AN ATTENUATION ADAPTED PULSE COMPRESSION TECHNIQUE TO ENHANCE THE BANDWIDTH AND THE RESOLUTION USING ULTRAFAST ULTRASOUND IMAGING

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Introduction

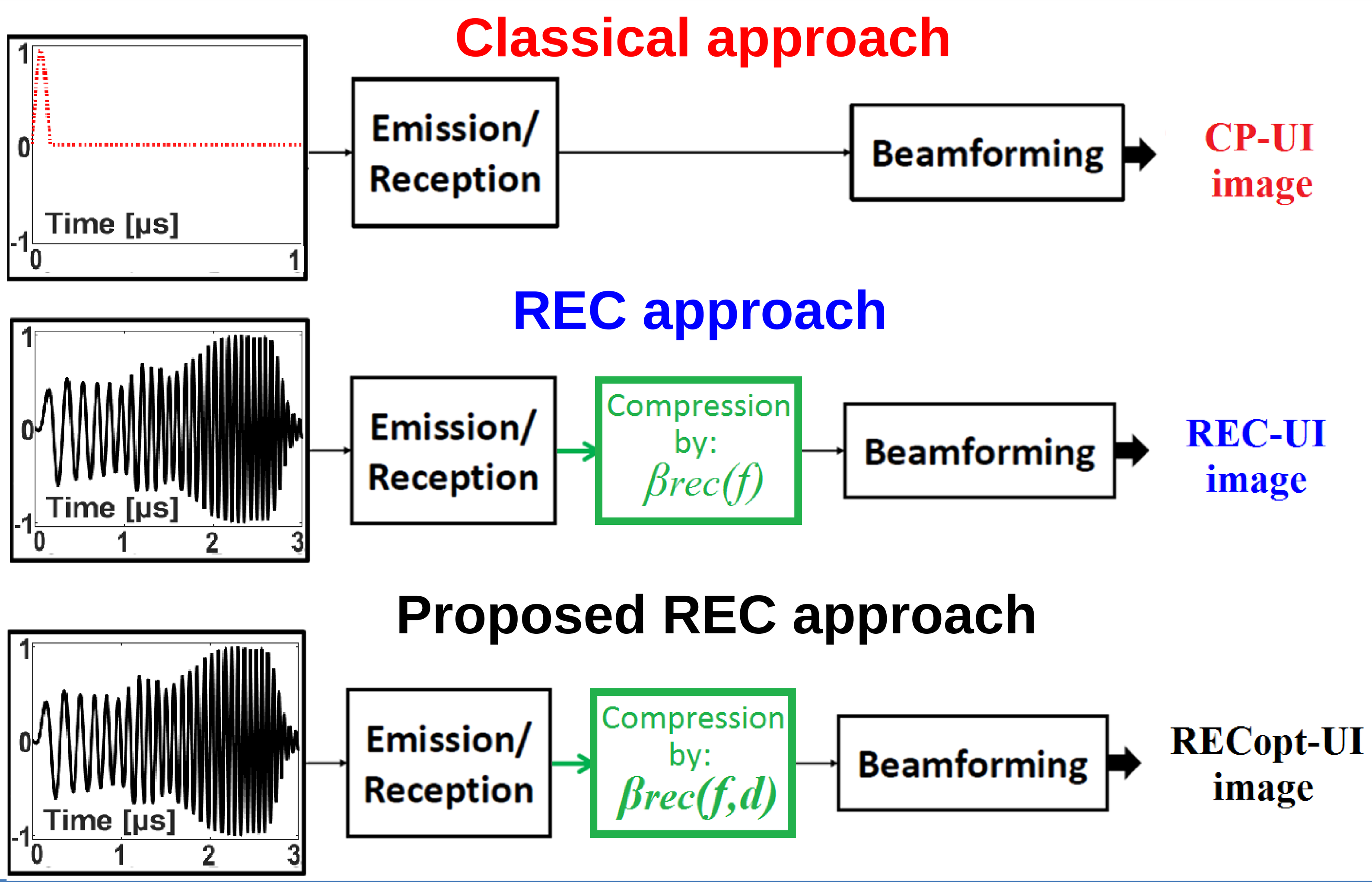
Background

- **Pulse compression technique called Resolution Enhancement Compression (REC) to increase the eSNR and the bandwidth of the received signals [1]**
- **Ultrafast Imaging (UI) through plane wave coherent compounding [2]**

Objective of this study

Experimental implementation on a research ultrasound scanner (UlaOp [3]) of a new method that combines UI with REC adapted to the attenuation effect of the imaged medium.

Methods

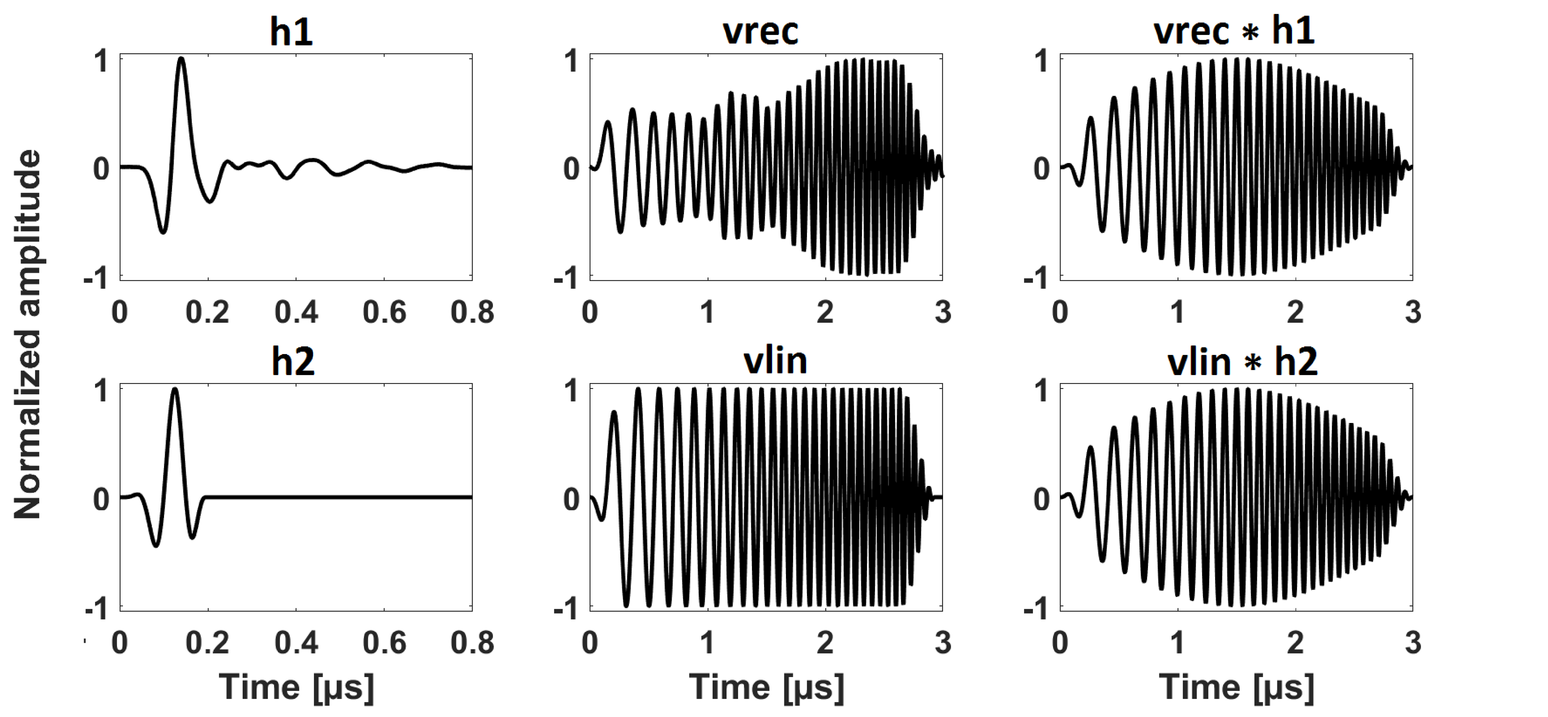


REC excitation signal $v_{rec}(t)$ comes from the equivalence between the real transducer and a fictive transducer with a higher bandwidth: $v_{rec}(t) * h_1(t) = v_{lin}(t) * h_2(t)$ **(1)**

- ✓ **$h_1(t)$: real impulse response** *(measured from a surface planar)*
- ✓ **$h_2(t)$: designed impulse response** *(broader than $h_1(t)$)*
- ✓ **$v_{lin}(t)$: linear chirp** *(weighted with a Tukey window)*

- **How to calculate $v_{rec}(t)$?** ⇒ **(1) in Fourier domain**

$$V_{REC}(f) = V_{REC}(f)\frac{H_2(f)}{H_1(f)} \rightarrow V_{REC}(f) = V_{REC}(f)\frac{H_2(f)H_1^*(f)}{|H_1(f)|^2 + |H_1(f)|^{-2}}$$



- **REC compression:**

$$\beta_{REC}(f) = \frac{V'^*_{LIN}(f)}{|V'_{LIN}(f)|^2 + \gamma \overline{eSNR}^{-1}(f)} \quad \text{with: } V'_{LIN}(f) = V_{REC}(f)\frac{H_1(f)}{H_2(f)}$$

- **RECopt compression**

$$H_{att}(f,d) = e^{-\alpha d|f|} \times e^{-j2\pi f \tau d} \times e^{-j\frac{2f\alpha d}{\pi}\ln(2\pi f)} \quad \text{with: } \tau = \tau_b + \frac{\alpha}{\pi^2}\tau_m$$

$\tau_b = 6.67\,\mu s/cm$, *is the bulk delay;* $\tau_m = 20$, *is the minimum-phase delay factor;* α *is the attenuation of the imaged medium,* d *is the distance between the probe and the considered depth* **[4]**.

$$\beta_{RECopt}(f,d) = \frac{V'^*_{LIN}(f,d)}{|V'_{LIN}(f,d)|^2 + \gamma \overline{eSNR}^{-1}(f)}$$

$$\text{with: } V'_{LIN}(f) = V_{REC}(f)\frac{H_1(f)H_{att}(f,d)}{H_2(f)}$$

✓ $\gamma \overline{eSNR}^{-1}$**: can be tuned in order to adjust the tradeoff between axial resolution and eSNR**

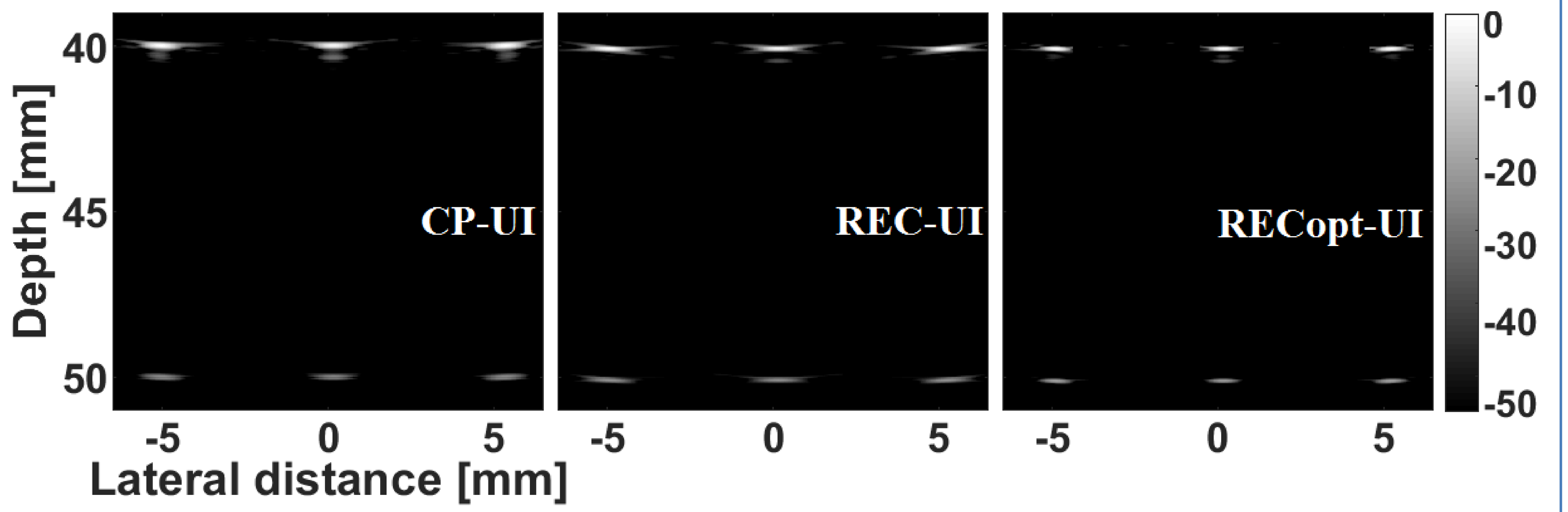
Acquisition parameters

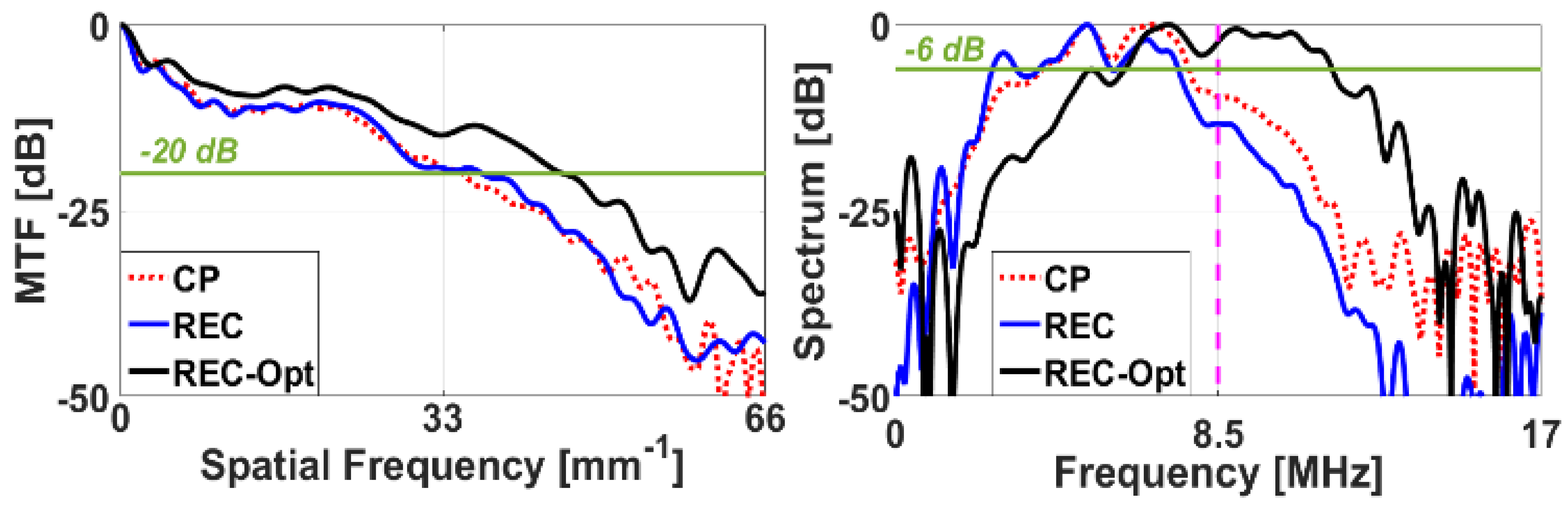
UlaOp having **64 channels data**, equipped with a linear array model **LA 523E**

- ✓ Pitch = 245 µm, f_0 = 8,5 MHz, f_s = 50 MHz
- ✓ 27 plane waves in transmission separated by 0,67º between -9º and +9º

Results

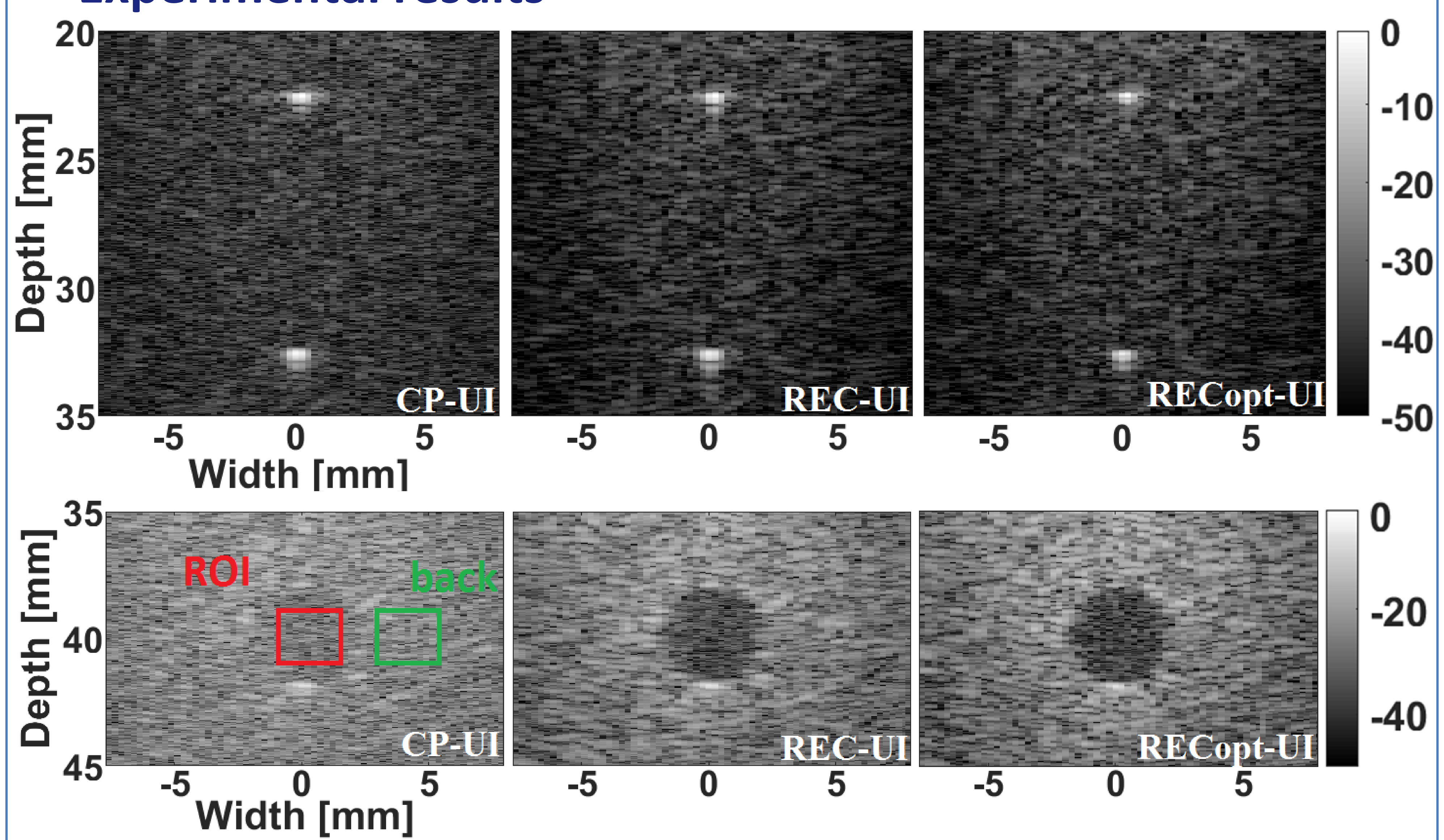
Simulation results





Metrics	CP-UI	REC-UI	RECopt-UI	Enhancements: RECopt-UI vs CP-UI	Enhancements: RECopt-UI vs REC-UI
MTF (mm⁻¹)	35.5	37.1	**47.2**	*+ 33.0 %*	*+ 27.2 %*
Bandwidth (MHz)	3.85	4.04	**5.45**	*+ 29.4 %*	*+ 25.9 %*
eSNR (dB)	19.9	27.7	**30.1**	*+10.2 dB*	*+2.4 dB*

Experimental results



Metrics	CP-UI	REC-UI	RECopt-UI	Enhancements: RECopt-UI vs CP-UI	Enhancements: RECopt-UI vs REC-UI
Axial resolution (µm)	218.2	211.6	**167.9**	*+ 30.0 %*	*+ 26.0 %*
Bandwidth (MHz)	2.54	2.61	**3.57**	*+ 28.9 %*	*+ 26.9 %*
SNR (dB)	14.8	16.1	**18.2**	*+ 3.4 dB*	*+ 2.1 dB*
CNR (dB)	-4.31	4.32	**5.49**	*+ 9.8 dB*	*+ 1.2 dB*

Conclusion

- **The experimental results show that REC adapted to the medium attenuation provides a better image quality than classical REC and than CP.**
- **This study proves that, by adapting the impulse response and the attenuation coefficient, this method can be implemented on a research scanner using any ultrasound probe.**

[1] M. L. Oelze, "Bandwidth and resolution enhancement through pulse compression," IEEE TUFFC ,2007.
[2] G. Montaldo, M. Tanter, J. Bercoff, N. Benech, and M. Fink "Coherent Plane-Wave Compounding for Very High Frame Rate Ultrasonography and Transient Elastography," IEEE TUFFC, 2009.
[3] P. Tortoli, L. Bassi, E. Boni, A. Dallai, F. Guidi, and S. Ricci, "UlaOp: an advanced open platform for ultrasound research," IEEE TUFFC, 2009.
[4] K. V. Gurumurthy, and R. Martin Arthur "A dispersive model for the propagation of ultrasound in soft tissue," Ultrasonic Imaging, 1982.

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