A Case for Chirp Modulation for Low-Power Acoustic Communication in Shallow Waters

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September 13th, 2018

Research Group smartPORT
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TUHH

Motivation

- Micro autonomous underwater vehicles (μAUVs) and underwater wireless sensor networks (UWSNs)
- Possible applications
  - Localization of pollution
  - Tracking and inspection of ships
- μAUVs and UWSNs need a stable and low-power communication interface
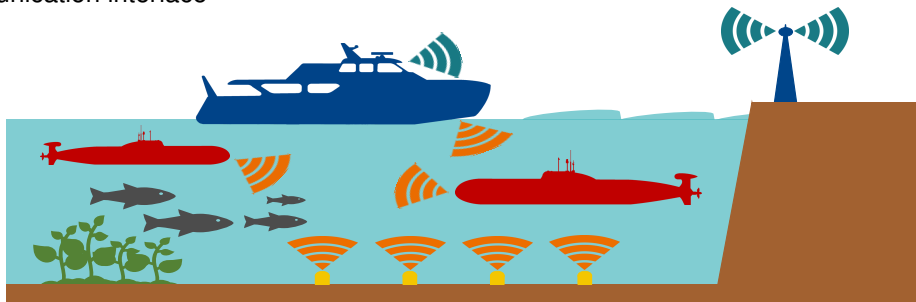
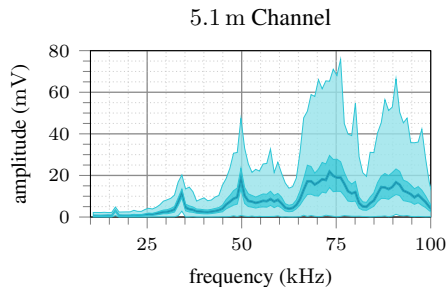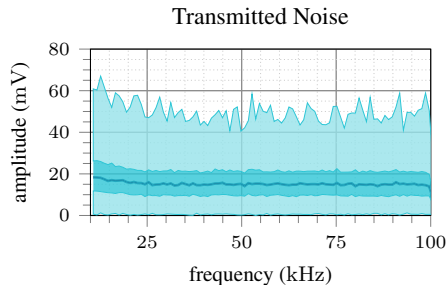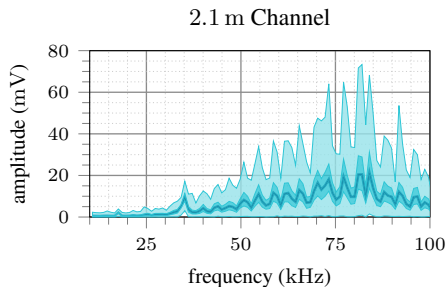# Underwater Channel (I)

- Acoustic wave
  $\Rightarrow$ speed of sound $c \approx 1500\,\mathrm{m/s}$
- Reflections and scattering
  $\Rightarrow$ frequency-selective and time-dependent channel
- Shallow water scenarios
  $\Rightarrow$ high impact of the surface reflection
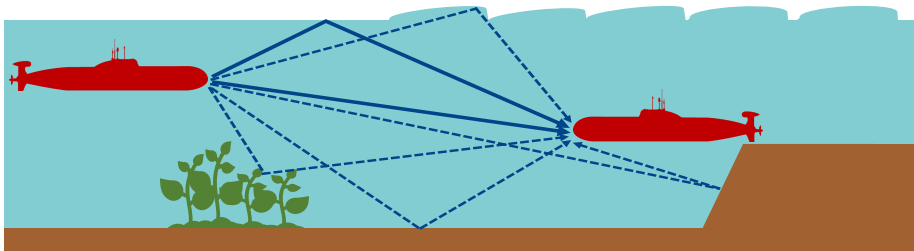
Underwater Channel II

- 1 s band-limited pseudo-random noise
- 10 kHz - 100 kHz
- Strong frequency dependency

Transmitted Noise

2.1 m Channel

5.1 m Channel

smartPORT Acoustic Underwater Modem

- Small and low-power device
- Contains of:
  - Mainboard with power supply and Cortex M4 microcontroller
  - Receiver with amplifiers, band-pass filter and AD-converter
  - Transmitter with DA-converter and power-amplifier
  - External hydrophone
- Frequency Shift Keying (FSK) based synchronization and data transmission
- Range up to 150 m and data rate 260 bit/s
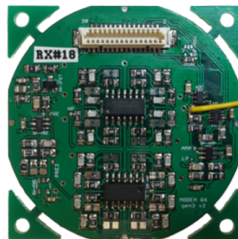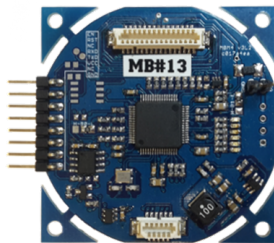
FSK and Chirp Keying

- Frequency Shift Keying (FSK)
  - A bit is transmitted with a constant frequency
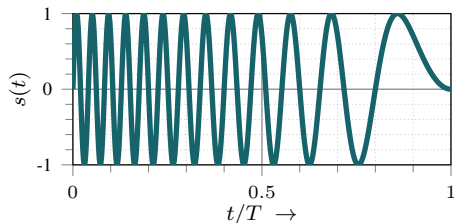 - Non-coherent detection (currently implemented)
  - Problem: synchronization
- Chirp Keying
  - Frequency sweep from f_s to f_e
    - $f_s < f_e \Rightarrow$ up-chirp
    - $f_s > f_e \Rightarrow$ down-chirp
  - Bandwidth $B = |f_e - f_s|$
  - Spread the information over spectrum
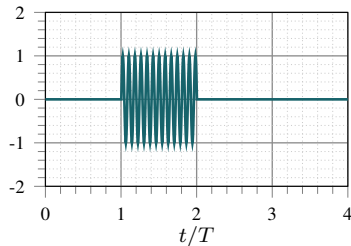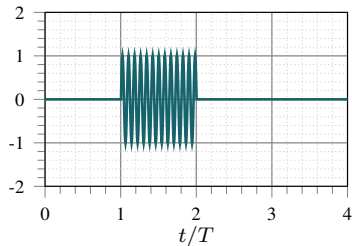 - Cross-correlation detection
  - Good correlation properties

Up-Chirp
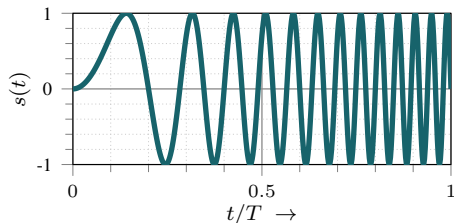
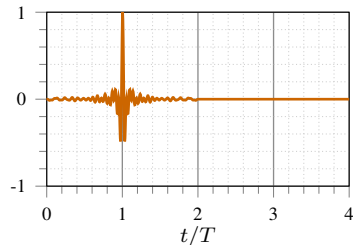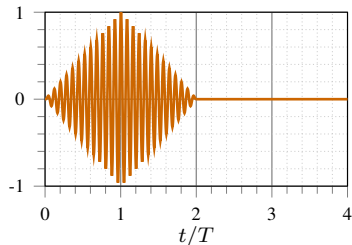Down-Chirp

FSK and Chirp Keying - Comparison
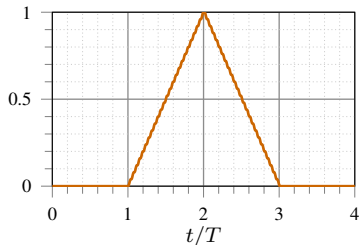
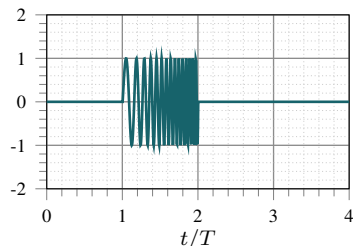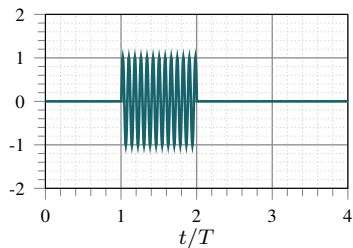# FSK and Chirp Keying - Comparison

FSK Non-Coherent

FSK Cross-Correlation
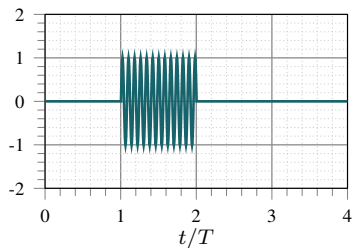
Chirp Cross-Correlation

FSK and Chirp Keying - Comparison

FSK and Chirp Keying - Comparison
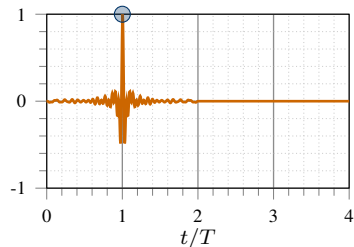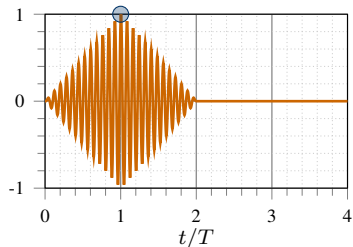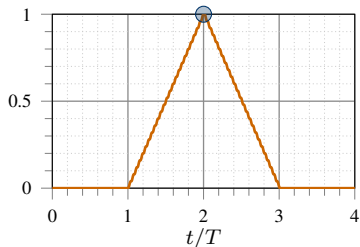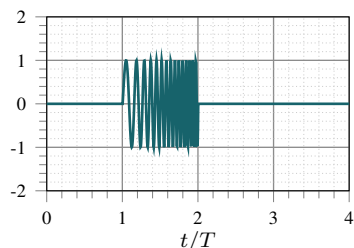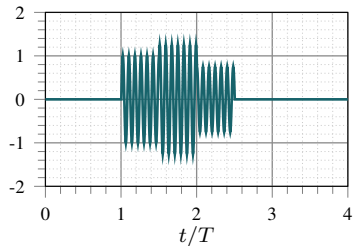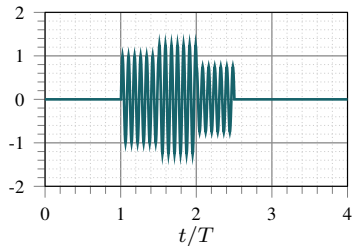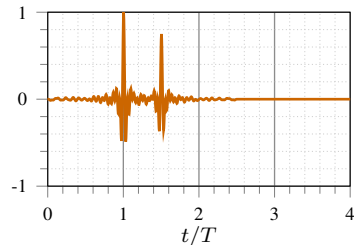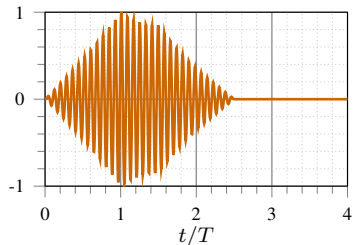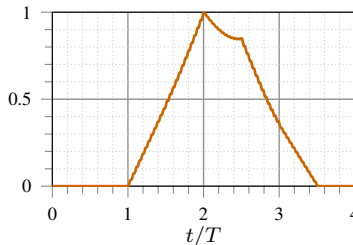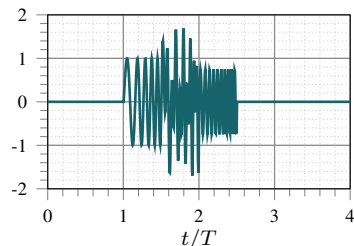

FSK Non-Coherent

FSK Cross-Correlation

Chirp Cross-Correlation
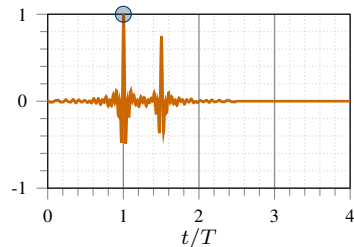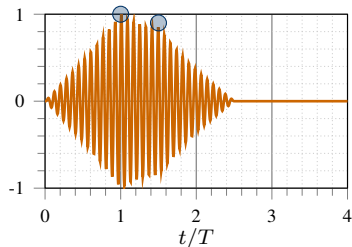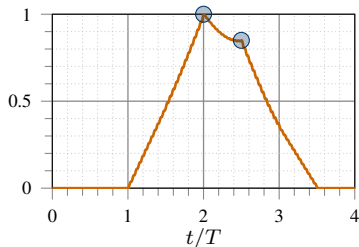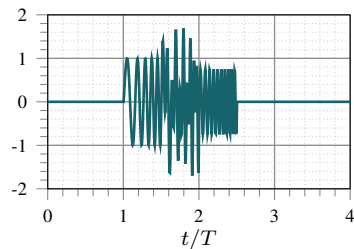
Preamble Based Synchronization

- Packet-based transmission
- Preamble and starting frame delimiter (SFD) before each data-packet
- Preamble with alternating symbols
  - Up- and down-chirps
  - Sinusoidal symbols with two frequencies
- Previous evaluations: Good sync $\Rightarrow$ correct data reception

- Parameter Settings:
  - Orthogonal symbols with $T = 2.5\,\text{ms}$
  - Chirp bandwidth $B = 2.342\,\text{kHz}$
  - FSK with 400 Hz symbol spacing
  - 16 preamble symbols + 4 SFD symbols

Experimental Setup

- Signal generation and processing with MATLAB
- USB oscilloscope and waveform generator
- Low sampling rate (200 kHz)
- RX and TX circuits
- Marina in Hamburg with LOS conditions
- long wide-band chirp (10 kHz to 100 kHz, 100 ms) to obtain a ground-truth
- 2.1 m and 5.1 m distance, 0.5 m depth

Synchronization Macroscope

- 100 synchronizations per frequency band over 5.1 m
- 40 kHz - 90 kHz in 2 kHz steps

FSK Non-Coherent

FSK Cross-Correlation

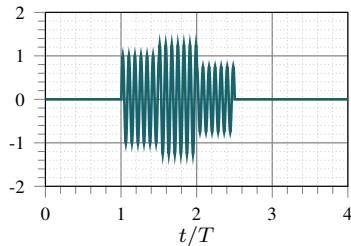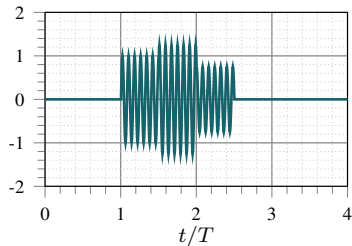Chirp Cross-Correlation
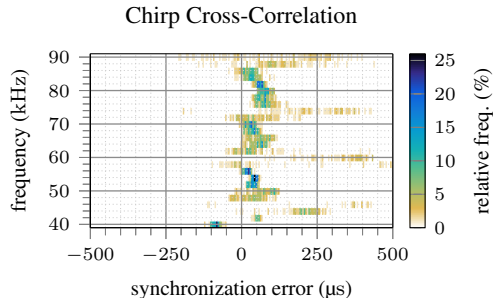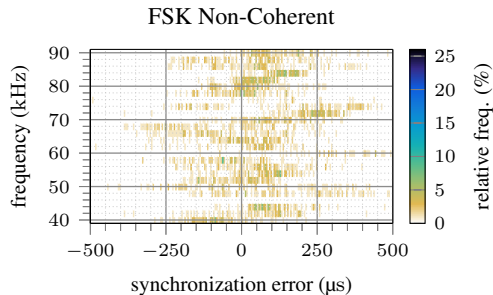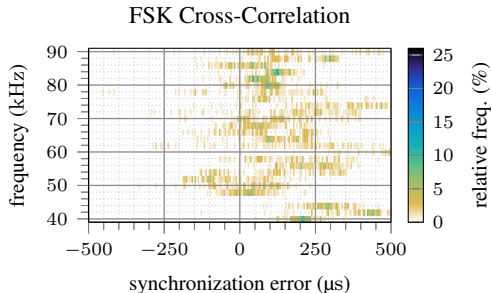
Synchronization Microscope (I)

- 1000 synchronizations over 2.1 m and 5.1 m
- Fixed frequencies
  - Chirp: 62.4 kHz - 64.8 kHz
  - FSK: 62.4 kHz and 62.8 kHz
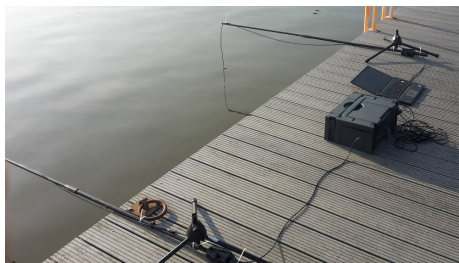

FSK Non-Coherent

FSK Cross-Correlation

Chirp Cross-Correlation
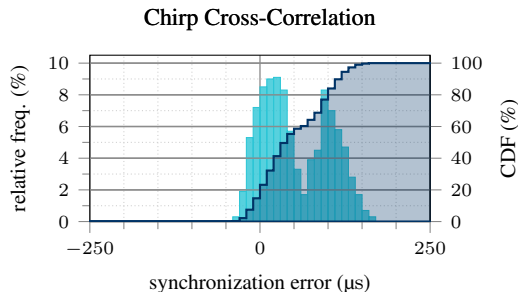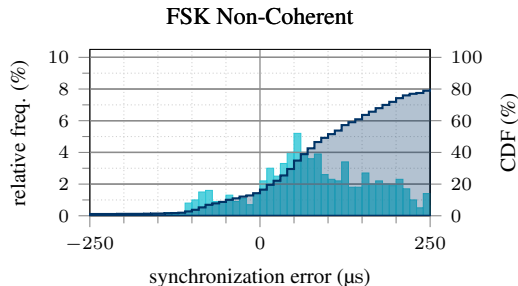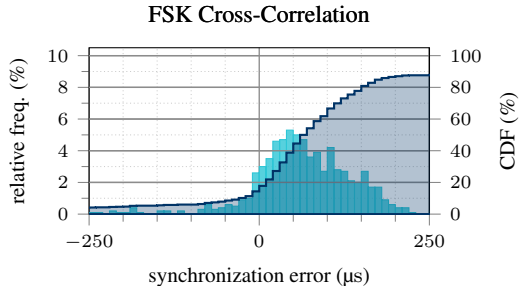
Synchronization Microscope (II)

	FSK non-coh	FSK xcorr	Chirp xcorr
2.1 m Channel			
Inside 10 % margin	72.8 %	77.9 %	91.6 %
Average sync. error	137.1 µs	122.2 µs	120.1 µs
Standard deviation	77.2 µs	76.7 µs	73.6 µs
5.1 m Channel			
Inside 10 % margin	76.7 %	72.3 %	100 %
Average sync. error	74.7 µs	62.3 µs	50.5 µs
Standard deviation	87.7 µs	70.6 µs	48.7 µs

Conclusion and Outlook

- A chirp-based synchronization enhances:
  - The number of received synchronizations
    72 % $\Rightarrow$ 100 %
  - The accuracy
    71 µs $\Rightarrow$ 49 µs (standard deviation)
  - The precision
    62 µs $\Rightarrow$ 51 µs (average sync. error)

- Outlook:
  - smartPORT modem implementation
  - Chirps with a larger bandwidth
  - Research on chirp-based data transmission
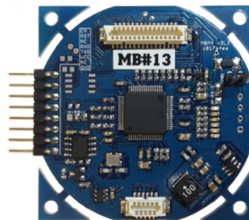
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