OFDM Project

Wireless receivers: algorithms and architectures

Group 4

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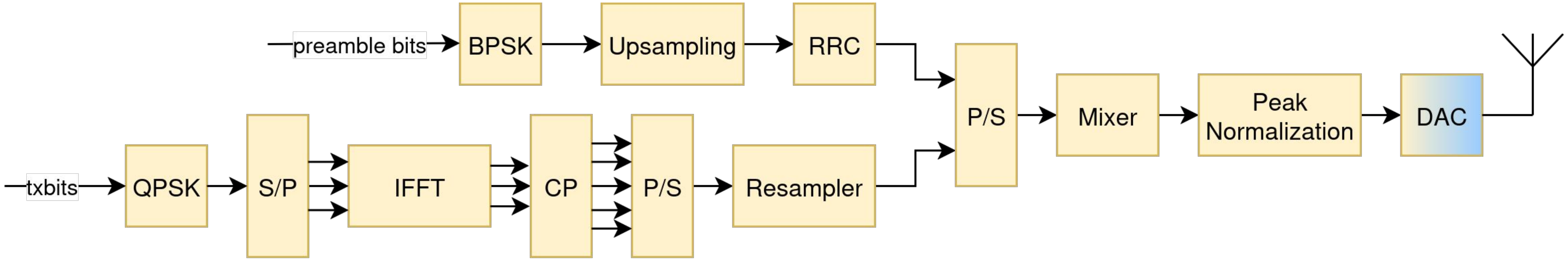
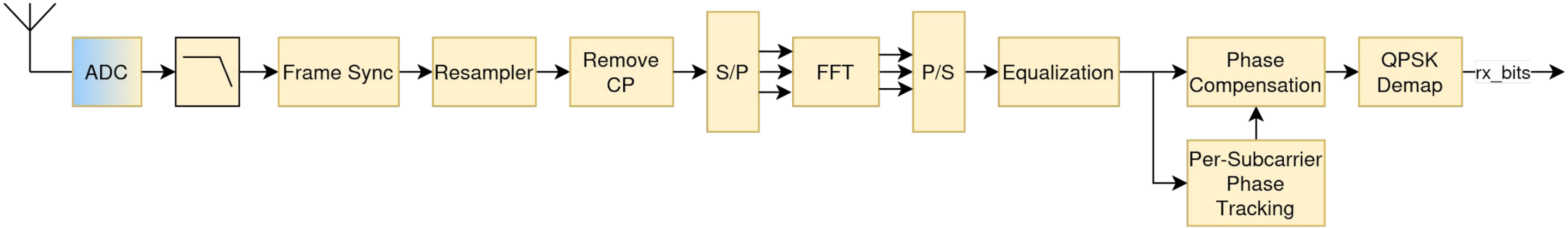
Outline

1. System Overview
2. Baseline System
3. Phase Tracking
4. Channel Characterization
5. Spectral Efficiency
6. Real Acoustic Transmission
7. Comb Type Training
8. Image Transmission
9. Channel Measurements
10. Conclusion

1. System Overview - Transmitter



1. System Overview - Receiver

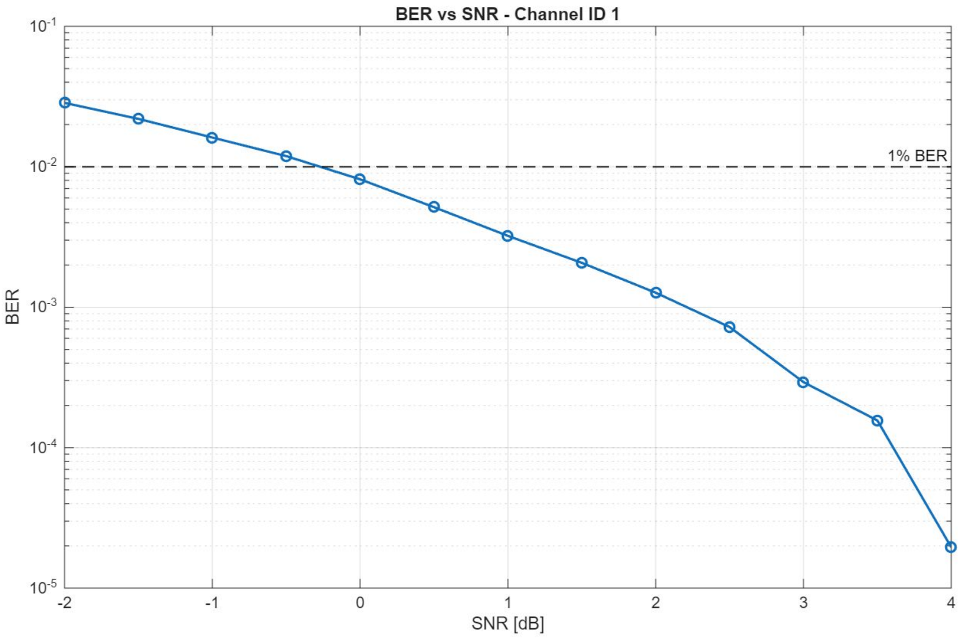


2. Baseline System

Task1 :

- default parameters -> results
- verification that the system works in a simple channel -> channel 1
- up to which BER can the system reach BER < 1% with default configuration = 0 dB
- We show results for a transceiver set up where we do not correct for any phase shifts. The first channel is just a AWGN channel and therefore we can easily get good results even with low SNRs.

2. Baseline System



OFDM Receiver Implementation

- Single-carrier **preamble** Frame Synchronization
- Channel estimation performed with one **training symbol**.
- Channel correction applied.

Parameter	Value
Channel Emulator	ID 1
Carrier Frequency	8 kHz
Sampling Rate	48 kHz
OFDM Bandwidth	2 kHz
# Subcarriers	512
CP Length	256 Samples
Modulation	QPSK

3. Phase Tracking

- verification using channel 2
- why does phase tracking fail after a certain number of OFDM symbols?
- The second channel appears to have an important effect on the phase of the channel, during our tests we foun out how the Viterbi-Viterbi estimation algorithm worked best by correcting the symbols with the direct estimation and without the actual phase tracking. More on subsequent channel estimations. Nevertheless the estimating algorithm fails after circa 36 - 35 ofdm symbols depending on the SNR, because the error on the phase grows quadratically as we will see.

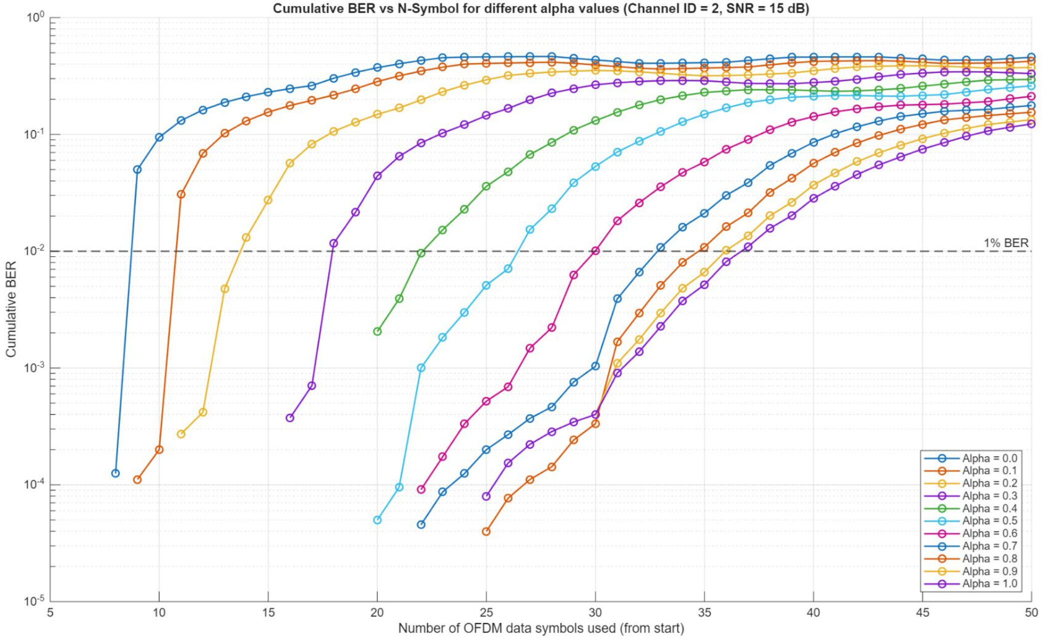
3. Phase Tracking

Implementation of the **Viterbi-Viterbi** phase estimation algorithm.

Phase tracking is performed by filtering the current estimate with the previous value.

The system fails after **36** OFDM symbols.

$$\theta[n] = \alpha \cdot \hat{\theta}[n] + (1 - \alpha) \cdot \theta[n-1]$$



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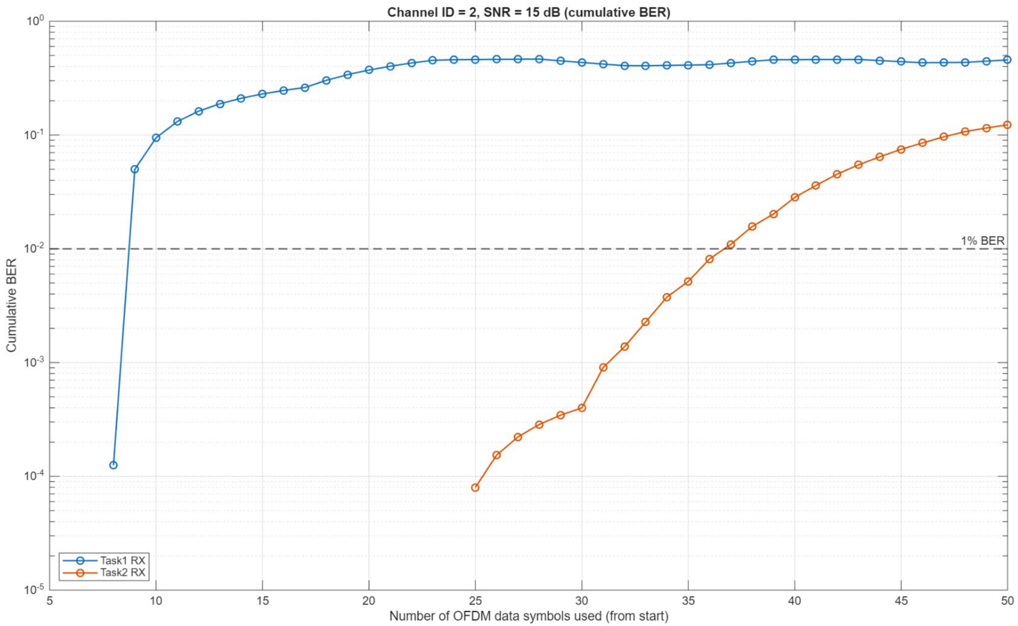


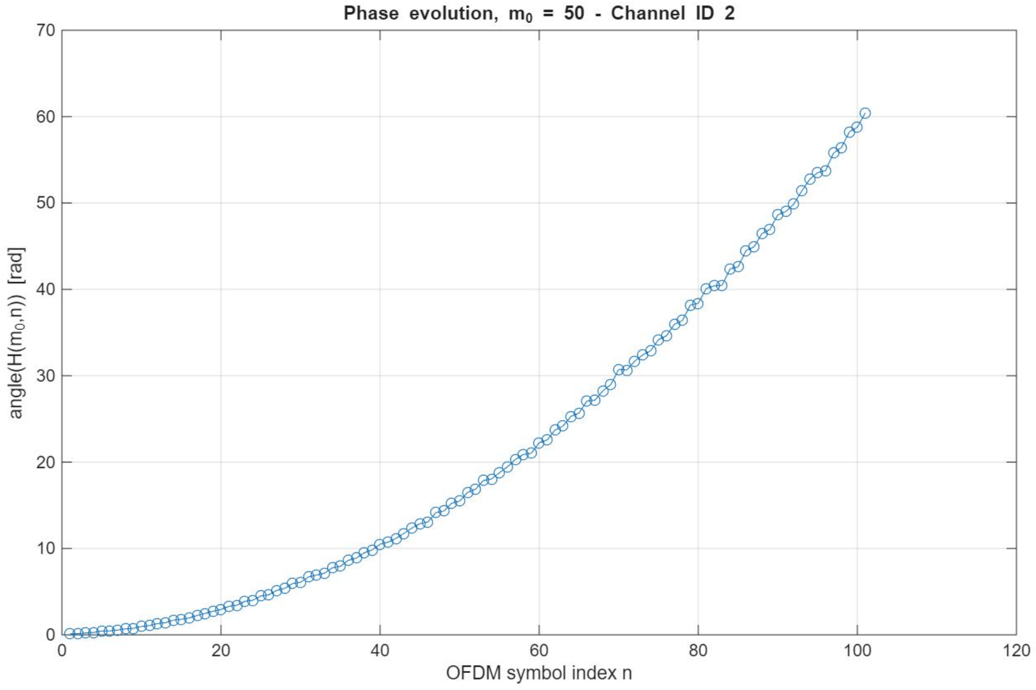
4. Channel Characterization

- channel 2 to 5 have each one or two special channel characteristics -> identify and describe them
- using following plots:
    - pdp
    - frequency response
    - channel evolution over time
    - etc.

4. Channel Characterization - ID 2

Main characteristics:

- Large, **non-linear** phase shifts causes phase ambiguity and unwrapping errors.
- Strong initial multipath with rapid PDP decay, typical of a dominant line-of-sight channel with weak reflections.
- CP length is well scaled.



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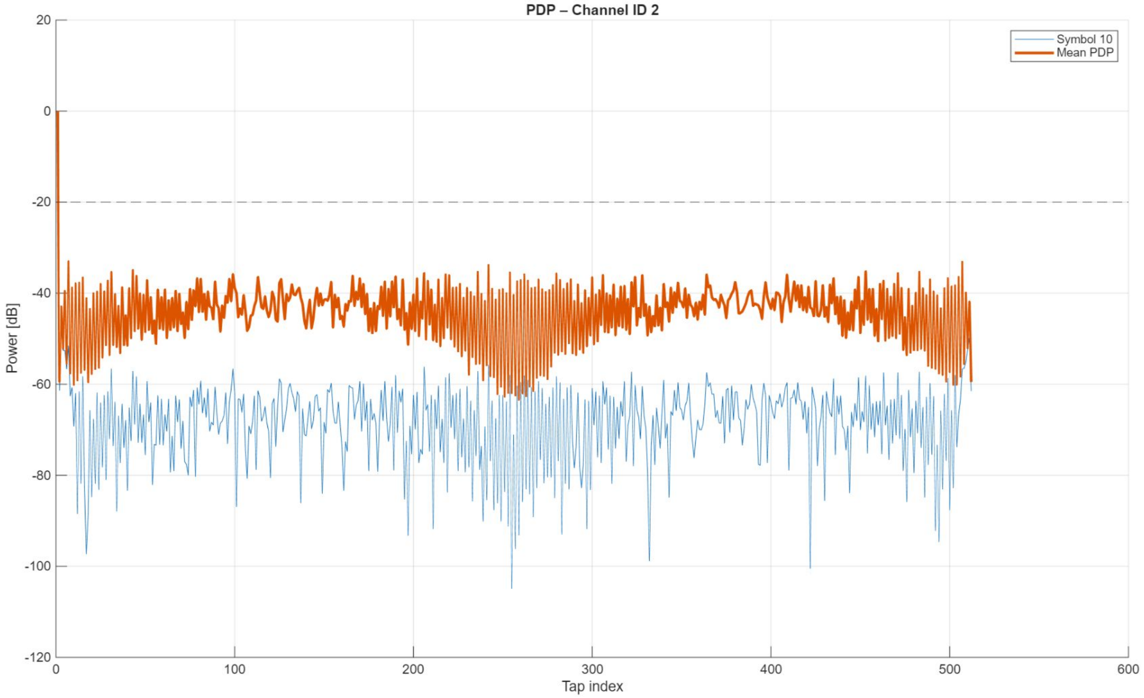
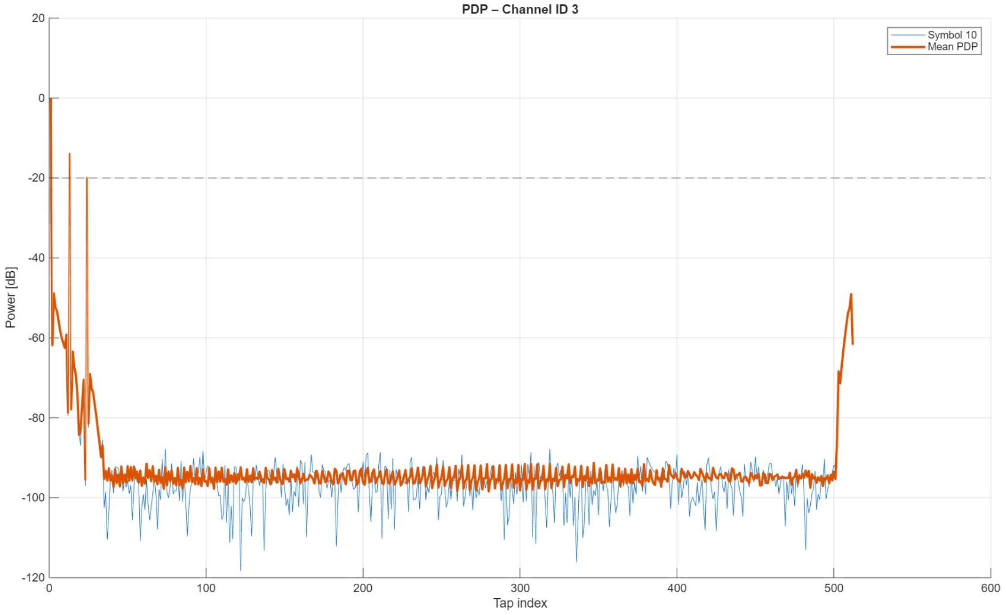


4. Channel Characterization - ID 3

Main characteristics:

- Multiple paths with three main peaks early in the PDP, but with a **short delay spread**.
- More **phase-stable** with less phase distortion.
- The **frequency-selective** response shows significant attenuation on certain subcarriers due to multipath fading. The oscillatory behavior suggests interference patterns.



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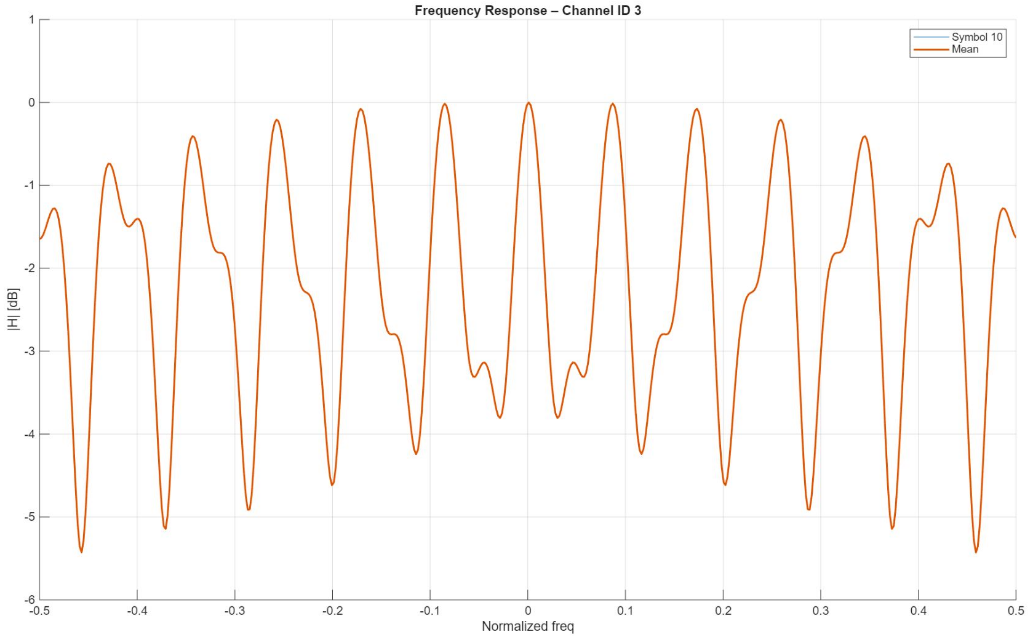
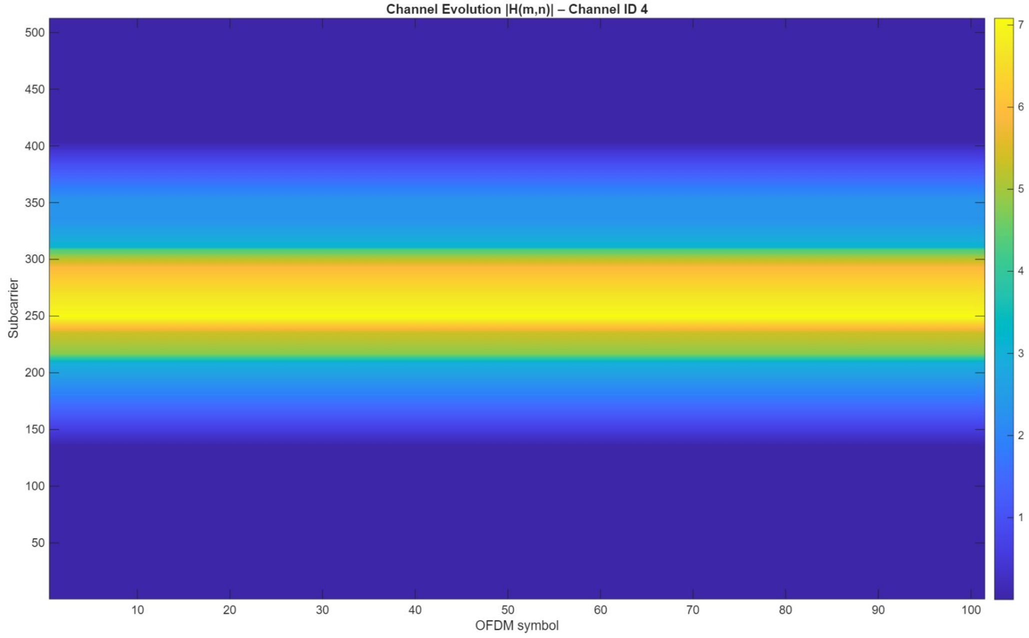


4. Channel Characterization - ID 4

Main characteristics:

- Sharp frequency response with significant attenuation, indicating **narrow bandwidth** and frequency-selective fading.
- Stable phase evolution with small, consistent shifts, indicating **phase stability** and easier phase tracking.



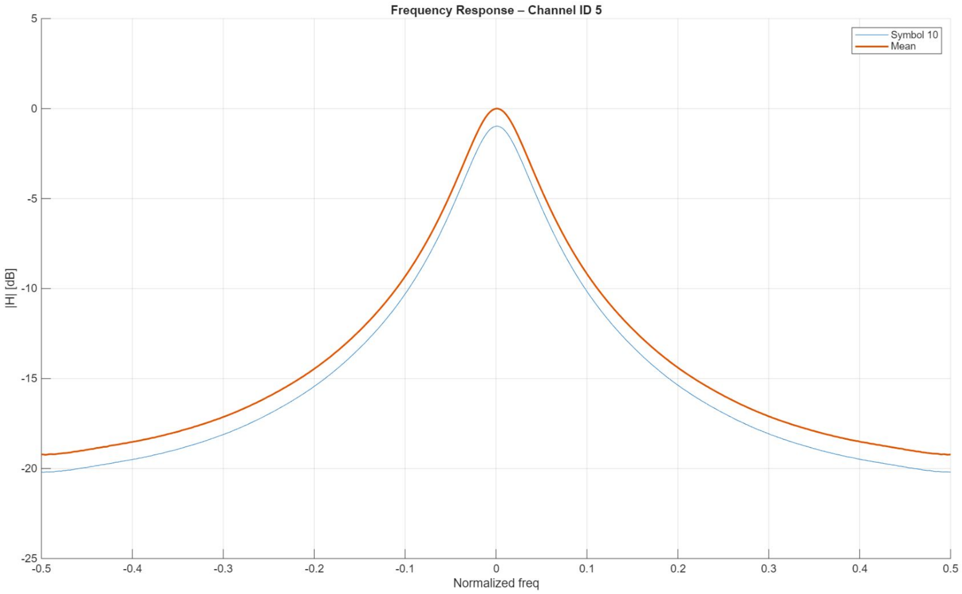
4. Channel Characterization - ID 5

Main characteristics:

- Narrowband response with a sharp peak, indicating **frequency-selective** behavior.

- Strong initial peak with long-lasting weak multipath, suggesting both direct and reflected paths.

- Phase Evolution: Frequent small phase shifts, indicating dynamic changes in phase due to multipath and selective fading.



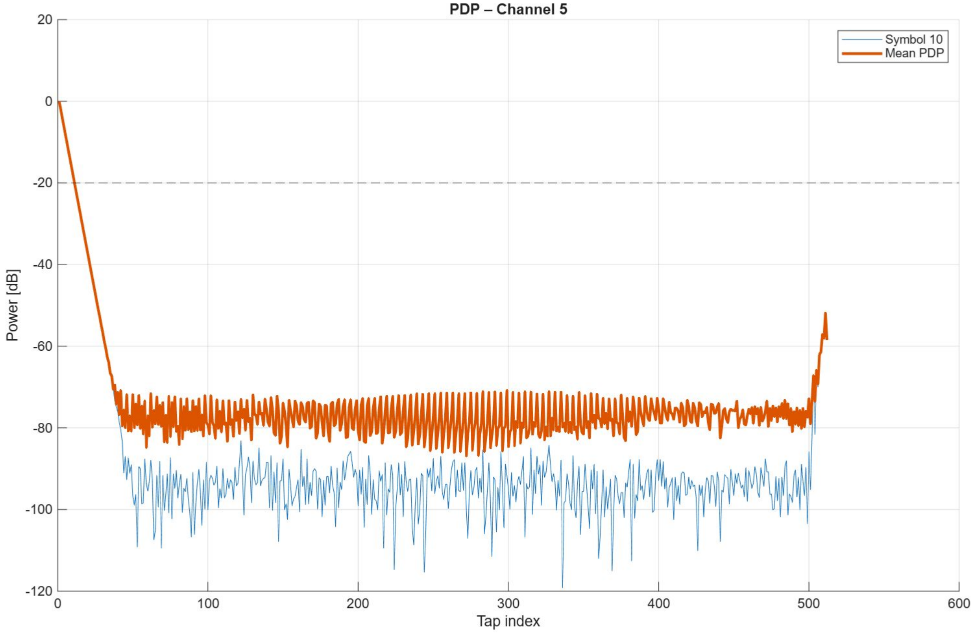
4. Channel Characterization - ID 5

Main characteristics:

- Narrowband response with a sharp peak, indicating **frequency-selective** behavior.

- Strong initial peak with long-lasting weak multipath, suggesting both direct and reflected paths.

- Phase Evolution: Frequent small phase shifts, indicating dynamic changes in phase due to multipath and selective fading.



5. Spectral Efficiency

- calculate spectral efficiency of our system in bit/s/Hz
- which parameters are involved
- how can it be improved and what are the limitations?

5. Spectral Efficiency

Parameter	Value
Bandwidth B	2000 Hz
Subcarriers N	500
Subcarrier spacing Δf	4 Hz
CP length N_{cp}	250
Modulation M	4 (QPSK)
Bits per symbol b	$\log_2 M = 2$ bits/sym
Data OFDM symbols N_{data}	25
Training OFDM symbols N_{tr}	1
SC preamble length	500 symbols @ $f_{\text{sym}} = 1$ kSym/s (≈ 0.5 s, plus RRC tails)

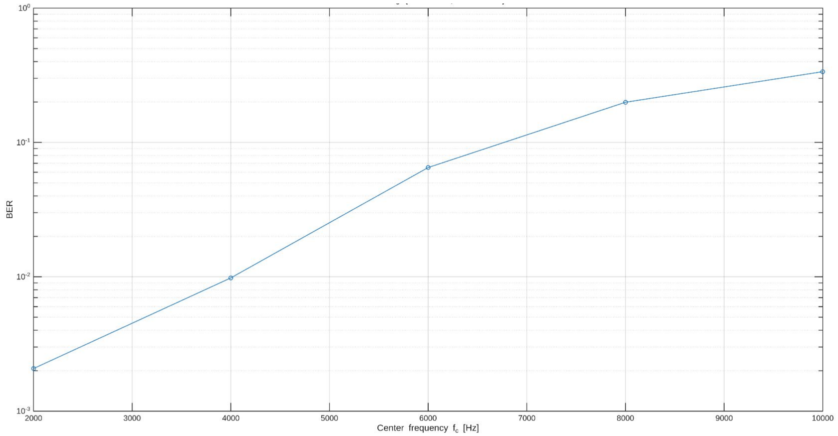
Quantity	Formula	Result
FFT duration T_{FFT}	$T_{\text{FFT}} = \frac{N}{B}$	0.25 s
OFDM symbol duration T_{sym}	$T_{\text{sym}} = T_{\text{FFT}}\left(1 + \frac{N_{\text{cp}}}{N}\right)$	0.375 s
Bits per OFDM symbol B_{sym}	$B_{\text{sym}} = b \cdot N$	1000 bits
Gross spectral efficiency η_0	$\eta_0 = \frac{b}{1+N_{\text{cp}}/N}$	1.33 bits/s/Hz
Frame spectral efficiency η_{frame}	$\eta_{\text{frame}} = \eta_0 \cdot \frac{N_{\text{data}}}{N_{\text{data}}+N_{\text{tr}}}$	1.28 bits/s/Hz
Payload bits per frame B_{payload}	$B_{\text{payload}} = B_{\text{sym}} \cdot N_{\text{data}}$	$25{,}000$ bits
Total frame duration T_{total}	$T_{\text{total}} = T_{\text{preamble}} + (N_{\text{data}} + N_{\text{tr}})T_{\text{sym}}$	10.25 s
Net spectral efficiency η_{net}	$\eta_{\text{net}} = \frac{B_{\text{payload}}}{B \cdot T_{\text{total}}}$	1.22 bits/s/Hz

6. Real Acoustic Transmission

- discuss characteristics of real channel -> plots
- what BER can we achieve?

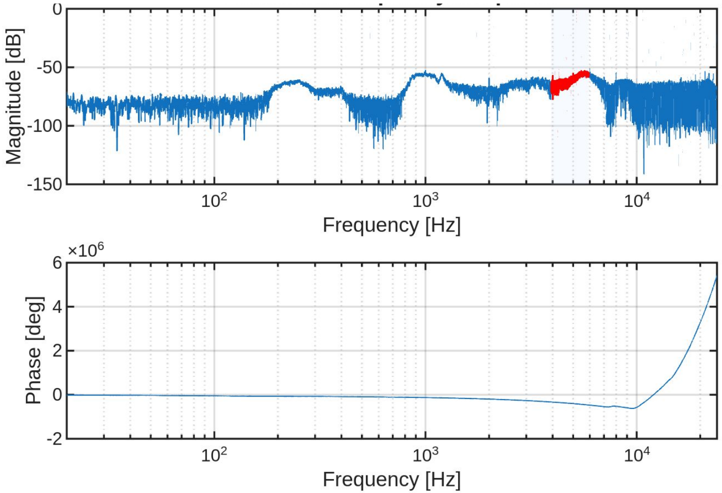
6. Real Acoustic Transmission + Demo

BER vs Center Frequency



BER_{MAX}= 0.01% @ f_C= 2 kHz

Estimated Frequency Response



most linear range: 4 - 6 kHz, RMSE = 1.87 dB

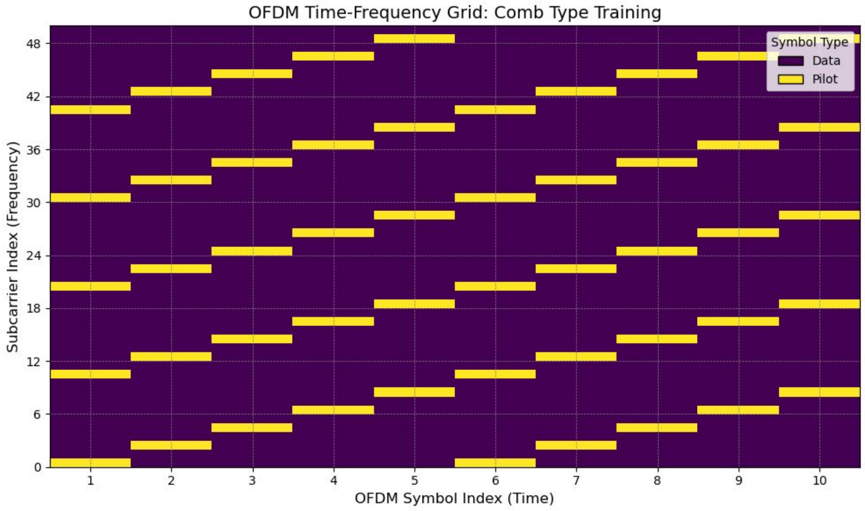
7. Comb Type Training

- comb type training as an alternative channel estimation method
- what happens if the microphone is moving
- how can the robustness be further improved?

- how is BER improved with this method

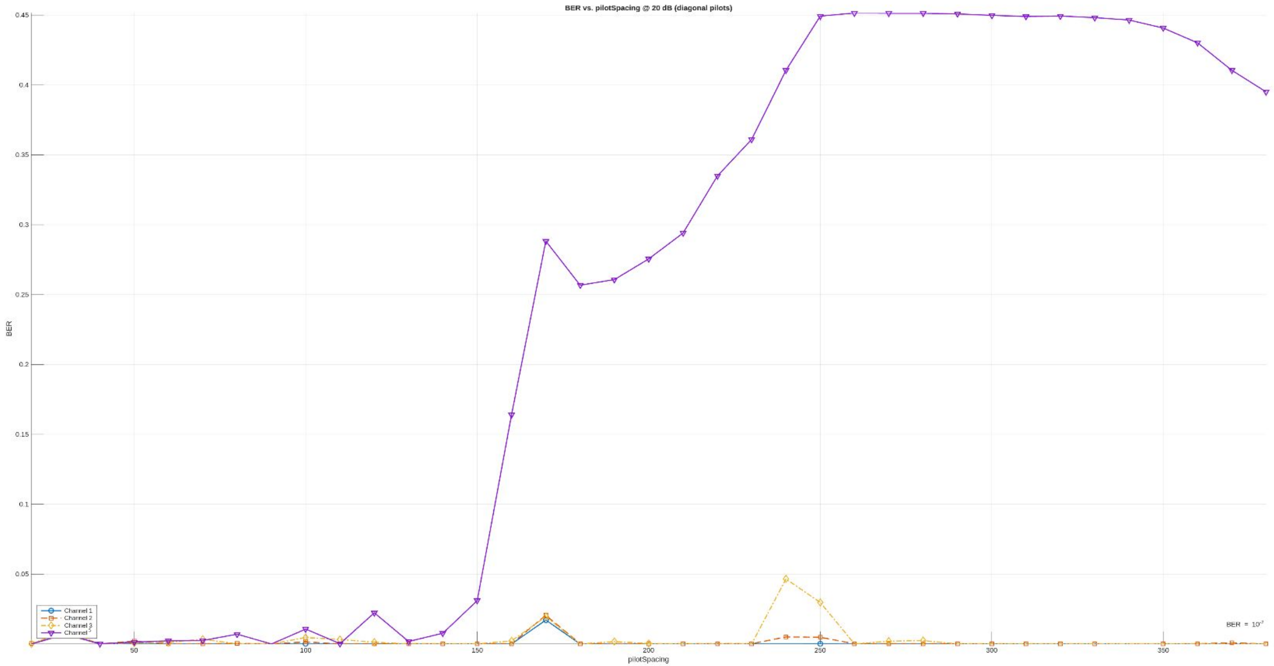
7. Comb Type Training

- Problem:
  Standard estimation uses only initial training symbol to get a static channel estimate
  → moving microphone causes ISI
- Solution:
  Comb pilots in every OFDM Symbol
  → dynamic channel estimation
- Trade-off:
  Low overhead per symbol necessitates temporal tracking across symbols



7. Comb Type Training

BER vs Pilot Spacing



9. Image Transmission

- issues
- particular care required compared to random bitstreams

8. Image Transmission

Goal: Reliable transmission of images, which entails handling large data volumes.

Challenges: Channel estimation and signal normalization.

Solution: Data **packetization**, employing packets of 20 symbols, alternating with training symbols. **Data scrambling** is implemented to mitigate peak power fluctuations caused by long sequences of ones or zeros, which arise from the image data structure.

Single Carrier Preamble	Training OFDM Symbol	OFDM Data Packet	Training OFDM Symbol	OFDM Data Packet	...

Sent Image

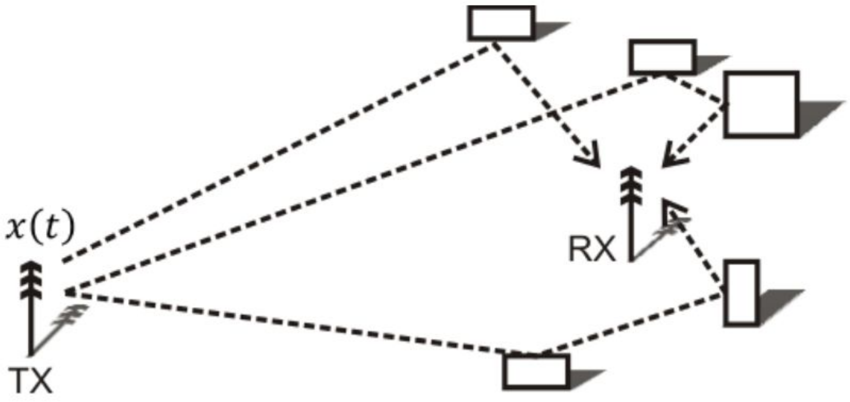
Received Image @ BER = 0.3%

10. Channel Measurements

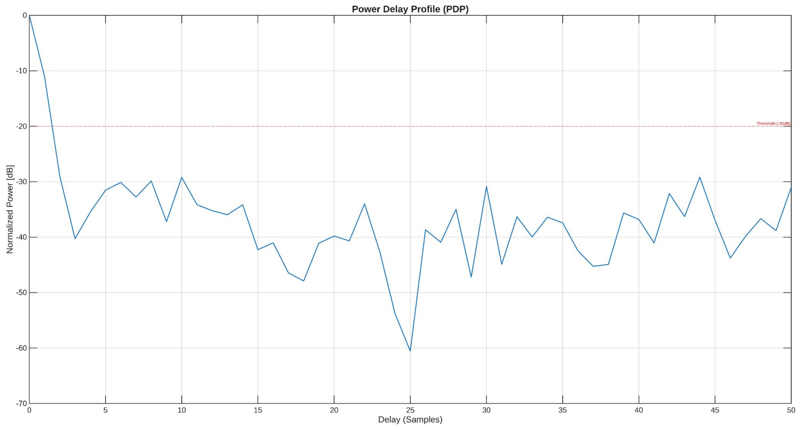
- measure different channels
- interpret results
- interesting channel conditions
- highlight specific effects

9. Channel Measurements

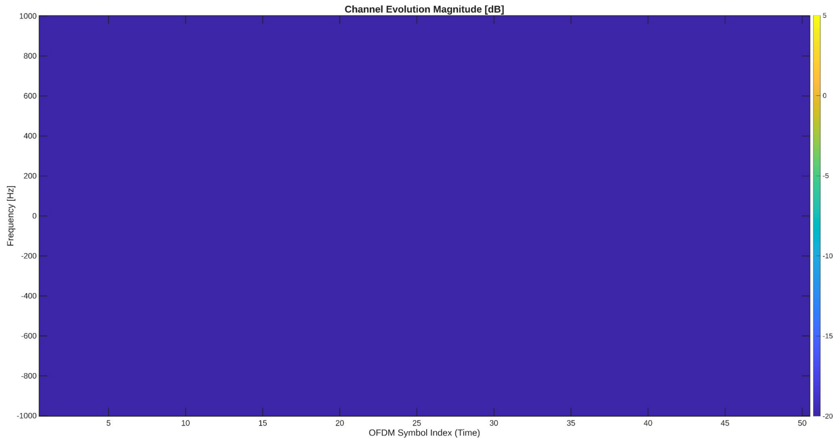
- **Goal**: Investigate the impact of room geometry and furnishings on the acoustic OFDM channel
- Common Setup: Microphone placed 30 cm away from the loudspeaker. No background noise
- Channel 1: Large, **Damped Room** (Low Multipath)
- Channel 2: **Small Room** (High Multipath)



9. Channel Measurements - Channel 1

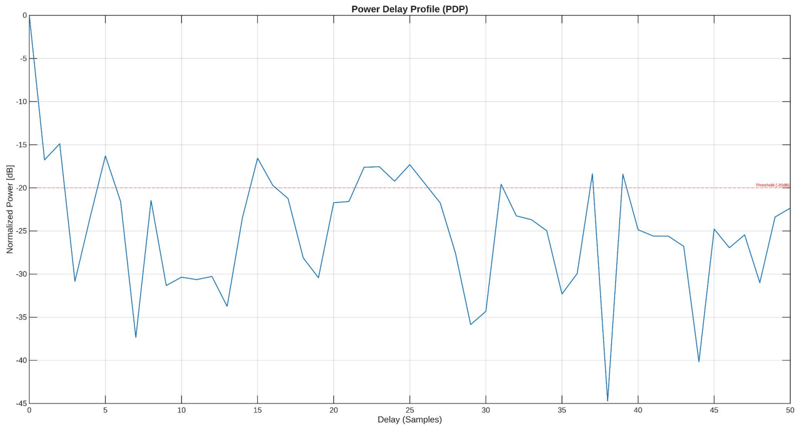


Power Delay Profile



Channel Evolution

9. Channel Measurements - Channel 2



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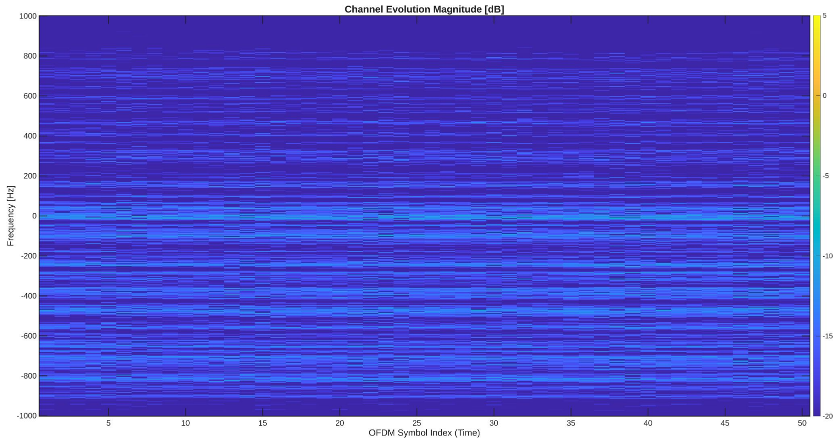

Channel Evolution

10. Conclusion

- conclude state of the system as it is now
- make proposals for further improvements, things we work on right now
- improvements of the systems to maximize throughput
- what changes did we make?
- what throughput can we reach while still achieving a BER < 10 %?
- using other modulation types? like higher order QAM

10. Conclusion

Achievements:

- Developed a functional audio transceiver for data transmission.
- Successfully implemented the transmission of real image data.

Future Work:

- Maximize throughput by exploring various channel estimation algorithms.
- Implement and test the system using larger data packets.
- Enhance transmission reliability through the integration of error correction methods.

Thank you for your attention!