New Measurement Results of the RF MEMS Toggle Switch

B. Schauwecker, W. Simon*, K.M. Strohm, T. Mack and J.-F. Luy

DaimlerChrysler Research Center Ulm, Wilhelm-Runge Str. 11, D-89081 Ulm, Germany
* IMST GmbH, Carl-Friedrich-Gauß-Straße 2, D-47475 Kamp-Lintfort, Germany

Abstract: New measurement results of the RF MEMS Toggle Switch [1-4] are presented.

I. Introduction

Microelectromechanical systems (MEMS) are being recognised as enabling components to switch or tune radio frequency (RF) components, modules or systems in manufacturing and operation. In short, they are referred to as RF MEMS. Although RF MEMS switches do not have as higher speed as that of their semiconductor counterparts (pin diode, FET), they have very low insertion loss due to the low resistivity of metal, high isolation due to the physical separation of the switch, and excellent linearity with the elimination of I-V non-linearities, which are inevitable for pin diode or FET associated with semiconductor junctions. In this paper we describe new measurement results (RF power measurements, switching time, switch cycles) of the RF MEMS Toggle Switch on high resistive silicon substrate.

II. Power Measurements on a single Toggle Switch

a) Self Actuation

The power measurements of the SPST Toggle Switch have been done at the DaimlerChrysler Research Center Ulm with the measurement set-up shown in Fig. 1. A HP 83650 synthesised Sweeper and a TWT (Model: 8010H15F00 SN 272, Option "J") was used. A working frequency range from 8 GHz up to 18 GHz was used and the cascade probe station was equipped with picoprobe probes. The RF power was measured with a HP 8487A power meter.

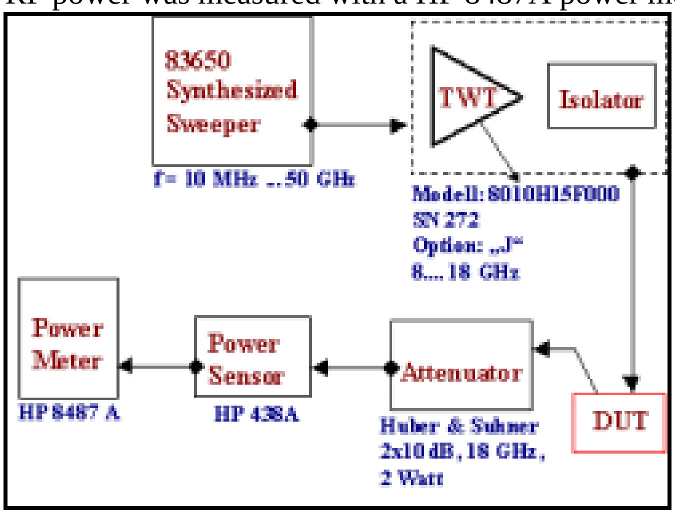

Fig. 1: Power measurement set-up

At first, we need to calibrate the power meter. Then, we need to measure the output transmission loss, without the TWT (synthesised Sweeper – RF-cable – 20dB Attenuator – Power Sensor – Power Meter). After this, we need to calibrate the transmission loss (synthesized Sweeper – RF-cable – Picoprobe – ISS 101190 THRU – Picoprobe – RF-cable – 20dB Attenuator – Power sensor – Power meter). These tree calibrations allow the calculation of the power that is transmitted to port one of the Toggle Switch in the measurement set-up. In the used frequency range we have applied 2 W RF power at an open Toggle Switch. In Fig. 2. the measurement results of a Toggle Switch is shown. Power measurements of this open Toggle Switch in the frequency range from 8 GHz to 18 GHz have shown that there is no power induced self actuation at least up to 2 W (measurement limit). The equipment did not allow the application of higher power in this frequency range.

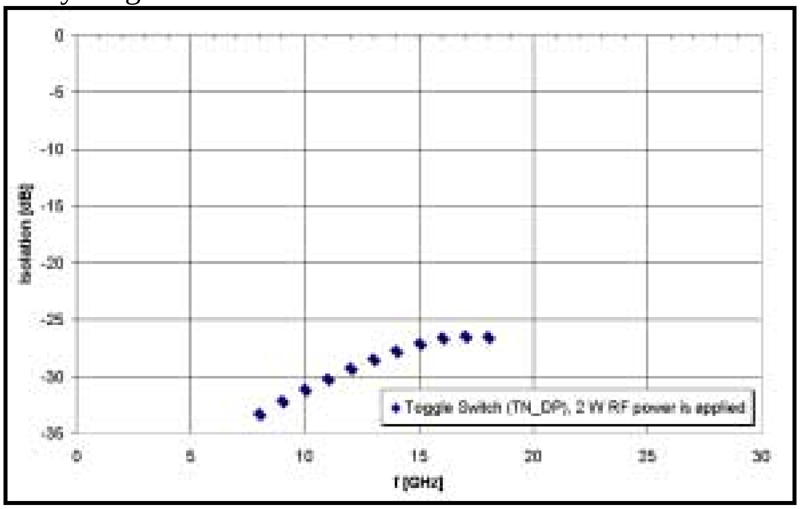

Fig. 2: RF Power measurement results of an open Toggle Switch

b) Latching / Hot Switching

This power measurements of the SPST Toggle Switch have been done at the IMST GmbH, Kamp-Lintfort. A Wiltron 360B network analyser was used to control the Wiltron 68069B source. The power amplifier was a HP 83020A working from 2 GHz up to 26 GHz and the Alessi probe station was equipped with Picoprobe probes. The RF power was measured with an Anritsu ML2438A power meter. In the measurement procedure the switch is closed with a DC voltage of 39 V. In the next step the RF power is applied and afterwards the DC voltage is turned off. In the last step the RF power is turned off. The RF power at the switch increases due to the nonlinearity of the power amplifier from 0.36 W at 25 GHz to 1.99 W at 5 GHz. Self actuation in this frequency range and this power was not observed. The switch could be reopened after a closed state 10 sec up to a RF power of 1.58 W. The closed switch could not be reopened when an RF power of 1.6 W was applied at 7 GHz. This failure was caused as the switch sticheddue to the high actuation voltage of 39 V and the high RF power of 1.6 W to the DC pad. The thin nitride isolation got broken and the Toggle cantilever welded with the DC pad. The RF power between 0.36 W at 25 GHz and 1.58 W at 8 GHz was enough to cause an RF-stitcking of the switch. At an RF power of 158 mW the switch opens when the DC voltage is turned off. A hot switching with a DC voltage of 42 V is possible for this case. If an RF power greater than or equal to 158 mW is applied to the closed switch for 60 sec the metal membrane stitckes to the metal contact pad. This should not be the case for the Toggle Switch with a TiW metallisation on the contact pad.

III. Switch cycles measurements at a single Toggle Switch

RF MEMS is an emerging technology capable of significantly reducing losses in passive circuits. However, before this technology can be inserted into mainstream systems, adequate lifetime of the electromechanical devices must be demonstrated. Presently, both capacitive cantilever and ohmic contact switches are limited in lifetime by mechanical considerations. Measuring the lifetime of MEMS switches consists in measuring the number of actuations until failure. In order to measure the lifetime, we use a dual-pulse waveform with 10 to 60 Volts of actuation voltage. Several waveforms can been used to actuate RF MEMS switches, including raised sine wave and square wave signals. The Fig. 3. below represents the voltage's timing diagram used to drive the switch, the measuring instants, and the capacitance valid domains.

Fig. 3: Set-up voltage's chronogram for life time measurements

Three phases are used for a cycle: an initial pulse provides enough electromotive force (for a short time) to deflect the switch cantilever down into the on-state (phase 1); once actuated, the switch requires considerably less holding voltage to maintain the on-state (phase 2). The off-phase (phase 3) in which 0V is normally used permits that the switch discharges itself. Below the devices which we used to measure the lifetime of the MEMS switches are listed:

- HP4275A LCR Meter
- Keithley 236 Source Measure Unit
- Keithley 195A Digital Multimeter
- Computer

All these devices are linked together with an IEEE 488 connection. We can drive all these devices through this IEEE 488 bus with the programming software HP VEE (Hewlett-Packard Visual Engineering Environment). The good working of the switch can be verified by measuring the capacitance or the resistivity in each state of the switch (with and without applied voltage). Measurements of the switch cycles of a standard Toggle Switch yield a very low variation of the capacitance between on- and off-state. Additionally, we have observed the running switch cycles through a microscope. During a measurement time of 8 hours we could measure more than 6500 successful switch cycles at one Toggle Switch. After this 8 hours we stopped the measurements. The Toggle Switch has not shown any degradation after these 6500 cycles.

IV. Switch time measurements

A laser Doppler vibrometer is used for measuring the switch time. We have measured the switch time of a Toggle Switch, which had a very high distance between the cantilever tip and the contact paddle. The cantilever tip is 10 µm above the contact paddle. Therefore 25 V was needed for pull-down. The advantage of such very wide open structure is the very good optical control over the switch cycle. We have measured at the two point A and B (see Fig. 4).

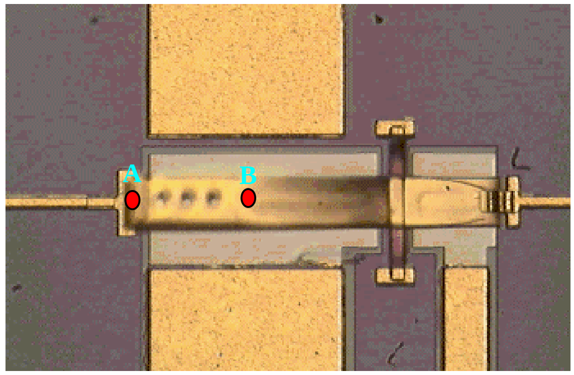

Fig. 4: Switch time measured Toggle Switch

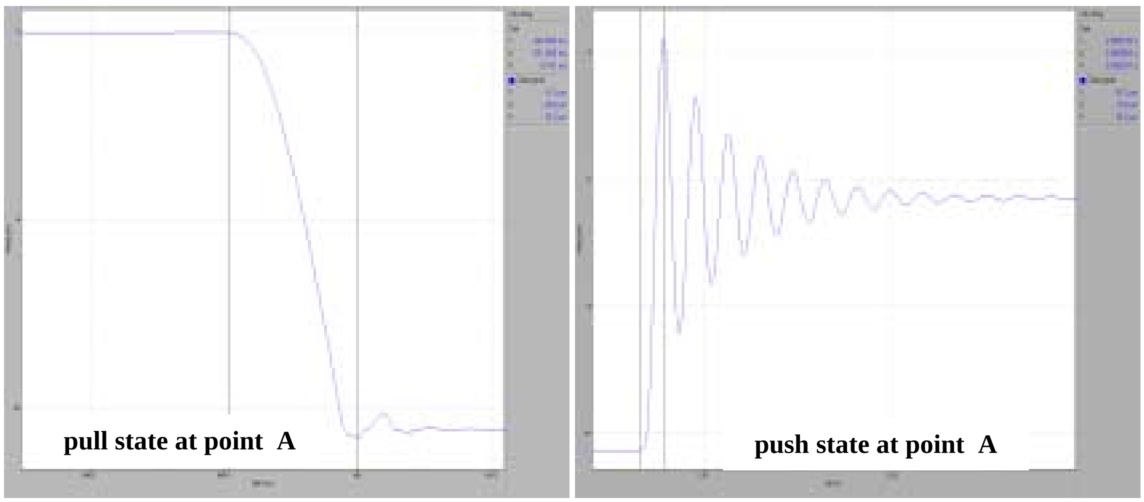

Fig. 5: Measured switch time at point A

The measured switch time (pull state with 25 V, see Fig. 5, left side) at the point A was 190 µs. After 300 µs the switching process was finished. After this, we have reduced the applied voltage to 0 V, and the cantilever jumped back to the inertial position. We have measured a release time of 240 µs (Fig. 5, right side). After release, the cantilever showed a damped oscillation for approximately 20 ms before reaching the quiescent state. The measured switching behaviour at point B is shown in Fig. 6. In both states (push and pull states) we observed a damped oscillation during the measured actuation- and release-process. If we apply 25 V the cantilever moves approximately 4 µm and touches the isolation layer of the pull electrode. After reducing the applied voltage to zero the measured point jumps back to the inertial position. In both states the cantilever needs approximately 4 ms till reaching the quiescent state.

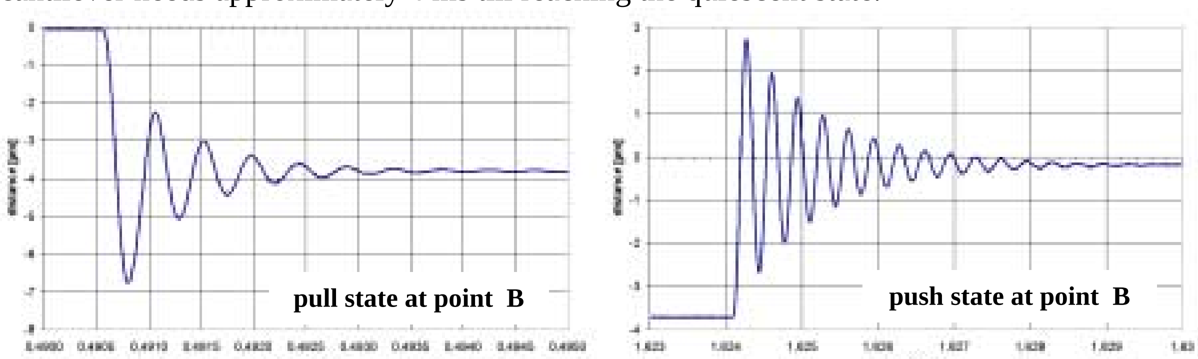

Fig. 6: Measured switching time at point B

V. Conclusion

On the fabricated Toggle Switches we have made various measurements. Besides conventional DC and RF measurements [1-4] we have performed power measurements, measurements of switching time and switch cycles. Power measurements in the range from 8 to 18 GHz with 2 W, we could not observed a self actuation of the Toggle Switch. Hot switching for RF power less than 160mW @ 25GHz is possible. The switching time for a wide open Toggle Switch is 190 µs, the release time is 240 µs (distance between cantilever and contact paddle greater than 10µm). We have measured more than 6500 switch cycles of the Toggle Switch in 8 hour without observing any degradation.

Due to the reported characteristics, these RF MEMS devices should enable a wide variety of new system capabilities. These MEMS switches are suitable for wireless and space systems where medium power consumption is essential.

Acknowledgement

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Reference:

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