Simulation of MEMS Piezoelectric Vibrational Energy Harvesters

Jorge Monsalve¹, Germán Giraldo¹, Alba Avila¹, Gerhard Klimeck².
¹Universidad de los Andes – Colombia. ²Purdue University – West Lafayette, IN
Microelectronics Research Center (CMUA) Universidad de los Andes, Colombia.
nanoHUB SURF internship: Discovery Learning and Research Center at Discovery Park. Purdue University, West Lafayette, IN

Abstract:
An online numerical simulation tool was developed to study and predict the electrical energy harvested from mechanical vibrations through a piezoelectric device. This device consists of a cantilevered beam of piezoelectric layers (either bimorph or unimorph) with a proof mass at its end. The developed tool allows the user to set-up the dimensions and materials of the beam, along with different excitation conditions. The simulations showed consistency with published experimental results.

Introduction:
This nanoHUB.org tool is intended to simulate the dynamical behavior of a MEMS piezoelectric energy harvesting device. These devices use the principle of the direct piezoelectric effect to convert the energy of a vibrating surface into an electrical current. This is done by shaking acantilevered beam which is coupled to a piezoelectric film. When the beam resonates, the piezoelectric material accumulates electrical charge and delivers it to a circuit.

Motivation:
Piezoelectric materials have proven to be effective for vibration utilization systems with small dimensions (Roundy, 2003). This could allow low-consumption electronic devices to be powered using mechanical oscillations. The physical modeling of piezoelectric cantilevered beams has been addressed in different publications (Erktug, 2009; Andosca et al, 2012). In this work, this electromechanical model is incorporated to an online numerical simulation tool that aids the design and characterization of these devices, and serves also as an educational resource.

Methods:
A system of ordinary differential equations is derived to model the first mode of oscillation of the piezoelectric beam (corrected lumped-parameter model). These equations describing the instantaneous tip displacement and output voltage are integrated using the 4th order Runge-Kutta algorithm. The numerical method is implemented in Octave and a GUI is incorporated using the Rappture Toolkit. After solving the dynamic equation, the program makes a frequency analysis and calculates some relevant statistics of the harvesting process such as the specific power and resonance frequencies. Other features include the possibility to simulate a full-wave rectifier circuit, test the device with measured vibrations sources, frequency sweeps and impulsive inputs.

Results:
Simulations were performed to compare the predictions of this tool against the experimental measurements reported by A. Erktug (2009). The calculations on the resonance frequencies match the experimental data. The output voltage is accurately estimated when a proof mass is added to the system but show deviation if there is no end-mass.

Conclusions and Future Work:
• An effective and fast simulation tool was designed and tested to predict the electrical power that a piezoelectric device can harvest from mechanical vibrations
• Future versions of the tool should include “multi-morph” and d33-type piezoelectric beams, which have been found to harvest more power.

References: