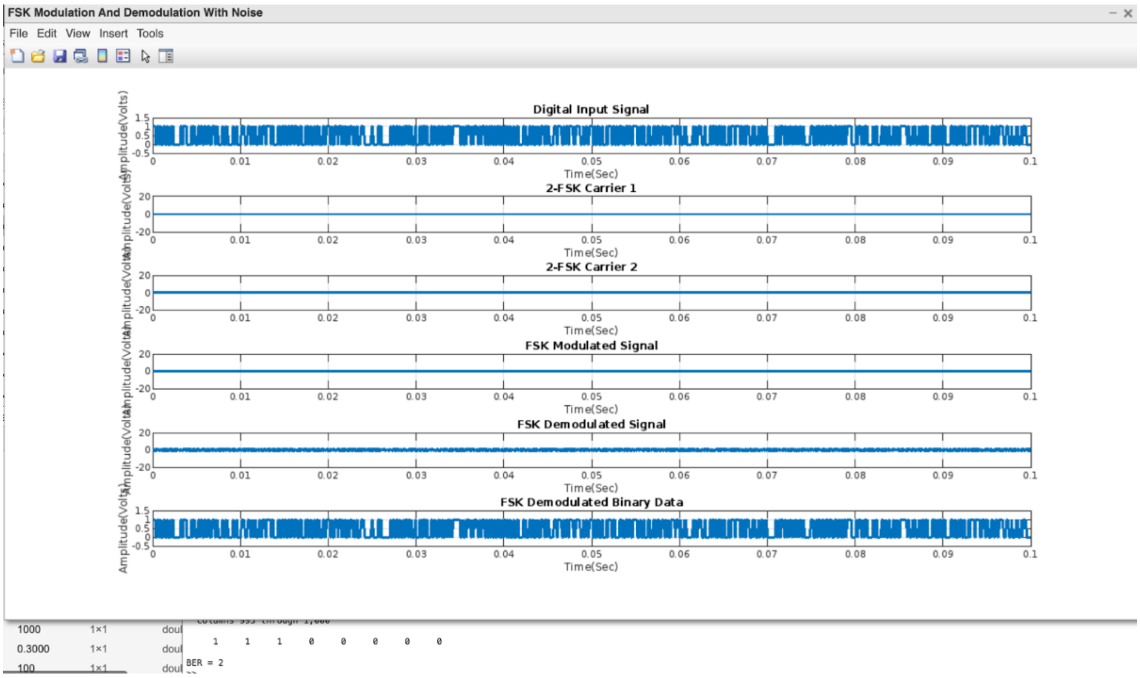

Figure 4.4: FSK Demodulation With Noise and BER = 0.002

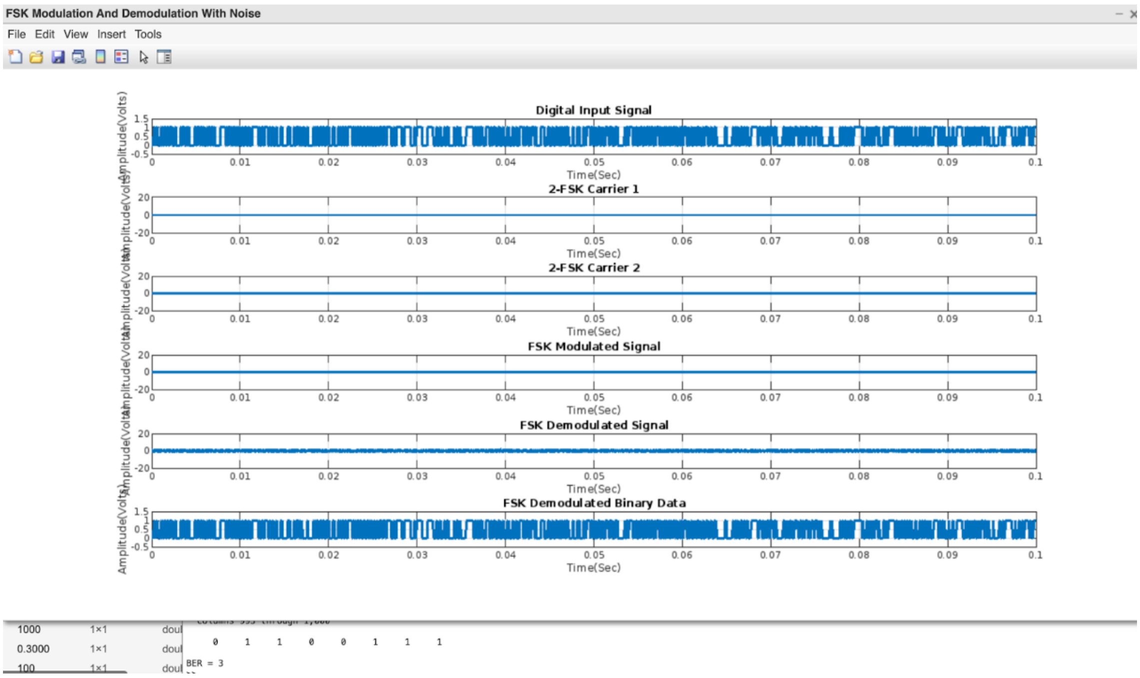

Figure 4.5: FSK Demodulation With Noise and BER = 0.003

Figure 4.6: FSK Demodulation With Noise and BER = 0.004

We get the average BER:

$$BER_{avg} = \frac{0.002 + 0.003 + 0.004}{3} = 0.003$$

4.4 Derive the bit error probability of a Gaussian channel using the FSK demodulation

We choose $M = \{s_1(t) = A\cos(2\pi f_1 t), \quad s_2(t) = A\cos(2\pi f_2 t)\}$ where $k = 1, m = 2$

Similar to BPSK, we have:

$$E_1 = \frac{A^2}{2}T_b$$

$$E_2 = \frac{A^2}{2}T_b$$

So that, $E_1 = E_2 = E$.

Apply the Gram-Schmidt algorithm, we have:

$$b_1(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_1 t)$$

$$b_2(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_2 t)$$

We have,

$$Q(z) = P(X > x) = \frac{1}{2}erfc\Big(\frac{x-\mu}{\sqrt{2}\sigma}\Big) = \frac{1}{2}erfc\Big(\frac{z}{\sqrt{2}}\Big)$$

with

$$z = \frac{x_o - \mu}{\sigma}$$

We also have,

$$P(X > x_o) = P\Big(Y > \frac{x_o - \mu}{\sigma}\Big) = P\Big(Y > \frac{d_{ij}}{2\sigma}\Big)$$

Because,

$$x_o - \mu = \frac{d_{if}}{2}$$

with

$$d_{ij} = distance\_between\_two\_signals$$

Thus,

$$Q\Big(\frac{x_o - \mu}{\sigma}\Big) = Q\Big(\frac{d_{ij}}{2\sigma}\Big) = Q\Big(\sqrt{\frac{(d_{ij})^2}{2N_o}}\Big)$$

with

$$\sigma = \sqrt{\frac{N_o}{2}}$$

So,

$$Q\Big(\sqrt{\frac{(d_{if})^2}{2N_o}}\Big) = \frac{1}{2}erfc\Big(\sqrt{\frac{(d_{ij})^2}{4N_o}}\Big)$$

$b_1(t)$ and $b_2(t)$ are orthogonal signals, the distance between two signals is $\sqrt{2E_b}$.

Thus,

$$P_b = \frac{1}{2}erfc\Big(\sqrt{\frac{E_b}{2N_0}}\Big)$$

Using MATLAB, we plot the waveform for modulating and demodulating amplitude shift keying (ASK) signals, phase shift keying (PSK) signals, and frequency shift keying (FSK) signals from a random binary sequence.

We derived the bit error probability of a Gaussian channel using the ASK, PSK, and FSK demodulation used in our work.

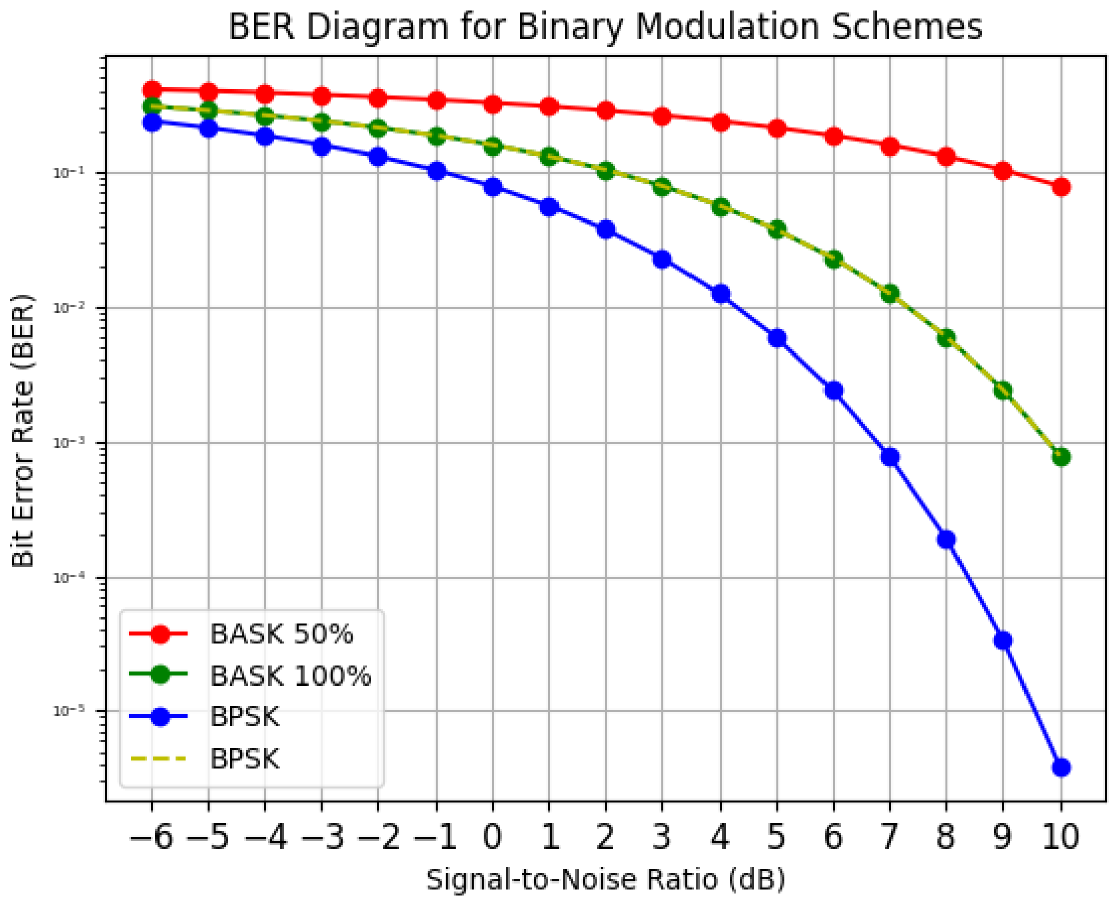

Figure 5.1: BER diagram for binary modulation schemas

Comments:

Figure 5.1 shows that compared to BFSK and BASK schemes, the bit error rate for the BPSK modulation is lower for various SNR levels for the same amount of bits transmitted and received. The ability to change the value of SNR has several limitations in real-world situations. For the output end to detect the message, higher performance with a minimal SNR and low bit error rate is needed. The BPSK modulation method performs best in this case while using less power and even with lower SNR.