Question 1: Set the transmission bandwidth of the bandwidth limited modulations (MPAM, MQAM, MPSK) as 1 MHz.

a) Plot Eb/N0 and Bit Error Rate (BER) curves of 16PAM and 16-QAM (Both theoretical and simulated BER). What is the data rate of each transmission? Show the constellation diagrams and bit to symbol mappings of each modulation and discuss which one is better in terms of BER and why?

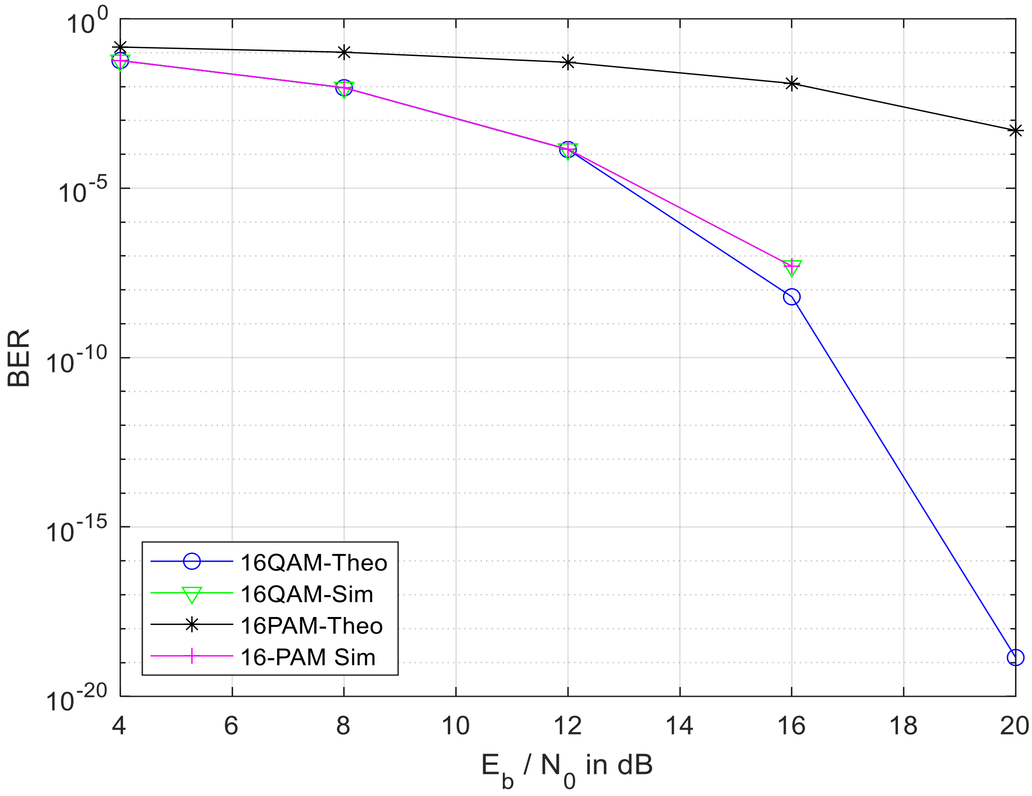

Figure 1: Comparison of Eb/N0 and Bit Error Rate (BER) Curves for Theoretical and Simulated 16PAM and 16-QAM

Figure 1 illustrates the Eb/N0 vs BER curves for 16PAM and 16QAM. Upon examining the MATLAB workspace, we observe that Eb/N0 ranges from 4dB to 20dB, with M = 16 and Rb (Data Rate) = 4000000 bps

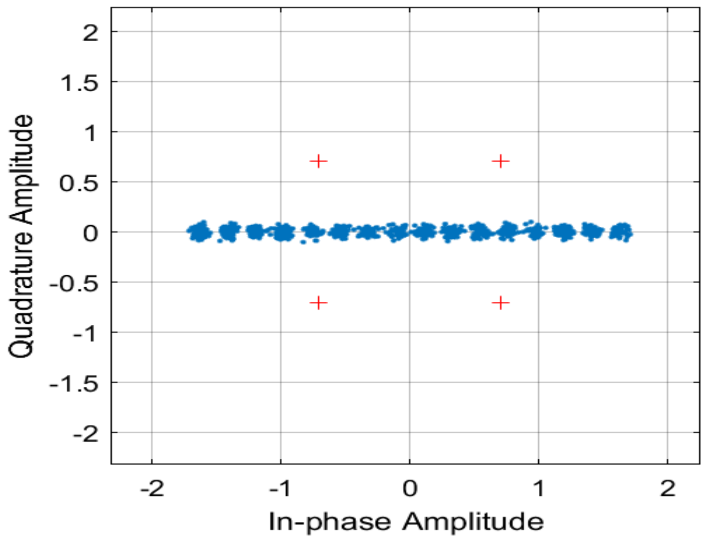

Figure 2 – 16PAM Constellation Diagram

As the Eb/N0 ratio of 16PAM increases towards 20dB, *Figure 2* demonstrates enhanced spacing between signal points, and larger amplitudes of the signal points within the constellation diagram. If Eb/N0 increases then the points be smaller so voice will be more clearer.

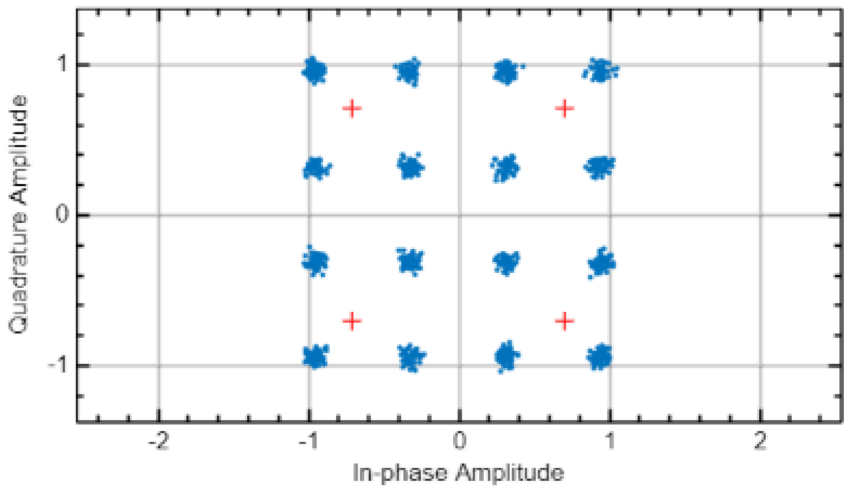

Figure 3 – 16QAM Constellation Diagram

Figure 3 shows that as the Eb/N0 ratio of 16PAM increases towards 20dB, there is an evident expansion in the spacing between signal points within the constellation diagram. When Eb/N0 increases the points be smaller and the voice will be more clearer.

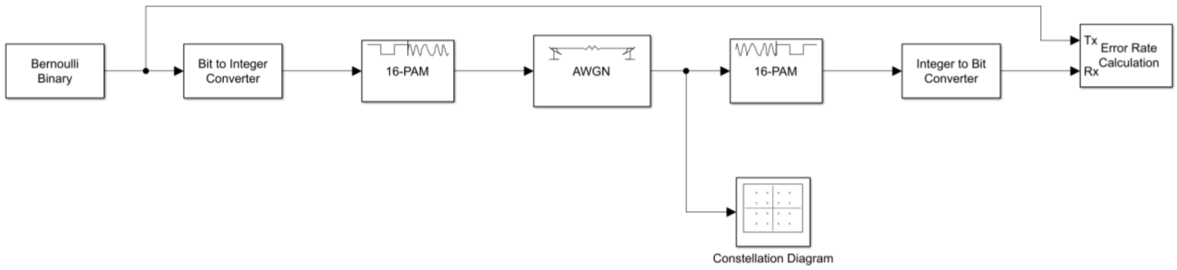

Figure 4 – 16PAM Simulink Diagram

Figure 4 displays the Simulink diagram of the code written for 16PAM.

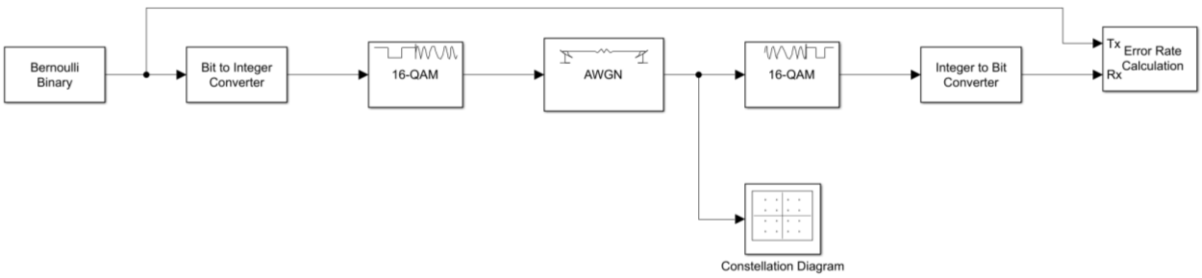

Figure 5 – 16QAM Simulink Diagram

Figure 5 displays the Simulink diagram of the code written for 16QAM.

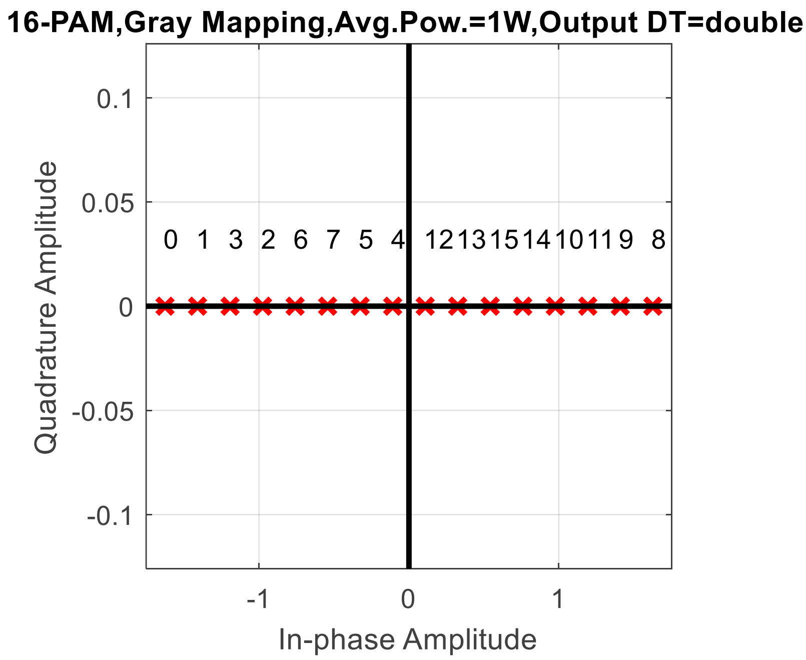

Figure 6 – 16PAM Gray Mapping

Figure 6 shows gray mapping of 16-PAM. The bits appearing on the graph are not randomly but arranged so that the bit difference between each point is 1.

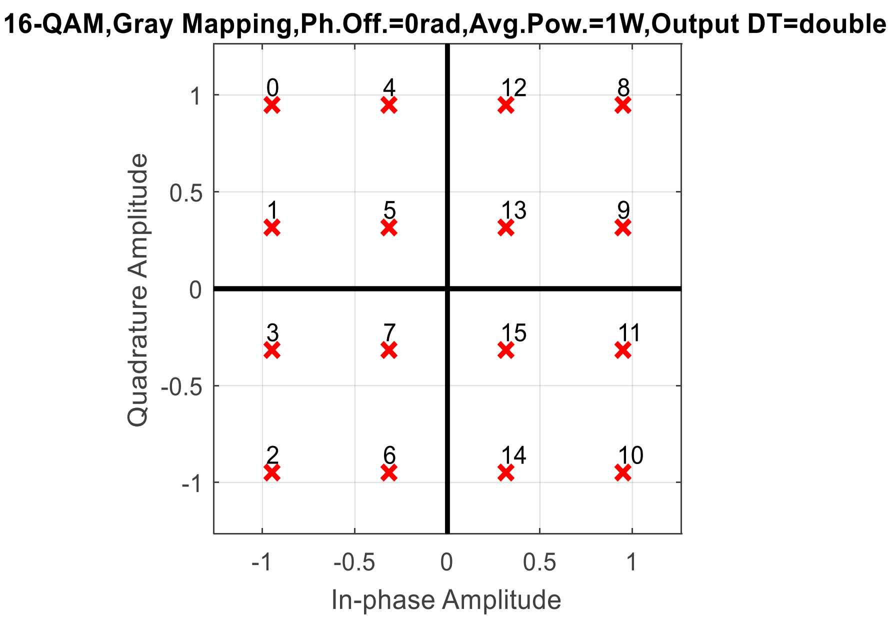

Figure 7 – 16QAM Gray Mapping

Figure 7 shows gray mapping of 16-QAM. The modulation bit in the graph is 4. There is a 1-bit difference between the adjacent points, so the order of the bits is not random.

Comment:

First, let's recall what we learned in class before comparing 16PAM and 16QAM. We know that as the value of M increases, the data rate of transmission (Rb) also increases, which is beneficial. However, at the same time, as M increases, the probability of error (Pb) also increases, which is undesirable. Additionally, we are aware that 16QAM is a 4PAM, and even by considering this alone, we can say that 16PAM has a higher probability of error compared to 16QAM. Moreover, by examining Figure 1, we can observe that 16QAM has a lower probability of error. Thus, 16QAM is more advantageous for our purposes.

b) Plot Eb/N0 and BER curves of 16PSK and 16-QAM (Both theoretical and simulated BER). What is the data rate of each transmission? Show the constellation diagrams and bit to symbol mappings of each modulation and discuss which one is better in terms of BER and why?

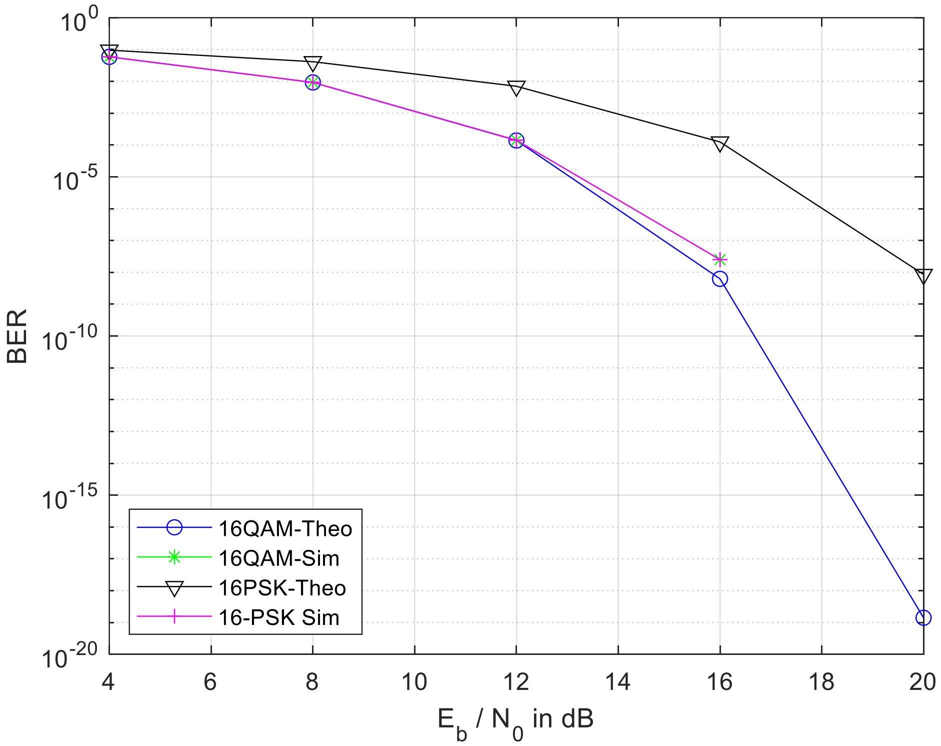

Figure 8 - Comparison of Eb/N0 and Bit Error Rate (BER) Curves for Theoretical and Simulated 16QAM and 16-PSK

Figure 8 illustrates the Eb/N0 vs BER curves for 16QAM and 16PSK. Upon examining the MATLAB workspace, we observe that Eb/N0 ranges from 4dB to 20dB, with M = 16 and Rb (Data Rate) = 4000000 bps.

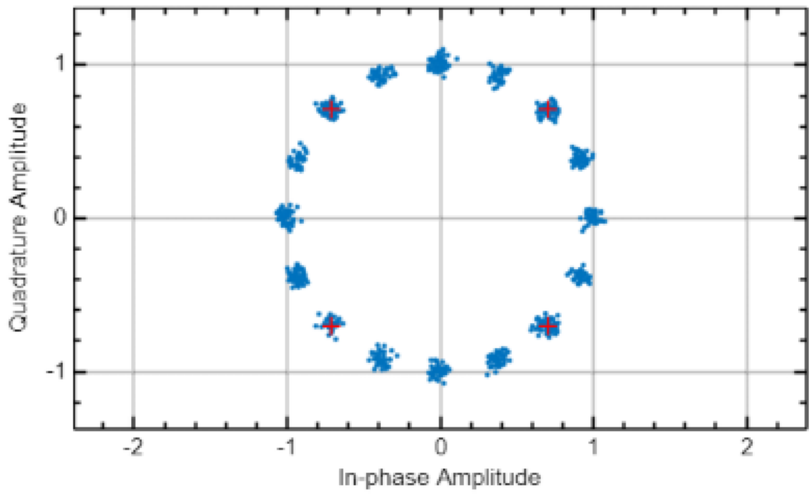

Figure 9 – 16PSK Constellation Diagram

Figure 9 shows the MPSK Constellation Diagram when Eb/N0 is 20 dB and M is equals to 16. When Eb/N0 increases the points be smaller and the voice will be more clearer however if Eb/N0 decreases, the purity of the voice decreases and starts to deteriorate.

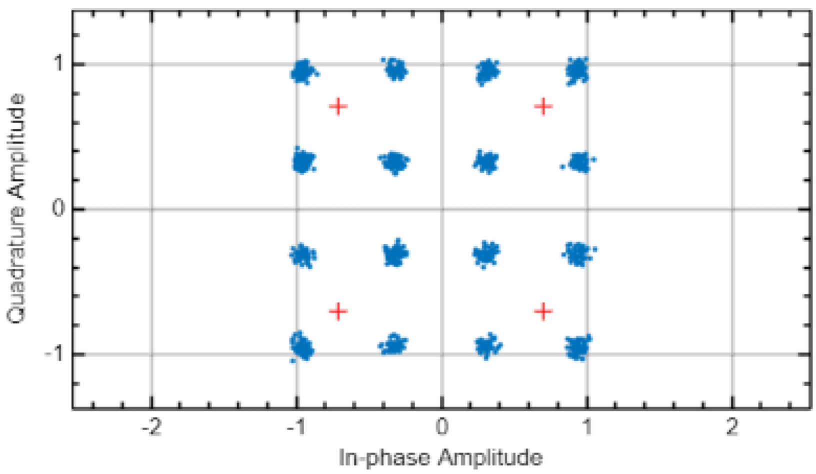

Figure 10 – 16QAM Constellation Diagram

Figure 10 shows that as the Eb/N0 ratio of 16PAM increases towards 20dB, there is an evident expansion in the spacing between signal points within the constellation diagram. When Eb/N0 increases the points be smaller and the voice will be more clearer.

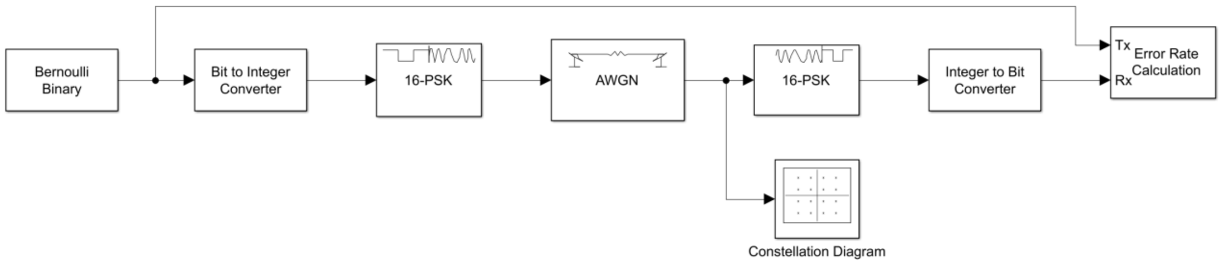

Figure 11 -16PSK Simulink Diagram

Figure 11 displays the Simulink diagram of the code written for 16PSK.

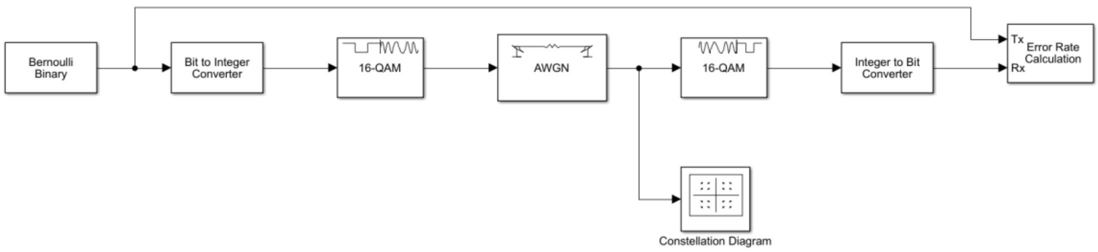

Figure 12 - 16QAM Simulink Diagram

Figure 12 displays the Simulink diagram of the code written for 16QAM.

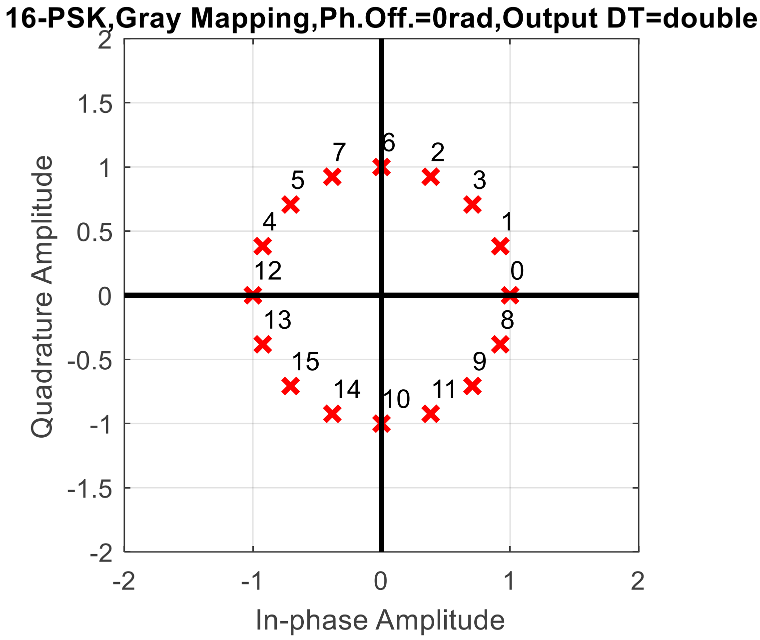

Figure 13 -16PSK Gray Mapping

Figure 13 shows the constellation diagram of MPSK when M is equals to 16. When Eb/N0 increases the points be smaller and the voice will be more clearer.

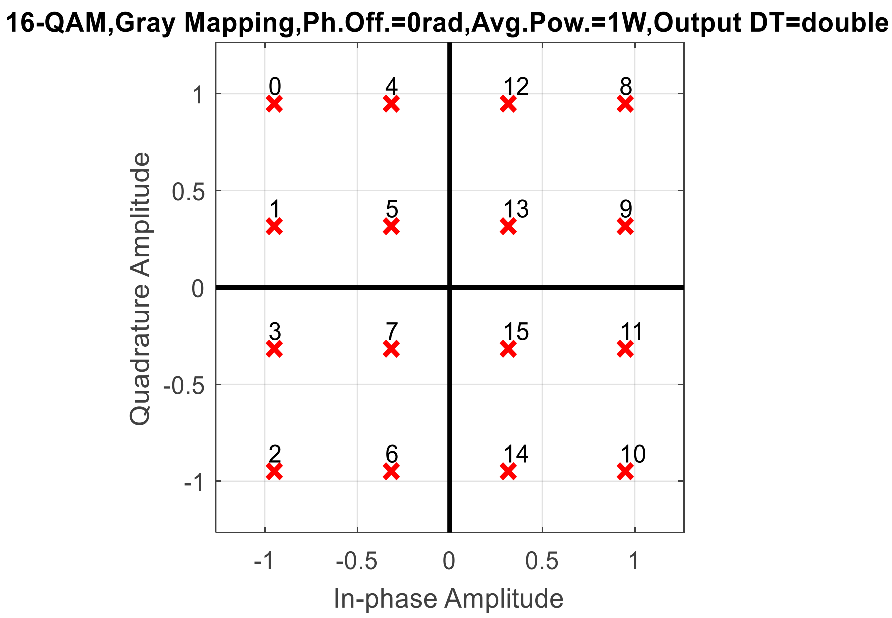

Figure 14 -16QAM Gray Mapping

Figure 14 shows gray mapping of 16-QAM. The modulation bit in the graph is 4. There is a 1-bit difference between the adjacent points, so the order of the bits is not random.

Comment:

When comparing 16PSK and 16-QAM, by referring to Figure 8, we observe that 16QAM has fewer error bits compared to 16PSK. If we directly examine the graph, for instance, by drawing a vertical line at an Eb/N0 value of 10, we notice that the BER (Bit Error Rate) of 16QAM is lower. This is something we already knew beforehand; in fact, even when comparing 64QAM to 32PSK, we observe that 64QAM has fewer error bits. Thus, we prefer 16QAM for BER considerations as it performs better. 16QAM is the preferred choice.

Question 2: Set the data rate of an MFSK (orthogonal, non-coherently detected) transmission as 10 kbps. Show the spectrum of the noisy MFSK signal under Eb/N0 = 10 dB. Compare the theoretical signal bandwidth with the ones observed in spectrum analyzer under BFSK, 4FSK and 8FSK. Plot Eb/N0 (in dB) and BER graph for BFSK, 4FSK and 8FSK (Both theoretical and simulated BER). For each case, comment on the BER when Eb/N0 = 7 dB, and comment on Eb/N0 when BER is around 1e-3

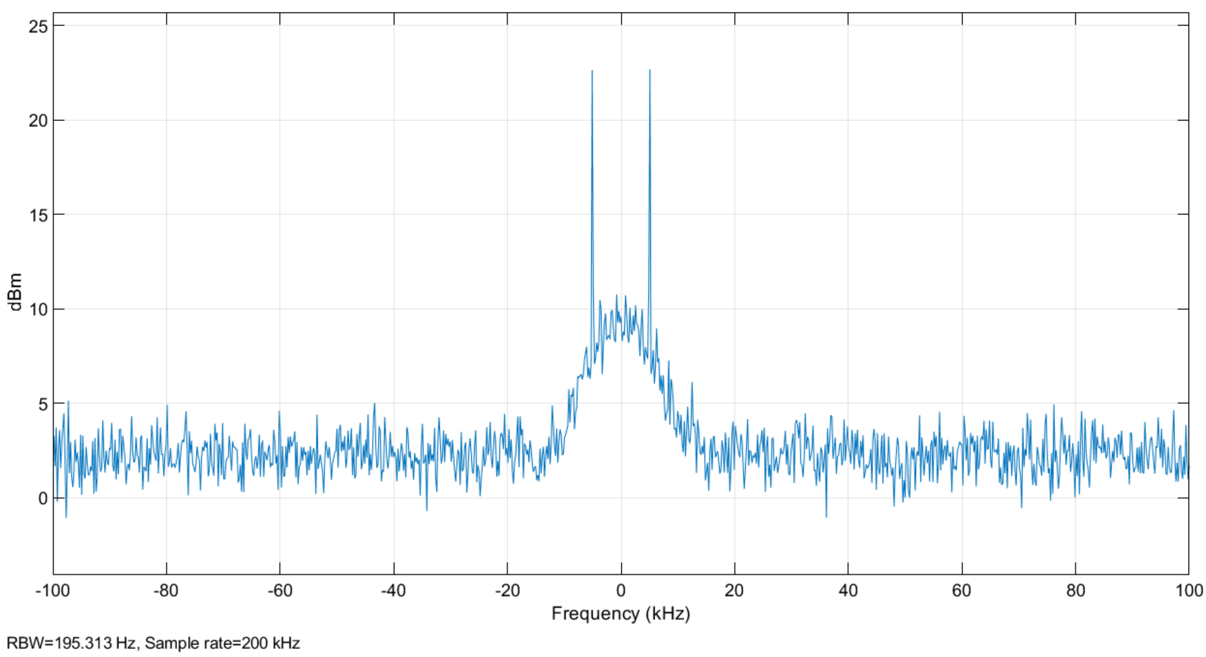

Figure 1 Spectrum Analyzer of AWGN Channel

Figure 15 shows the Spectrum Analyzer of M-FSK at M=2 , Rb=10kbps , EbN0dB = 10. Also It's sample rate is 200k Hz and RBW is 195.313 Hz.

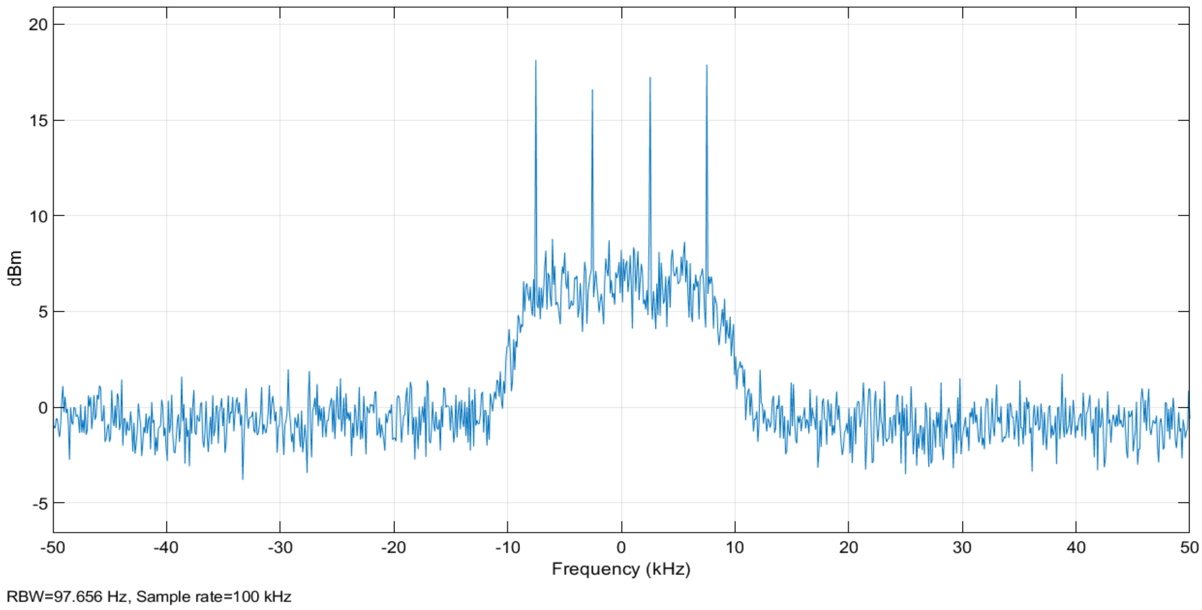

Figure 16 Spectrum Analyzer of AWGN Channel

Figure 16 shows the Spectrum Analyzer of M-FSK at M=4 , Rb=10kbps , EbN0dB = 10. Also It's sample rate is 100k Hz and RBW is 97.656 Hz.

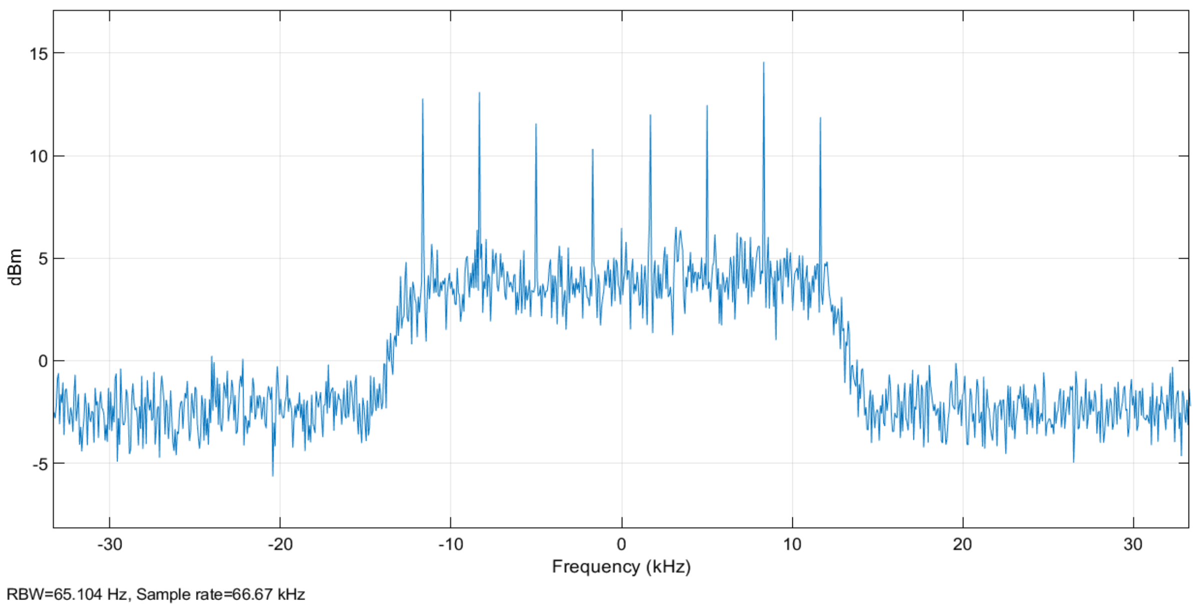

Figure 17 Spectrum Analyzer of AWGN Channel

Figure 17 shows the Spectrum Analyzer of M-FSK at M=8 , Rb=10kbps , EbN0dB = 10. Also It's sample rate is 66.67 Hz and RBW is 65.104 Hz.

Comment 1:

In the above three graphs, all Rb values were the same and set to 10kbps. Each graph had a different value for M, and additionally, for MFSK noncoherently detected transmission bandwidth, we can utilize the following formula:

$$W = \frac{M}{log_2 M} * (R_{b)}$$

If we assume that all Rb values are constant, we observe that the bandwidth value is the same for M = 2 and M = 4. However, for M = 8, we observe a wider bandwidth compared to M = 2 and M = 4.

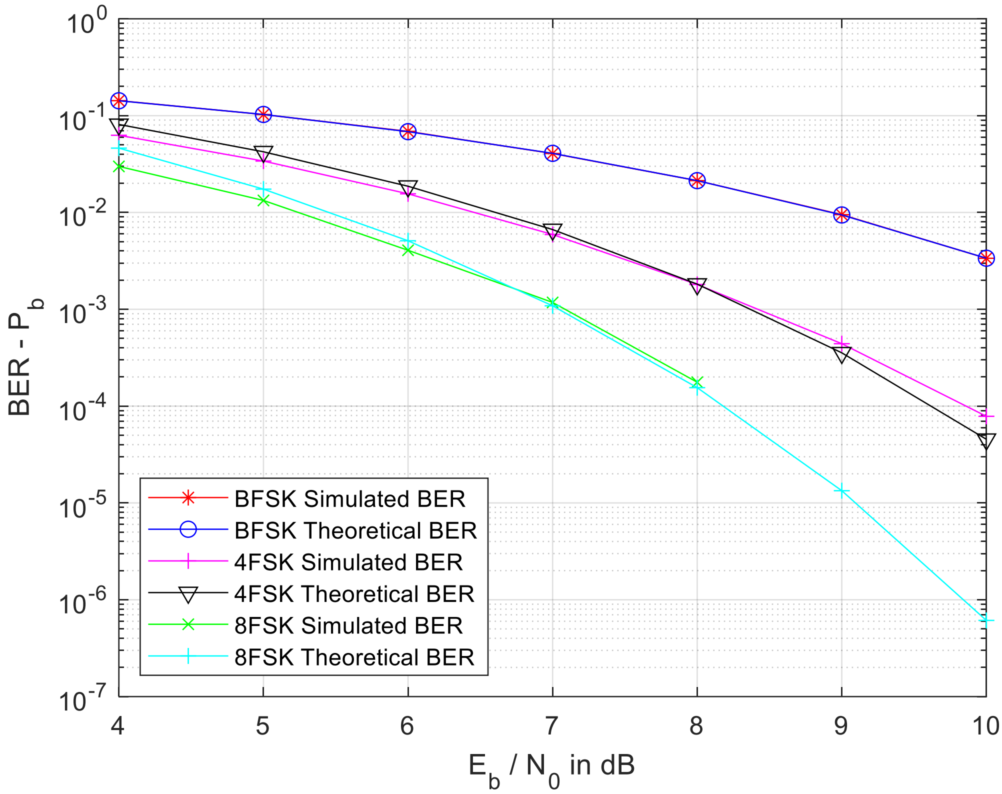

Figure 18 – Eb/N0 and Bit Error Rate (BER) curves of MFSK

Figure 18 displays the graphs of BFSK, 4FSK, and 8FSK, with each scenario represented by different colored lines.

Comment 2:

When examining the graphs of MFSK, we observe that unlike MQAM and MPSK, as the value of M increases, the probability of bit error decreases. Conversely, in MQAM and MPSK, the opposite trend is observed. Following the given question, let's draw a vertical line at EB/N0 = 7 dB and analyze the graph accordingly. At EB/N0 = 7 dB, 8FSK has the lowest Bit Error Rate (BER), while BFSK has the highest BER value. On the other hand, let's draw a horizontal line at BER = 1e-3; in this case, BFSK has the highest Eb/N0 value, while 8FSK has the lowest Eb/N0 value. Thus, we have demonstrated our initial claim that as the value of M decreases, Eb/N0 value increases. Consequently, if we were to select one modulation scheme for minimizing error bits, we would choose 8FSK because it has the lowest error rate.