STUDY AND ANALYSIS FOR REDUCING PULL IN VOLTAGE OF ELECTROSTATIC MEMS ACTUATOR

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ABSTRACT

This project investigates the performance of a hybrid MEMS actuator integrated with a ferroelectric negative capacitor, focusing on both series and parallel capacitor configurations. By leveraging the voltage amplification of ferroelectric materials, the system aims to enhance actuation efficiency, reduce power consumption, and improve CMOS compatibility. A SPICE-based simulation framework was developed to model the coupled dynamics of the actuator and ferroelectric component, with results validated against theoretical models in Python. Static pull-in analysis shows strong agreement between simulations and theory. The parallel configuration demonstrated superior performance with lower pull-in voltage, better energy efficiency, and improved stability for low-power applications.

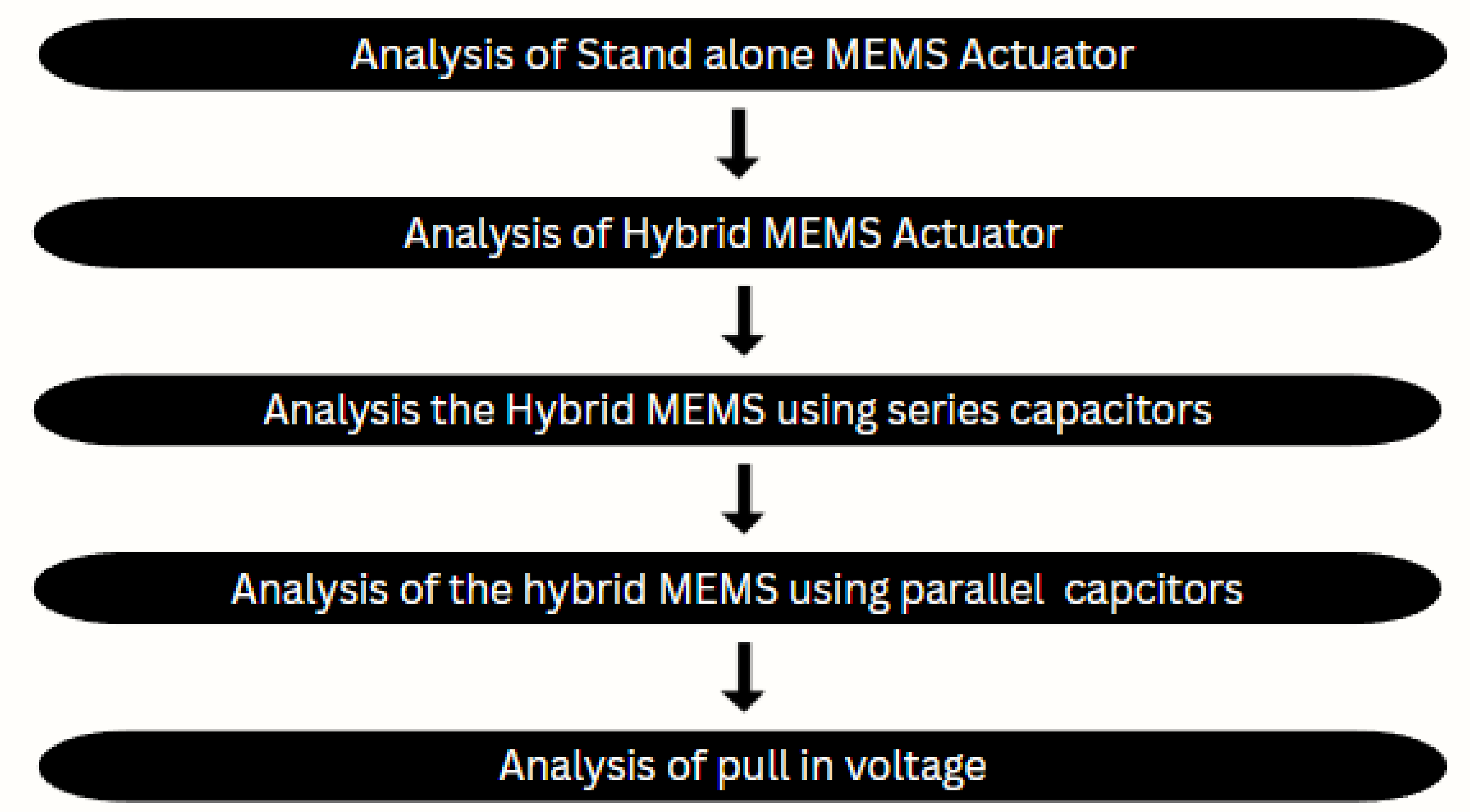
INTRODUCTION

MEMS actuators are known for their accuracy and ability to scale in microelectronic systems.Integrating CMOS and MEMS technologies is essential for building compact and intelligent microsystems used in fields like healthcare, consumer devices, and IoT. CMOS handles signal processing and control, while MEMS provides sensing or actuation. One key challenge in this integration is the voltage mismatch—CMOS typically runs below 1V, whereas traditional MEMS actuators need much higher voltages (around 10V or more). This mismatch complicates direct interfacing and reduces system efficiency.To overcome this limitation, MEMS actuators utilizing ferroelectric negative-capacitance materials have been put into practice.These materials lower the required actuation voltage, making the system more compatible with low-voltage CMOS platforms while maintaining actuator performance.

OBJECTIVES

1. A SPICE-based simulation framework is developed to analyze the transient behavior of hybrid MEMS actuators.
2. Four configurations are investigated: a standalone electrostatic MEMS actuator, a hybrid with one ferroelectric capacitor, two ferroelectric capacitors in series, and two in parallel.
3. Each configuration is evaluated in terms of pull-in voltage, energy consumption, and dynamic response.
4. The CMOS compatibility of these configurations is assessed based on voltage requirements and system stability.

BLOCK DIAGRAM



IMPLEMENTATION

In this project, we implemented and simulated different MEMS configurations: standalone, hybrid, and series-parallel combinations of hybrid MEMS with two capacitors. The goal was to study both theoretical and real-time performance metrics of these configurations.

The simulations were conducted using **Python** for documenting theoretical calculations and **Ltspice** for modeling and real-time simulations. Python's numerical and simulation libraries, such as the result obtained were used to model the dynamic behavior of MEMS actuators under various conditions. Theoretical values were derived based on electrostatic principles, while real-time values were obtained by simulating the actuators' response to different voltages, displacements, and environmental factors.

By comparing these configurations, we evaluated key parameters like pull-in voltage, displacement, and settling time, ultimately highlighting the benefits of the hybrid parallel configuration, which showed superior performance in terms of reduced voltage, improved efficiency, and better CMOS compatibility.

RESULTS

Table 1. Comparison of performance parameters across different MEMS configurations. Hybrid Parallel configuration is highlighted.

Parameter	Standalone MEMS	Hybrid MEMS	Hybrid Series	Hybrid Parallel
Pull-In Voltage (V)	18.67 V	1.8 V	1.2 V	0.66 V
Pull-In Displacement	1.50 μm	0.79 μm	0.44 μm	0.44 μm
Settling Time	Very Slow	Slower	Improved	Improved
CMOS Compatibility	Very Poor	Moderate	High	Very High

CONCLUSION

In this study, we used a SPICE-based modeling framework to analyze the transient response of ferroelectric negative capacitance integrated MEMS actuators. Simulations comparing series, parallel, and original capacitor configurations showed that parallel capacitors provide the best overall performance. Integrating ferroelectric negative capacitance significantly reduces pull-in and pull-out voltages, lowering power and energy consumption compared to standalone MEMS. Applying voltages slightly above the pull-in threshold helps synchronize contact timing in hybrid actuators while maintaining energy efficiency. This reciprocal effect between voltage and actuation time boosts performance, making the system ideal for low-power, low-voltage applications. The SPICE model's CMOS compatibility further enables the development of compact, efficient hybrid CMOS–MEMS actuator systems.

REFERENCES

1. R. T. Raman and A. Ajoy, "Spice-based multiphysics model to analyze the dynamics of ferroelectric negative-capacitance–electrostatic MEMS hybrid actuators," *IEEE Transactions on Electron Devices*, vol. 67, no. 11, pp. 5174–5181, 2020.
2. M. Masuduzzaman and M. A. Alam, "Effective nanometer airgap of NEMS devices using negative capacitance of ferroelectric materials," *Nano Letters*, vol. 14, no. 6, pp. 3160–3165, May 2014.
3. K. Choe and C. Shin, "Adjusting the operating voltage of a nanoelectromechanical relay using negative capacitance," *IEEE Transactions on Electron Devices*, vol. 64, no. 12, pp. 5270–5273, Dec. 2017.
4. G. M. Rebeiz, *RF MEMS: Theory, Design, and Technology*. Hoboken, NJ, USA: Wiley, 2004.