MIMO Telecommunications with Near Ultrasounds

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Abstract

Ultrasound telecommunications are a relevant alternative when radio frequencies are not allowed or appropriate. Performance of a **near-ultrasound (15 - 20 kHz)** telecommunication system with linear-frequency-modulated symbols (**LFM**), or **chirps**, is studied:

- formal study of **BER** (Bit Error Rate) with varying **chirp-symbol time** and **chirp-overlap ratio**;
- comparison with numerical simulations.

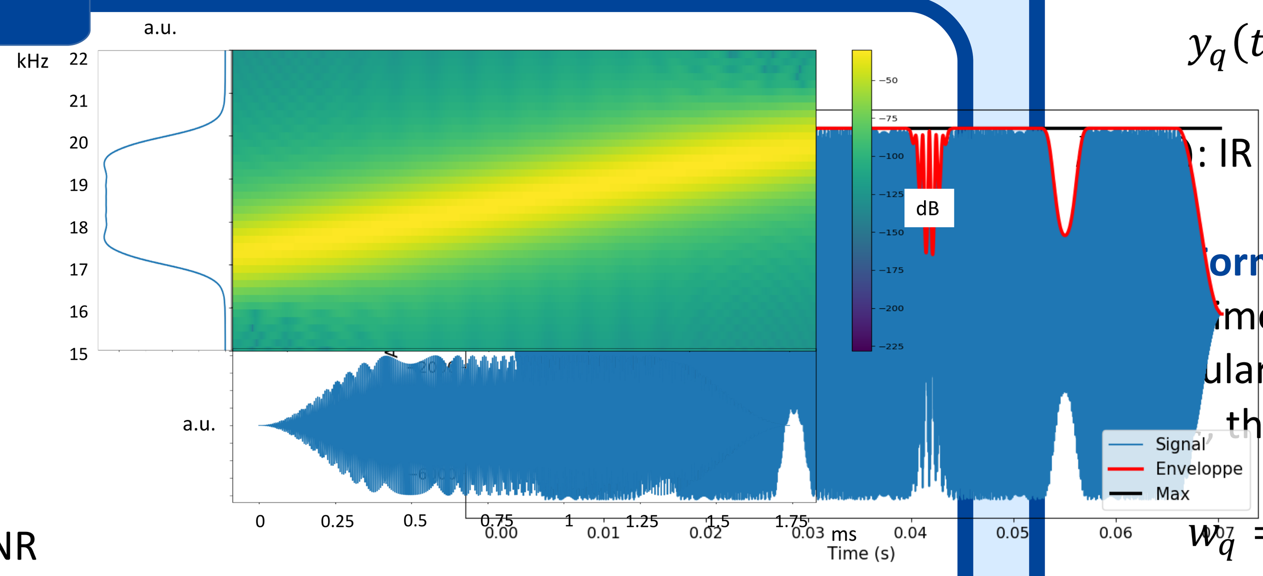
We designed an 8-element linear network to achieve **MIMO** telecommunications, using **Beam Forming (BF)** and **Time Reversal (TR)** for focalization:

- assessment of the **propagation channel** (impulse response (IR) of the environment);
- comparison of **BF** and **TR**, at a constant emission power, in several **LOS** (Line Of Sight) and **NLOS** (Non Line Of Sight) configurations.

Chirp and overlap

Chirp:

- Linear, from f_1 to f_2
- Narrow band
- Tuckey windowing
- + or – frequency slope, for bit encoding



Optimal overlap:
Successive chirps overlap without SNR degradation (constant signal amplitude at emission)

Simulation results:

- LFM optimal overlap on `10011` sequence $= 24$ %
- Related rate gain $= 19.2$ %

BER model

Analytical model:

$$\mathrm{BER} = \frac{1}{2}\mathrm{erfc}\left(\frac{\sqrt{R_{cc} - R_{cc'}}}{2\sqrt{p_b}}\right)$$

p_b: spectral power density of noise
R_{cc}: chirp auto-correlation
$R_{cc'}$: chirp cross-correlation

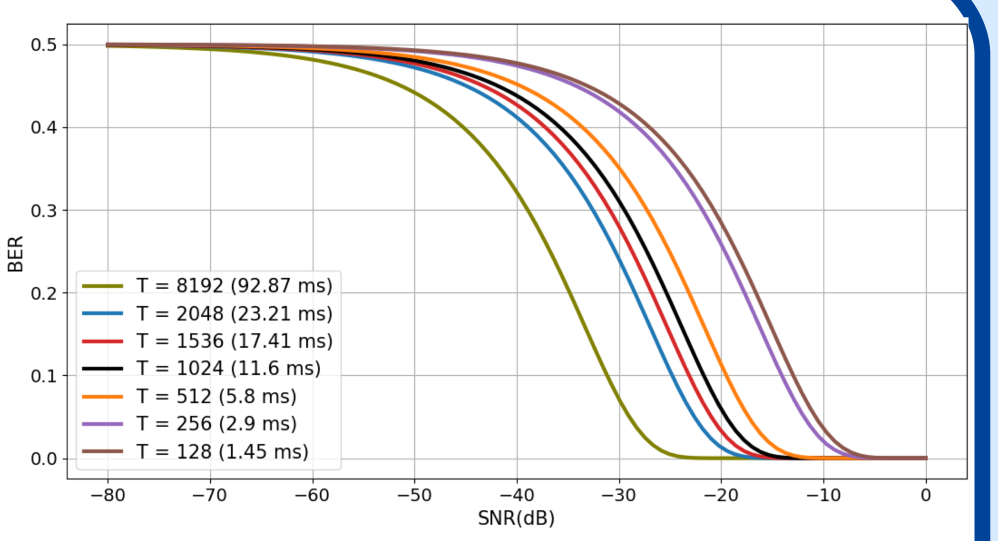


Fig. 1: Numerical integration of BER

Approximation (constant noise in B):

$$\mathrm{BER} \approx \frac{1}{2}\mathrm{erfc}\left(\frac{1}{2}\sqrt{\frac{(NA)^2}{2p_bB}}\sqrt{BT}\right)$$

B: bandwidth
T: symbol time
A: symbol amplitude
N: number of focalized sources

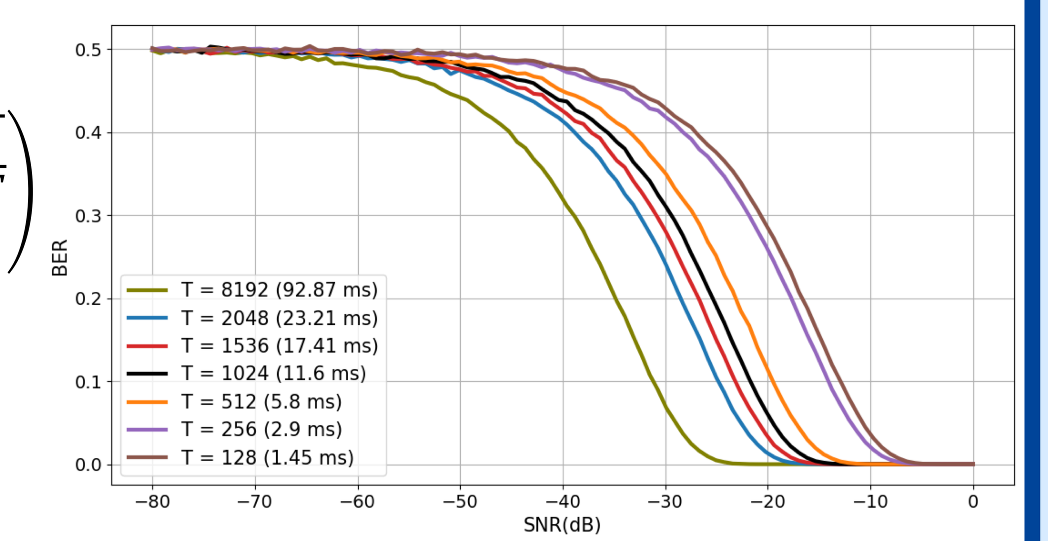


Fig. 2: Simulation of BER (50k iterations)

Results:

- Good fit between analytical model and simulation (Fig. 1 and 2)
- SISO-to-MIMO gain ~15 dB for $N = 8$ (Fig. 3)

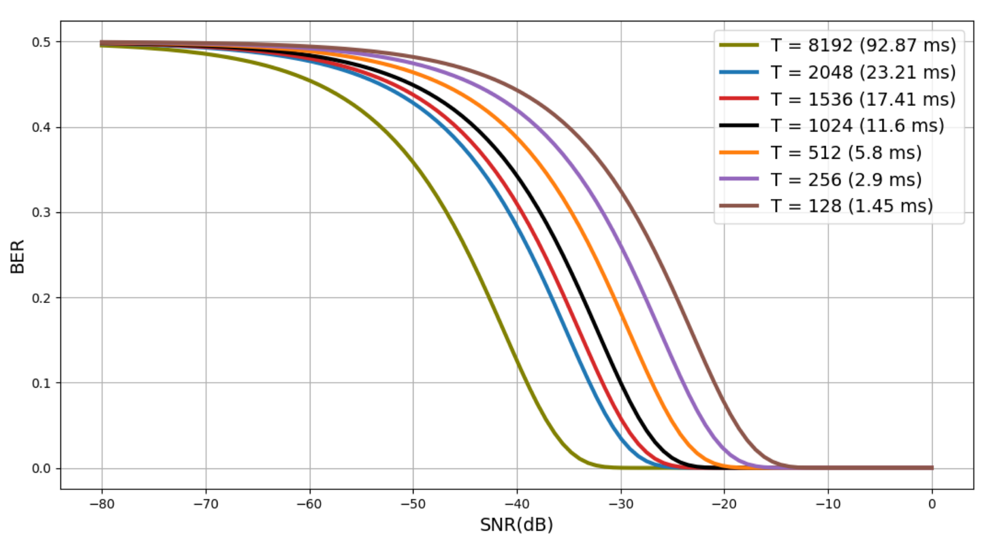
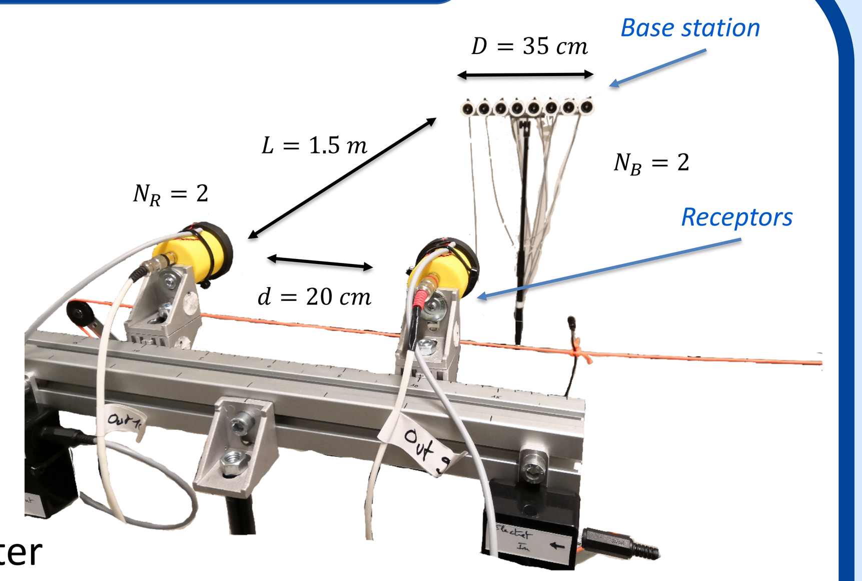


Fig. 3: BER approximation for 8 sources

Beam Forming and Time Reversal

MIMO setup:

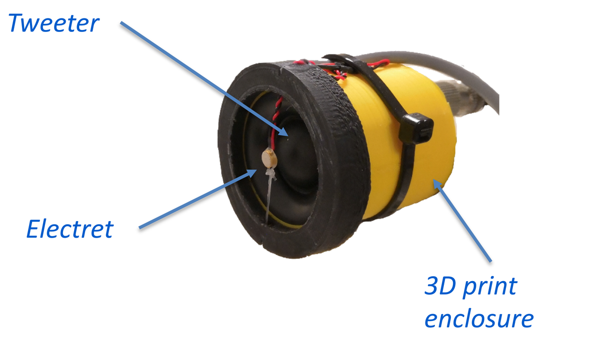
- Element = speaker + mic
- 8-element base station
- Two 1-element receptors
- 1 mic for control on a linear rail



Hardware and software setup:

- Custom-made phantom mic power
- Custom-made amp
- Ø 0.4 electret mic and Ø 3.3, 10W tweeter
- Processing in Python3

Calibration using known chirp *x(t)*:
Signal $y_q(t)$ received by element $q \in [1, N_B]$ of the base station from receptor $p \in [1, N_R]$:



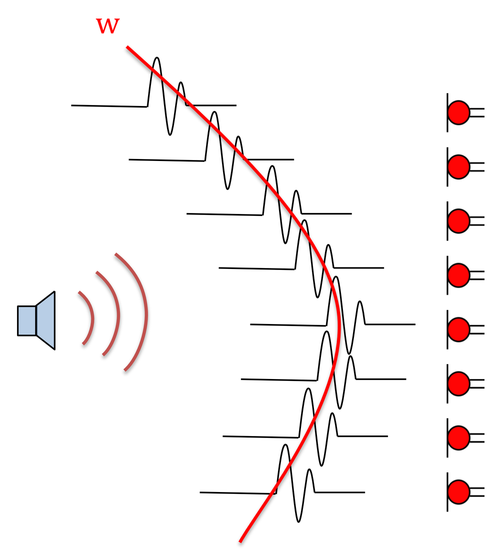
$$y_q(t) = h_{pq}(t) \otimes x(t)$$

…: IR between elements p and q

…orming:

…mensional steering vector **w**
…ular delays w_q of correlation phases ϕ_q
… the central frequency of *x(t)*:

$$w_q = \phi_q(f_c)$$



- Focalized signals $s_q^{BF}(t)$ for user signal $s(t)$:

$$s_q^{BF}(t) = FT^{-1}[e^{j2\pi w_q} FT[s(t)]]$$

- Measured acoustic field levels (Fig. 4)

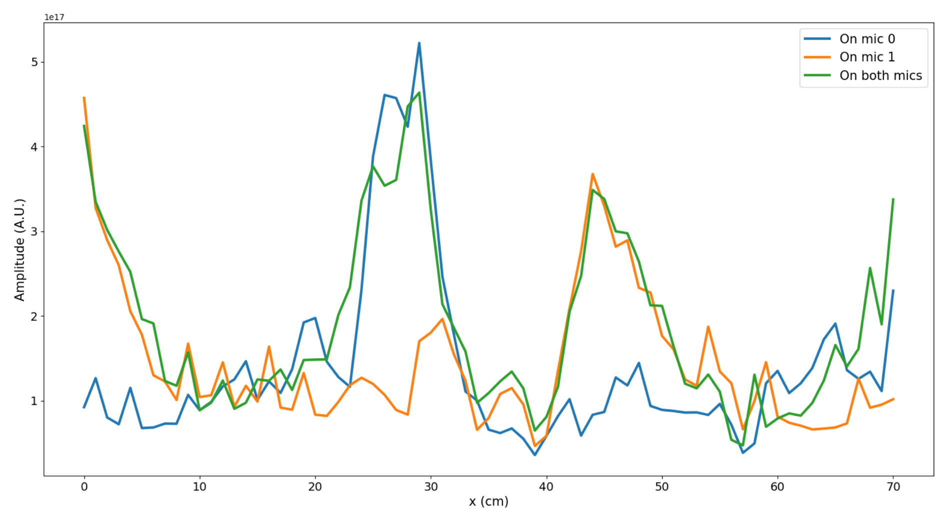


Fig. 4: Acoustic levels for Beam Forming

Time Reversal:

- Focalized signals $s_q^{TR}(t)$

for user signal $s(t)$:

$$s_q^{TR}(t) = h_{pq}(-t) \otimes s(t)$$

- Measured acoustic field levels (Fig. 5)

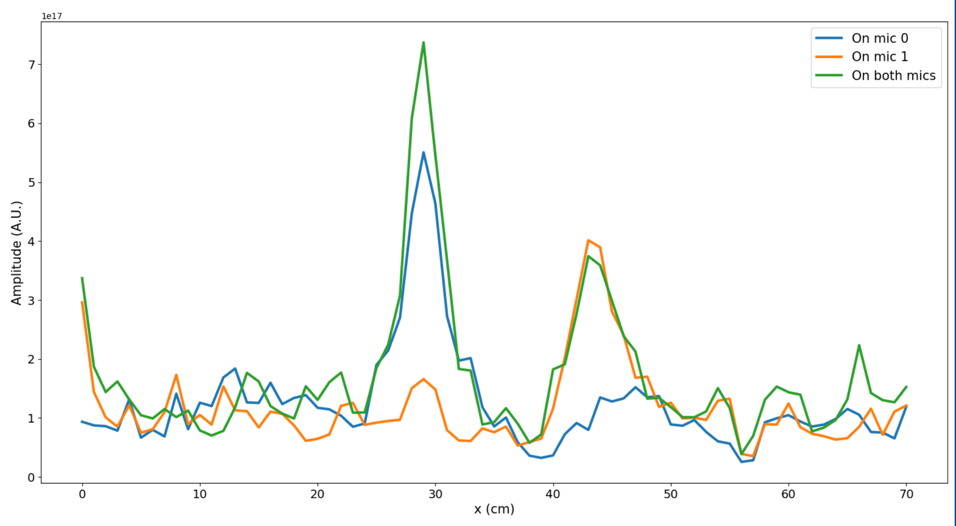


Fig. 5: Acoustic levels for Time Reversal

Telecommunication results:

- LOS
- Small distances (L, d)
- 5-symbols signals
- Long symbol as prefix for synchronization
- BF and TR BER $= 0$ %

Conclusion

BER model:
Accurate BER model approximation

Comparison of focalization methods:
Time Reversal better fitted (includes the environment IR)

Future work:

- Various configurations of 2-axis distance between receptors
- Measurements in various room configurations
- Adaptive f_c to avoid antenna-lobes overlap
- Passive focalization: focalization from a network of receptors

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