Analysis and simulation of a MEMS based accelerometer used to monitor the movement of a sea waves

Valerica Baban [a)], Dănuț Argintaru [a)] , Eliodor Constantinescu [a)]

[a)] Department of Fundamental Sciences and Humanities, Constanta Maritime University, Constanța, Romania

Abstract

In the marine environment the waves generated by the flow of the wind or by natural phenomena such as earthquakes inside the oceans need to be monitored and known before it takes effect. The sea waves are a complex phenomenon and their behavior is quite difficult to predict. The first step is to take accurate and low cost measurements of the sea surface oscillations. In this paper we model and analyze MEMS capacitive accelerometers using Comsol Multiphysics simulation software for monitoring low amplitude sea waves.

Introduction

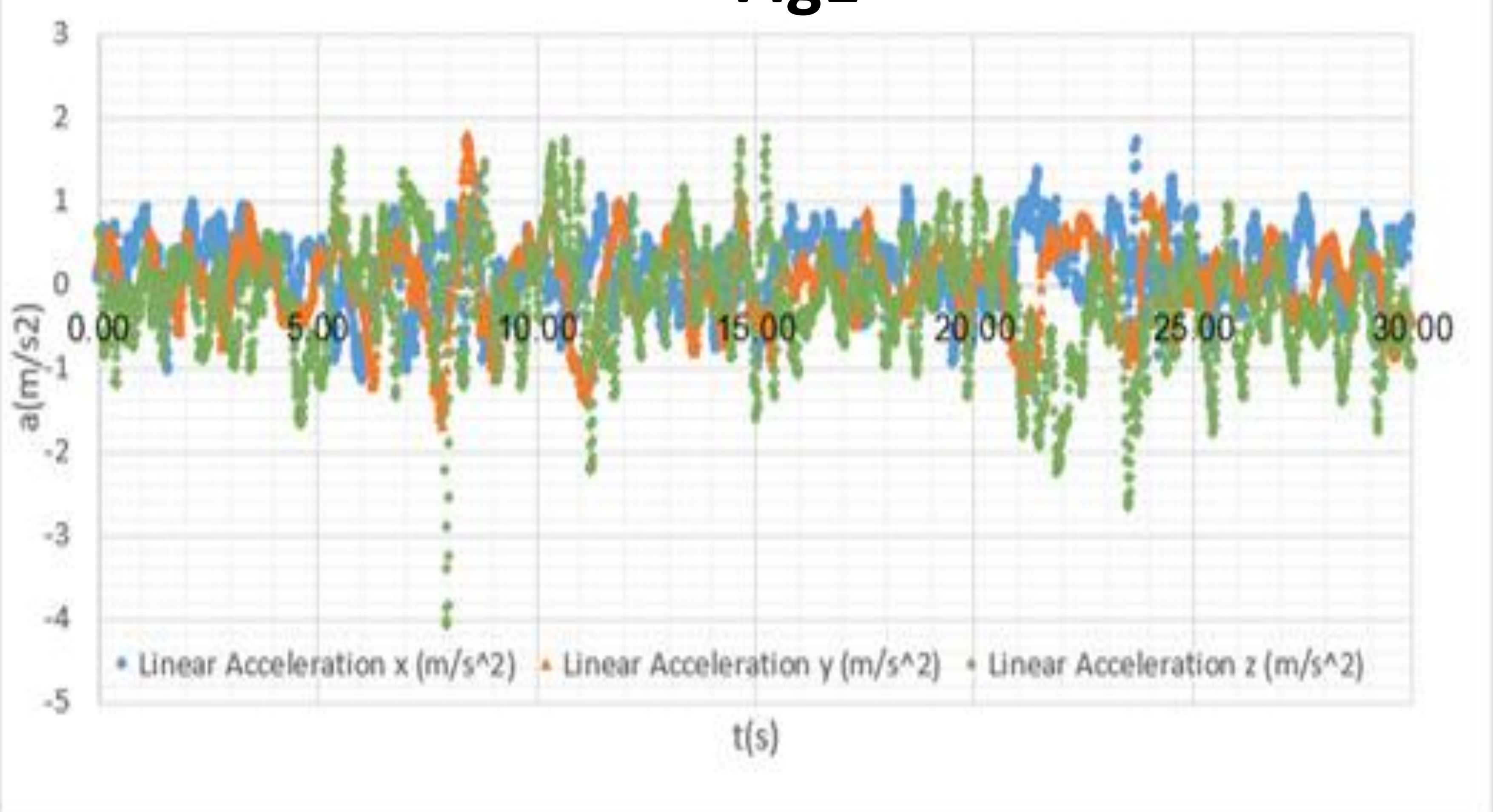
Sea waves are group waves meaning a superposition of a large number of quasiperiodic individual waves having different frecquencies, amplitude and propagation directions. We can define their behavior by the equation below, where y(t) is the surface height of a certain point at t time, a_n , ν_n , α_n are the amplitude, frequency and phase of the nth sinusoidal component .

$$y(t) = \sum_{n=1}^{\infty} a_n \sin(2\pi \nu_n t + \alpha_n)$$

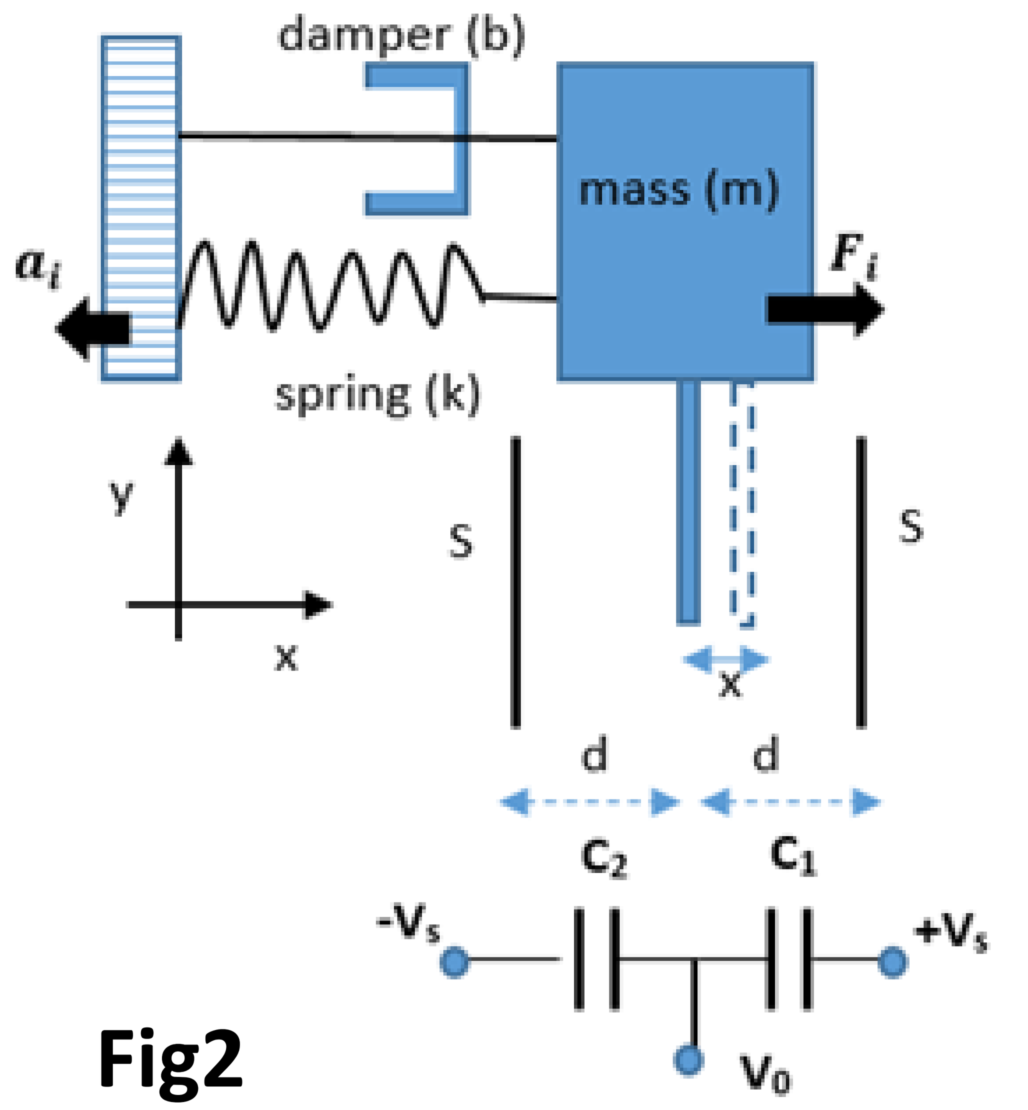
We see in the figure below a typical low amplitude sea wave measured by a linear accelerometer sensor (Samsung Electronics v3) used in an experiment.

We propose and discuss a conceptual model of an one-dimensional capacitive accelerometer able to detect accelerations of this order of magnitude providing several building options. Our work is based on Finite Element Analysis (FEA) with Comsol Multiphysics software.

Fig1



CAPACITIVE ACCELEROMETER MODEL



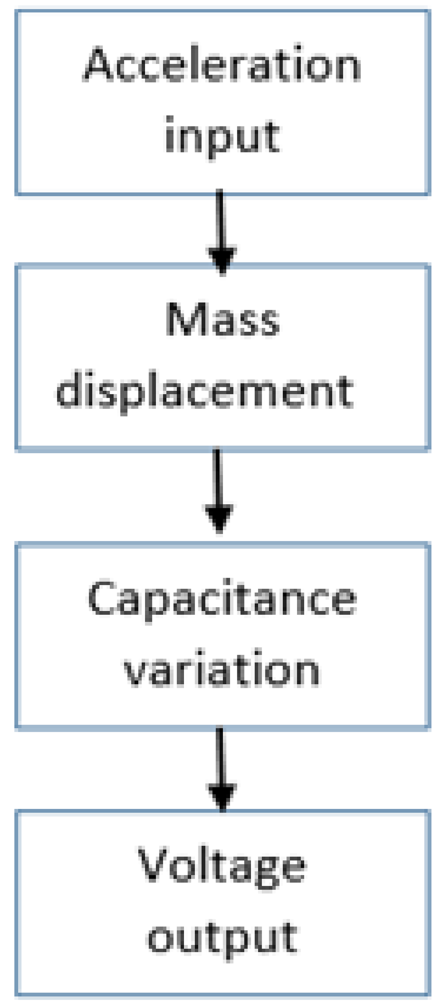


Fig2

The movement of the proof mass under the external force can be describe by the differential equation (2), k is the stiffness of the spring, b is the damping coefficient and a_i the acceleration of the inertial frame.

$$m\ddot{x} + b\dot{x} + kx = ma_i$$

The system has also a natural frequency and the quality factor according to

$$\omega_0 = \sqrt{\frac{k}{m}}$$

$$Q = \frac{\sqrt{km}}{b}$$

e displacement of the proof mass leads to a change of capacitance C_1 d C_2 of the differential system, C_0 is the value of the electrical pacitance corresponding to the symmetrical initial position.

$$\Delta C = C_1 - C_2 = \varepsilon S \frac{2x}{d^2 - x^2} \cong \frac{2C_0}{d} x$$

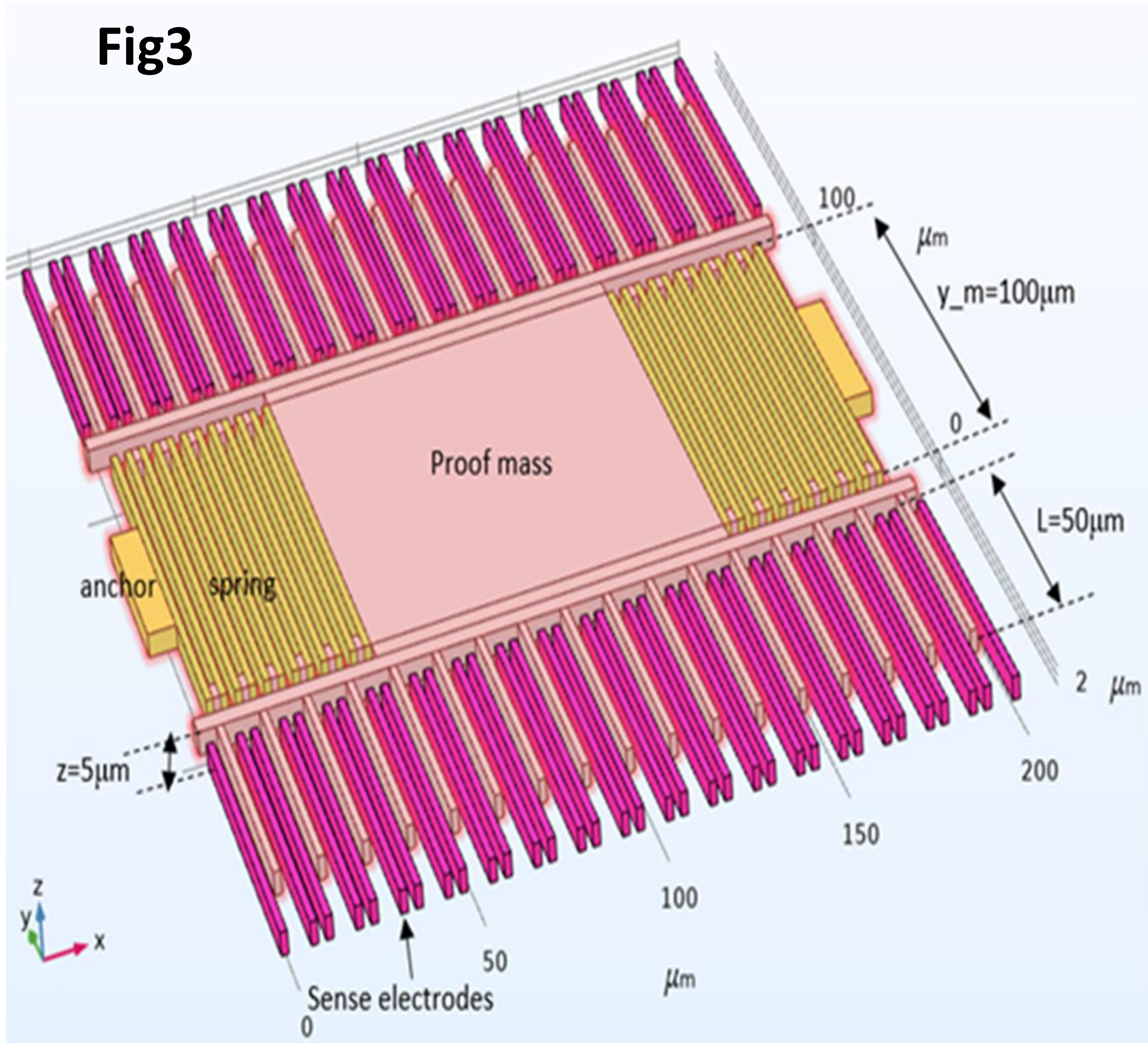
SENSOR MODELING AND ANALYSIS

For design and simulation Comsol Multiphysics software has been used. Four model for one dimensional open loop capacitive accelerometer are proposed and analyzed. The 3D geometrical structure is build in order to test the response to external accelerations between 0.1 and 10 . The first case is described in Figure 3. The basic structure consists in a proof mass with two folding beam and anchoring supports.. The electrical sensors consists in a number of cantilever electrodes attached to the lateral sides of the proof mass. These cantilever are positioned between fixed electrodes forming a number of differential capacitors on each side of the proof mass

Table 1. Geometric parameters and performances comparation

Parameter	Case 1	Case 2	Case 3	Case 4
Proof mass width-x, depth-y, height-z (µm)	100, 100, 5 +Side elements	100, 100, 5 +Side elements	136, 100, 5 +Side elements	136, 100, 5
Proof mass+side elements (µg)	0.15	0.14	0.2	0.126
Suspension beam (spring)	Folding beam, 6 elements, width 100µm, depth 2µm, height 5µm)	Folding beam, 6 elements, width 100µm, depth 2µm, height 5µm)	Folding beam, 6 elements, width 100µm, depth 2µm, height 5µm)	Folding beam, 6 elements, width 100µm, depth 2µm, height 5µm)
Material	Polycristalline Silicon	Polycristalline Silicon	Polycristalline Silicon	Polycristalline Silicon
Capacitor length L(µm)	50	25	25	25
Sensivity (ΔC(fF)/g)	1620	177	115	219
First and the second eigenfrequency (Hz)	2273.4 2933.7	2451.6 3063qu	2959.2 3538.9	1868.2 2277.2

SENSOR MODELING AND ANALYSIS



Case 1 – one-dimensional capacitive accelerometer

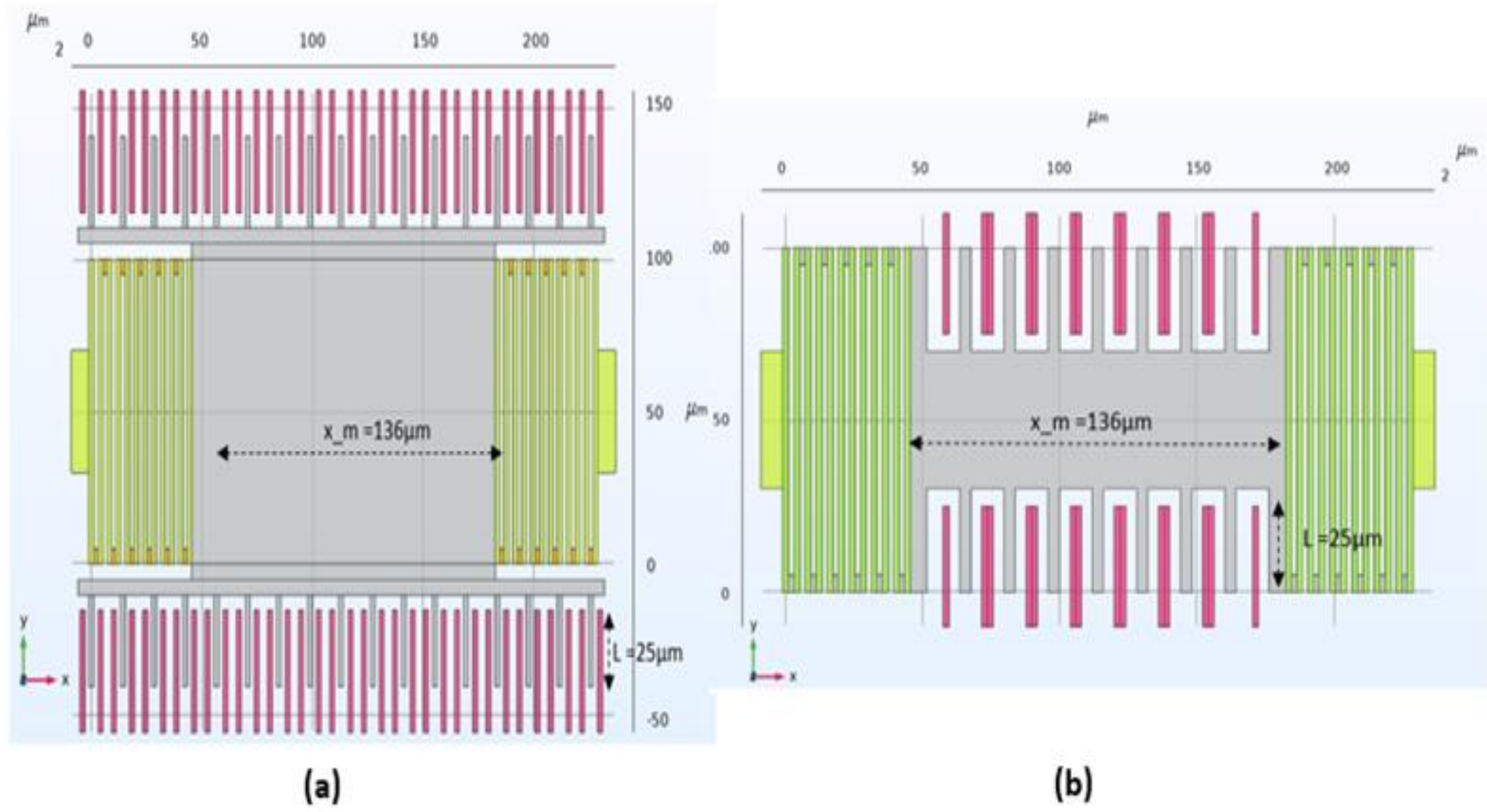
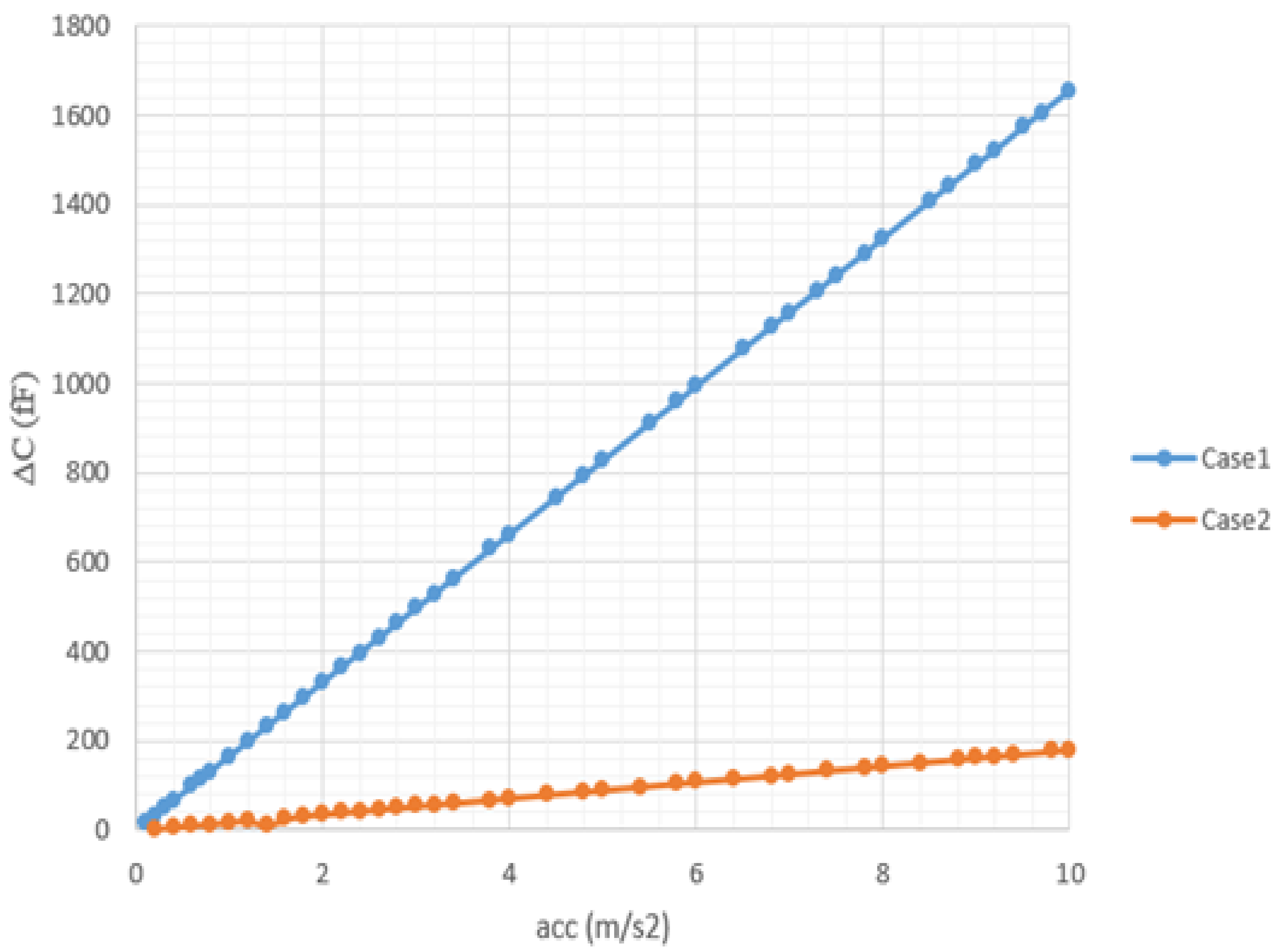
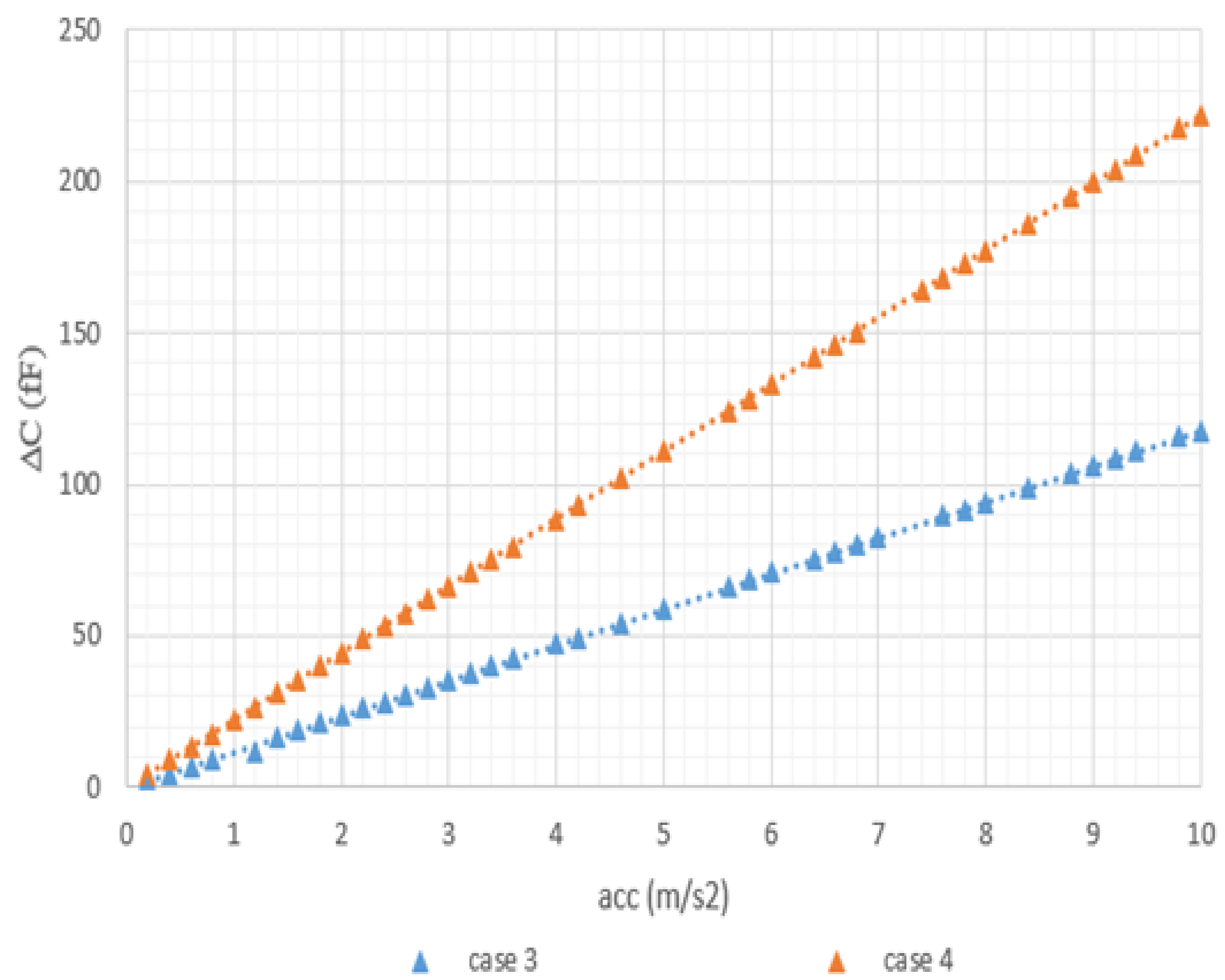
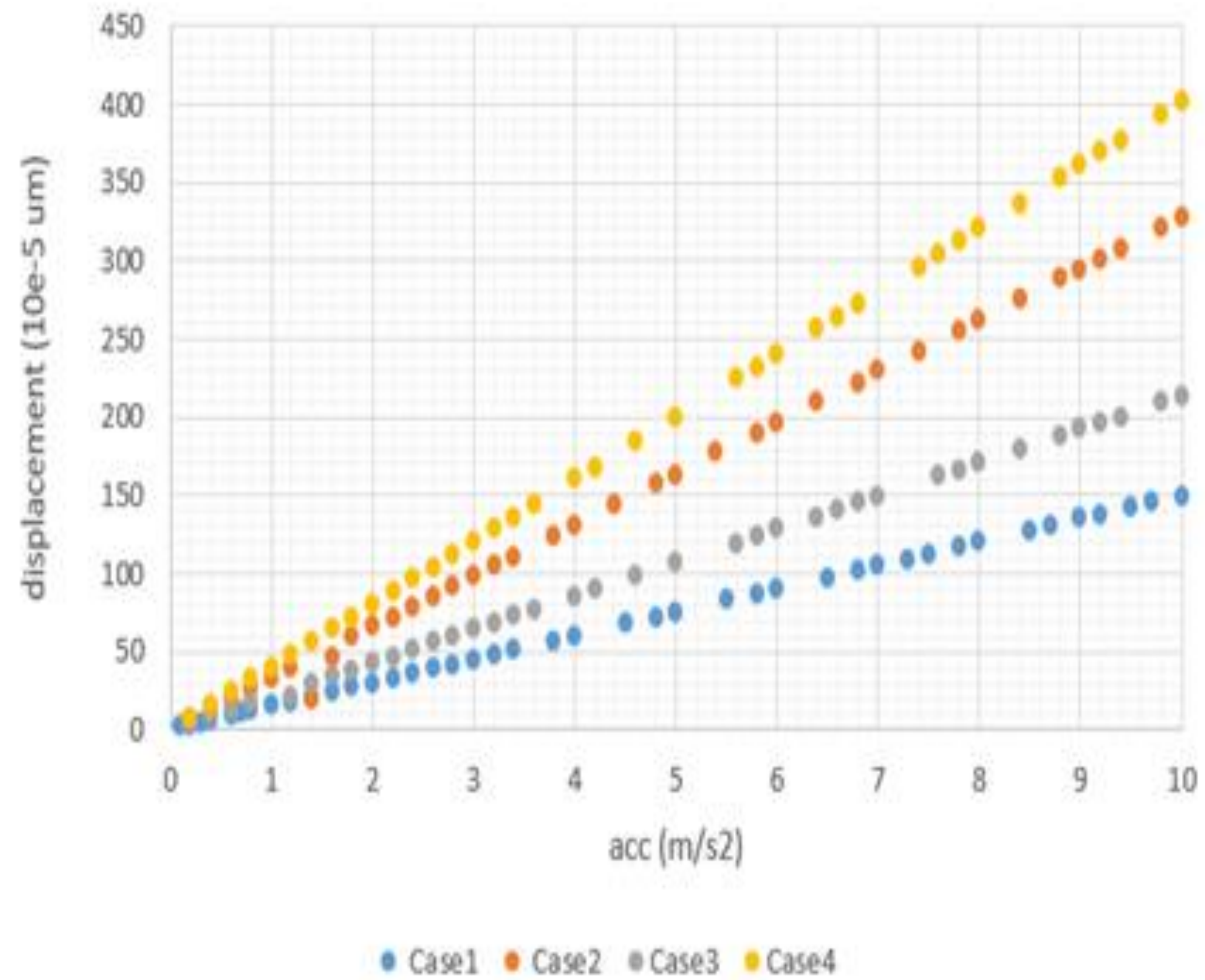


Fig4 Case 3 and 4 accelerometer design.

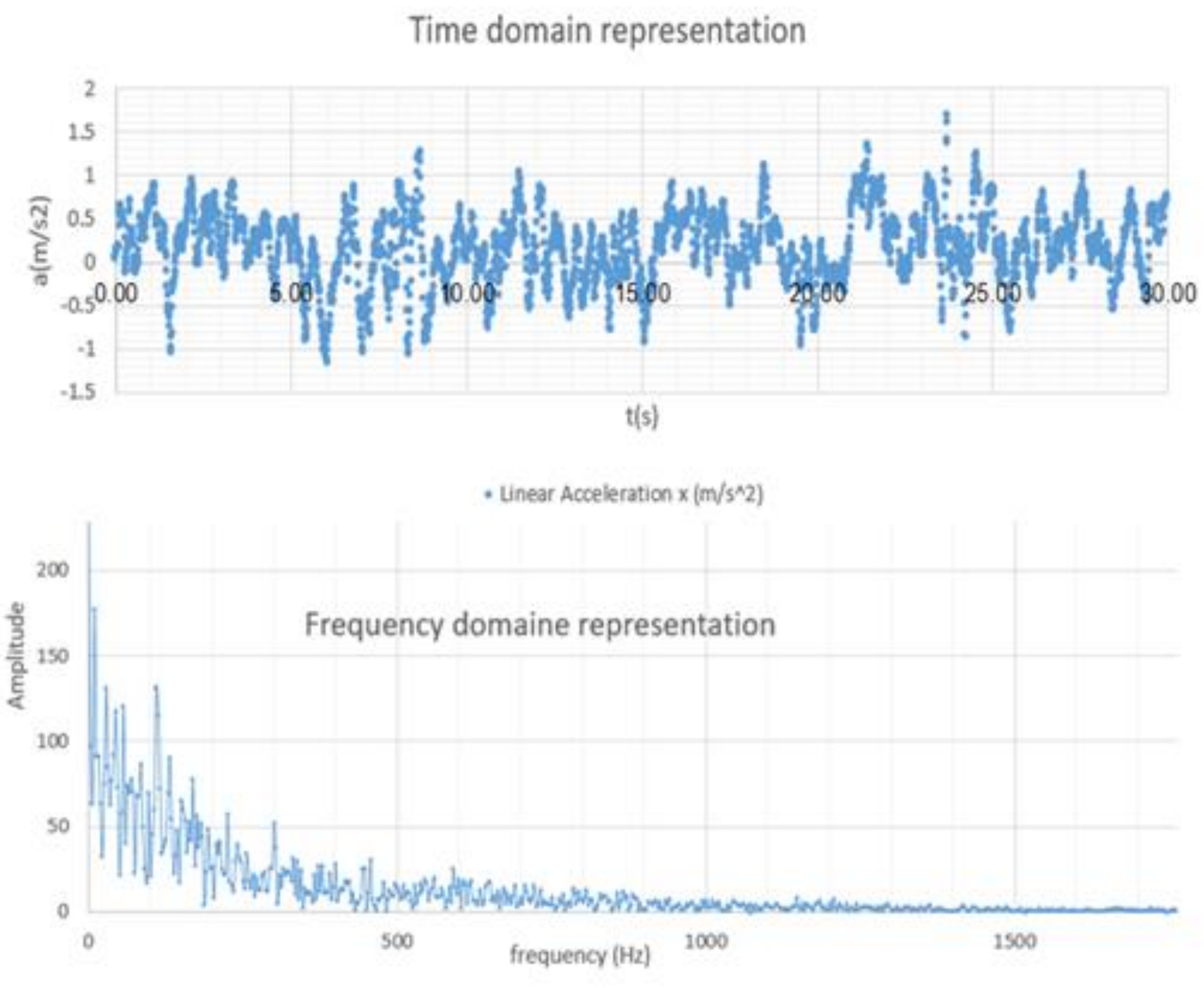






Considering the measurement of the sea waves whose acceleration-time dependence is similar to those represented in Figure 1 we can take, for exemple, the acceleration component with respect to an axis and we can compute the Fourier transform in order to move from the time domain representation to the frecquency domaine representation. As a results we can visualize the frequency of the main components of the group waves. The inertial acceleration input in the case of an accelerometer located on a buoy for exemple has a complex structure and the temporal dependence is quasiperiodic as in Figure 5. Performing the Fourier transform we can see whether or not the components frequencies of the group are in the vicinity of the resonance frequency of the accelerometer.

Fig5



. Time domain and frequency domain representation of a sea group waves.

Comparing with the first resonance frequency for all accelerometer models presented we can see that the frequency componentes of the wave are below. Regarding the ability to discriminate small acceleration values from the noise it depend on the value of the damper coefficient and on a flow model between accelerometer parts and medium which will be investigated in a future paper.

CONCLUSIONS

This study was performed in order to design and analizes some conceptual model of an open loop unidimensional capacitive accelerometer potential to be used to monitor low amplitudes sea waves. The analysis investigates four cases of accelerometers using FEA simulation. The results are predicted in terms of sensitivity and resonance frequencies modes depending on the proposed geometric parameters. The resonance frequencies modes for each case are compared with the frequencies domain representation resulting from a Fourier transform of a generic sea group waves. In our next investigation we will consider a more detailed analysis on a 3-dimensional model

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