EE-442 — WIRELESS RECEIVERS: ALGORITHMS AND ARCHITECTURES

Final Project

Acoustic OFDM Transceiver

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Introduction

Our problem:

- We have seen that **multipath channel distortion** were hard to handle using single carriers, as the delay spread was larger than the symbol duration, and the coherence bandwidth smaller than the signal bandwidth

Our solution:

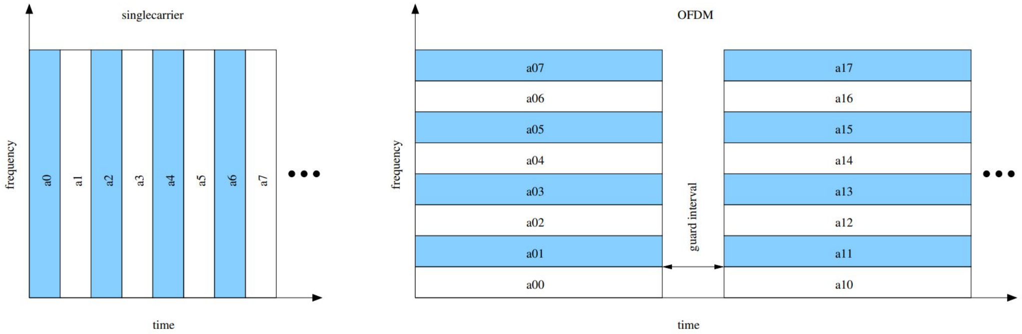
- Working with frequency-division multiplexing (FDM) makes it easier. We **“reallocate” our resources** by converting our high-frequency wideband signal into multiple parallel lower rate data streams of narrower bandwidth.
- That way, the coherence bandwidth is larger than our subcarriers bandwidth, and the delay spread smaller than the symbol duration, which allows **limiting ISI**

What is OFDM?

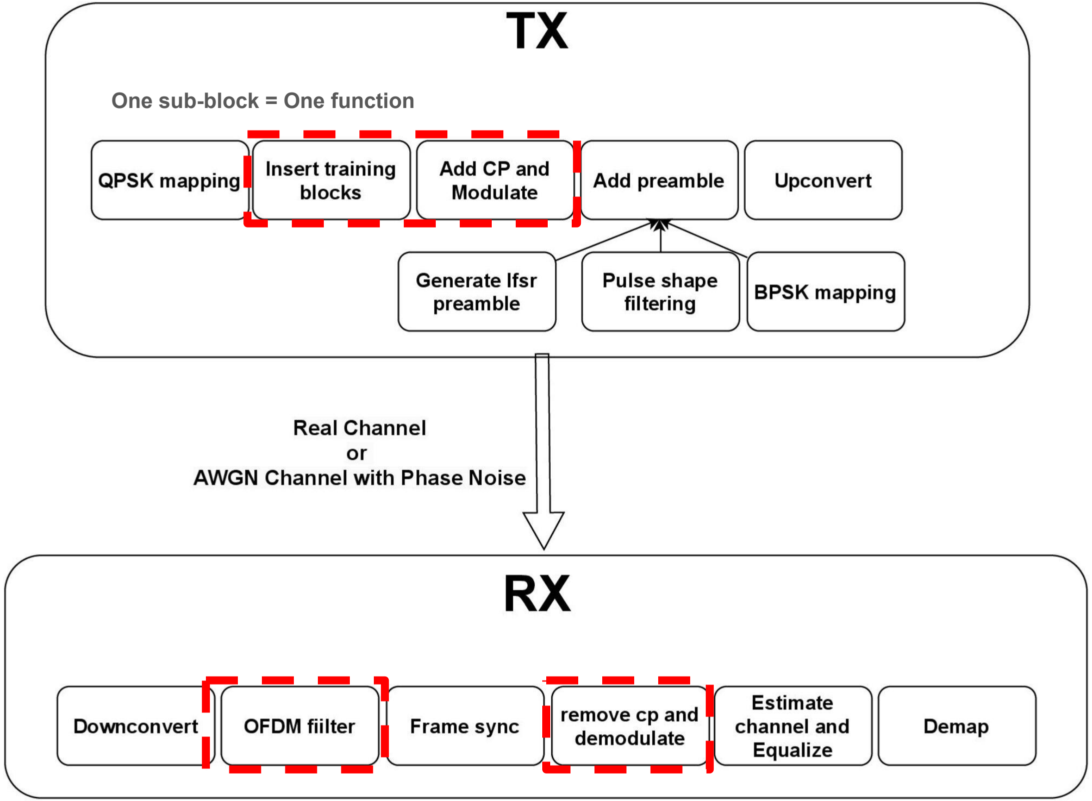
- OFDM is a type of FDM that allows to avoid inter-symbol interference by using **orthogonal sub-carriers**
- OFDM allows for a **better bandwidth efficiency** and for less interference.

Our Goal:

- Implementing an OFDM Transceiver for acoustic transmission



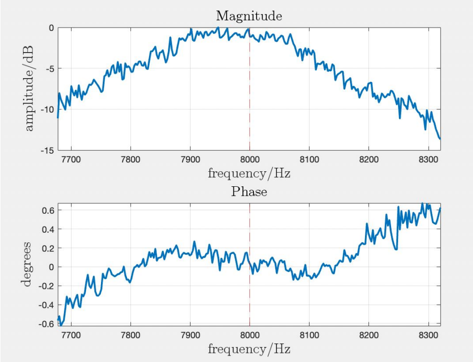
SETUP



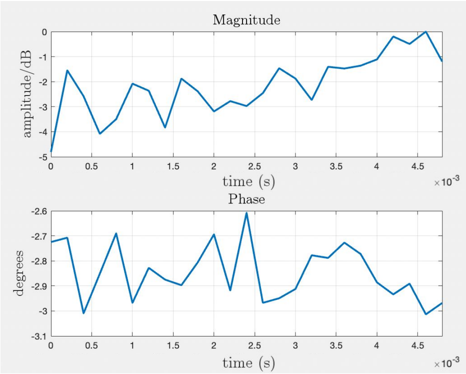
+ **Plotting functions, Experiment scripts and config files**

Question 2: Evolution of the channel, delay spread, CP length and system efficiency:

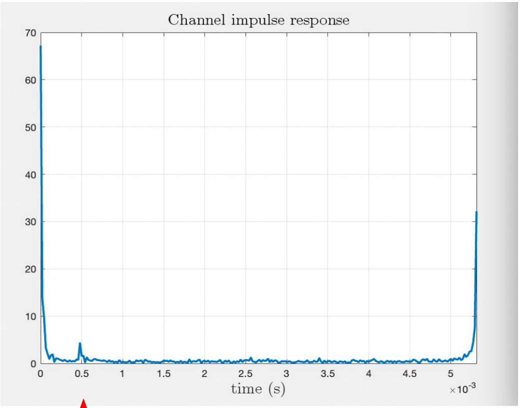
Channel (magnitude and phase) against frequency, beginning of the transmission:

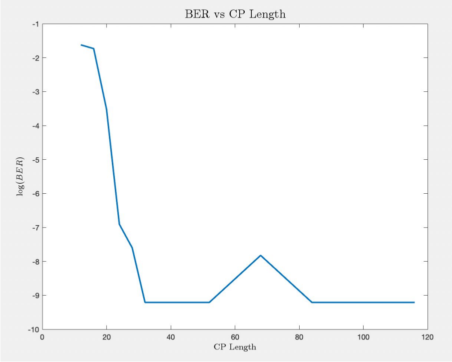


Evolution of the magnitude and phase over time:



Estimation of the delay spread (inverse FFT of the channel):





Efficiency with "default" CP length of $N_G = N/2 = 128$:

$$\eta = \frac{N}{N + N_G} = \frac{2}{3}$$

Power Delay $\delta = 0.5 \cdot 10^{-3} ms$
sampling frequency $f_s = 48kHz$
Optimal CP length $\hat{N_G} = \delta \cdot f_s^{-1} = 24$

A CP length of 24 should be enough to avoid most of the ISI !

$$\hat{\eta} = \frac{N}{N + \hat{N_G}} = \frac{256}{256 + 24} \approx 0.91$$

We get a 36% increase in efficiency (from 0.67 to 0.91) **and keep a low BER** = 0.001 (against BER = 0.0001 when using a CP length of 128)

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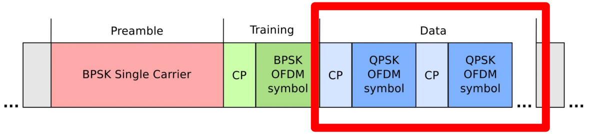
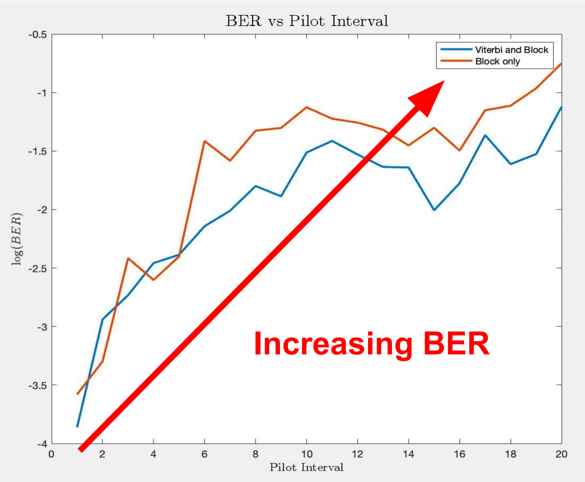
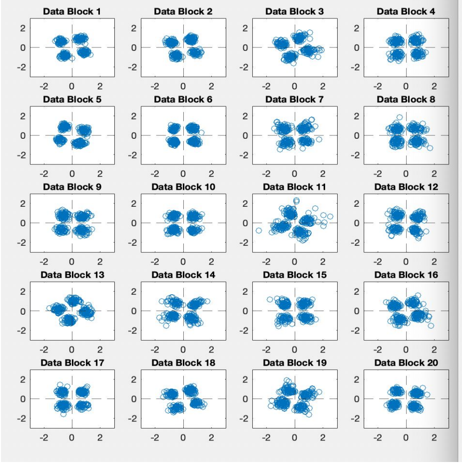
Pilot Interval (Question 3)

We measured the **BER** as we increased the number of data blocks between each training block



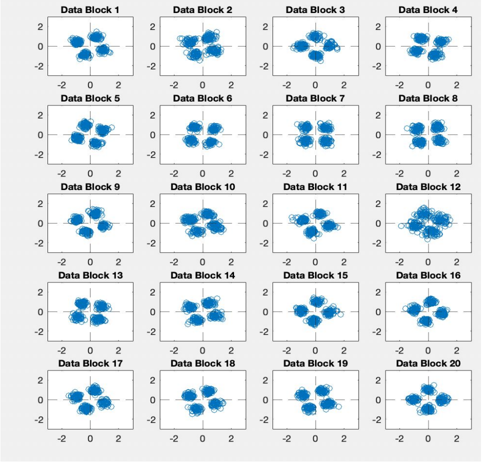


Symbols received for each data block



Training between every block

Symbols received for each data block



training between every 20 blocks

- Sending more data blocks between training blocks increases the BER.
- The phase offset is less often corrected (Training per 20 data blocks).
- As Viterbi-Viterbi corrects phase offset for every symbol, the distortion is mitigated, but the BER still increases as there is less block update that give initial phase offset estimate

Experiments on Frequency Spacing

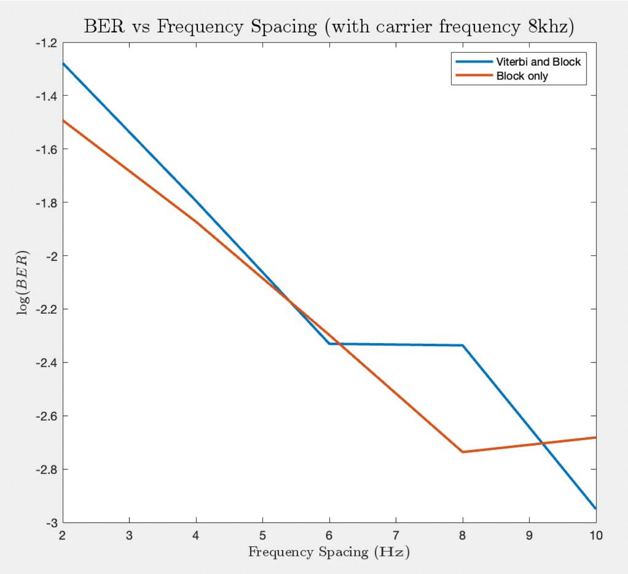
In this experiment, we compared the BER at different frequency spacing.

Theory

With bigger frequency spacing, the frequency guard band is bigger, which reduces intercarrier interference.

Observation

We observe the plot on the right using both phase correction method. We observe a linear-like decrease in BER when increasing frequency spacing.



Carrier Spacing improves BER, but widens signal spectrum!

EPFL

Experiments on Different Channel

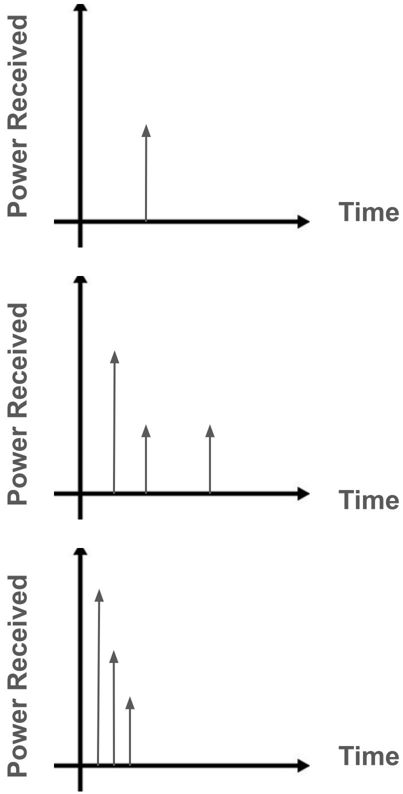
To observe how our transmit signal performs in different channel, we conducted three experiments to observe channel delays in each case.

Theory
Multipath channel due to reflection should be more obvious in indoor environments where lots of echos are observed.

Experimental Setups
- Outdoor (By EPFL Sign)
- Indoor (Rolex Center Rooms)
- Tight space (Figure 3)

Delay Spread Profile changes a lot!

Theory



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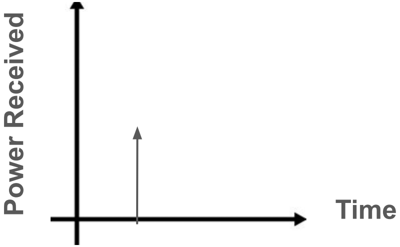
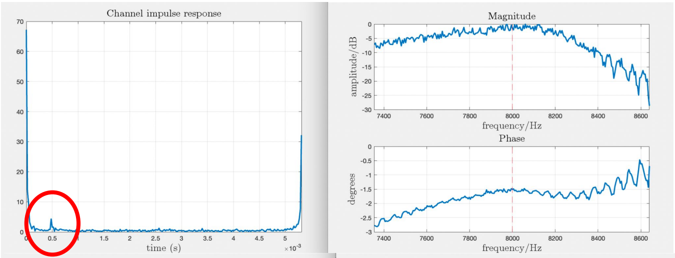
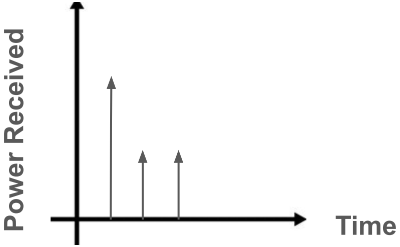
Experiments on Different Channel

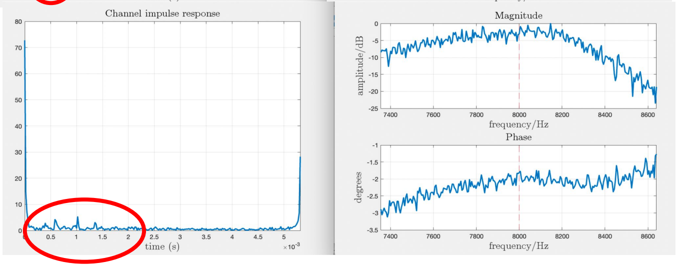
Theory

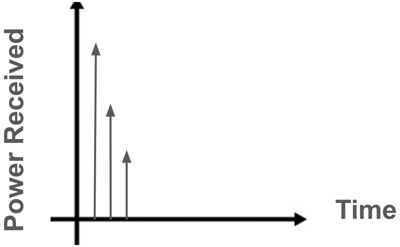
Result

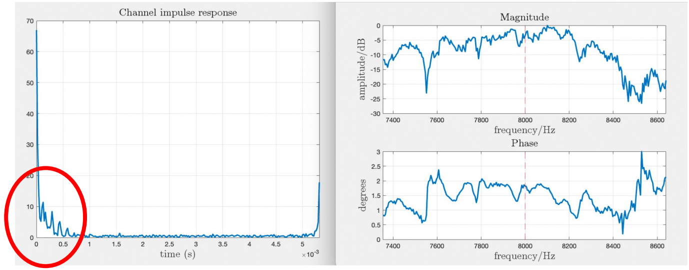












Experiments with Carrier Frequency

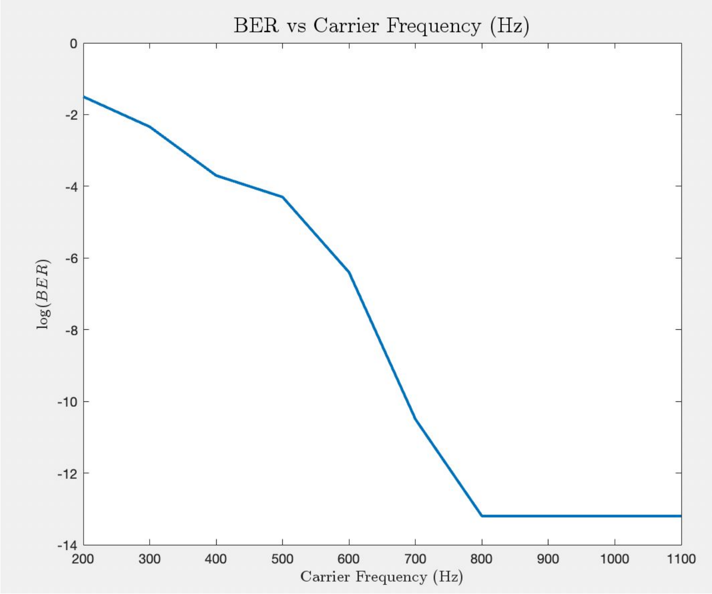
In this experiment, we compared the BER at different carrier frequency.

Theory

With lower frequency spacing, due to the nature of low frequency signals, our signal is easily affected from background signals from everywhere.

Observation

We observe a decrease in BER when increasing carrier frequency (from the 200 Hz to 800 Hz range). However, we do not observe any significant variation of BER at high frequency (5kHz to 8kHz)



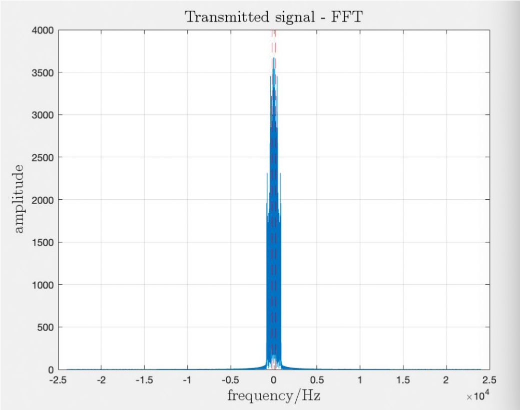
Low carrier frequency is detrimental to BER!

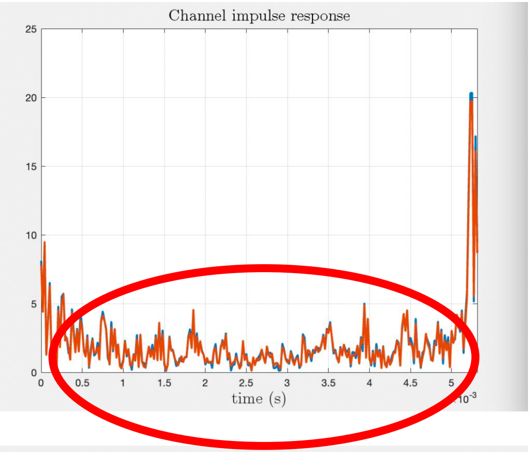
Key Learnings and Encountered Difficulties

- **CP length and trade-off between BER and efficiency.**
  - Increasing the CP length gives a lower BER, but decreases the efficiency of the system
  - Choosing the right CP length allowed us to increase the efficiency by 36%, while keeping the BER small.
- **Data block length and trade-off between phase offset correction and transmission efficiency.**
  - Fewer data symbols between training blocks helps improve offset, but decreases the transmission efficiency.
- **Frequency spacing.**
  - We did observe a substantial decrease in BER as we increased the spacing.
  - However, increasing the spacing occupies more bandwidth, which non-ideal in real life conditions.
- **Carrier Frequency**
  - Low carrier frequency (200-800 Hz) is detrimental to BER due to signal interference.
  - Transmission at this range (200-800 Hz) should be dealt with caution.
- **Choice of the CP length.**
  - We had to drastically change our experiment environment to observe changes in the power delay profile.
  - Taking into account the channel characteristics (e.g., Power delay profile) is important to set the right CP length

Appendix: Experiments with Carrier Frequency

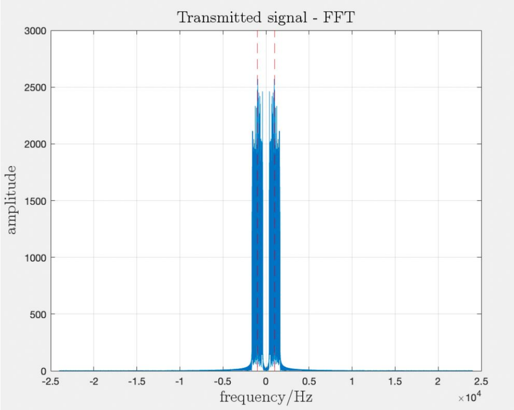
200 Hz

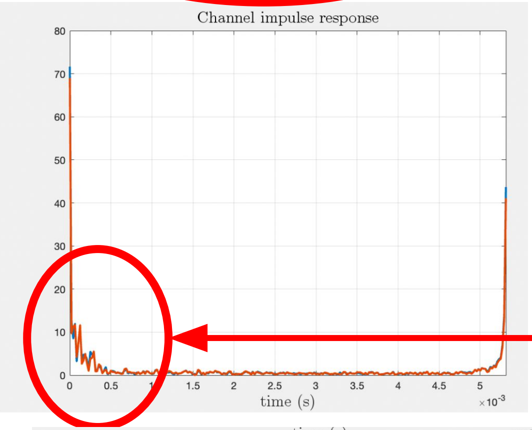




Lots of interference

800 Hz





Much less interference

time (s) ×10^-3