ECSE308 Lab 3

Digital Transmission Techniques

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ECSE308

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2023-10-26

Lab 3: Digital Transmission Techniques

Part 1: Baseband digital transmission

Introduction:

In this part, we took a close look at the techniques to pass from digital data to an analog signal and vice versa. We also simulated baseband digital transmission over AWGN channels and their effect on Signal-and-noise ratio and Bit rate ratio. Figure 1 shows the setup of the DAC/ADC system.

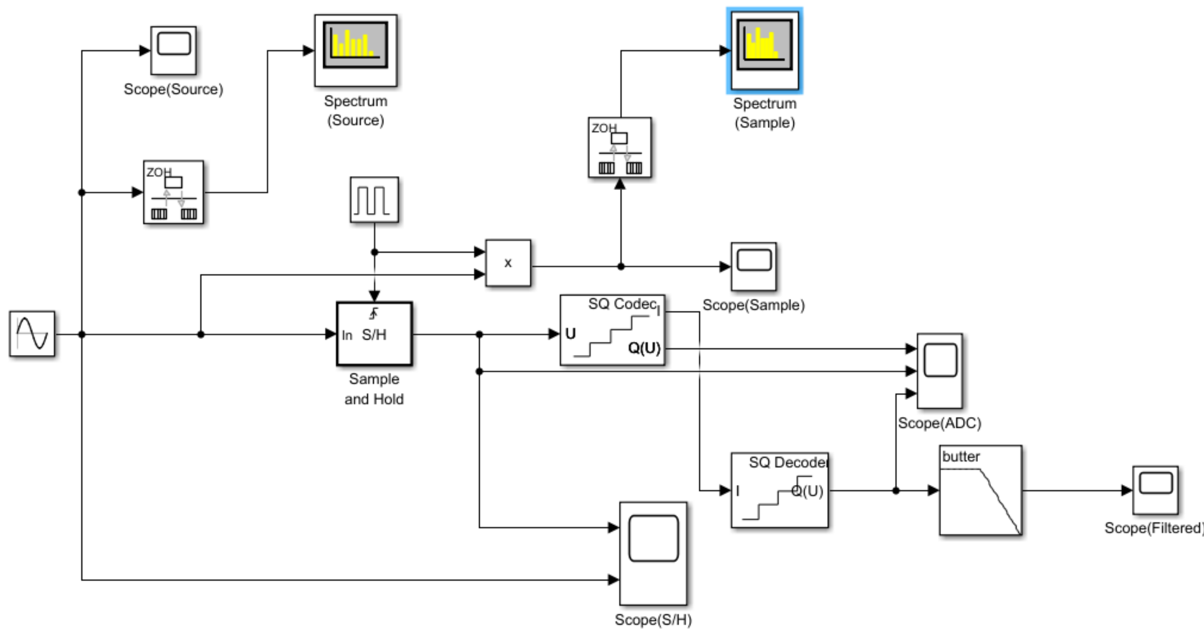

Fig.1. ADC/DAC System

Experiments:

We first compared the outputs on Scope(ADC) and Scope(S/H). We then multiply the source signal with a pulse train and observe the sample spectrum. Finally, we changed the number of quantization levels and quantization bits utilized and then observed their effects.

Questions:

Q1: Compare the outputs on Scope (ADC) and Scope(S/H). Explain how the Scalar Quantizer Encoder converts the analog input to the digital output.

Answer: We can see that SQE divides the range of possible analog amplitudes into a number of levels. The SQE compares the sampled analog amplitude to the boundaries of these levels and assigns the corresponding digital values.

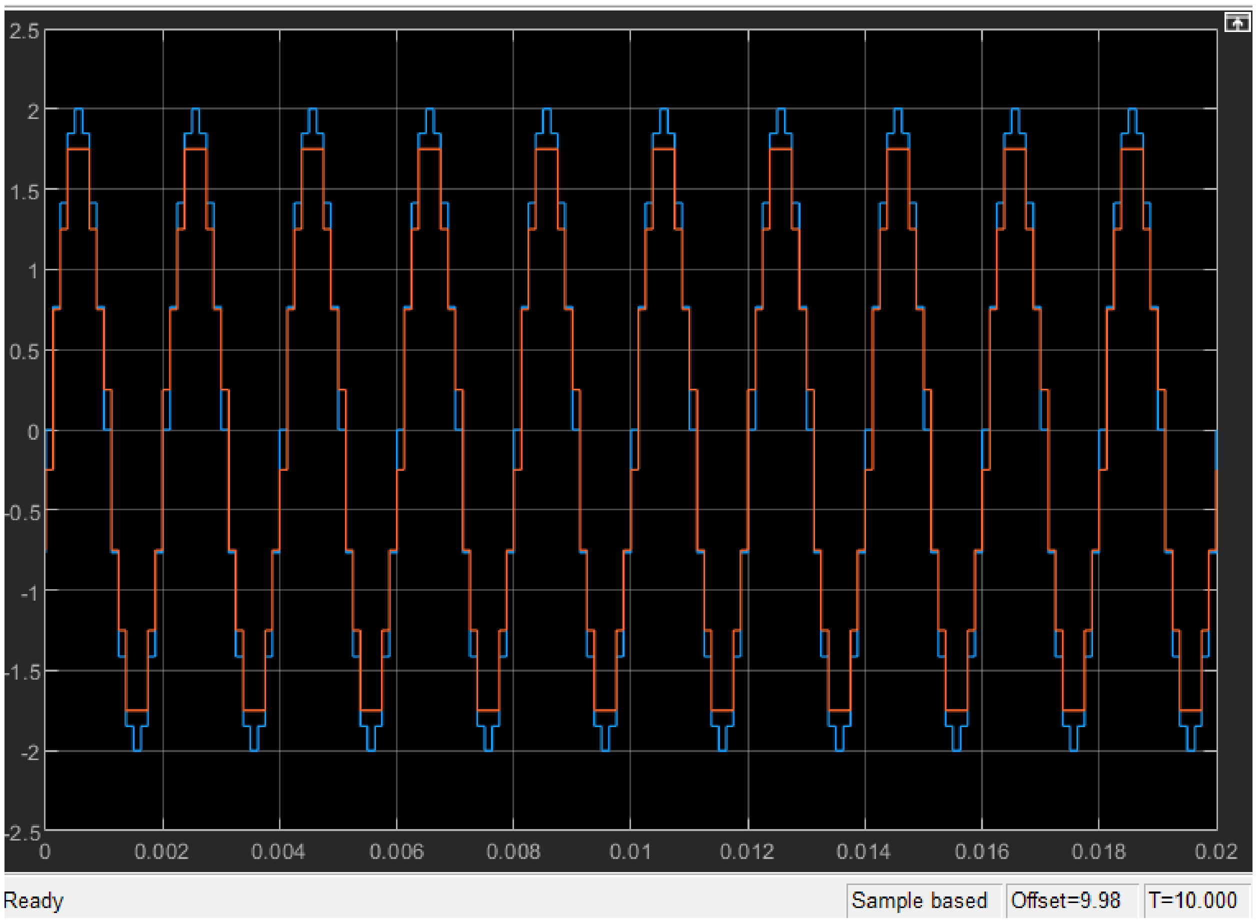

Fig.2. Output on the Scope(ADC)

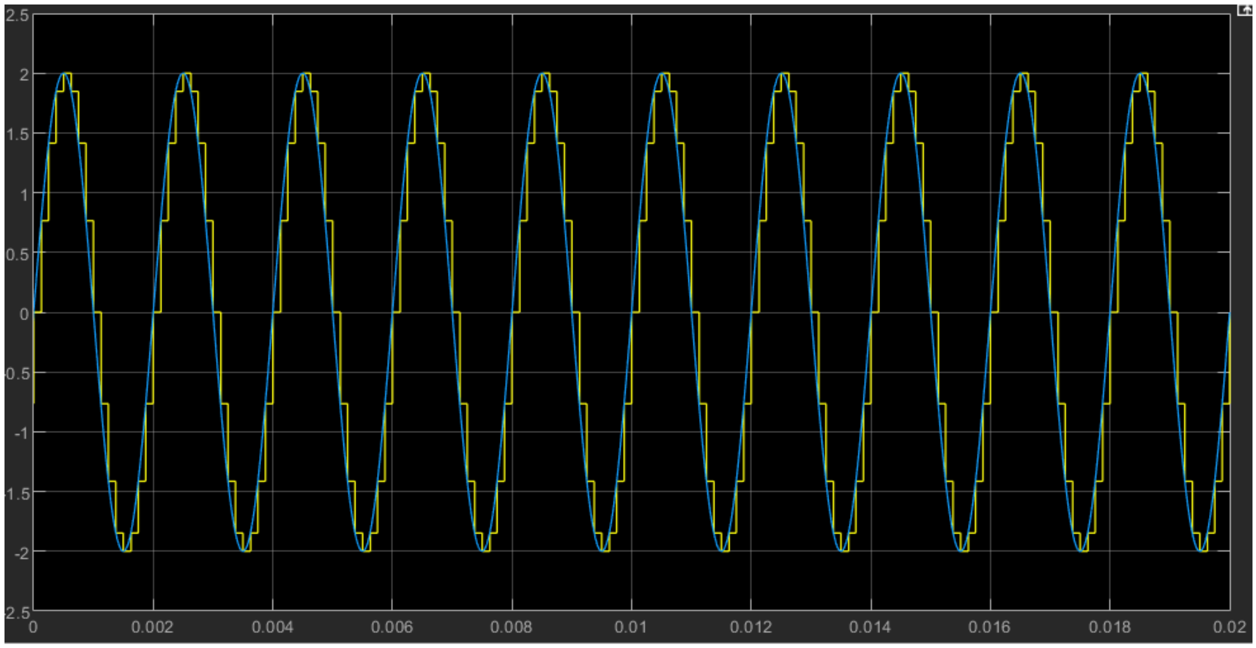

Fig.3. Output on the Scope(SH)

Q2: Compare the outputs on Spectrum (Source) and Spectrum (Sample). Comment on the effect on the spectrum of the source signal when multiplying with a pulse train. Explain why the output of the analog lowpass filter is the recovered source signal.

Answer: When multiplied with a pulse train, we can clearly see that the spectrum has shifted to higher and lower frequencies centered around the pulse train's frequency. The spectrum has been duplicated many times. Using a low pass filter will remove all but one original spectrum.

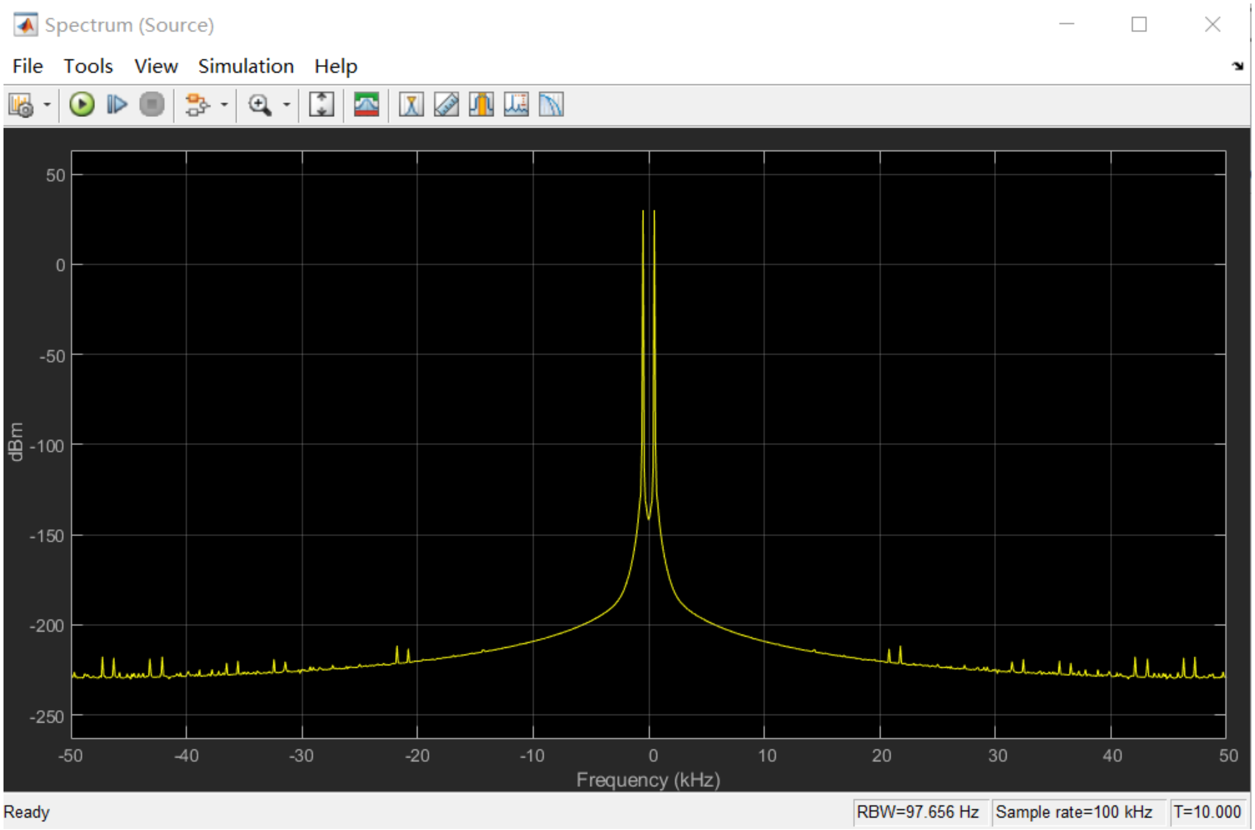

Fig.4.Spectrum of source signal.

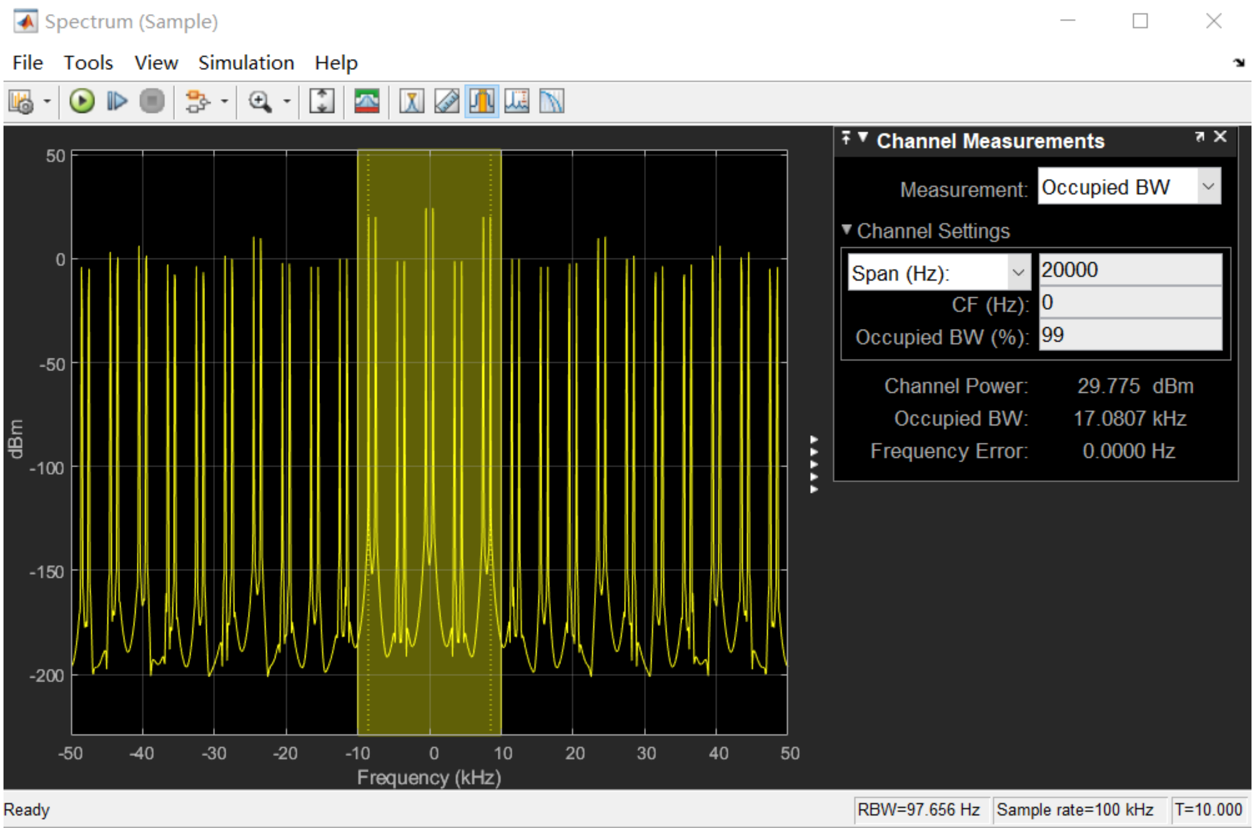

Fig.5.Spectrum of sample signal.

Q3: Observe the output on Scope (ADC). Comment on the number of quantization levels and quantization bits utilized. Repeat for the following parameter setup: Scalar Quantizer Encoder Boundary points: [-2:2] | Codebook values: [-1.5:1:1.5]; Scalar Quantizer Decoder Codebook values: [-1.5:1:1.5]. Comment on the performance difference.

Answer:
We can figure out the number of quantization levels by counting the number of plateaux for one period. We can find, by using the new setup parameters, quantization levels have been reduced to 4 from 7. Also, for the number of quantization bits, $N = log2(L)$. We can get N = 2.8 for the old setup and N = 2. By lowering the bits, the accuracy could be lost since the quantization has been reduced.

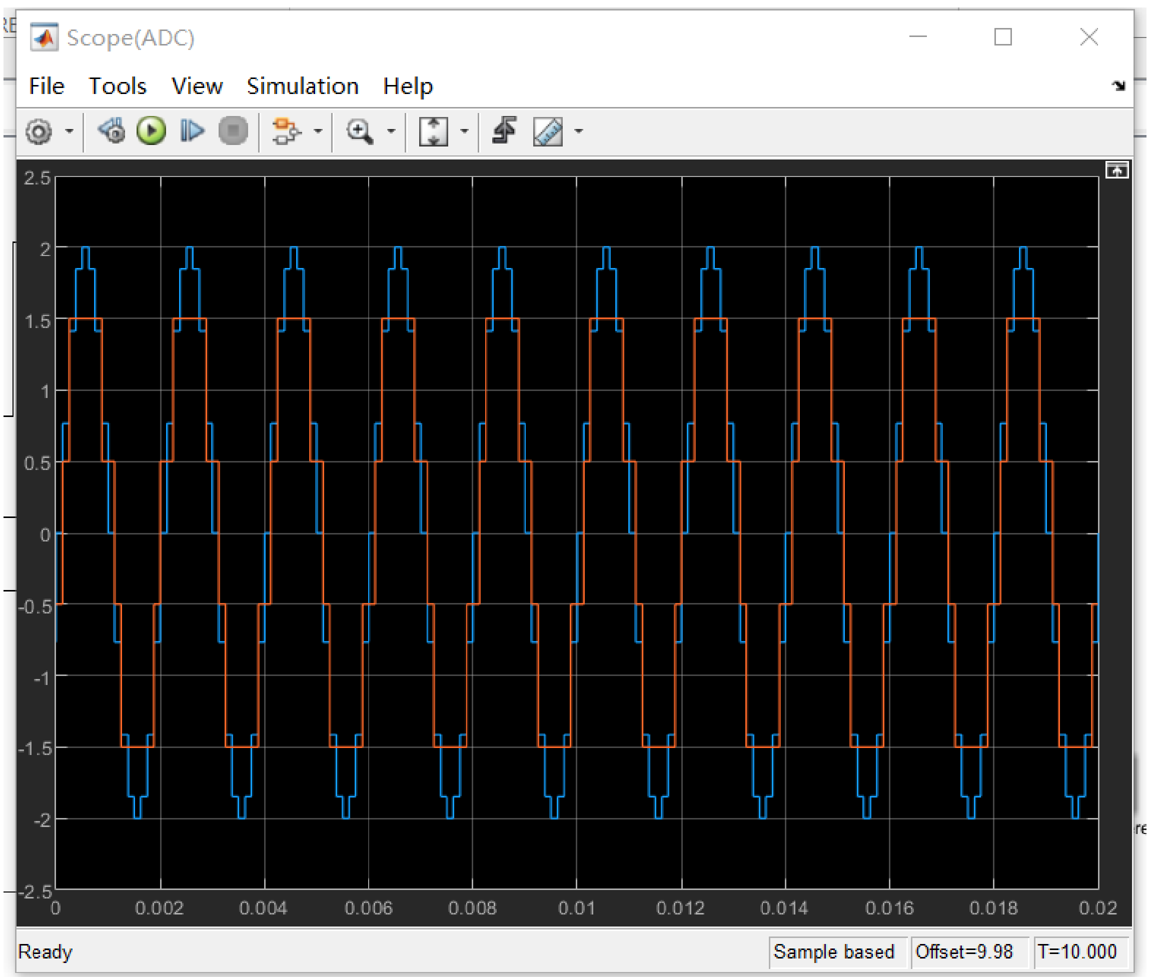

Fig.6. Output on the Scope(ADC) when we changed the setup.

Part 2: Basic digital modulation schemes: Binary ASK, PSK, FSK, and 4-QAM

Introduction:

In this part, this report delves into fundamental concepts of digital modulation schemes: Binary Phase Shift Keying (PSK), Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and 4-Quadrature Amplitude Modulation (4QAM). It aims to clarify their principles and applications. Additionally, the study investigates the power spectra of modulated signals, providing critical insights into spectral efficiency and signal performance.

Experiments:

1. Binary ASK:

We started with building a Binary ASK system as illustrated. (Fig. 1)

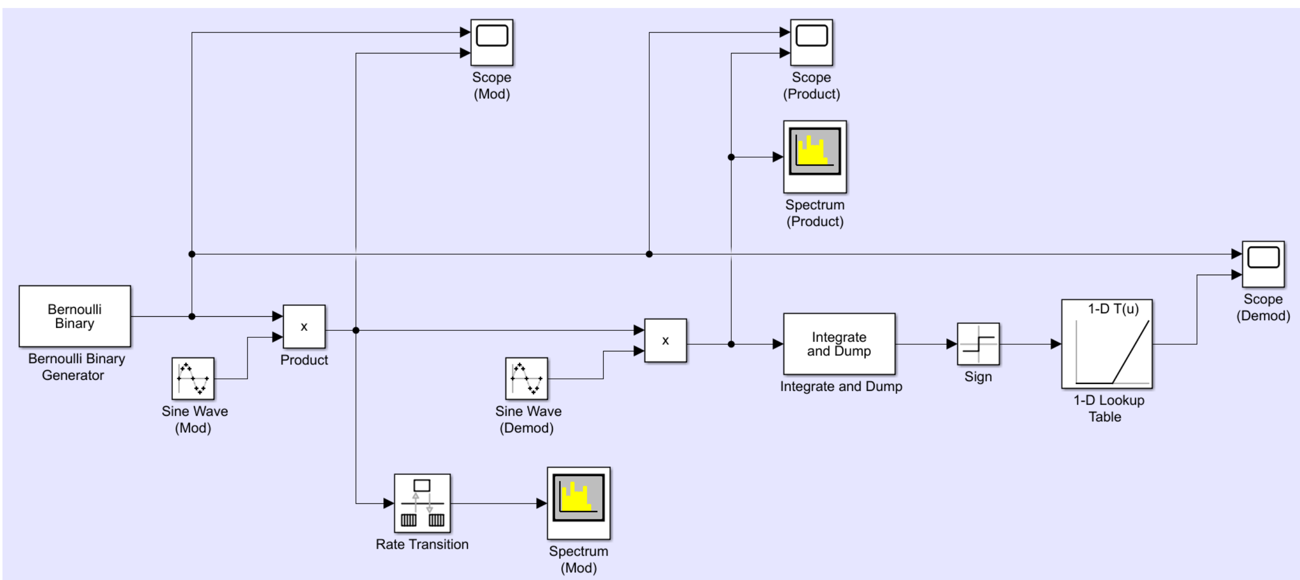

Fig.1. Binary ASK System

We set up the parameters as follows:

- Bernoulli Binary Generator (Source):

  Probability of zero: 0.5 | Source of initial seed: Parameter | Initial seed: 67 | Sample time: 1e-3

- Sine Wave (Mod) and Sine Wave (Demod):

  Sine type: Sample-based | Samples per period: 5000 | Sample time: 1e-7

- Rate Transition: Output port sample time: 0.5e-4
- 1-D Lookup Table: Table data: [0,0,1] | Breakpoints 1: [-1,0,1]

2. Binary PSK:

We built a Binary BSK system as illustrated in Fig. 2.

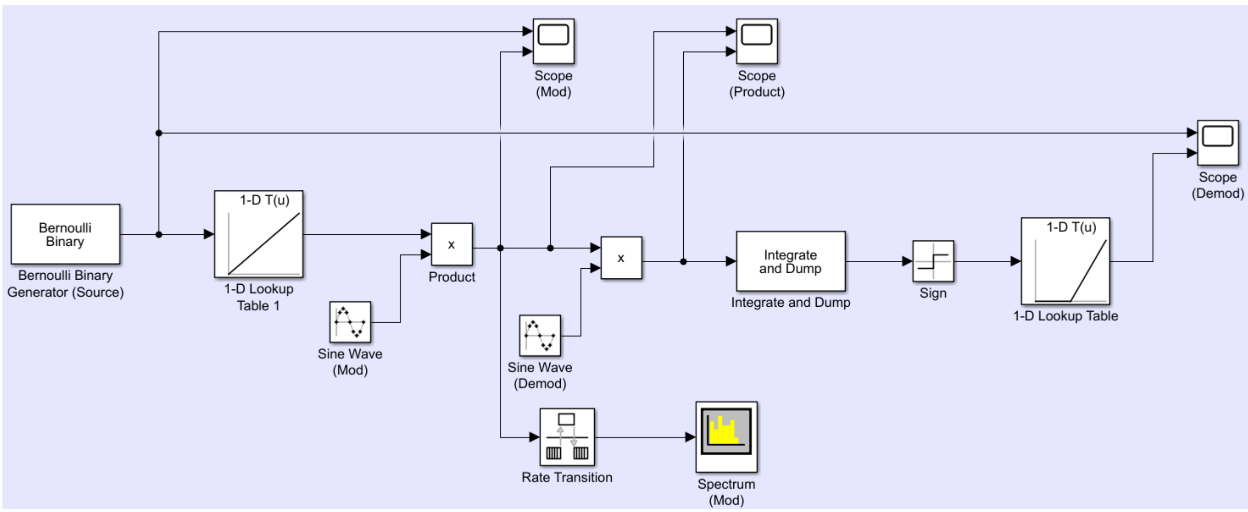

Fig. 2. Binary PSK System

Our set-up parameters are listed as follows:

- Bernoulli Binary Generator (Source):

  Probability of zero: 0.5 | Source of initial seed: Parameter | Initial seed: 67 | Sample time: 1e-3

- 1-D Lookup Table 1: Table data: [-1,1] | Breakpoints 1: [0,1]
- 1-D Lookup Table: Table data: [0,0,1] | Breakpoints 1: [-1,0,1]
- Sine Wave (Mod) and Sine Wave (Demod):

  Sine type: Sample-based | Samples per period: 5000 | Sample time: 1e-7

- Rate Transition: Output port sample time: 0.5e-4

3. Binary FSK:

We started with building a Binary FSK system as illustrated. (Fig. 3)

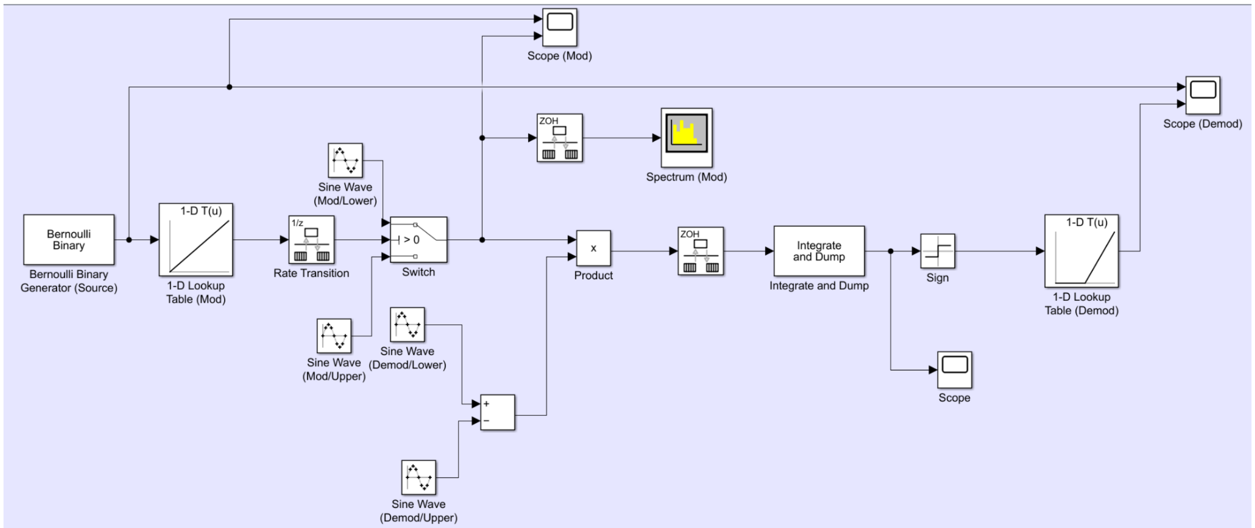

Fig. 3. Binary FSK System

We set up the parameters as follows:

- Bernoulli Binary Generator (Source):

  Probability of zero: 0.5 | Source of initial seed: Parameter | Initial seed: 67 | Sample time: 1e-3

- 1-D Lookup Table 1: Table data: [-1,1] | Breakpoints 1: [0,1]
- 1-D Lookup Table: Table data: [0,0,1] | Breakpoints 1: [-1,0,1]
- Sine Wave (Mod/Lower) and Sine Wave (Demod/Lower):

  Sine type: Sample-based | Samples per period: 4000 | Sample time: 1e-7

- Sine Wave (Mod/Upper) and Sine Wave (Demod/Upper):

  Sine type: Sample-based | Samples per period: 2857 | Sample time: 1e-7

- Rate Transition: Output port sample time: 0.5e-4

4. 4-QAM:

We built a Binary BSK system as illustrated in Fig. 4.

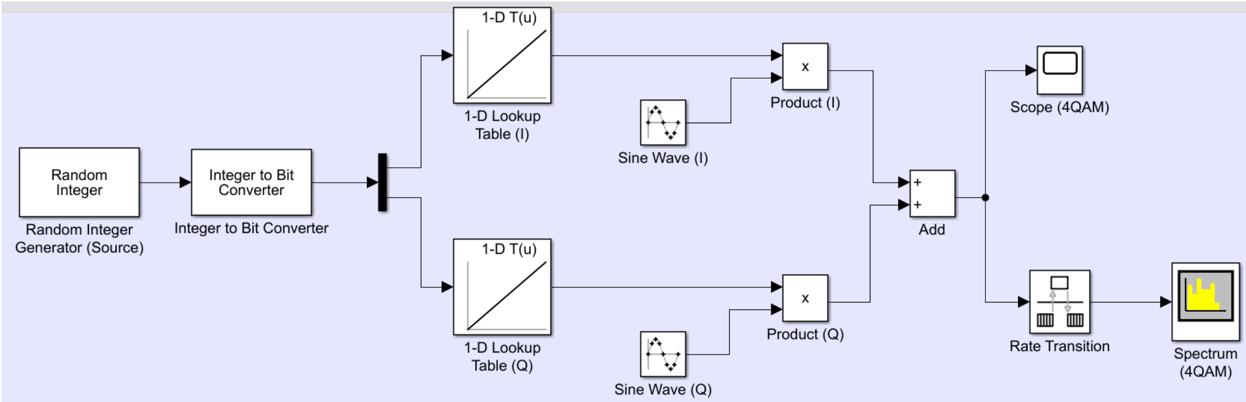

Fig. 4. 4-QAM System

Our set-up parameters are listed as follows:

- Random Integer Generator (Source): Set size: 4 | Sample time: 1e-3
- Integer to Bit Converter: Number of bits per integer(M): 2
- 1-D Lookup Table (I) and 1-D Lookup Table (Q):

  Table data: [-sqrt(0.5), sqrt(0.5)] | Breakpoints 1: [0,1]

- Sine Wave (I):

  Sine type: Sample-based | Samples per period: 5000 | Number of offset samples: 1250 | Sample time: 1e-7

- Sine Wave (Q):

  Sine type: Sample-based | Samples per period: 5000 | Number of offset samples: 0 | Sample time: 1e-7

- Rate Transition: Output port sample time: 0.5e-4

Questions:

Q1: Consider binary ASK. Observe the output on Scope (Mod). Describe how the transmitted signal is generated from the binary data streams.

Answer:

Binary ASK encodes digital information into two states. One amplitude level represents binary 0, and the other represents binary 1. In the case of this lab, an amplitude level of 1 is representative of binary 1, whereas an amplitude level of 0 denotes binary 0. The output is shown in Fig. 5.

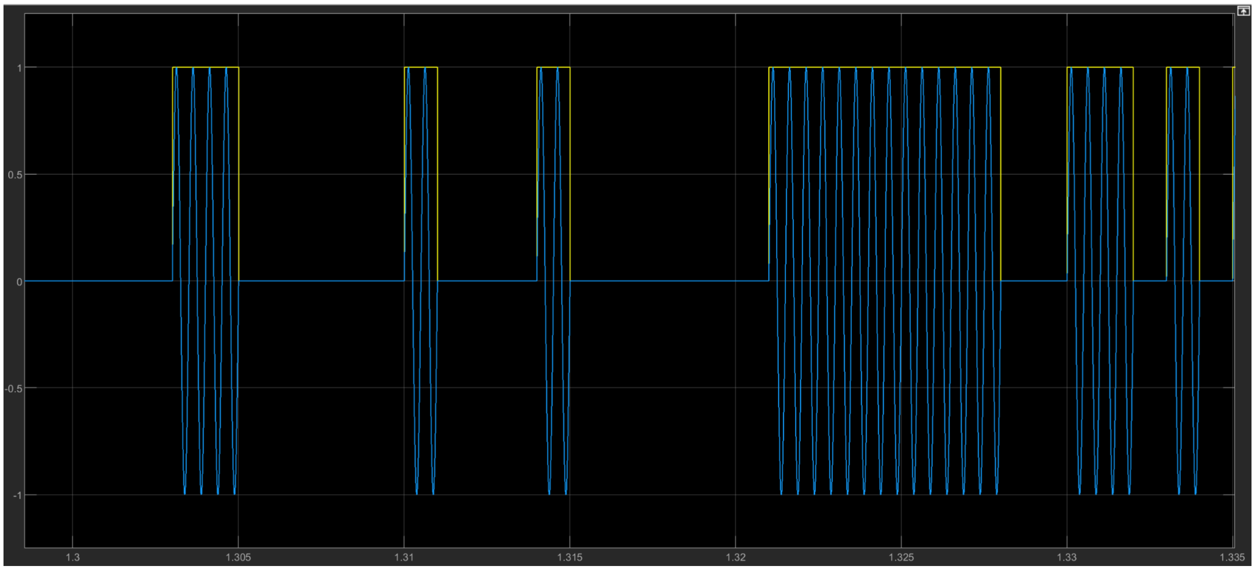

Fig. 5. Output of Binary ASK on Scope (Mod)

Q2: Consider binary PSK. Observe the output on Scope (Mod). Describe how the transmitted signal is generated from the binary data streams.

Answer:
In BPSK, binary 0 and binary 1 are represented by two different phase states of the signal. The phase of the signal is shifted based on the binary data. We can observe that the phase of the signal is shifted to represent the binary information from Fig. 6.

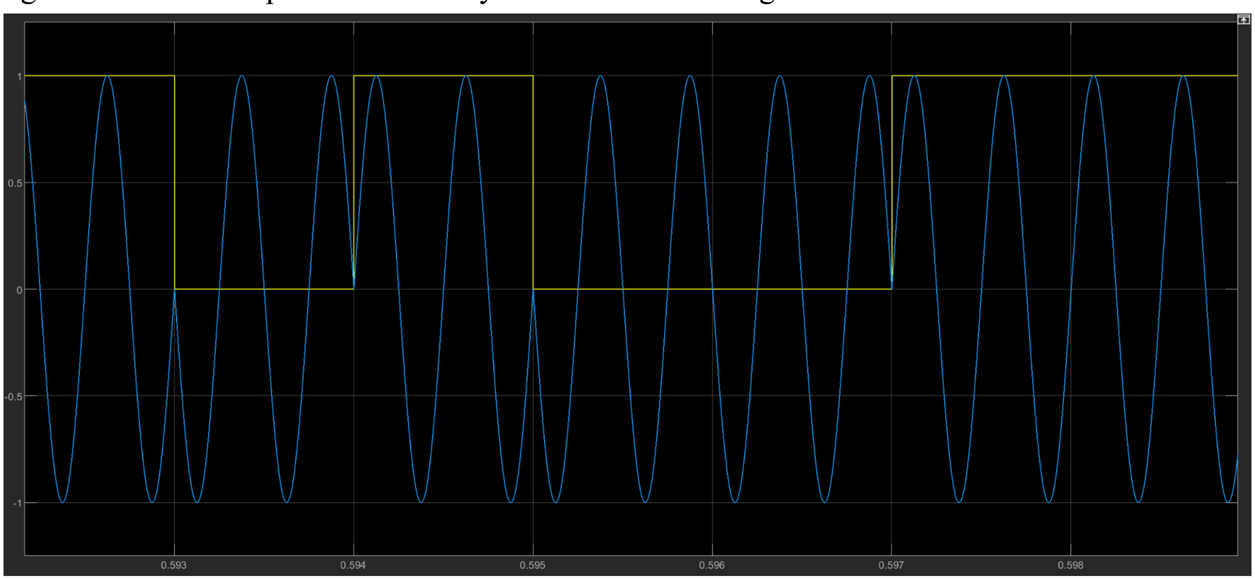

Fig. 6. Output of Binary PSK on Scope (Mod)

Q3: Consider binary FSK. Observe the output on Scope (Mod). Describe how the transmitted signal is generated from the binary data streams. Specify the carrier frequencies used for modulation and the corresponding frequency separation

Answer:

In FSK, the carrier frequency is shifted to represent digital data. In our case, in which a binary FSK is implemented, there are two distinct carrier frequencies used to represent the binary 0 and binary 1. This is achieved by increasing the frequency spacing for binary 0 and decreasing it for binary 1. As a result, in the transmitted signal, a lower frequency is observed for a binary value of 0, while a higher frequency is observed for a binary 1 (Fig. 7.)

The signal frequency for binary 0 is 2430Hz, and for binary 1 is 3352Hz. The carrier frequency is 2891Hz, and the corresponding frequency separation is 461Hz.

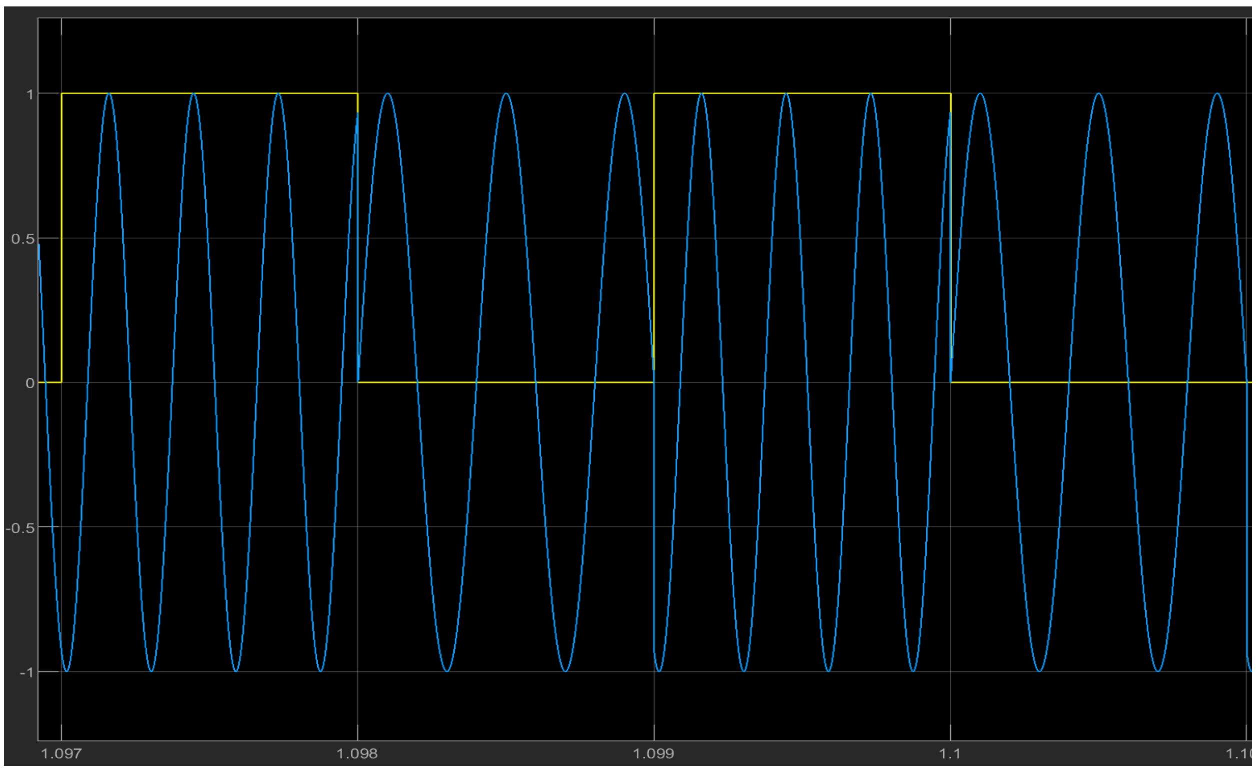

Fig. 7. Output of Binary FSK on Scope (Mod)

Q4: Consider 4-QAM. Observe the output on Scope (Mod). Describe how the transmitted signal is generated from the binary data streams. Explain how 4-QAM can be implemented from binary PSK. Explain how the power spectrum of 4-QAM is related to that of binary PSK.

Answer:

In 4-QAM, two bits are encoded into one symbol. Each symbol represents a unique combination of amplitude and phase. A 4-QAM is generated by modulating one bit using the carrier frequency, while the corresponding bit is modulated using the same carrier frequency but with a 90-degree phase shift. This combination results in a 4-QAM, where the carrier signal is also subject to amplitude modulation (Fig. 8.).

Binary PSK uses two phases to represent binary symbols. In 4-QAM, we maintain the same phase concept, but we add amplitude modulation as well. This allows us to implement 4-QAM from BPSK.

Both 4-QAM and Binary PSK are digital modulation schemes used for transmitting binary data. From 4-QAM's and BPSK's outputs on the spectrum (Fig. 9 and Fig. 10), we could tell that they have almost the same power spectrum. Moreover, their bandwidths are almost the same as well.

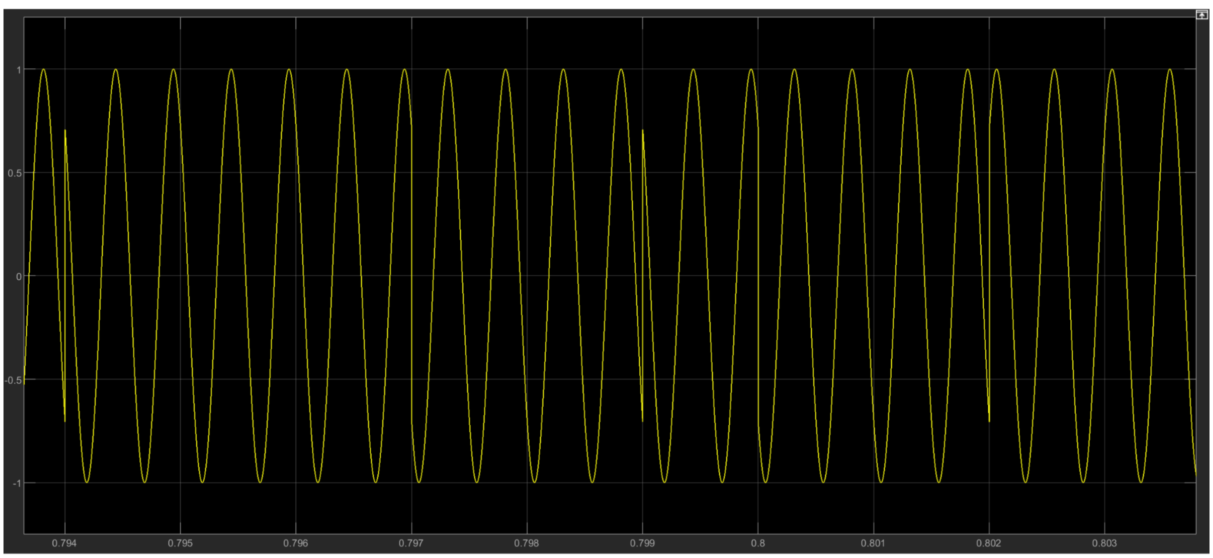

Fig. 8. Output of 4-QAM on Scope (Mod)

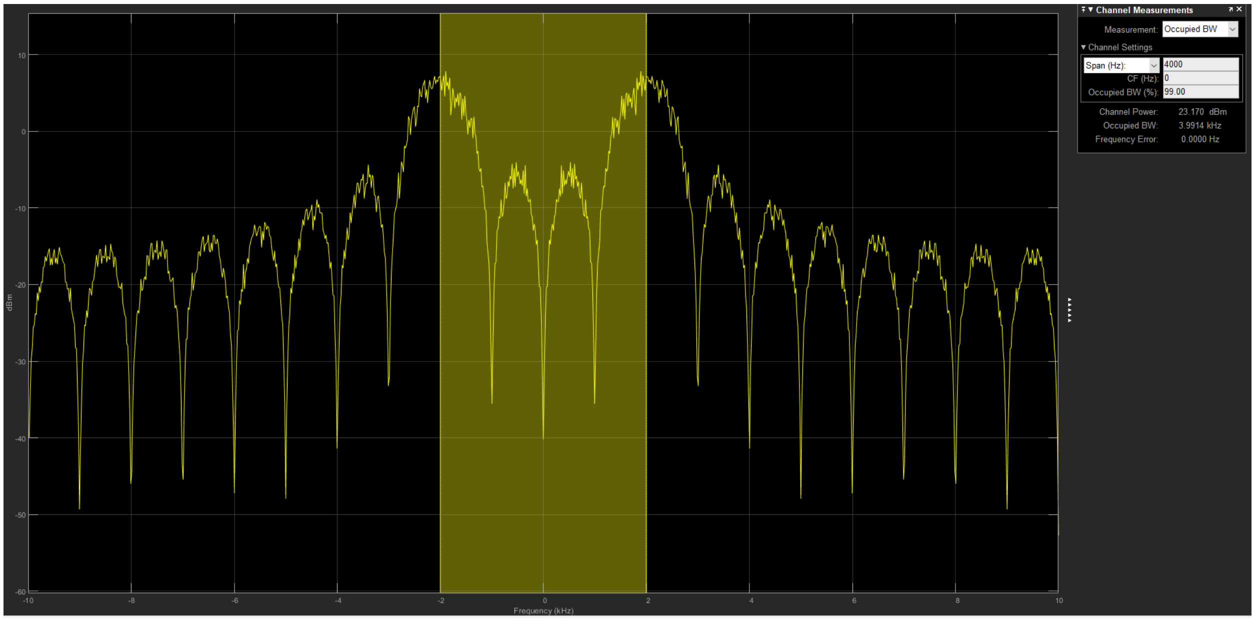

Fig. 9. Output of 4-QAM on Spectrum

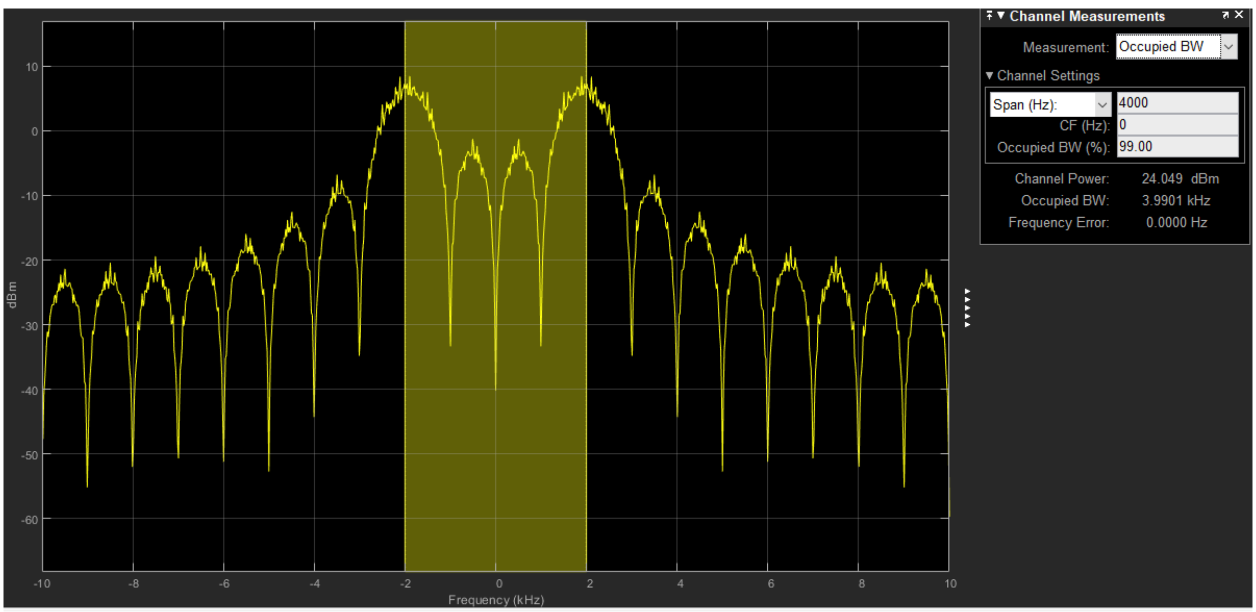

Fig. 10. Output of binary PSK on Spectrum

Q5: What are the transmission bandwidths of binary ASK and binary PSK? Explain how their power spectra are related.

Answer:

The transmission bandwidth of BASK is 3.9994kHz (Fig. 11.), and the transmission bandwidth of BPSK is 3.9901kHz(Fig. 10.)

The power spectrum of BPSK is 24.049dBm, and the power spectrum of BASK is 21.688dBm. Their power spectra are similar, but BPSK has a slightly higher power spectrum.

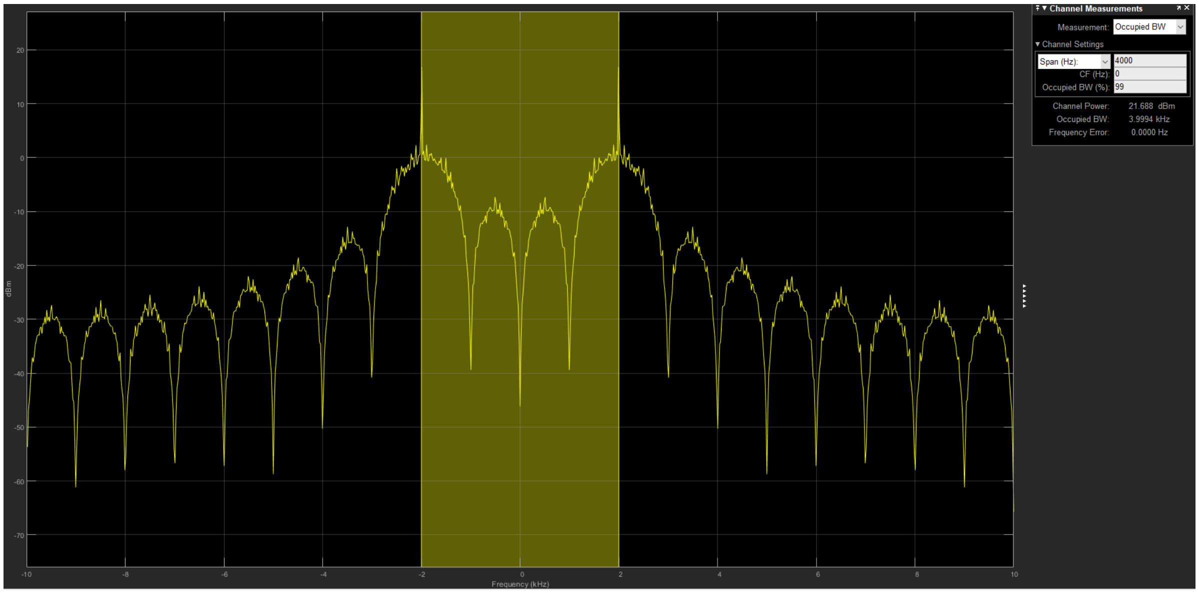

Fig. 11. Output of binary ASK on Spectrum

Q6: What is the transmission bandwidth of binary FSK? For binary ASK, PSK, and FSK, which one(s) is most bandwidth-efficient?

Answer:

From Fig. 12., we can tell that the transmission bandwidth of BFSK is 3.9954kHz. Among BASK, BPSK, and BFSK, BPSK is the most bandwidth-efficient.

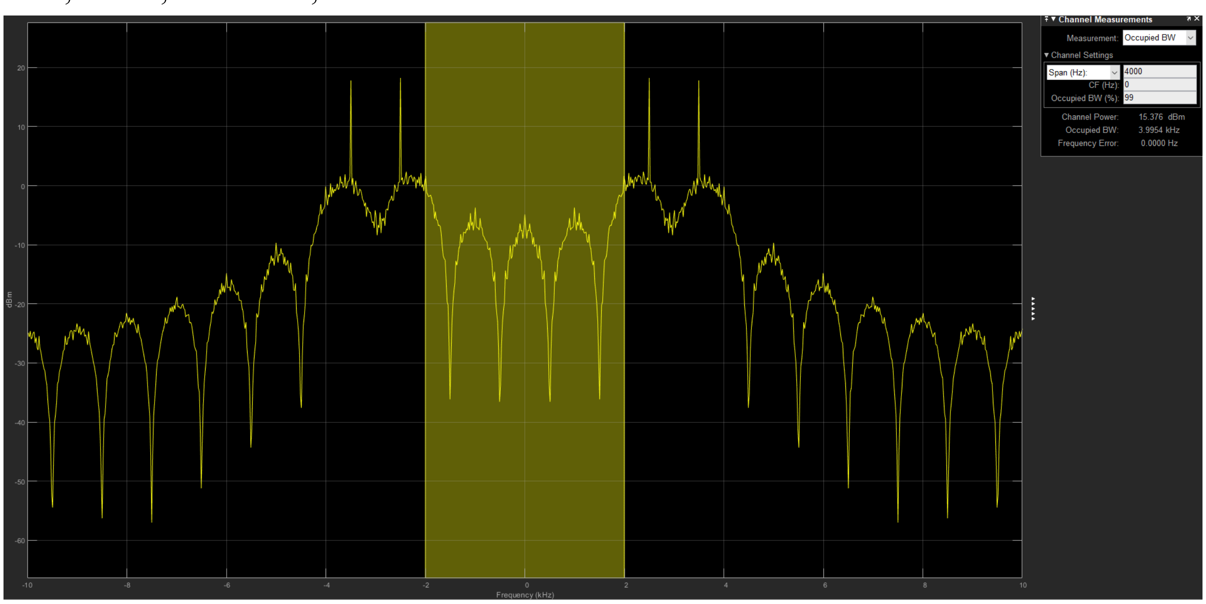

Fig. 12. Output of binary FSK on Spectrum

Part 3: M-QAM modulation & demodulation

Introduction:

This section delves into 16-QAM modulation and demodulation fundamentals, noise impact visualization via scatterplots, the relationship between SNR and BER, and examines M-QAM's power and bandwidth efficiencies. Insights gained from this section provide a foundational understanding crucial for optimizing communication systems in noisy environments.

Experiments:

We built the 16-QAM system as shown in Fig. 1.

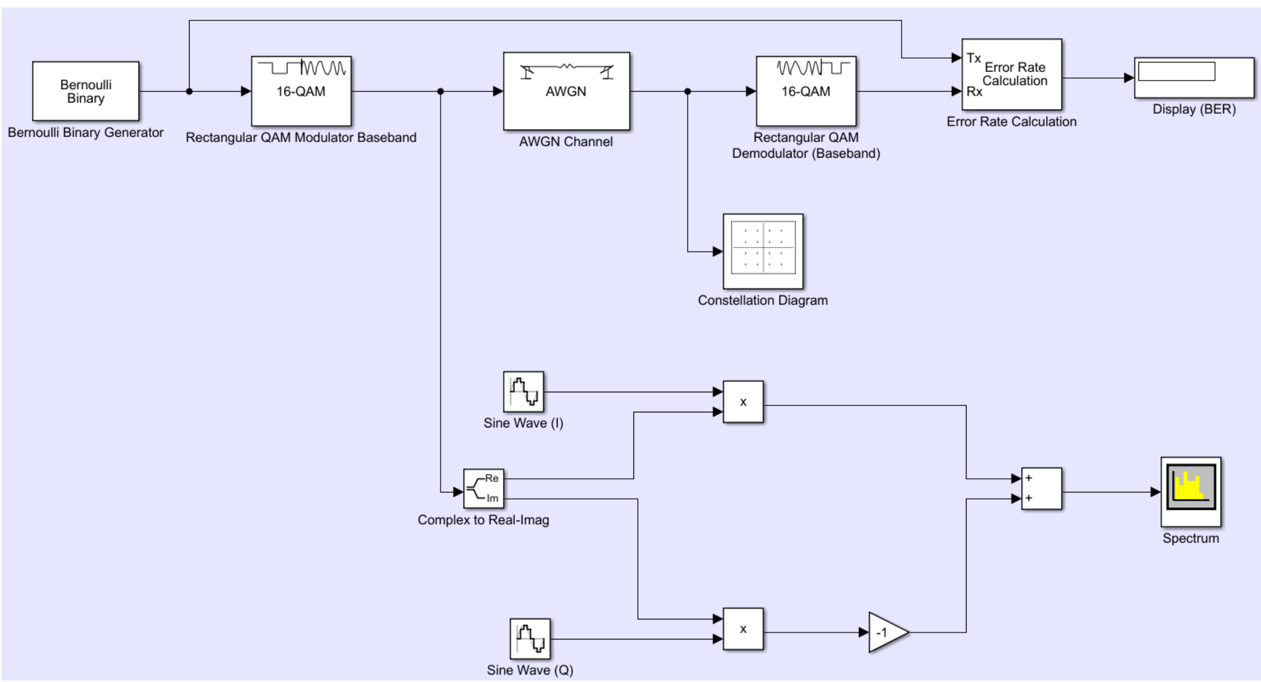

Fig.1. 16-QAM System

We set up the parameters as follows:

- Bernoulli Binary Generator (Source):

  Probability of zero: 0.5 | Sample time: 1e-6 | Samples per frame: 4

- Rectangular QAM Modulator:

  Baseband M-ary number: 16 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1

- AWGN Channel:

  Initial seed: 67 | Mode: Signal to noise ratio (Es/No) | Es/No (dB): 15 | Input signal power, referenced to 1 ohm (watts): 1 | Symbol period (s): 4e-6

- Constellation Diagram:

  Samples per symbol: 1 | Symbols to display: 1e6 | Reference constellation: 16-QAM | Average reference power: 1

- Rectangular QAM Demodulator Baseband:

  M-ary number: 16 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1

- Sine Wave (I): Frequency 100 | Phase offset (rad): $\frac{\pi}{2}$ | Sample time: 1e-6
- Sine Wave (Q): Frequency 100 | Phase offset (rad): 0 | Sample time: 1e-6
- Error Rate Calculation:

  Stop simulation: Target number of errors: 200 | Maximum number of symbols: 1e6

- Gain: -1

Questions:

Q1: Observe the output on Constellation. How many bits does each symbol carry? Describe the mapping between bits and symbols. Explain how 16-QAM can be expressed as an orthogonal superposition of two lower-order real modulation schemes.

Answer:
16-QAM is a modulation scheme that carries 4 bits per symbol.
In 16-QAM, we have 16 different combinations of amplitude and phase. These symbols can be organized in a 4x4 grid on a graph. We use Gray coding to ensure that nearby symbols only differ by one bit.
We can generate a 16-QAM by Combining ASK with four varying amplitude levels and PSK with four distinct phase levels. It allows for simultaneous modulation in both amplitude and phase, effectively transmitting 4 bits per symbol.

Q2: Describe how a noisy received signal is demodulated.

Answer:
In 16-QAM, a noisy received signal is demodulated by downconverting it to baseband, extracting in-phase (I) and quadrature (Q) components, identifying the closest symbol on the 16-QAM constellation, applying error correction if needed, and then decoding the symbol to retrieve the transmitted information.

Q3: Observe the output on Constellation Diagram. Explain the effect of additive white Gaussian noise on the transmitted signals.

Answer:
Additive White Gaussian Noise (AWGN) makes the transmitted signals in 16-QAM more unstable. This causes more mistakes in understanding the symbols, making it harder to decode correctly. When the SNR is low, it slows down the data and requires stronger techniques to fix errors for a reliable conversation.

Q4: Change Es/No (dB) in AWGN Channel. Run the simulation. Observe the output on Constellation Diagram. Explain how SNR affects the received constellation and therefore the BER.

Answer: When we increase the Es/No(dB) from 10 to 20 dB as shown below, we can clearly observe that the output on the constellation diagram becomes more centered around the points. When Es/No increases, which means the SNR increases, the received constellation becomes more concentrated.The bit error rate should thus decrease. From the display, we can see that bit error rate has decreased from 0.05896 to 10^(-6) when we increase the Es/No from 10 to 20dB.

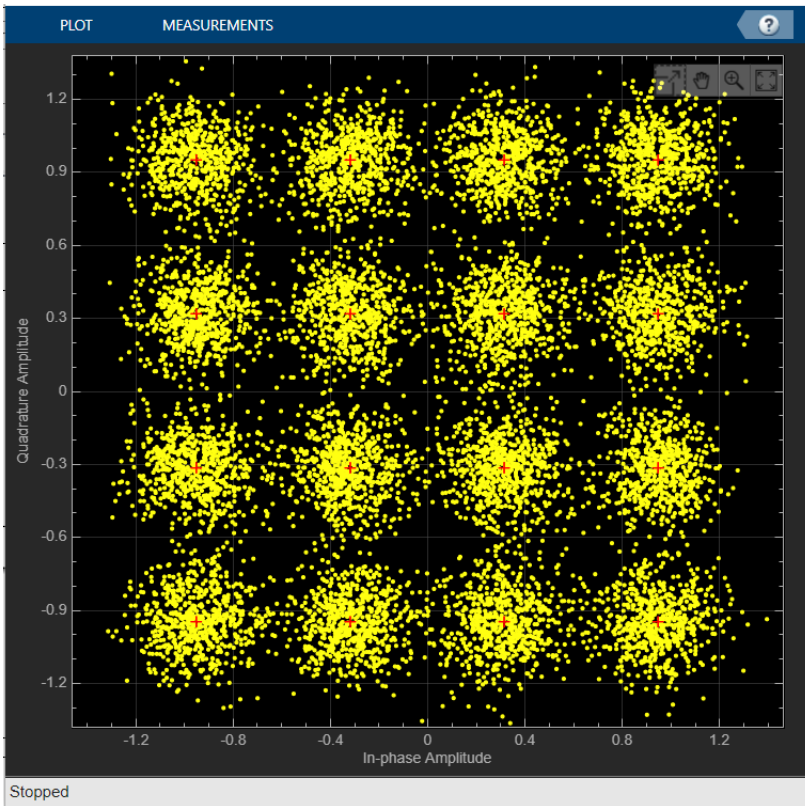

Fig. 2 . Constellation diagram when Es/No = 15.

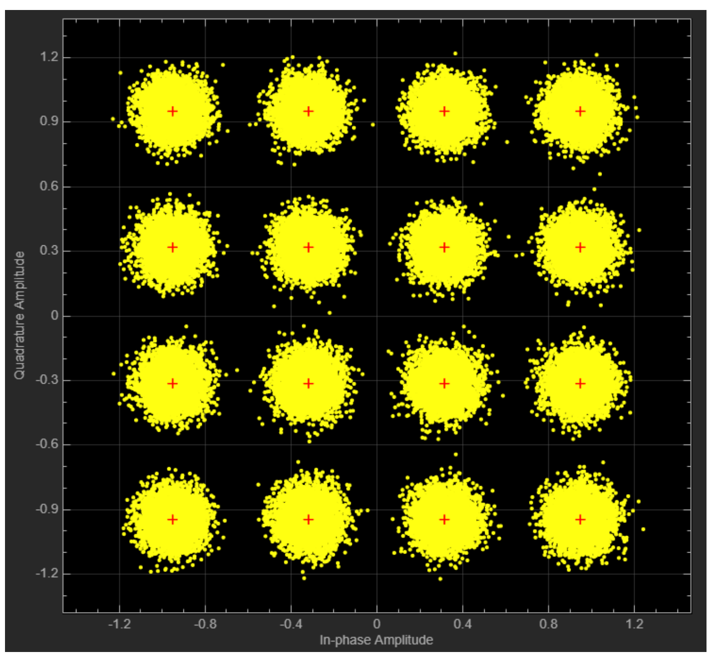

Fig. 3. Constellation diagram when Es/No = 20.

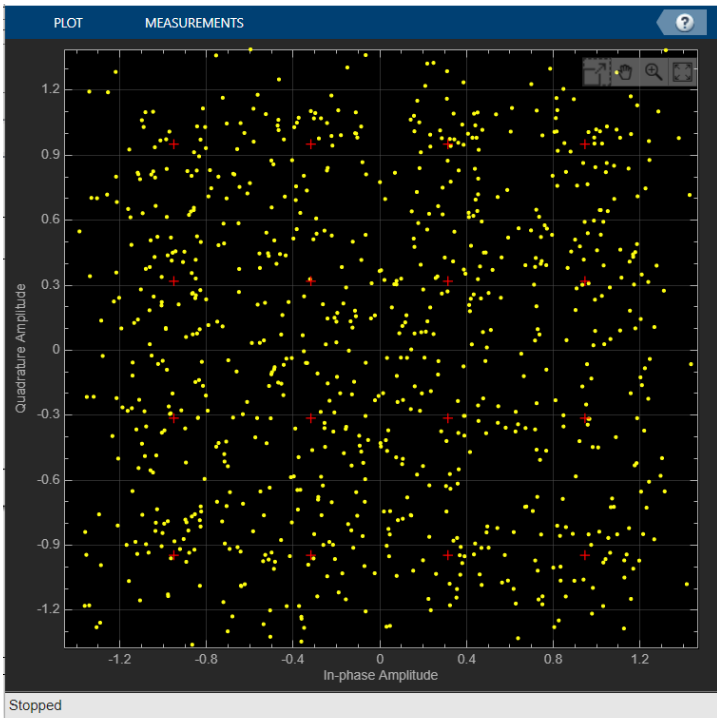

Fig. 4. Constellation diagram when Es/No = 10.

Q5: Plot the BER-versus- Es/No curve for Es/No from 5 dB to 20 dB.

Answer:

Es/No	BER
5dB	0.1709
8dB	0.104
10dB	0.05495
14dB	0.009016
17dB	0.0005351
20dB	$2 * 10^{-6}$

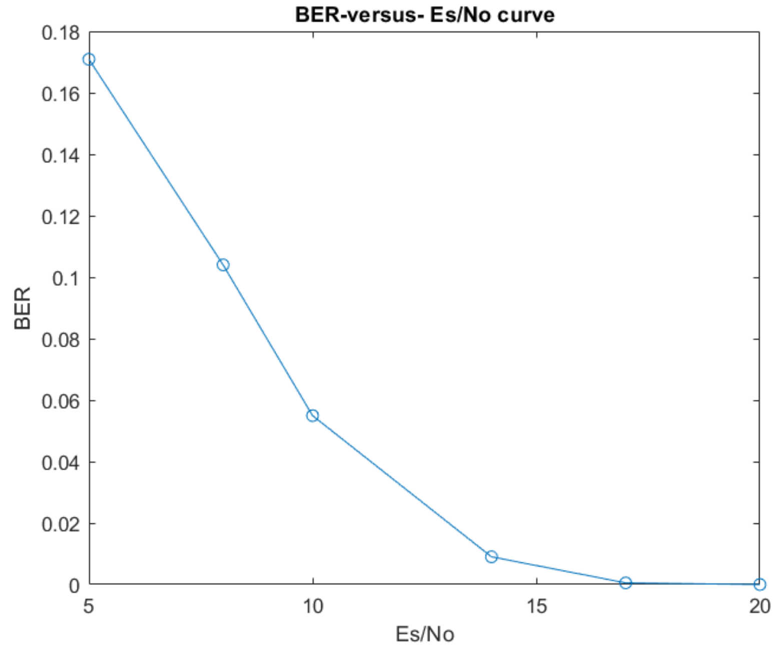

Fig. 5. BER-versus- Es/No curve (16-QAM)

Q6: Repeat Step 5 for 64-QAM

Answer:
For 64-QAM:

Es/No(dB)	BER
5	0.2557
10	0.1475
15	0.06693
20	0.0082

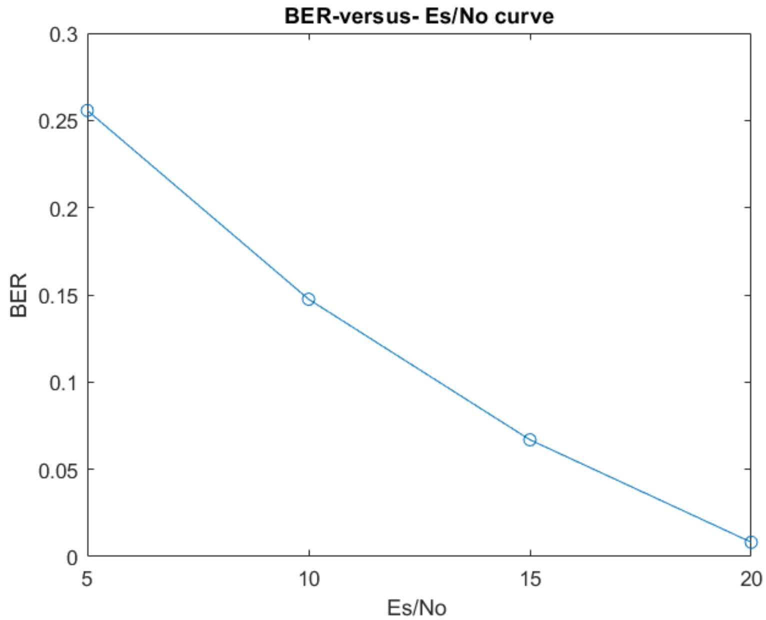

Fig. 6. BER-versus- Es/No curve (16-QAM)

Q7: Repeat Step 5 for 256-QAM. How to set Bernoulli Binary Generator (Source), Rectangular QAM Modulator Baseband, Rectangular QAM Demodulator Baseband, AWGN Channel, and Constellation Diagram? Comment on the differences in BERs. Observe the outputs on Constellation Diagram and Spectrum. Explain why the BER performances are different from the viewpoint of transmission bandwidth and the distance between constellation symbols.

Answer:

We set up the parameters as follows:

- Bernoulli Binary Generator (Source):

  Probability of zero: 0.5 | Sample time: 1e-6 | Samples per frame: 8

- Rectangular QAM Modulator:

  Baseband M-ary number: 256 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1

- AWGN Channel:

  Symbol period (s): 8e-6

- Constellation Diagram:

Samples per symbol: 1 | Symbols to display: 1e6 | Reference constellation: 256-QAM | Average reference power: 1

- Rectangular QAM Demodulator Baseband:

  M-ary number: 256 | Input type: Bit | Normalization method: Average power | Average power, referenced to 1 ohm (watts): 1

Es/No(dB)	BER
5	0.318
10	0.2166
15	0.133
20	0.06667

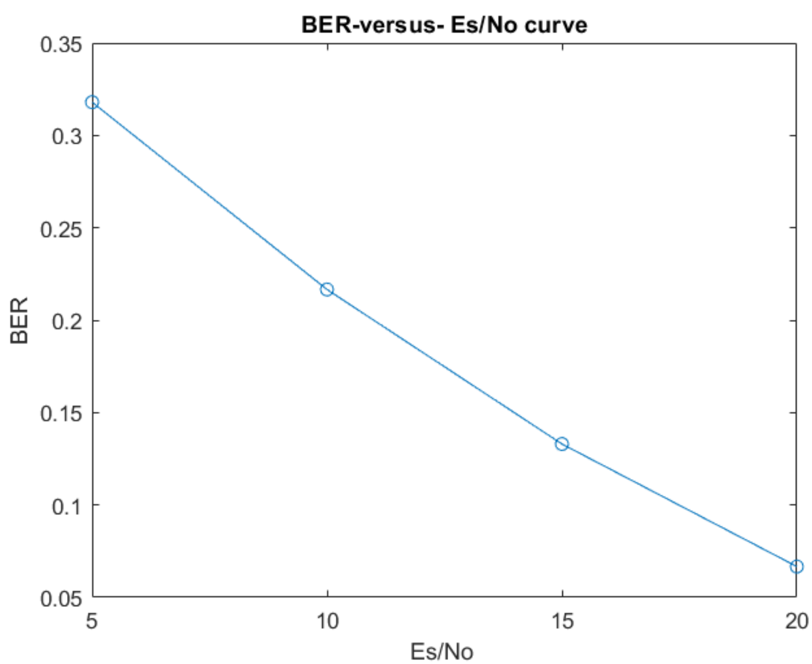

Fig. 7. BER-versus- Es/No curve (256-QAM)