Simscape Library for Large-Signal Physical Network Modeling of Inertial Microelectromechanical Devices

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Abstract : The information flow (e.g. block-diagram or signal flow graph) paradigm for the design and simulation of Microelectromechanical (MEMS)-based systems allows to model MEMS devices using causal transfer functions easily, and interface them with electronic subsystems for fast system-level explorations of design alternatives and optimization. Nevertheless, the physical bi-directional coupling between different energy domains is not easily captured in causal signal flow modeling. Moreover, models of fundamental components acting as building blocks (e.g. gap-varying MEMS capacitor structures) depend not only on the component, but also on the specific excitation mode (e.g. voltage or charge-actuation). In contrast, the energy flow modeling paradigm in terms of generalized across-through variables offers an acausal perspective, separating clearly the physical model from the boundary conditions. This promotes reusability and the use of primitive physical models for assembling MEMS devices from primitive structures, based on the interconnection topology in generalized circuits. The physical modeling capabilities of Simscape have been used in the present work in order to develop a MEMS library containing parameterized fundamental building blocks (area and gap-varying MEMS capacitors, nonlinear springs, displacement stoppers, etc.) for the design, simulation and optimization of MEMS inertial sensors. The models capture both the nonlinear electromechanical interactions and geometrical nonlinearities and can be used for both small and large signal analyses, including the numerical computation of pull-in voltages (stability loss). Simscape behavioral modeling language was used for the implementation of reduced-order macro models, that present the advantage of a seamless interface with Simulink blocks, for creating hybrid information/energy flow system models. Test bench simulations of the library models compare favorably with both analytical results and with more in-depth finite element simulations performed in ANSYS. Separate MEMS-electronic integration tests were done on closed-loop MEMS accelerometers, where Simscape was used for modeling the MEMS device and Simulink for the electronic subsystem.

Keywords : across-through variables, electromechanical coupling, energy flow, information flow, Matlab/Simulink, MEMS, nonlinear, pull-in instability, reduced order macro models, Simscape
Conference Title : ICNDD 2019 : International Conference on Nonlinear Dynamics and Diagnosis
Conference Location : London, United Kingdom
Conference Dates : September 25-26, 2019