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# Optimal Stochastic Excitation for Linear Flaw Detection in a Solid Material

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## Context

The present study constitutes a first step in the validation of the stochastic optimization approach of the excitation waveform for linear systems since our ultimate goal remains its application on nonlinear systems. The optimal excitation wave enables us the best discrimination between two media: a reference one without flaw and a medium with a linear flaw, without *a priori* informations about the medium and the transducer.

**What is the Optimal Excitation which gives the best discrimination between the two media: a reference intact medium and a medium with a linear flaw?**

**Parametric Optimization**  
 Search of the Optimal Excitation Frequency

**The Cost Function** is an Euclidean distance between the temporal signal power received from the reference medium and those received from the medium with a flaw:

$$d_k = \sqrt{(E_{1,k} - E_{2,k})^2}$$

**Shape Optimization**  
 Search of the Optimal Excitation Waveform

### Gradient Descent Algorithm

**Recurrence relation:**  $f_{k+1} = f_k + \mu_k(\nabla d(f_k))$

$f_k$  is the transmitted frequency at the iteration  $k$ . The coefficient  $\mu_k$  governs the speed of convergence and  $\nabla d(f_k)$  is the Euclidean distance gradient at the iteration  $k$  for the transmitted frequency  $f_k$  and is given by the expression:

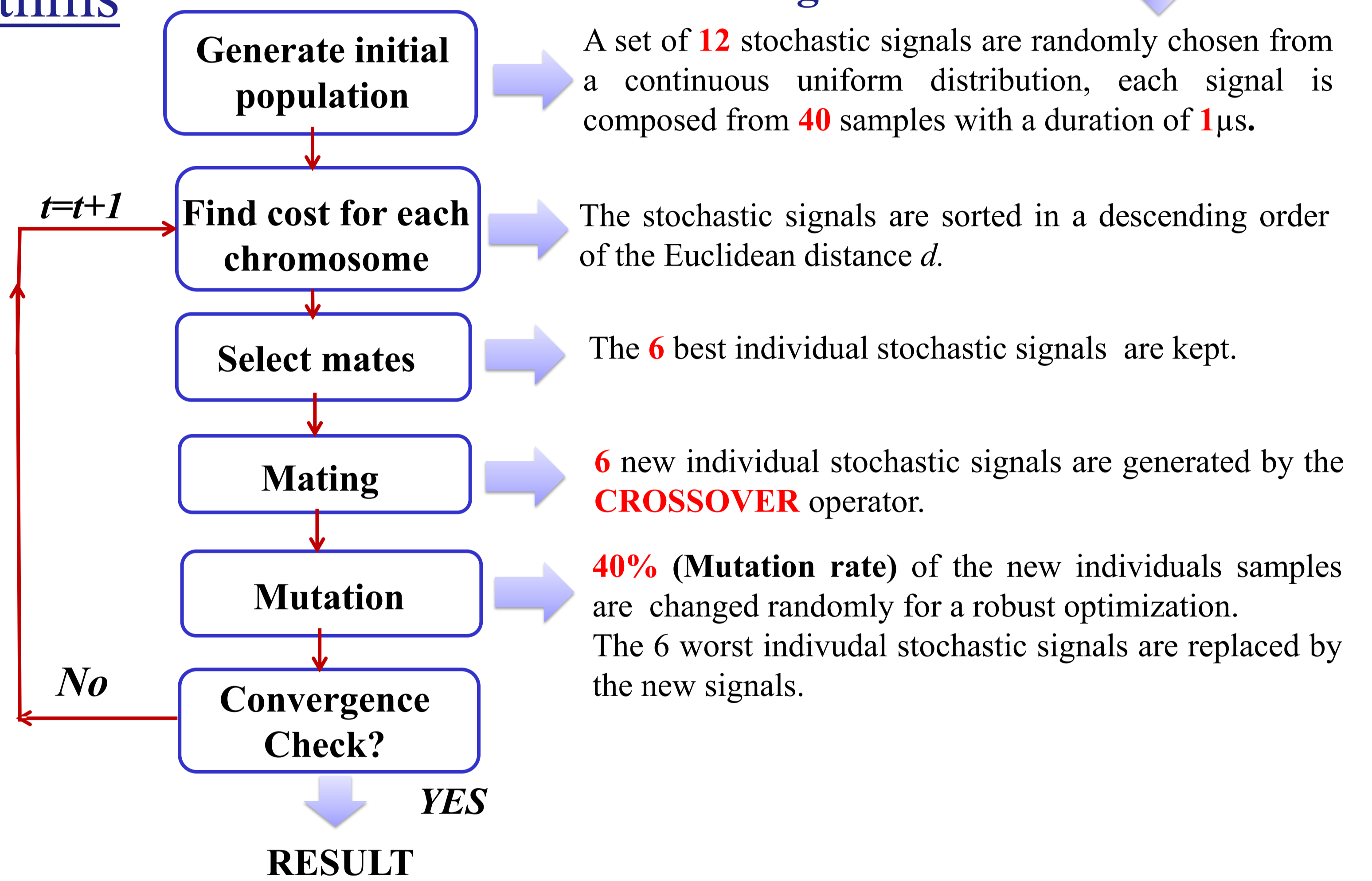
$$\nabla d(f_k) = \frac{\partial d}{\partial f} \approx \frac{d_{k-1} - d_k}{f_{k-1} - f_k}$$

$\mu_k$  governs the speed of convergence as follows:

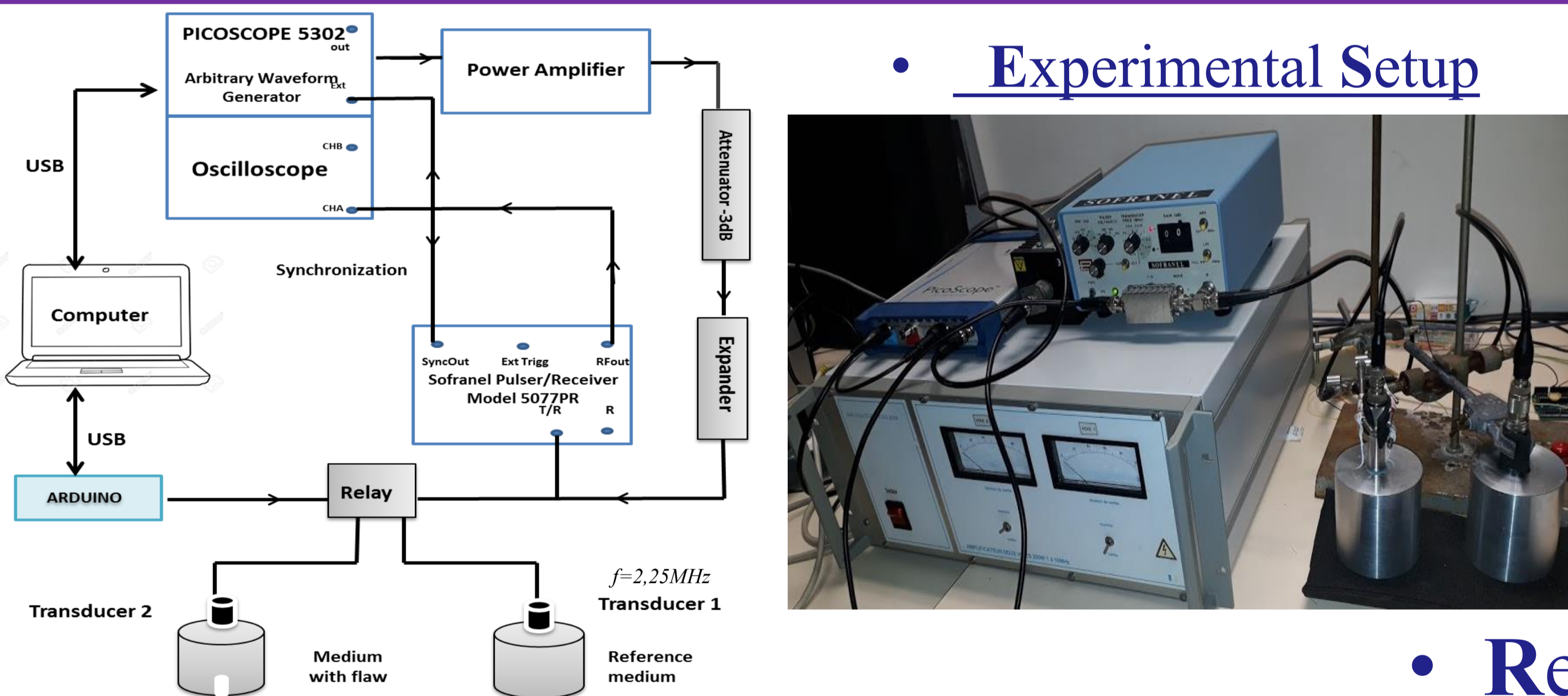
$$\mu_k = \begin{cases} 0 & \text{if } k < 3; \\ \Delta f & \text{if } k = 4; \\ \mu_{k-1} & \text{if } \text{sgn}[\nabla d(f_k)] = \text{sgn}[\nabla d(f_{k-1})] \\ -\frac{\mu_{k-1}}{2} & \text{if } \text{sgn}[\nabla d(f_k)] \neq \text{sgn}[\nabla d(f_{k-1})] \end{cases}$$

Where  $\Delta f = 1\text{MHz}$ , for  $k=\{1,2,3\}$ , the first three frequencies must be given initially.

### Algorithms

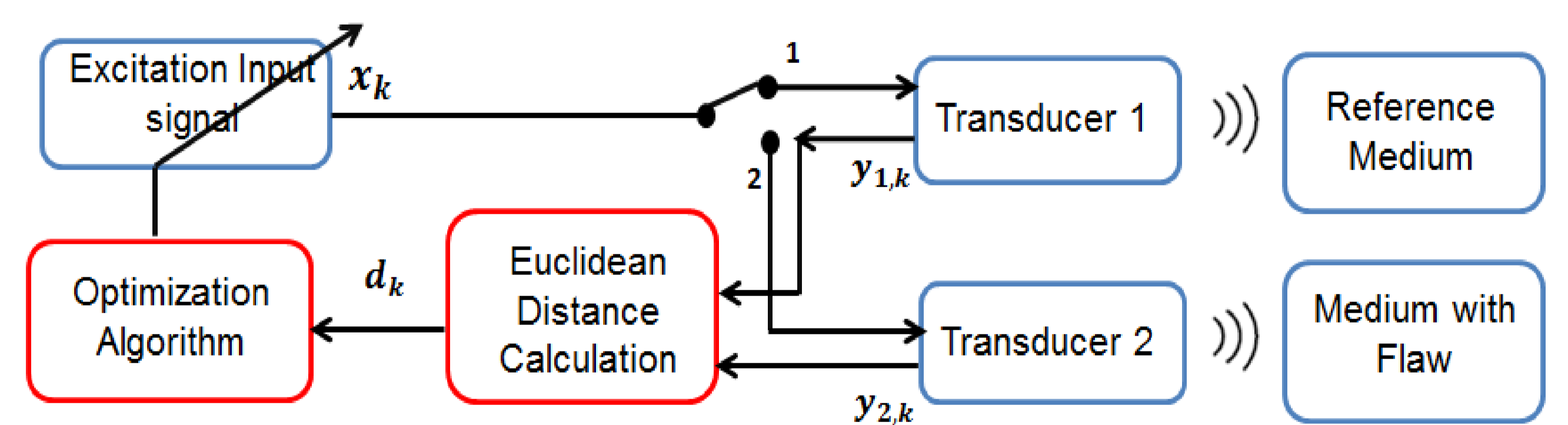


### Experimental Setup

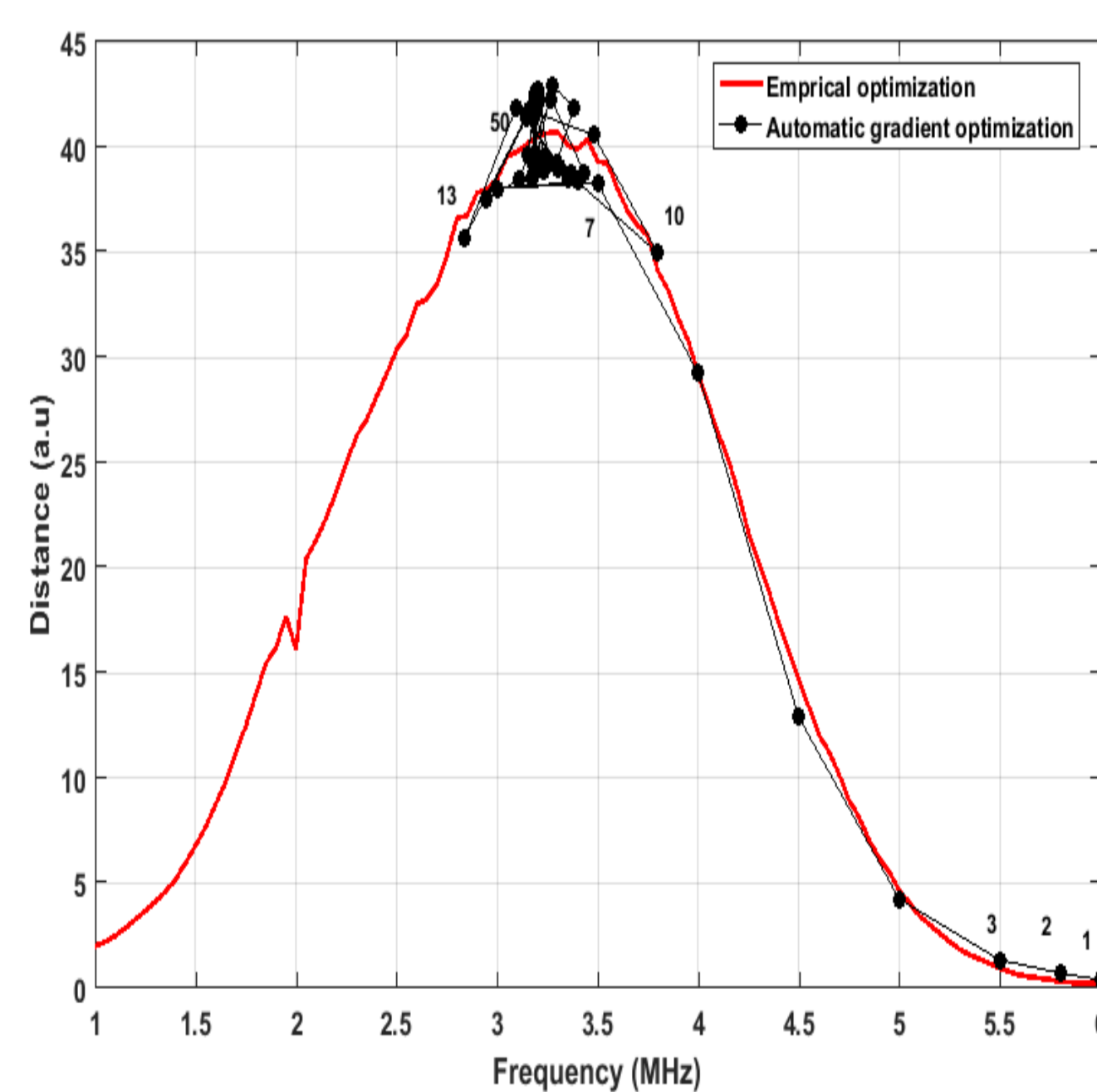


### Results

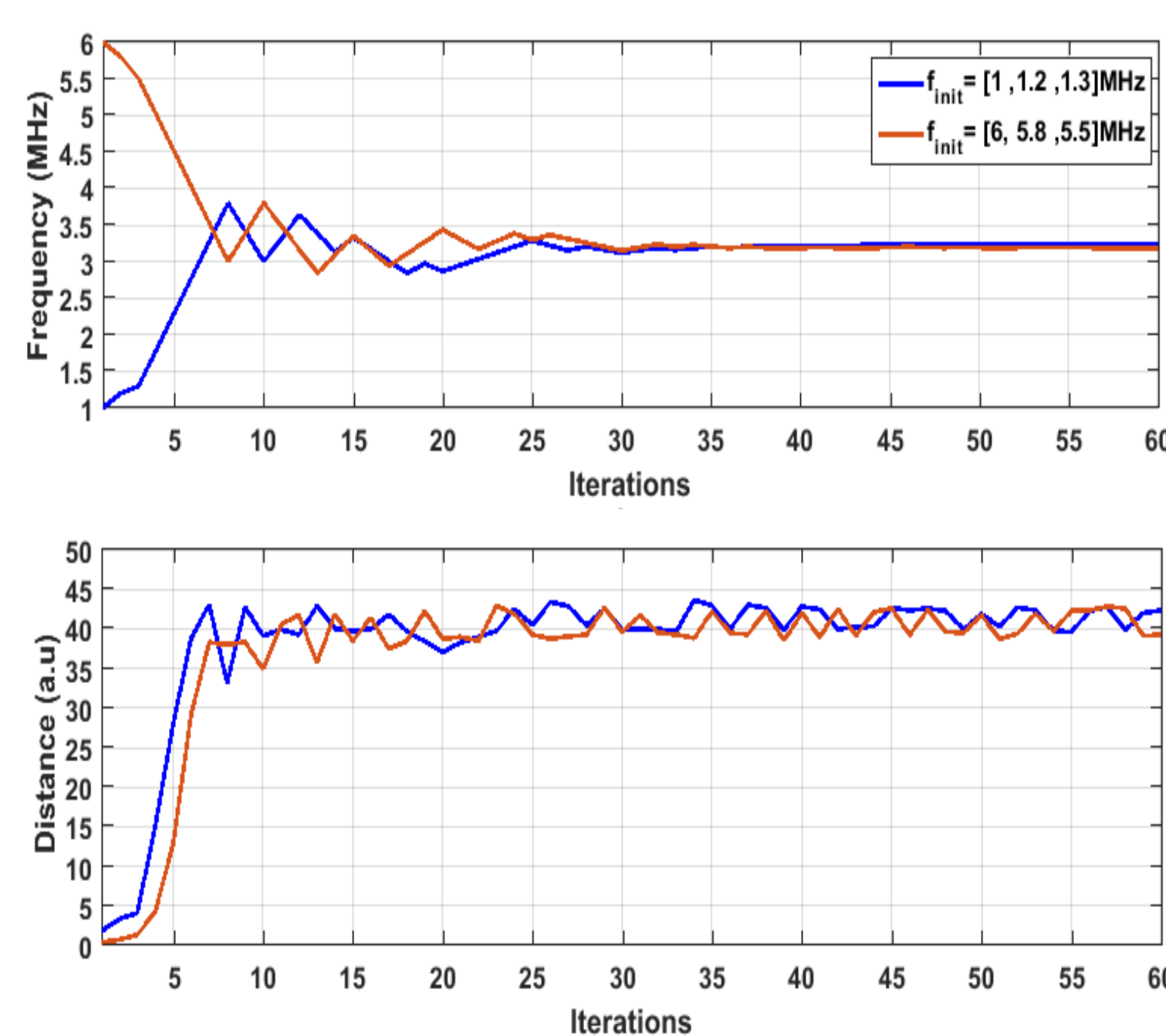
#### Closed Loop Optimization System



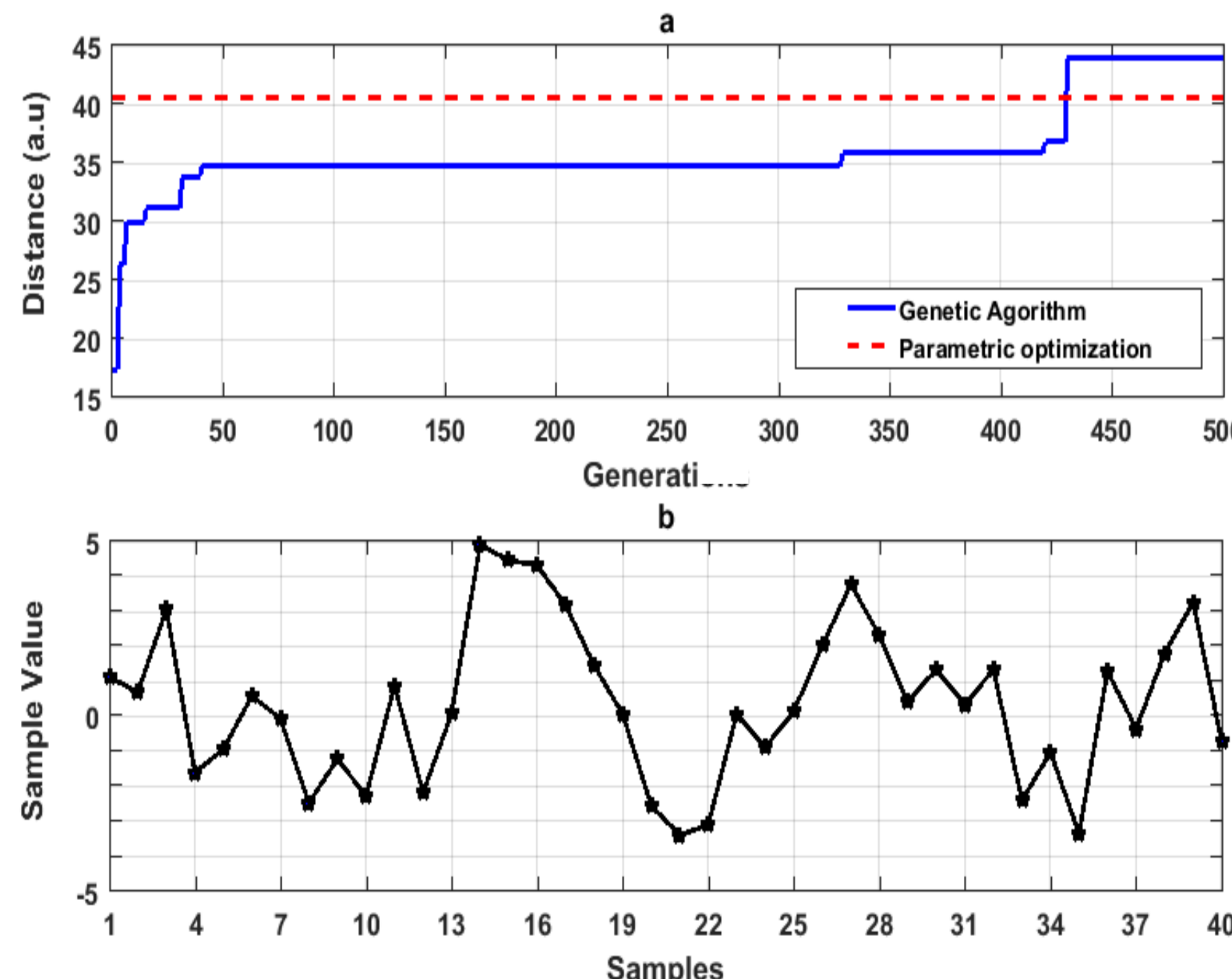
#### Empirical Optimization



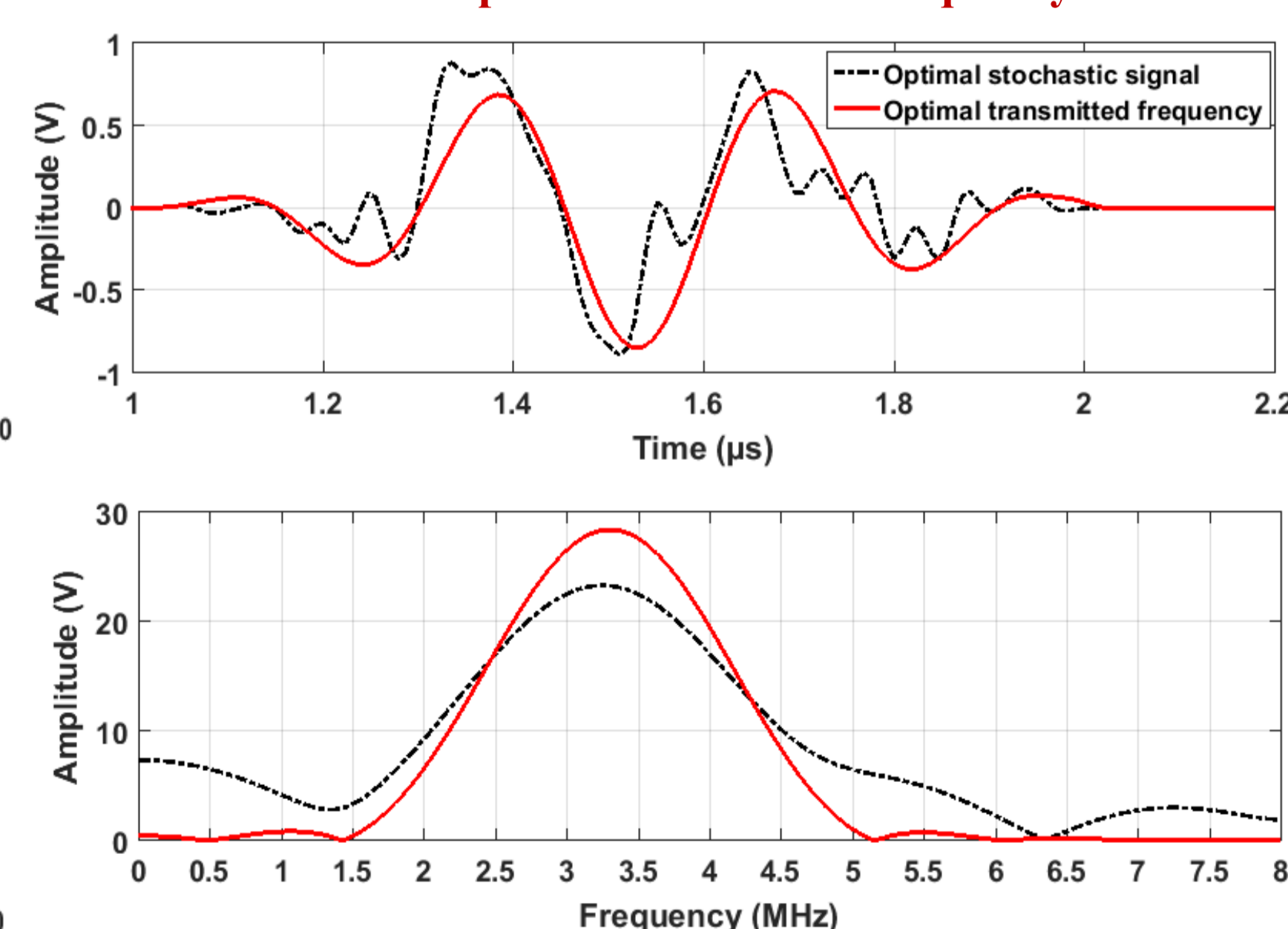
#### Gradient Descent Algorithm Optimization



#### Genetic Algorithm Optimization



#### Optimal transmitted stochastic signal and the sinusoidal pulse at the optimal transmitted frequency



Optimal transmitted stochastic signal

Frequency amplitude spectra of the signals represented above

### Conclusion and Perspectives

In the present study, the best excitation wave which enabled to maximize the linear flaw detection was investigated through two process types, parametric and shape optimization. An experimental closed loop system was set up to find automatically the suboptimal/ optimal command. The cost function considered was an Euclidean distance between two media: a reference one and a medium with a linear flaw. The main outcome was the performance similarity between the parametric and the stochastic approaches. Nevertheless, the stochastic approach didn't require any *a priori* knowledge nor initialization values. For a linear flaw type, the optimal stochastic command tends to the time reversal solution which is a sinusoidal pulse at a fixed frequency. The stochastic approach may be more efficient for nonlinear systems, even for cases where the cost function is no longer convex, for which the use of simple parametric optimization is compromised.