



MIMO Telecommunications with Near Ultrasounds

Arthur Aubertin, Julien de Rosny, Pierre Jouvelot

► To cite this version:

Arthur Aubertin, Julien de Rosny, Pierre Jouvelot. MIMO Telecommunications with Near Ultrasounds. 1ère édition des Journées Jeunes Chercheurs en Acoustique Physique, Jun 2019, Paris, France. hal-02437001

HAL Id: hal-02437001

<https://minesparis-psl.hal.science/hal-02437001>

Submitted on 13 Jan 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

MIMO Telecommunications with Near Ultrasounds

Arthur Aubertin^{1, 2, 3}, Julien de Rosny², Pierre Jouvelot³

(1) Stimshop, 14-16 rue Soleillet, 75020 Paris, France (e-mail : arthur@stimshop.com)

(2) MINES ParisTech, Université PSL, Paris, France

(3) ESPCI Paris, Université PSL, Institut Langevin Ondes et Images, Paris, France

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:

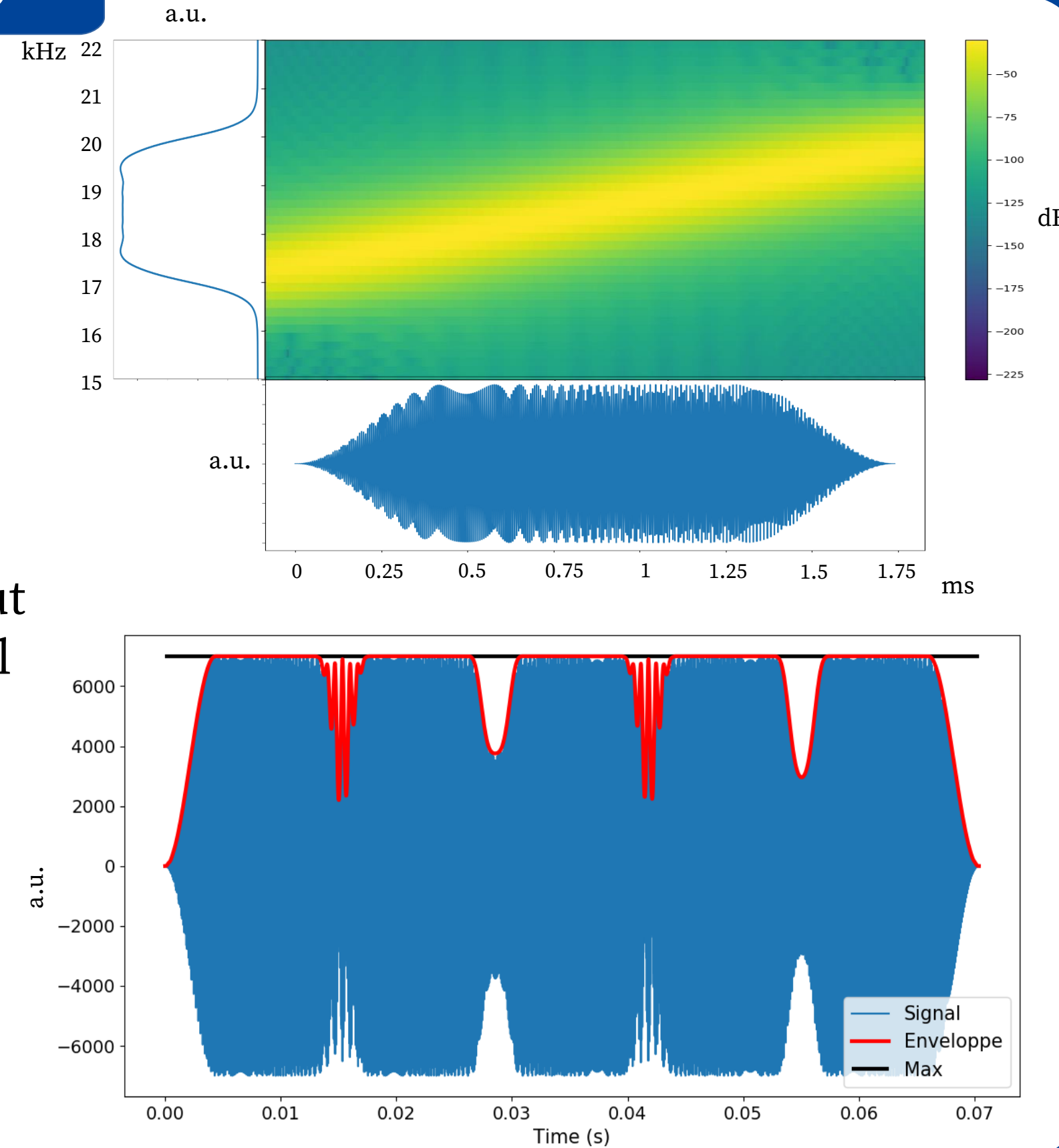
- Linear, from f_1 to f_2
- Narrow band
- Tuckey windowing
- + or - frequency slope, for bit encoding

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:

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

p_b : spectral power density of noise

R_{cc} : chirp auto-correlation

$R_{cc'}$: chirp cross-correlation

Approximation (constant noise in B):

$$BER \approx \frac{1}{2} \operatorname{erfc} \left(\frac{1}{2} \sqrt{\frac{(NA)^2}{2p_b B}} \sqrt{BT} \right)$$

B : bandwidth

T : symbol time

A : symbol amplitude

N : number of focalized sources

Results:

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

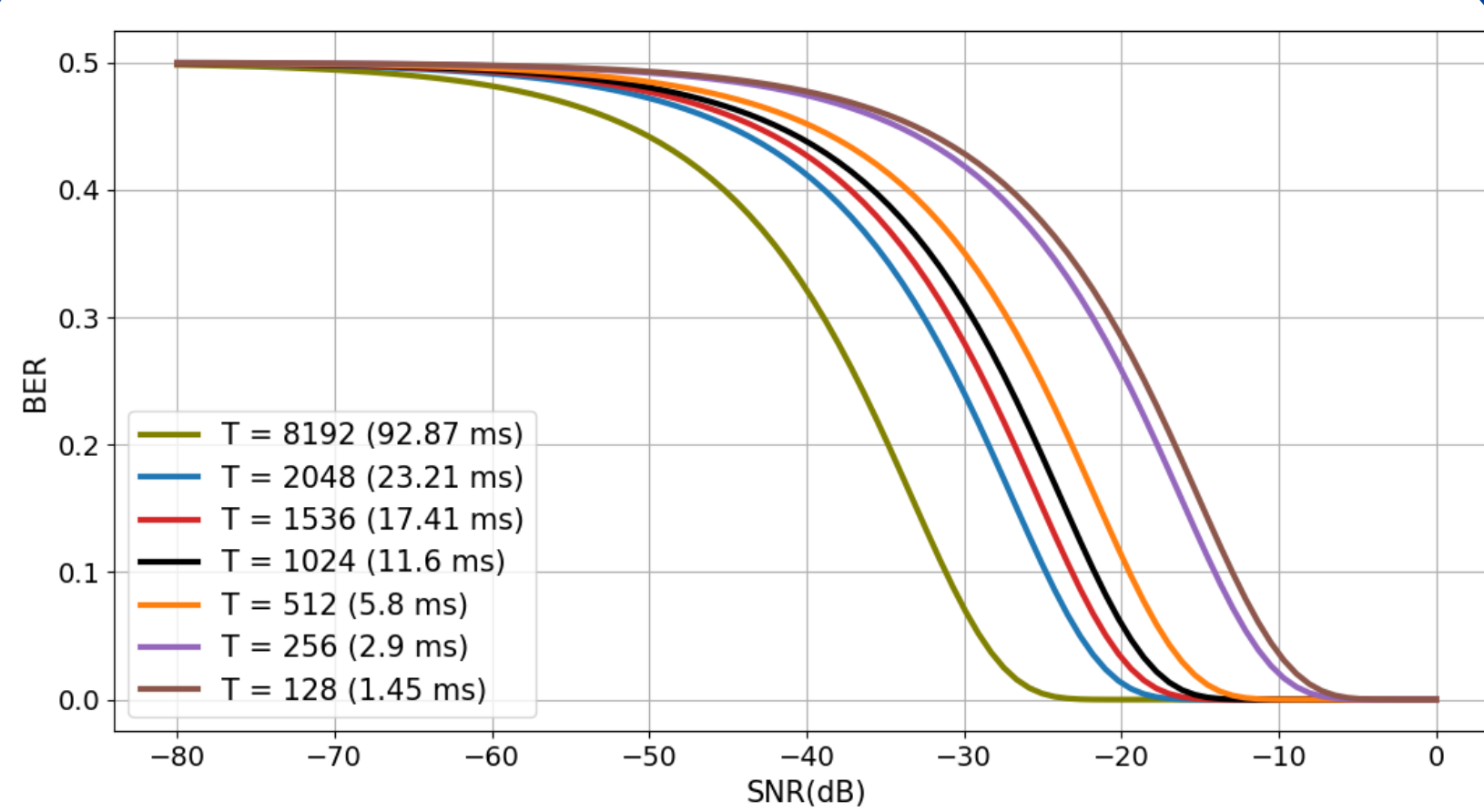


Fig. 1: Numerical integration of BER

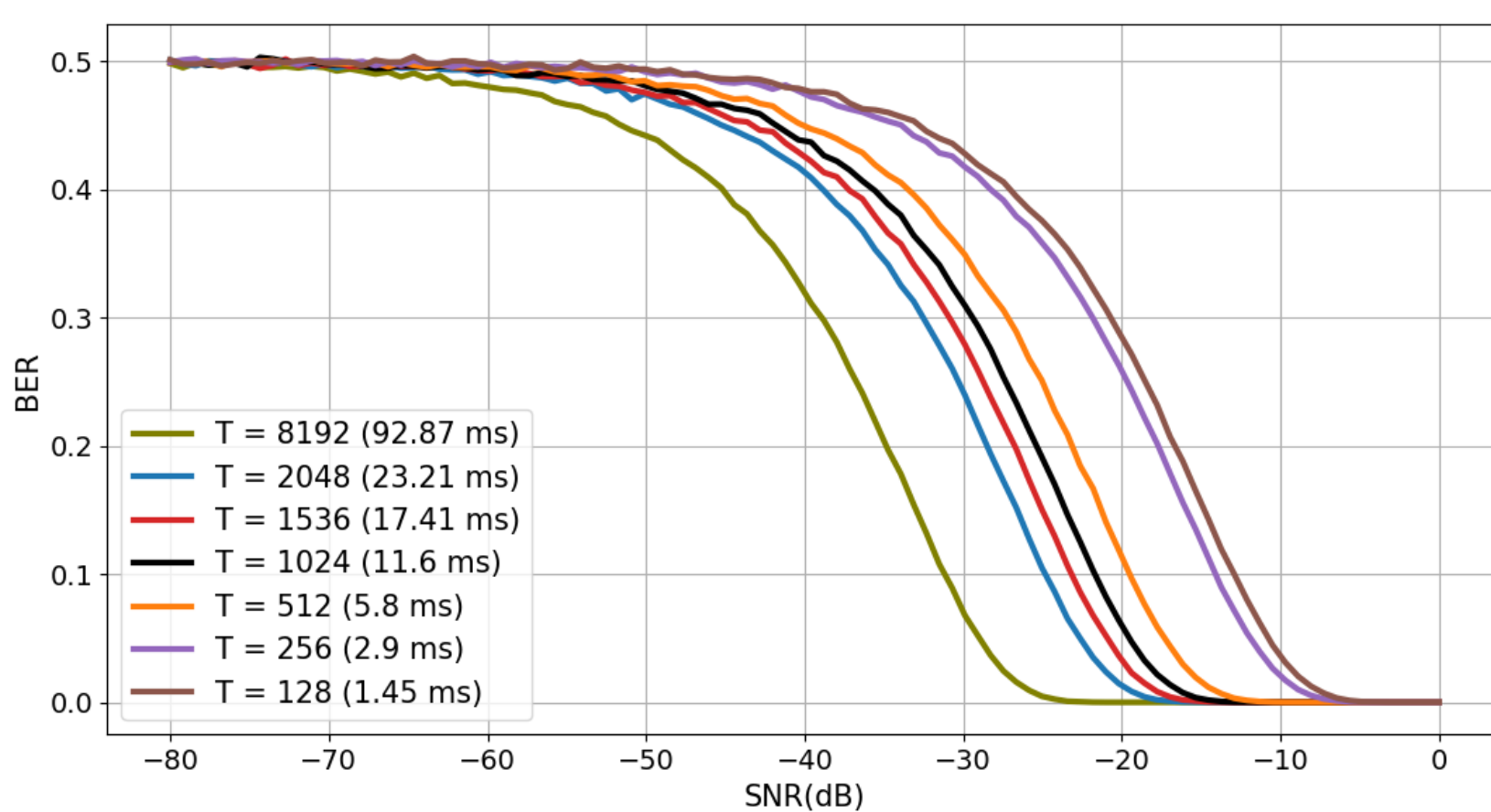


Fig. 2: Simulation of BER (50k iterations)

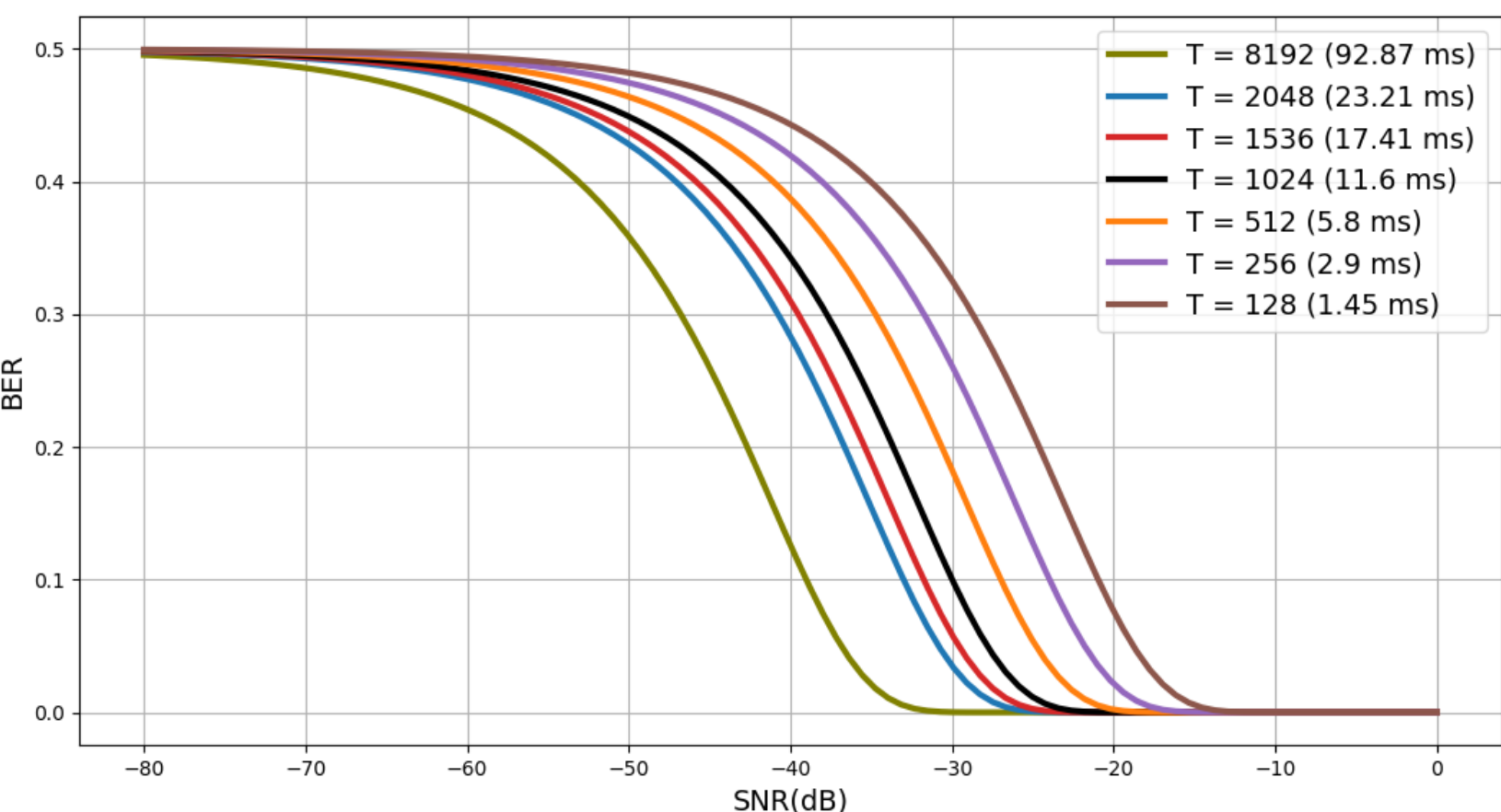


Fig. 3: BER approximation for 8 sources

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 $p \in [1, N_R]$:

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

$h_{pq}(t)$: IR between elements p and q

Beam Forming:

- N_B -dimensional steering vector \mathbf{w}
- Angular delays w_q of correlation phases ϕ_q at f_c , 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)

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)

Telecommunication results:

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

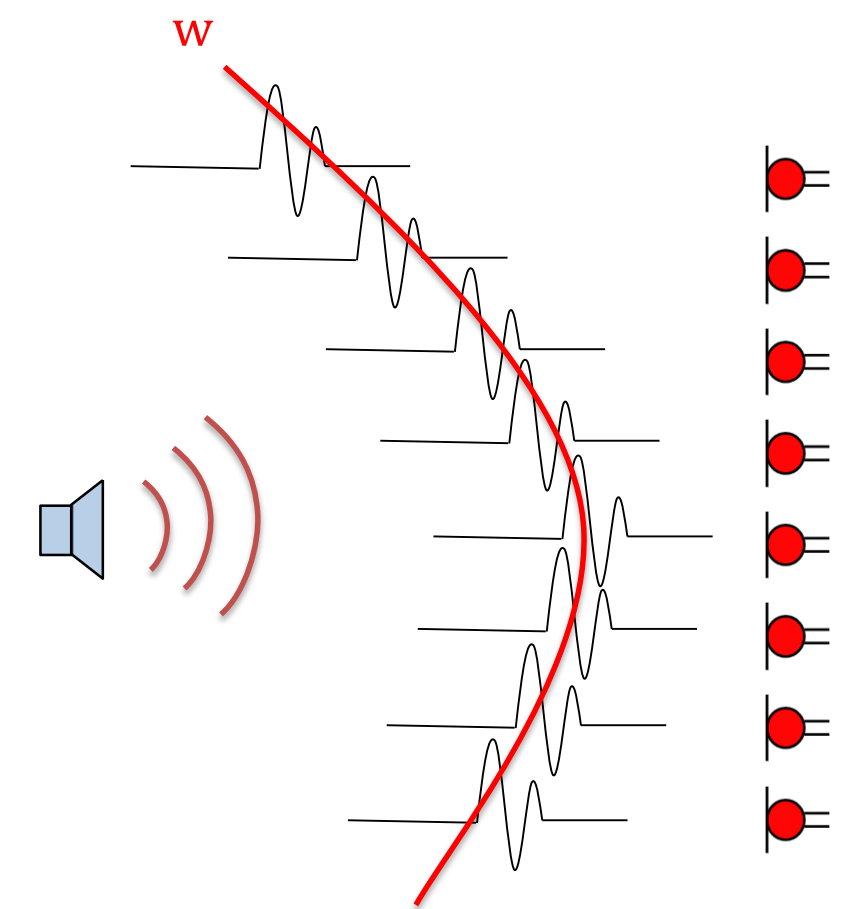
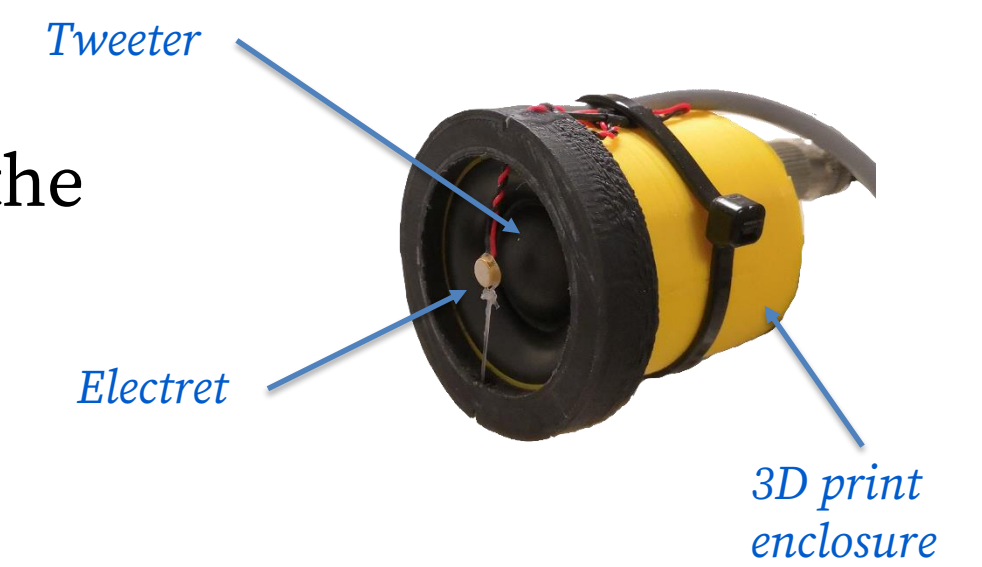
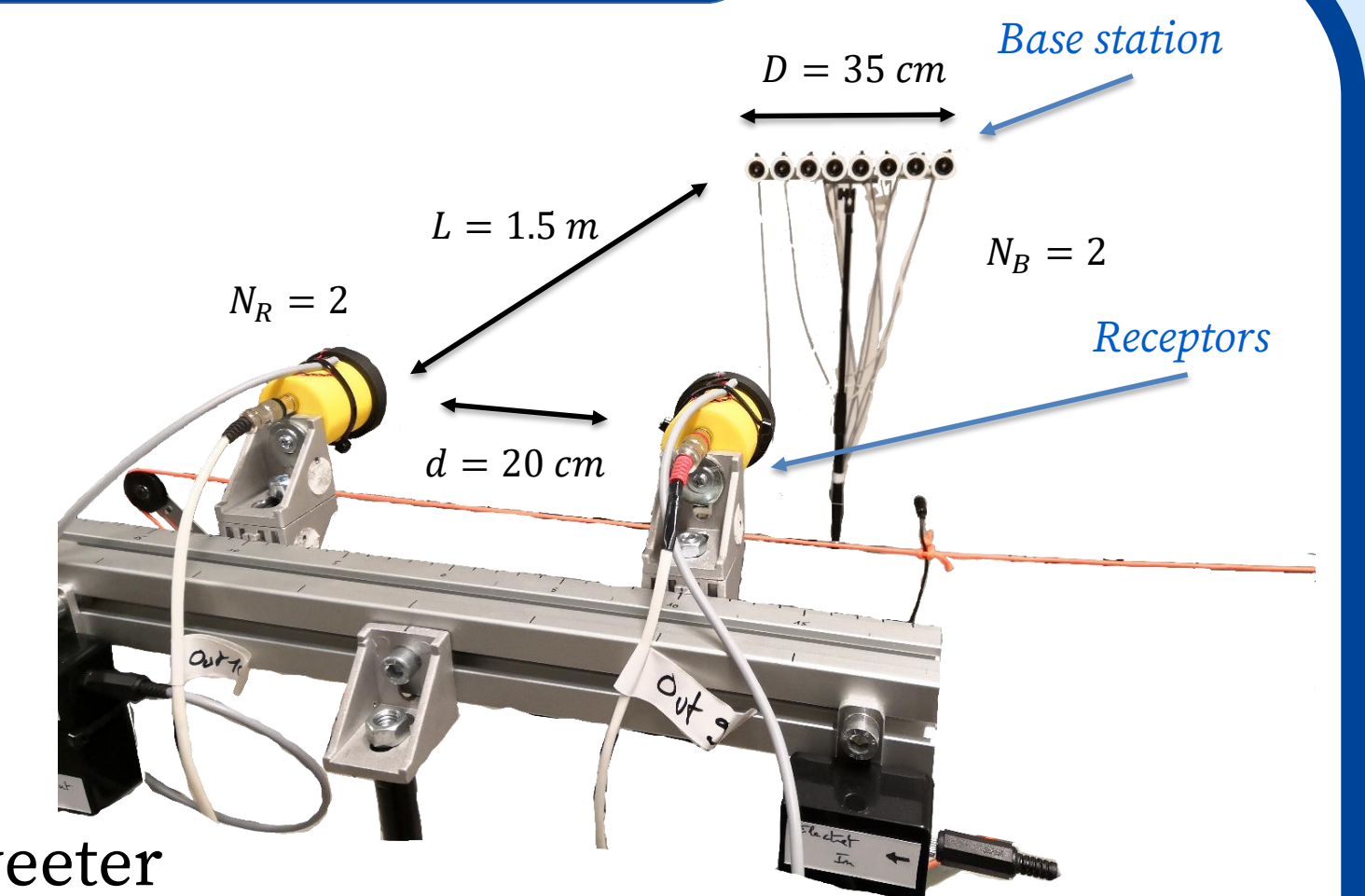


Fig. 4: Acoustic levels for Beam Forming

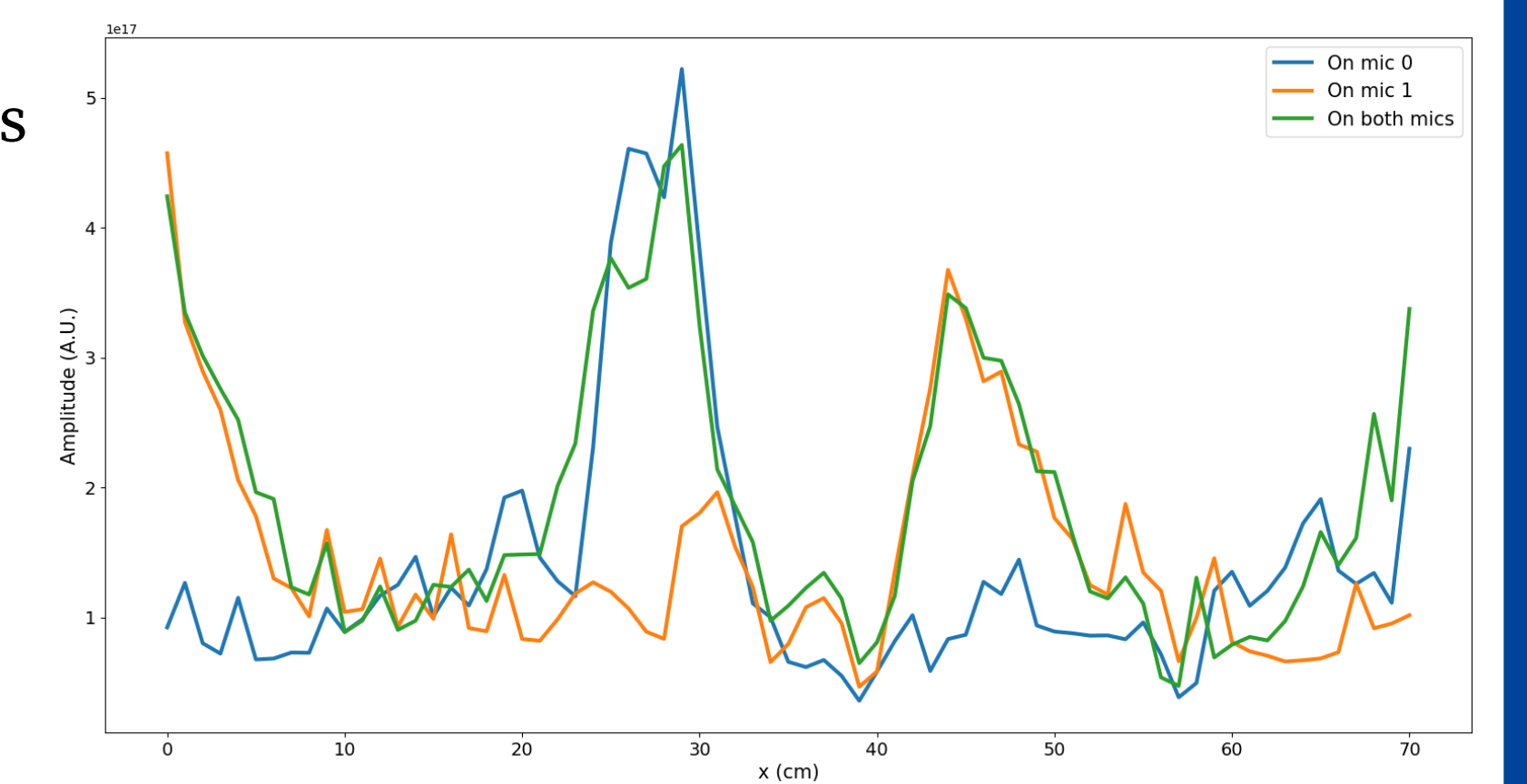


Fig. 5: Acoustic levels for Time Reversal

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