Cover-Page/Mark-Setting for Project Assignment
ANALYSIS AND SIMULATION OF A QPSK SYSTEM
EQ2310 Digital Communications

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the text is easy to follow and the language correct	yes ☐	mostly ☐	sometimes ☐	no ☐
results and conclusions are clearly stated	yes ☐	most of them ☐	only a few ☐	no ☐
results are correct	yes ☐	most of them ☐	only a few ☐	no ☐
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the mathematics/theory is correct	yes ☐	mostly ☐	no ☐	hard to tell ☐
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Abstract

In this report, we investigate the influence of mutlitple parameters in a simulated QPSK radio communication channel. First, we show how the bit error rate varies with the signal-to-noise ratio in a perfectly synchronized environment.

Then we study how synchronization and phase estimation modify the BER, how theses algorithms behave under AWGN and how they are influenced by the training sequence.

Finally, we examine how a phase increase deteriorates the BER and how it can be reduced with differential demodulation.

1 Ideal Bit Error Rate (BER) performances

1.1 Exact expression

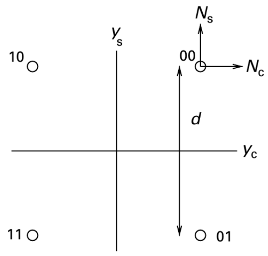


Figure 1: Gray coded bitmap from [1]

The exact expression of the BER can easily be derived as:

$$p_b = Q(\sqrt{\frac{2E_b}{N_0}}) \tag{1}$$

1.2 Simulation results and comparison

In order to simulate an environment with perfect synchronization, we forced the value of t_{samp} which equals to the samples coming from the guards bits and the delay caused by the matched filter. The phase offset is set to 0. As shown in Figure 2, the simulated values are very similar

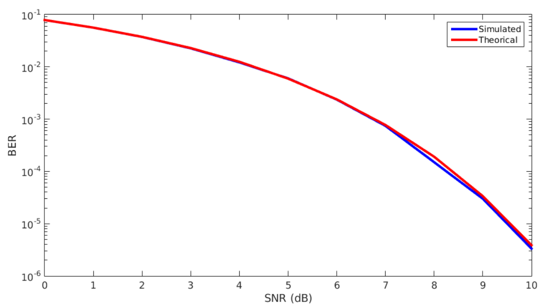


Figure 2: BER comparison

to the theorical ones. However, for very high SNR, the BER is so small that our testing set (here 300 blocks of 1000 data bits) is not large enough to be relevant.

2 Non-ideal synchronization and phase estimation

2.1 Influence of time and phase estimation on the BER

For a SNR of $5dB$, we created errors in synchronization and phase estimation to see how it modifies the BER.

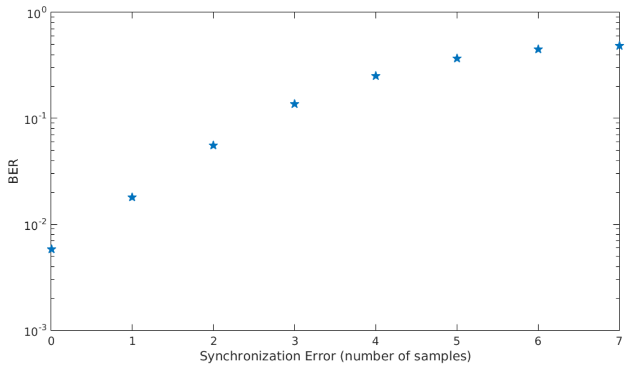


Figure 3: BER with synchronization errors

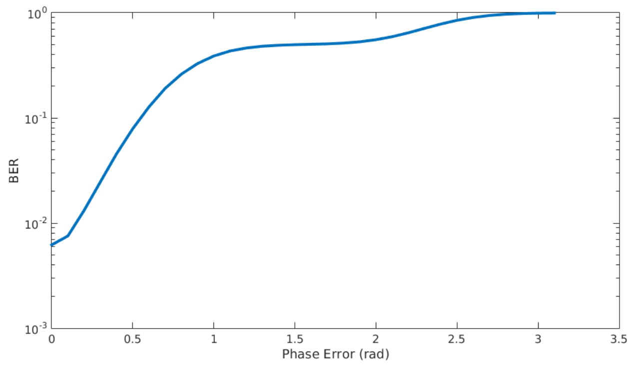
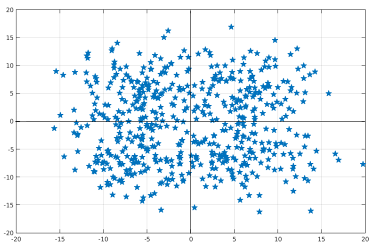


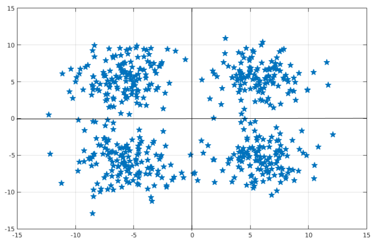
Figure 4: BER with phase errors

Figure 3 shows that one single error in the synchronization is catastrophic, the BER is multiplyed by 2. With a shift of 2 samples, the BER is 10 times higher.

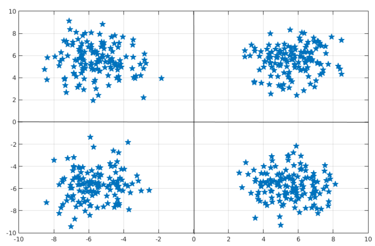
Figure 4 shows that phase estimation can greatly increase the BER. However, for small error (typically less than 0.1 rad) the loss is acceptable. To better understand the influence of a phase error on the BER, we can look at the constellation on Figure 5. We can see that when we increase the noise power, a lot of samples are detected near a border of a decision region. Therefore, a phase estimation error can easily move the sample in a wrong region thus creating detection errors.



(a) $SNR = 0$



(b) $SNR = 5$



(c) $SNR = 10$

Figure 5: Constellation Diagrams

2.2 Synchronization and phase estimation under AWGN

We implemented the recommanded synchronization algorithm (maximum cross-correlation between the filtered signal and a copy of the training sequence). Figure 6 shows that this algorithm is very resilient to the noise. For a reasonable SNR, errors never occur. However, one should take into account that we used a small window (around 6 symbols) centered on the real value. In a real environment we would need another sytem to position the window (like a power detector).

In order to estimate the phase, we searched for the angle that would minimize the norm of the difference between the rotated signal and the training sequence. We can see on Figure 7 that the estimate is quite sensible to noise. But, as stated before, a phase error of less than 0.1 rad has a resonable effect on the BER. It could be improved by using another algorithm, or a phase-locked loop.

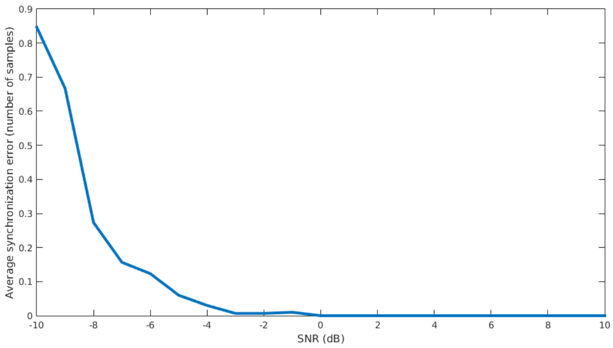


Figure 6: time estimation error

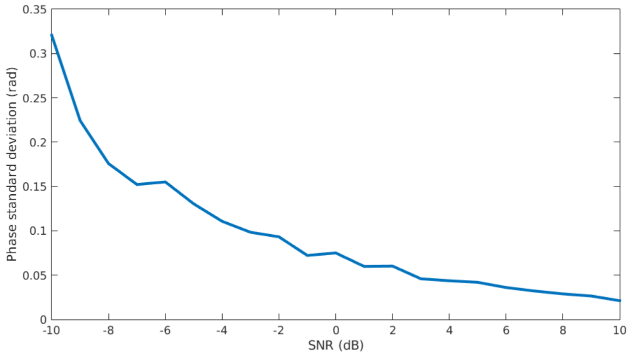


Figure 7: Phase estimation error

2.3 Influence of the training sequence

We computed the synchronization and phase estimation errors when changing the number of training bits at a fixed SNR of 0. Figure 8 shows that with a training sequence of more than 20 bits, we have less than 10% chance of having a synchronization error.

For the phase estimation, if we want less than 0.1 rad deviation, as we concluded before, we need at least 50 training bits. With a fixed sequence of 1000 data bits, this would corresponds to a 5% overhead.

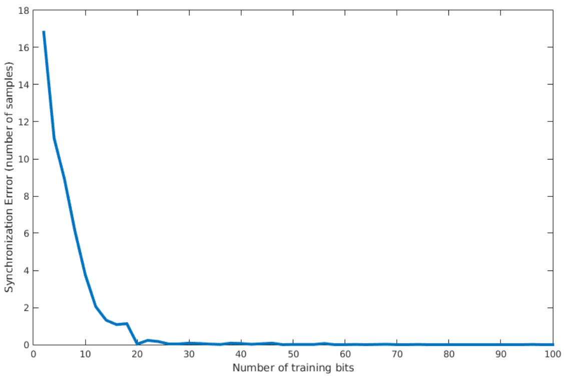


Figure 8: time estimation error

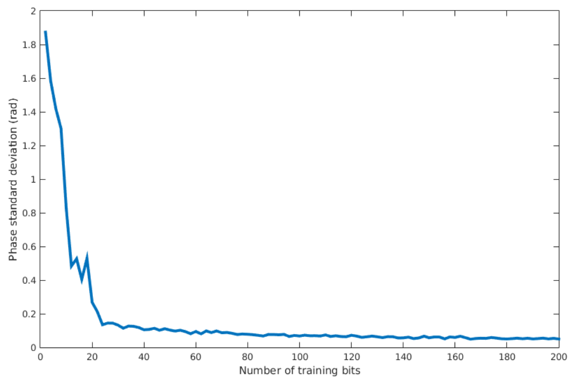
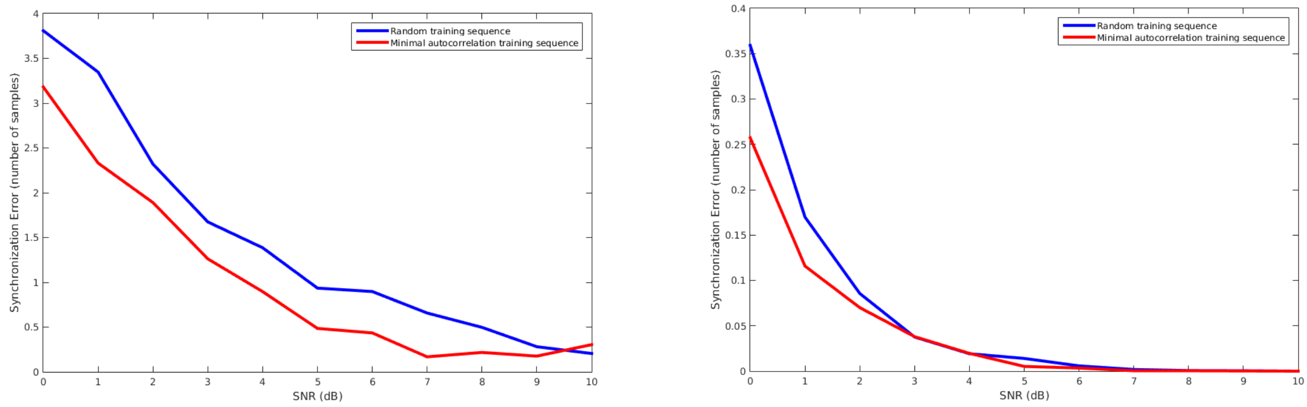


Figure 9: Phase estimation error

To improve the training sequence, we need to find one that has an autocorrelation function that is similar to a Dirac. To do this, we tested a number of random training sequences for which we computed its autocorrelation function. Then we chose the one that had the autocorrelation function most similar to a Dirac. Figure 10 shows that for a small training sequence it can improve a little the performances of the synchronization.



(a) 10 bits

(b) 20 bits

Figure 10: Difference between random and chosen training sequence

3 Differential modulation

3.1 Influence of a linear phase increase

First, we added a linear phase increase during the transmission of the block. This phase varies from 0 to $\frac{\pi}{4}$. It is a modelisation of a small frequency offset on the local oscillator. Here we chose 50 training bits in order to satisfy previous requirements. With this phase increase, we can expect the phase detection to select a correct phase for the training bits. However, as the phase increase along the data symbol sequence, more and more errors will occur. For the last symbol, the $\frac{\pi}{4}$ phase shift should result in a 50% probability of error a QPSK channel.

Figure 11 shows that such a phase increase greatly deteriorate the channel performances.

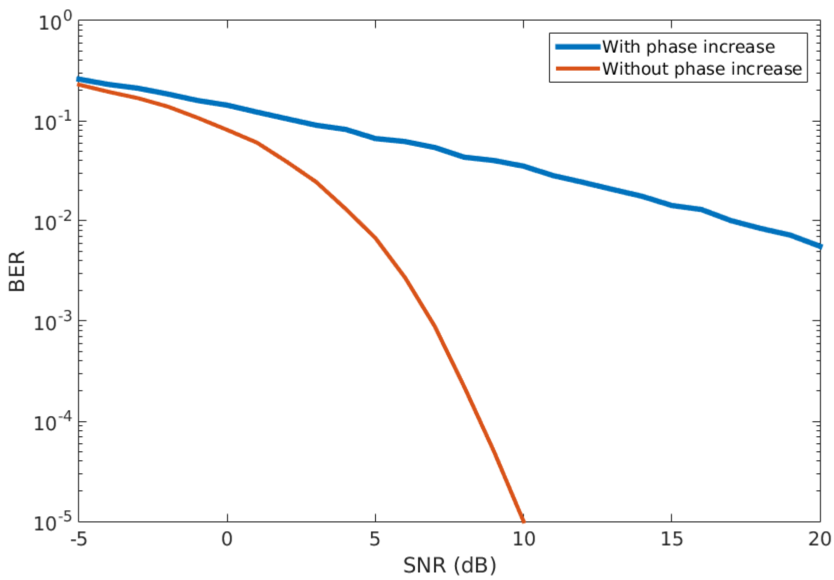


Figure 11: BER comparison under phase increase

3.2 Differential modulation/demodulation

In order to alleviate the phase increase effect, we can think to implement a differential modulator. Such a demodulation scheme would only rely on the phase shift from the previous symbol to detect the transmitted bits instead of the phase shit from the first symbol of the block. We can expect this to greatly alleviate the phase shift increase as in our model, this phase increase is slow so the phase is almost constant between two symbols.

The Figure 12 shows that, as expected, the differential modulation solves this issue for high SNR. We can also note that differential QPSK under phase increase gives worse BER than QPSK without the phase increase. It could still be intersting to solve this frequency offset in another way.

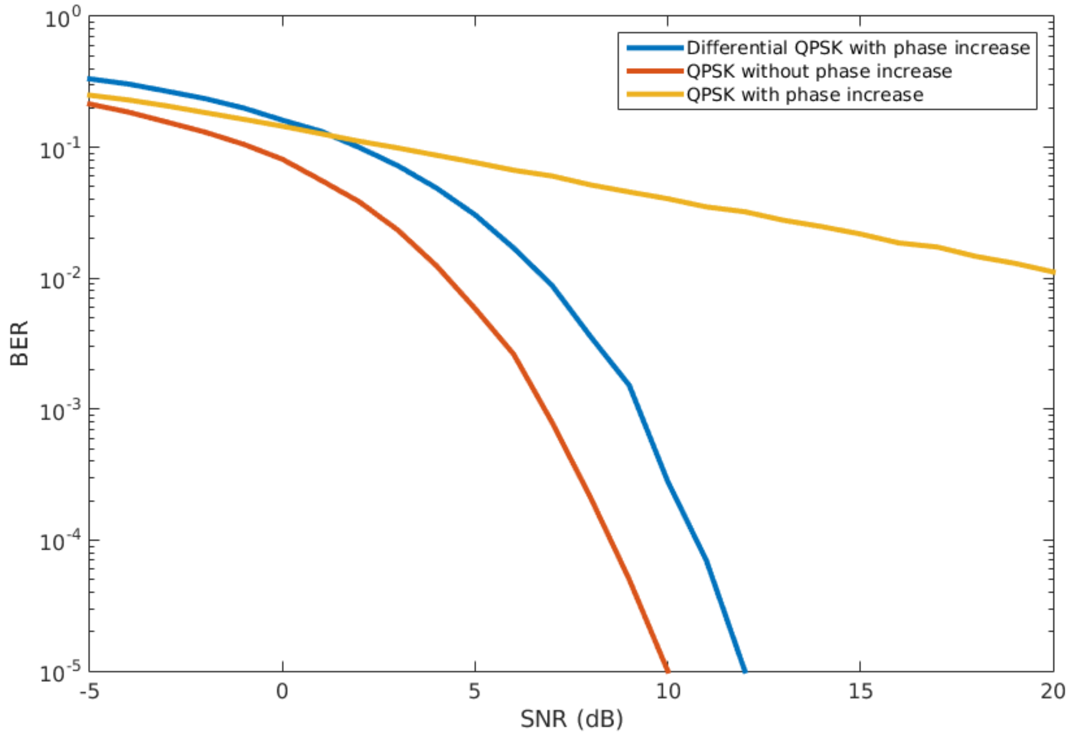


Figure 12: Differential modulation performances

Conclusion

To conclude this analysis and simulation of a QPSK signal, we can say that we were able to simulate a basic QPSK channel composed of a transmitter and a receiver. The results from these simulations allowed us to verify basic results of QPSK communication. Moreover, we dealed with synchronization and phase estimation which are common issues of wireless communication and we made basic test to see how differential modulation can solve some of this problems.

This study, however, only used a simple AWGN channel. Further research on QPSK communication should focus on modeling and simulating more complex channels with fading.

References

[1] Upamanyu Madhow. *Fundamentals of Digital Communications*. Cambridge Univeristy Press, 2008.