# ASSIGNMENT COVER SHEET

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All assessment items submitted in hard copy are due at 5pm unless otherwise specified in the course outline.

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| **Course Code** | ENGN4536 | | |
| **Course Name** | Wireless Communications | | |
| **Assignment Item** | Simulink Project | | |
| **MATLAB Version Used** | R2019b | | |
| **Due Date** | 26/10/2020 | | |
| **Date Submitted** | 25/10/2020 | **Extension Granted** | No |

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- ✓ is original, except where collaboration (for example group work) has been authorised in writing by the course convener in the course outline and/or Wattle site;
- ✓ is produced for the purposes of this assessment task and has not been submitted for assessment in any other context, except where authorised in writing by the course convener;
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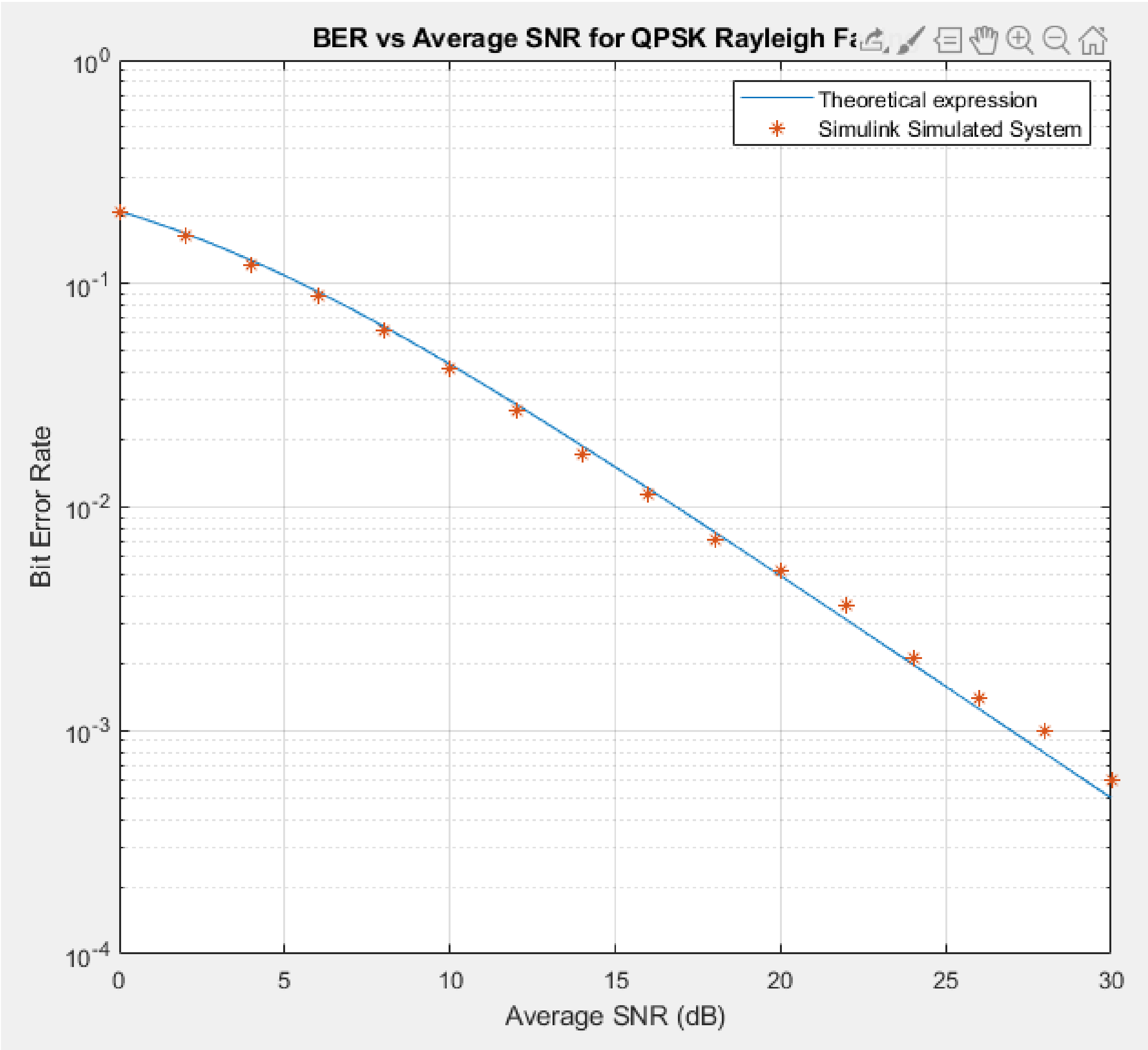
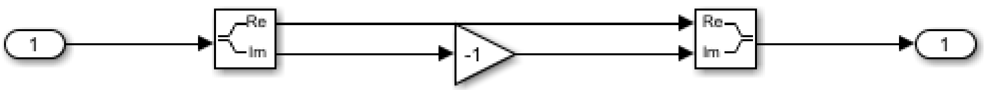
# Task I QPSK Modulation over Flat Rayleigh Fading Channel

### 1.3. Report Deliverables

| | | |
|---|---|---|
| **1.** | Present a BER v.s. SNR plot with BER values in log-scale and for the SNR range of 0:2:30 in dB. In this plot, you should present two curves: (i) the BER obtained from simulation you did in Simulink, and (ii) the BER obtained using the theoretical expression in (6). Use Matlab to compute the theoretical BER values and to generate the plot. Please display (i) and (ii) using different ways, e.g., using different ways, e.g., using solid lines to represent the theoretical BER and symbols to represent the simulated BER. | **4 Marks** |
| | **Answer:**  **MATLAB and Simulink files attached, points were recorded in excel and then imported into MATLAB using 'xlsread'.** | |

### 1.4. Evaluation Questions

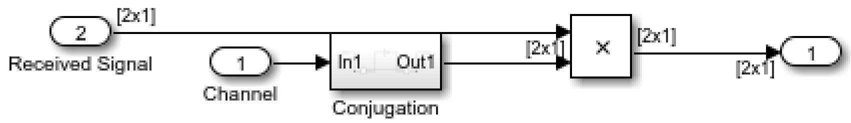
| | | |
|---|---|---|
| **1.** | Explain in your own words how the self-built i.i.d. Rayleigh fading model works and what the effect of each of the blocks included is. Also explain how you choose the values of the parameters in each block in the system, such as the mean, variance, SNR, sample time, and power gain (which is a parameter in the block of power amplifier), if applicable. | **5 Marks** |
| | **Answer:**<br>Based on the given equation, we want to manipulate the modulated values accordingly. We are using normalised signal power so we say it is the same as SNR. Hence in the AWGN block we keep the power gain as 1.<br>So the equation below:<br>$y = h\sqrt{P_r}x + w = h\sqrt{\frac{P_t}{d^\eta}(Kd_0^\eta)}\, x + w = \frac{h}{\sqrt{d^\eta}}\sqrt{P_t K d_0^\eta}x + w,$<br>Becomes: $y = hx + w'$.<br>**The i.i.d Rayleight fading channel** was built using two random number generator blocks and a Real-Imag to Complex converter block. Hence the real and imaginary part were independently randomly generated using different seed parameters. And **mean of 0**, with **variance ½** as required**.** The sample time parameter based on sampling frequency given was then set as 1e-6.<br>The model has no inputs and generates one output that is multiplied with the modulated signal. | |
| **2.** | Explain in your own words how the self-built coherent channel detection model works and what the effect of each of the blocks included is. Also, explain how you choose the values of the parameters in each block, such as the mean, variance, SNR, and power gain, if applicable. | **5 Marks** |
| | **Answer:**<br>The coherent channel detection model is taking the received signal, and multiplying it to the conjugate of the known original signal. So as described in the project description we utilise two inputs for the coherent channel detection model and one output. To find the conjugate we can simply use a 'conj' math block which outputs the complex conjugate or we can construct a conjugate block ourselves:<br><br> | |
| **3.** | For a fixed SNR value/setting for the AWGN block, how would you set the equivalent $E_b/N_0$ and $E_s/N_0$? | **4 Marks** |
| | **Answer:**<br>For EsNo we set the symbol period using sample time to 2e-6 since a bit every 1e-6 and therefore 2 bits for a symbol hence symbol period is 2e-6, and then for the EbNo we use 2 bits per symbol which we know for QPSK, and set the period to 1e-6. These parameter changes would effectively keep the same SNR value. | |

# Task II: QPSK Modulation over Flat Rayleigh Fading Channel with Receiver Diversity

## 2.3. Report Deliverables

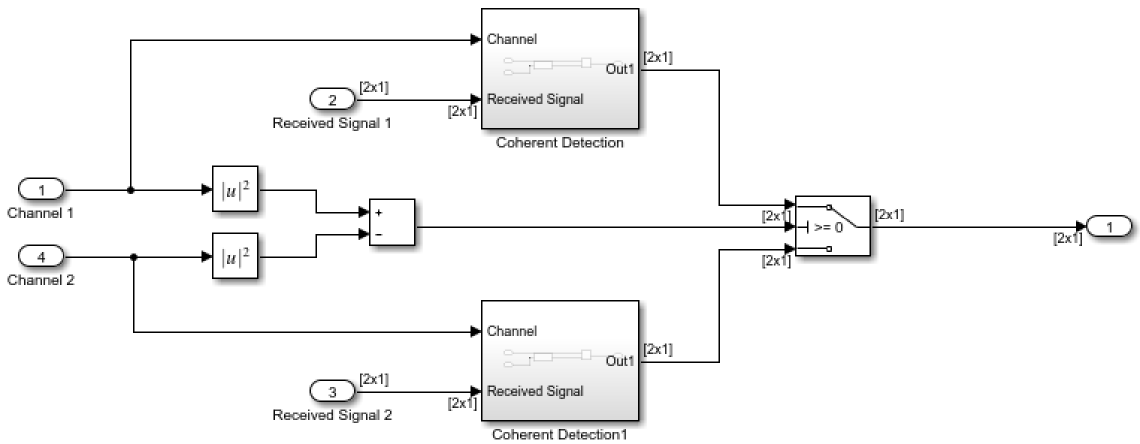
| 1. | Present the block diagrams of SC and MRC detection models. | 8 Marks |
|---|---|---|

**Answer:**

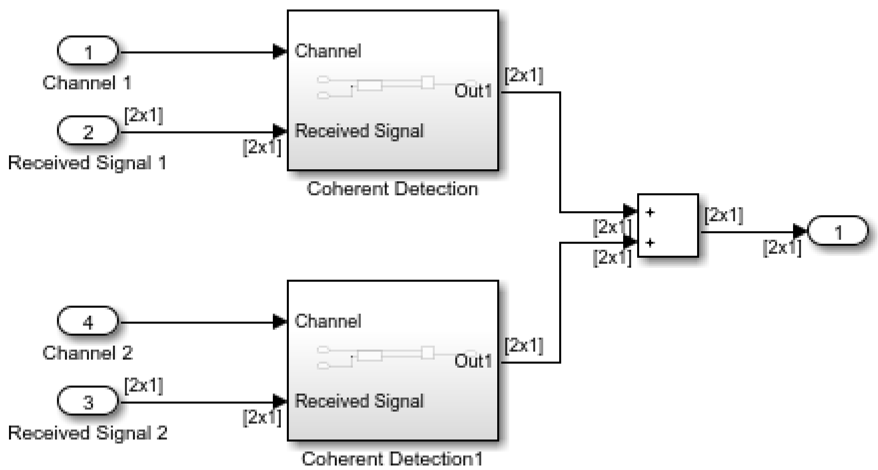



Using the 'Coherence Detection' model from the previous part, based on the design provided in the Simulink lecture.
The **SC Model** was then designed as such based on the required equation as provided in the description.

$$i^* = \arg \max_{i \in \{1,2\}} |h_i|^2.$$

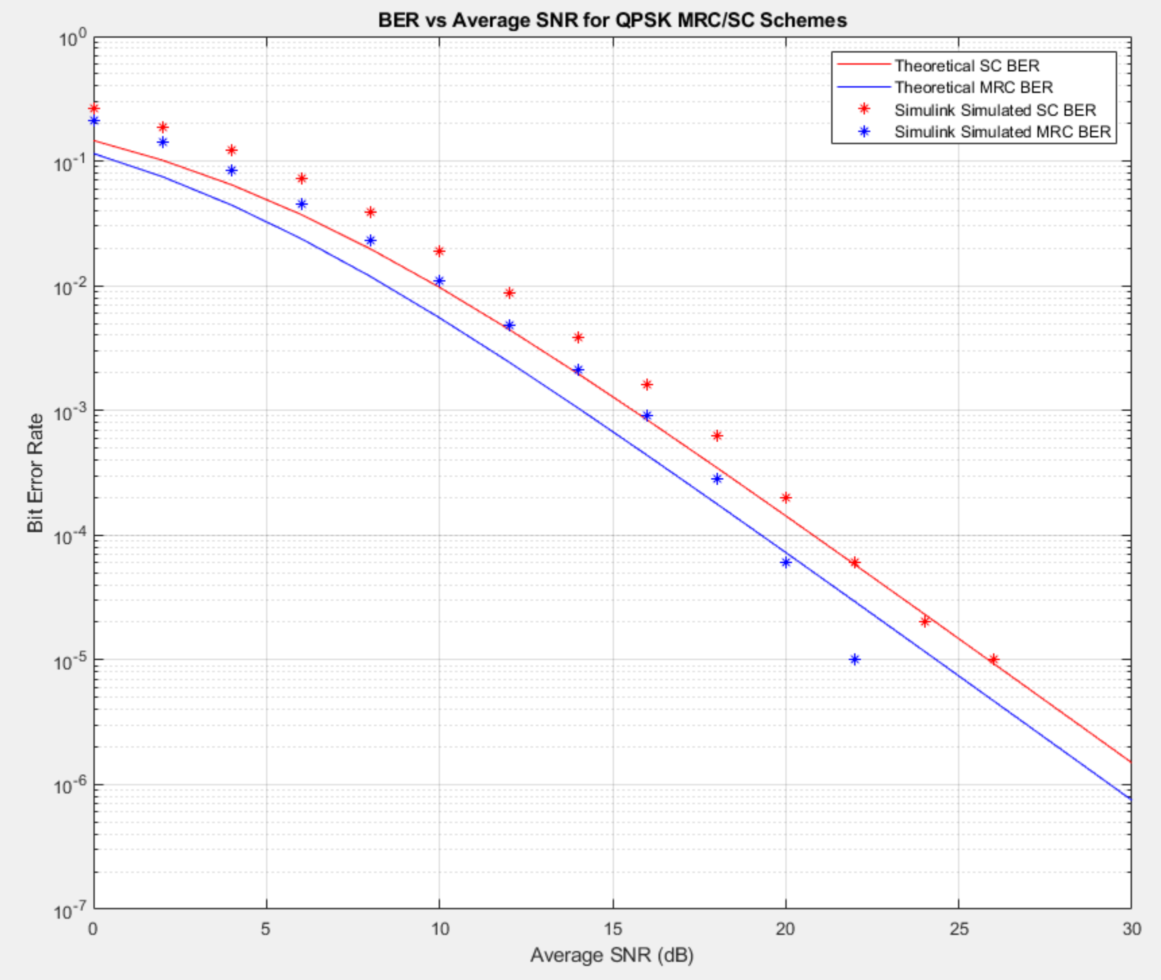



For **MRC Model**:



| | | |
|---|---|---|
| **2.** | Present a BER v.s. SNR plot with BER values in log-scale and SNR from 0:2:30 in dB. In this plot, you should present four curves: (i) the BER obtained from simulation you did in Simulink for both SC and MRC, and (ii) the BER obtained using the theoretical expressions for both SC and MRC. Use Matlab to compute the theoretical BER values and to generate the plot. Please display (i) and (ii) using different ways. | **4 Marks** |

**Answer:**




**Using the Task2.m MATLAB file all four plots have been shown. The code runs the simulation to obtain its results, which is why the Simulink files do not contain the 'display' module.**

## 2.4. Evaluation Questions

| | | |
|---|---|---|
| **1.** | Explain in your own words how the self-built SC and MRC models work and what the effect of each of the blocks included is. Also explain how you choose the values of the parameters in each block in SD and MRC, such as the mean, variance, SNR, and power gain, if applicable. | **6 Marks** |
| | **Answer:**<br>**The Selection Combining:**<br>The aim is to select the received signal which received the 'best' fading and then pass that through coherent detection and use it as the output for demodulation.<br>This 'selection' is done through first taking the absolute value squared of the Rayleigh Channel and then comparing it with the other channel. In the diagram shown channel 2 is subtracted from channel 1 input which then is passed to the switch which uses a >= 0 parameter. This is so that if channel 1 is greater then the Received signal from channel 1 through coherent detection will be outputted. Else the received signal 2 through coherent detection will be output. With the same coherent detection block as Task 1. We are using a simple switch and add block to determine the selection.<br><br>**The Maximal Ratio Combining Model:**<br>The aim is to simply add the two signals through coherent detection. As shown in the mathematical logic in the lectures and project description. So in order to do this we simply take the two received signals and their known channel as input and pass them respectively through coherent detection blocks and then use an add block to combine the two. Which gives us the sum of the weighted signals as required by MRC scheme. | |
| **2.** | Compare the BER-SNR curves for the system having receiver diversity techniques in 2.3.2 with the BER-SNR curves in Task I. Describe your observation and explain why receive diversity can improve the performance. | **2 Marks** |
| | **Answer:**<br>Compared to the BER-SNR curves in Task 1, the graph in 2.3.2 shows that using diversity techniques greatly improves the error performance. We can observe this because the BER is lower as the SNR values increases in comparison to the dataset obtained in Task 1. Receiver diversity can improve the performance due to the receiver taking a measurement based on multiple paths or multiple received signals and using some math logic to determine which one is 'best' or combining them to obtain the best result. By using multiple points of reference it intuitively makes sense that there is a higher probability of the correct symbol being interpreted. | |
| **3.** | Explain in your own words why MRC performs better than SC. Despite such a performance gain, what is the disadvantage of MRC relative to SC? | **2 Marks** |
| | **Answer**:<br>MRC performs better than selection combining because it uses all the branches of the transmitted signal simultaneously, we can see this happening in our Simulink simulation. The MRC is using a smart weighting to combine the two received signals to then reduce the probability of a symbol being detected in error. Despite this performance gain, the disadvantage of MRC compared to SC is that it is much more complex to implement, it requires more resources in the form of multiple antennas compared to selection combining which only requires an antenna switch and SNR monitoring. | |

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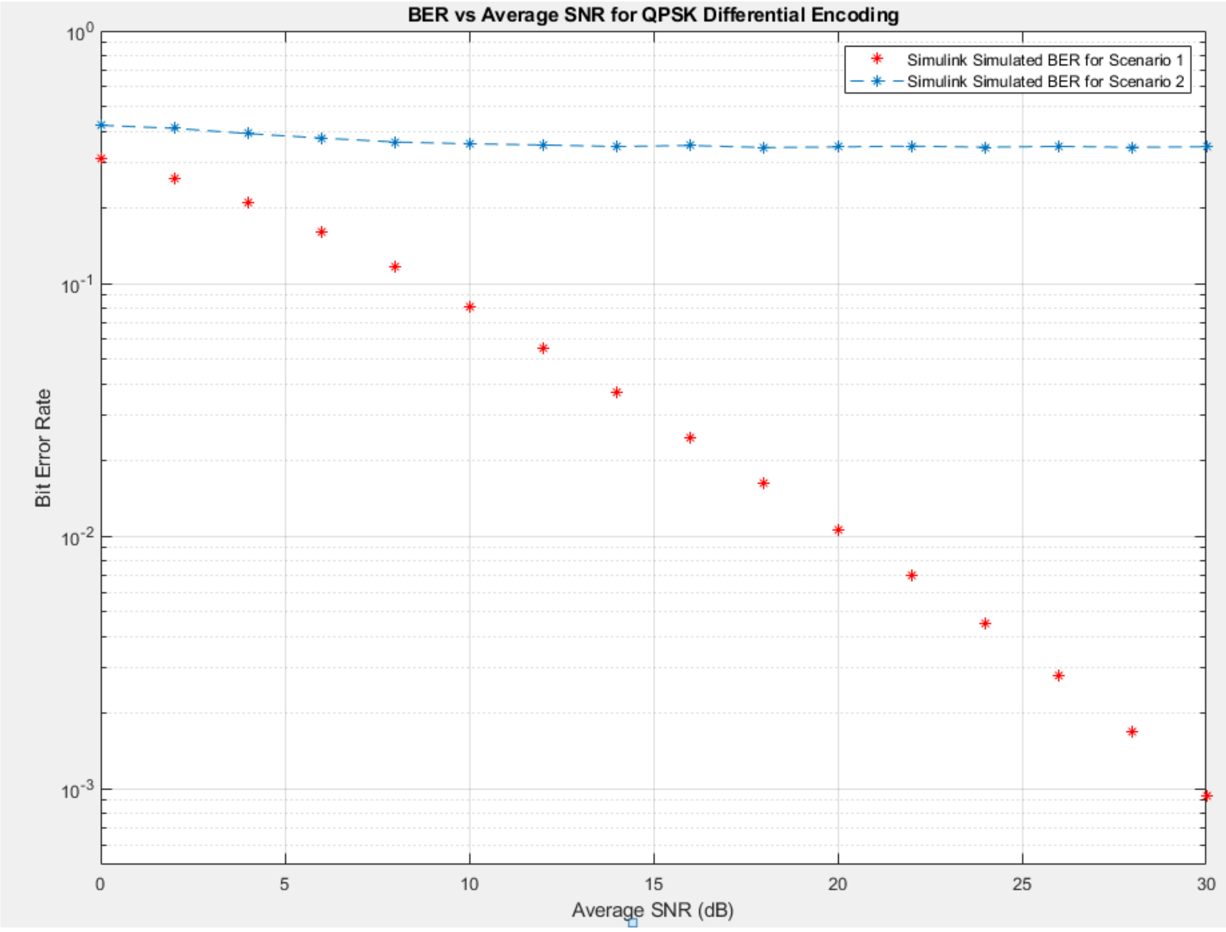
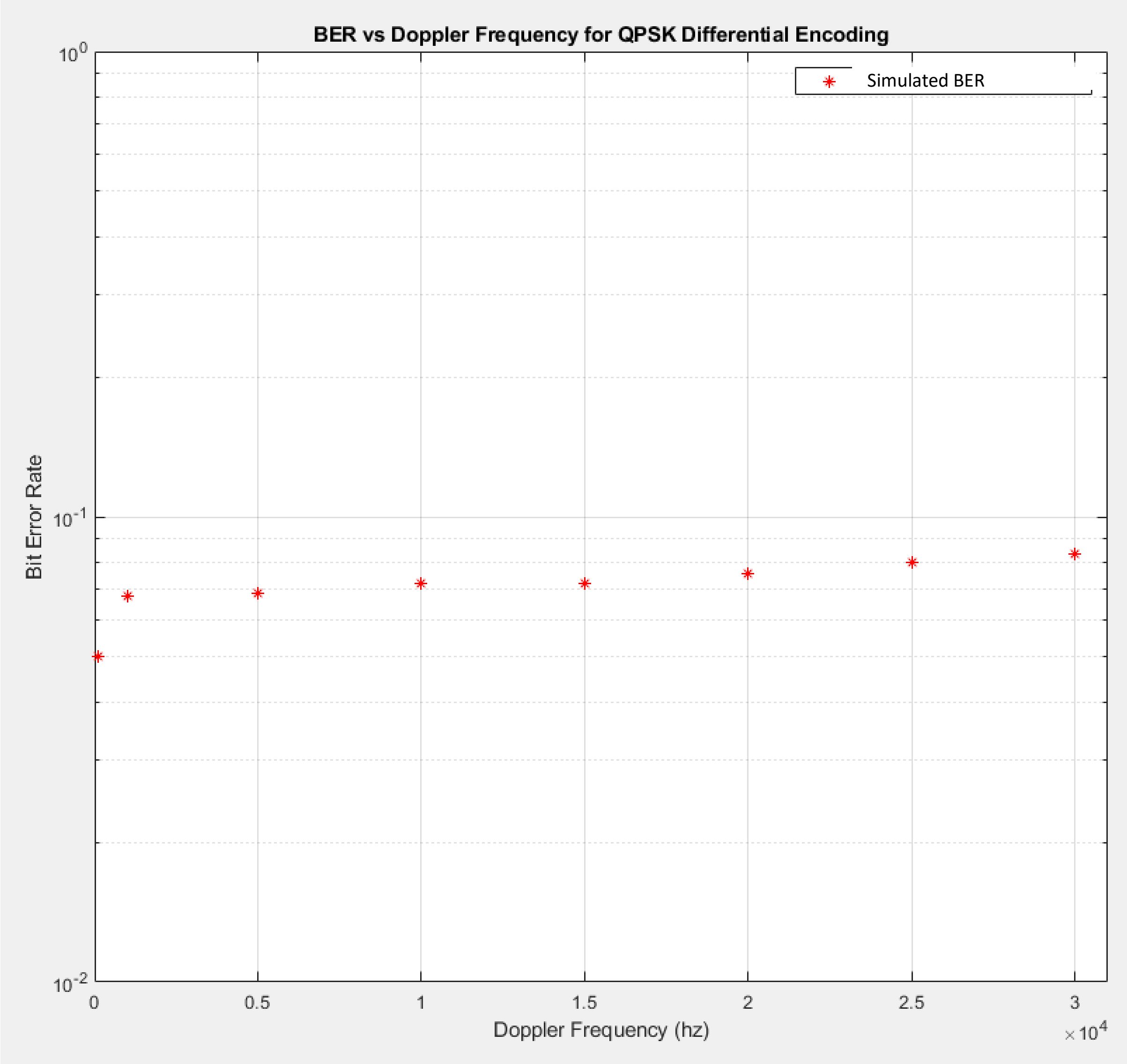
| **4.** | Do you think i.i.d. Rayleigh fading channel really happens in practice? If not, what would be a better model? | **3 Marks** |
| | **Answer:**<br>**T**he Rayleigh fading channel does happen in real life it is best used to model fading when there is no direct line of sight from the transmitter to the receiver. It is generally a worst-case scenario. Other fading channel models exist and serve to better model certain conditions such in rural areas where line of sight is more than likely. And also in the case of signals interacting with a moving target. But it is generally accepted | |

# Task III: Differential QPSK Modulation over Multipath Rayleigh Fading Channel

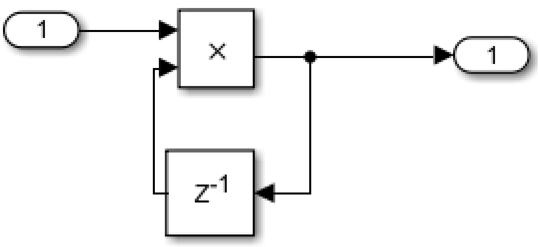
### 3.3. Report Deliverables

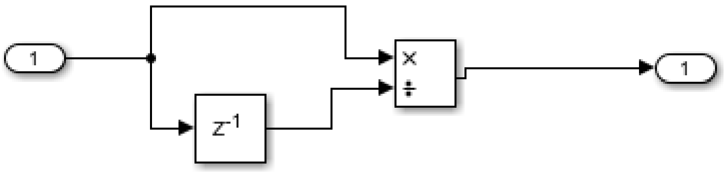
| | | |
|---|---|---|
| **1.** | Present a BER-SNR plot with BER values in log-scale and SNR from 0:2:30 in dB. In this plot, you should have two curves: One from simulation for Scenario 1 and one from simulation for Scenario 2. The difference between the two curves shows the effect of different delay spread. | **3 Marks** |

| | | |
|---|---|---|
| | **Answer:**<br> | |
| **2.** | Present a plot of BER v.s. Doppler shift with BER values in log-scale using the simulation result for Scenario 3. | **3 Marks** |
| | **Answer:** | |



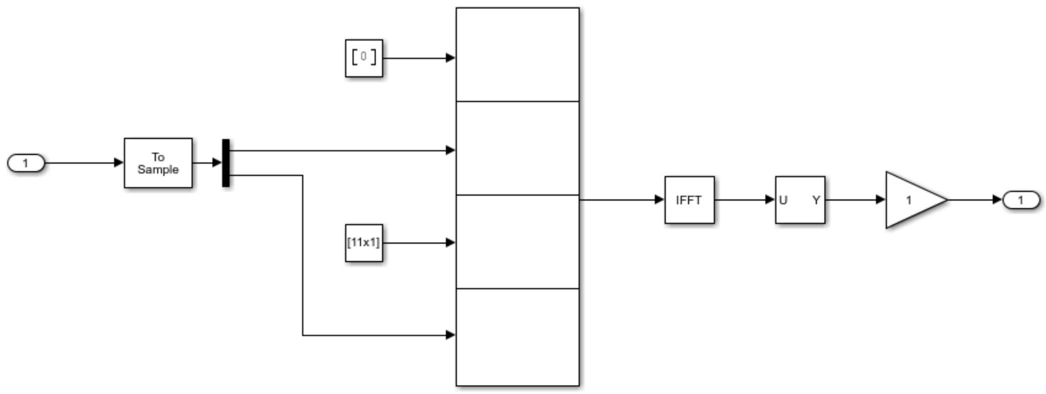
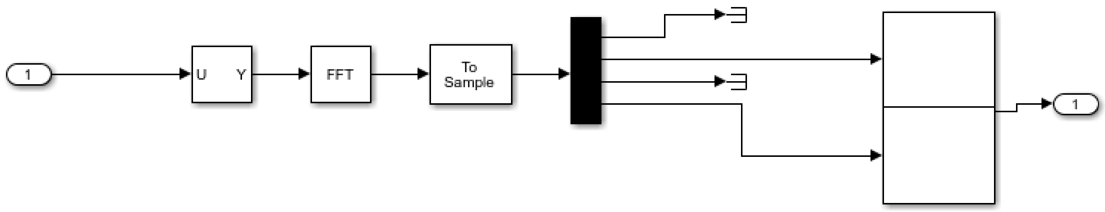

### 3.4. Evaluation Questions

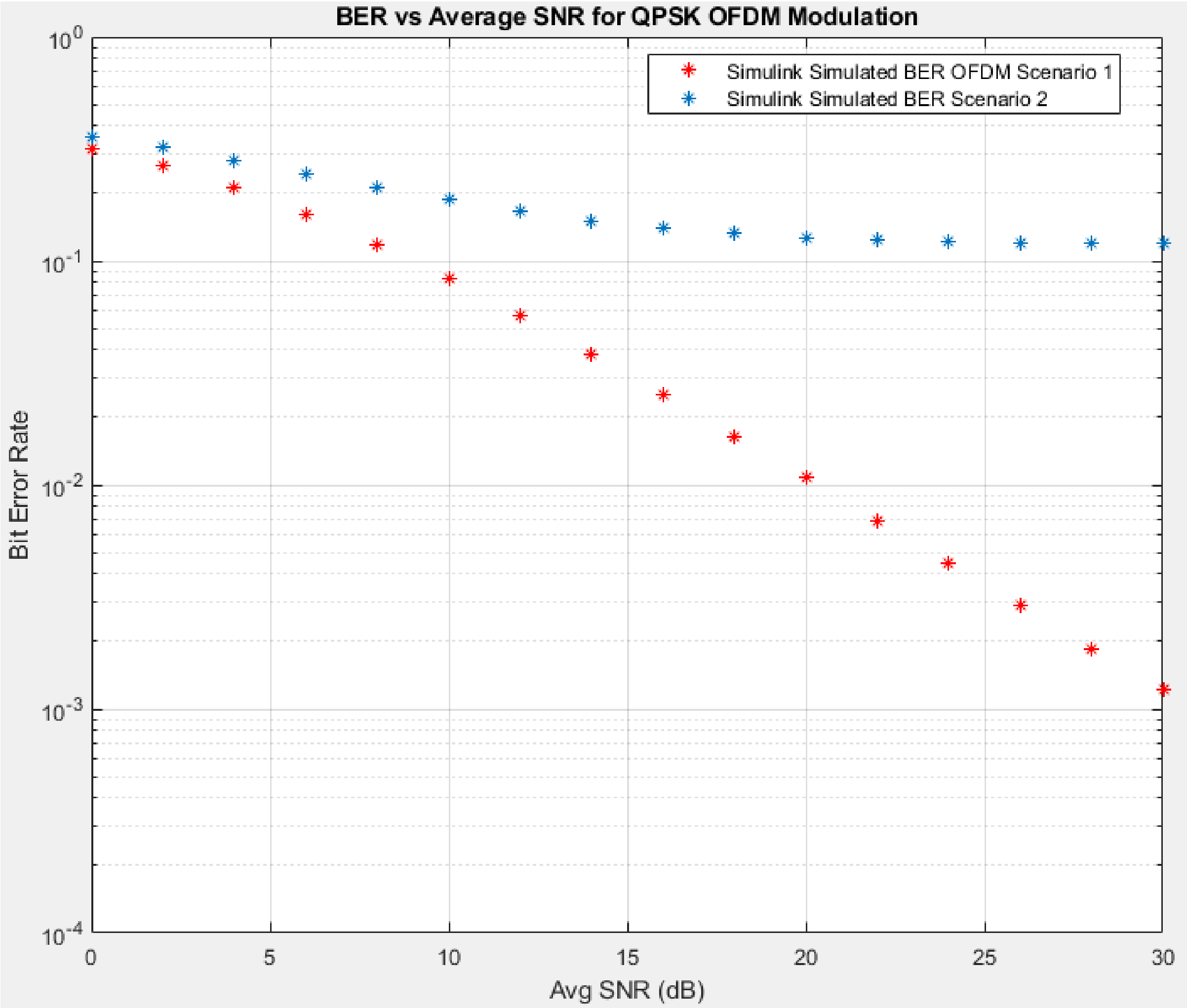
| | | |
|---|---|---|
| **1.** | Explain in your own words how the self-built differential encoding/decoding model works and what the effect of each of the blocks included is. Also, explain how you choose the values of the parameters in each block in the differential encoding/decoding block, such as delay, and power gain, if applicable. | **6 Marks** |
| | **Answer:**<br>**The Differential Encoder** <br>Using a delay block and multiplying the output delayed by one-time instance with the current input, we obtain the differential encoder. Which is simply multiplying the previous time instances output with the current input.<br>The **differential decoder** | |

| | | |
|---|---|---|
| | <br>The delay block being setup in both cases with delay length 1, and initial condition of 1. Input processing as 'elements per channel' and sample is inherited.<br>The division block is used here for the decoder to essentially do the opposite of the encoder, hence dividing the current symbol by the previous input. | |
| **2.** | Can you explain why the first symbol is often detected in error, even in slow fading channels at high SNRs?<br>(Hint: Think about differential coding/decoding.) | **3 Marks** |
| | **Answer:** Because the differential coding/decoding is based on future value detection in the sense that when the first symbol is transmitted and encoded, there will be NO previous symbol as there cannot be a symbol from before the 0 time instance i.e. before we started transmitting. The first symbol has no previous symbol hence the decoder cannot accurately pickup the value of the symbol on decoding hence the first symbol will often be detected in error. | |
| **3.** | Compare the BER plot obtained from simulation for Scenarios 1 and 2 with the BER plot obtained in Task I. Describe your observation and explain why the performance with differential coding is better/worse than that with coherent detection? | **3 Marks** |
| | **Answer:** We can see that the BER performance is worse marginally at high SNR in Scenario 1, 2 than in Task 1. So we can say that Task one has better performance than the graph pointed in Task 3. This is because of the Flat Rayleigh Fading channel which we have used, in this Task 3 compared to Task 1. | |
| **4.** | Using the criteria we have learned in [Lecture 7] to determine the range of Doppler shift, $D_s$, for fast, medium-rate, and slow fading channel. | **3 Marks** |
| | **Answer:**<br>From lecture 7, we know:<br>• $T_C/T_S > 100$ or $f_D T_s < 0.01$ can be considered as slow fading;<br>• $1 < T_C/T_S < 100$ or $0.01 < f_D T_S < 1$ is medium-rate fading;<br>• $T_C/T_S < 1$ or $f_D T_S > 1$ is really fast fading.<br>Given that Ts =1e-6<br>For slow fading we have $f_D < 10000$hz<br>Medium Rate Fading 10khz < $f_D$ < 1000hz<br>Fast Fading $f_D > 1000$hz | |

# Task IV: OFDM with PSK Modulation over Multipath Rayleigh Fading Channel

## 4.3. Report Deliverables

| | | |
|---|---|---|
| **1.** | Present the block diagrams of OFDM modulator and demodulator. [6 marks] | **6 Marks** |
| | **Answer:**<br>**OFDM Modulator**<br><br><br>**OFDM Demodulator**<br><br> | |

| 2. | For QPSK modulation, present a BER-SNR plot with BER values in log-scale and SNR from 0:2:30 in dB. In this plot, you should have two curves: One from simulation for Scenario 1 and one from simulation for Scenario 2. | **2 Marks** |
|---|---|---|
| | **Answer:**  | |
| **3.** | For 8-PSK modulation in simulation for Scenario 3, present a BER-SNR plot with BER values in log-scale and SNR from 0:2:30 in dB. | **2 Marks** |
| | **Answer:** | |

| | | |
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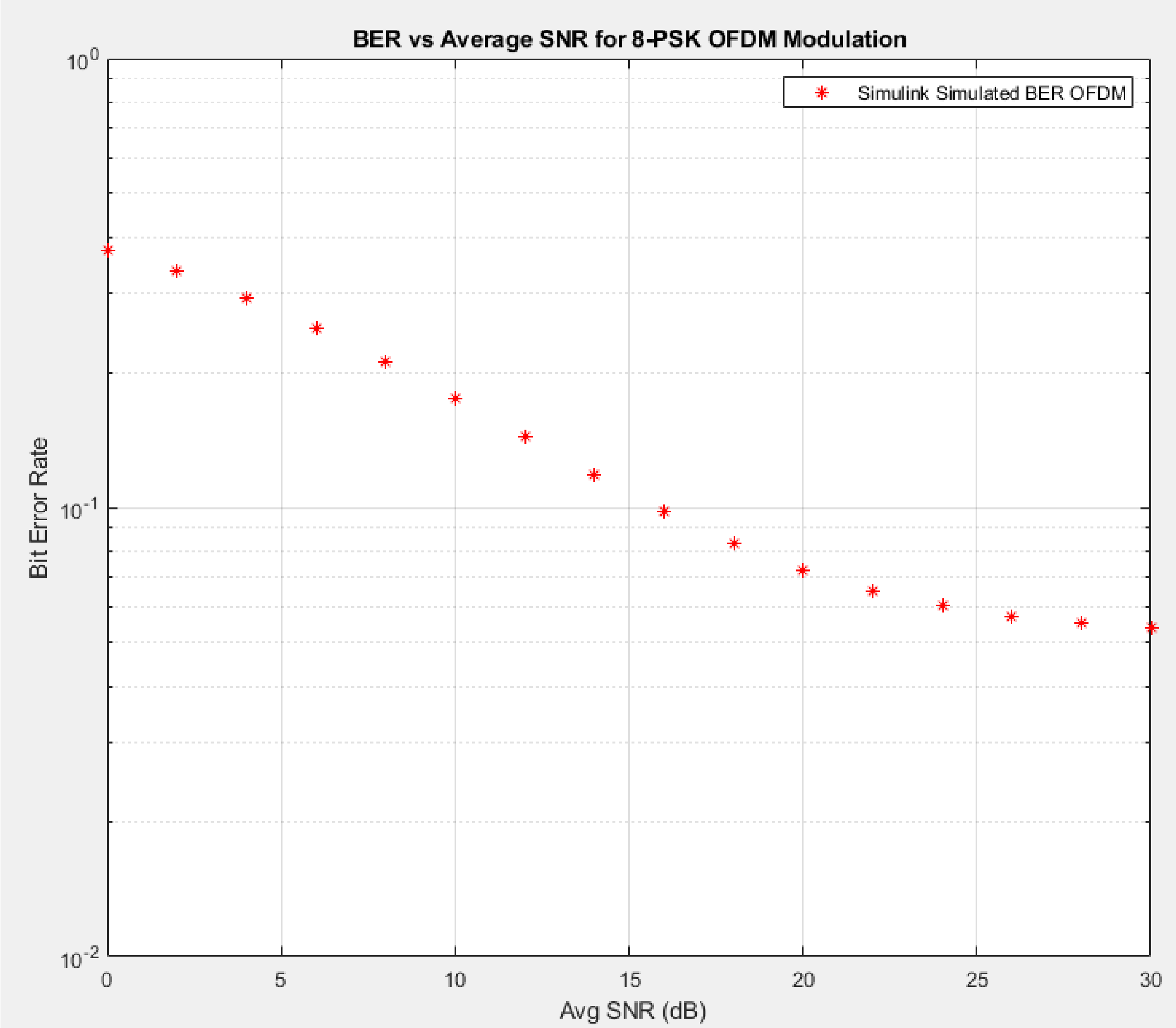
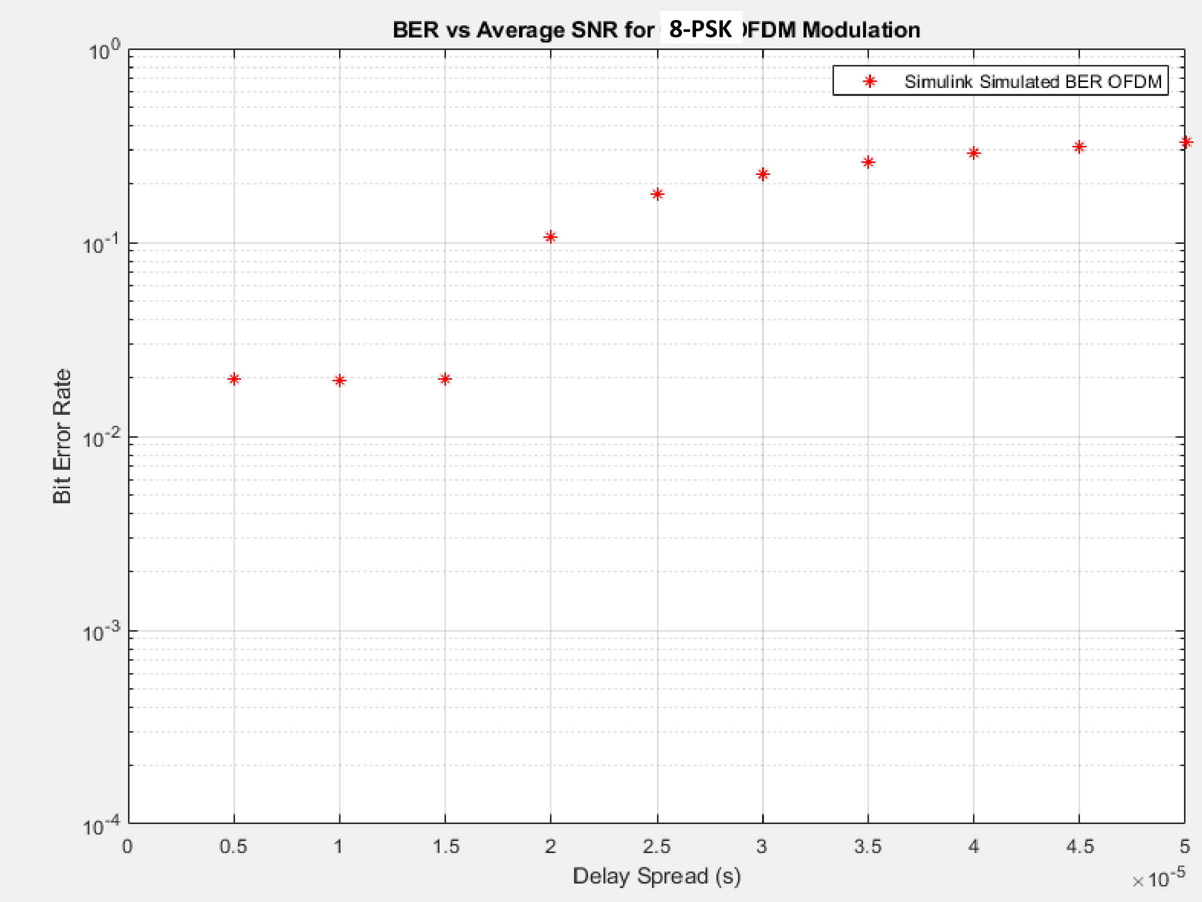
| |  | |
| **4.** | For 8-PSK modulation in simulation for Scenario 4, present a plot of BER v.s. delay spread with BER values in log-scale. | **2 Marks** |
| | **Answer:** | |




### 4.4. Evaluation Questions

| | | |
|---|---|---|
| **1.** | Explain in your own words how the self-built OFDM modulator/demodulator models work and what the effect of each of the blocks included is. Also, explain how you choose the values of the parameters in each block in differential encoding/decoding and OFDM modulator/demodulator block, such as delay, mean, variance, SNR, and power gain, if applicable. | **6 Marks** |
| | **Answer:**<br>**The modulator block** takes the input and converts it into sample based input using the 'To Sample' Block. Next, the 'Demux' block splits the output into a vector using the 'Matrix Concantenate' as outlined in the Simulink Description. This vector is made into 64x1 by adding 12 elements. Then the inverse fast fourier transform block (IFFT) because the subcarriers must be orthogonal so that they can be separated at the receiver during demodulation. A selector block is then used to create a 80x1 vector adding the cyclic prefix as required.<br>Finally, we multiply this vector by a gain of 8.<br><br>**The demodulator block** uses the selector block first to remove the cyclic prefix so the first 16 values. The next 64 values are sent through the FFT block to reverse the IFFT from the modulator. Then the signal is converted to sample based, using the 'to sample' block, with the 'Demux' block to get rid of the inserted 0 values in the vector initially. The matrix concatenate block takes the blocks of 26 values from the signal and these are the 52 symbols demodulated.<br><br>The matrix concatenate blocks should be set to 'vector' mode. | |

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| **2.** | What is the valid value of the power amplify in the OFDM modulator? Explain why.<br>(Hint: For $N$ point IFFT, the output power is $1/N$ of the input power.) | **2 Mark s** |
| | **Answer:**<br>Power amplify value is set to 8, because N point IFFT has output of 1/sqrt(N) output power, which we want to remove during the processing part hence multiplying by sqrt(N) = 8. | |
| **3.** | Compare the BER-SNR curve of 4.3.2 with 3.3.1, describe your observation and explain why this OFDM system performs worse/better/almost the same compared with the previous non-OFDM system. Discuss the comparison for different values of the delay spread. | **2 Mark s** |
| | **Answer:** The OFDM system performs almost the same in terms of the Scenario 1 values for BER performance, which we can see roughly from the graphs, however for Scenario 2 the performance of the OFDM is better under some path delay. Meaning then that the delay spread of OFDM is lower than that of the non-OFDM system. | |
| **4.** | Compare the BER-SNR curve of 4.3.3 with 4.3.2, describe your observation. Is 8-PSK always worse than QPSK? If so, why do we need this kind of high-order modulation? | **2 Mark s** |
| | **Answer**:<br>The 8-PSK error performance is much worse than QPSK under this same simulation bounds. 8PSK will be worse than QPSK for the same SNR. We use 8-psk simply because we can transmit more data per second, i.e. higher bit-rate. It transmits 3 bits per symbol rather than 2 of QPSK. The downside in reality being that in order to lower the BER of 8PSK we need more signal power. | |
| **5.** | For a fixed SNR value/setting for the AWGN block, how would you set the equivalent $E_b/N_0$ and $E_s/N_0$? Is this different from that in Task I? Any intuitive reason for being different/the same? | **2 Mark s** |
| | **Answer:**<br>The answer is same as that of Task1 for QPSK (will be different for 8PSK slightly), we set the values based on the bits per symbol in QPSK and the sample time is once again the same as in Task 1. Intuitively this makes sense, because the AWGN can handle the multiple carriers and add noise as required. So this block does its thing based on the given input parameters as required which would remain the same as Task 1. | |
| **6.** | If the maximum delay spread of the channel is $\sigma_\tau$ = 30 $\mu$s, calculate the minimum CP length, $\mu$, for OFDM modulation. | **2 Mark s** |
| | **Answer:**<br>Minimum CP length is 30 symbols. | |
| **7.** | What problem will occur if the CP length is shorter than the maximum delay spread of the channel? What problem will occur if the CP length is designed to be too large (e.g., 10 times larger than the maximum delay spread)? | **2 Mark s** |
| | **Answer:**<br>If the cyclic prefix is shorter than the maximum delay then linear convolution and circular convolution will yield different results meaning that different results will occur in the frequency and time domain for a given signal. If the CP length is designed to be far too large then the effective data rate will be reduced since for every block length there will be more of it being the cyclic prefix. So the percentage rate loss will be greater. | |

| | | |
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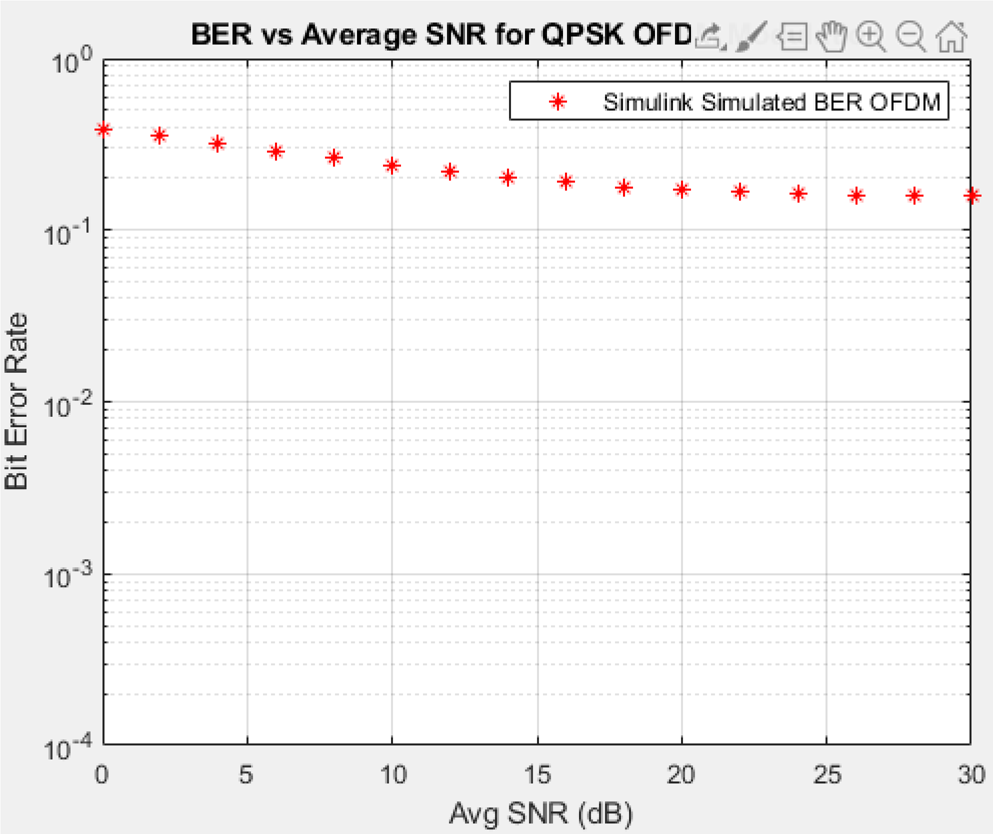
| **8.** | In lab procedure - Simulation for Scenario 2, reset the multi-path gain as [0 20] dB, see if the BER changes significantly, i.e., whether the change in BER is greater than 10%. Explain why. | **2 Marks** |
| | **Answer:**<br>**The BER does not change significantly as seen in the simulated image below. At around 30dB SNR the BER is very slightly greater than in the initial case.**<br><br><br>This is due to the increased gain on the delay spread in Scenario 2. This has a minimal effect. | |

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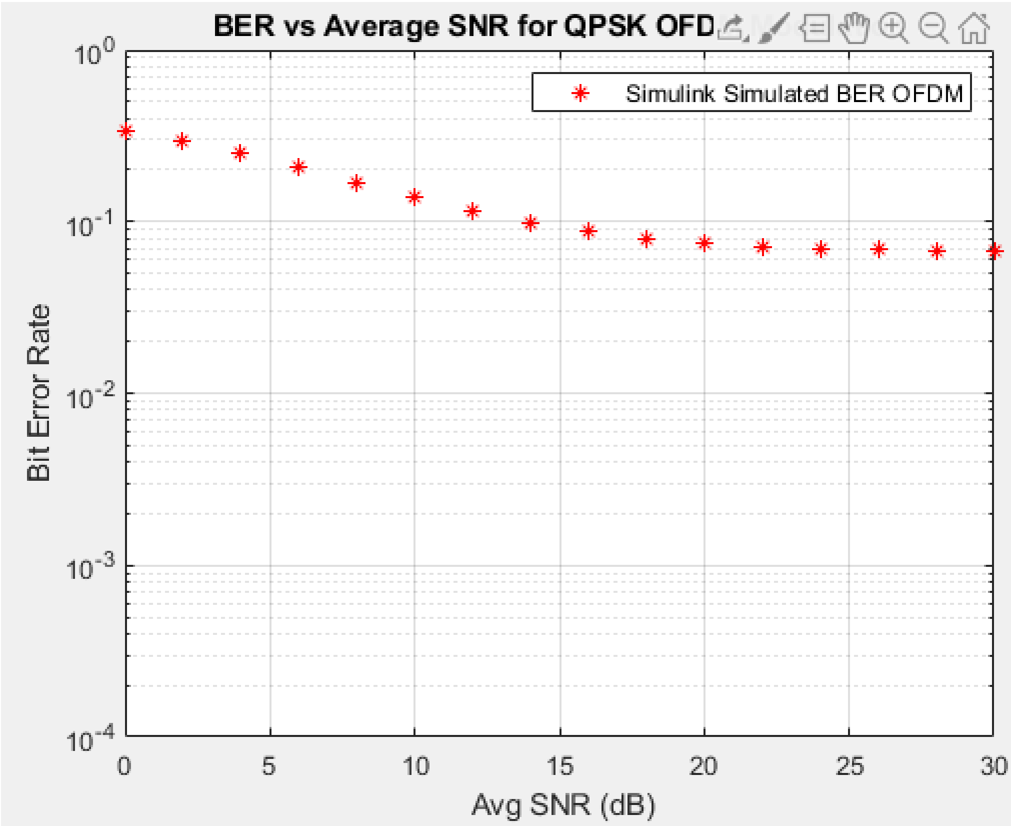
| **9.** | In lab procedure - Simulation for Scenario 2, add several more paths each with delay spread less than $1.8 \times 10^{-5}$ s, see if the BER changes. Explain why. | **2 Marks** |
| | **Answer:**<br>**As seen the BER is lower if we use 0 path gains for each of the added paths of delay spread less than $1.8 \times 10^{-5}$.**<br><br><br>Adding more paths with delay spread below the capacity actually reduces BER at higher SNR's. This is due to, intuitively, the additional paths providing greater likelihood of the correct symbol being detected. | |
| **10.** | In this OFDM system, if we do not use differential coding/encoding, how can we enable the channel estimation?<br>(Hint: Please read the last part of [Lecture 12].) | **2 Marks** |
| | **Answer:**<br>As explained in lecture 12, a certain number of the symbols can be used as 'pilot' symbols for channel estimation. So out of the 64 carriers some can be kept for channel estimation, reducing data transmission but removing the need for differential encoding/decoding. | |