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**Technical University of Crete**  
**School of Electrical and Computer Engineering**  
Course: **Wireless Communications 2022-2023**

Exercise 1 (100/400)  
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1 We create a flat fading complex channel utilizing the AR-1 model.

$$h[k] = b \cdot h[k-1] + e[k], \quad k = 1, \dots, N$$

where,

$$h[1] = 0$$

$$0 < b < 1$$

$$R_h[0] := E[|h[k]|^2] = 1$$

$$e[k] \text{ i.i.d } \mathcal{CN}(0, \sigma_e^2)$$

Calculation of  $\sigma_e^2$ :

$$E[|h[k]|^2] = R_h[0] \iff$$

$$E[|bh[k-1] + e[k]|^2] = R_h[0] \iff$$

$$E[|bh[k-1]|^2] + E[|e[k]|^2] \geq R_h[0] \iff$$

$$b^2 R_h[0] + \sigma_e^2 \geq R_h[0] \iff$$

$$\sigma_e^2 \geq R_h[0](1 - b^2)$$

Therefore we can choose  $\sigma_e^2 = R_h[0](1 - b^2)$

In figures 1 and 2 is evident that for  $b \approx 1$  the channel takes longer to become stationary and therefore if a mean is taken in a small interval it will be inaccurate. For  $b \ll 1$  the mean is observable even in smaller intervals even in the first samples.

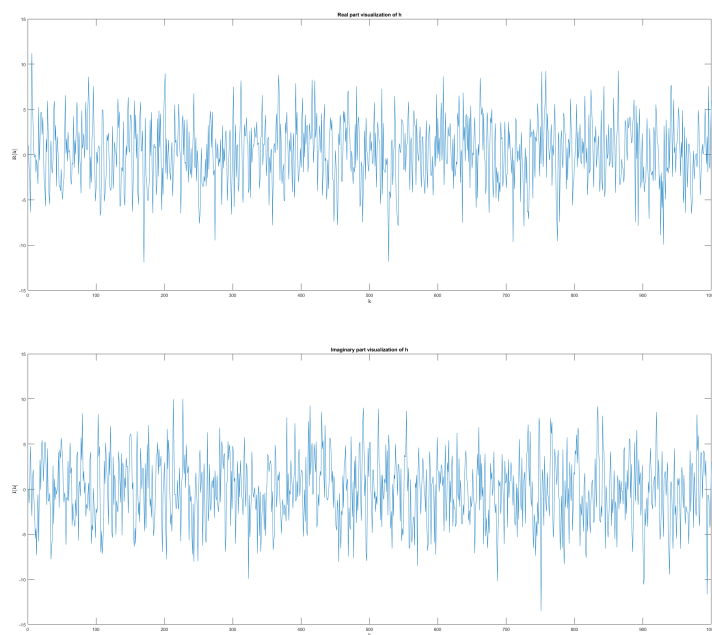


Figure 1:  $b \ll 1$

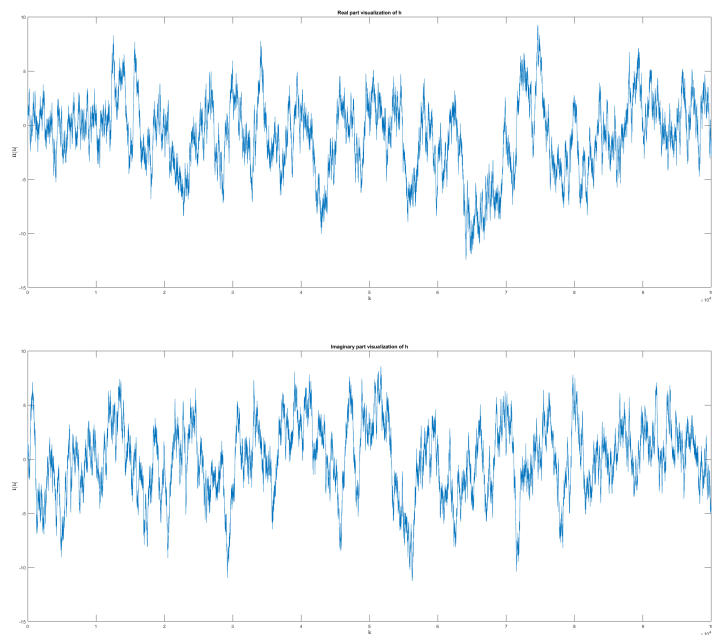


Figure 2:  $b \approx 1$

**3** Calculating the mean received snr:

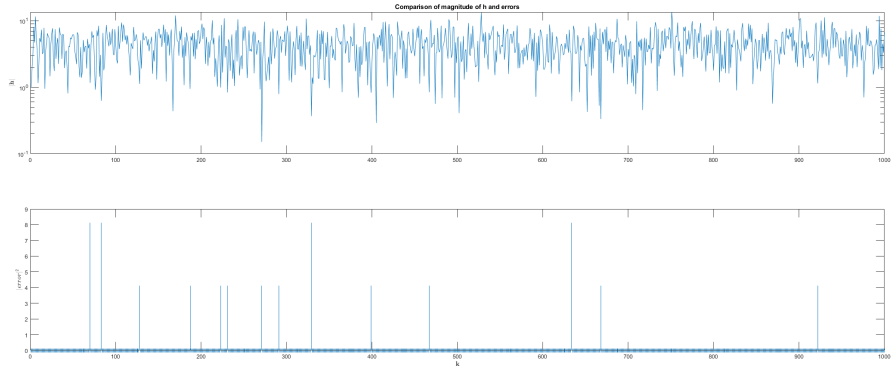
$$SNR = \frac{E[|h[k]s[k]|^2]}{E[|n[k]|^2]} = \frac{E[|h[k]|^2]E[|s[k]|^2]}{E[|n[k]|^2]} = E[|s[k]|^2] = R_h[0]E[|s[k]|^2] = 2R_h[0]$$

Therefore  $SNR_{db} = 10\log_{10}2R_h[0]$

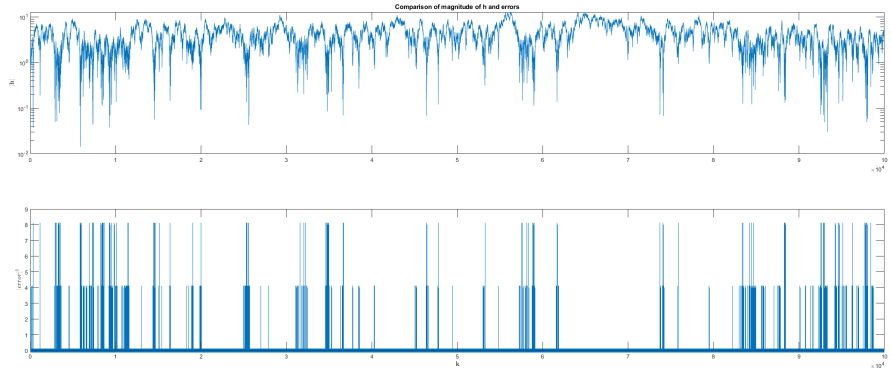
**4** Using the Maximum Likelihood (ML) method we arrive at the following rule:

$$\max_{x \in 4-QAM} f_{Y|X=x}(y) = \min_{x \in 4-QAM} |y - hx|^2$$

Therefore we choose the  $x \in 4-QAM$  closest to  $r[k]$



(a)  $b \ll 1$



(b)  $b \approx 1$

Figure 3:  $SNR_{db} \approx 17$

- 5 We observe that for both cases of  $b$  and for  $SNR_{db} > 15$  that the errors are grouped around the points that the channel has the lowest magnitudes.

- 6 From (figure 3) the channel seems to create more "prominent" lows regarding its magnitudes for  $b \approx 1$ , (because in this case the channel "takes" longer to become stationary). Therefore the errors are more grouped together.

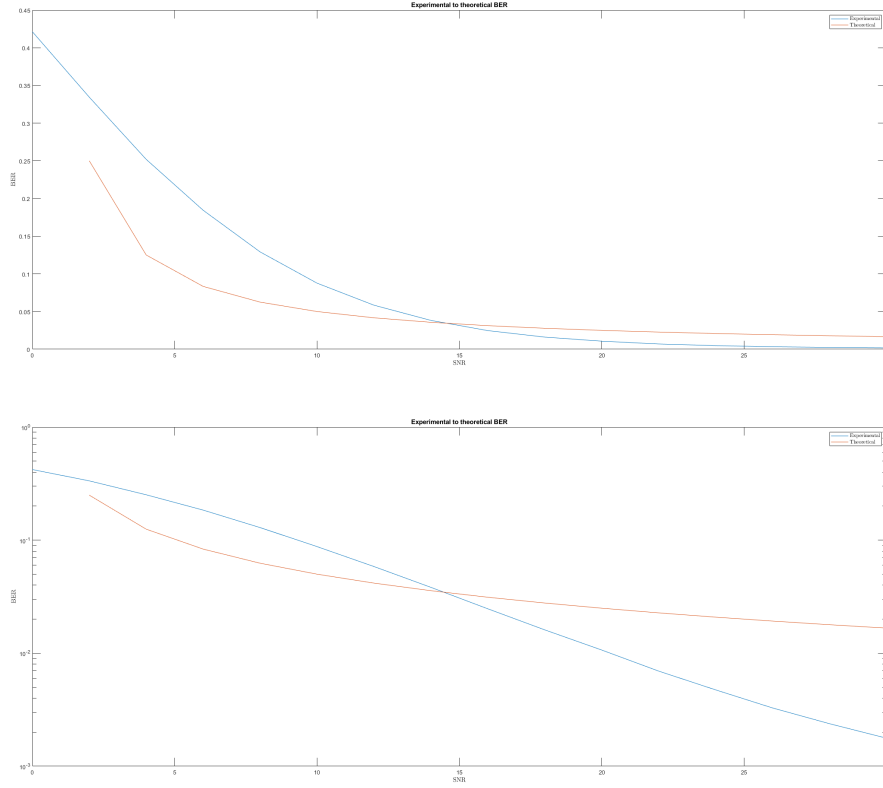


Figure 4:  $b \ll 1$

- 7 By observing the regular and semi-log scale plots in (figure 4) we can see that the BER decreases significantly when increasing the SNR.

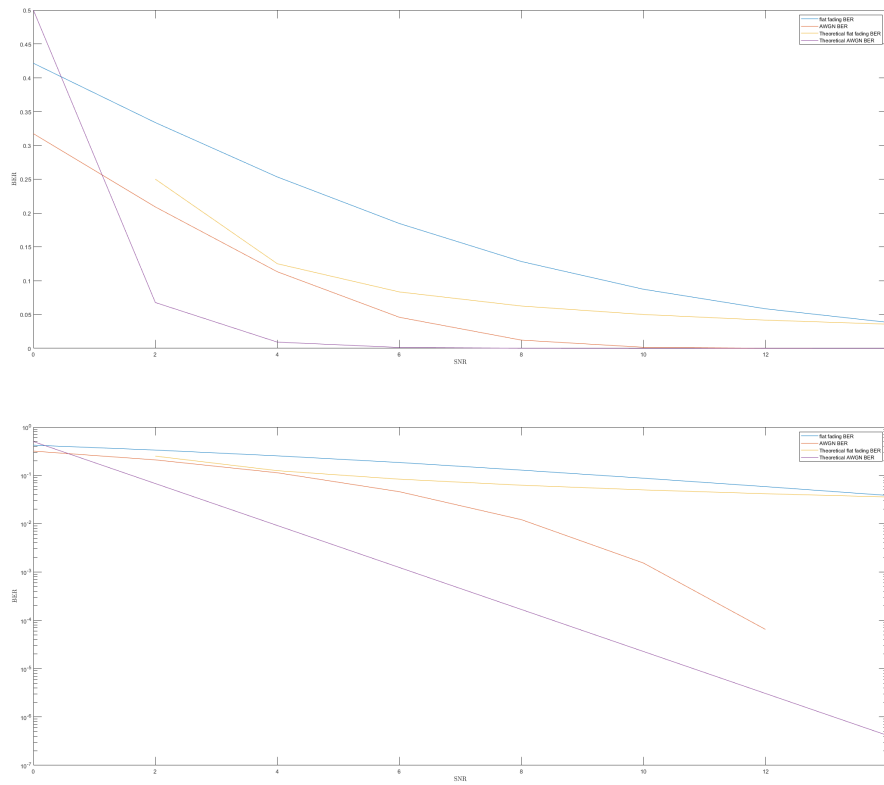


Figure 5:  $b \ll 1$

8 Again in every case BER decreases for higher SNRs and, as expected the AWGN model performs better than the flat fading since it does not account for the fading.

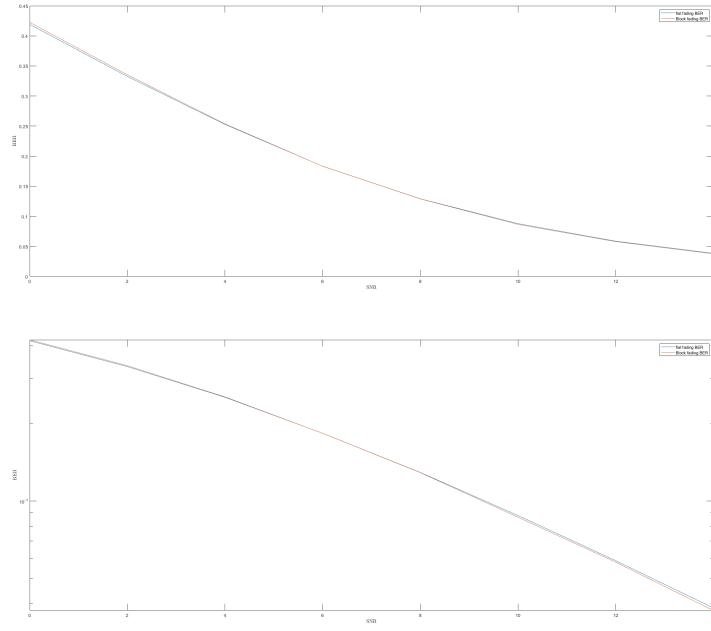


Figure 6:  $b \ll 1$

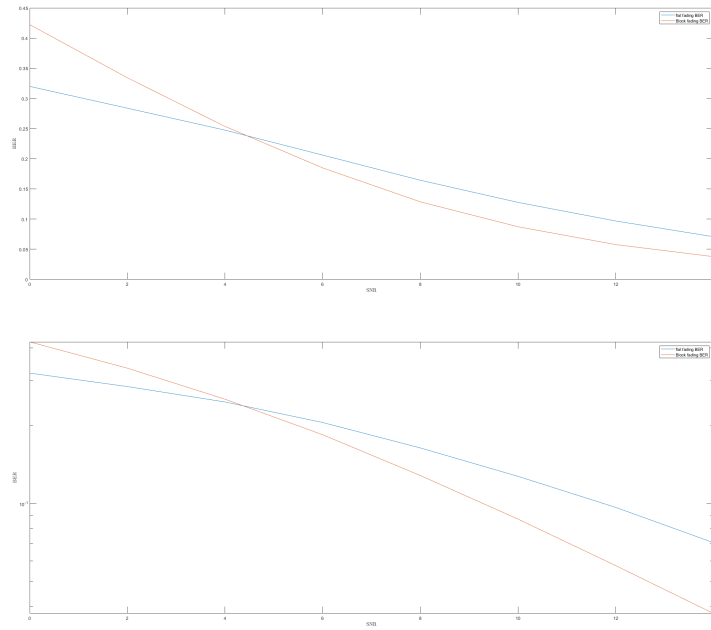


Figure 7:  $b \approx 1$  for first samples of  $h$

9 According to figure 6, we discern that when  $b \ll 1$  and therefore the flat fading

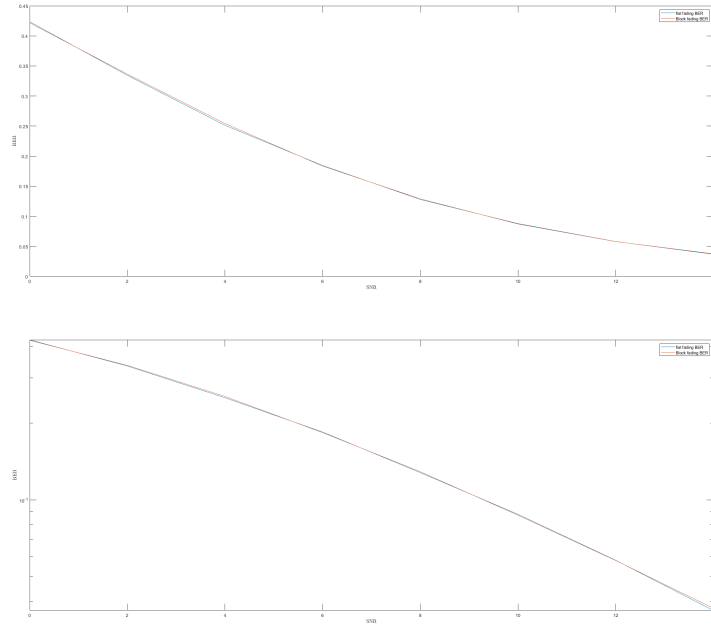


Figure 8:  $b \approx 1$  for later samples of  $h$

channel is stationary, the two channels have comparable performance.

By observing figures 7 and 8 for  $b \approx 1$ , if the flat fading channel has become stationary yet the block fading one provides better performance for higher snrs. Although if the channel has become stationary the performances are again comparable.