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# Optimal Filtered Stochastic Transmitted Waves for Fat Inclusion Detection in Milk with Harmonic Ultrasound

Sébastien Ménigot, Nesrine Houhat, Jean-Marc Girault

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## Introduction

In non destructive testing, improvements have been made possible by taking into account the **harmonic frequencies**, as in agri-food domain. The transmitted signal are often selected manually as a fixed-frequency Gaussian pulse, by taking into account the transducer bandwidth only. However, **waveform should take into account all the features of the ultrasound system and of the medium**. To design the waveform, a **genetic algorithm looks for the best stochastic wave** [1]. One of limitations in this optimization process is the high amount of transmitted waves required to reach the optimal signal-to-noise ratio (SNR). To reduce this amount, instead of transmitting wide band stochastic waves by the transducer, stochastic waves were **prefiltered by a narrow band filter** similar to the transducer bandwidth. The optimization was thus applied on the **detection of fat cluster in milk by maximizing the SNR**, while decreasing the amount of transmitted waves.

## Main Objectives

1. **Waveform design of pulse inversion system.**
2. **Optimizing the SNR** defined as the ratio between the backscattered power of fat cluster  $P_{fat\ cluster}$  and the backscattered power of the surrounding milk  $P_{milk}$ , such as:

$$SNR = 10 \log_{10} \left( \frac{P_{fat\ cluster}}{P_{milk}} \right). \quad (1)$$

3. **Finding the best prefiltered stochastic waveform  $w_{filtered}$  with a genetic algorithm.**

$$w_{filtered}^* = \arg \max_{w_{filtered}} (SNR), \quad (2)$$

4. **Finding the cut-off frequencies to compute stochastic signals.**

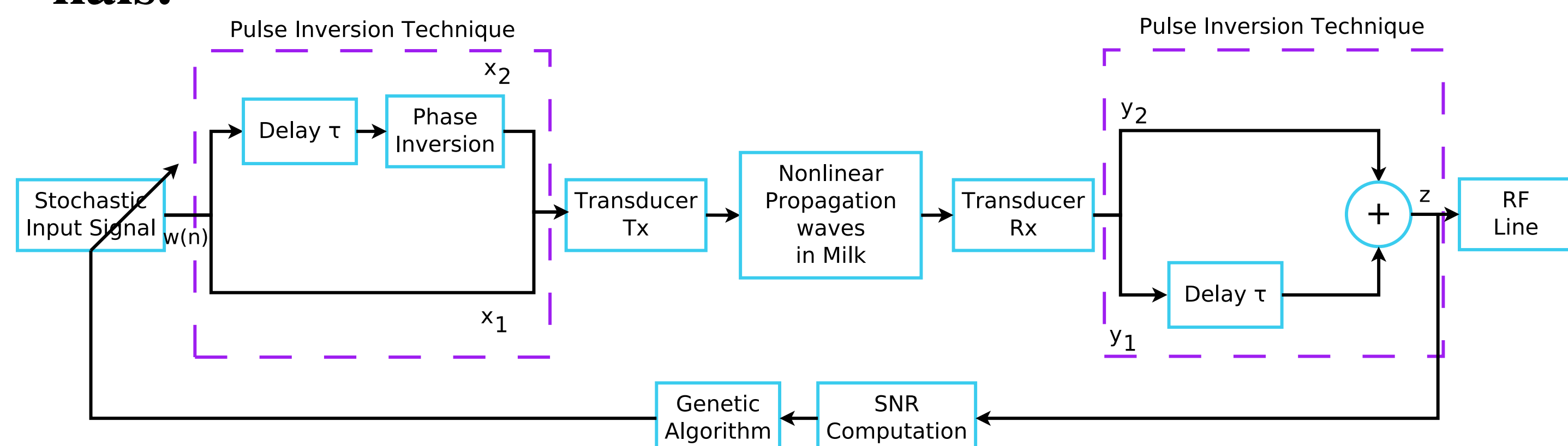


Figure 1: Block diagram of the pulse inversion system with SNR optimization

## Optimization with Filtered Stochastic Waves

1. **Generating 12 prefiltered stochastic waveforms  $w_{filtered}$  from white noise (between -1 and 1) prefiltered by a finite impulse response (FIR) filter between the low cut-off frequency  $f_{low}$  and the high cut-off frequency  $f_{high}$ .**
2. **Transmission** of each of prefiltered stochastic waveforms  $w_{filtered}$  and its opposite phase

$$x_q = (-1)^q \cdot A \cdot w_{filtered}, \quad (3)$$

with  $q = 1, 2$ ,  $A = \sqrt{\frac{A_0^2 P_{xref}}{w_{filtered}^T w_{filtered}}}$  and  $P_{xref}$  the power of the impulse response of the transducer driving pressure  $A_0$ .

3. **Harmonic Extraction in reception** by the sum  $z$  of their 2 respective echoes  $y_1$  and  $y_2$ .
4. **Generating new prefiltered stochastic waveform  $w$  by genetic algorithm:**
  - Keeping the 6 best individual waveforms and mixing them by crossover operator.
  - Changing randomly 40% of samples by mutation operator.
  - Filtering the new prefiltered stochastic waveform by the FIR filter.
5. Return to step 2.

## Simulation

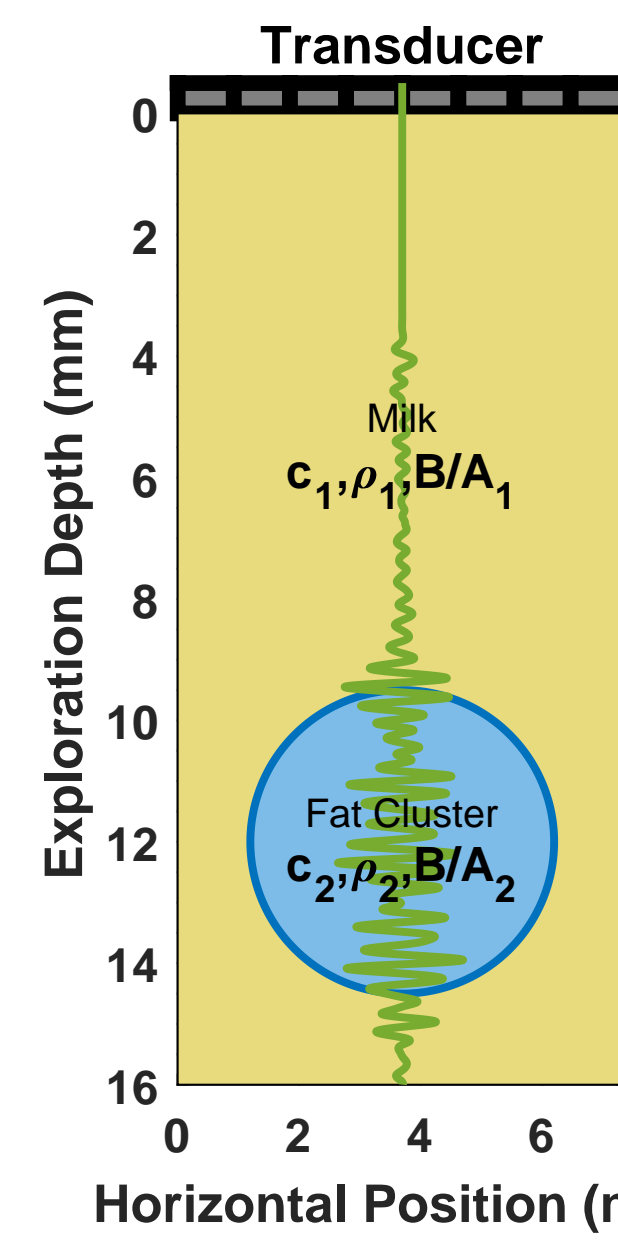


Figure 2: Grid on the medium in simulation.

- 2D simulation of nonlinear propagation by pseudo-spectral method
- Transducer centred at 4 MHz with a bandwidth of 80% at -3 dB (2.4 – 5.6 MHz).
- Speeds of sound  $c_1 = 1531$  m/s and  $c_2 = 1060$  m/s
- Densities of sound  $\rho_1 = 1025$  kg/m<sup>3</sup> and  $\rho_2 = 928$  kg/m<sup>3</sup>
- Nonlinearity parameters  $B/A_1 = 5.1$  and  $B/A_2 = 10.3$

## Results

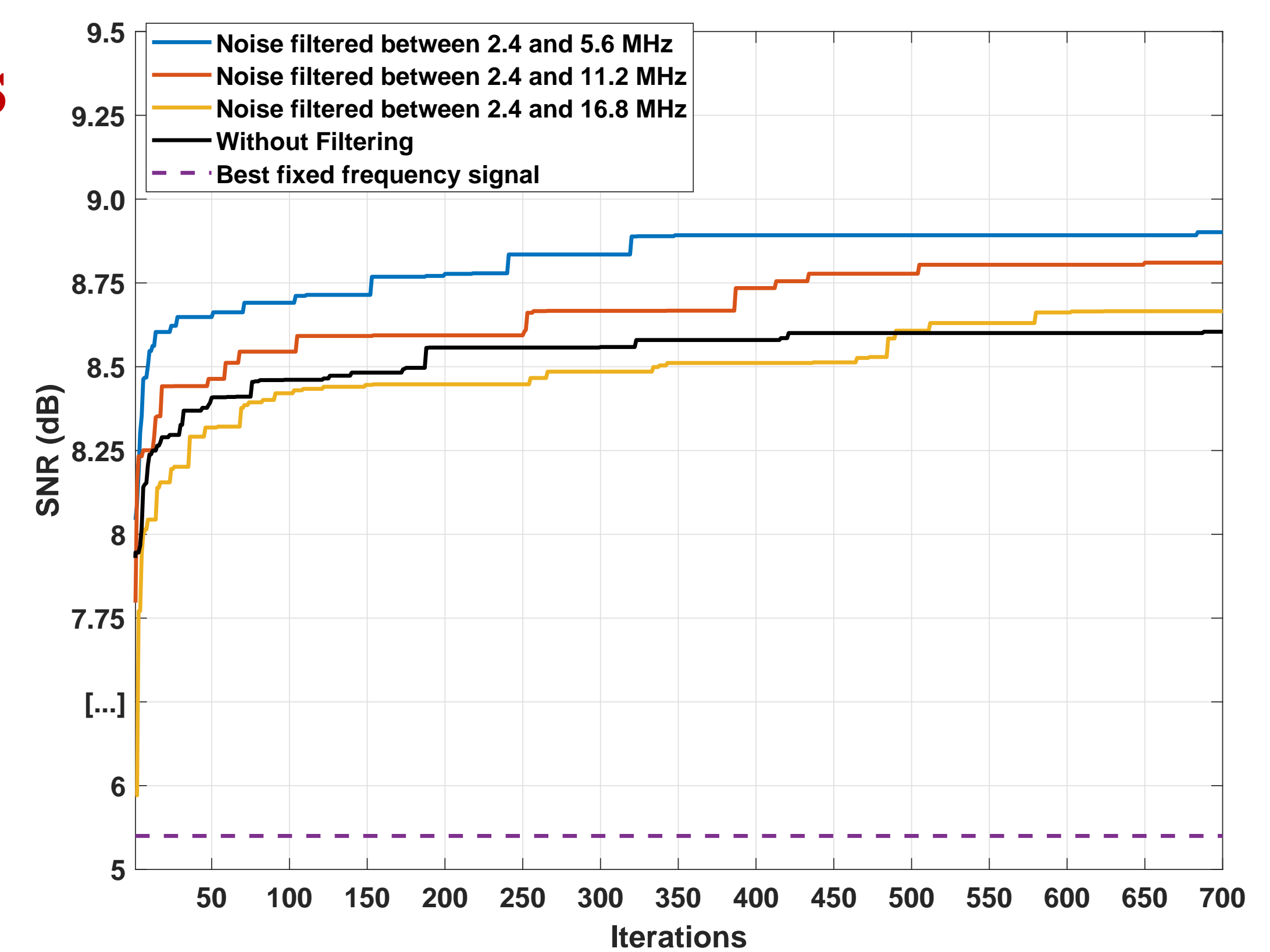


Figure 3: Median of optimized SNR from 10 simulations as a function of the genetic algorithm iteration for different high cut-off frequencies of the prefiltered waveform.

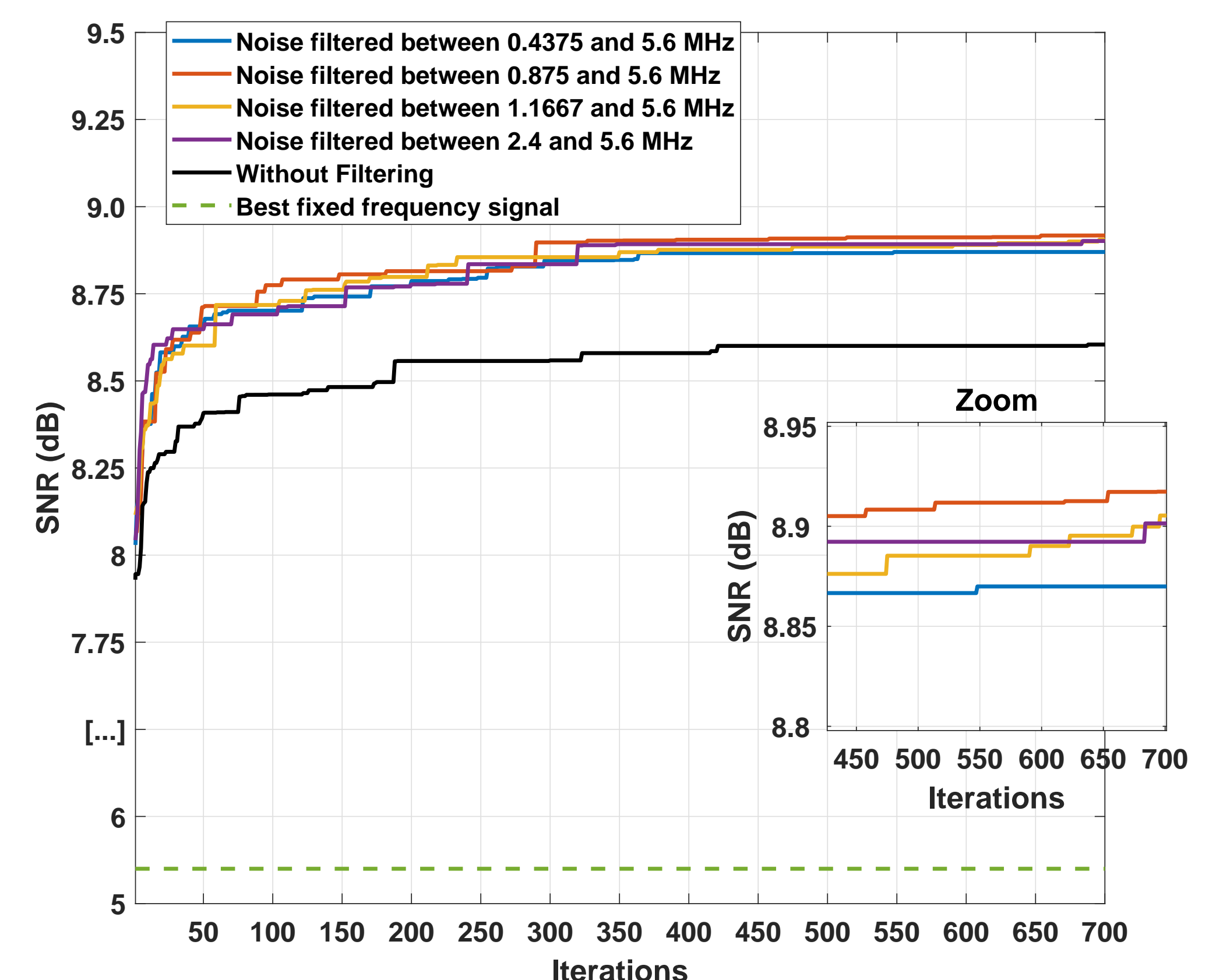


Figure 4: Median of optimized SNR from 10 simulations as a function of the genetic algorithm iteration for different low cut-off frequencies of the prefiltered waveform.

Low cut-off frequency	High cut-off frequency	Iterations to reach 8.5 dB	Maximal SNR
0.88 MHz	5.6 MHz	15	8.9 dB
None	None	187	8.6 dB

Table 1: Number iterations to reach 8.5 dB with the genetic algorithm and the maximal SNR at the end of the optimization.

## Conclusions & Forthcoming Research

- **SNR increase by 5%** compared to the optimization without prefiltering and 62% compared to a Gaussian pulse.
- **No influence of the low cut-off frequency** on the better SNR obtained after optimization.
- **High cut-off frequency must be close to the cut-off frequency of the transducer.**
- Optimization can be done **twelve times faster and better in just one iteration.**
- Facilitate the application of waveform design by using stochastic signals.