Advanced Tools and Methodologies for the Multiphysics Modeling and Simulation of RF MEMS Switches

Aurel-Sorin Lup

Politehnica University of Bucharest

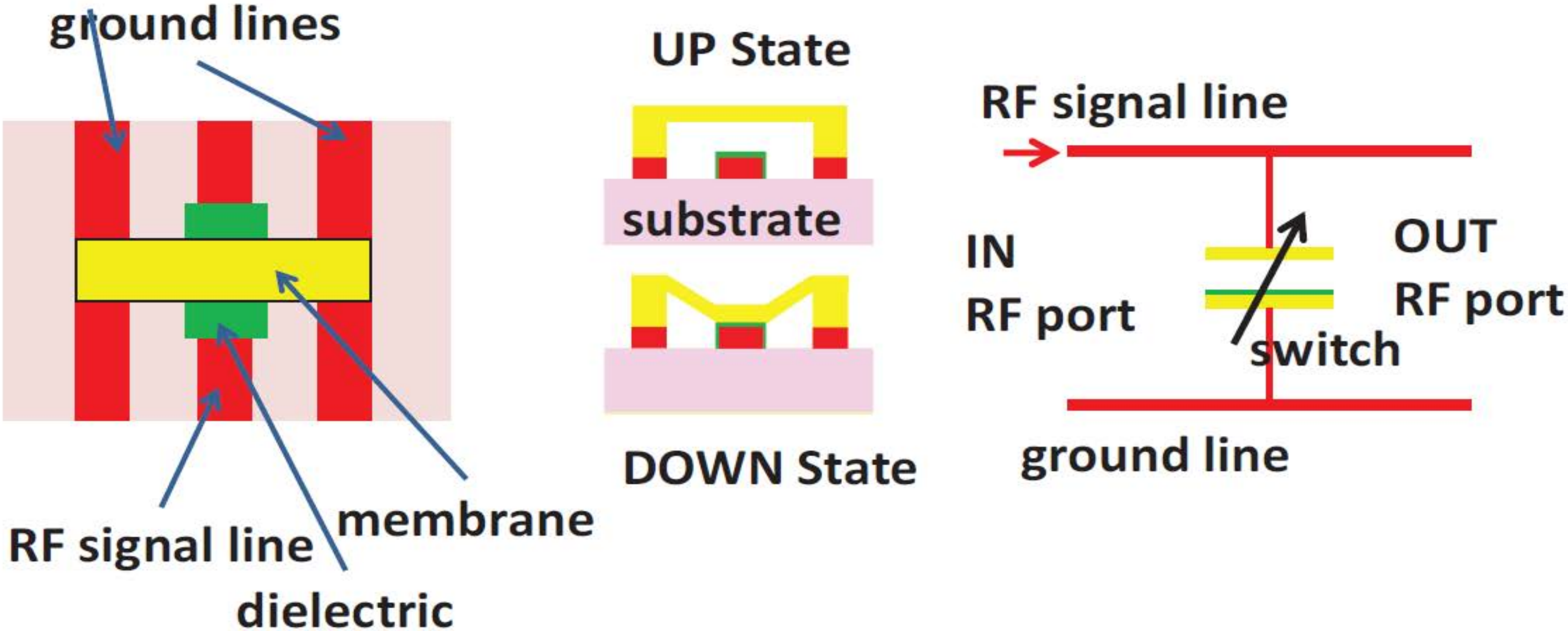
sorin@lm.pub.ro

COST MORNET Workshop, March 19-20, 2015, Bucharest, Romania

Content

1. Introduction
2. Coupled MEC+ES Modeling
3. RF Modeling
4. Reduced-order model MEC+ES+RF
5. Conclusions

1) Introduction

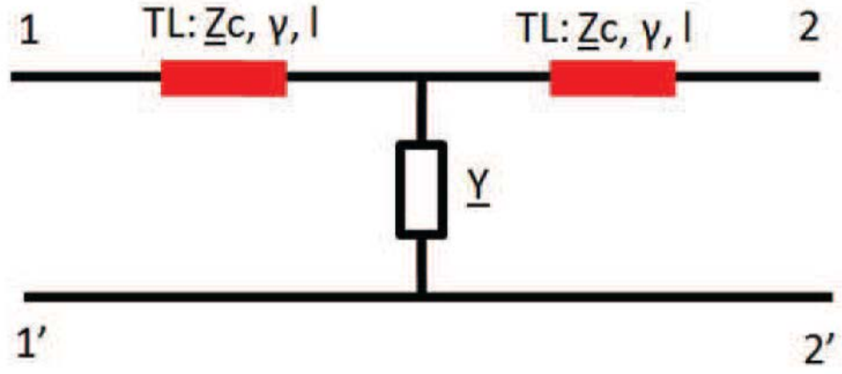


Up – down => multiphysics phenomena
(coupled mechanical, electrical, fluid interaction)

1) Introduction

- Compact models (circuit netlists)

RF =>



Multiphysics => **?**

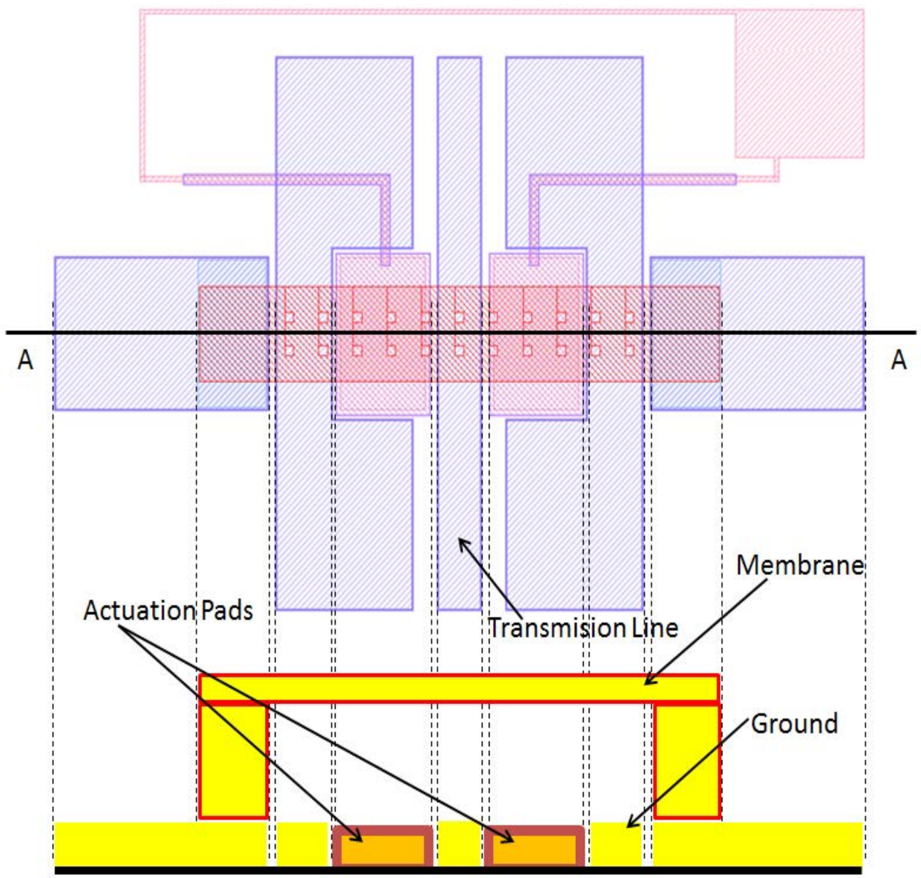
Easy simulation and design (if parameterized).

Goal: to obtain a reduced-order model to find:
- Multiphysics: V_{pi}, V_{po}, switch time
- RF: S parameters

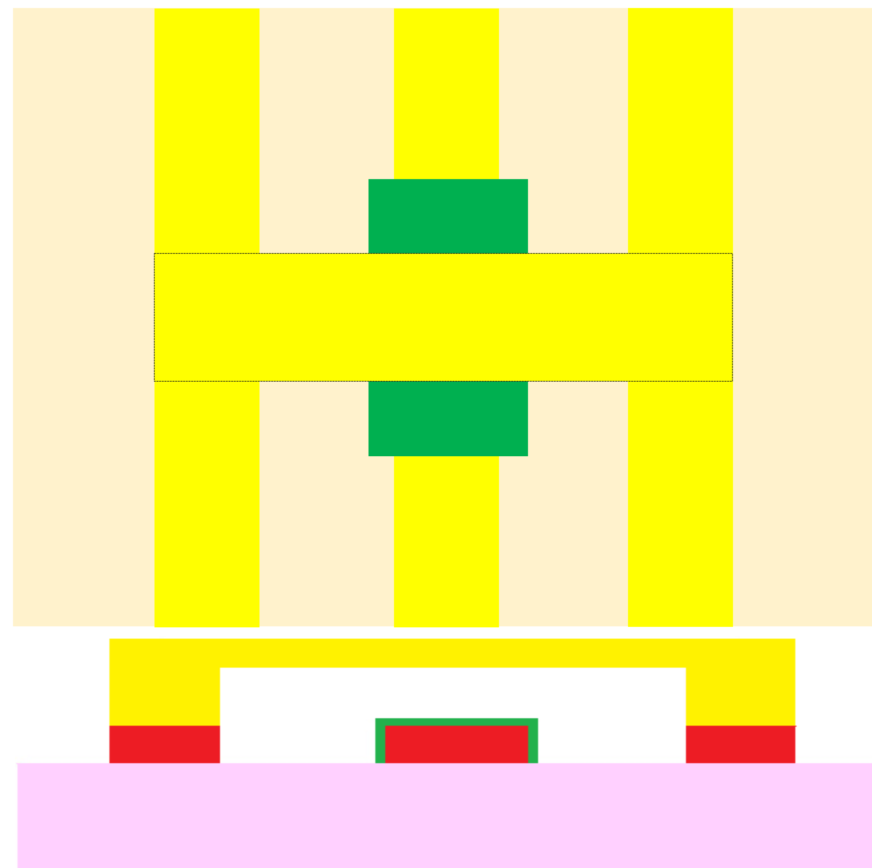
1) Introduction

RF-MEMS switches

Our Proposal - IMT



Test benchmark - Qian



2) Coupled MEC+ES Modeling

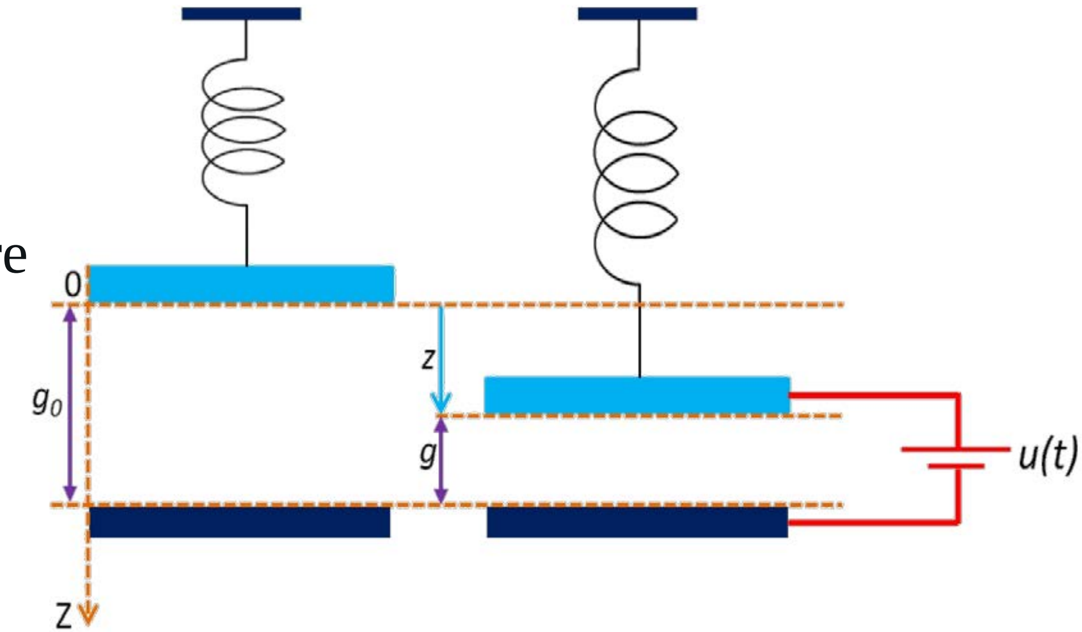
a) Problem Formulation

The most simple model of a switch

- movement equation is based on Newton's law

$$m\frac{\mathrm{d}^2 z}{\mathrm{d}t^2}+b\frac{\mathrm{d}z}{\mathrm{d}t}+kz=F_{\mathrm{ES}}(z,V_0),$$

m = mass of the armature
k = spring elastic constant
b = damping coefficient
z = displacement of the armature



$$kz=F_{\mathrm{ES}}(z,V_0)$$

$$F_{\mathrm{elastic}}(z)=F_{\mathrm{ES}}(z,V_0)$$

$$F_{\mathrm{elastic}}(z)=kz+k_s z^3$$

2) Coupled MEC+ES Modeling

Static simulation of the model above for increasing values of the actuation voltage, reveals that at $V = V_{pi}$ a numerical instability occurs.

Given: a switch (geometry, materials) with an arbitrary geometry

Find:

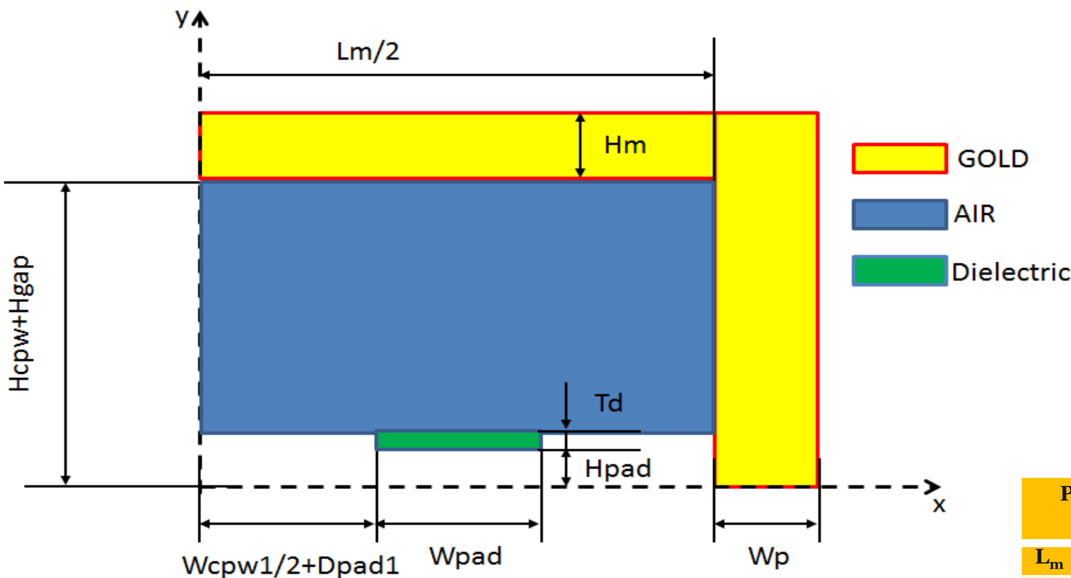
1) An algorithm to extract an equivalent k, k_s so that V_{pi} is recovered
2) A macromodel described as a SPICE netlist that implements the solving of the nonlinear equation in z

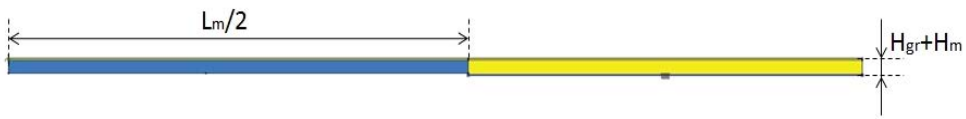
How to proceed: by using results obtained from a multiphysics static simulations, for increasing values of the actuation voltage.

Question to be answered: what is the accuracy (in V_{pi}) of such a coarse 1D reduced order model?

2) Coupled MEC+ES Modeling

b) Geometry Modeling and Materials





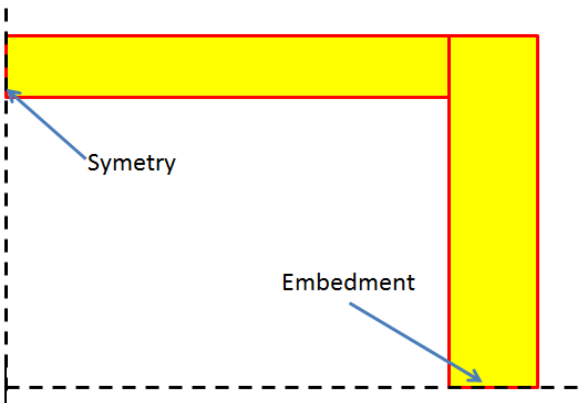
Material	Gold	Air	Dielectric
Relative permittivity ε_r	-	1	3.9
Poisson's ratio ν	0.44	-	-
Elasticity (Young's) modulus E [Pa]	$78 \cdot 10^9$	-	-
Mass density ρ [kg/m³]	19280	-	-

Parameter	Value (µm)	Significance
L_m	910	Length of the membrane
W_m	200	Width of the membrane
H_m	2	Height of the membrane
H_{cpw}	0.6	Height of the signal line
H_{gap}	2.5	Height of the gap
H_{pad}	0.45	Height of the electrode
W_{cpw1}	100	Width of the signal line
W_{pad}	200	Width of the electrode
W_p	160	Width of the membrane support
D_{pad1}	30	Distance between the CPW and electrode
T_d	0.1	Height of the dielectric

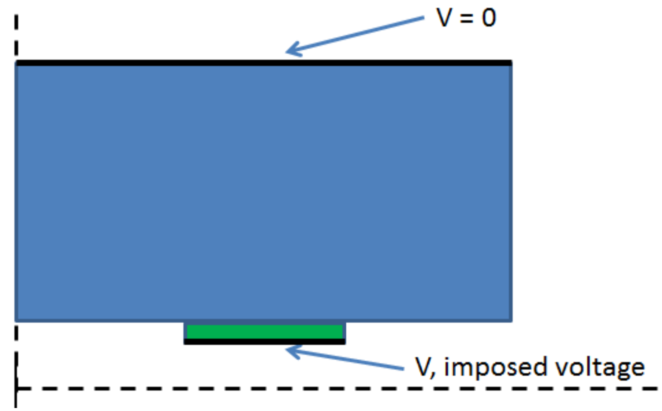
2) Coupled MEC+ES Modeling

c) Multiphysics Formulations

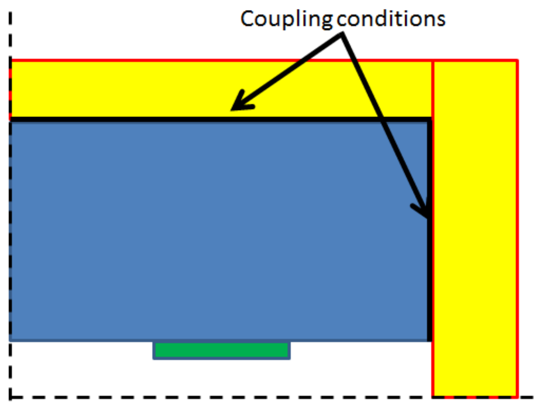
1) ***Structural*** *Domain*



2) ***Electrostatic*** *Domain*



3) ***Coupling***
strong MEC-ES coupling



Unknowns

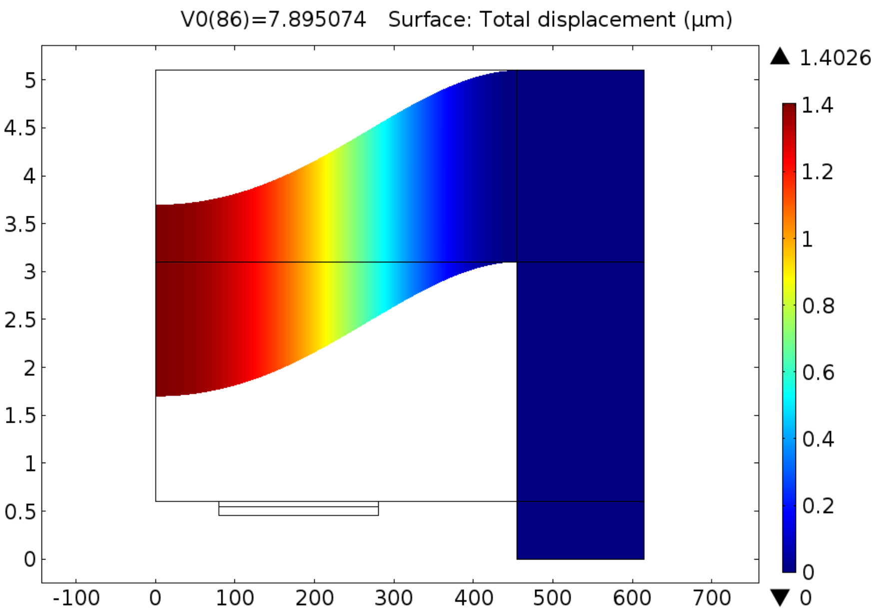
MEC: $\boldsymbol{u} = [u_x, u_y]$

ES: V

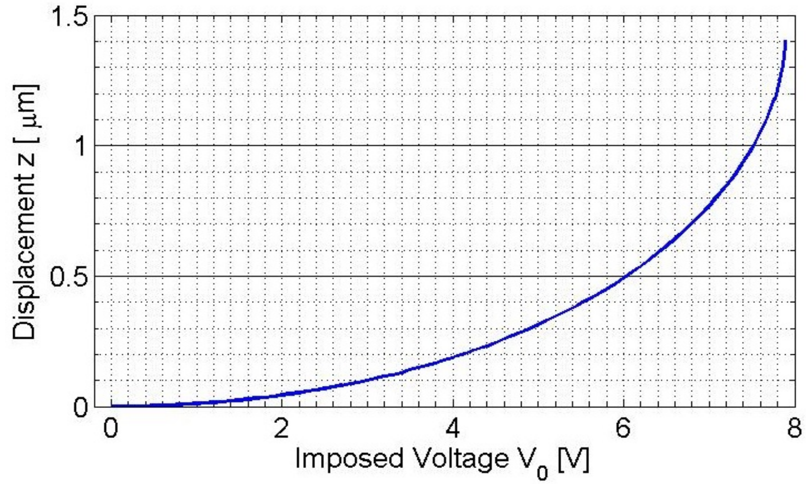
2) Coupled MEC+ES Modeling

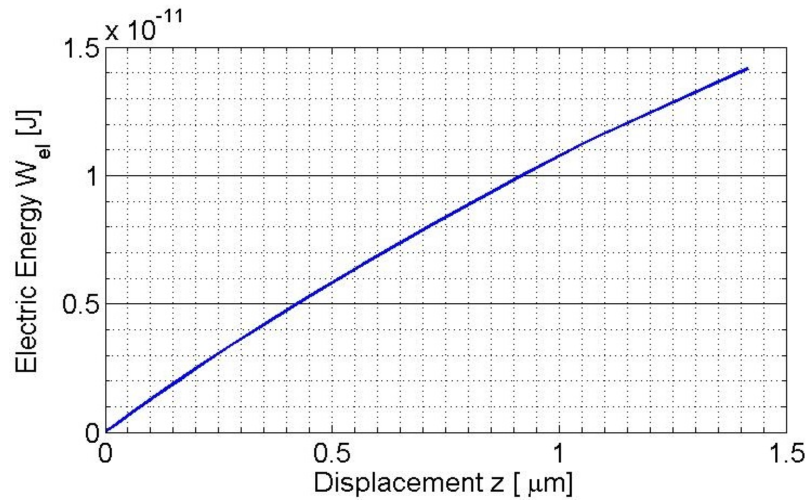
d) Results

Cross-section at scale



Cross-section not at scale





2) Coupled MEC+ES Modeling

e) Extraction of elasticity coefficient

From static simulations $\Rightarrow (V_0, z, W_e)$

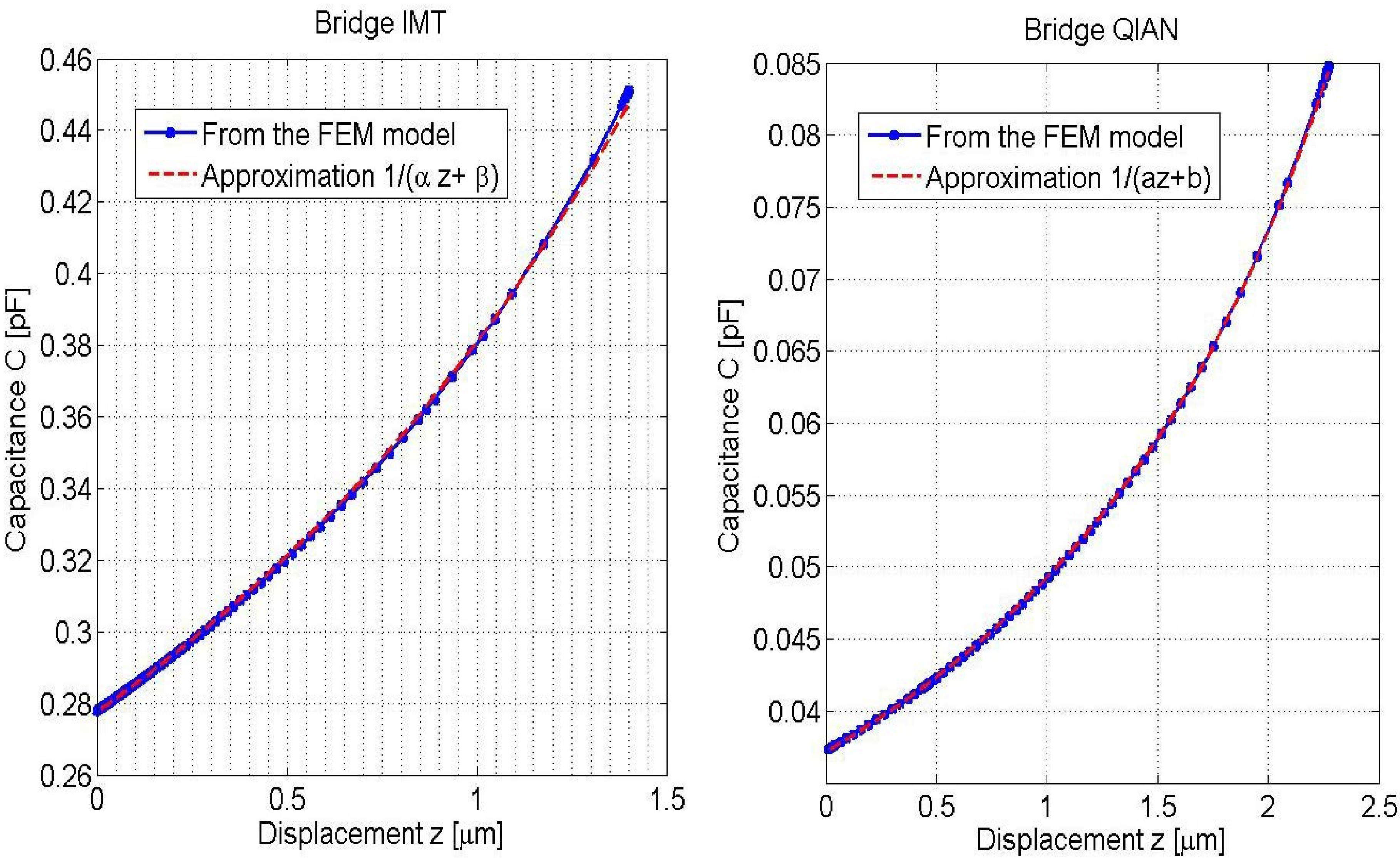
$$F_{ES} = \frac{\partial W_{ES}}{\partial g}, \text{ were } g = g_0 - z \rightarrow \text{generalized coordinate}$$

$$W_{ES}(z, V_0) = C(z)\frac{V_0^2}{2}$$

$$C(z) = \frac{1}{\alpha z + \beta} \Leftarrow 1^{st}\, order\, LS\, for\, \frac{1}{C(z)}$$

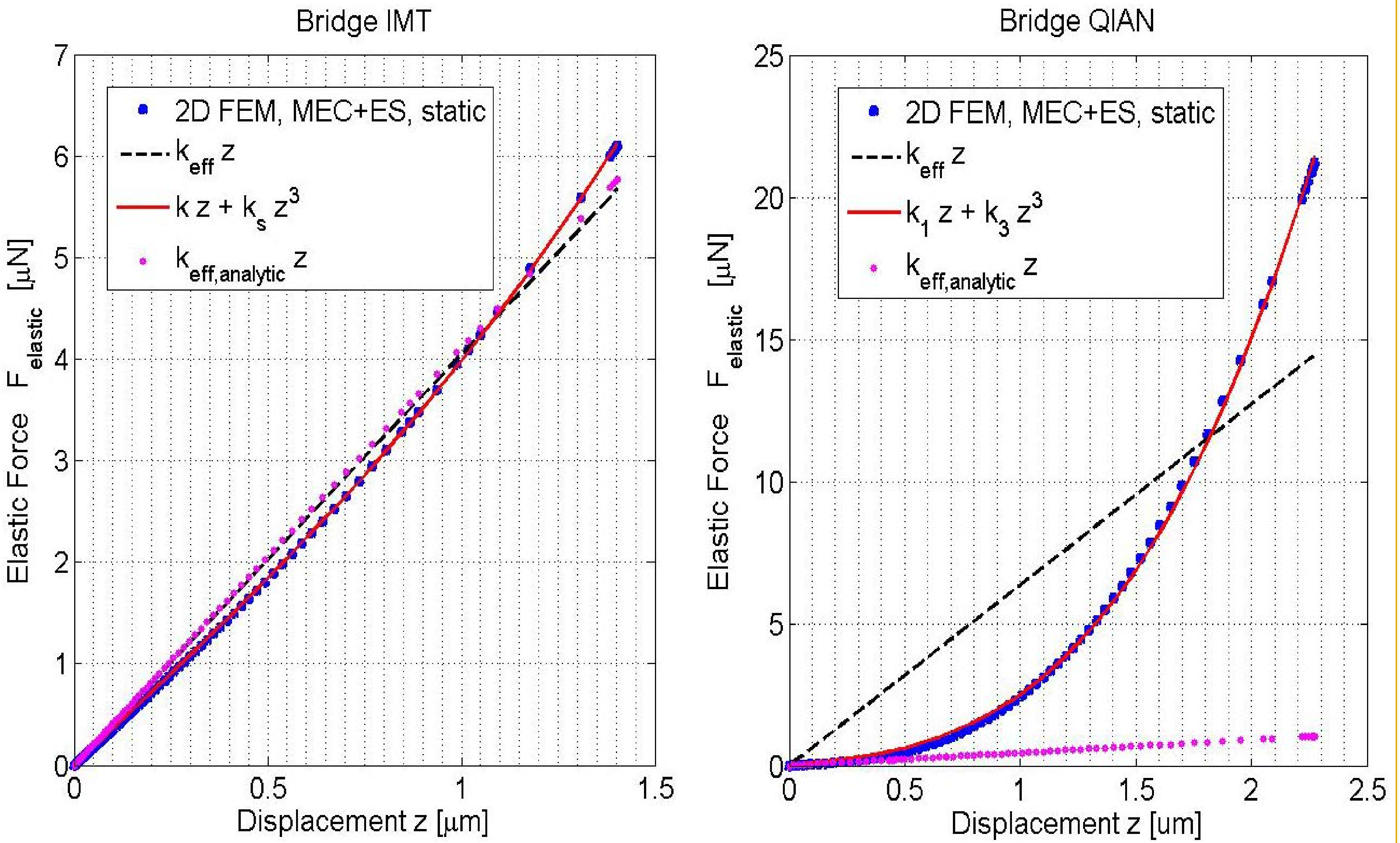
$$F_{ES}(z, V_0) = \frac{\alpha}{(\alpha z + \beta)^2}\frac{V_0^2}{2}$$

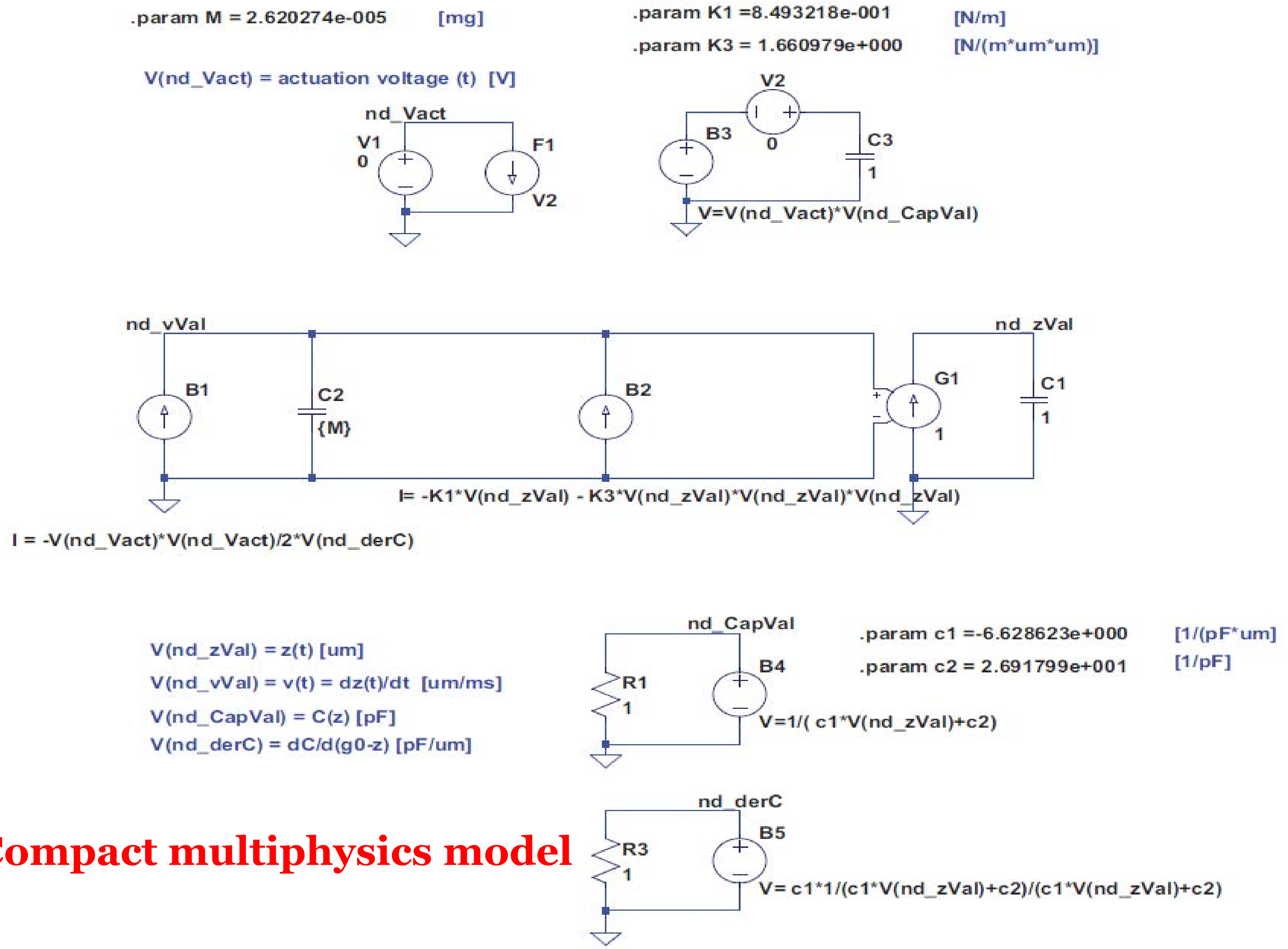
Capacitance from 1st order least square approximation of $\frac{1}{C(z)}$



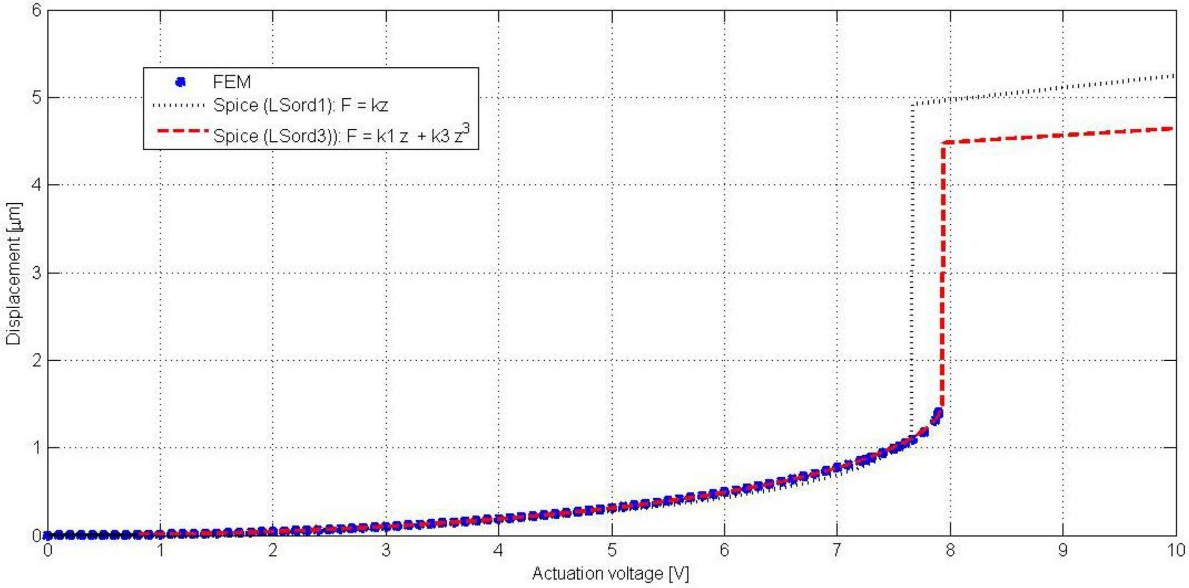
Best Method

3rd order least square approximation $\{z, F_{ES}\} \rightarrow \{k, k_s\}$



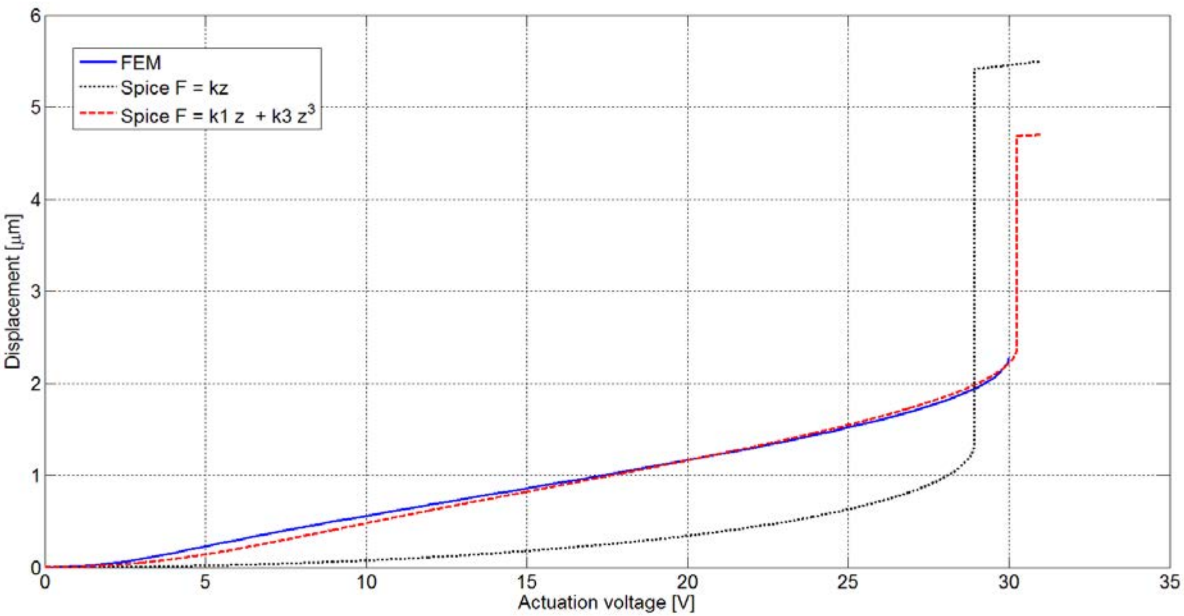


Compact multiphysics model



Our Proposal - IMT

Relative error 0.51 %



Test benchmark - Qian

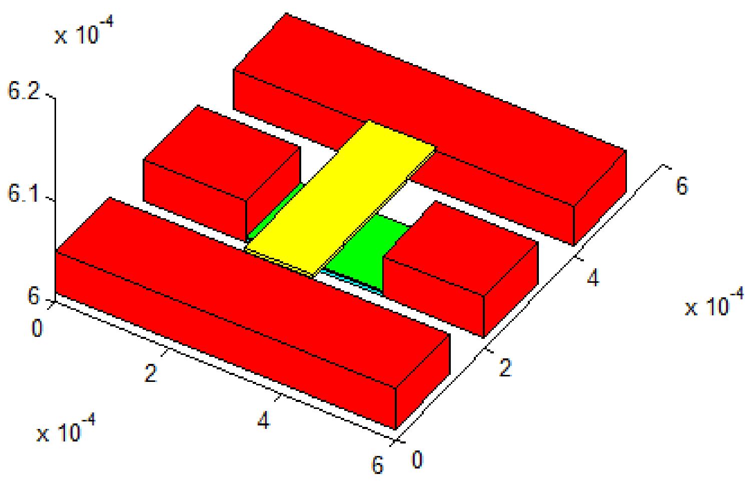
Relative error 0.82 %

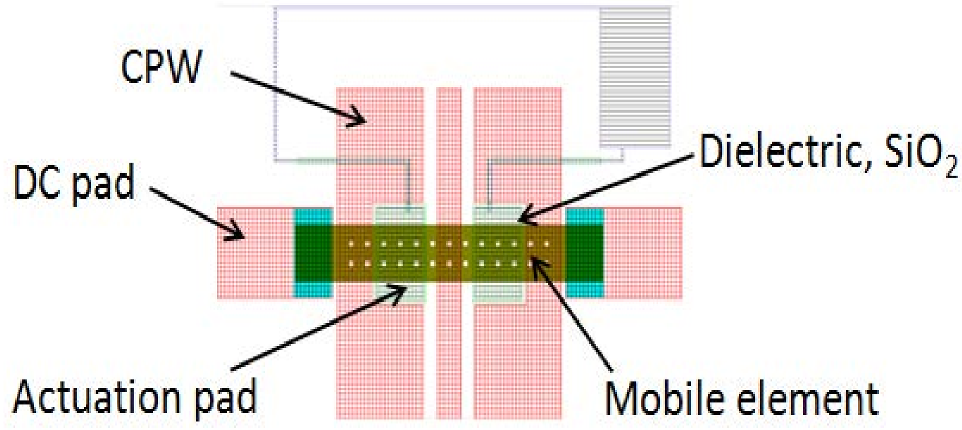
3) RF Modeling

Given: a switch (geometry, materials) with an arbitrary geometry

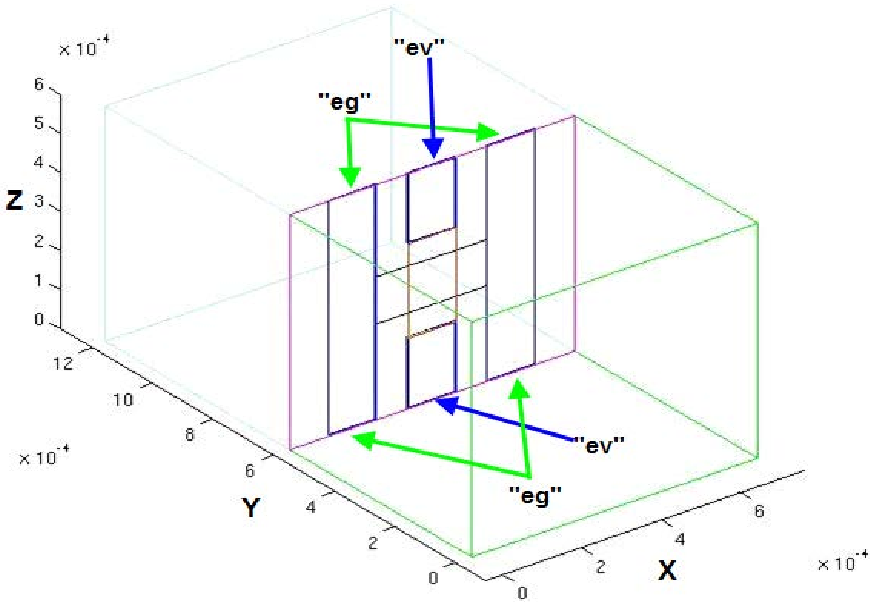
Find:

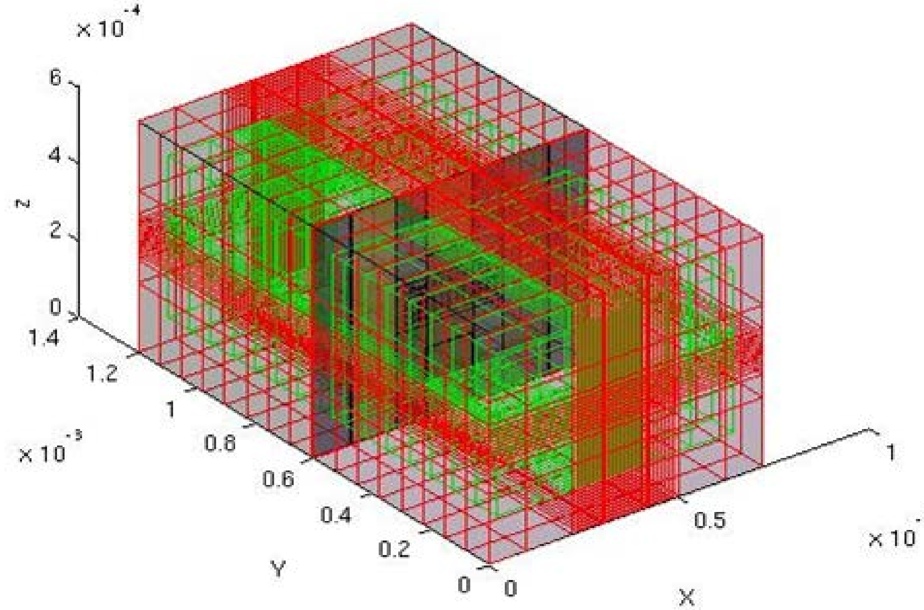
1) S parameters
2) Lump parameters for the 2 stable states (Up-Down)

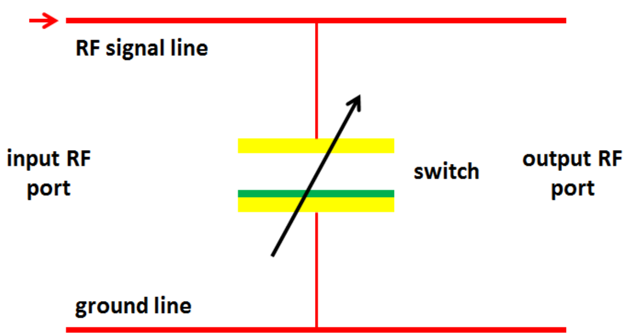




Numerical Model -> FIT (*chamy*)





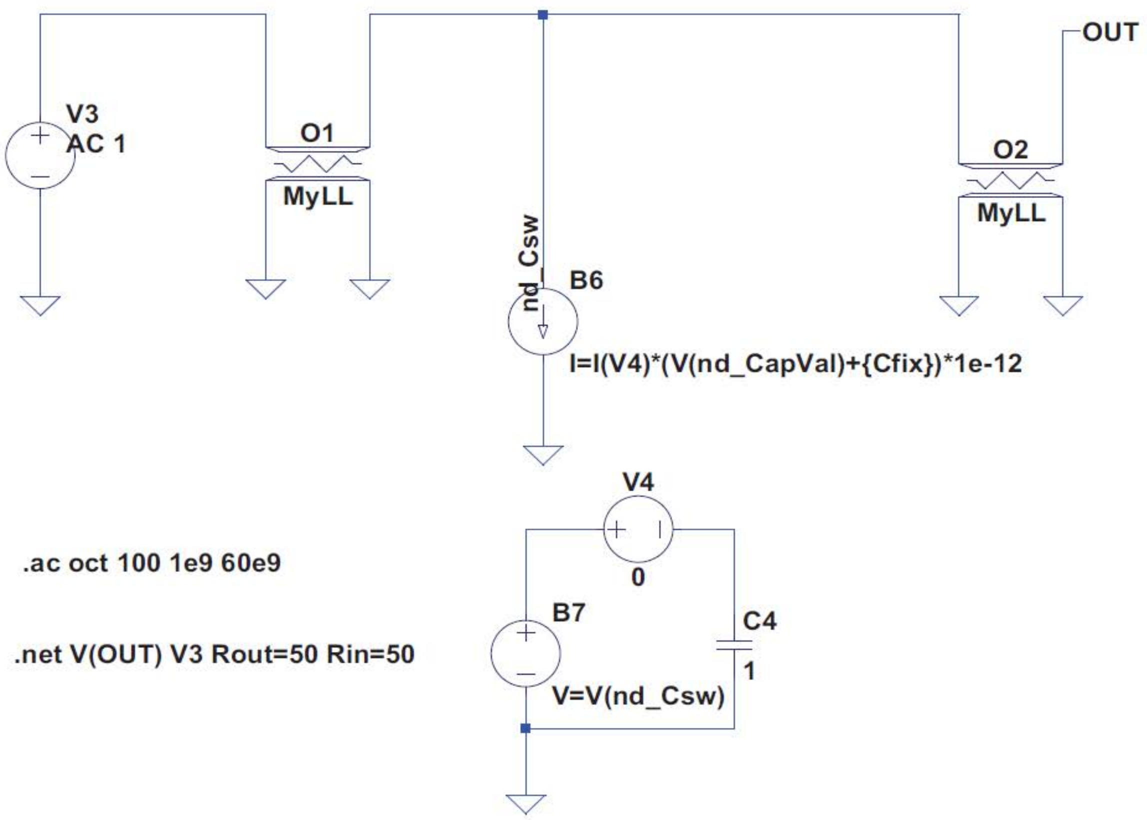


	Down, first approx.	Down, after line params correction	Up with const L_{mem}	Up with freq.dep L_{mem}
Qian	8.5 %	2.8 %	8.1 %	2.5 %
IMT	13 %	4.2 %	7.1 %	7.1 %

Relative errors for **S** parameters

4) Reduced-order model MEC+ES+RF

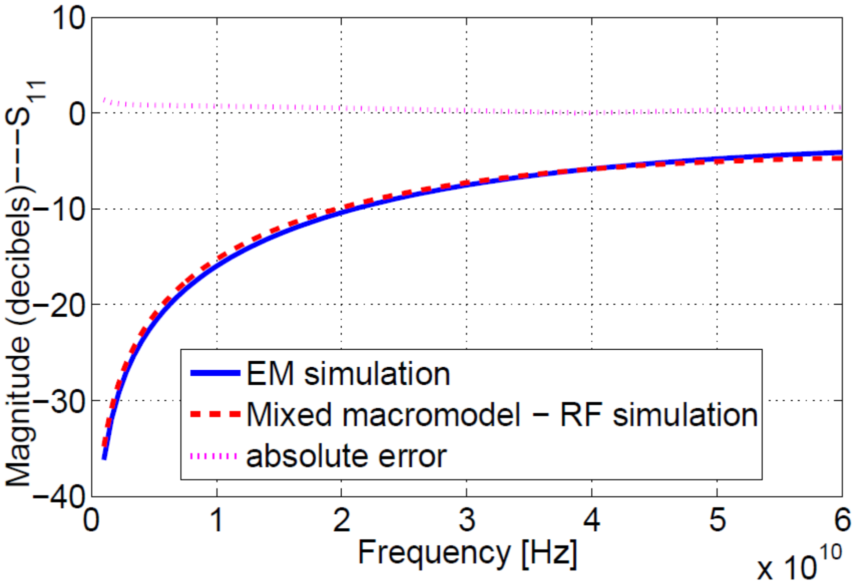
.model MyLL LTRA(len=300e-6 R=6.711595241681713e+002 L=2.825059038922490e-007 C=2.063713228210645e-010)
.param Cfix = 2.140112e-002

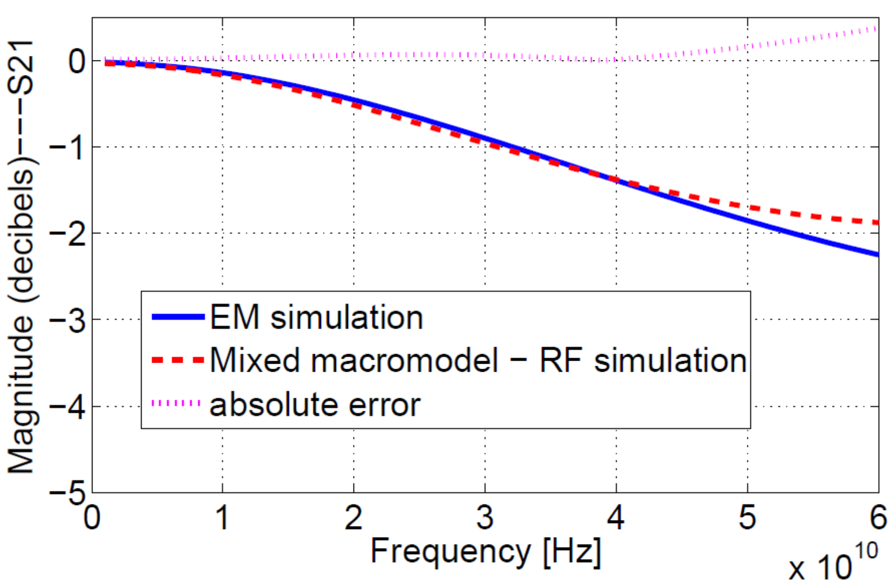


4) Reduced-order model MEC+ES+RF

Up position

Relative error 2.5 %





Reflection loss (*S*11)

Insertion loss (*S*21)

5) Conclusions. Accuracy

- The extracted V_{pi} and of the z(V) dependence are very accurate with respect to the numerical model used for extraction (less than 1 % for V_{pi}).
- The Reduced order model MEC+ES+RF reconstruct the S parameters with a relative error less than 3%.
- The accuracy with respect to the reality depends on the quality of the numerical model.
- Parametric studies have been made in preparation for optimization
- Construction of 3D parametric models in progress
- Next Step: fluid interaction

Thank you for your attention