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# Optimization of Bifrequential Pump Excitation Parameters by Genetic Algorithm in Nonlinear Vibro Acoustic Wave Modulation Technique

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## Context

The nonlinear Vibro-Acoustic wave Modulation (VAM) is a widely used technique in nonlinear nondestructive testing. Many research, in this area, are devoted to find the best combination of the excitation parameters, especially the right frequencies to the optimization of the damage detection sensitivity. In a previous study [1], we have proposed a novel method using the optimal command principle for a VAM system. Indeed, this method has permitted to find automatically the best pump frequency maximizing the nonlinear modulation (NM) effects in a multiple scattering sample. The cost function to be optimized thanks to the pump wave frequency is the correlation coefficient (CC) between a reference output signal without pump and an output modulated probe signal with the presence of the pump wave. In the present work, we aim to improve the nonlinear damage detection by exciting simultaneously two resonance modes of the medium. We consider a new excitation waveform for the pump wave, composed by the sum of 2 frequencies, instead of a monochromatic sine wave.

## Main Objectives

- Improving the nonlinear damage detection in VAM technique by exciting the medium at two resonance frequencies.
- Optimizing the correlation coefficient  $\rho$  between a reference output signal without pump and an output modulated probe signal with the presence of the pump wave.
- Finding automatically the frequencies  $f_{p1}$  and  $f_{p2}$  giving the optimal sensitivity for damage detection, such as:

$$[f_{p1}^*, f_{p2}^*] = \arg \max_{f_{p1}, f_{p2}} [\rho(f_{p1}, f_{p2})]$$

## VAM System for Bifrequential Pump Optimization

1. Random generation of N pump frequency couples  $f_{p1,k}$  and  $f_{p2,k}$  from a continuous uniform distribution in a frequency range between 10 Hz and 900 Hz (generation k).
2. Transmission of the same probe excitation signal  $x_s(t)$  without the pumping signal (switch position 1)
3. Simultaneous transmission of the probe excitation signal  $x_s(t)$  with the pumping signal  $x_{p,k}(t) = A[\sin(2\pi f_{p1,k}t) + \sin(2\pi f_{p2,k}t)]$  with the frequencies  $f_{p1,k}$  and  $f_{p2,k}$  (switch position 2) and the amplitude A.
4. Generation of new pump frequency couples  $f_{p1,k+1}$  and  $f_{p2,k+1}$  by genetic algorithm (GA):
  - Evaluation of the cost function  $\rho$ .
  - Sorting  $f_{p1,k}$  and  $f_{p2,k}$  in a descending order of the correlation coefficient  $\rho$  and keeping N/2 pump frequency couples.
  - Generation of N/2 new pump frequency couples by the crossover operator.
  - Changing randomly 40% (Mutation rate) of the new frequency couples for a robust optimization.
5. Return to step 2 (generation k+1).

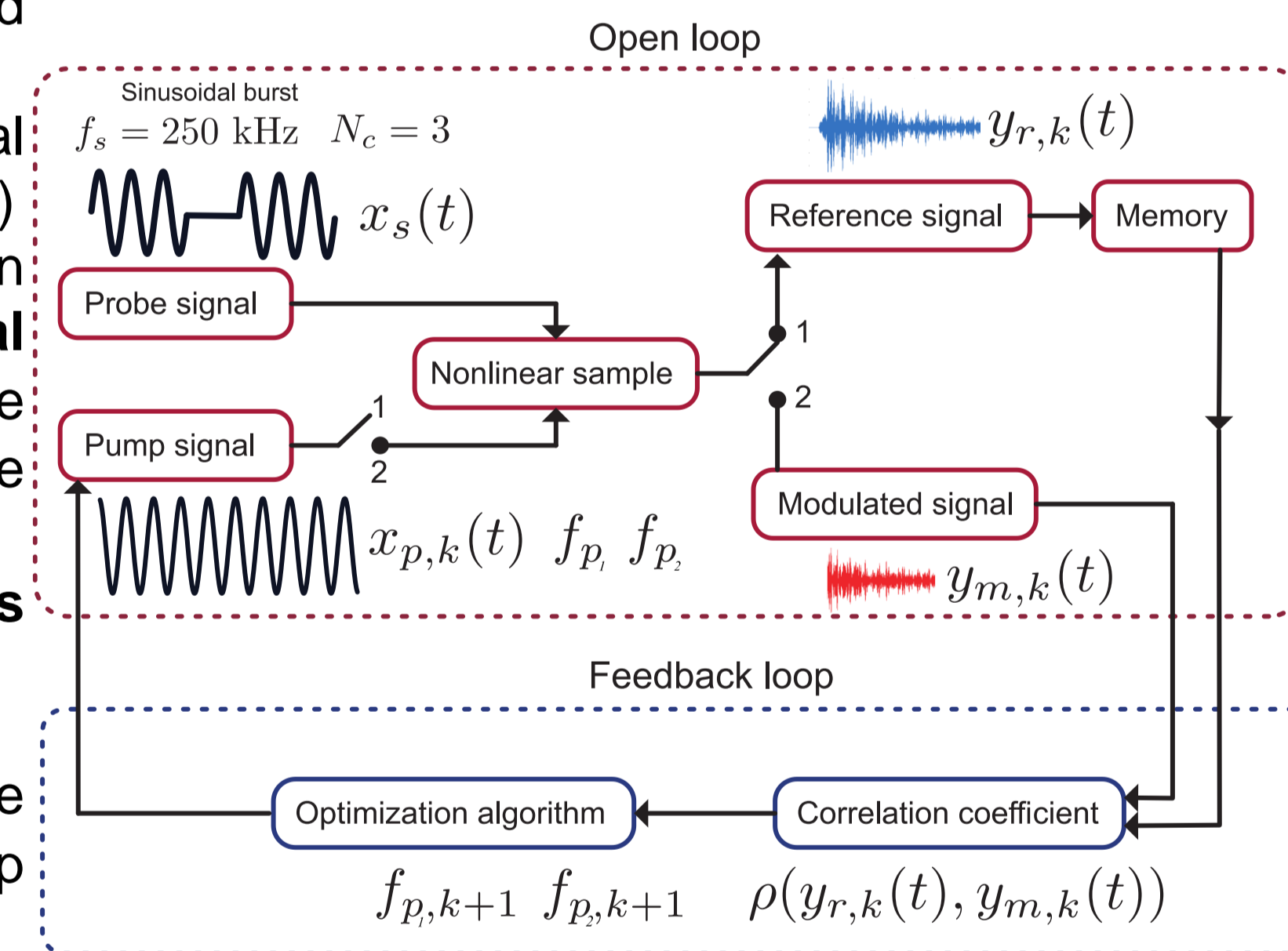


Figure 1: Bloc Diagram of the closed loop VAM system.

## Experimental Setup

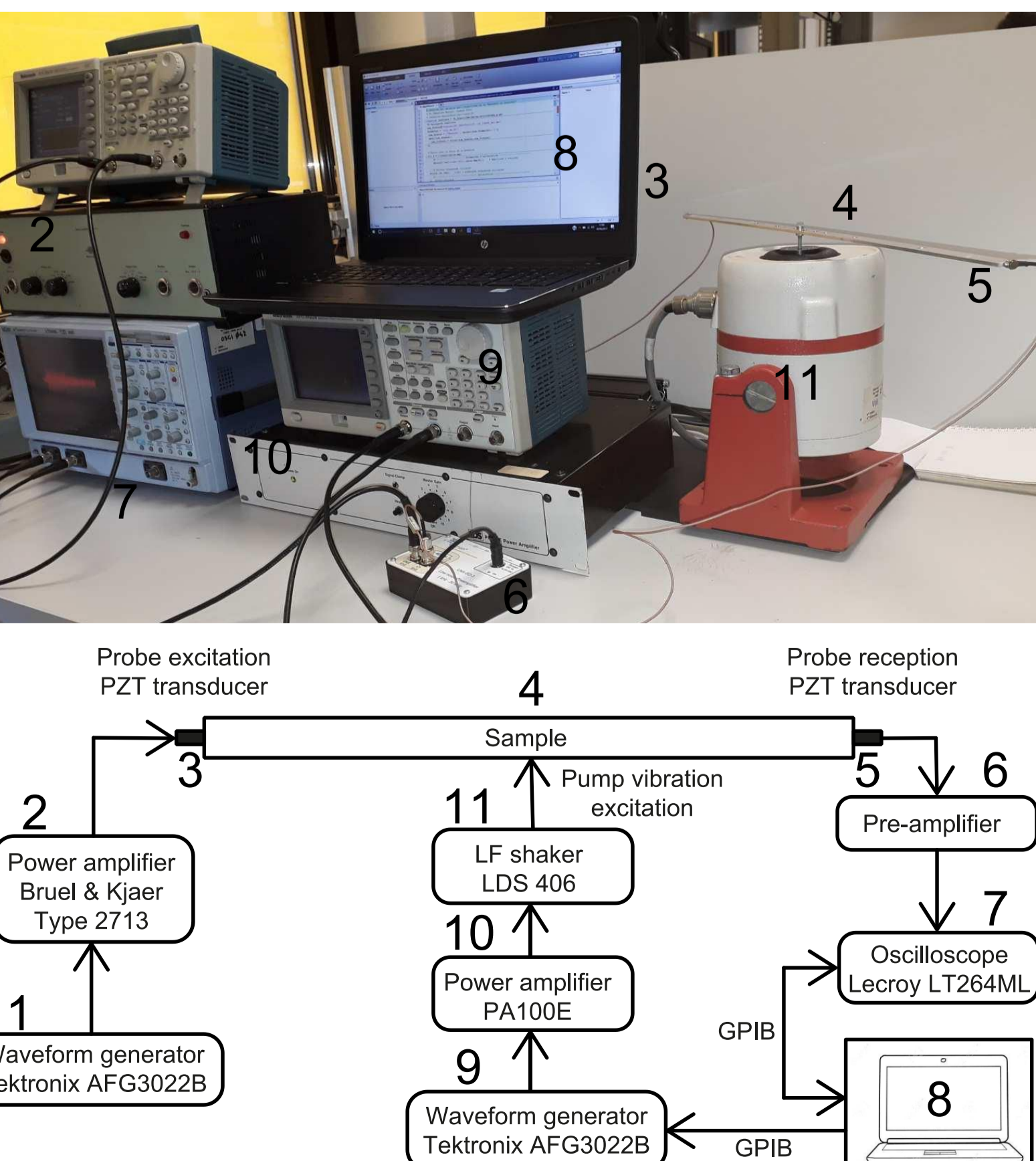


Figure 2: Experimental Setup.

## Specimen Description

The tested sample is an aluminium bar where nonlinear scatterers can be controllably added or removed. Identical screws can be placed in the tapped holes to mimic nonlinear solid contacts (cracks).

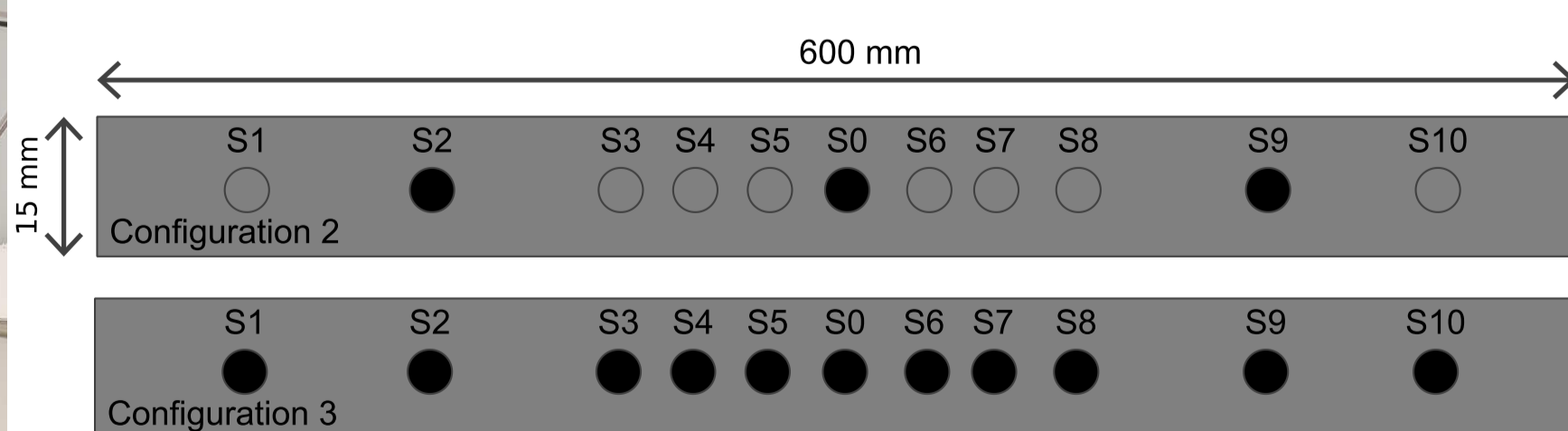


Figure 3: Specimen schemes of the three configurations. Config. 1: all the screws are placed on the bar. Config. 2: 2 screws are placed at S2 and S9.

Name	Value
Density	2700 kg/m <sup>3</sup>
Poisson ratio	0.33
Young modulus	69 GPa
Wave velocity	4828 m/s
Screw mass	4.42 g

Table 1: Specimen Characteristics.

## Results

### Empirical Optimization

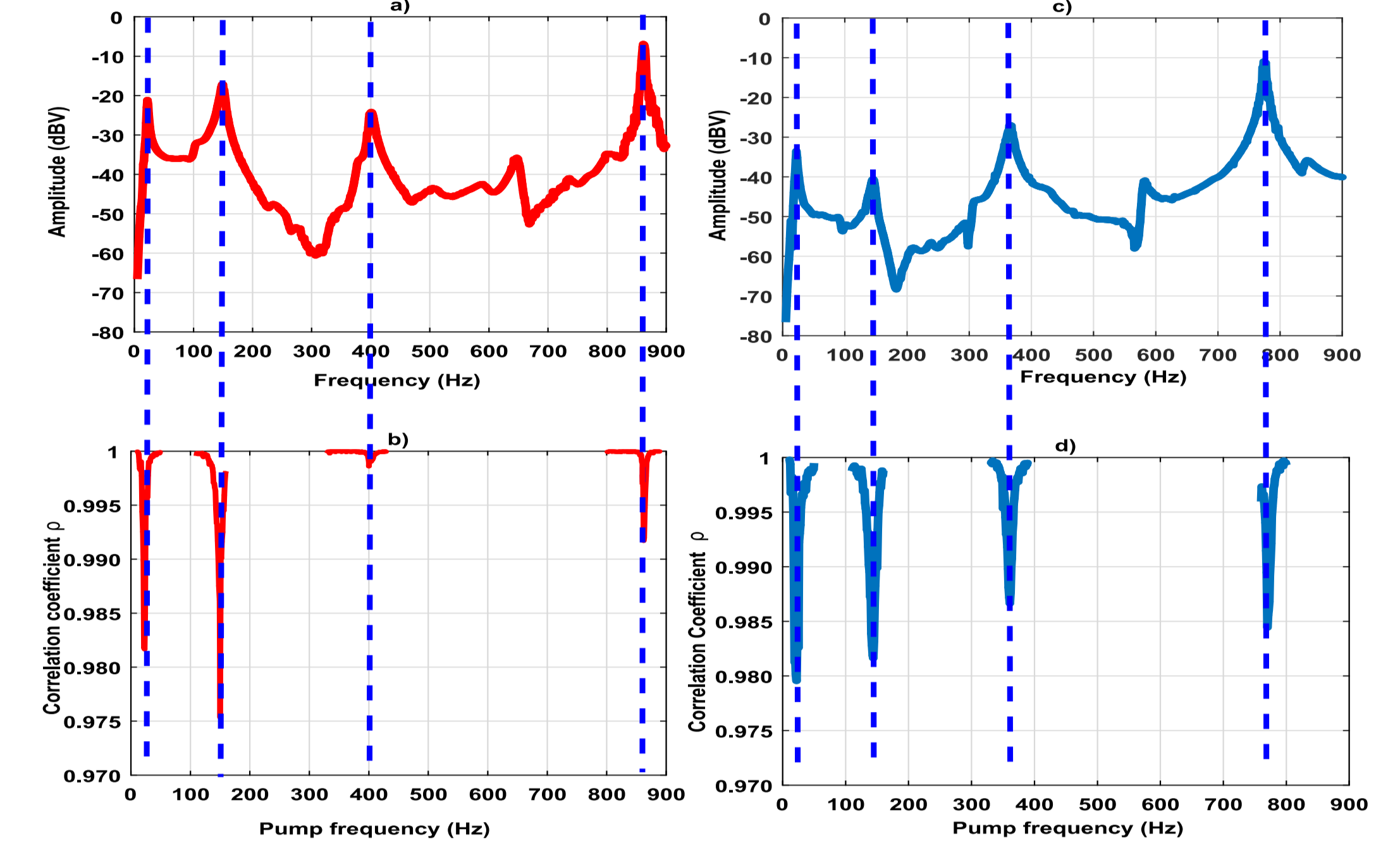


Figure 4: Comparison between the resonance frequencies obtained from the experimental Frequency Response Function (FRF) of the Config. 2 (a) and the Config. 1 (c). Experimental results of correlation coefficient vs. pump frequency at the sample resonance frequencies areas for the two sample configurations: b) Config. 2 and d) Config. 1. The FRF peaks coincide with the minimum peaks of the correlation coefficient vs. pumping frequency.

Modes	Config. 1			Config. 2		
	$\rho_{EO}$	$f_{p,EO}$ (Hz)	$f_{p,FRF}$ (Hz)	$\rho_{EO}$	$f_{p,EO}$ (Hz)	$f_{p,FRF}$ (Hz)
1 <sup>st</sup> Mode	0.979	22	22	0.981	23	22.1
2 <sup>nd</sup> Mode	0.981	144	146	0.975	150	149
3 <sup>rd</sup> Mode	0.986	361	366	0.998	400	401
4 <sup>th</sup> Mode	0.984	770	774	0.991	862	861

Table 2: Correlation coefficient  $\rho$  and the  $f_p$  values corresponding to the minimum peaks obtained from the empirical optimization (EO) and resonance frequencies obtained from the Frequency Response Function (FRF) for Config. 1 and 2.

### Genetic Algorithm Optimization

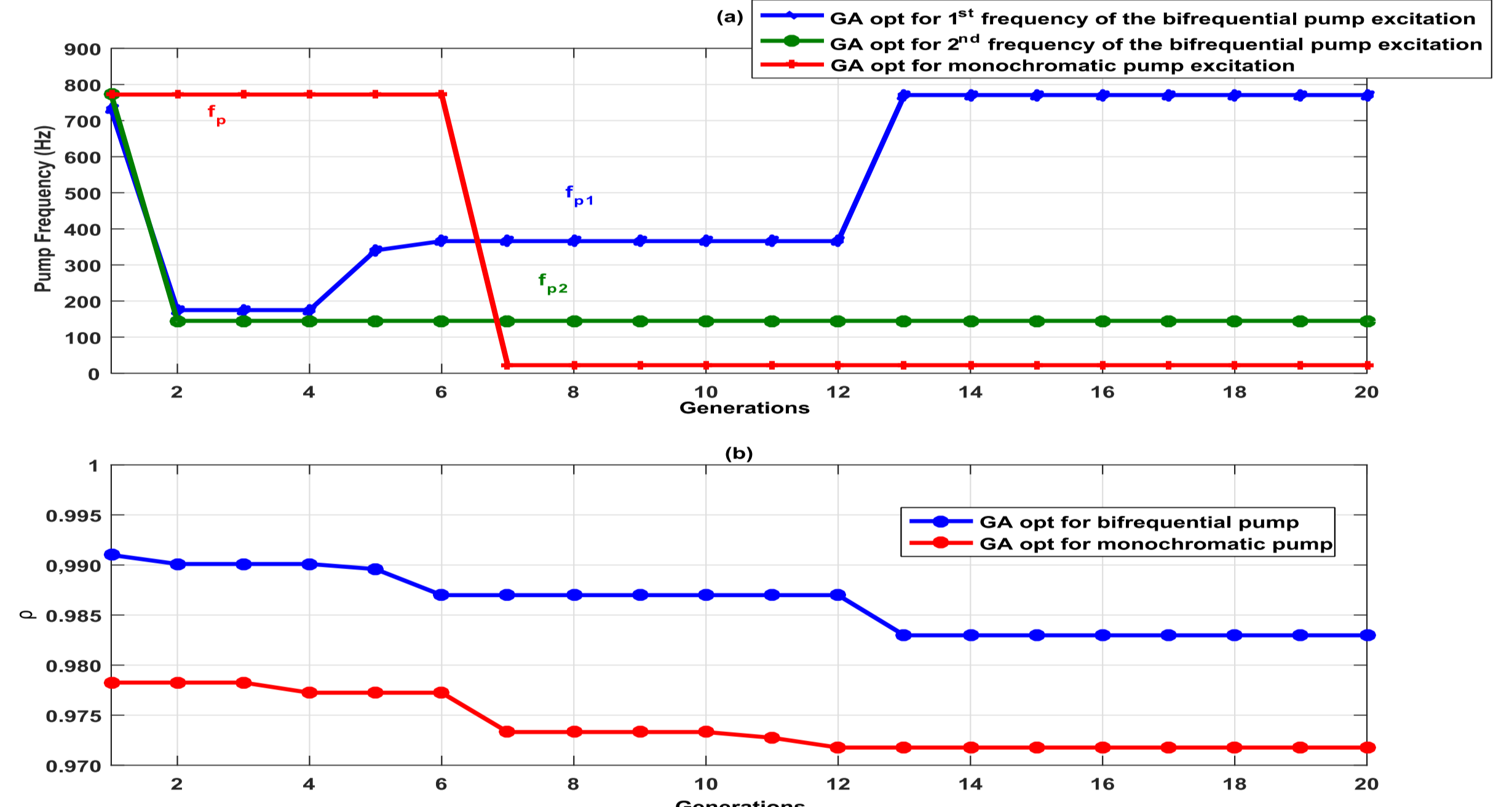


Figure 5: Optimization results with the genetic algorithm for the Config. 1: (a) The pump frequencies vs. generations. The GA converges to  $f_{p1}^* = 145$  Hz after the 7<sup>th</sup> generation for the monochromatic pump. For the bifrequential pump,  $f_{p1}^* = 145$  Hz and  $f_{p2}^* = 770$  Hz. (b) The corresponding correlation coefficient  $\rho$  vs. generations for the bifrequential and the monochromatic pump excitation.

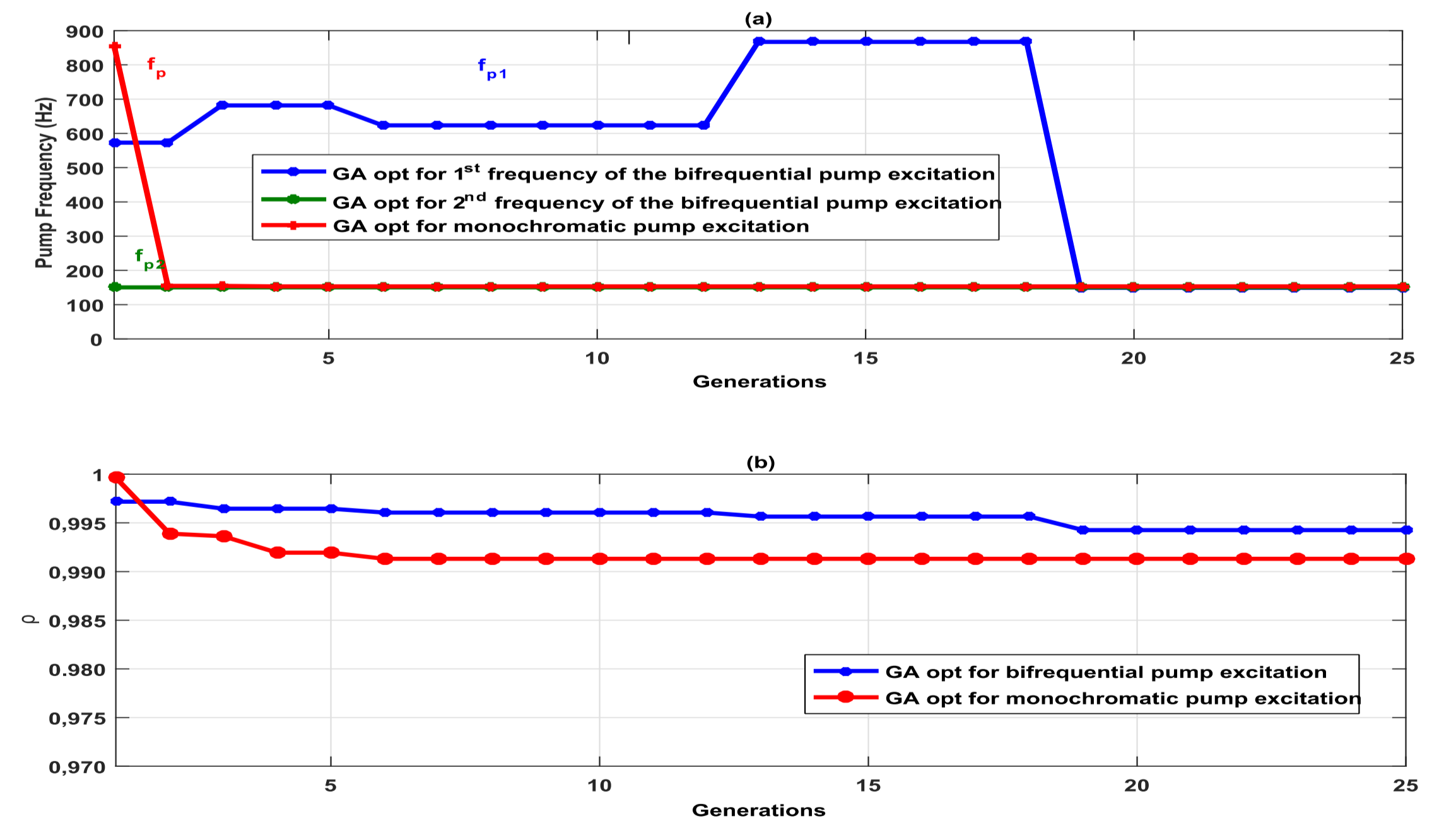


Figure 6: Optimization results with the genetic algorithm for the Config. 2: (a) The pump frequencies vs. generations. The GA converges to  $f_{p1}^* = 153$  Hz after the 4<sup>th</sup> generation for the monochromatic pump. For the bifrequential pump,  $f_{p1}^* = 150$  Hz and  $f_{p2}^* = 149$  Hz. (b) The corresponding correlation coefficient  $\rho$  vs. generations for the bifrequential and the monochromatic pump excitation.

$f_{p,EO}$ (Hz)	Config. 1		Config. 2			
	$f_p^*$ (Hz)	$f_{p1}^*$ (Hz)	$f_{p2}^*$ (Hz)	$f_{p,EO}$ (Hz)	$f_{p1}^*$ (Hz)	$f_{p2}^*$ (Hz)
22	22	770	145	150	153	149

Table 3: The pump frequencies obtained from the monochromatic and the bifrequential pump optimization, and the global minimum of the empirical cost function  $f_{p,EO}$ .

## Conclusion and Perspectives

- The GA proposed only a solutions close to the resonance frequencies of the sample.
- The optimal pumping frequencies corresponded to a resonance frequencies of the sample.
- The corresponding values of the CC are quite similar to those obtained by a single pump frequency. This observation may be due to the GA precision.
- A GA hybridization with a more accurate algorithm like the Descent Gradient algorithm should refine the results.
- The optimization of the phase between the two sinusoidal pump frequencies will be considered in a future work.