Reliability Enhancing Circuit for Capacitive MEMS Switch

Ruth Houlihan[1], P. Collins[2], Z. Olszewski[1] and A. Mathewson[1]

[1]Tyndall National Institute, University College Cork, Ireland

[2]Cork Institute of Technology, Cork, Ireland

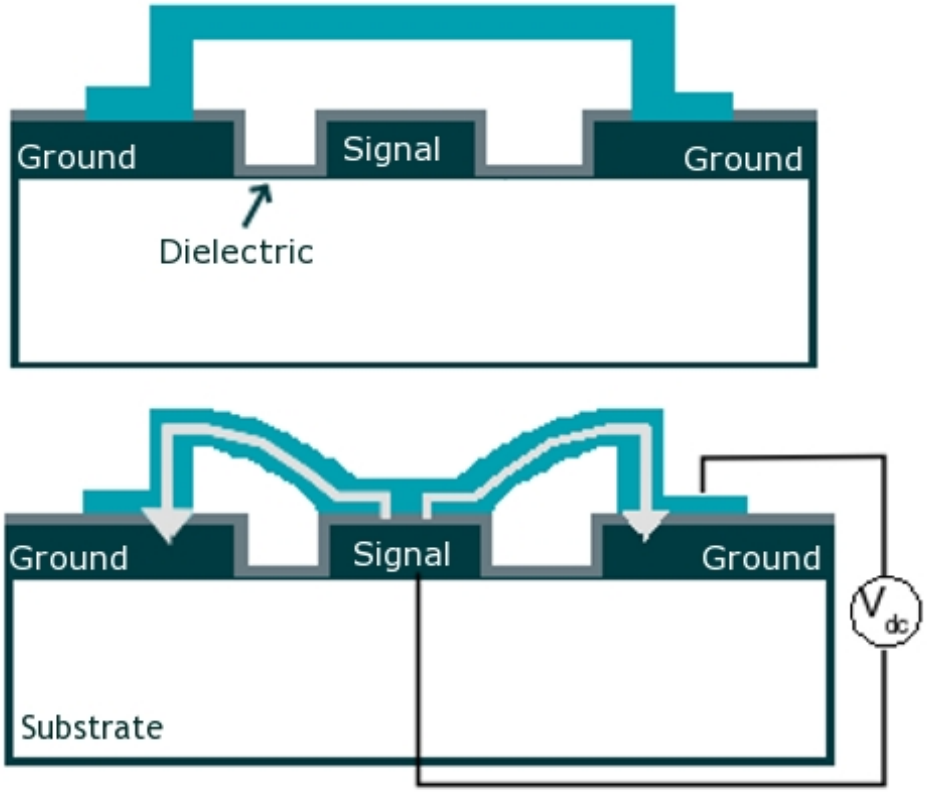
ruth.houlihan@tyndall.ie

Outline

- Introduction
  - Capacitive MEMS Switches
- Dielectric Charging Failure Modes
  - CV shift
  - CV narrowing
- Charging model
- System level switch model incorporating charging
- A circuit based approach towards improved reliability
  - Concept
  - Implementation
- Conclusions

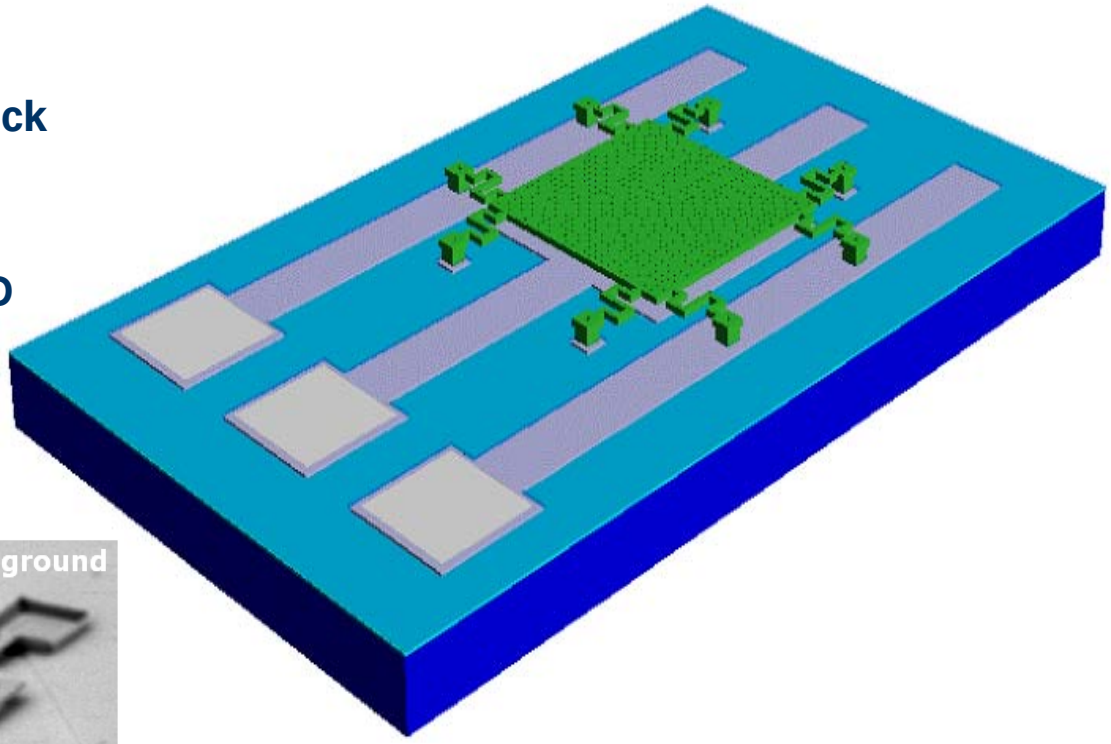
Capacitive RF Switches

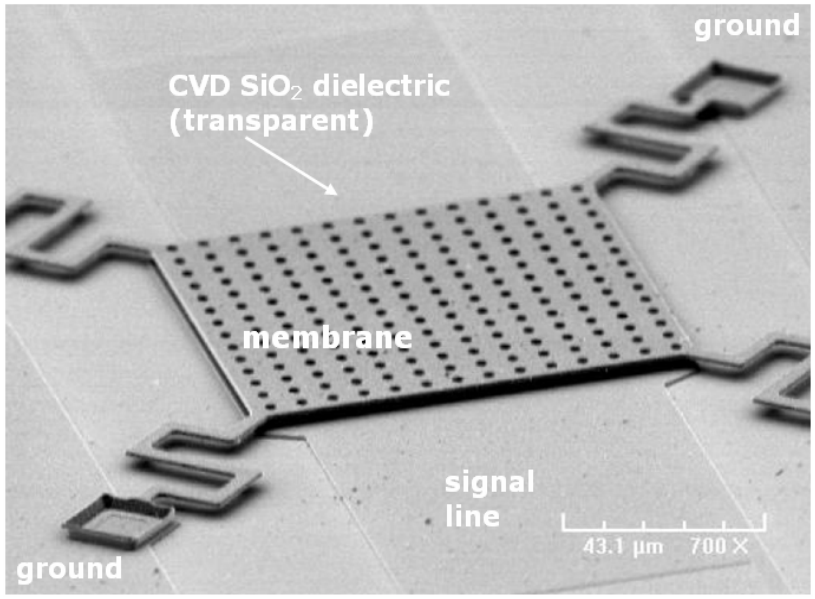
- Operation
  - shunt
- Advantage
  - Low loss
  - Low power consumption
  - IC compatible
- Applications:
  - Satellite switching networks
  - Telecommunications e.g. tunable matching networks, phase shifters, tunable antennas
- Challenges: Reliability
  - Stiction: Primary failure mechanism

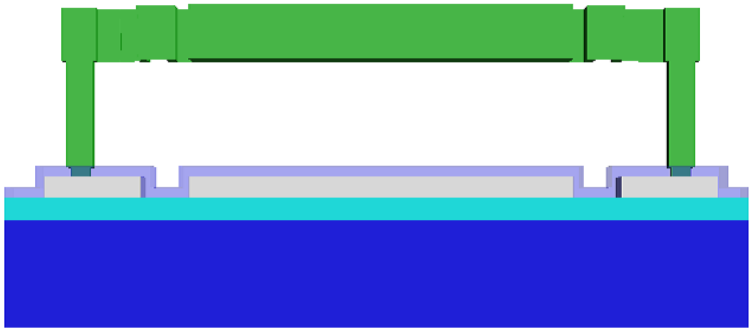


Capacitive MEMS Switches

- Surface Micromaching Process
- Suspended electrode: 1um thick Aluminium (tensile)
- Bottom Electrode: Al1%Si
- Dielectric: 100nm thick PECVD silicon dioxide
- Sacrifical Layer: polyimide
- Air-gap typically 2um-2.5um

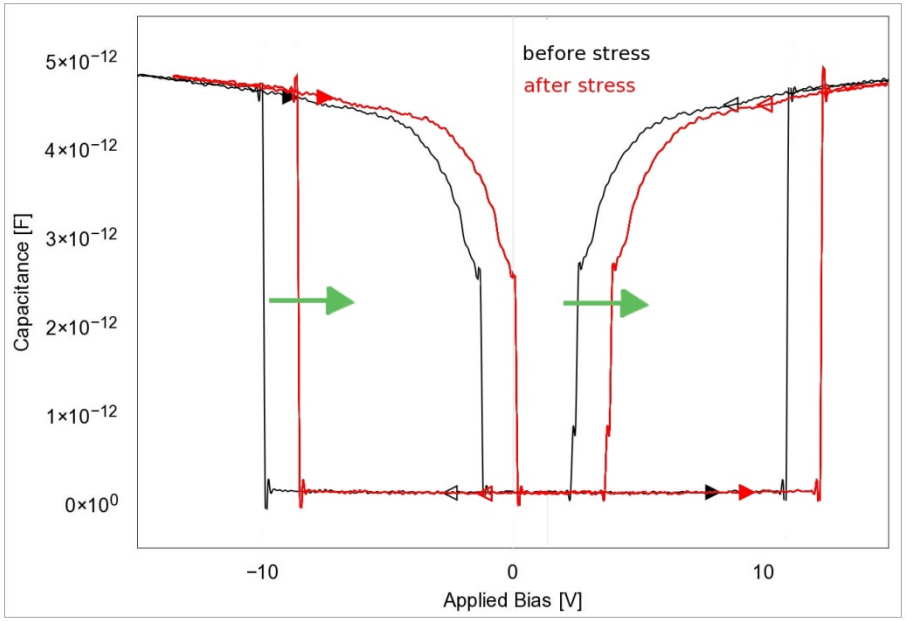


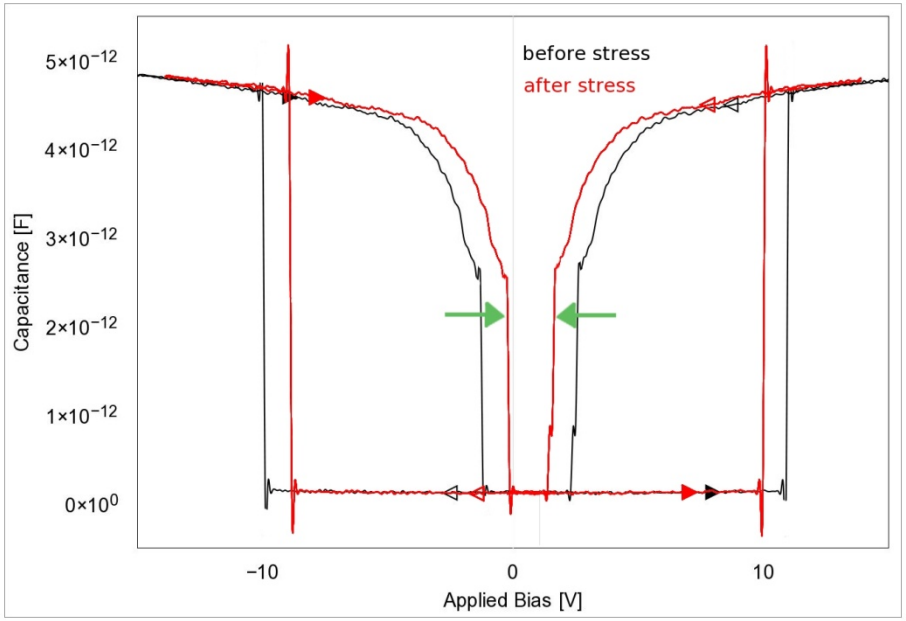




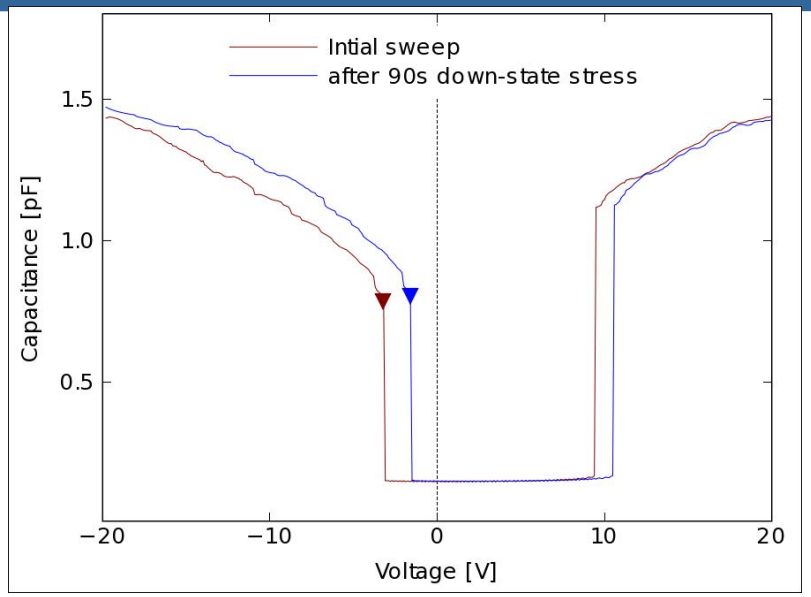
MEMS and Reliability: Stiction

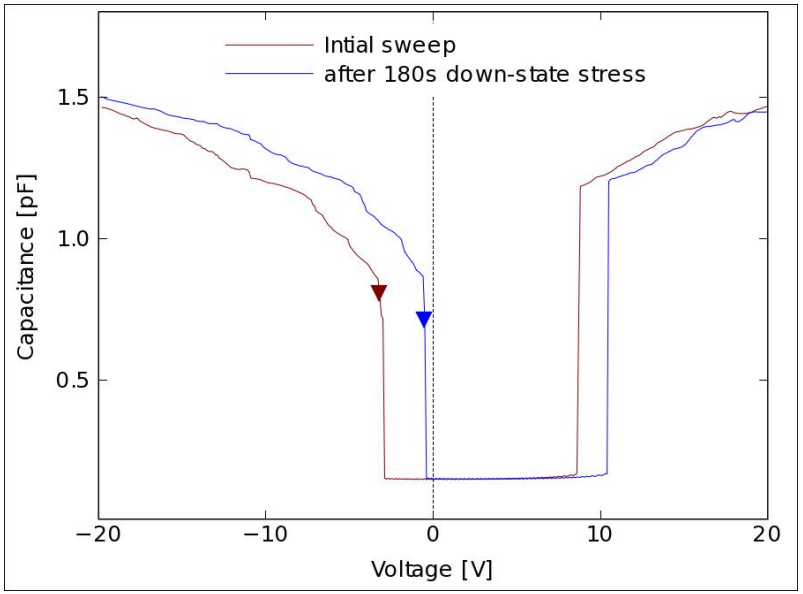
- Stiction is the primary failure mechanism of capacitive MEMS switches
- Research efforts are intensive
  - Many charging mechanisms and theories have been proposed
  - Physical understanding of the problem is still not comprehensive
  - Highly device and process dependent
- There are two primary manifestations of charging:
  - CV shift & CV narrowing



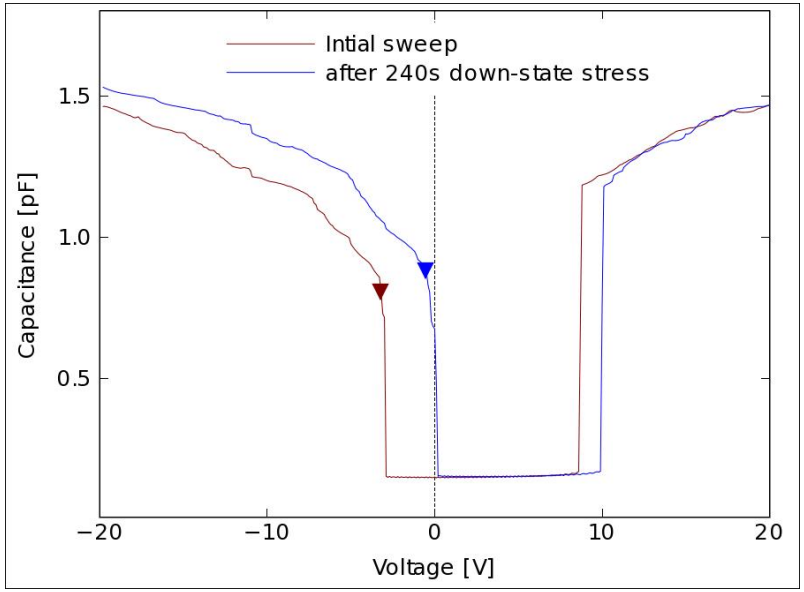


Failure due to CV Shift

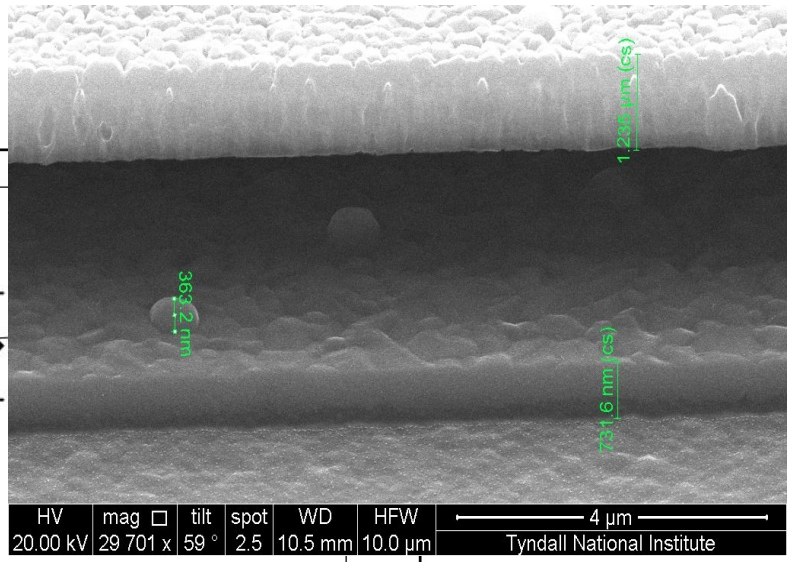


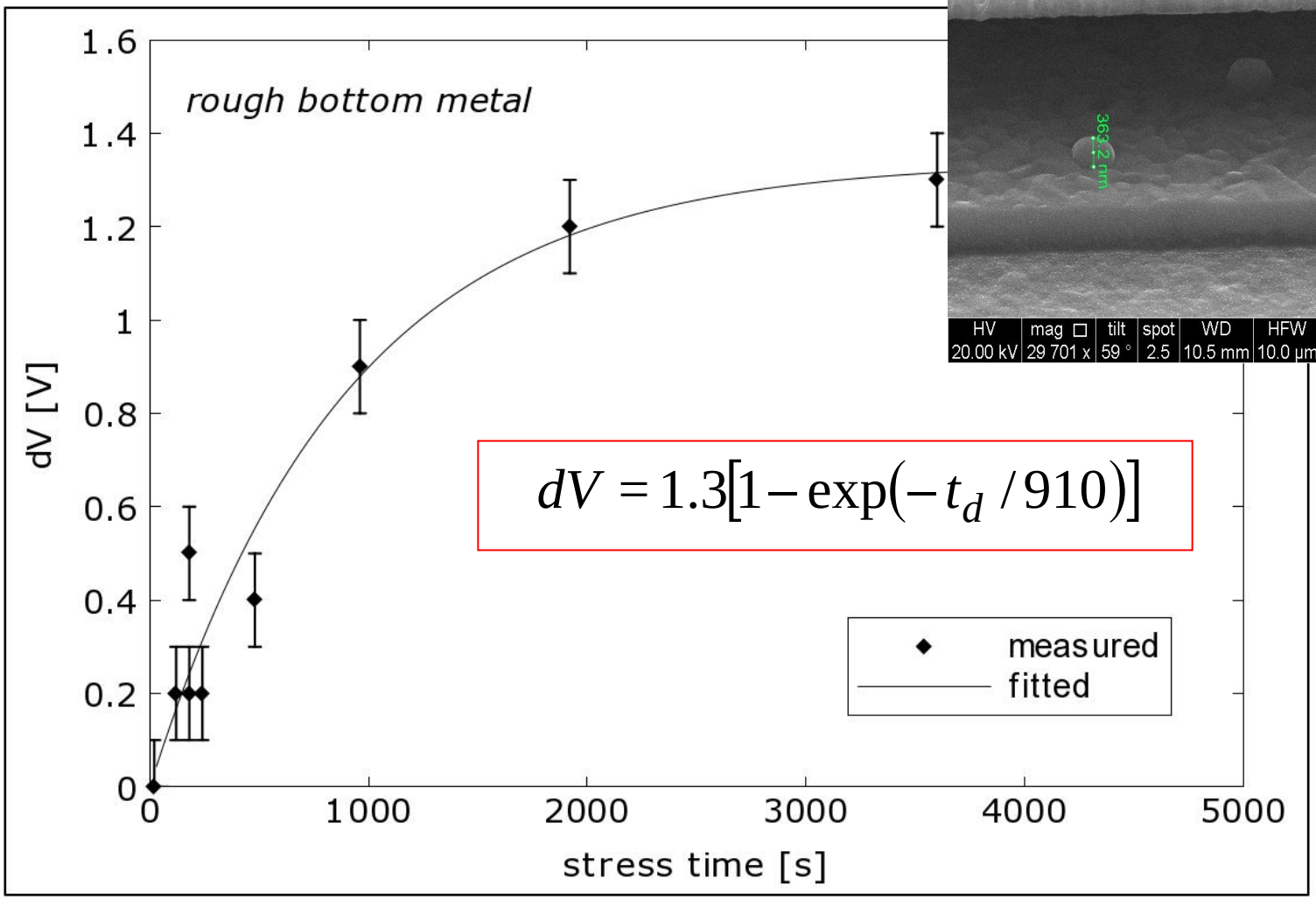


- **Charge accumulation in the dielectric results in a shift in the CV characteristic**
- **Failure occurs when the release voltage exceeds 0V line and so the switch does not return to the up-state after the applied bias is removed.**



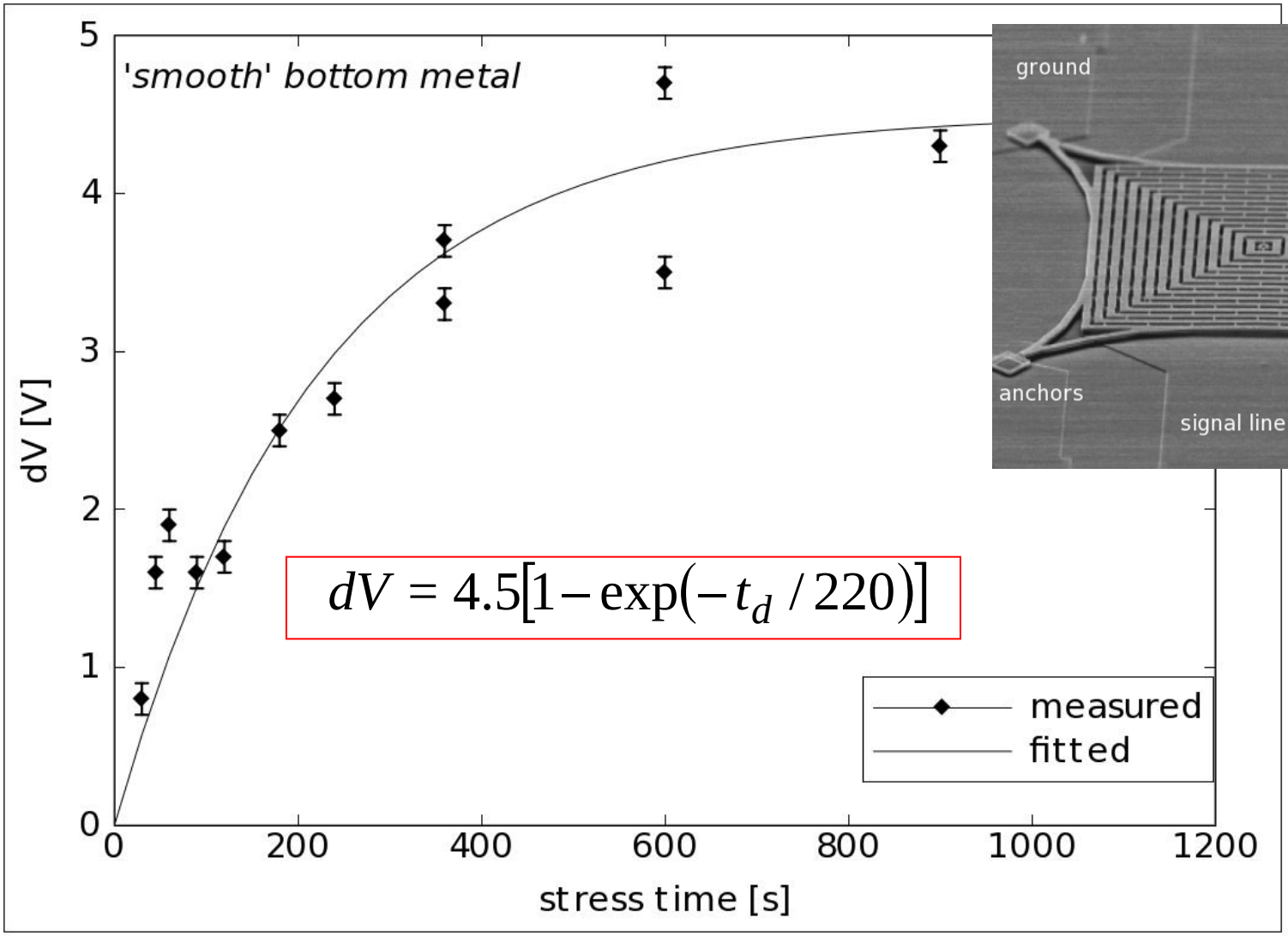
Modelling CV Shift





$$dV = 1.3\left[1 - \exp\left(-t_d / 910\right)\right]$$

Modelling CV Shift



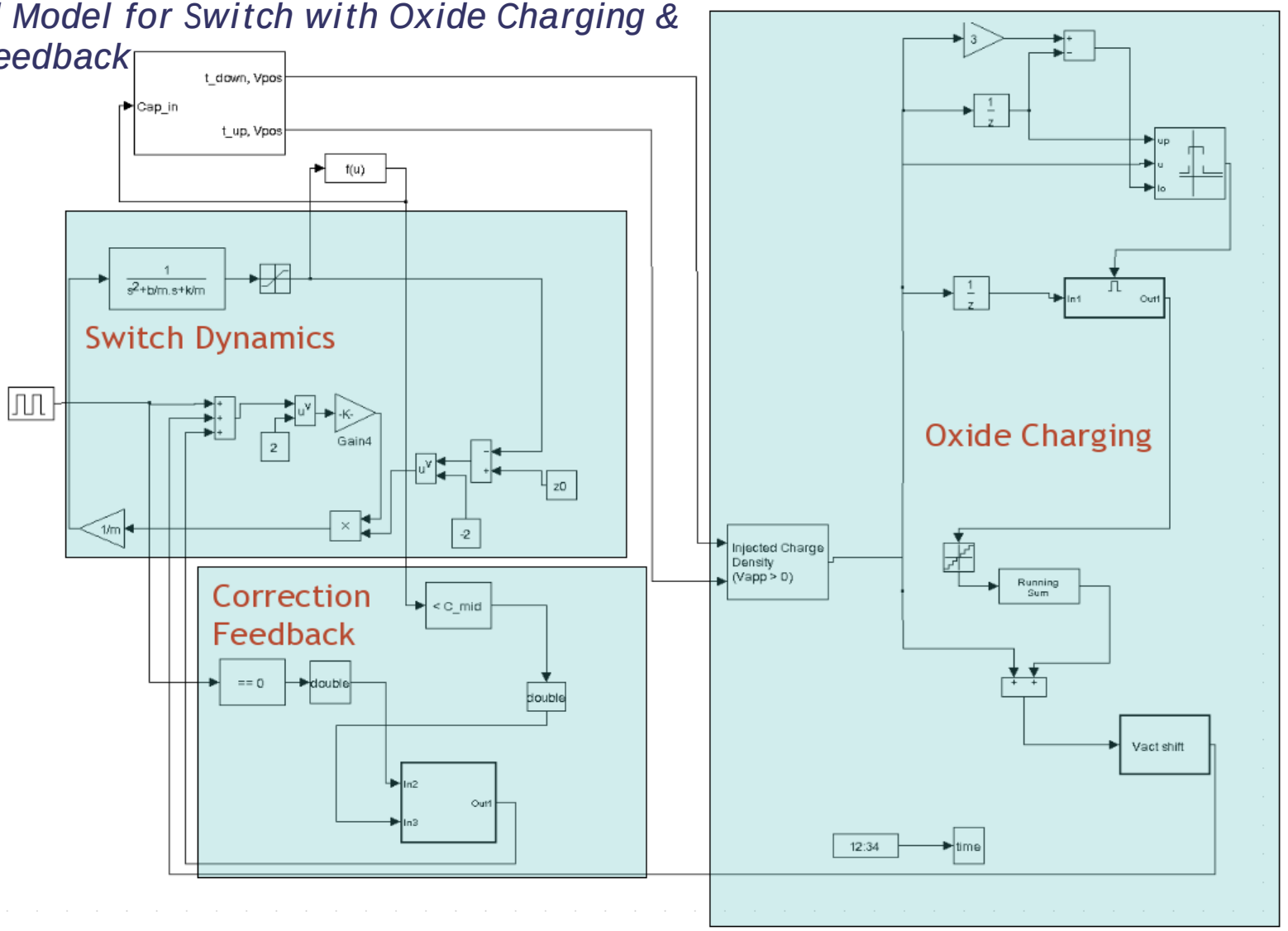
Stiction: Solutions to Date

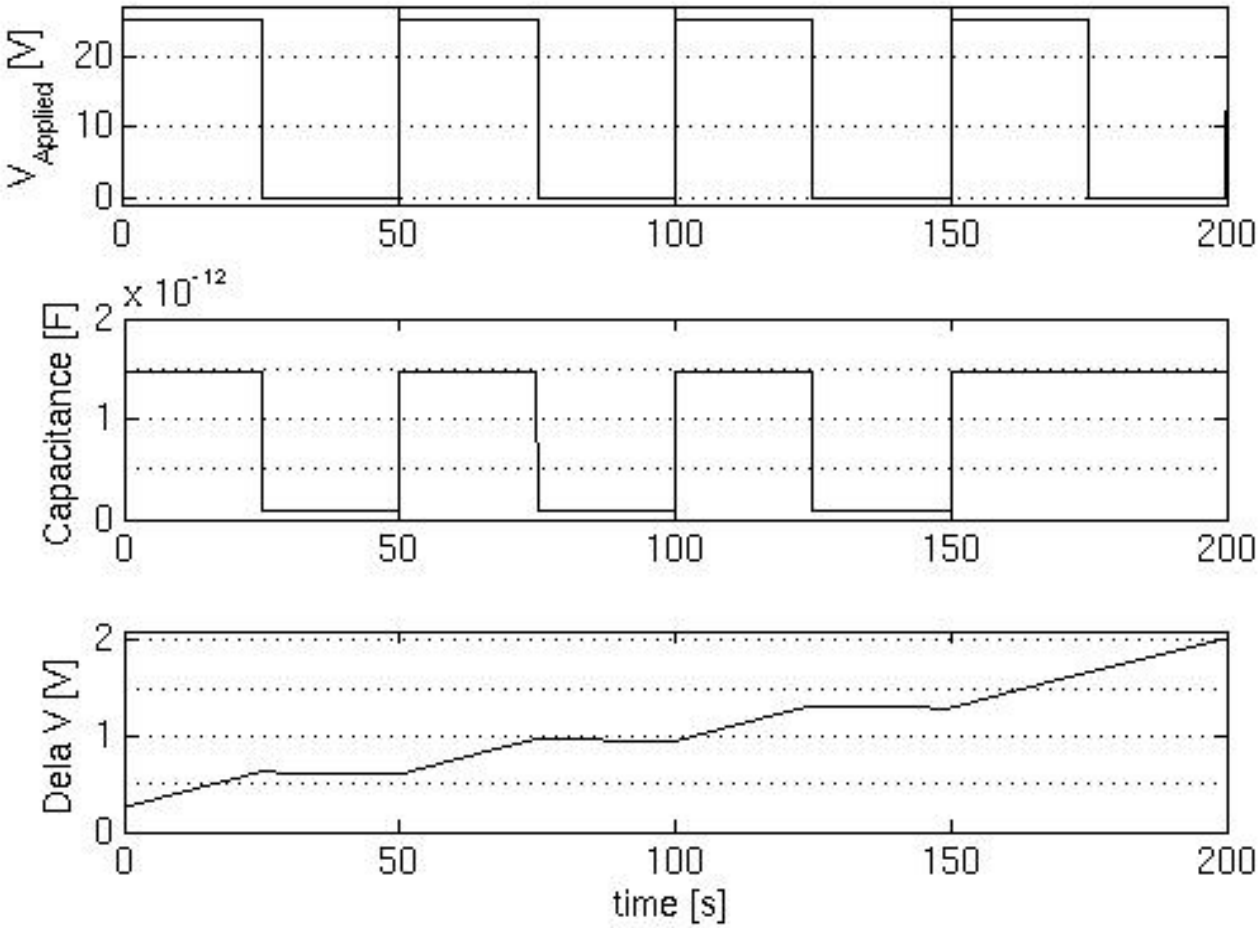
- **Efforts to Date largely concentrated on**
  - **Developing a physical understanding of problem**
  - **Structure/Process based solutions**
  - **Electrical approaches: hold down voltages, bipolar actuation, smart bipolar actuation**

- **What is proposed here:**
  - **accept charging**
  - **Make your switch smart so CV shift no longer causes failure**

A switch whose reliability is limited due to CV shift always has a pull-in voltage and always has a release voltage

System Level Model for Switch with Oxide Charging & Corrective Feedback

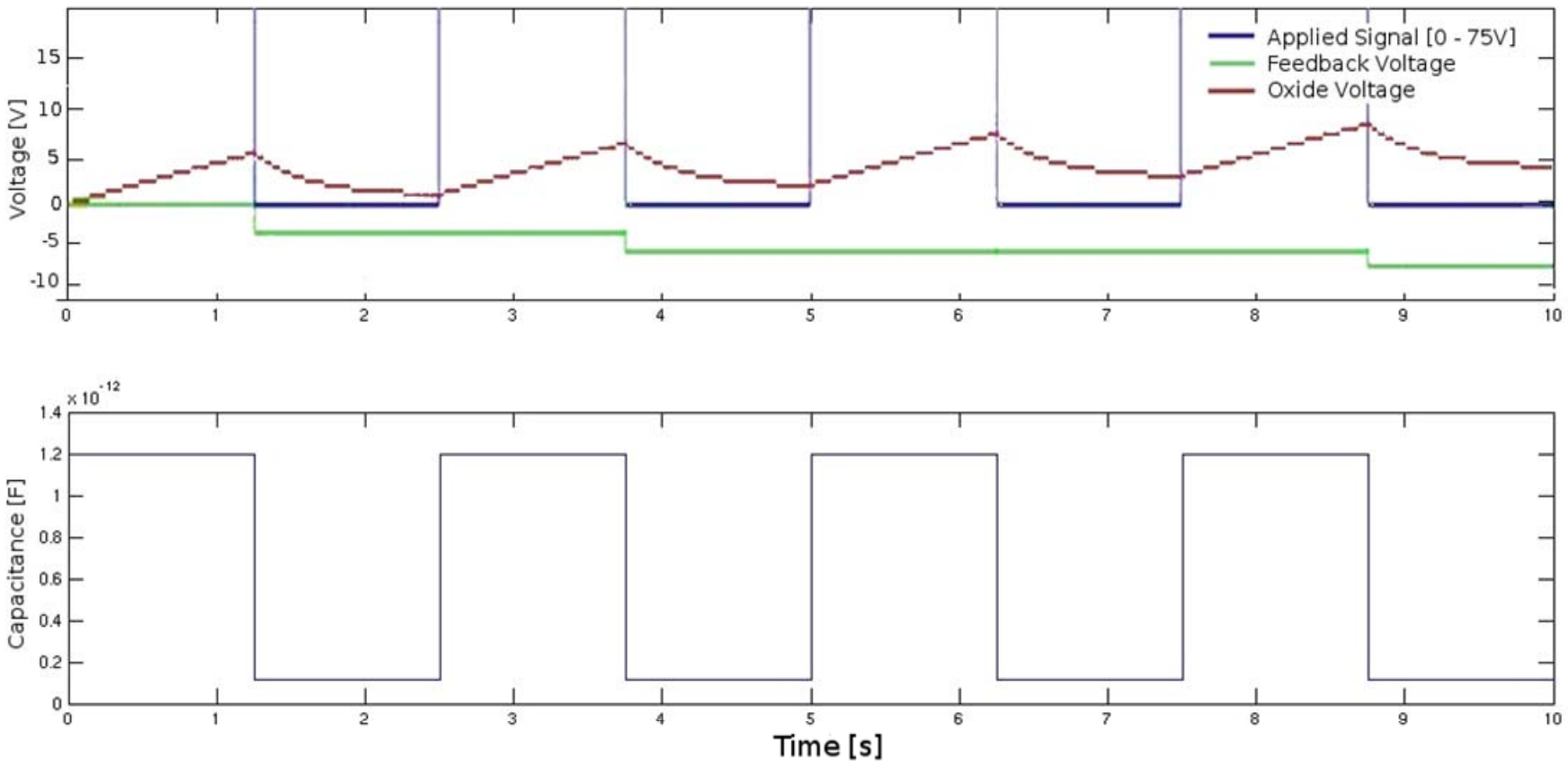




Basic Model used to:

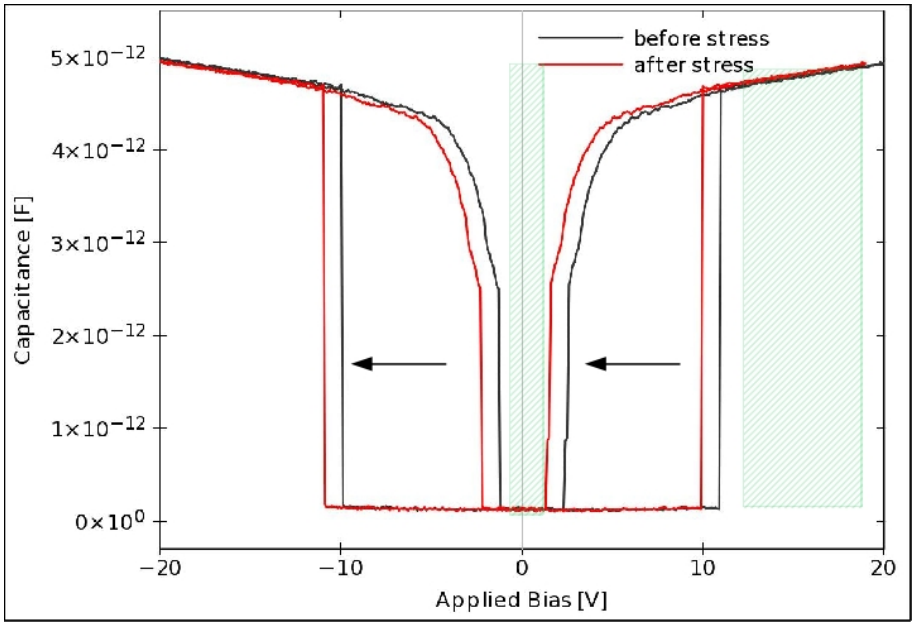
- Determine cycles to failure
- Investigate effects of charging on switch dynamics
- Bipolar actuation

System Level Model for Switch with Oxide Charging & Corrective Feedback

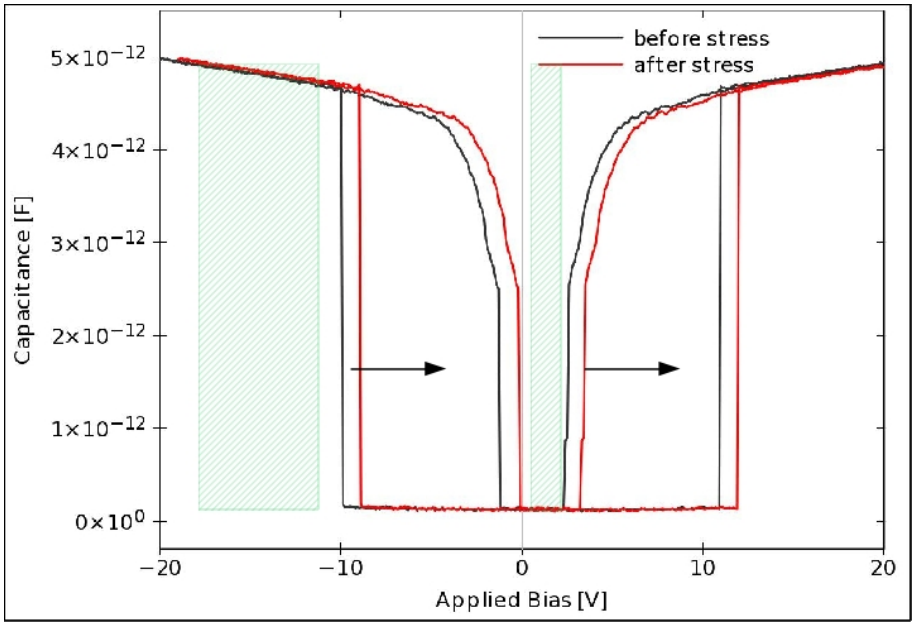


Circuit Based Solution: Principle Of Operation

Negative bias applied to membrane
=> CV shifts left

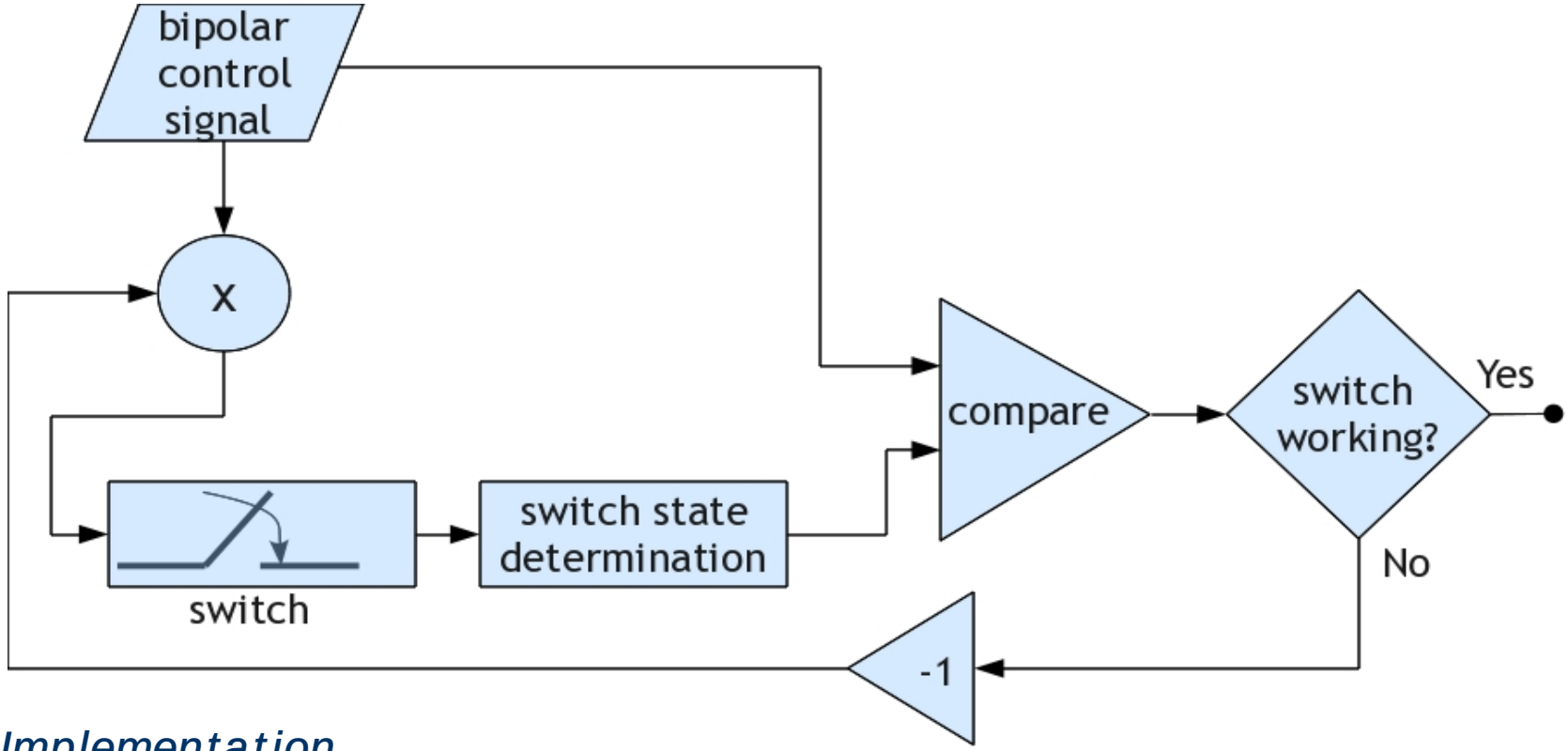


Positive bias applied to membrane
=> CV shifts right



Principle of Operation

- Charge injection results in a shift in the CV characteristic
- The direction of the shift depends on the polarity of the charge
- **There always exists a release voltage and a pull-in voltage**

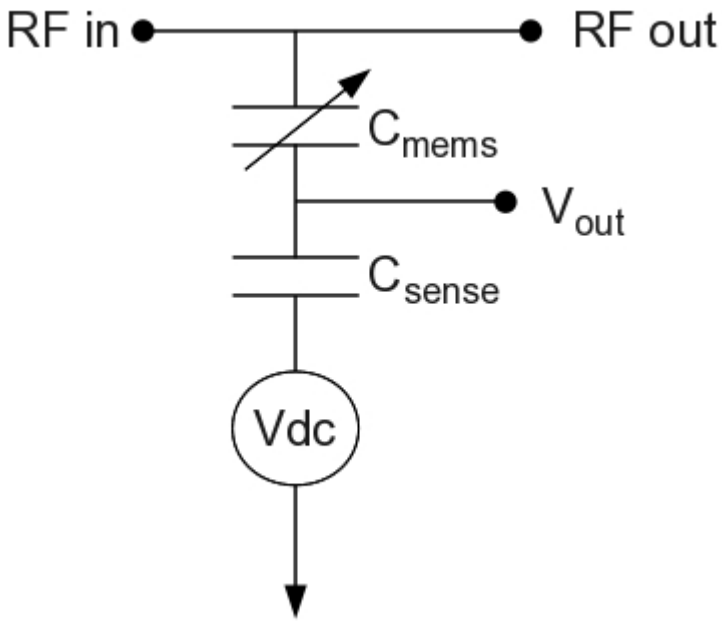


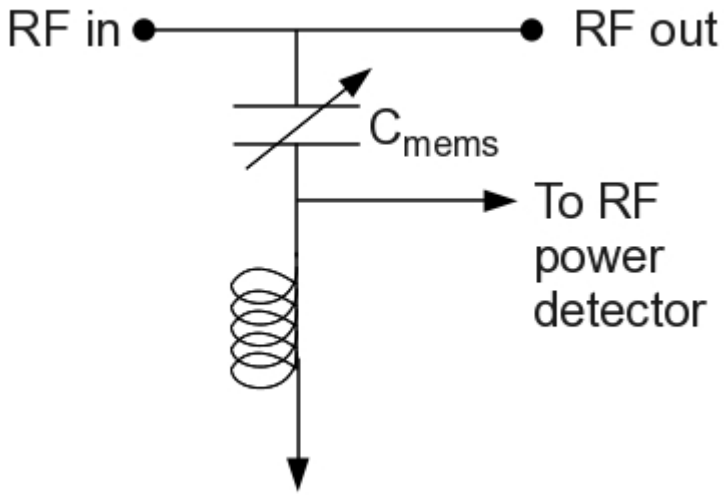
Implementation

- Generate two actuation voltages: V_{high} for pull-in & V_{low} for release
- Polarity of V_{high} and V_{low}: opposite to previous cycle (bipolar actuation)
- Switch state is monitored, compared with control signal and corrective feedback applied when necessary

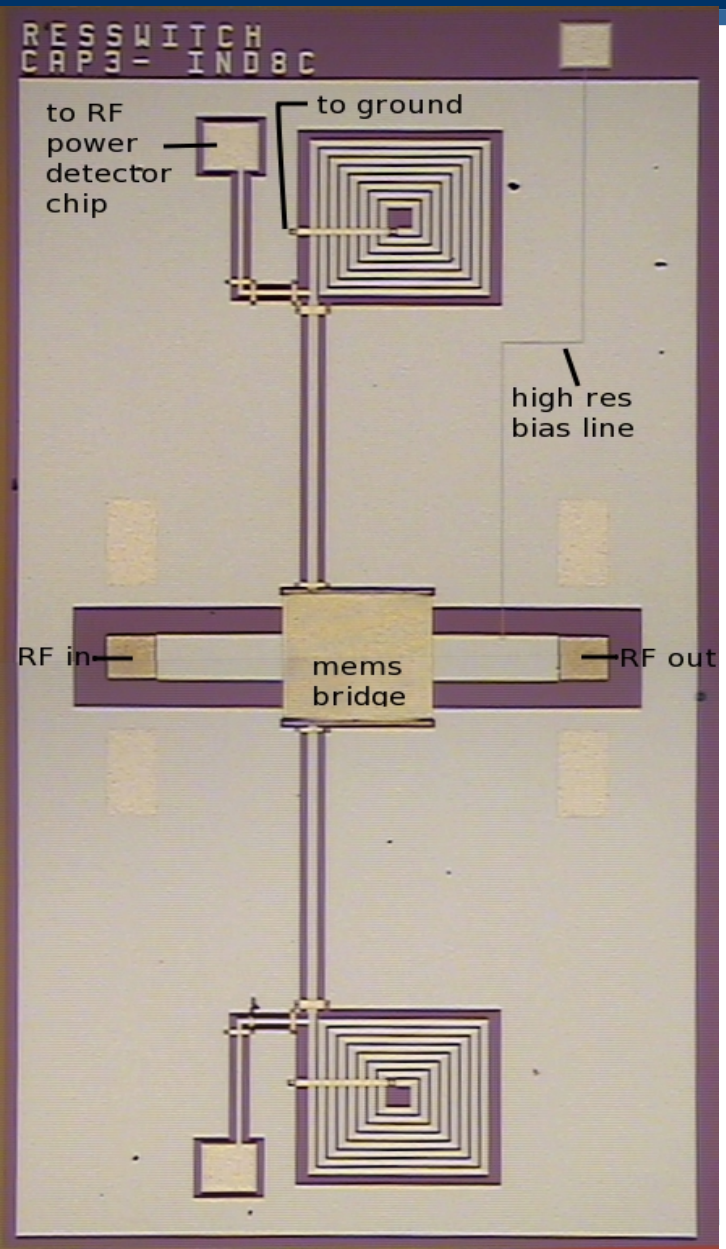
Determining the state of the switch

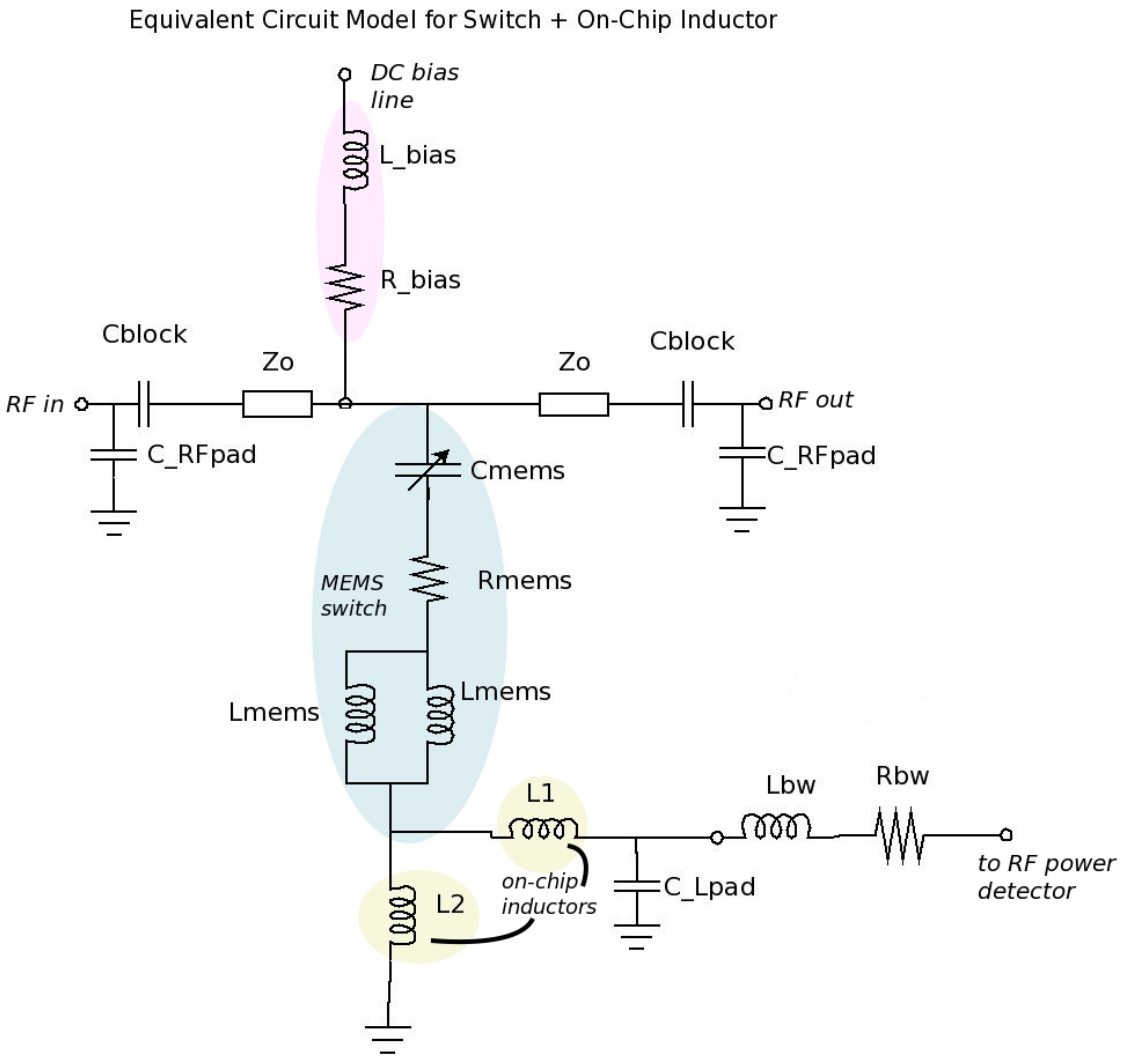
- **Two approaches are being investigated:**
  - **Capacitor Divider and Resonant Detection**



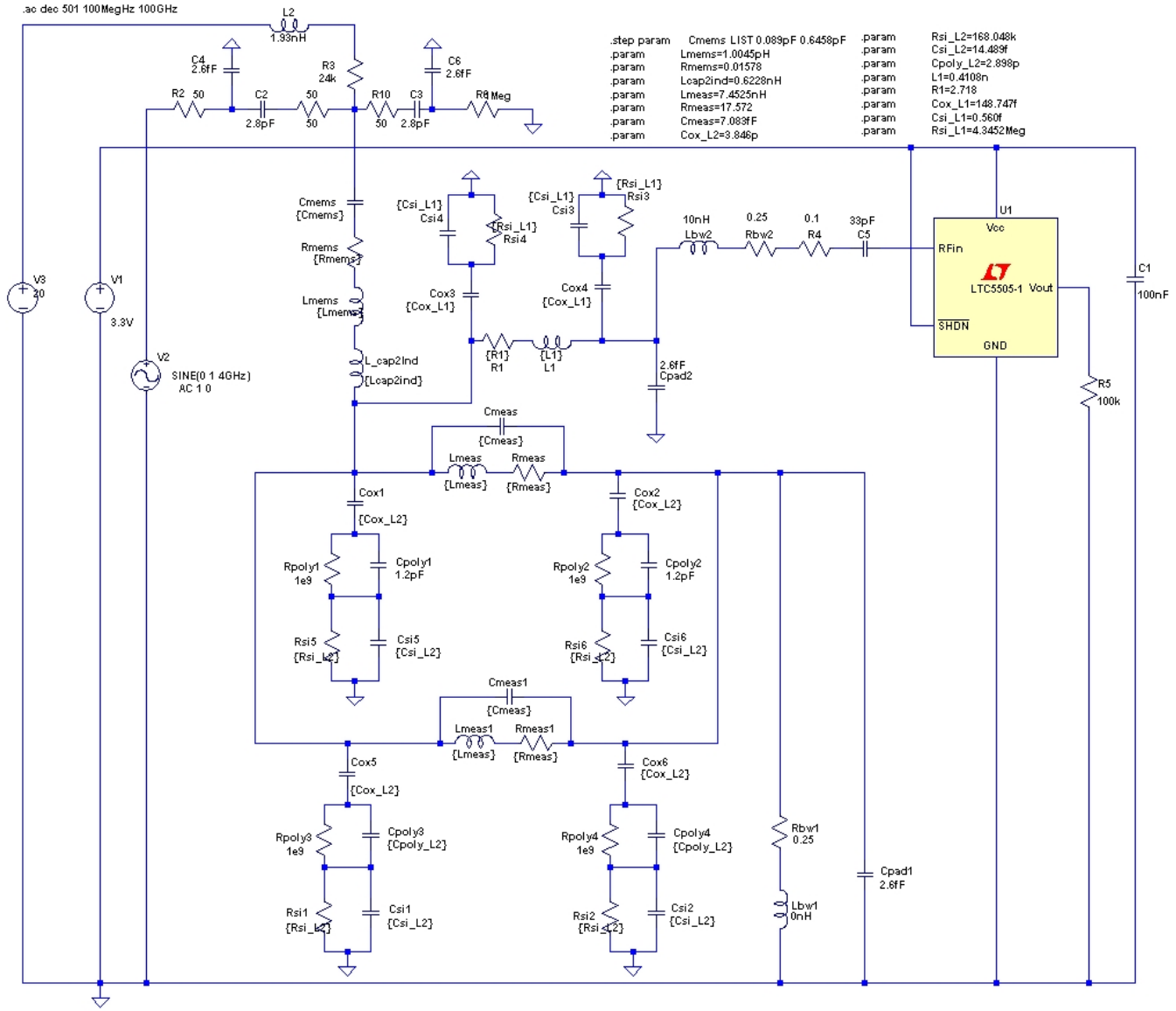


Determining the state of the switch II

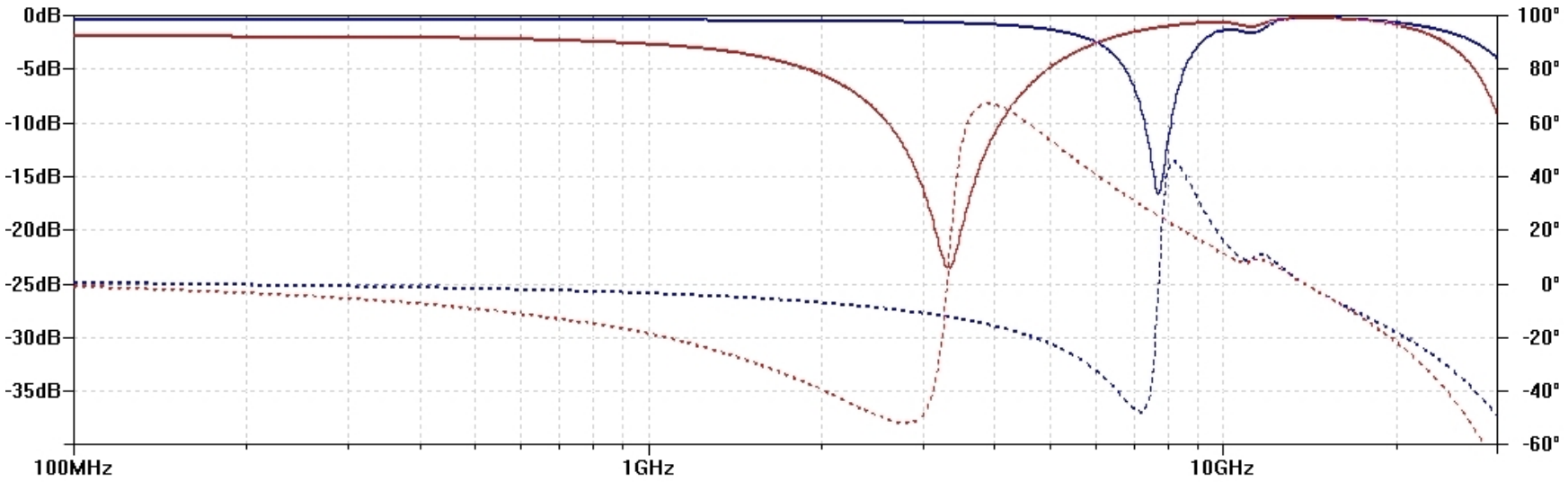


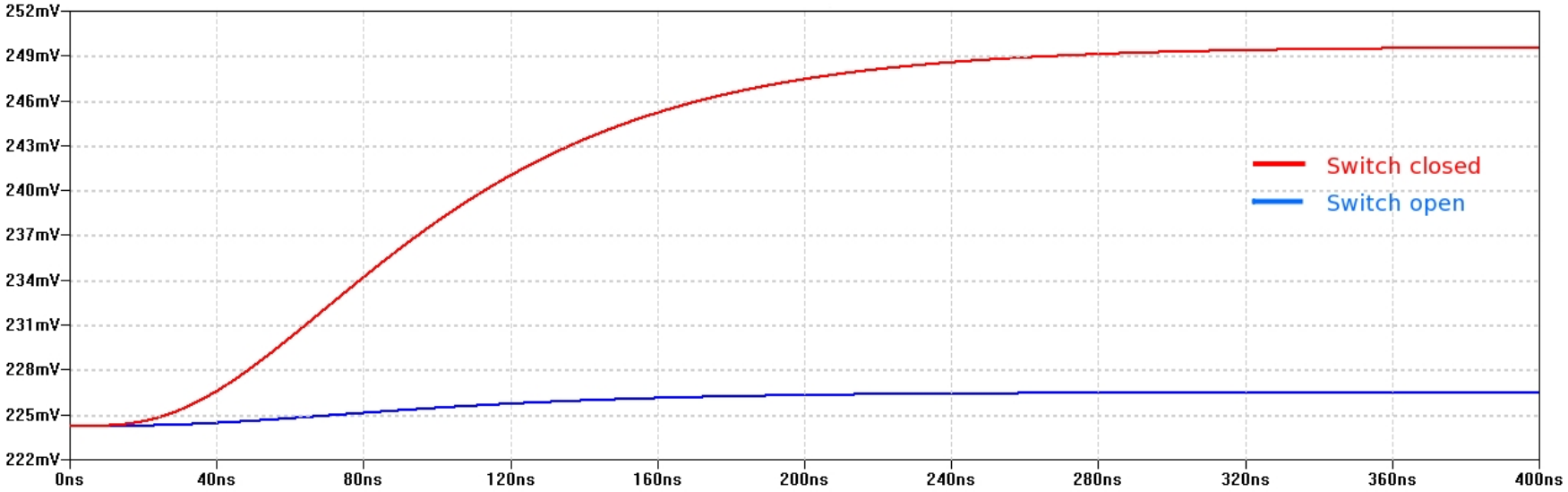


Pick-off: Circuit Model



Pick-off: Circuit Model





Conclusions

- Presented a system level model that incorporates mechanical, dielectric charging and feedback effects in single model
- Circuit based approach aims to enhance switch lifetime and ultimately to guarantee reliability
- Works where charge accumulation in the dielectric manifests itself as a shift in CV
- Will come at a cost in terms of power consumption and size
- Approach is aimed at space applications where the outcome is still substantially smaller and consumes substantially less power than coaxial and waveguide switches