Optimal Control by Transmit Frequency in Tissue Harmonic Imaging

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Inserm U930 - *Imaging and Brain*
Team 5 - *Imaging and Ultrasound*
Tours, France

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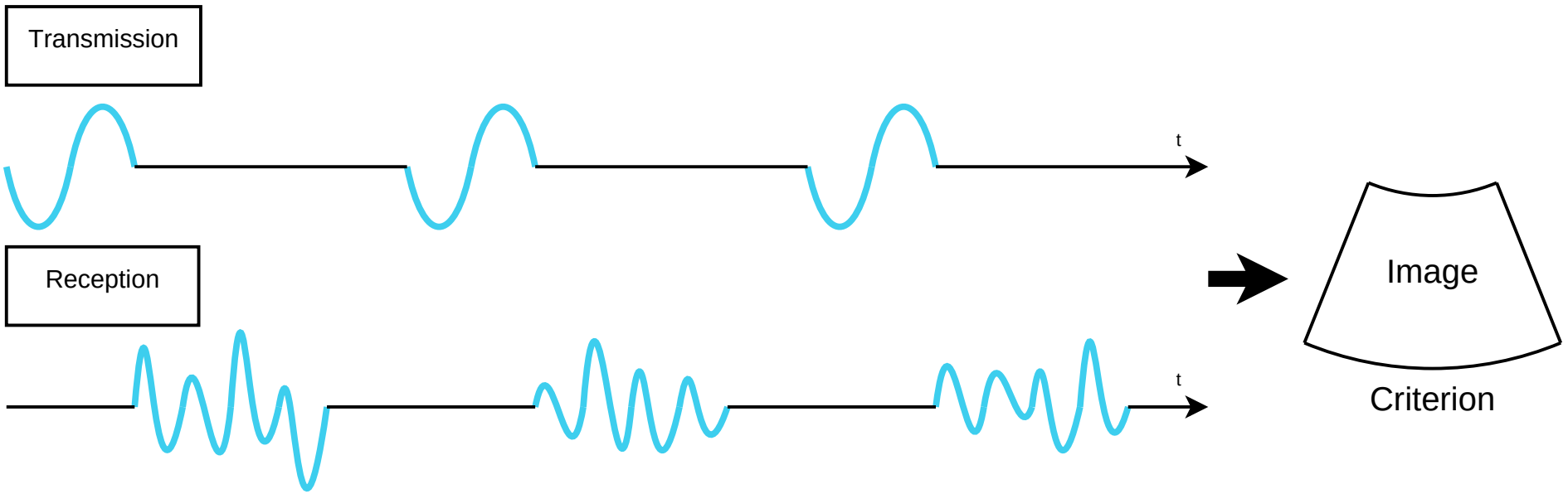
Outline

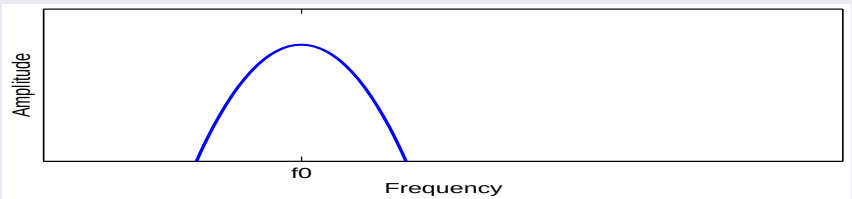
Introduction

Ultrasound Imaging System



Ultrasound Imaging System

Transmission



Reception

Ultrasound Imaging System

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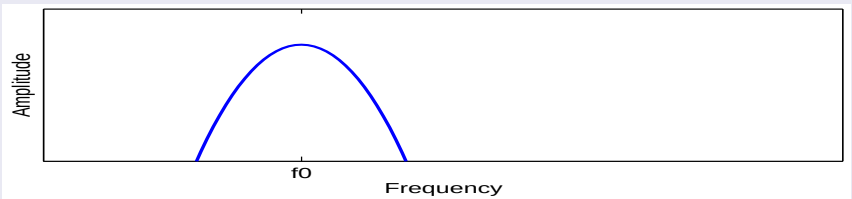

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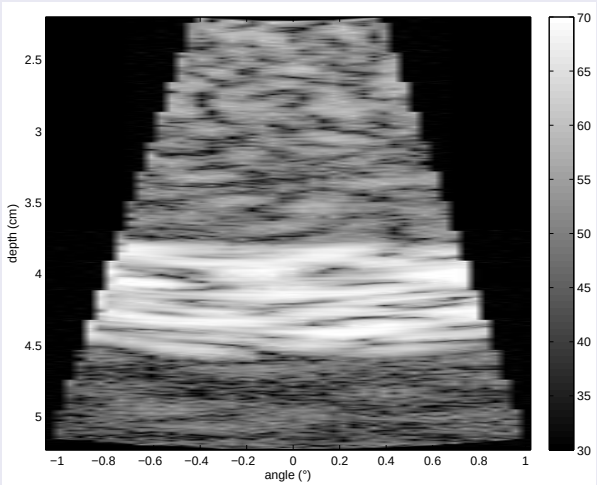

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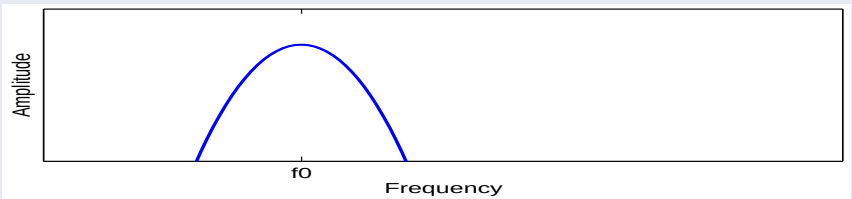

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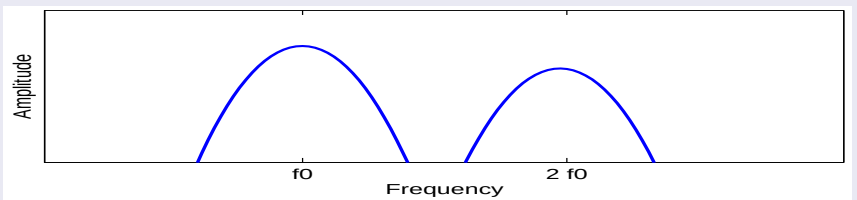
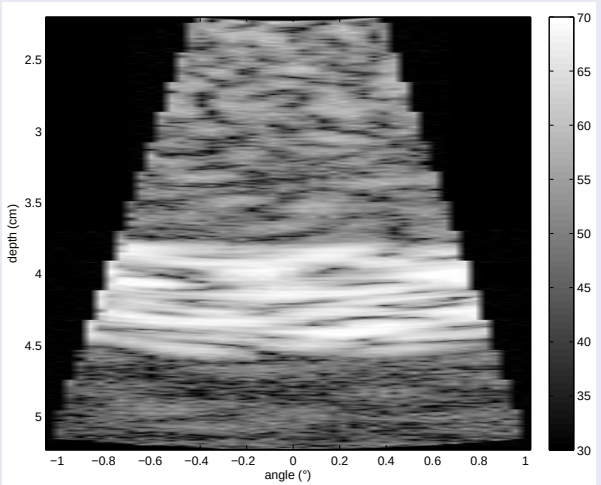
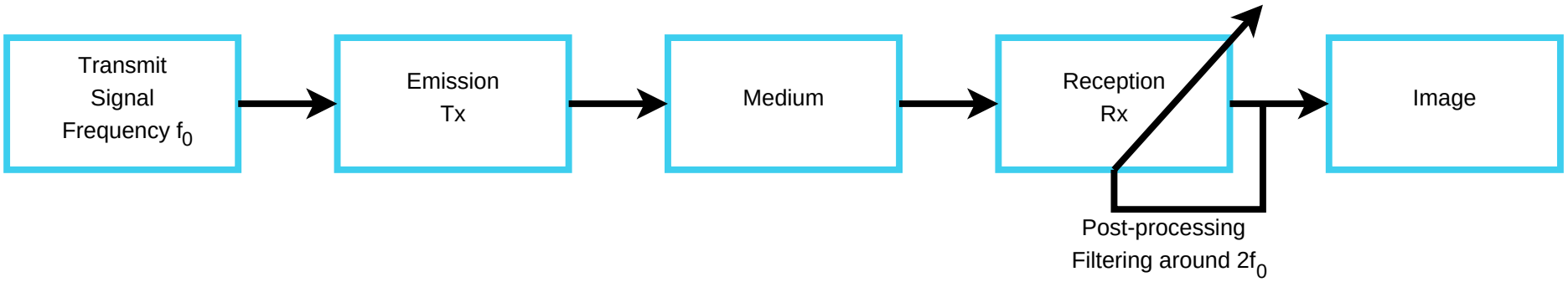
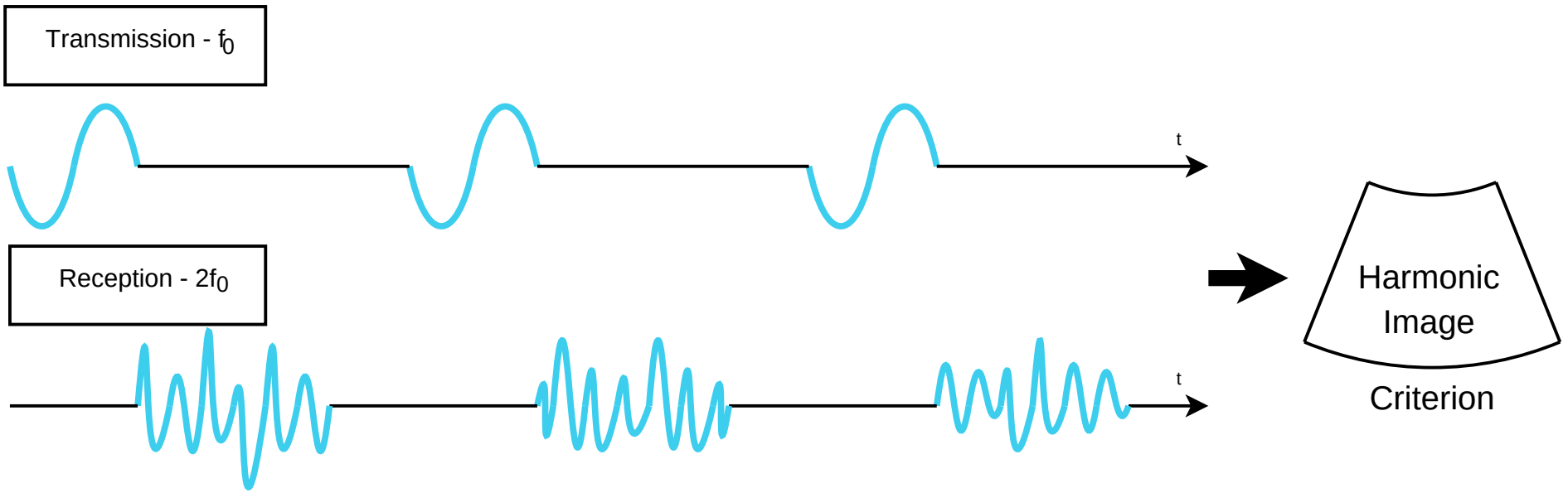




Ultrasound Second Harmonic Imaging





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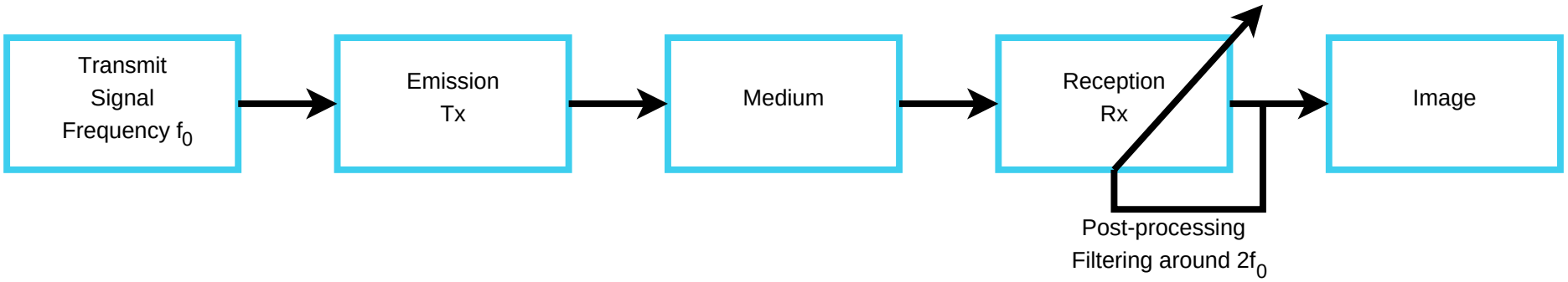

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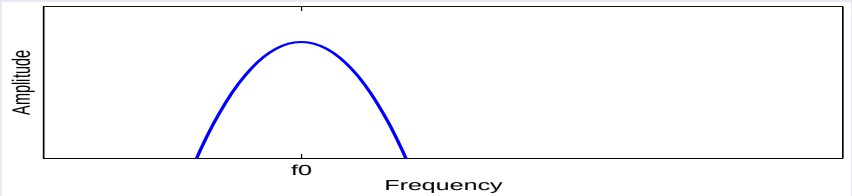

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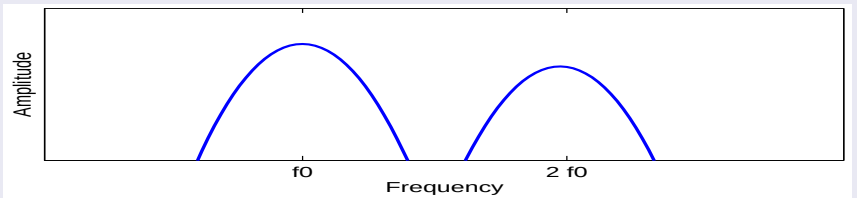

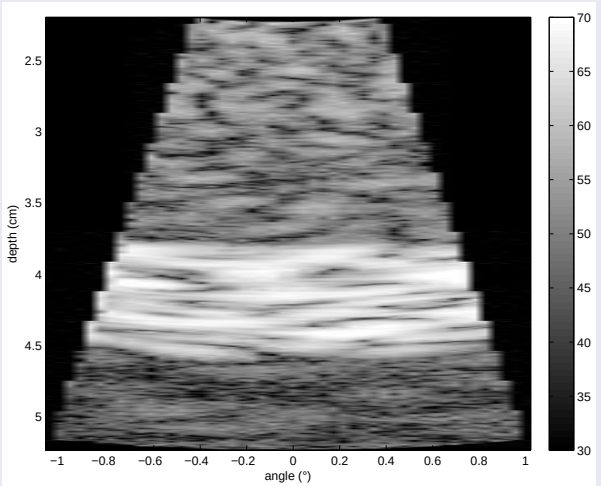

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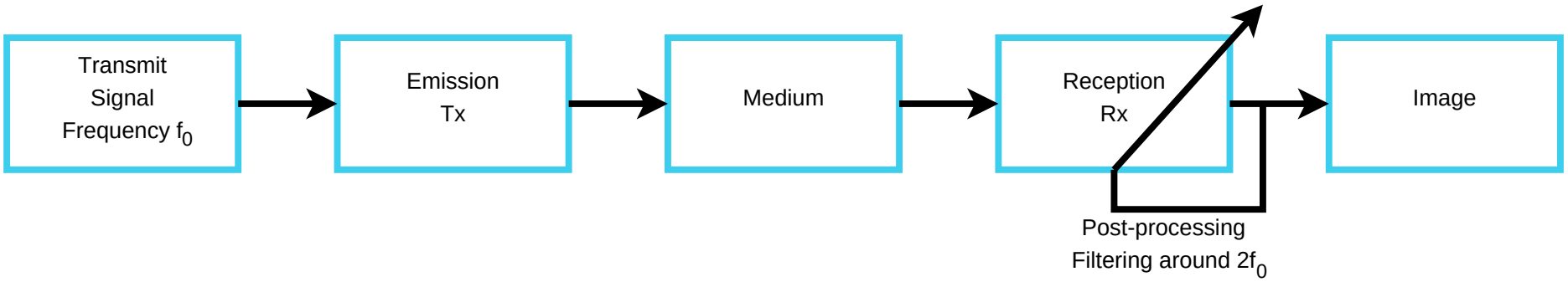

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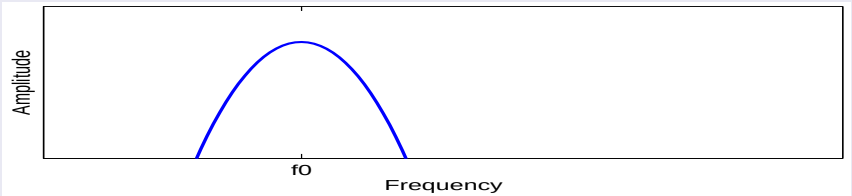

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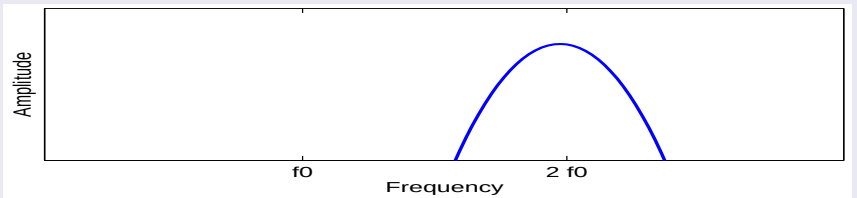

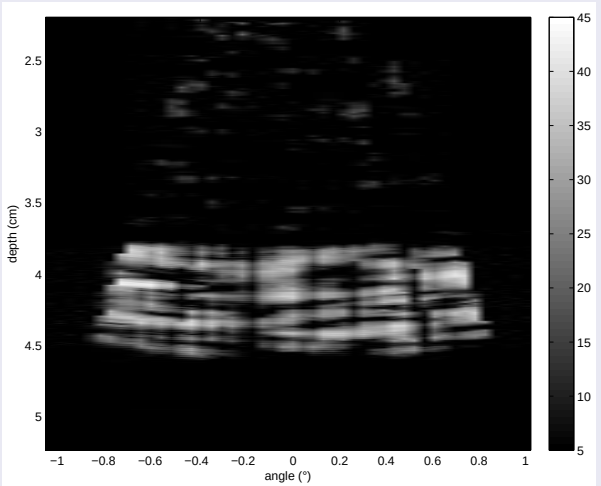

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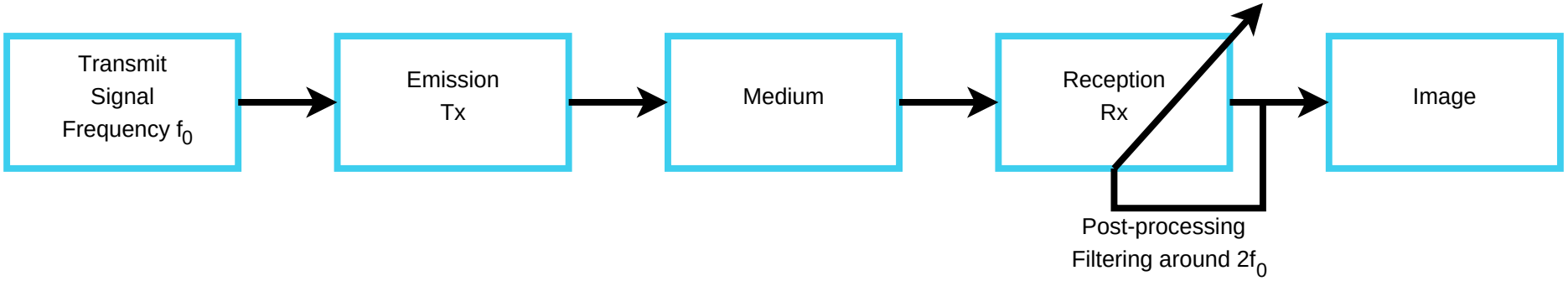

How to choose the transmit frequency f_0 ?

- Advice : $2/3 f_c$ with f_c = central frequency of the transducer
- Is it optimal ?

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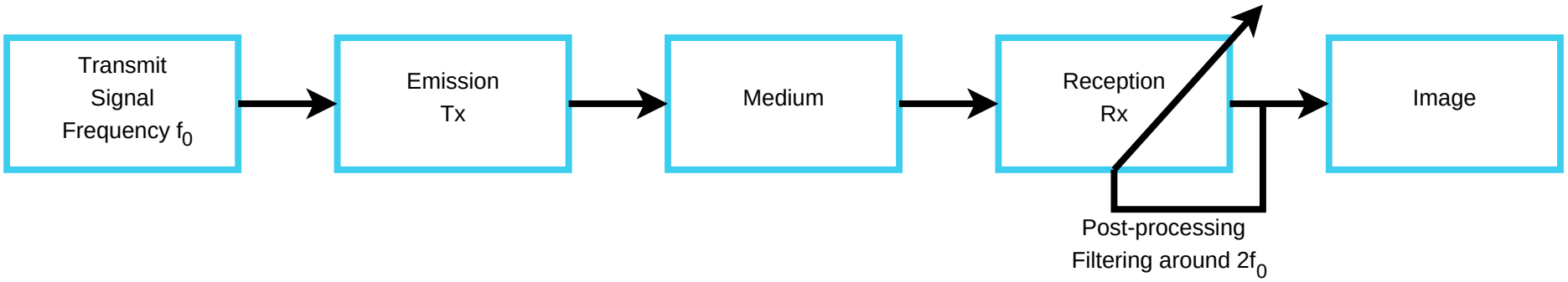

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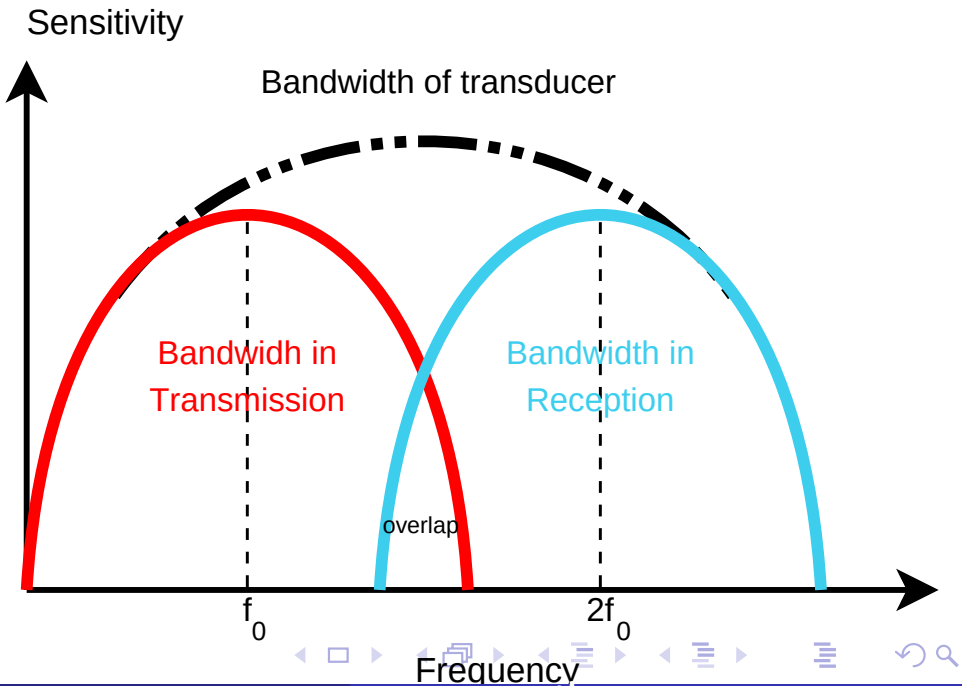

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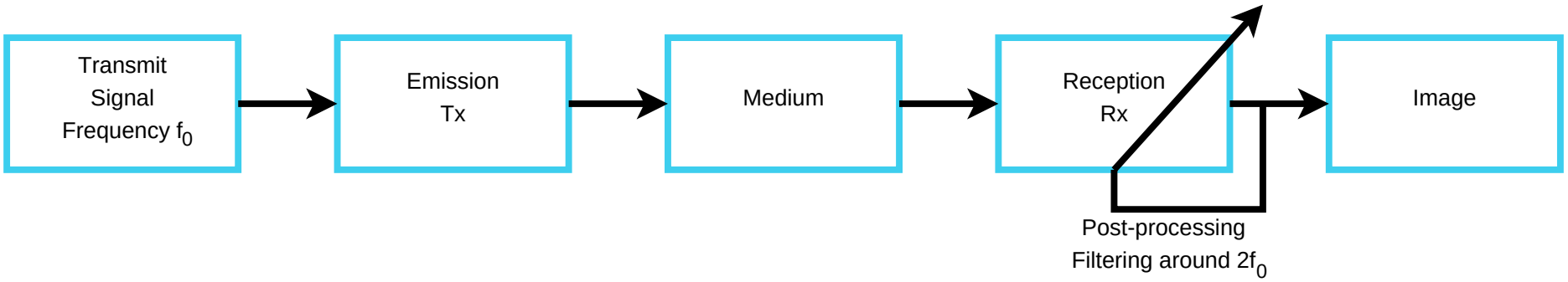

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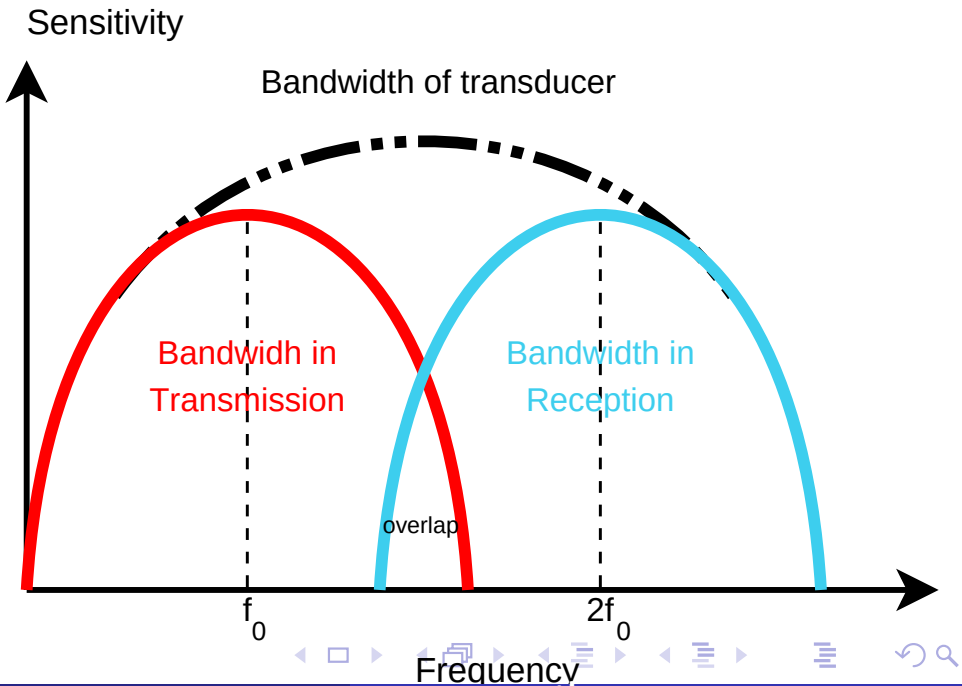
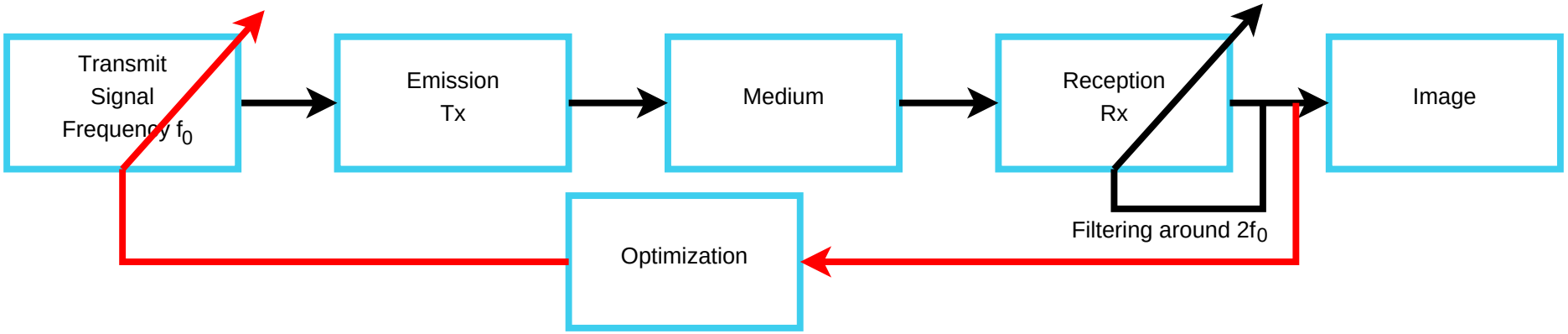
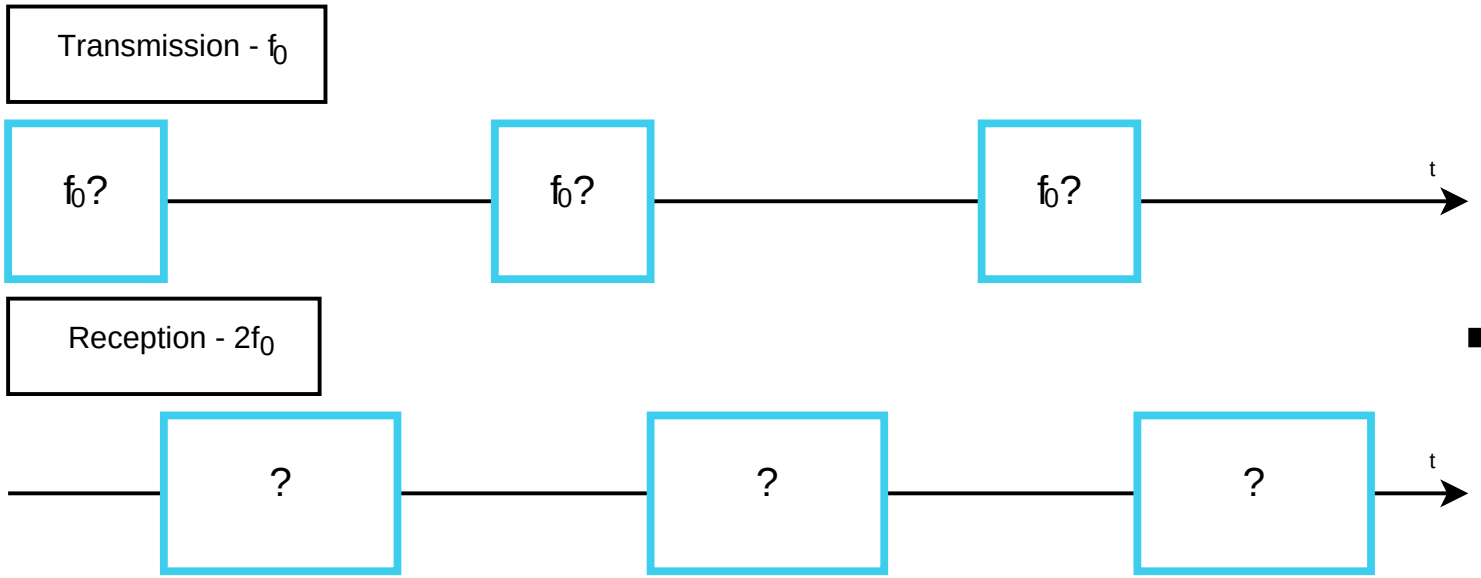
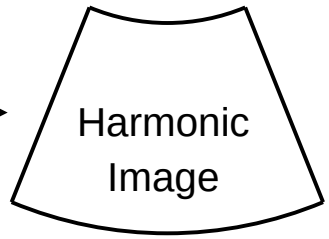


Optimal Transmit Frequency for Ultrasound Imaging System







OPTIMAL
Criterion

Implementation of the Closed Loop System

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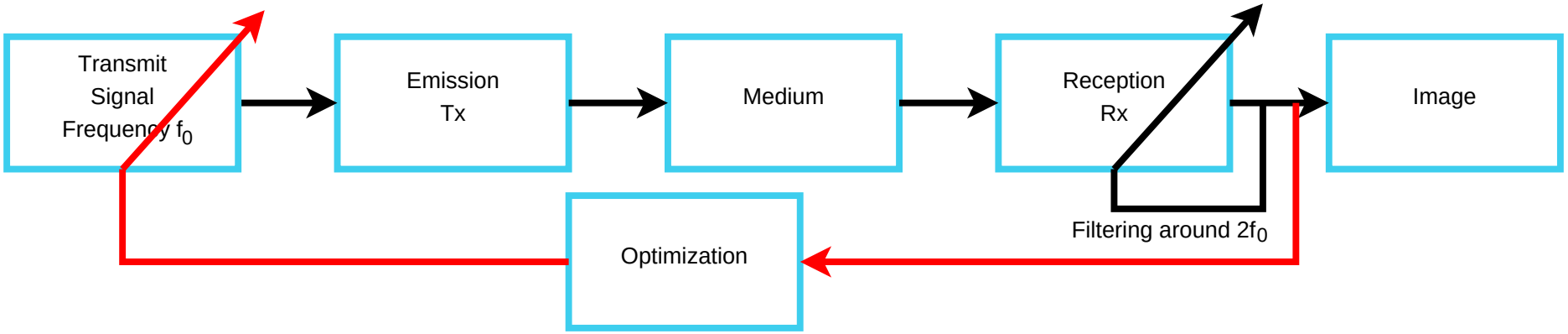

Setting of Iterative Optimization

1. Choice of the Cost Function $J(\theta)$
2. Choice of the parameters θ
3. Choice of the optimization algorithm

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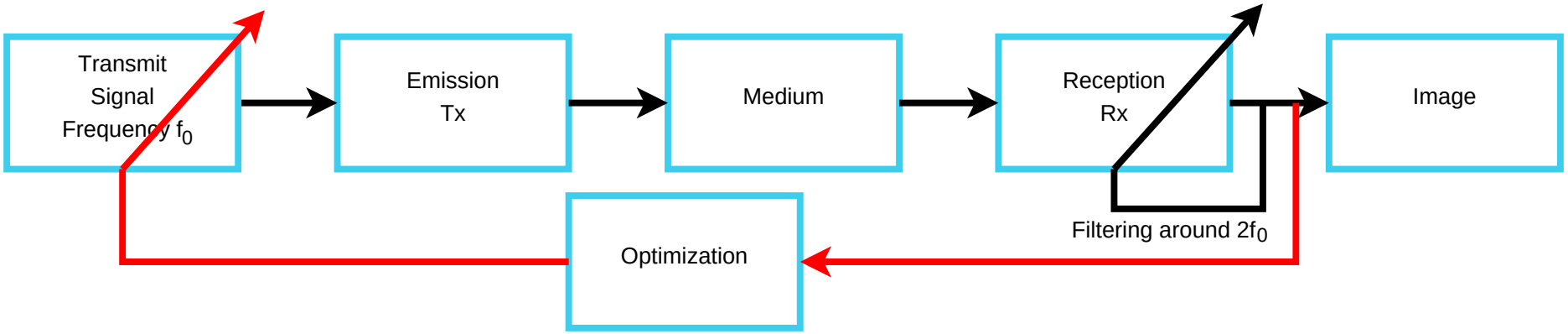

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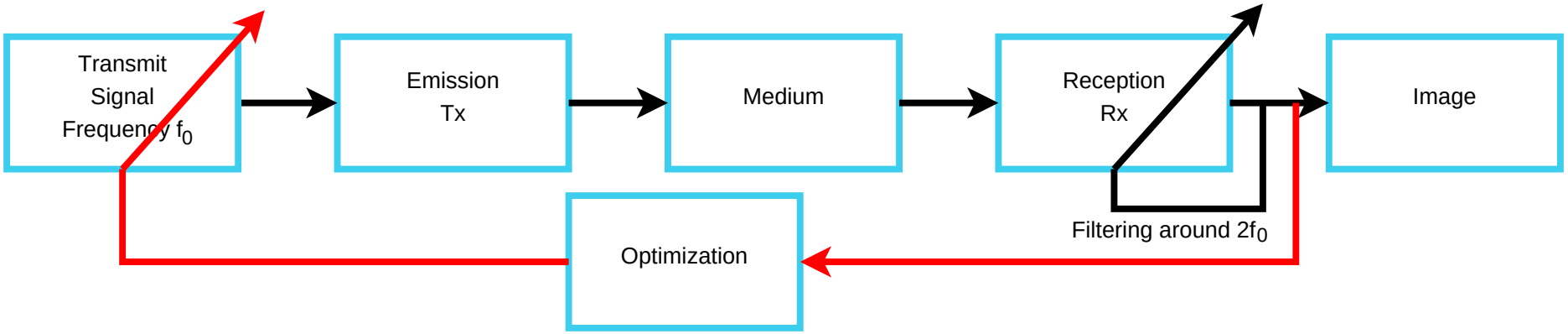

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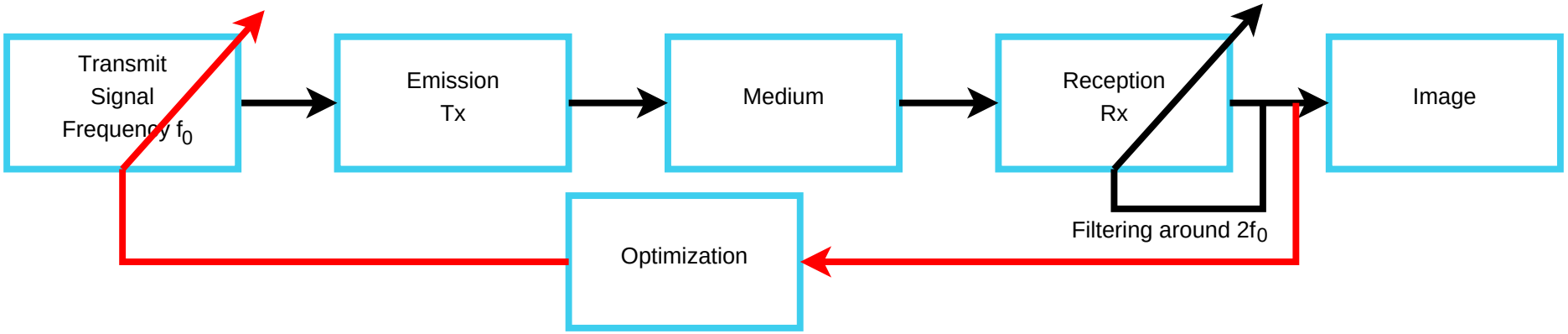

Setting of Iterative Optimization

1. Choice of the Cost Function $J(\theta)$
2. Choice of the parameters $\theta \rightarrow$ Transmit frequency f_0
3. Choice of the optimization algorithm

Find the Cost Function for the Goal

Goal

Maximize the contrast by the transmit frequency f_0

① Choice of the Cost Function

- Maximize nonlinear behavior
- Minimize linear behavior
- Cost Function "*Contrast Harmonic to Fundamental Ratio*" :

$$CHFR(f_0) = \frac{\text{Second Harmonic Power}}{\text{Fundamental Power}}$$

- Constraint : constant transmitted power

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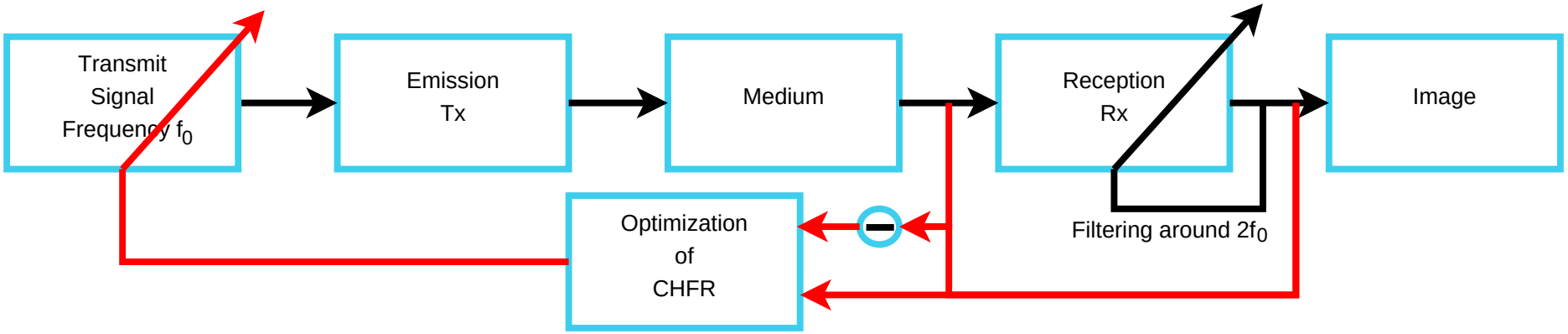
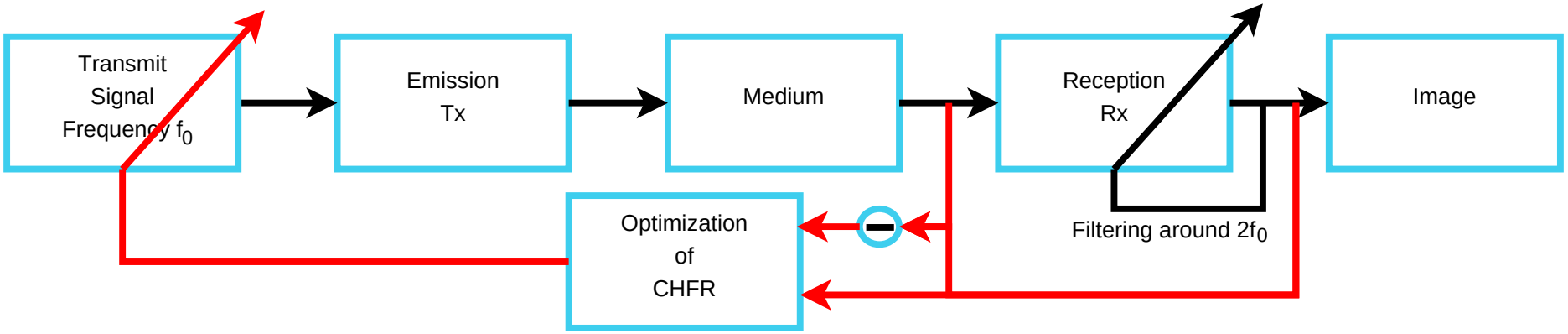

Transmit
Signal
Frequency f_0
Emission
Tx
Medium
Reception
Rx
Image
Optimization
of
CHFR
Filtering around $2f_0$

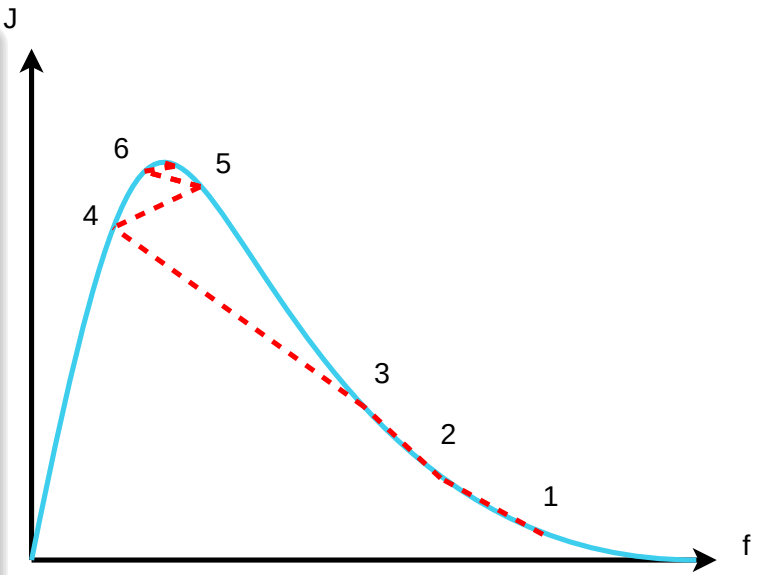
Algorithm



③ Algorithm and Principle

- **Method of Gradient**
- Seek the maximum by "going up the descent"

$$f_{k+1} = f_k + \alpha_k \cdot \nabla CHFR(f_k)$$



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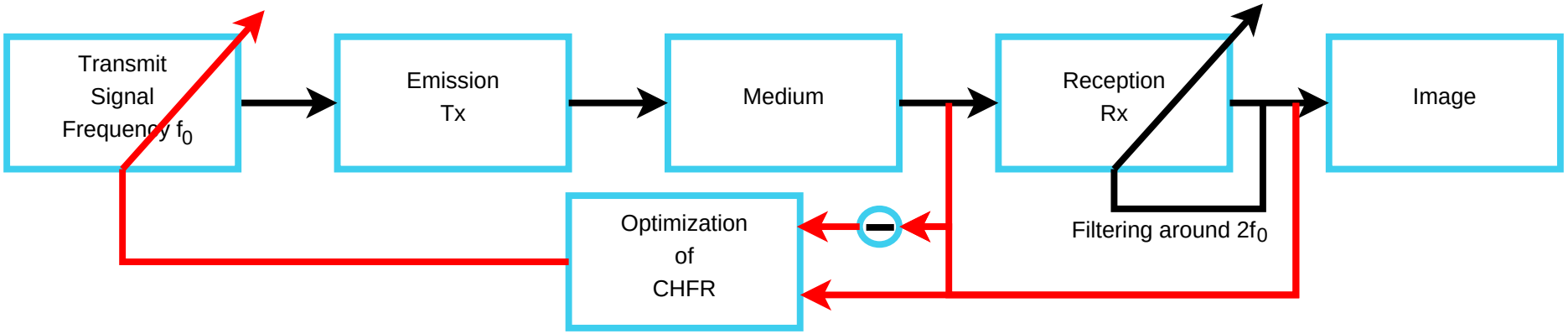

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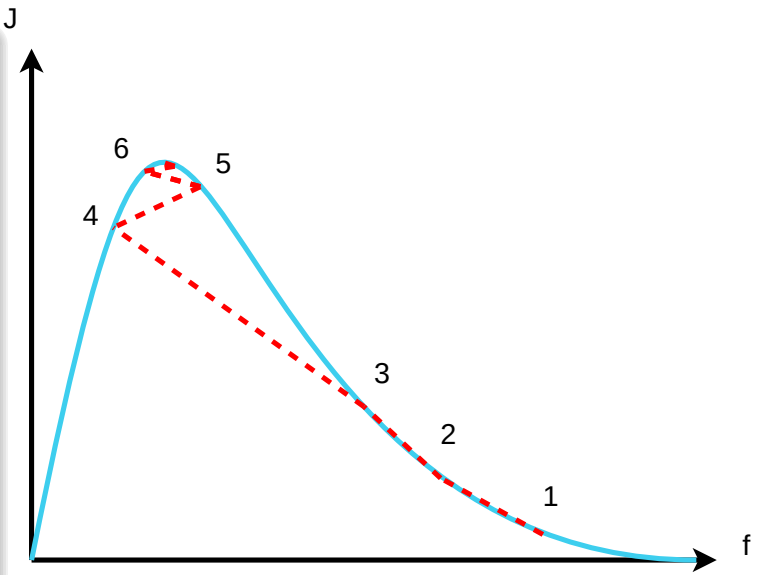
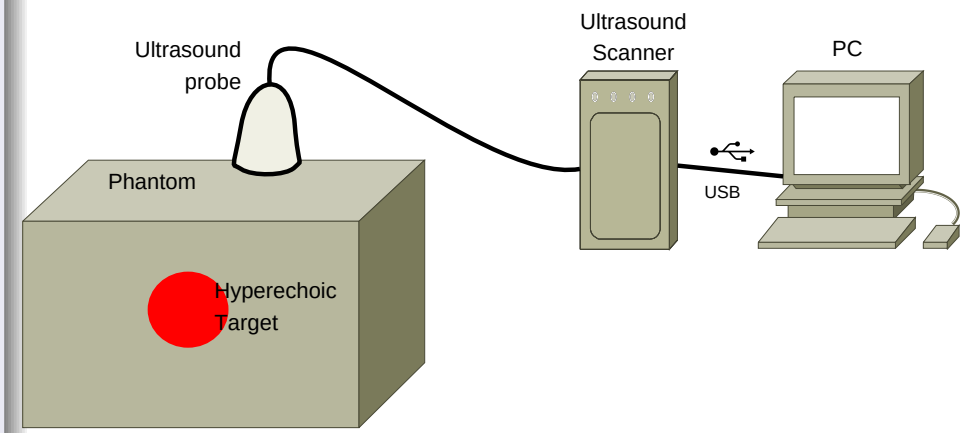


Materials

Simulation and Experimental Setup

Experiment

- "Open" Ultrasound Scanner
  (MultiX WM, M2M, Les Ulis, France)
- Probe centred at $f_c = 4$ MHz
  (Vermon SA, Tours, France)
- Phantom with hyperechoic target
  (CIRS, Norfolk, VA, USA)



Simulation

- Transducer centred at $f_c = 3.5$ MHz
- Nonlinear propagation: pseudo-spectral method [Anderson, 2000]
- Tissue with a blood vessel

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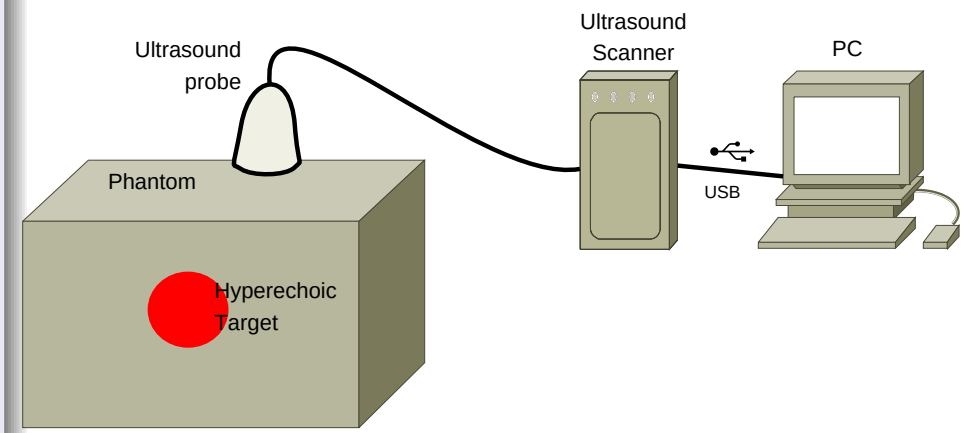

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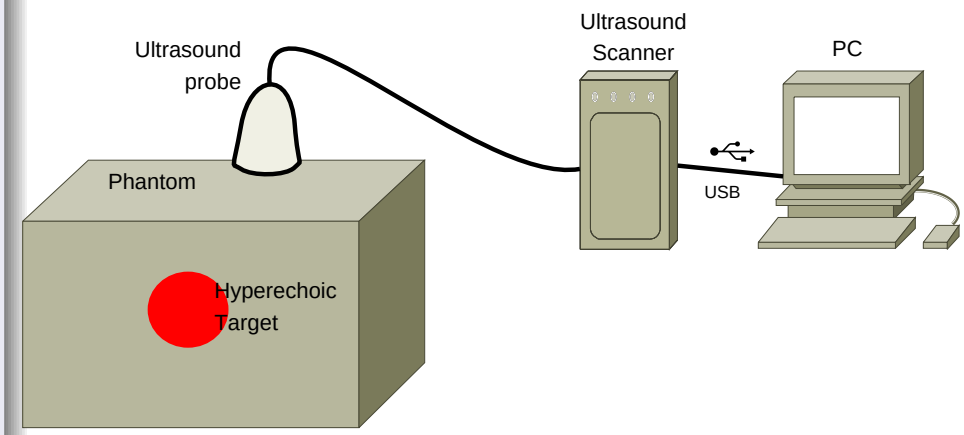

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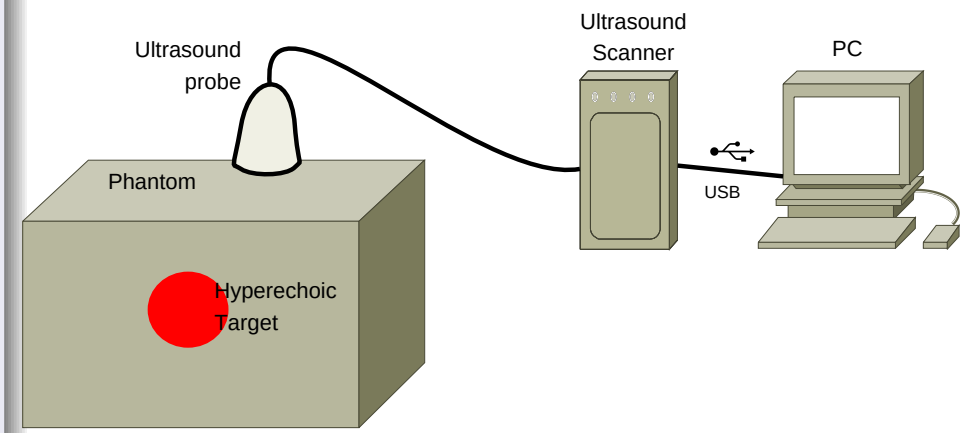

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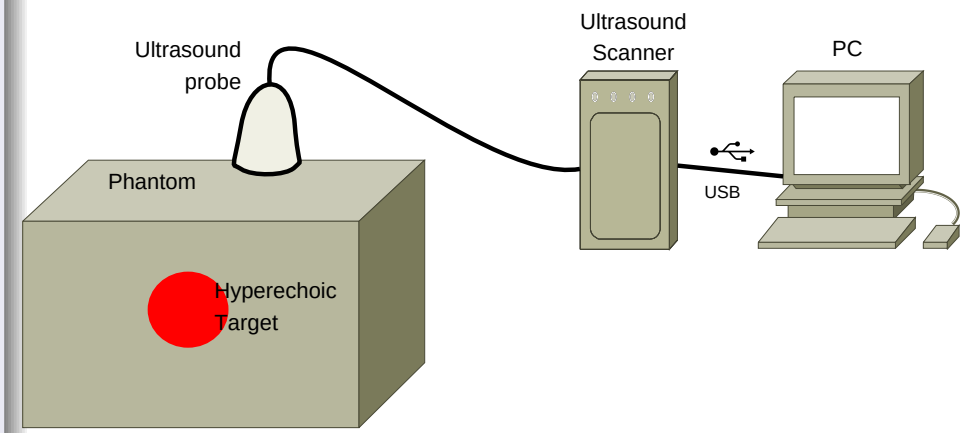

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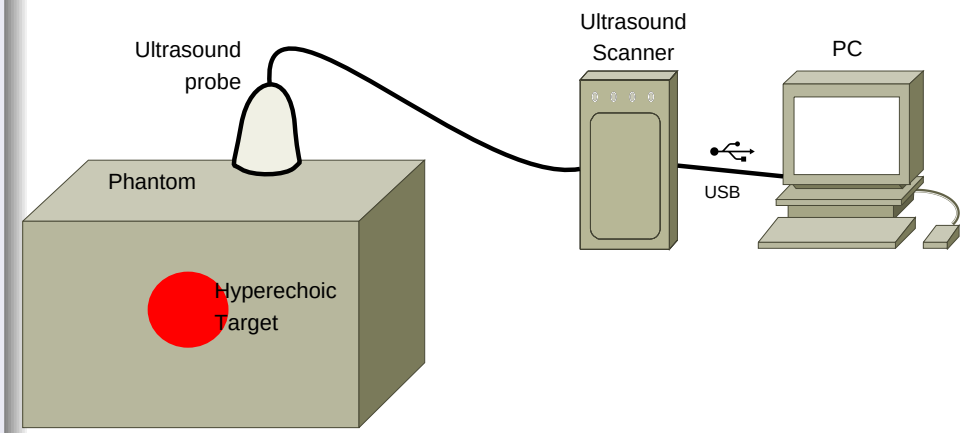

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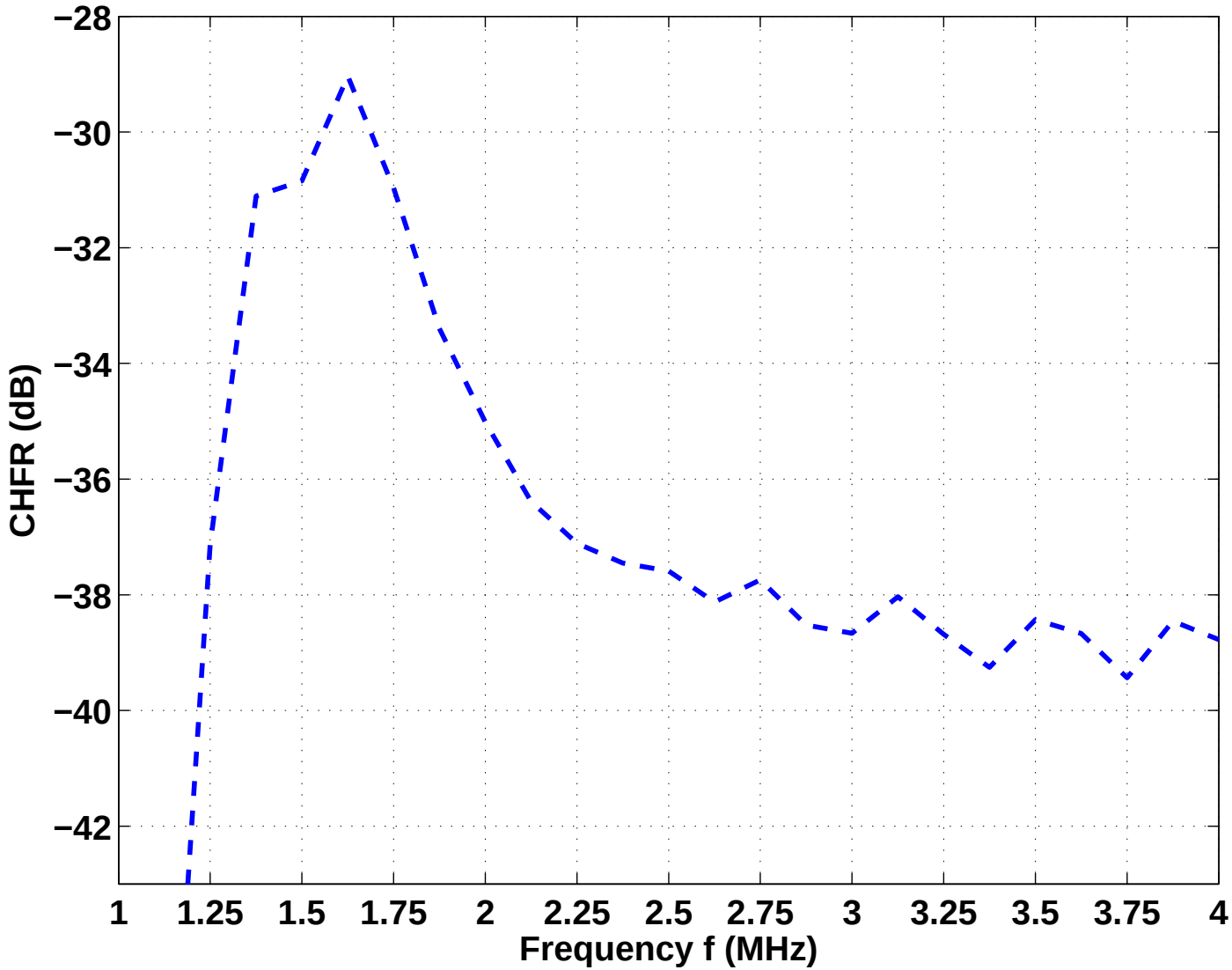
Results

Simulation: Empirical Optimization



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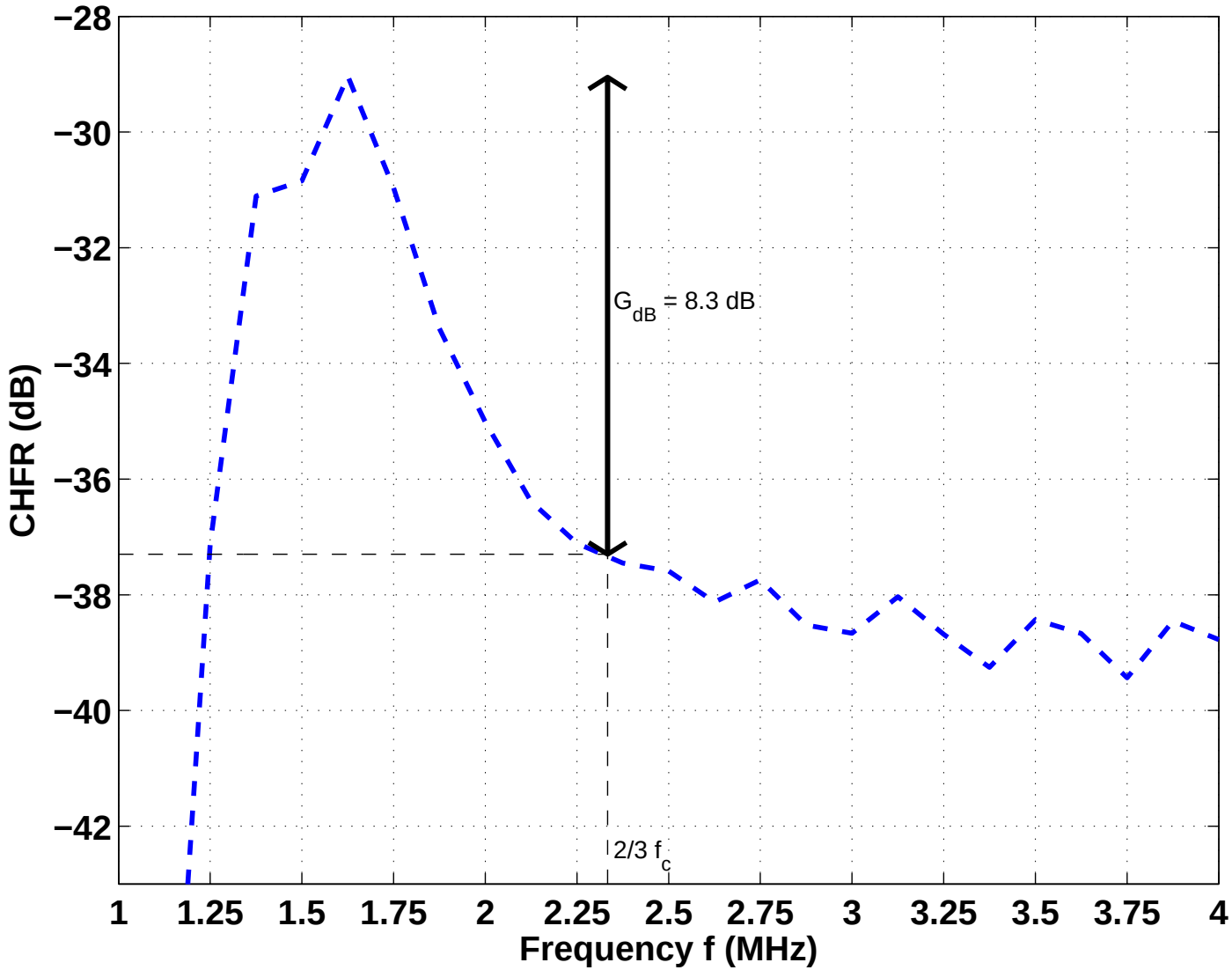
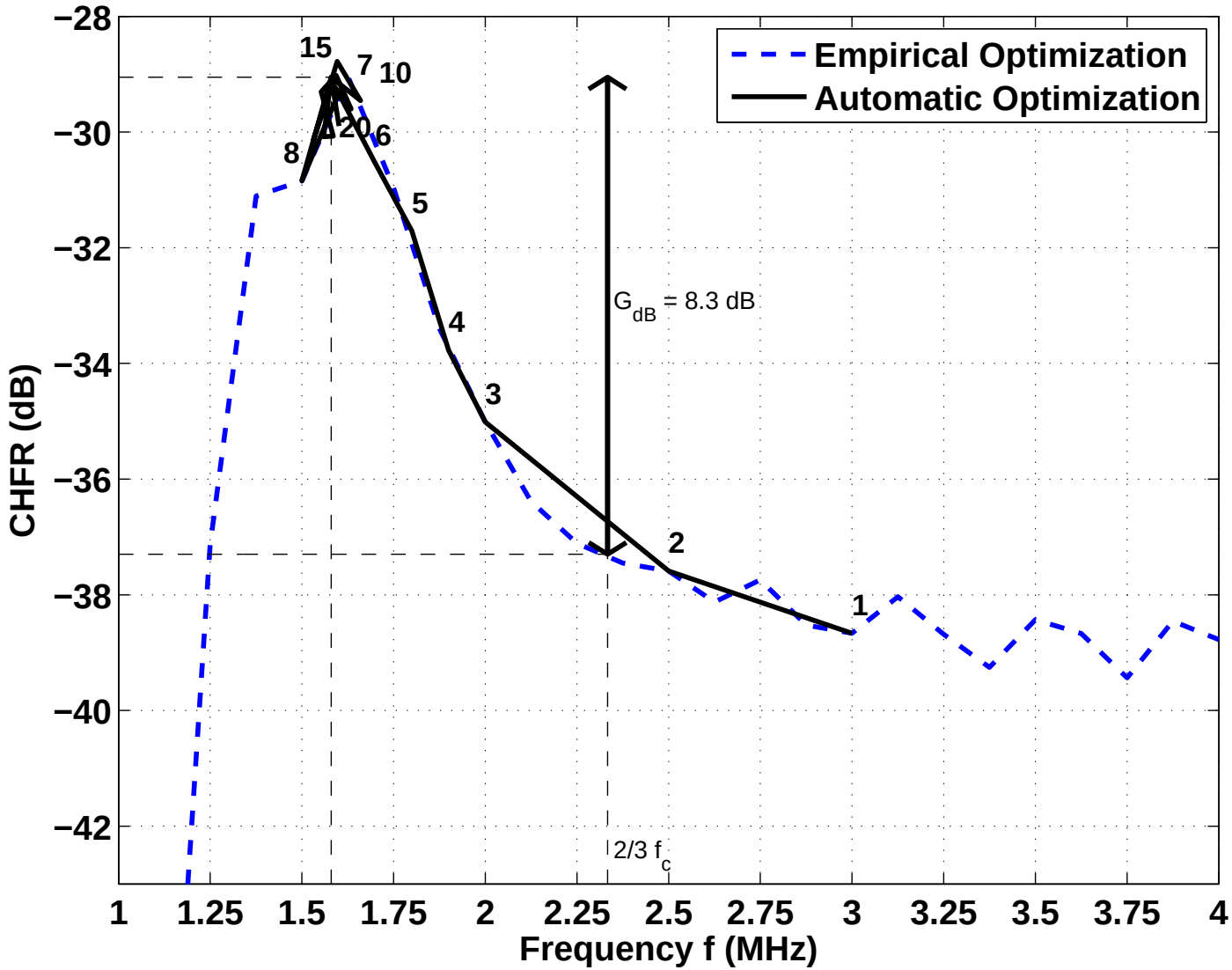
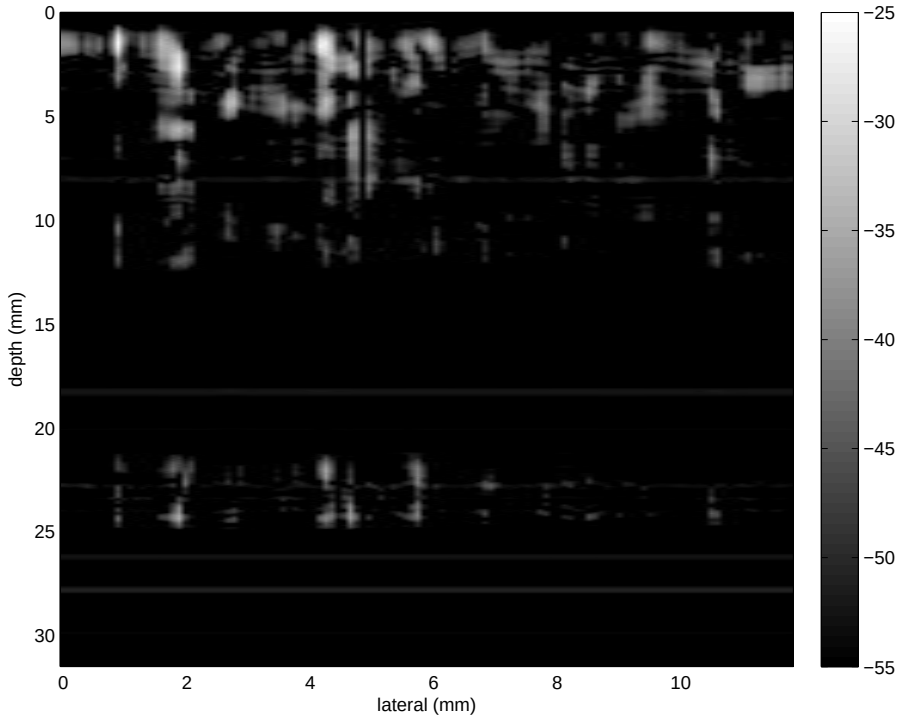


Simulation: Automatic Optimization



Simulation: Synthetic Images



$$f_0 = 2/3 f_c = 2{,}3 \text{ MHz}$$

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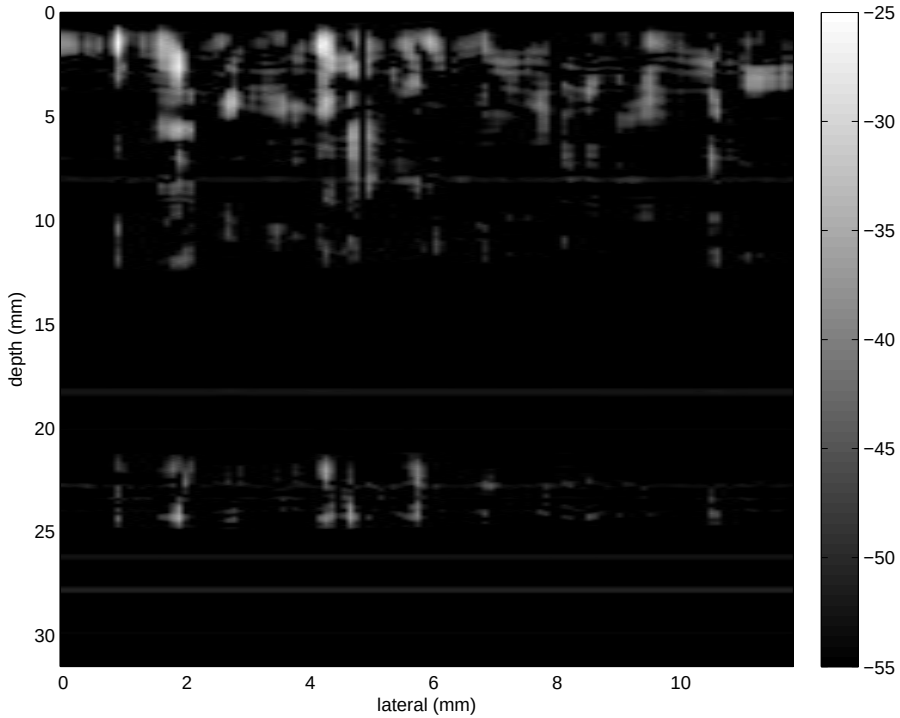

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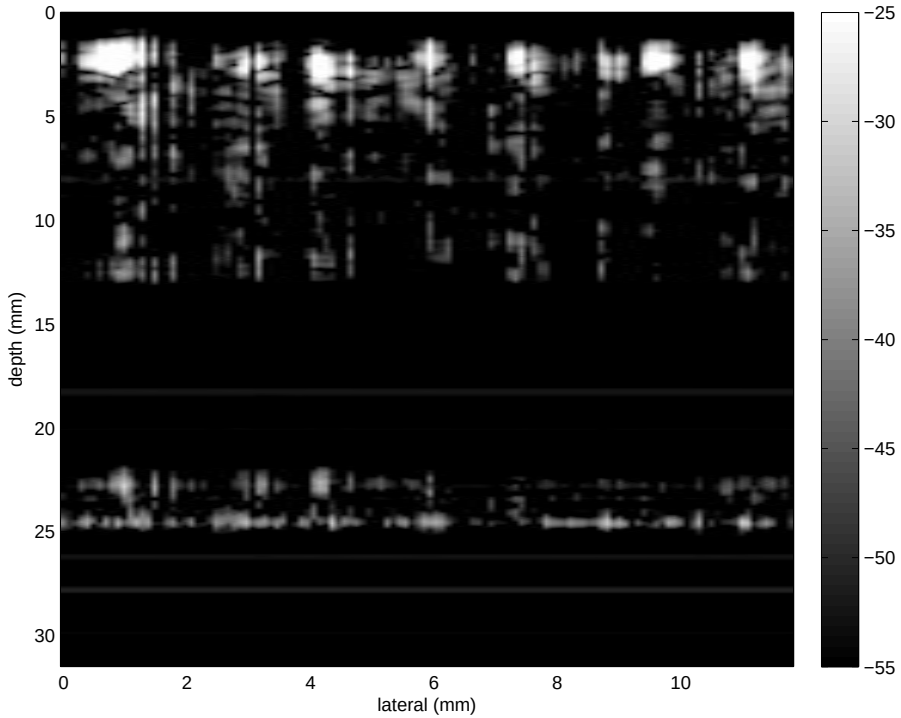
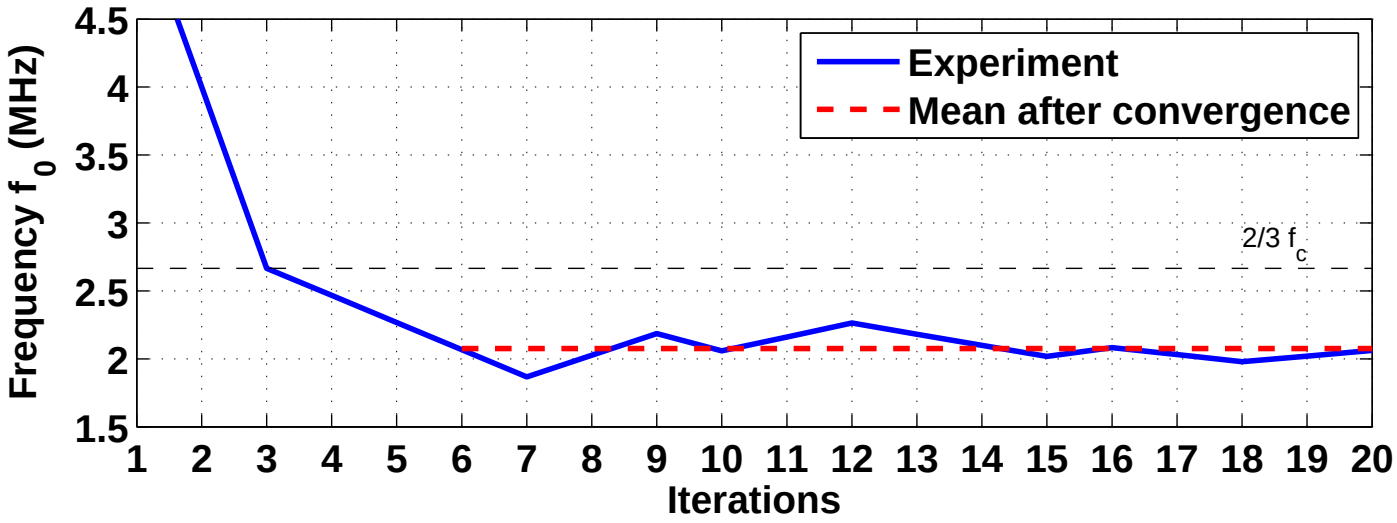
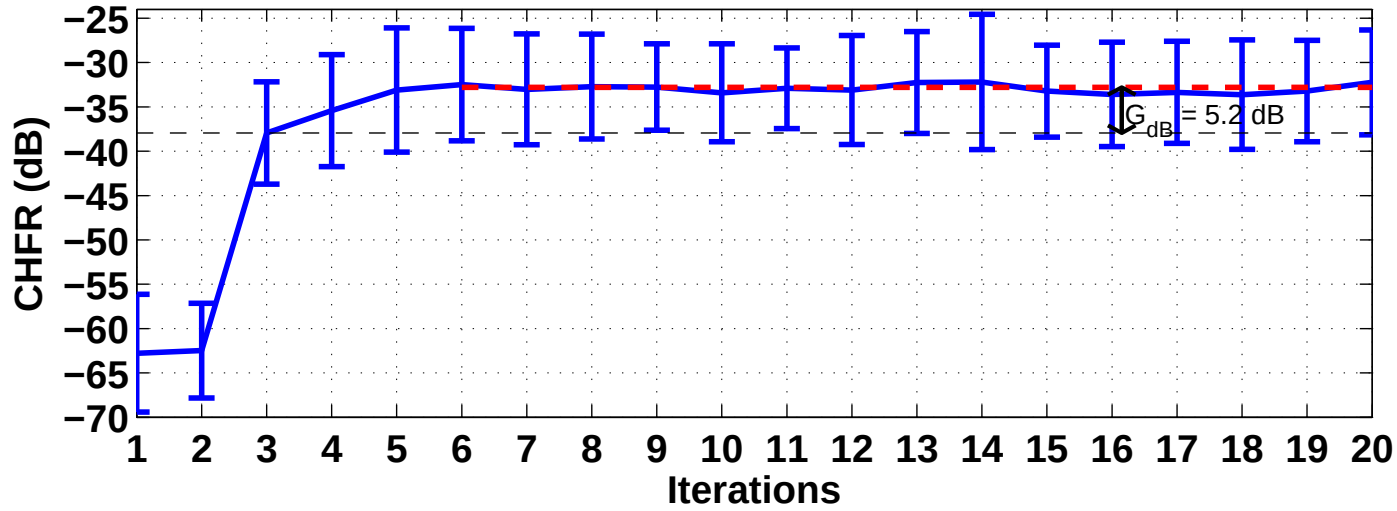


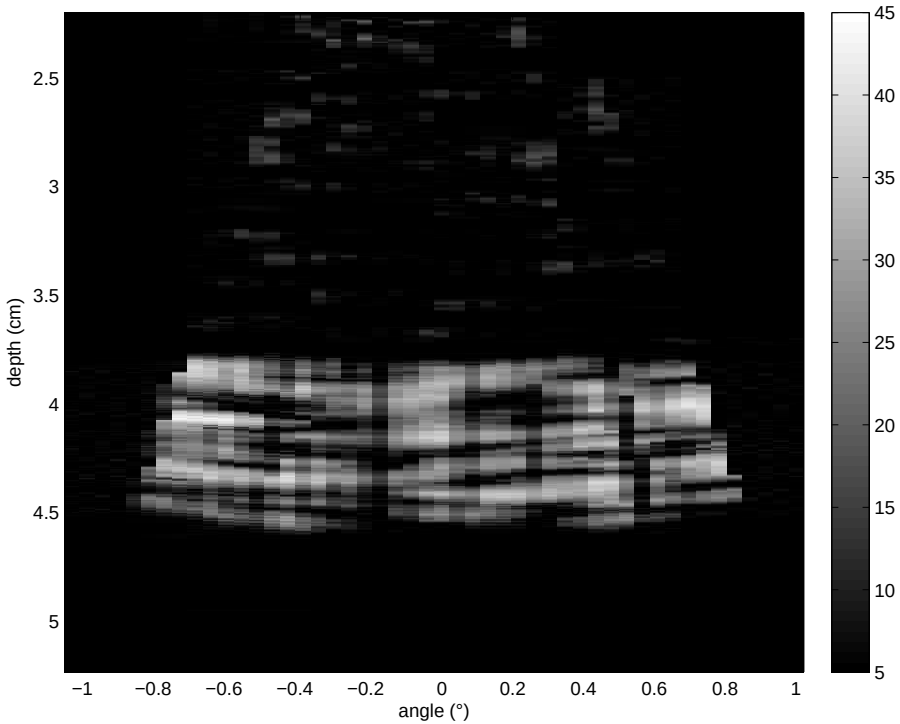
$f_0 = f_{0,opt} = 1{,}6$ MHz

Experiment: Automatic Optimization



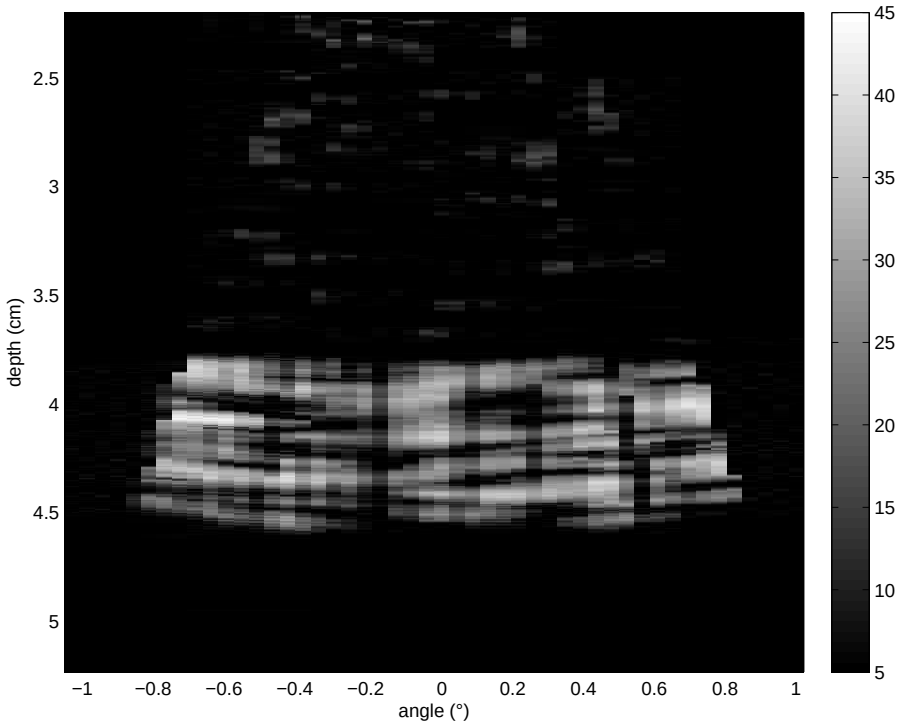


Experiment: Images

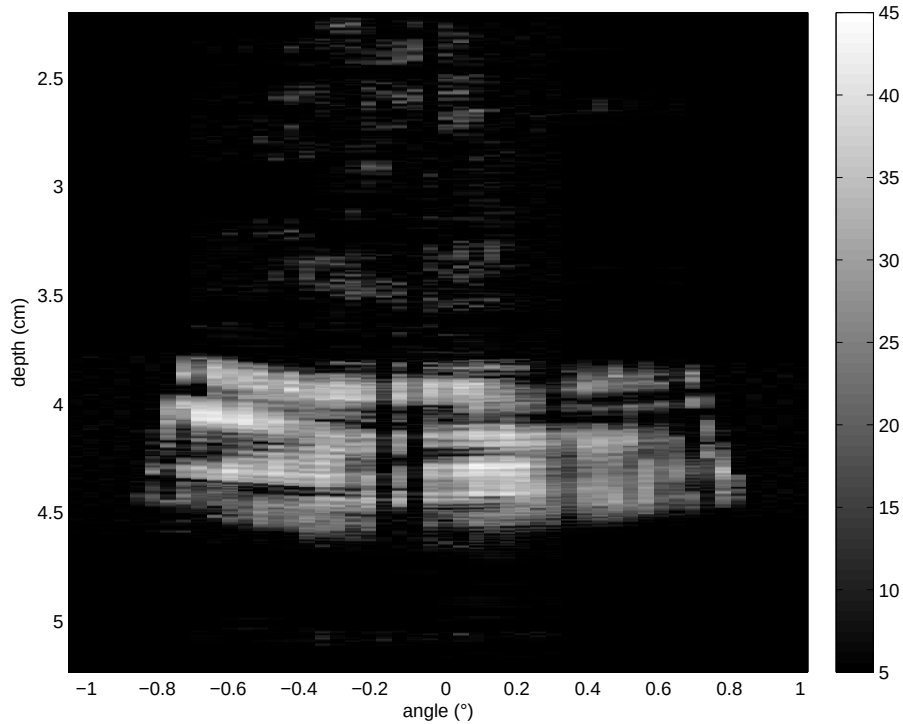


$$f_0 = 2/3 f_c = 2{,}3 \text{ MHz}$$

Experiment: Images



$f_0 = 2/3 f_c = 2{,}3$ MHz



$f_0 = f_{0,opt} = 1{,}6$ MHz

Conclusion & Prospects

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- Automatic optimization of the contrast (*CHFR*)
- Adapt itself to optimize the contrast
- Setting without knowlegde of medium or transducer
- Gain of around 5 dB with our closed-loop system
- Prospects: application to another harmonic imaging methods

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Thank you for your attention

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