Performance and Dynamics of a RF MEMS Switch

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SUMMARY

A torsional RF-switch with low actuation voltage for use in mobile communication is presented. The device is fabricated in a BiCMOS compatible process with an additional back-end electroplating procedure. Electrical characterization from DC up to 6 GHz has been performed showing good RF characteristics. Optical measurements of the first resonance modes are in good agreement with simulated results. The transient behavior was analyzed by interferometry in order to study the damping parameter of the device. Comparison with simulation has led to the relative damping coefficients for different designs.

Keywords: switch, transient, resonance modes

INTRODUCTION

MEMS-based devices for telecommunication application, such as switches, tunable capacitors and mechanical filters, have been intensively studied over the last few years. Especially micromechanical RF-switches offer advantages over their solid state counterparts (FETs and PIN diodes) because of their low drive power requirement, high isolation and good linearity. Different types of MEMS switches are being studied by various groups with the designs focussing on two types of switches: Shunt switches for applications at 10-100 GHz [1, 2] and series switches with a low ohmic contact for the lower Gigahertz range. The latter have been realized in different design variations such as bridges, cantilevers [3] and torsional devices [4, 5].

Because of their superior electrical performance, RF-switches are an alternative to standard solid-state devices for signal routing, filter-path selection and GSM/UMTS-switching. Depending on the specific application, switching times in the microsecond range have to be achieved. This can be a serious challenge for MEMS switches because of their mechanical nature. To study the dynamic performance of a switch, resonance modes and transient behavior have been measured.

DESIGN AND FABRICATION

The design of the switch presented here is based on a torsion-type actuator with two contacts for dual-mode switching. Mechanical operation of the switch is performed by electrostatic actuation with switching voltages in the range of 10 V.

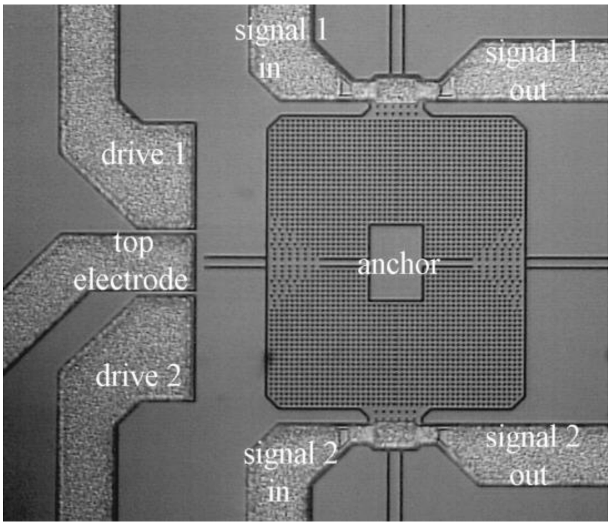


Figure 1: *Topview micrograph image of a micromachined RF switch.*

Figure 1 shows a topview micrograph image of the switch device. A movable poly plate around a centered support post is supported by two torsional springs situated at the left and right side of the anchor. The center-based suspension enables stress relaxation in the structural polysilicon. The plate is perforated to allow for the sacrificial layer etch underneath and to reduce damping effects during operation later on. A reduced hole density in the transition area from spring to mainplate increases the stiffness of the structure. The drive voltage is applied to actuation electrodes positioned underneath both sides of the switch. The electrostatic actuation causes a tilt of the torsion plate resulting in a switch operation by shorting the signal lines with the contact on one side, the other side being deflected upward respectively. Micrograph images of the completed device and a close-up of one switch contact in the open position can be seen in Figures 2 and 3.

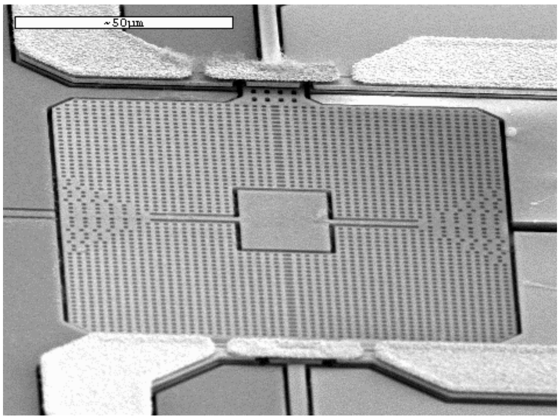


Figure 2: *SEM micrograph of torsional switch device.*

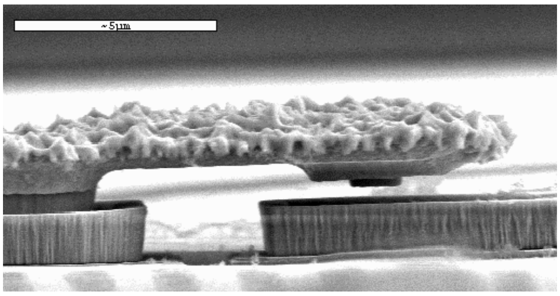


Figure 3: *SEM of one half of the switch contact.*

The devices are fabricated in surface micromachining technology using a two-layer poly-Si process with oxide as sacrificial layer. The first poly-layer is used for the actuation electrodes, leads and as an anchor, whereas the second layer forms the movable plate. The lower signal line electrodes are fabricated using tungsten. Additive gold electroplating is applied for creating the top-electrodes. The sacrificial layer is finally removed with a wet etch in hydrofluoric acid, resulting in the freely movable switch structure.

ELECTRICAL CHARACTERIZATION

Measurements of the switch plate deflection with white light interferometry have verified the mechanical pull-in to be below 10 V. These results match well with previously simulated data. Satisfactory switch contacts for the electrical signal however are only achieved at voltages up to 25 V. This observation is attributed to increased contact forces working at higher voltages. RF-tests of the devices have been performed with a HP 8722 ES S-Parameter Network Analyzer using 150 micron pitch coplanar probes.

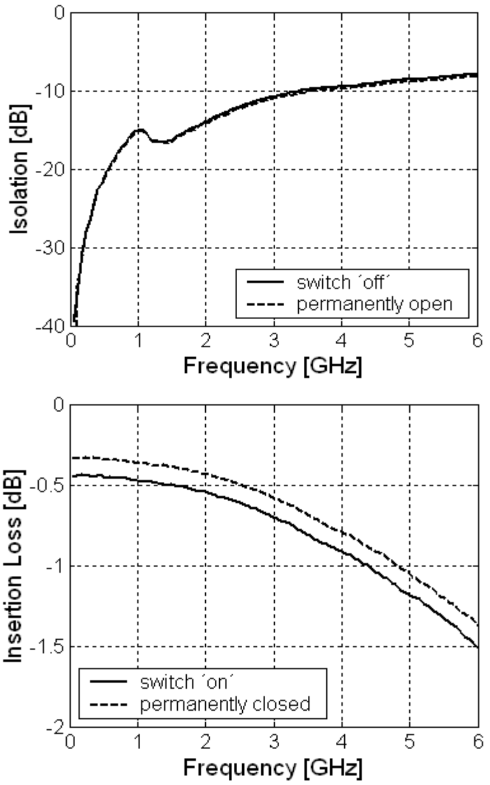


Figure 4: *Measured isolation (top) and insertion loss (bottom) compared to test structures 'permanently open' and 'permanently closed'.*

Figure 4 shows the RF-characteristics of the device up to 6 GHz compared to test structures 'permanently open' and 'permanently closed'. At 1 GHz the insertion loss in the 'on'-state is below 0.5 dB and the isolation in the 'off'-state is better than 15 dB. Comparison with measurements on test structures shows that most of the loss in the 'on'-state is caused by the signal lines. In the 'off'-state the isolation of the device is almost identical to the 'permanently open' test structure. Therefore it is possible to greatly improve the electrical characteristics of the device by minimizing parasitic capacitances and inductances of the signal lines.

DYNAMIC PERFORMANCE

Dynamic measurements have been performed with a modified Mach-Zehnder laser-interferometer. The results for resonance modes and transient behavior are presented in the following.

Resonance Modes

The resonance modes of the plate have been modeled using FEM software Memcad. Meshing of a simplified device can be seen in Figure 5.

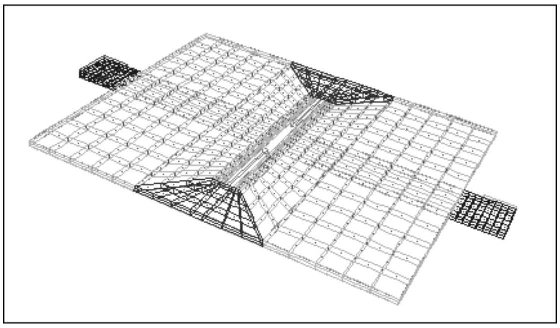
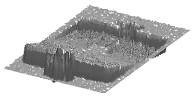
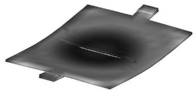
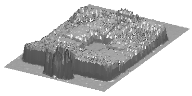
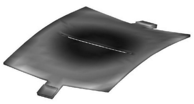
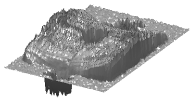
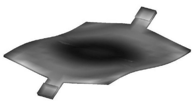
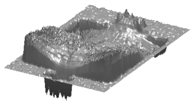


Figure 5: *Meshing of the torsion plate for FEM-modeling of the resonances.*

For measurement of the modes an AC voltage together with a small bias voltage is applied to one of the actuation electrodes and the harmonic response of each point is determined interferometrically. A comparison of simulated and measured mode shapes together with resonance frequencies is displayed in Table 1.

Table 1: *Simulated and measured resonance modes of the torsional plate.*

f [kHz]	Mode shape		f [kHz]
	Simulation	Measurement	
44			55
185			164
595			546
1028			916

By applying a voltage to one of the actuation electrodes not all modes can be excited. For example lateral displacements can be neither excited nor detected. The simulated values of those modes are omitted in the table above.

Improved Switching

Instead of having the movable switch contacts pulled down as shown on the left side of Figure 6, the seesaw-type structure enables a downward electrical actuation on one side of the plate and an upward movement on the other side to close the contacts (Fig. 6, right side). This allows the omission of the contact head from the movable poly-plate. The mass of the switch plate is thus reduced, resulting in faster switching times for this type of design. The contact area of a device with upward switching is shown in the SEM micrograph of Figure 7.

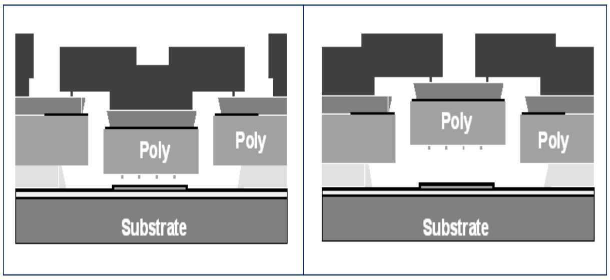


Figure 6: *Schematic illustration of downward (left) and upward (right) switching (not to scale).*

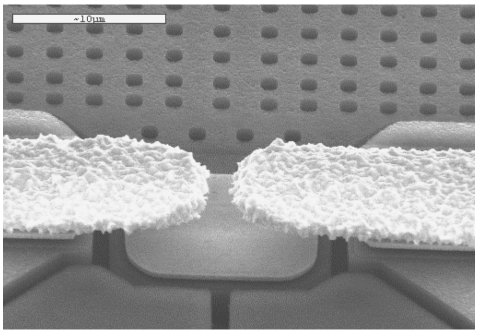


Figure 7: *SEM image of improved switch design.*

Transient behavior

Transient measurements of the switch contact have been performed for ’on/off’ and ’off/on’ switching cycles. Because of the laser wavelength of 532 nm, all larger displacements lead to ambiguities in the photodetector signal. Those can be removed by evaluation of different phase shifts. Figure 8 shows the measured data converted into vertical displacement for the ’on/off’ switching. Three designs with different size and number of anti-damping holes have been examined.

The governing equation for the movement of the torsion plate is the second order equation of a damped oscillator with an additional electrostatic force. Fitting the relative damping ζ, including the geometric parameters of the designs, results in values of 0.45 to 1.1 (shown for ζ=0.45 in Fig 9).

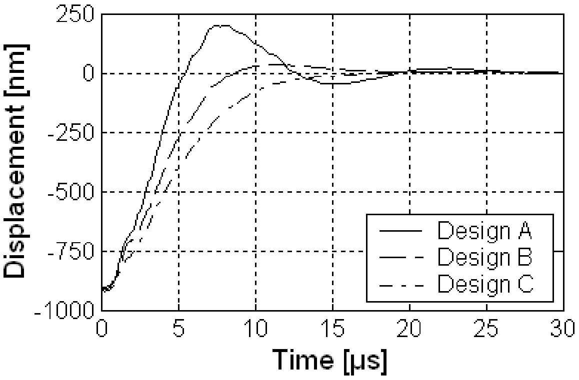


Figure 8: *Transient response of switch devices with different damping coefficients.*

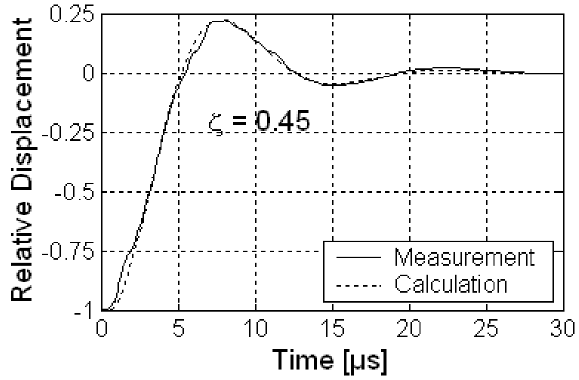


Figure 9: *Measurement of switch and calculated oscillation including a fitted damping coefficient ζ.*

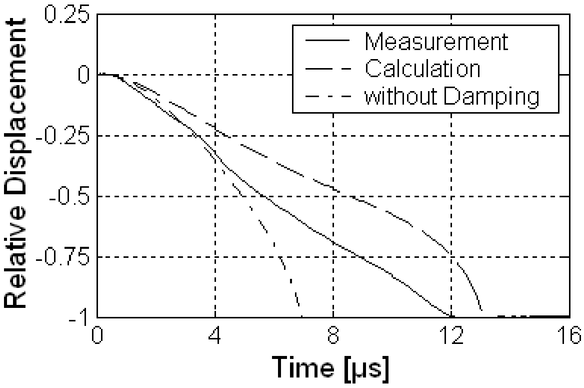


Figure 10: *Measured transient behavior for 'off/on'-switching compared to calculation.*

Using the relative damping of the 'on/off'-switching, the differential equation with additional electrostatic force for the 'off/on'-switching can be solved numerically. Figure 10 shows that in contrast to the case before, the damping can no longer be assumed constant and increases especially at small gap distances and large velocities.

CONCLUSION

A surface micromachined switch for dual mode operation has been presented. At 1 GHz it is characterized by an insertion loss of 0.5 dB and an isolation of 15 dB. In order to study the dynamic behavior, the first resonance modes of the switch have been measured interferometrically and were found to be in good agreement with previously simulated results. The transient analysis of the device shows switching times of 5 µs for 'on/off'-switching and of 12 µs at 10 V actuation for 'off/on'-switching.

ACKNOWLEDGMENTS

The authors would like to express their special thanks to M. Hurzlmeier for RF-measurements. Also acknowledged are A. Meckes, K.-G. Oppermann, H. Kapels, M. Franosch and T. Bever for their support as well as M. Handtmann for valuable discussions.

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