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Project 4

EE 479
Fall 2020

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A random integer generator is designed to be fed to the digital bandpass communication system. A sample of the generator output of $N = 4$, the length of 8, and the sampling time of $1\mu s$ is shown in the Fig. 1.

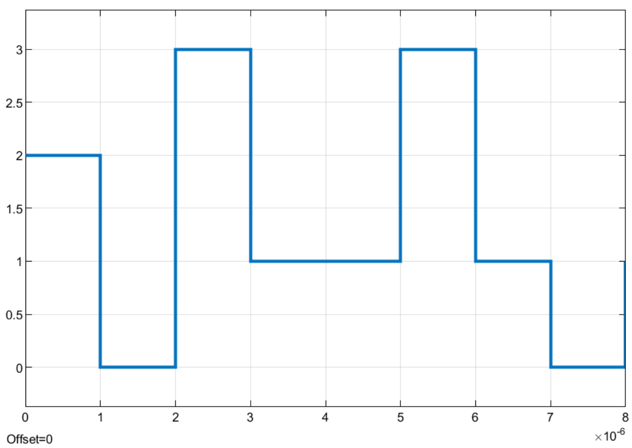


Fig. 1. An example of random sequence of length 8

2

To be able to calculate the bit error rate (BER), the integer symbols should be converted to its corresponding bits. So, for the above random integer generator, a subsystem is constructed and a sample of bits of integer sequence of length 8 is shown in the Fig. 2.

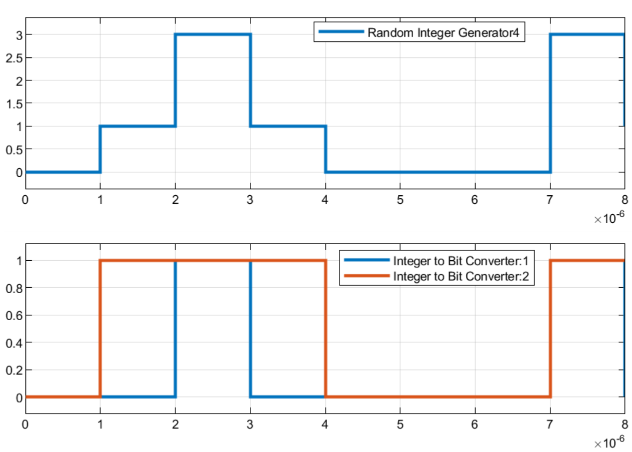


Fig. 2. An example of bits of integer sequence of length 8

3

A baseband BPSK modulator and demodulator are implemented in Simulink. In order to observe the system works properly, a sample integer sequence of length 8 is feed to the modulator and its output is passed through the demodulator. The resulting inputs and outputs of the modulator and demodulator are given in the Fig. 3.

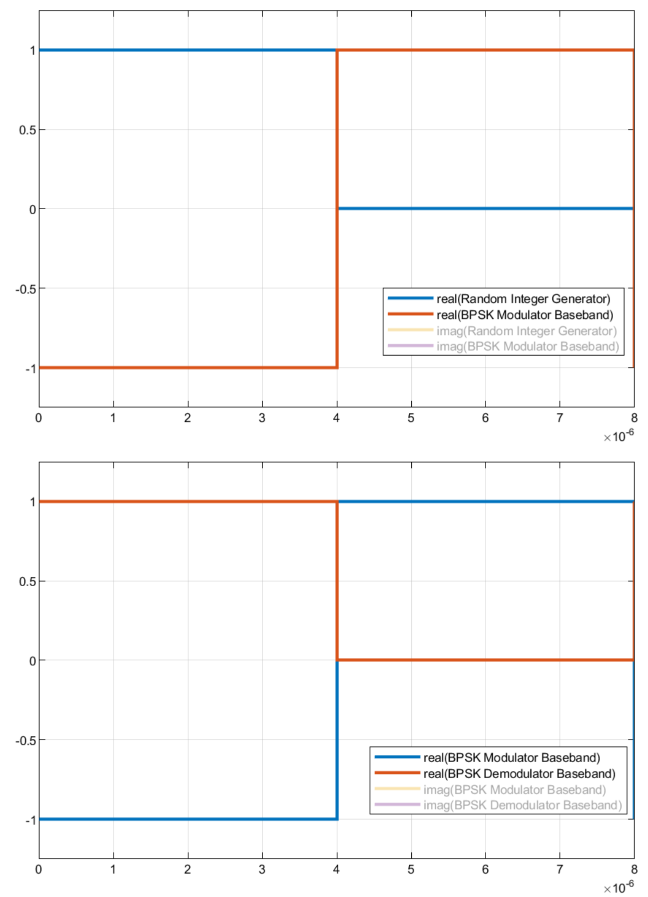


Fig. 3. The inputs and outputs of the modulator and demodulator of BPSK

4

A baseband 4-PAM modulator and demodulator are implemented in Simulink. In order to observe the system works properly, a sample integer sequence of length 8 is feed to the modulator and its output is passed through the demodulator. The resulting inputs and outputs of the modulator and demodulator are given in the Fig. 4. The constellation mapping is selected as Gray.

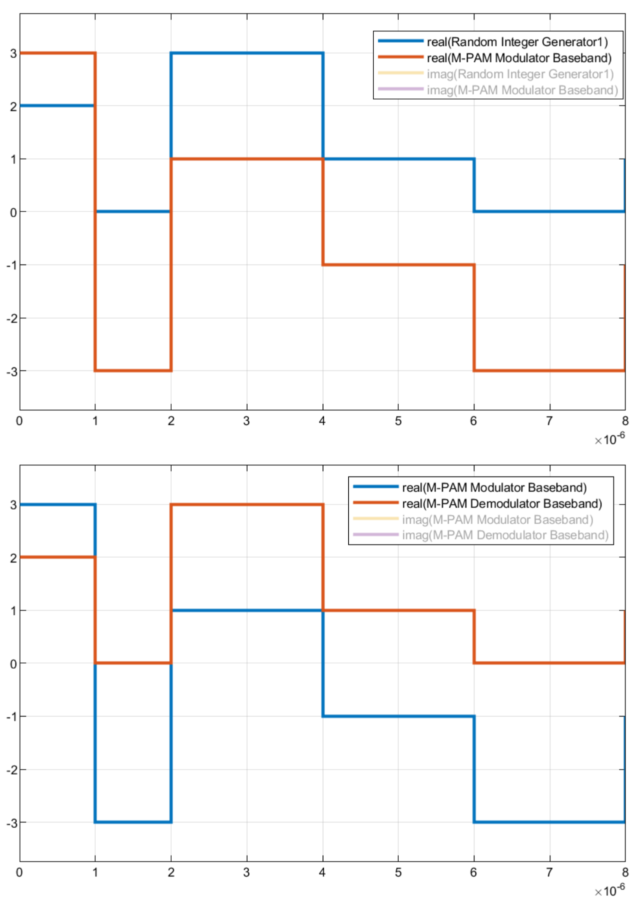


Fig. 4. The inputs and outputs of the modulator and demodulator of 4-PAM

5

A baseband 8-PSK modulator and demodulator are implemented in Simulink. In order to observe the system works properly, a sample integer sequence of length 8 is feed to the modulator and its output is passed through the demodulator. The resulting inputs and outputs of the modulator and demodulator are given in the Fig. 5. The constellation mapping is selected as Gray.

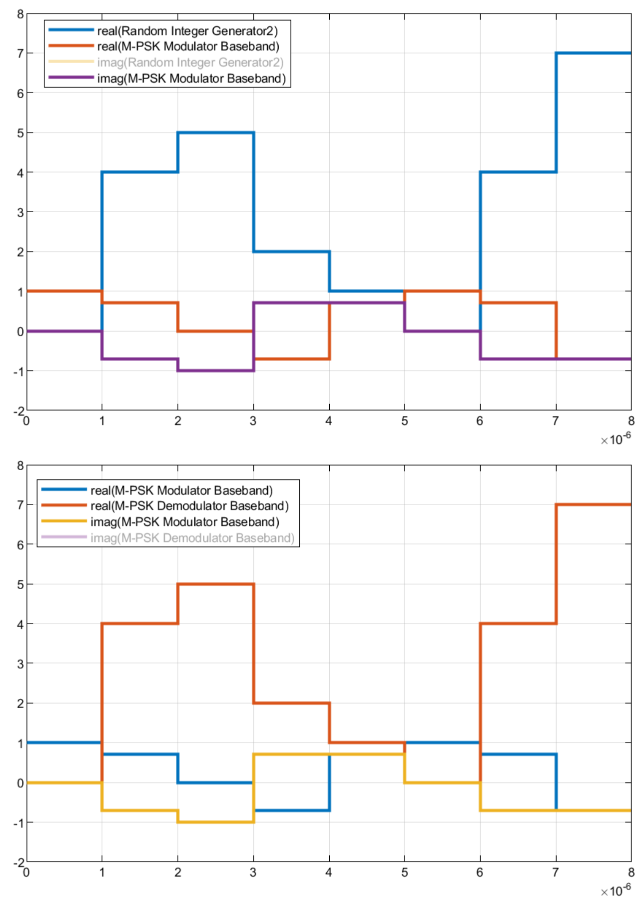


Fig. 5. The inputs and outputs of the modulator and demodulator of 8-PSK

6

A baseband 16-QAM modulator and demodulator are implemented in Simulink. In order to observe the system works properly, a sample integer sequence of length 8 is feed to the modulator and its output is passed through the demodulator. The resulting inputs and outputs of the modulator and demodulator are given in the Fig. 6. The constellation mapping is selected as Gray.

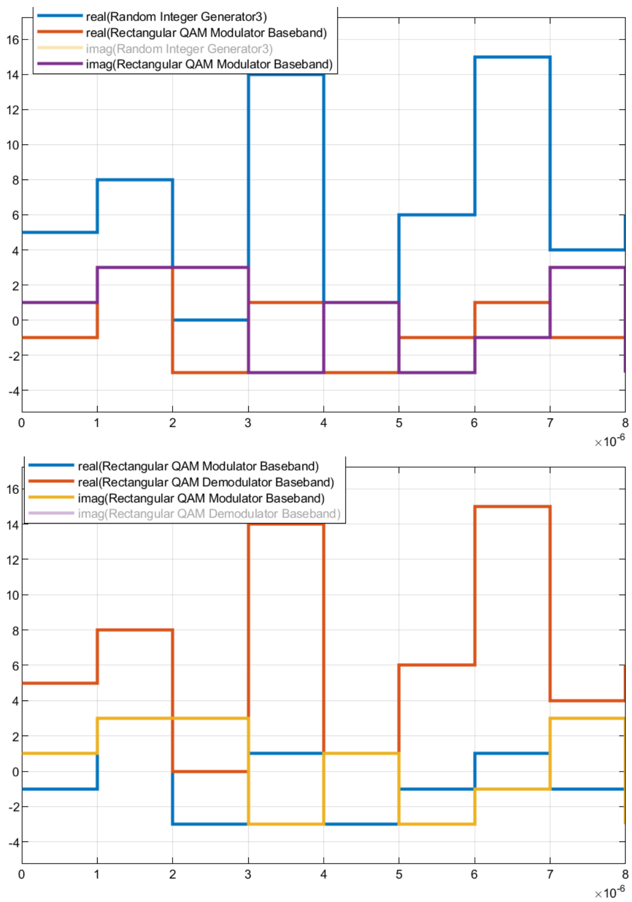


Fig. 6. The inputs and outputs of the modulator and demodulator of 16-QAM

7

Square-root raised-cosine filters with the roll-off factor of 0.2 are used for pulse shaping. The impulse response and the frequency response of the transmit filter are shown in the Fig. 7.

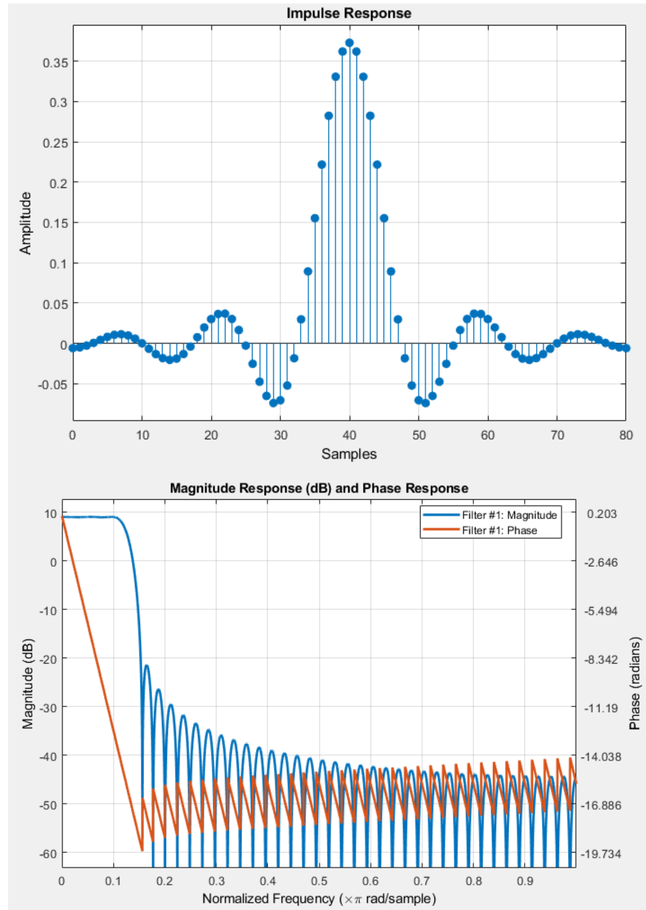
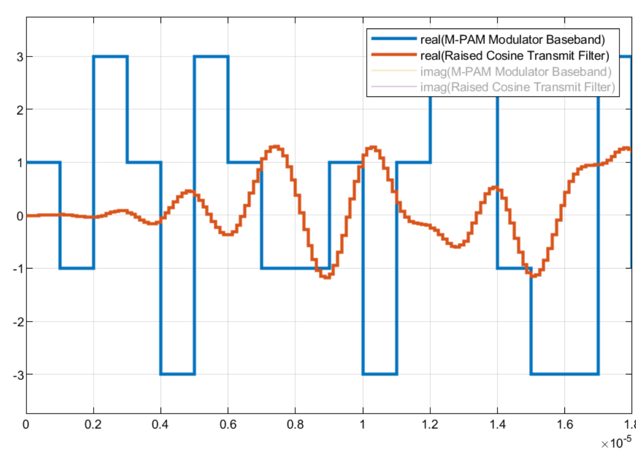


Fig. 7. The impulse and frequency response of the transmit filter

A transmit and receive filter of square-root raised-cosine are implemented in Simulink. In order to observe the system works properly, a sample integer sequence of length 18 is feed to the transmit filter and its output is passed through the receive filter. The resulting inputs and outputs of the modulator and demodulator are given in the Fig. 8.



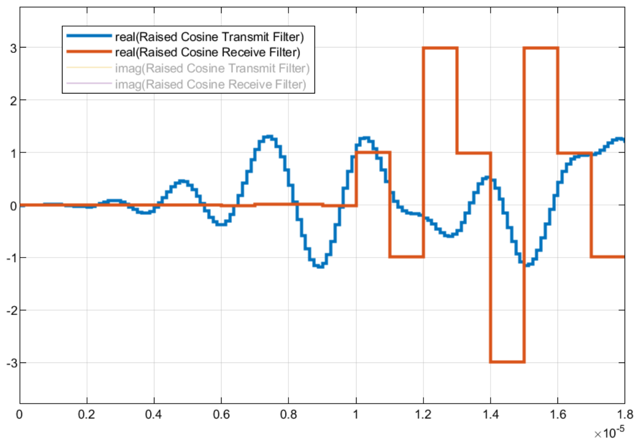


Fig. 8. The inputs and outputs of the transmit and receive filter.

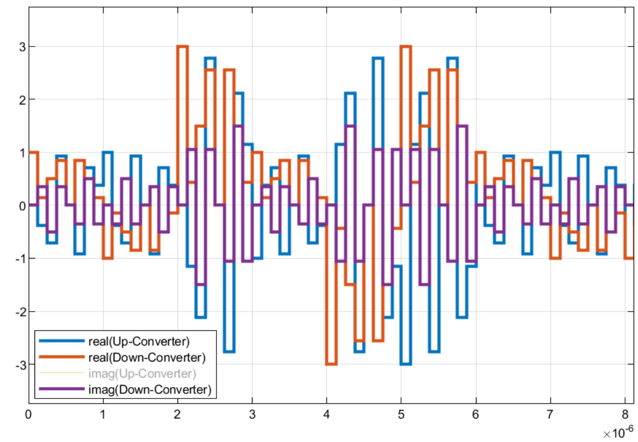


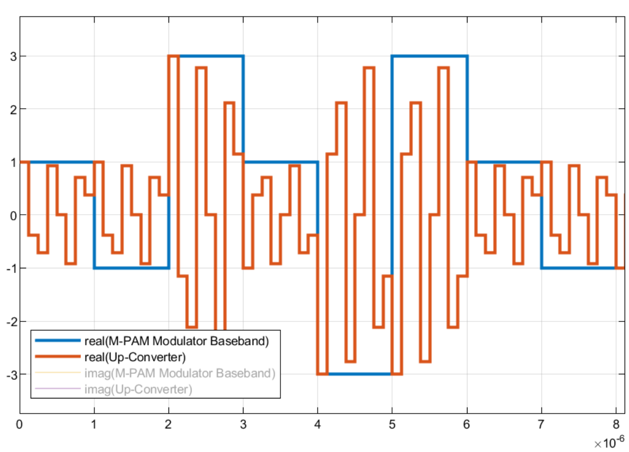
Fig. 9. The inputs and outputs of the up-converter and down-converter

Since the span of the filters is 10 symbols, a symbol is constructed back itself by using 10 symbols; so, the first symbol can be recovered by 10 symbols, so that there occurs a delay of 10 symbols.

It can be seen from the above figures that with the pair of transmit/receive square-root raised-cosine pulse shaping filters, the signal can be transmitted and received successfully. In fact, with these pulse shaping filters, the signals can be transmitted as band-limited.

8

In order to transmit the baseband signal in the bandpass region of $2.5MHz$, an up-converter and down-converter are implemented. In order to observe the system works properly, a sample integer sequence of length 8 is feed to the up-converter and its output is passed through the down-converter. The resulting inputs and outputs of the modulator and demodulator are given in the Fig. 9.



It can be seen from the figure of the up-converter, the signal is up-converted with a sinusoidal with sampling time of $10^{-6}/8s$ and the frequency of $2.5MHz$. And with the down-converter, the up-converted signal is shifted to baseband and the higher frequency region of $5MHz$. With the receive filter of square-root raised-cosine filter, the only version of baseband will be processed further. Also, the gain of 2 is added to the receiver filter since with the up and down converter, the signal is being multiplied with $1/2$.

9

For the transmission channel in the digital communication system, AWGN is used. In order to observe the system works properly, a sample integer sequence of length 8, which is passed through square-root raised-cosine transmit filter and up-converter, is feed to the AWGN with $10 - SNR$ value of E_s/N_0. The resulting inputs and outputs are given in the Fig. 10.

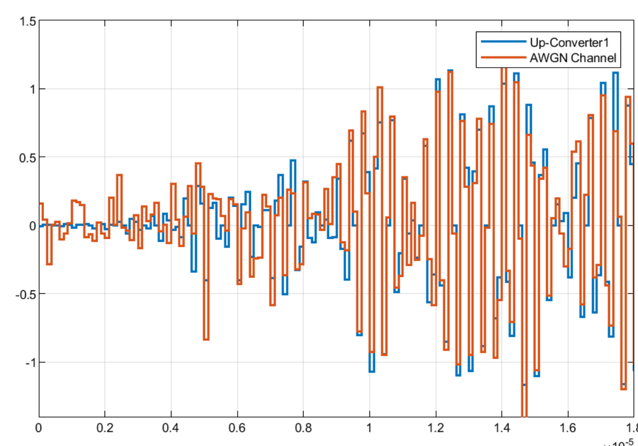


Fig. 10. The inputs and outputs of AWGN

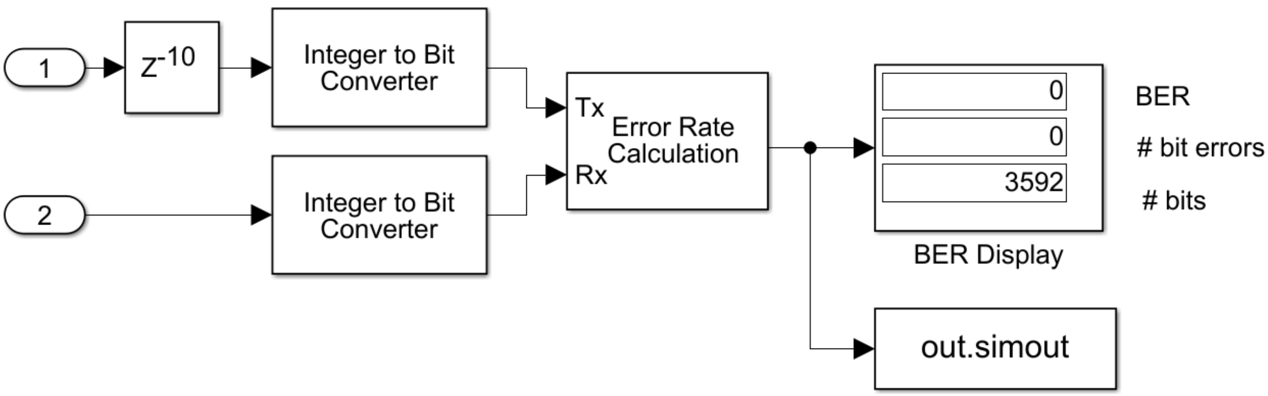


Fig. 11. The diagram of the BER counter and display

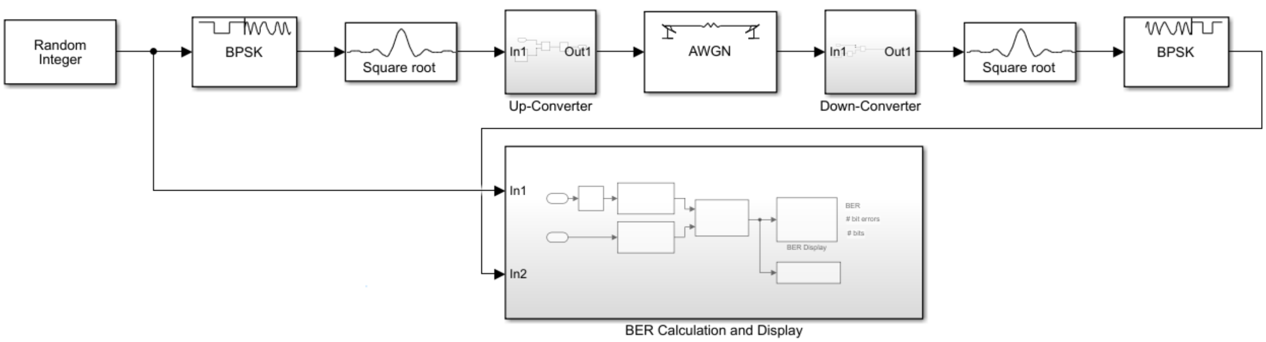


Fig. 12. The diagram of the complete BPSK digital communication

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A subsystem for the calculation and display of BER is implemented and its block diagram is shown in the Fig. 11.

Since the signal is received with 10 symbols delayed; when comparing the bits of transmitted and received bits, the first 10 symbols are ignored by shifting transmitted symbols and neglecting the corresponding bits in the calculation.

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With the above sections of the digital communication system, a complete bandpass BPSK digital communication is constructed, and its block diagram is shown in the Fig. 12.

For the following parts, the below MATLAB script is used to run the Simulink according to corresponding signal-to-noise ratio (SNR) values.

```
%% BPSK
snr_db = 0:2:10;
snr = 10.^(snr_db/10);
err = zeros(6,3);
mdl='BPSK_DigitalBandpassComm.slx';
load_system(mdl);
for i = snr_db
   SNR = i;
   sim_out = sim(mdl);
   err(i/2+1,:) = sim_out.simout.Data(end,:);
end

semilogy(snr_db, err(:,1), 'b-x', 'DisplayName','
    BERvsSNR_s_i_m');hold on;
semilogy(snr_db, qfunc(sqrt(2.*snr)), 'bs', '
    DisplayName','BERvsSNR_t_h_e_o');hold on;

grid on;
axis square;
legend;
xlabel 'SNR';
ylabel 'Error Rates';
set(gca,'FontSize',13);

%% 4-PAM
snr_db = 0:2:14;
snr = 10.^(snr_db/10);
err = zeros(8,3);
mdl='PAM4_DigitalBandpassComm.slx';
load_system(mdl);
for i = snr_db
   SNR = i;
```

```
    sim_out = sim(mdl);
    err(i/2+1,:) = sim_out.simout.Data(end,:);
end

semilogy(snr_db, err(:,1), 'b-x', 'DisplayName','BERvsSNR_s_i_m');hold on;
semilogy(snr_db, (1/2)*(3/2)*qfunc(sqrt(2/5.*snr)), 'bd', 'DisplayName','BERvsSNR_t_h_e_o');hold on;

grid on;
axis square;
legend;
xlabel 'SNR';
ylabel 'Error Rates';
set(gca,'FontSize',13);

%% 8PSK
snr_db = 0:2:14;
snr = 10.^(snr_db/10);
err = zeros(8,3);
mdl='PSK8_DigitalBandpassComm.slx';
load_system(mdl);
for i = snr_db
    SNR = i;
    sim_out = sim(mdl);
    err(i/2+1,:) = sim_out.simout.Data(end,:);
end

semilogy(snr_db, err(:,1), 'b-x', 'DisplayName','BERvsSNR_s_i_m');hold on;
semilogy(snr_db, (1/3)*2*qfunc(sqrt(2.*snr).*sin(pi/8)), 'bd', 'DisplayName','BERvsSNR_t_h_e_o');hold on;

grid on;
axis square;
legend;
xlabel 'SNR';
ylabel 'Error Rates';
set(gca,'FontSize',13);

%% 16QAM
snr_db = 0:2:20;
snr = 10.^(snr_db/10);
err = zeros(11,3);
mdl='QAM16_DigitalBandpassComm.slx';
load_system(mdl);
for i = snr_db
    SNR = i;
    sim_out = sim(mdl);
    err(i/2+1,:) = sim_out.simout.Data(end,:);
end

semilogy(snr_db, err(:,1), 'b-x', 'DisplayName','BERvsSNR_s_i_m');hold on;
semilogy(snr_db, (1/4)*3.*qfunc(sqrt(snr./5)), 'bd', 'DisplayName','BERvsSNR_t_h_e_o');hold on;

grid on;
axis square;
legend;
xlabel 'SNR';
ylabel 'Error Rates';
set(gca,'FontSize',13);
```

[0] The theoretical values of BER are adopted from the projects of EE477.

12

The simulation is applied for BPSK in order to observe BER. Since in BPSK, a symbol has a single corresponding bit, BER is equal to SER value. The theoretical values of SER for BPSK is given in the following expression.

$$P_{BER} = P_{SER} = Q(\sqrt{2SNR})$$

The resulting graphs are plotted BER as a function of SNR and shown in the Fig. 13.

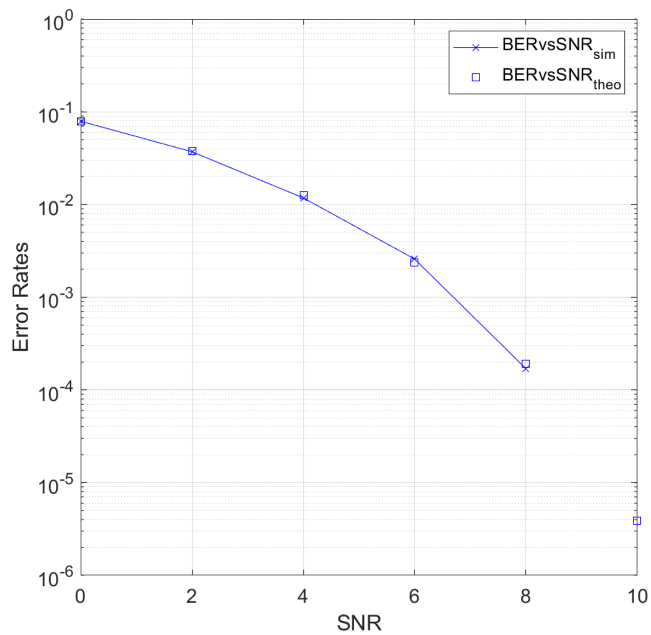

Fig. 13. The simulation and theoretical values of BER for BPSK

So, it can be seen from the figure that the simulation results almost match with the theoretical ones. In the last SNR value of the simulation result, the BER is 0 since the number of simulation points is not sufficient to observe an error in the transmission.

13

The simulation is applied for 4PAM in order to observe BER in gray mapped constellation diagram. The theoretical values of BER can be found from SER values. The SER for 4PAM is given in the following expression.

$$P_{SER} \approx \frac{3}{2} Q\left(\sqrt{\frac{2}{5} SNR}\right)$$

In a gray mapped constellation diagram, one symbol error corresponds to one bit error in according to the nearest neighbors. So,

$$P_{BER} \approx (1/2) P_{SER}$$

The resulting graphs are plotted BER as a function of SNR and shown in the Fig. 14.

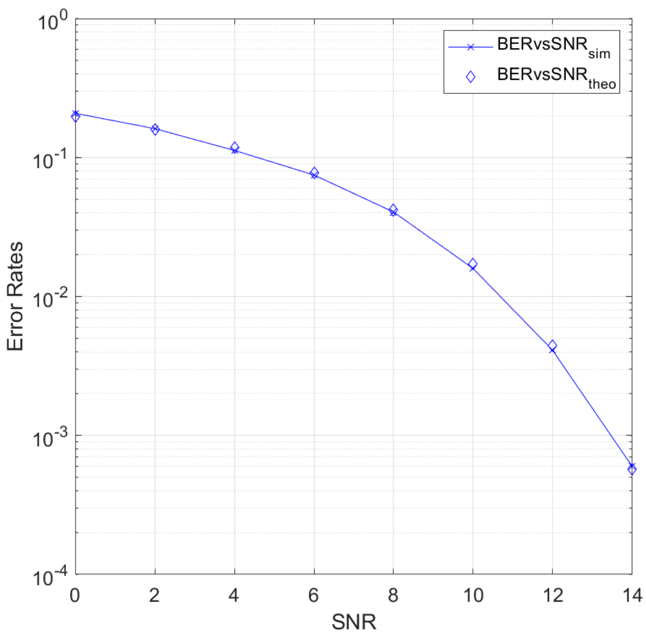

Fig. 14. The simulation and theoretical values of BER for 4PAM

So, it can be seen from the figure that the simulation results is consistent with the theoretical ones.

14

The simulation is applied for 8PSK in order to observe BER in gray mapped constellation diagram. The theoretical values of BER can be found from SER values. The SER for 8PSK is given in the following expression.

$$P_{SER} \approx 2Q(\sqrt{2SNR}sin(\pi/8))$$

In a gray mapped constellation diagram, one symbol error corresponds to one bit error in according to the nearest neighbors. So,

$$P_{BER} \approx (1/3)P_{SER}$$

The resulting graphs are plotted BER as a function of SNR and shown in the Fig. 15.

So, it can be seen from the figure that the simulation results almost match with the theoretical ones. In fact, at the first three SNR values, there exists an offset between the simulation and theoretical results; however, the gap is closed as continued.

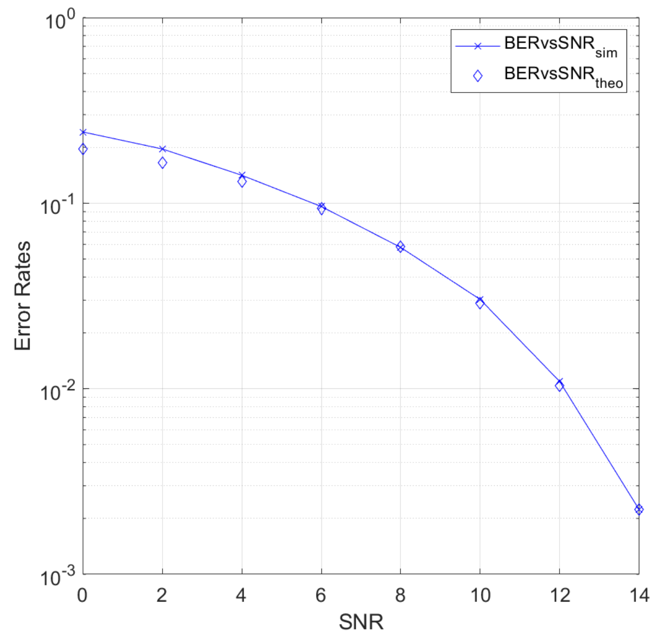

Fig. 15. The simulation and theoretical values of BER for 8PSK

15

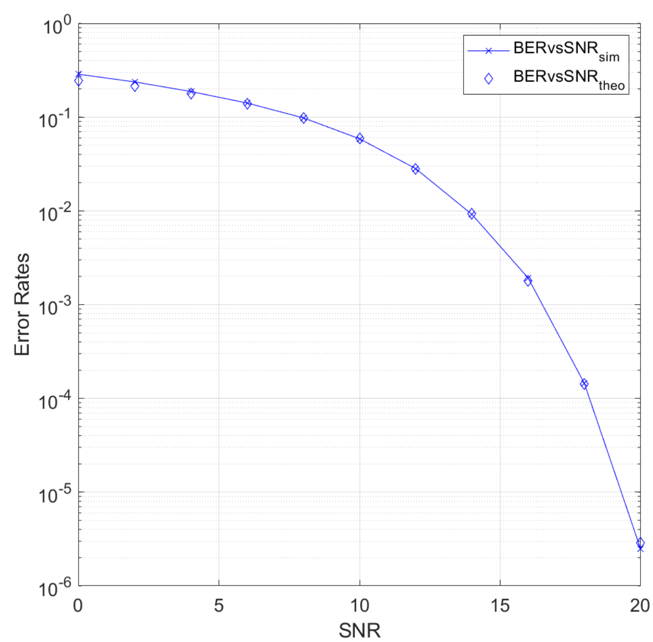

Fig. 16. The simulation and theoretical values of BER for 16QAM

The simulation is applied for 16QAM in order to observe BER in gray mapped constellation diagram. The theoretical values of BER can be found from SER values. The SER for 16QAM is given in the following expression.

$$P_{SER} \approx 3Q\left(\sqrt{\frac{1}{5}SNR}\right)$$

In a gray mapped constellation diagram, one symbol error corresponds to one bit error in according to the nearest neighbors. So,

$$P_{BER} \approx (1/4)P_{SER}$$

The resulting graphs are plotted BER as a function of SNR and shown in the Fig. 16.

So, it can be seen from the figure that the simulation results is consistent with the theoretical ones.

APPENDIX

The MATLAB and Simulink codes that are used in this project is in the *EE479Project4(Sefa Kayraklık).zip* file. The content of file is following m, slx files and the report:

- Intermediate.slx and Modulations.slx for the first 10 parts of the project
- BPSK_DigitalBandpassComm.slx, PAM4_DigitalBandpassComm.slx, PSK8_DigitalBandpassComm.slx, QAM16_DigitalBandpassComm.slx for the remaining parts
- PlotBER.m for plotting the figures
- EE479Project4.pdf for the report