Advanced Telecommunication Systems
Project 2

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I. General Instructions

All files have been developed and tested in **Matlab 2017b 64-bit**. In the current folder there are four code files (.m files). Each one implements a different question of the project. Specifically, Question_A.m implements the project's question A, etc.

II. Question A

In the beginning, of the code file (Question_A.m) there is a variable with name *equalization*. We can choose if we want to enable or disable our equalizer, by setting this variable to true or false accordingly.

```
T_period = 1;  % secs
Rb = 1000;     % bps
equalization = false;
```

Fig. 1. Equalization Option: Here we choose to run the program without equalization

First, we run the code for a specific value for h, which is *h = 0.4 + 0.6j*, and see the results with and without equalization. After that, we test it for many values for h from distribution $h = CN(0, \frac{1}{\sqrt{2}})$.

A. h = 0.4 + 0.6j

1) Without Equalization: By executing the code without equalization and with h = 0.4 + 0.6j we observe the following:

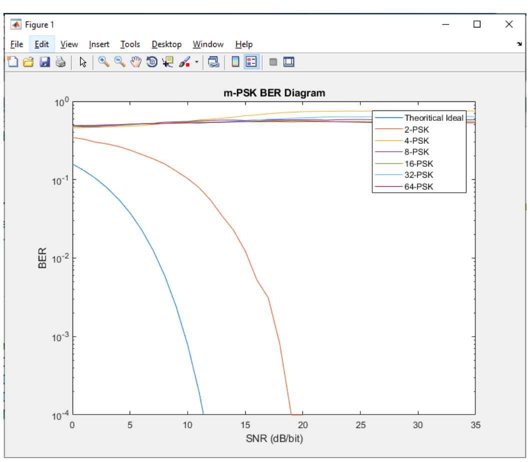


Fig. 2. BER without Equalizer, h = 0.4 + 0.6j

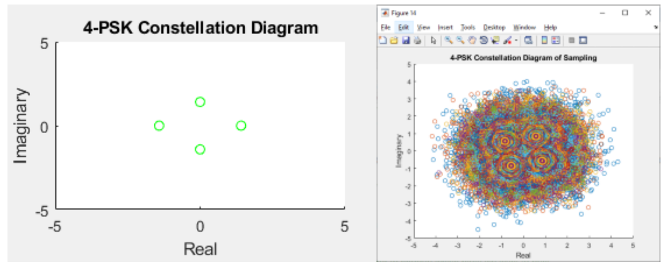


Fig. 3. Constellation Diagram: Rotation without Equalizer, h = 0.4 + 0.6j

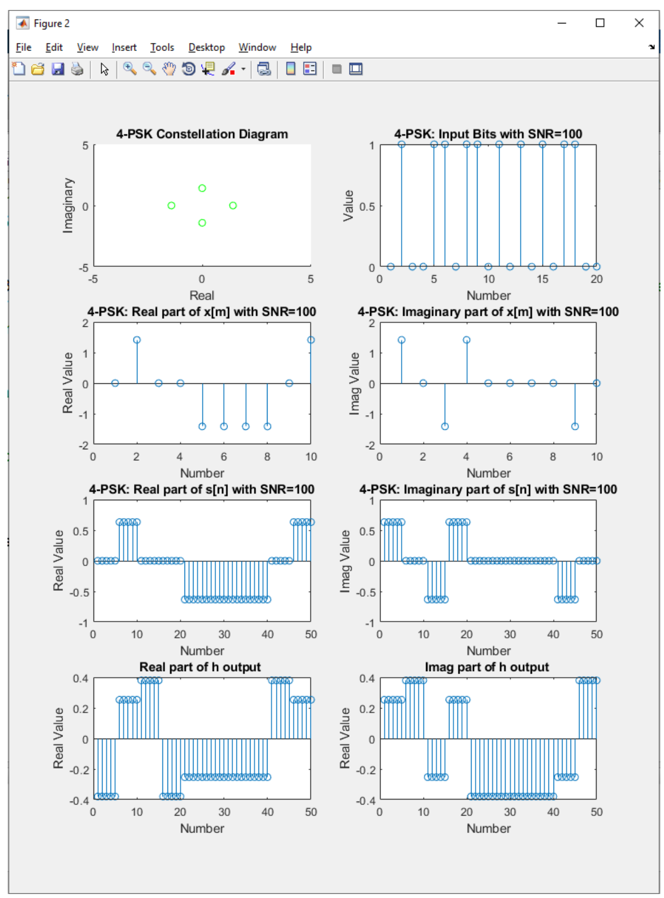


Fig. 4. Part A, QPSK: h = 0.4 + 0.6j, Without Equalizer, SNR = 100 dB

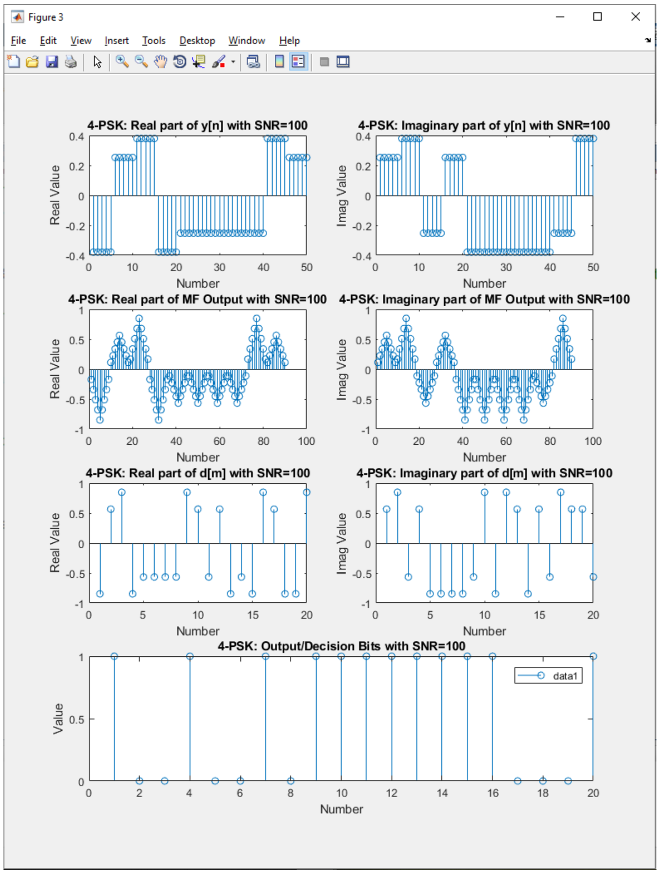


Fig. 5. Part B, QPSK: h = 0.4 + 0.6j, Without Equalizer, SNR = 100 dB

2) With Equalization: By executing the code with equalization and with h = 0.4 + 0.6j we observe the following:

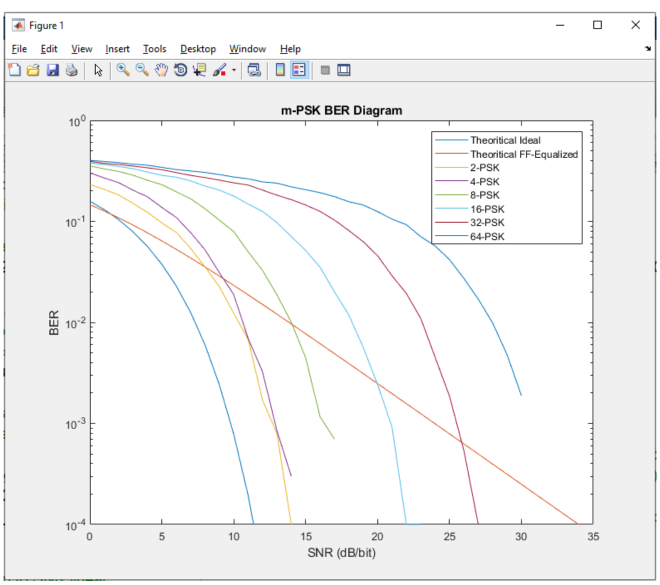


Fig. 6. BER with Equalizer, h = 0.4 + 0.6j

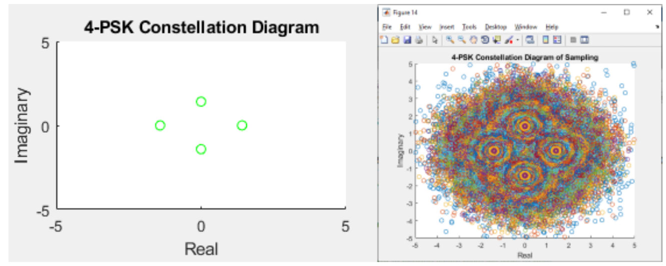


Fig. 7. Constellation Diagram: No Rotation with Equalizer, h = 0.4 + 0.6j

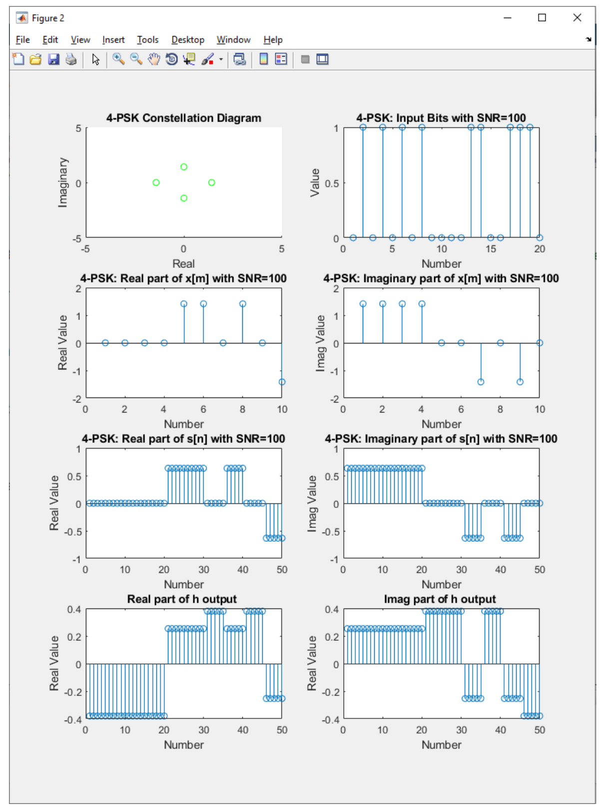


Fig. 8. Part A, QPSK: h = 0.4 + 0.6j, With Equalizer, SNR = 100 dB

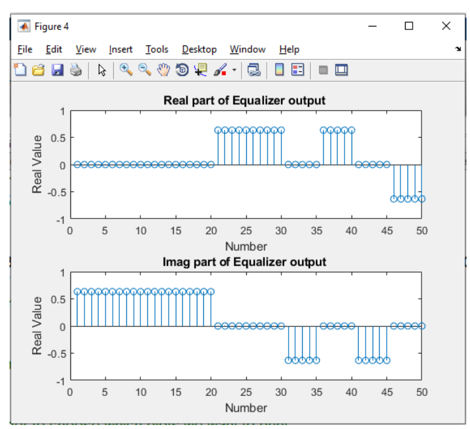


Fig. 9. Part B, QPSK: h = 0.4 + 0.6j, With Equalizer, SNR = 100 dB

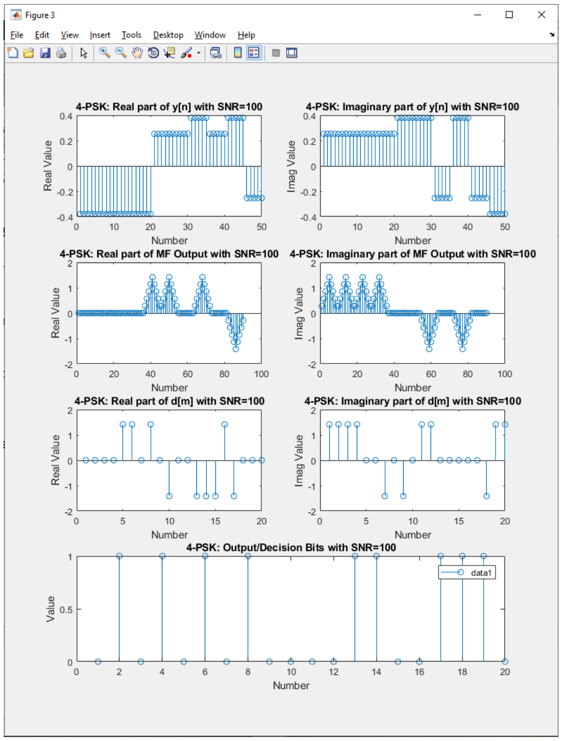


Fig. 10. Part C, QPSK: h = 0.4 + 0.6j, With Equalizer, SNR = 100 dB

B. $h = CN(0, \frac{1}{\sqrt{2}})$

1) Without Equalization: By executing the code without equalization and with $h = CN(0, \frac{1}{\sqrt{2}})$ we observe the following:

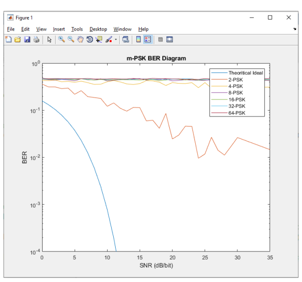


Fig. 11. BER without Equalizer, $h = CN(0, \frac{1}{\sqrt{2}})$

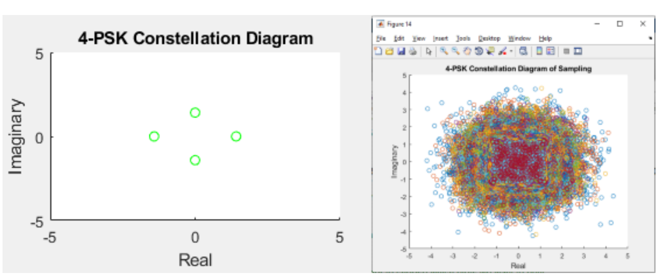


Fig. 12. Constellation Diagram: Rotation without Equalizer, $h = CN(0, \frac{1}{\sqrt{2}})$

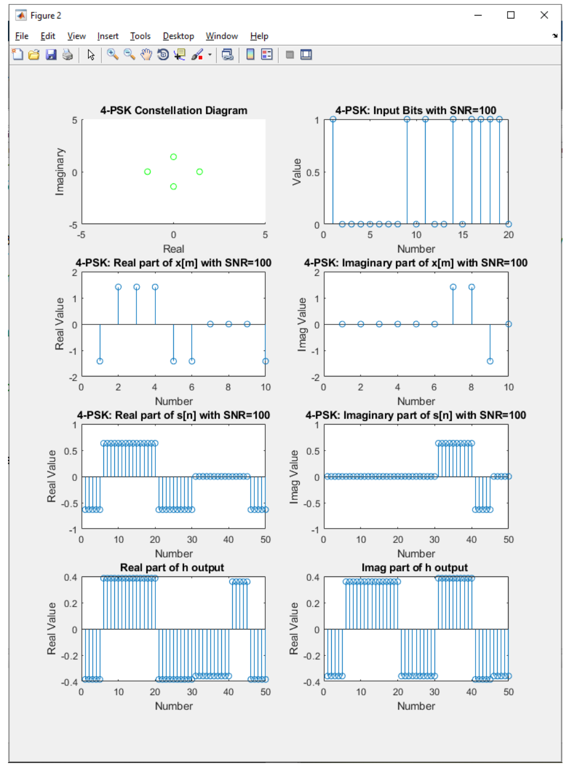


Fig. 13. Part A, QPSK: $h = CN(0, \frac{1}{\sqrt{2}})$, without Equalizer, SNR = 100 dB

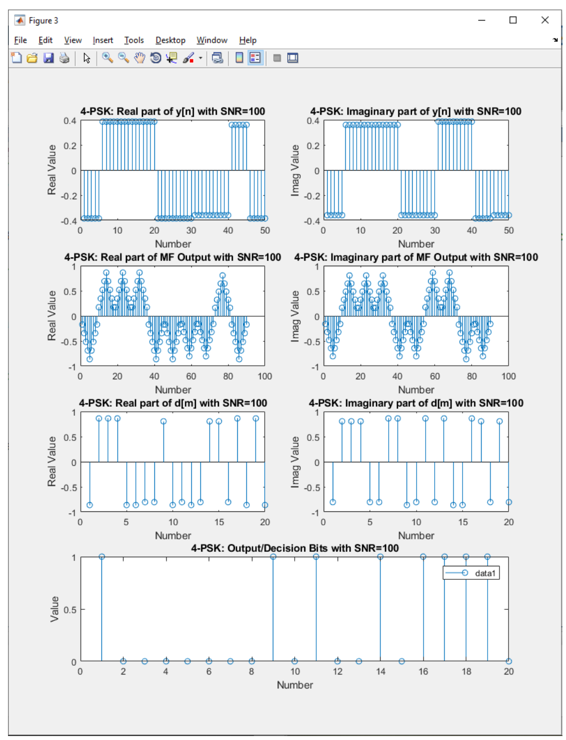


Fig. 14. Part B, QPSK: $h = CN(0, \frac{1}{\sqrt{2}})$, without Equalizer, SNR = 100 dB

2) With Equalization: By executing the code with equalization and with $h = CN(0, \frac{1}{\sqrt{2}})$ we observe the following:

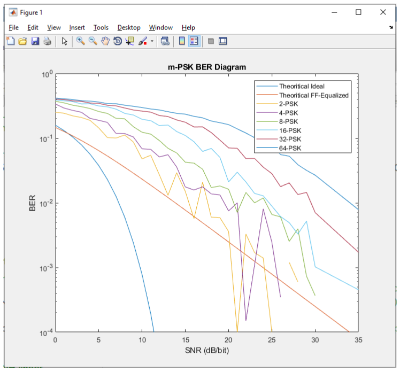


Fig. 15. BER with Equalizer, $h = CN(0, \frac{1}{\sqrt{2}})$

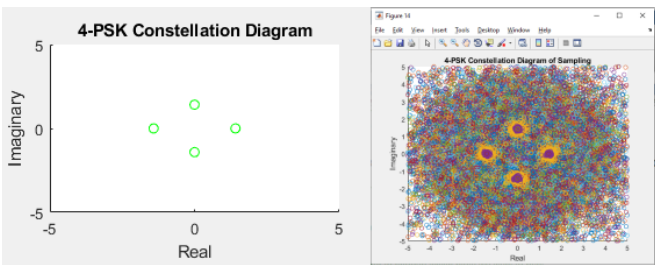


Fig. 16. Constellation Diagram: No Rotation with Equalizer, $h = CN(0, \frac{1}{\sqrt{2}})$

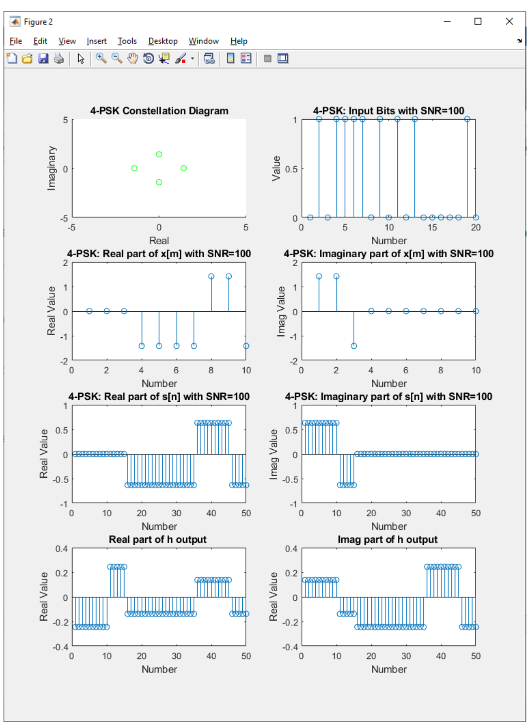


Fig. 17. Part A, QPSK: $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer, SNR = 100 dB

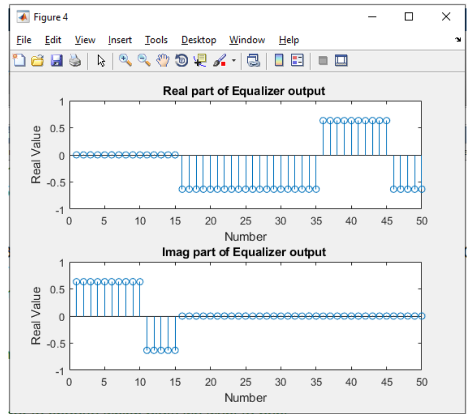


Fig. 18. Part B, QPSK: $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer, SNR = 100 dB

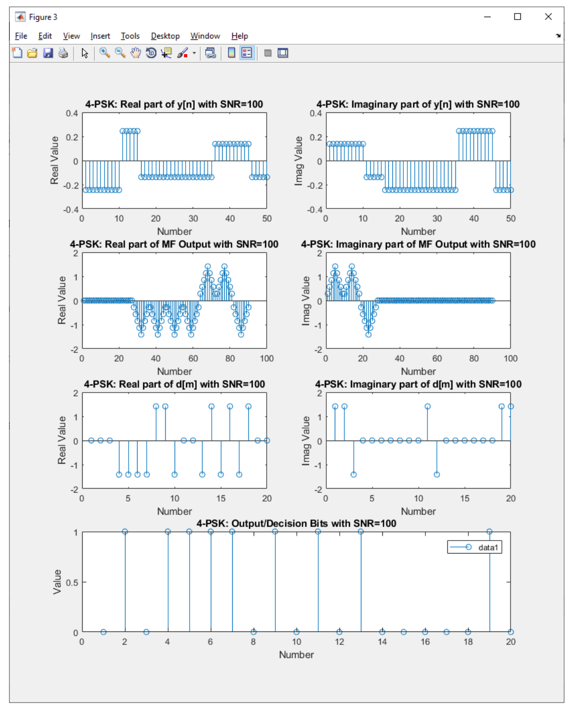


Fig. 19. Part C, QPSK: $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer, SNR = 100 dB

III. QUESTION B1

We execute the code with properties:

- Flat Fading Estimator has some bias (h+c)
- Bias values (c): 0.0, 0.1, 0.2, 0.4, 0.7 and 1.0

The results are:

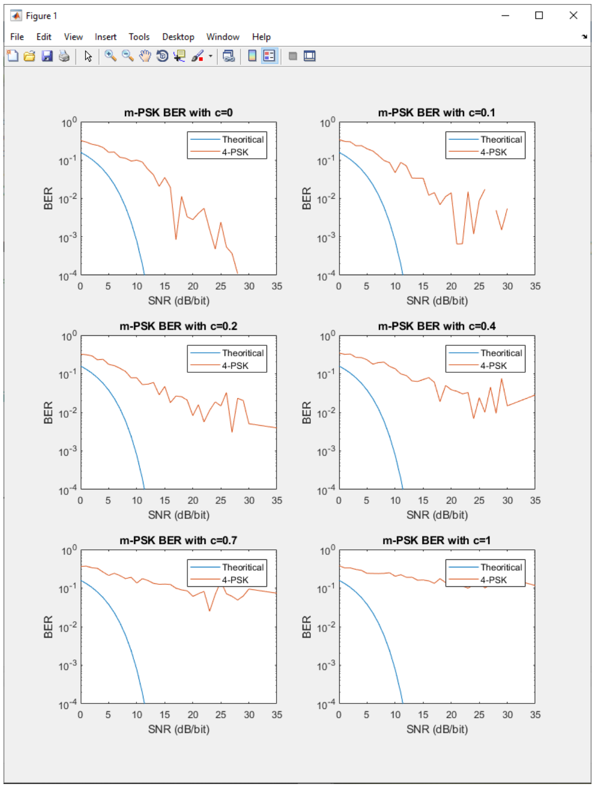


Fig. 20. QPSK BER for c = 0.0, 0.1, 0.2, 0.4, 0.7 and 1.0

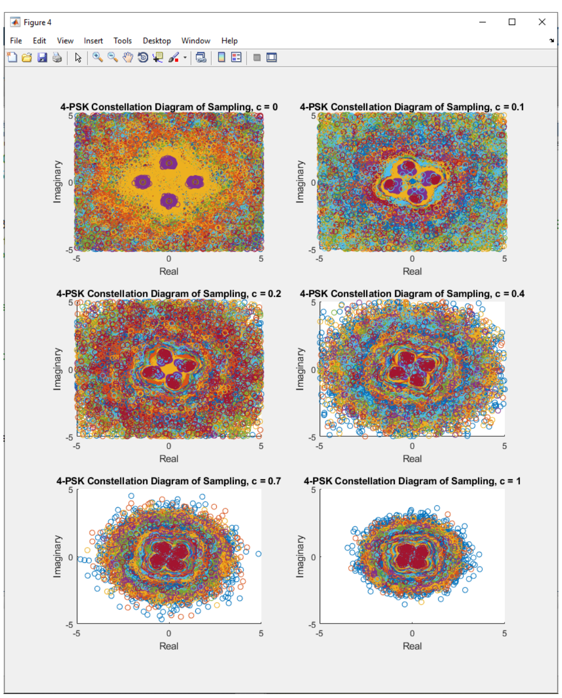


Fig. 21. QPSK Sampling Constellation Diagram: Rotation for bigger values of c

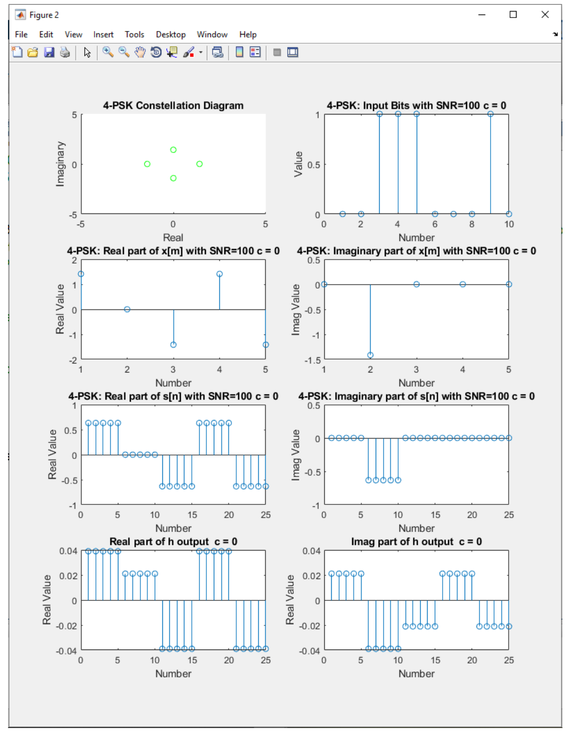


Fig. 22. Part A, QPSK: c = 0, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer, SNR = 100 dB

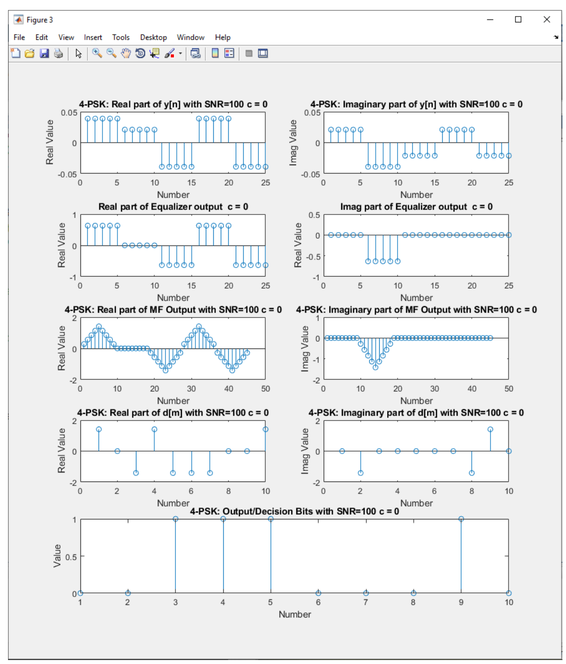


Fig. 23. Part B, QPSK: c = 0, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer, SNR = 100 dB

IV. QUESTION B2

We propose a way to compute bias value c. At the Receiver we do not know the exact value of h, but only the biased value h+c. Nevertheless, we do know the distribution of real h values, which is $h = CN(0, \frac{1}{\sqrt{2}})$. Thus, we create, at the receiver side, one thousand values from this distribution and store them to a vector *h_simulation*.

Now we could estimate the bias value computing:

$$c = E[h + c] - E[h];$$

$$c = E[Re(h\_biased)] - E[Re(h\_simulation)];$$

The results from this method are:

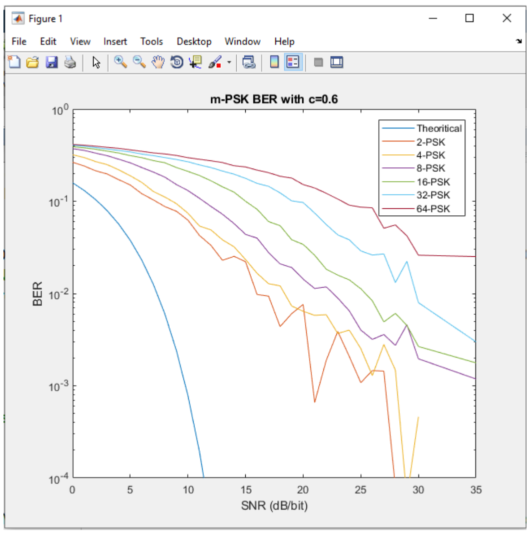
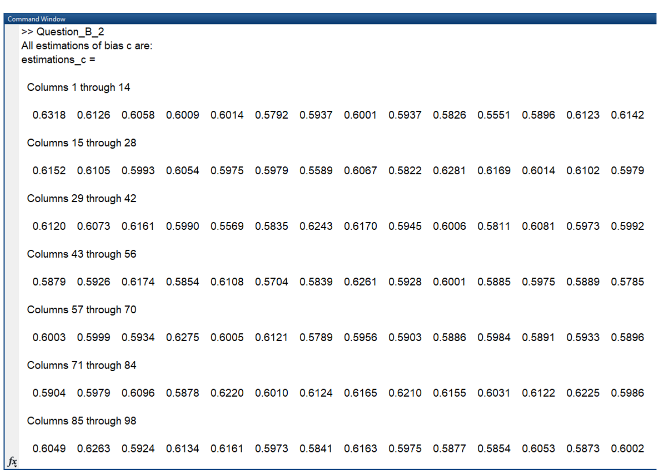


Fig. 24. QPSK BER with bias correction: Improved with our method, c=0.6



Command Window

```
>> Question_B_2
All estimations of bias c are:
estimations_c =

  Columns 1 through 14

    0.6318    0.6126    0.6058    0.6009    0.6014    0.5792    0.5937    0.6001    0.5937    0.5826    0.5551    0.5896    0.6123    0.6142

  Columns 15 through 28

    0.6152    0.6105    0.5993    0.6054    0.5975    0.5979    0.5589    0.6067    0.5822    0.6281    0.6169    0.6014    0.6102    0.5979

  Columns 29 through 42

    0.6120    0.6073    0.6161    0.5990    0.5569    0.5835    0.6243    0.6170    0.5945    0.6006    0.5811    0.6081    0.5973    0.5992

  Columns 43 through 56

    0.5879    0.5926    0.6174    0.5854    0.6108    0.5704    0.5839    0.6261    0.5928    0.6001    0.5885    0.5975    0.5889    0.5785

  Columns 57 through 70

    0.6003    0.5999    0.5934    0.6275    0.6005    0.6121    0.5789    0.5956    0.5903    0.5886    0.5984    0.5891    0.5933    0.5896

  Columns 71 through 84

    0.5904    0.5979    0.6096    0.5878    0.6220    0.6010    0.6124    0.6165    0.6210    0.6155    0.6031    0.6122    0.6225    0.5986

  Columns 85 through 98

    0.6049    0.6263    0.5924    0.6134    0.6161    0.5973    0.5841    0.6163    0.5975    0.5877    0.5854    0.6053    0.5873    0.6002
fx
```

Fig. 25. Estimation of bias c=0.6: Our method estimates c with a very small error, which is reduced for bigger values of Input Bits. This happens, because then there are more biased h values and the E[h+c] is computed more accurately.

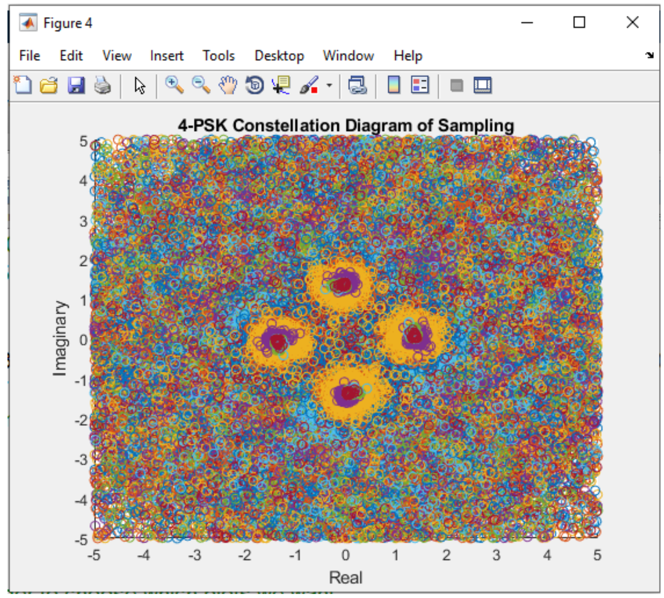


Fig. 26. QPSK Constellation Diagram with bias correction: There is not significant rotation

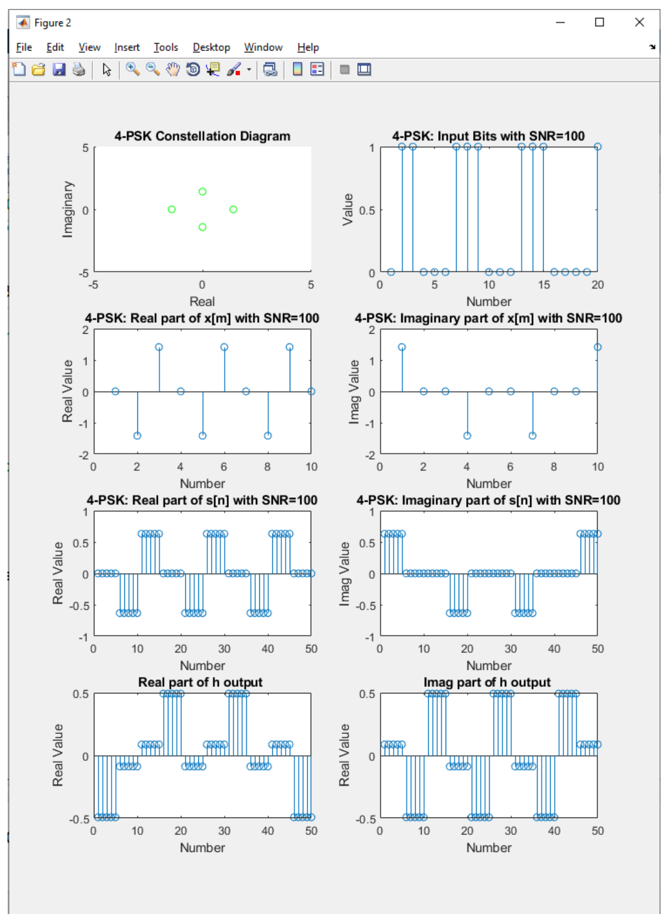


Fig. 27. Part A, QPSK: c = 0.6, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer and bias correction, SNR = 100 dB

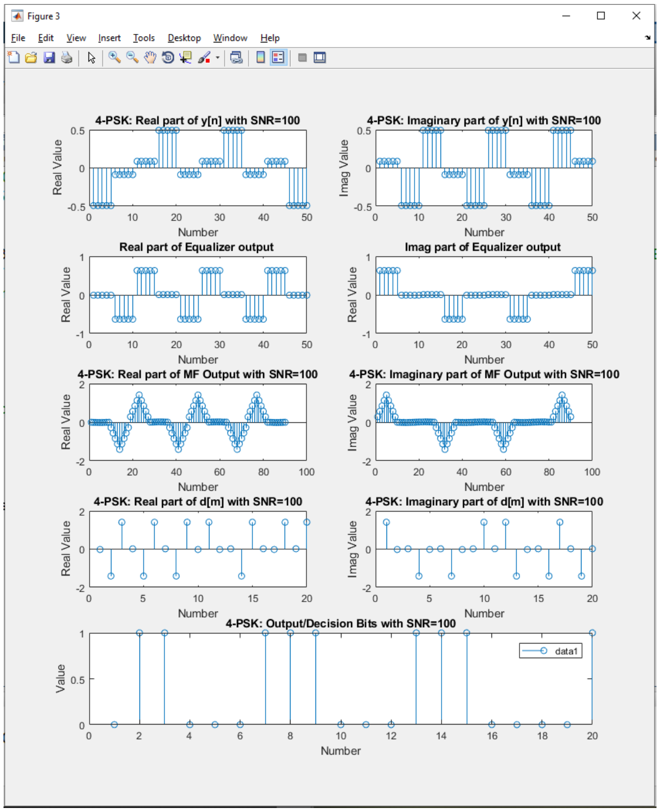


Fig. 28. Part B, QPSK: c = 0.6, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer and bias correction, SNR = 100 dB

V. Question C

We implemented MRC equalization method and we demonstrate our results for Diversity = 5

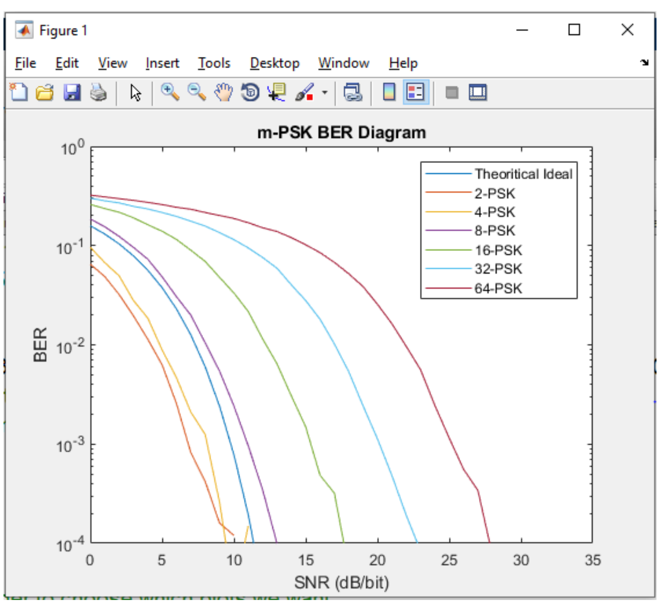


Fig. 29. BER Diversity = 5: Extremely Improved

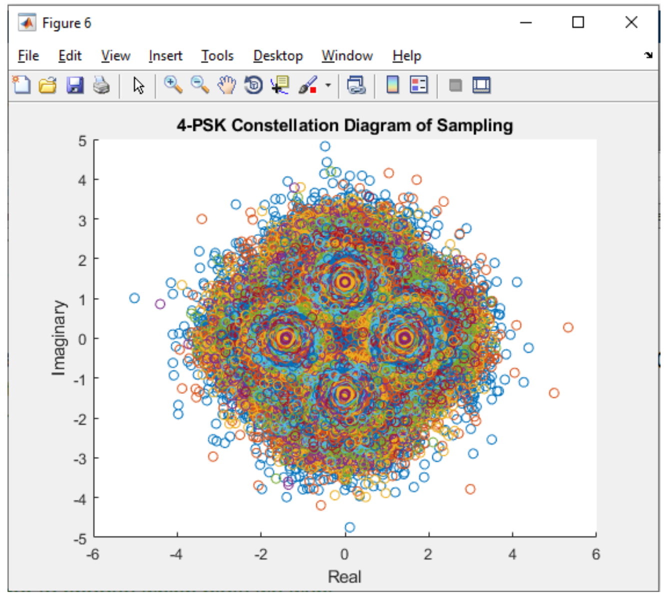


Fig. 30. QPSK Constellation Diagram Diversity = 5

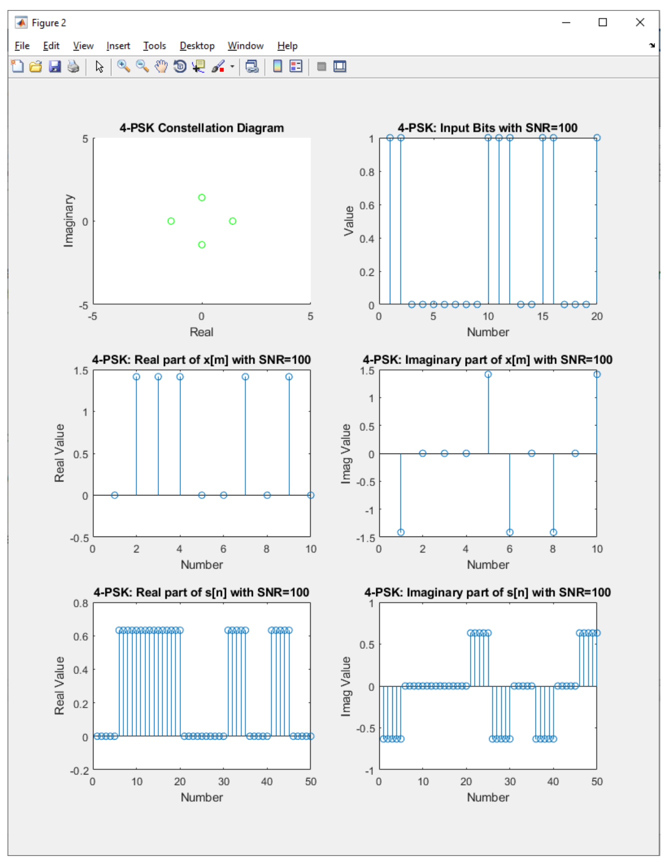


Fig. 31. Part A, QPSK: Diversity = 5, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer MRC, SNR = 100 dB

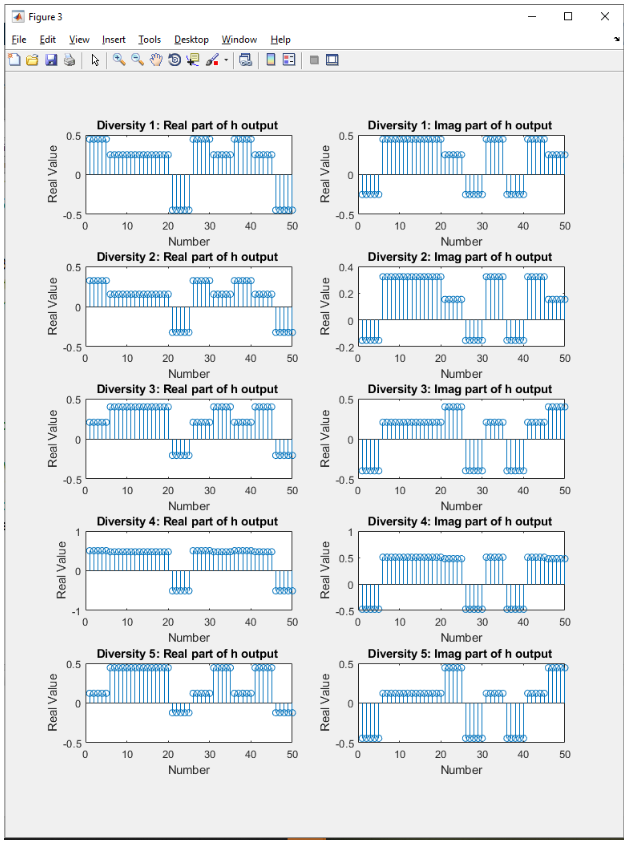


Fig. 32. Part B, QPSK: Diversity = 5, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer MRC, SNR = 100 dB

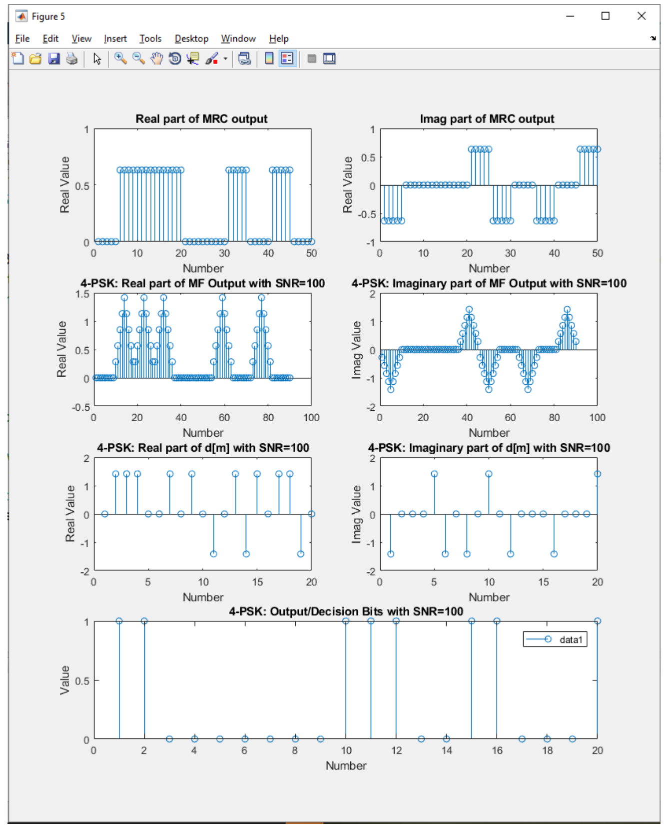


Fig. 34. Part D, QPSK: Diversity = 5, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer MRC, SNR = 100 dB

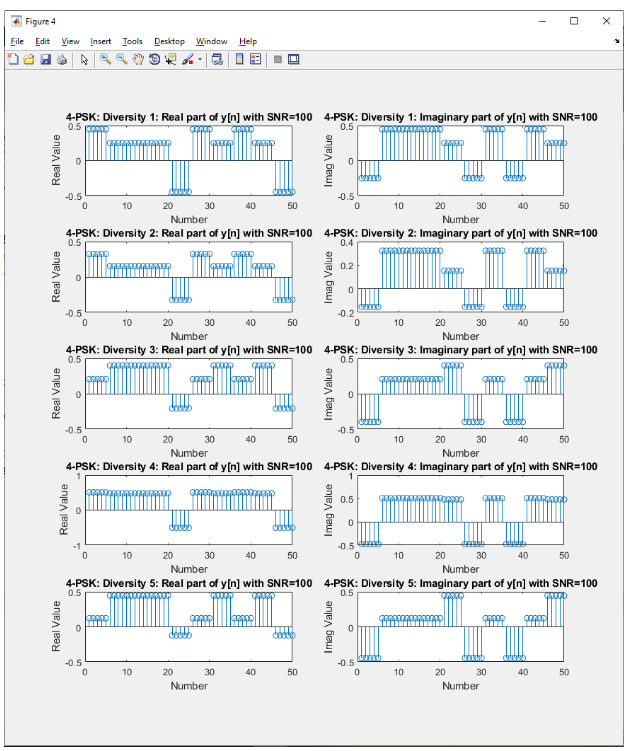


Fig. 33. Part C, QPSK: Diversity = 5, $h = CN(0, \frac{1}{\sqrt{2}})$, with Equalizer MRC, SNR = 100 dB