

Integrated Electromagnetic/Thermal/Mechanical Analysis for MEMS Reliability

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Motivation

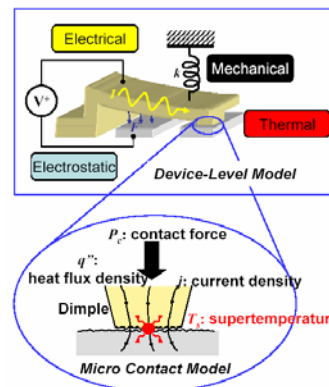
- RF-MEMS hold the promise of **revolutionizing** (life span, size and functionality) electrical systems because of their extremely low power and miniature size.
- the reliability of RF MEMS is **not** acceptable for switch operation over several billion cycles and life spans of over 10 years.

Objective:

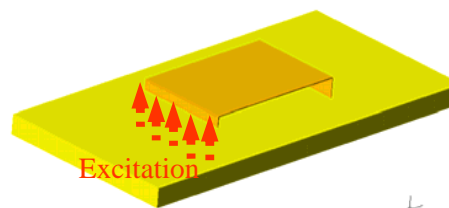
- Understanding of the phenomena governing the reliability of RF MEMS devices through **integrated electromagnetic/thermal/mechanical multi-physics analysis and characterization.**

Accomplishments to date

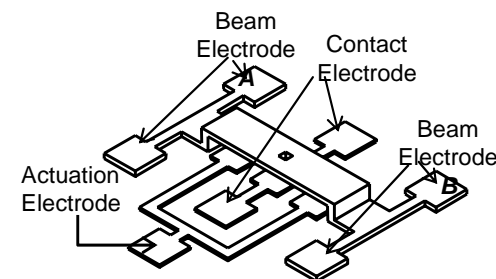
- Developed **new** electromagnetic modeling technique called the Extended Finite Element-Boundary Integral Method (EFE-BI) - well-suited for MEMS simulation.
- Constructed **Fast and accurate** integral technology – semi-analytic integral formulations for double surface integration - well suited to MEMS electric dimensions;;
- Applied Highly **efficient preconditioner** – near-zone preconditioner - to EFE-BI for fast convergence;
- Multi-physics model integration using **full-wave** electromagnetic modeling for prediction of MEMS switch failure.
- Our experimental testing identified the **contact softening** mechanism in RF MEMS metal contact switches leading to a reduction in contact resistance.
- Identified methods for mitigating failure



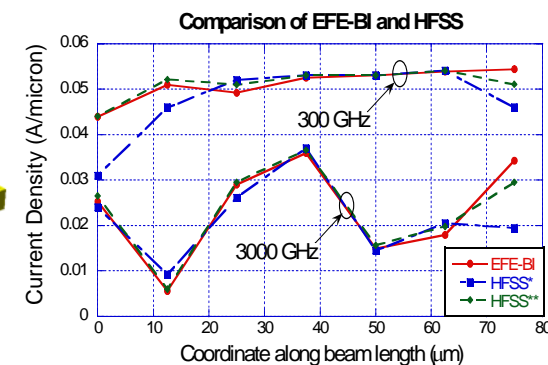
Conceptual multi-physics model



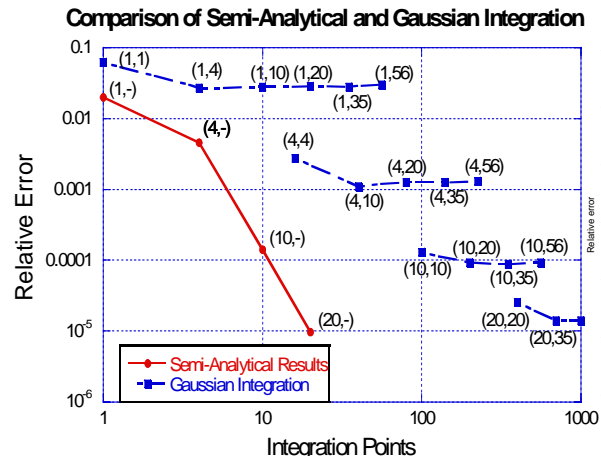
RF-MEMS switch in up-state with impressed current source



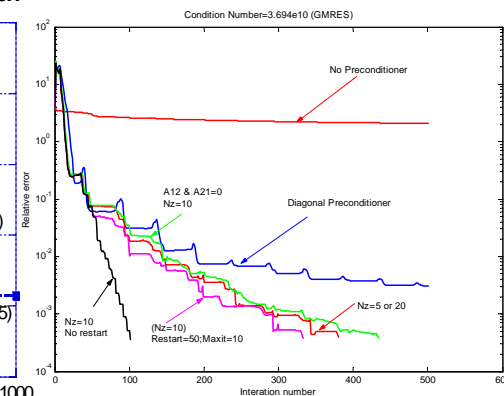
Schematic of a RF-MEMS switch



Current density distribution along the beam for different frequency



Maximum relative errors of semi-analytical and Gaussian integrations



Comparison of convergence rates for different preconditioners

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Journal Papers

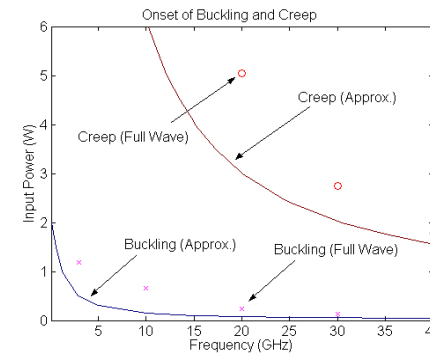
- Jensen, B. D., Saitou, K., Volakis, J., and Kurabayashi, K., "Fully Integrated Electrothermal Multi-Domain Modeling of RF MEMS Switches," *IEEE Microwave and Wireless Components Letters*, vol. 13, pp.364-366, Sept. 2003.
- Z. Wang, J. Volakis, K. Saitou, and K. Kurabayashi, "Comparison of semi-analytical formulations and Gaussian quadrature rules for quasi-static double surface potential integrals," *IEEE Antenna Prop. Magazine* in press.
- Z. Wang, B. Jensen, J. Volakis, K. Saitou, and K. Kurabayashi, "Integrated Electrothermal Analysis of RF-MEMS Switches by Using Extended Finite Element-Boundary Integration Method," *IEEE Trans. MTT*, submitted for review.

Conference Papers

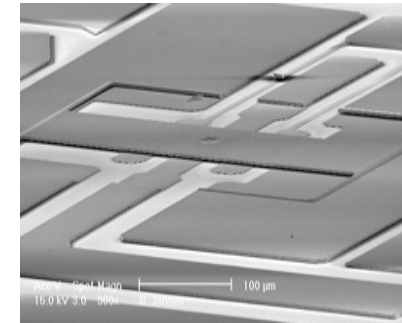
- Z. Wang, B. Jensen, J. Volakis, K. Saitou, and K. Kurabayashi, "Analysis of RF-MEMS switches using finite element-boundary integration with moment method," *Proc. IEEE Society International Conference on Antennas and Propagation*, vol. 2, pp. 173 -176, June 22-27, 2003.
- Jensen, B., Z. Wang, Saitou, K., Kurabayashi, K., and Volakis, J., "Simultaneous Electrical and Thermal Modeling of a Contact-Type RF MEMS Switch," *Proc. 2003 ASME International Mechanical Engineering Congress and R&D Expo*, paper IMECE-41422.

Broader Impact/Educational/Outreach

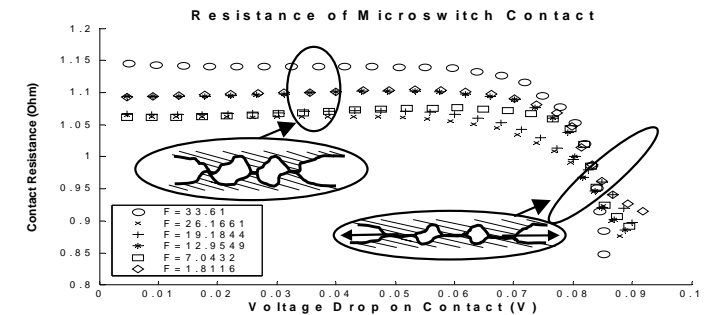
- MEMS are important components to many RF devices used in antennas, filters and communication equipment. This work combined an interdisciplinary approach to propose new MEMS analysis with micro-fabrication and design methodologies to develop highly reliable MEMS switches
- A student team consisting of 1 PhD student in EE, 1 PhD student in ME/EE, 1 PhD female student in ME, and 1 female undergraduate student (though RUE supplement), trained in highly multidisciplinary environments.



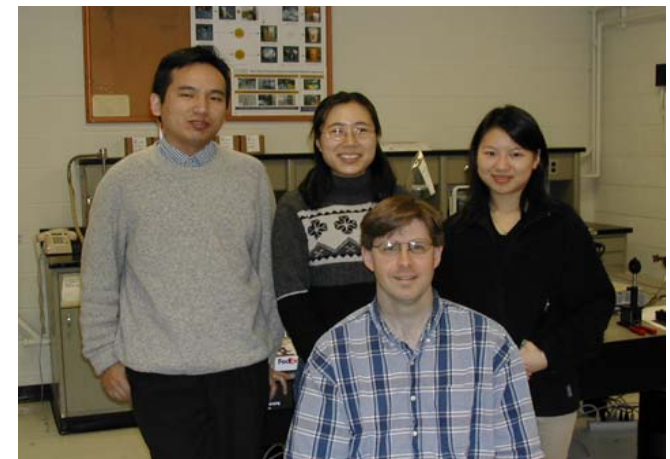
Prediction of switch failure, showing buckling as the dominant failure mode for one switch geometry



SEM images of testing RF MEMS Switches



Experimental Data showing contact softening



Team of students working on the project