Computational Assignment - 1

EE4140 – Digital Communication Systems

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I certify that this experiment submission is my own work and not obtained from any other source

1) Raised cosine pulse transmission

- In this experiment, the impulse response of the discrete-time raised cosine filter has been generated using the function 'rcosdesign'. The appropriate filter parameters have been used as mentioned in the question.
- The random input signal has been generated using the 'binornd' function.
- After performing BPSK modulation, the output signal has been obtained by the 'upfirdn' function.
- We observe that a change in the number of symbol durations (L) of the filter has very minimal effect on the output signal. This is because the magnitude of the impulse response dies down as we move away from the center of the plot. However, there would be an increase in the number of output samples due to such a change.
- As the value of β is increased from 0 to 1, we observe that the shape of the output signal becomes more smooth and more shaped. This happens because, as the value of β is increased, the extent of Gibbs phenomenon that appears in the output signal reduces. Hence we get a more well-shaped signal as the output.
- We observe that the power spectral density of the RC pulse shaped signal readily falls down as the frequency is increased, whereas the power spectral density of the rectangular pulse shaped filter follows a hump shaped pattern in the dB scale.

2) Theoretial and experimental average SER of various linear modulation schemes.

- The theoretial average SER for various modulation schemes could be computed using the below expression:

$$SER_{BPSK} = q \qquad q = Q\left(d/\sqrt{N_0/2}\right)$$
$$SER_{QPSK} = 2q - q^2 \qquad d_{BPSK} = d_{QPSK} = \sqrt{E_B}$$
$$SER_{16QAM} = 3q - (9/4)q^2 \qquad d_{16QAM} = \sqrt{E_B/2.5}$$

where E_B is the energy per bit and $N_0/2$ is the noise variance per dimension.

- The following are the expressions for the theoretial average SER calculated using various approximations (for QPSK):

- Union bound using all pairwise symbol errors.

$$P_E \approx 2Q\left(d/\sqrt{N_0/2}\right) + Q\left(2d/\sqrt{N_0}\right)$$

- Union bound using only the nearest neighbours.

$$P_E \approx 2Q\left(d/\sqrt{N_0/2}\right)$$

- Union bound along with Chernoff bound

$$P_E \approx 2\exp\left(-d^2/N_0\right)$$

- We notice that the approximate SER obtained by using both the union bounds almost overlaps with the theoretically accurate SER, whereas the one obtained using Chernoff bound lies uniformly higher on the dB plot when compared to the accurate SER.

- Inorder to experimentally calculate SER, we have simulated a QPSK modulator, QPSK demodulator and AWGN channel from scratch in MATLAB. The details regarding the implementation could be found in the submitted code. In order to get the noise variance from E_b/N_0 (dB), the following steps have been implemented.

(i) E_b/N_o (linear) = 10 ^ (E_b/N_o (dB) / 10)

(ii) Noise variance (σ^2) = $N_o/2$ = $E_B/[2\, E_b/N_o(\text{linear})]$

- The experimentally evaluated SER is found to overlap with the theoretical SER. Once E_b/N_o (dB) crosses 8 dB, the experimental SER drops down to 0 which is approximately close to the theoretical values.
- For experimentally evaluating the SER of 16-QAM, we have developed a 16-QAM modulator and demodulator. Every combination of 4 bits have been mapped to a particular point in the complex plane. In the demodulator, the standard decision regions have been used for mapping back to the symbols / bits.
- We find that the experimental and theoretical SER for 16-QAM overlaps, hence confirming the theoretical derivations.
- The approximate average P_E for 16-QAM calculated using the union bound considering only the nearest neighbours is,

$$P_E \approx 3\,Q\left(d/\sqrt{N_o/2}\right) \quad \text{where} \quad d = \sqrt{E_B/2.5}$$

- From the figure, it is clear that the theoretical, approximate and experimental average SER for 16-QAM are very similar and the differences are negligible.

3) Experimental BER of QPSK and 16-QAM

- In order to experimentally evaluate BER of QPSK and 16-QAM, modulator and demodulators following gray mapping have been developed from scratch in MATLAB. A random binary signal is generated using 'binornd' function and fed into the modulator followed by the AWGN channel. The demodulator used here directly converts the noisy symbols back into the appropriate bits based on the standard decision regions. The demodulated signal is then compared with the original signal to evaluate the BER.

- The BER is minimized when grey mapping is used as the adjacent symbols are separated by one hamming distance. Also from the plots, it can be noted that BER would be lower than SER for a given modulation scheme.

4) Required Figures

Figure (1)

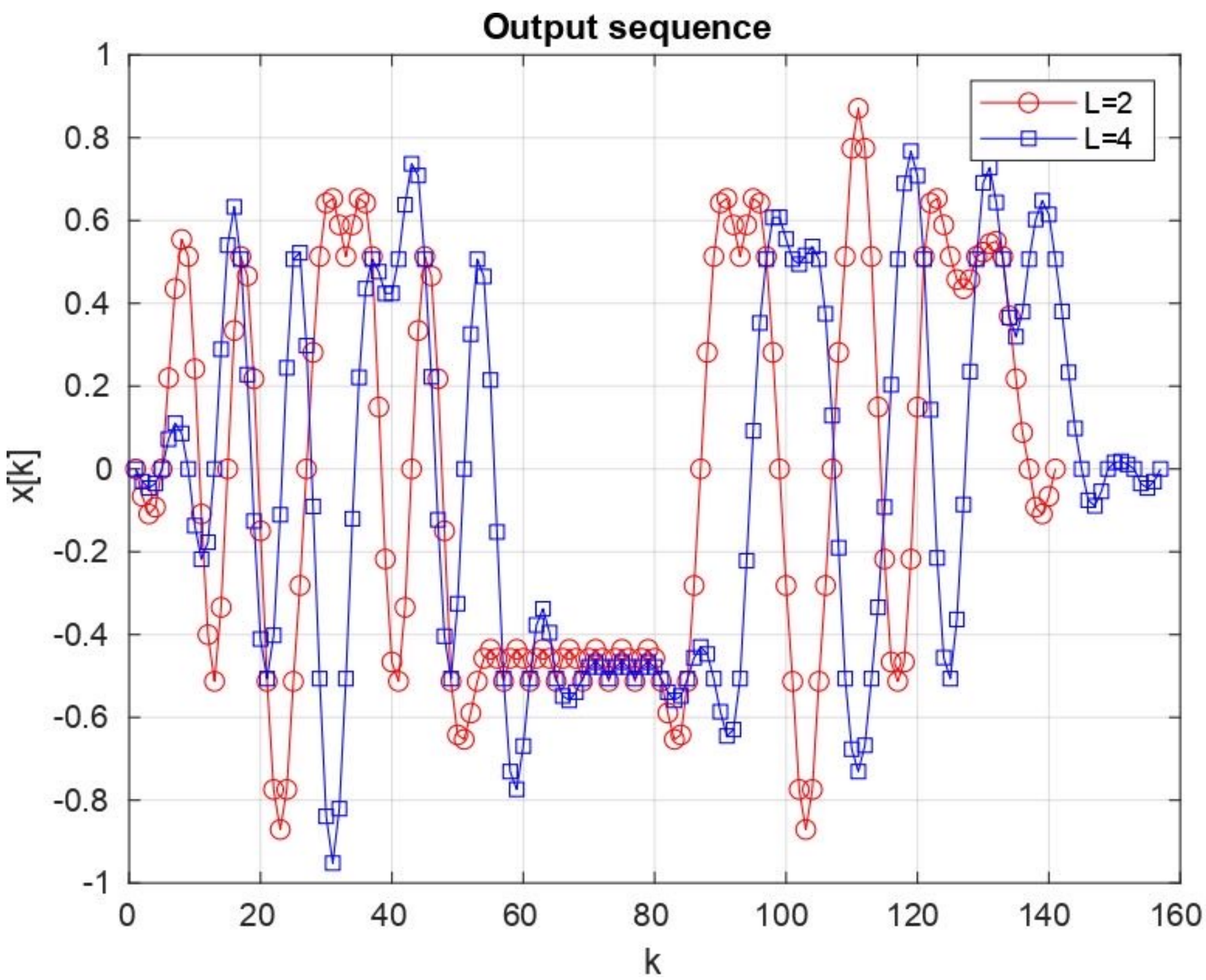

Figure (2)

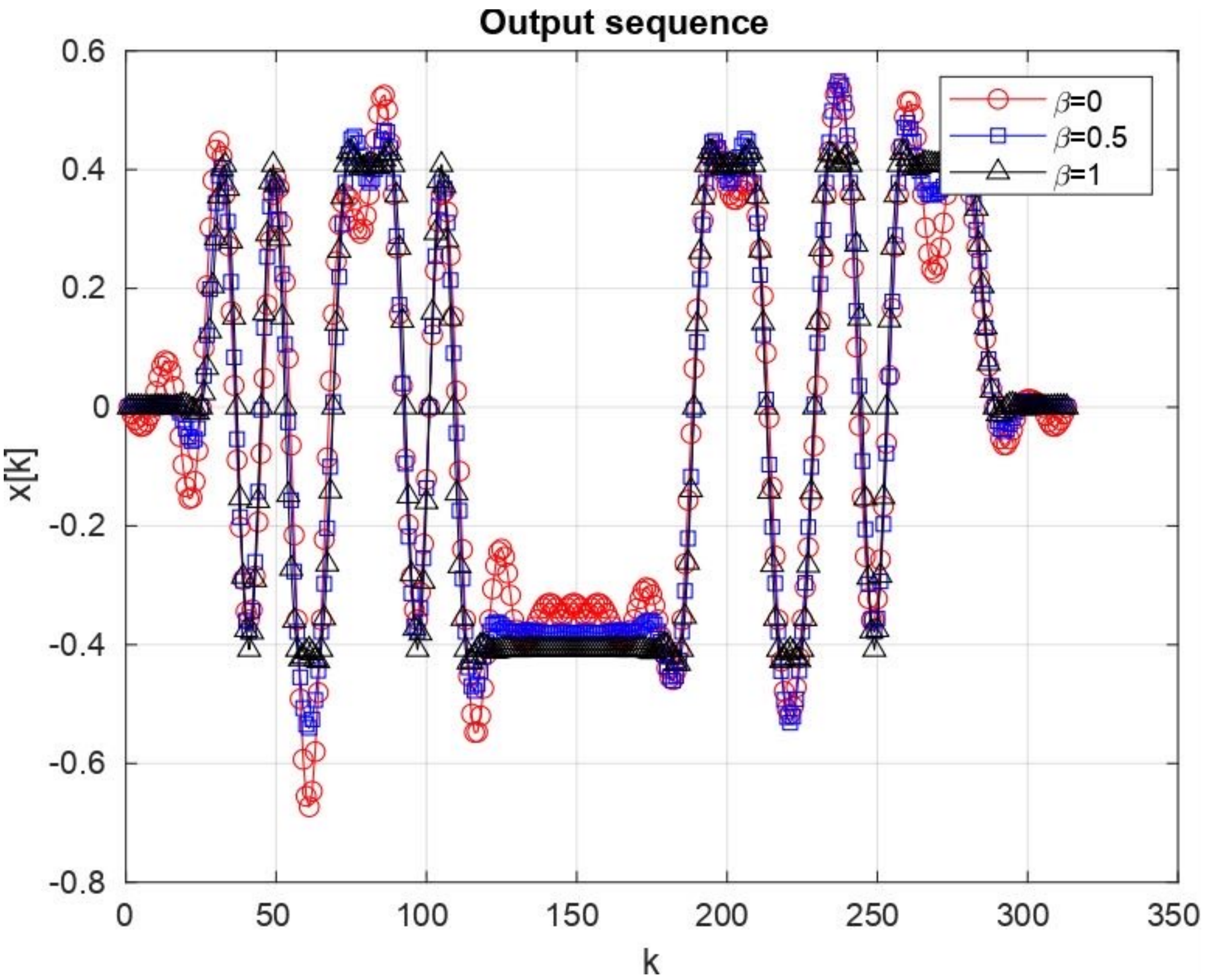

Figure (3)

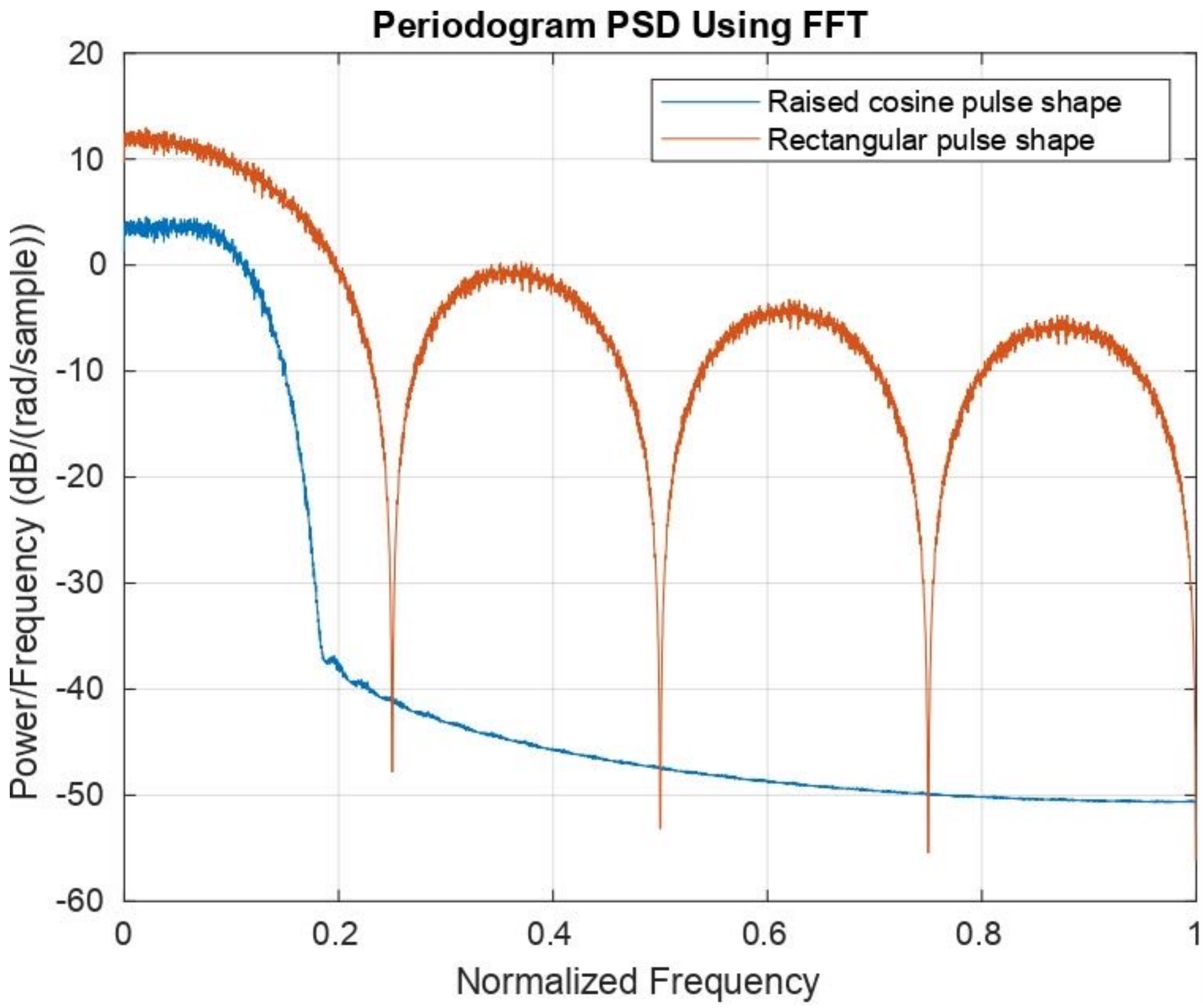

Figure (4)

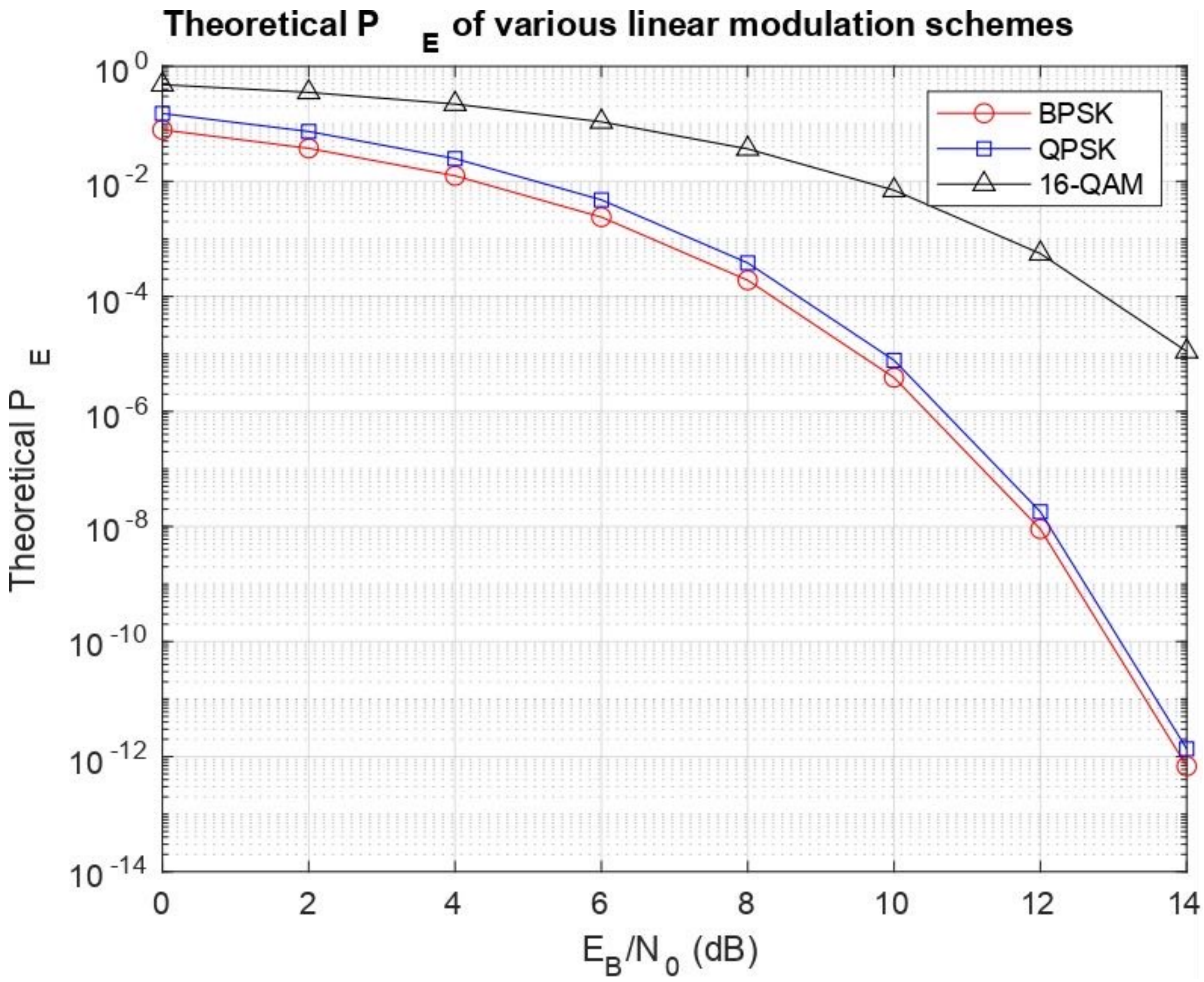

Figure (5)

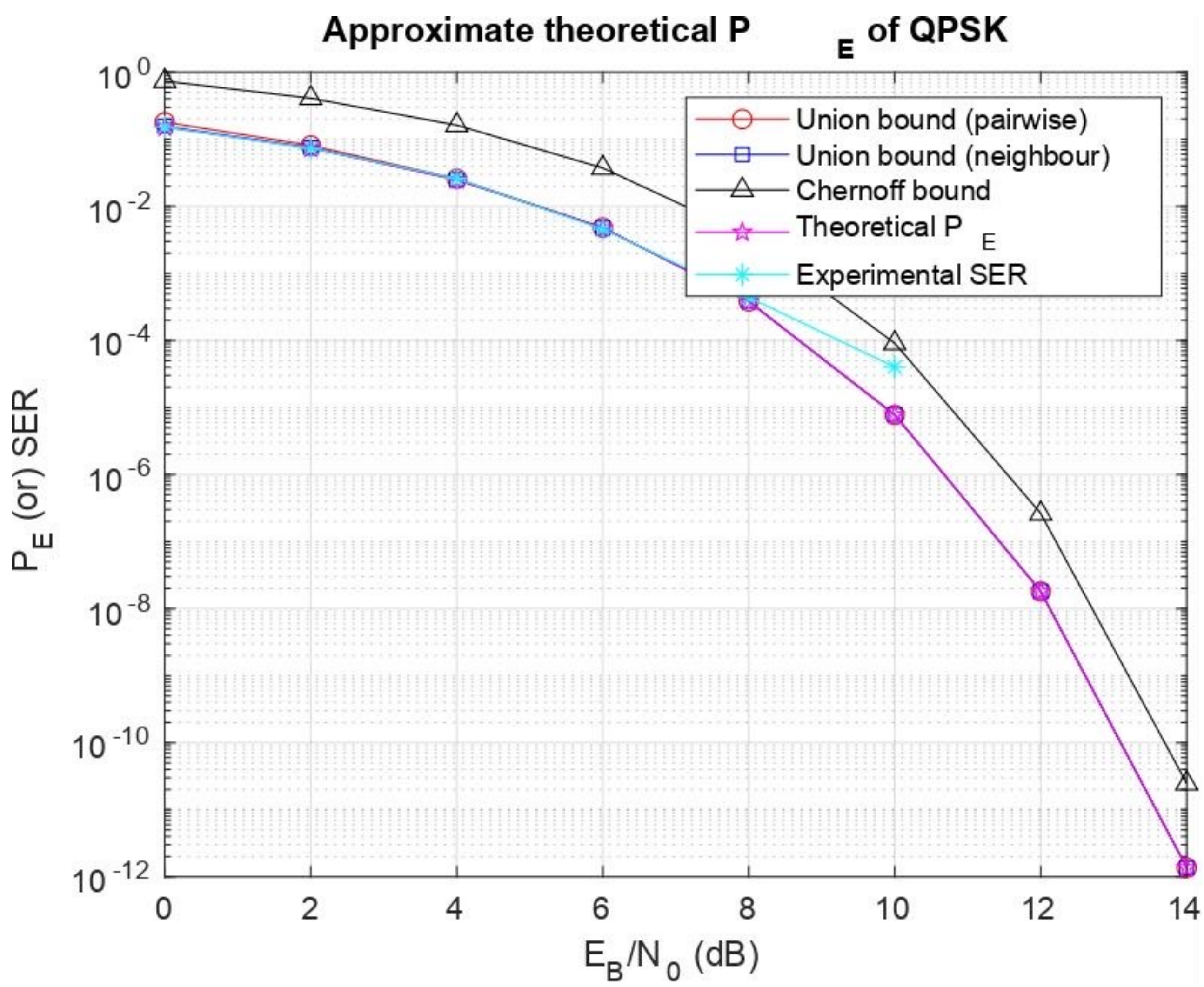

Figure (6)

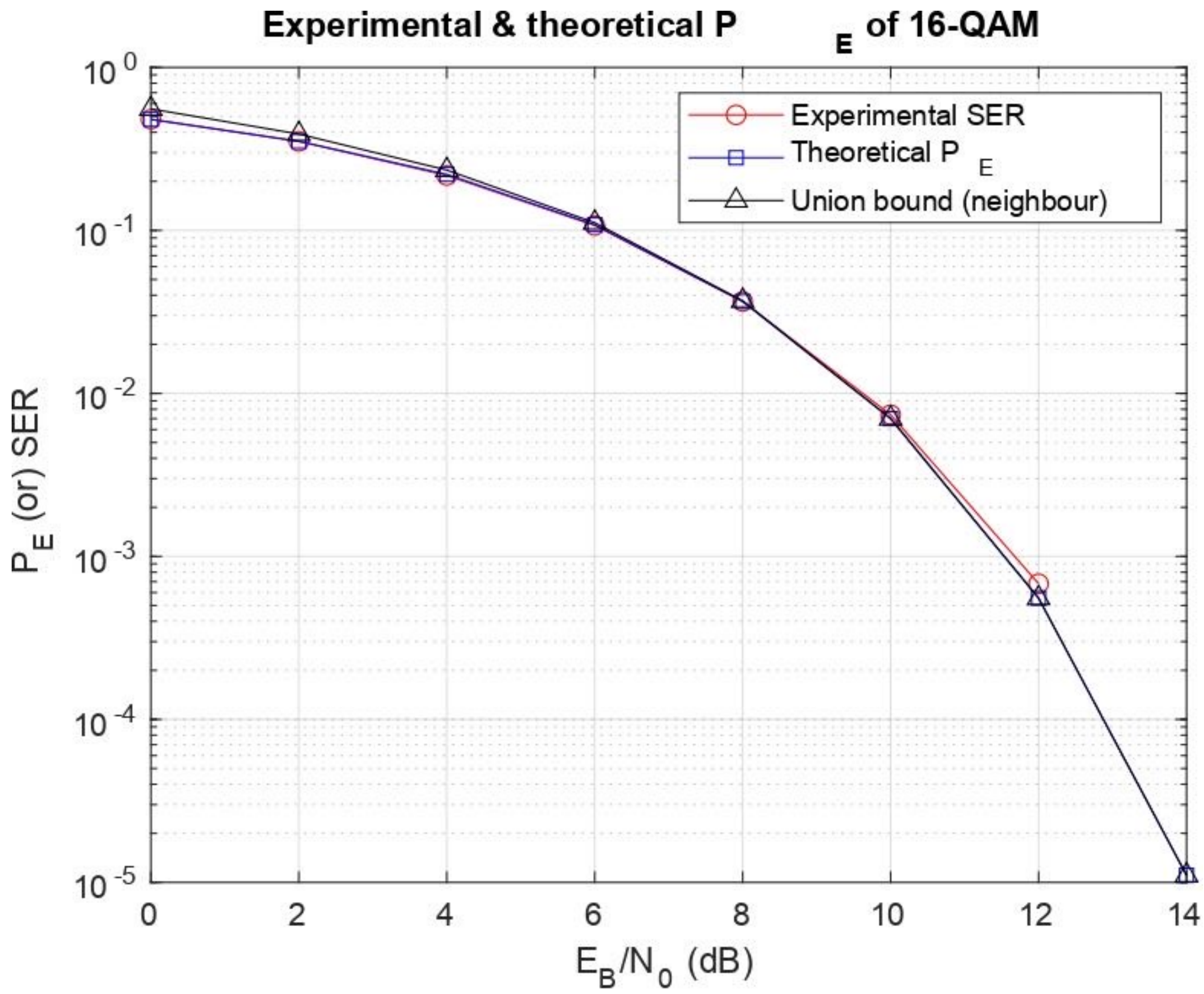

Figure (7)