Analyzing the amplification of signals in chains of unidirectionally coupled MEMS

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Over the past decade, electromagnetically transduced microelectromechanical systems (MEMS) have garnered significant interest due to their scalability, self-sensing capabilities and distinct applications ranging from mass sensing to electromechanical signal processing and computing. MEMS are systems whose dimensions are at the order of millimeter and micrometer. They are made of mechanical branches (beams, gears, plates and membranes) and microelectronic circuits for electrical branches. The main actuation and properties used in MEMS are piezo-resistivity, piezoelectricity, electrostatics, thermal, electromagnetism and optics. MEMS have a large area of applications such as automotive industry, portable devices, consumer electronic products and cell phone industries. They play a significant role on the magnetic field sensors.

MEMS can sometimes be subject to very weak signals when they are used as sensors or when they are used as actuators. In this case, one can therefore ask if such signal can propagate, be amplified or be detected in a MEMS network.

The aim of this work is to analyze the propagation and the amplification of an input signal in a chain of identical unidirectionally coupled MEMS [1]. The dynamics of the system is described by:

$$\ddot{x}_1 + \gamma_1\dot{x}_1 + \omega_e^2 x_1 + \beta x_1^3 + \lambda_1\dot{y}_1 = f(t) \quad (1)$$

$$\ddot{y}_1 + \gamma_1\dot{y}_1 + \omega_m^2 y_1 + \beta y_1^3 - \lambda_2\dot{x}_1 = 0 \quad (2)$$

$$\ddot{x}_i + \gamma_1\dot{x}_i + \omega_e^2 x_1 + \beta x_i^3 + \lambda_1\dot{y}_i = kx_{i-1} \quad (3)$$

$$\ddot{y}_i + \gamma_1\dot{y}_i + \omega_m^2 y_i + \beta y_i^3 - \lambda_2\dot{x}_i = 0,\ i = 2,\dots,n \quad (4)$$

where the variables x and y represent respectively the current in the electrical part and the displacement of the mechanical part, $f(t)$ is the external signal injected in the first MEMS, k is the coupling coefficient and we consider $\gamma_1 = 0.01$, $\gamma_2 = 0.3$, $\lambda_1 = 1.01$, $\lambda_2 = 1.06$, $\omega_e = 1$, $\omega_m = 1.1$ and $\beta = 0.9$.

Two types of external excitations are considered: sinusoidal and stochastic signals. We show that sinusoidal signals are amplified up to a saturation level which depends on the transmission rate and, despite MEMS being nonlinear the sinusoidal shape is well preserved if the number of MEMS is not too large. However, increasing the number of MEMS, there is an instability that leads to chaotic behavior and which is triggered by the amplification of the harmonics generated by the nonlinearities (see Fig. 1). We also show that for stochastic input signals, the MEMS array acts as a band-pass filter and after just a few elements the signal has a narrow power spectra (see Fig. 2).

In addition the case of non identical units is also studied and particular attention is paid to the effect of disorder in the natural frequency of electric part ω_e in the performance of the chain to amplify weak signals.

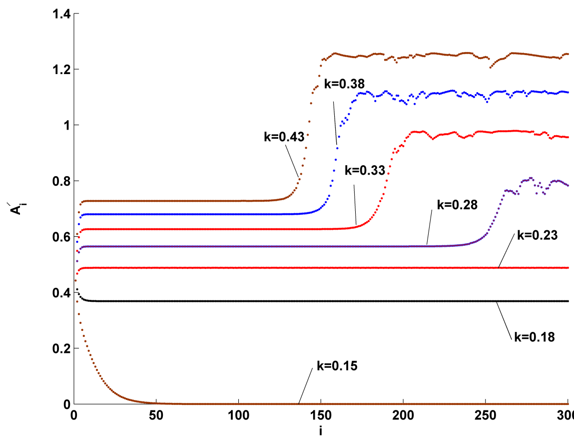

Figure 1: Variation of the response amplitude of the mechanical part versus the rank i of the MEMS in the network for seven values of the coupling strength, $f = 0.1$ and $\omega = 0.67$

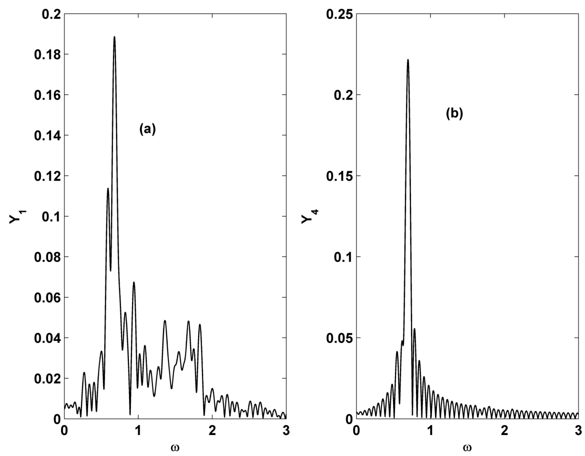

Figure 2: Power spectra of the time trace for $x_i(t)$ for $i = 1$ (a) and $i = 4$ (b).

[1] M.V. Tchakui, P. Woafo, and P. Colet, Eur. Phys. J. B **12**, 89 (2016).