Designing a Novel RF MEMS SWITCH for Broadband Power Applications

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The design of a new type of RF MEMS "toggle" switch for broadband power applications is described. The switching element consists of a cantilever, which is fixed by a torsion spring to the outer conductor of the coplanar line. Two electrodes below the cantilever are used to toggle the switch between open and closed position. The switching voltages are approximately 10V. The single switch exhibits low loss (<0.4dB for DC-35GHz) with good isolation (>15dB for DC-30GHz). Based on this single switch a SPDT switch has been designed which consists of two toggle switches and two capacitive shunt switches. The combination of these two switch types makes it possible to achieve an excellent performance of 50 dB isolation and less than 0.3 dB insertion loss in a frequency range up to 30 GHz.

INTRODUCTION

Many microwave and mm-wave applications like phased array antennas, radar sensors or low power communication systems could be improved in their performance using low loss and high power capable switching devices. The development of Micro-Electro-Mechanical Systems (MEMS) has made exciting progress during the last years. The first micro mechanical switches were demonstrated in 1971 [1] as electrostatically actuated cantilever arms used to switch low-frequency electrical signals. Since then, these types of switches have demonstrated useful performance even at microwave frequencies [2,3]. The advantage of using MEMS over conventional solid state switching devices such as FETs or p-i-n diodes is their low insertion loss and low power consumption. The three aspects where the RF MEMS switches lack in performance compared to the conventional switches are the switching voltage, the switching speed and the power handling capabilities. It has been shown that the switching voltage could be reduced using a meander spring suspension [4]. This paper now describes a switch designed to handle up to several Watt RF power from DC up to 30 GHz.

SPST-SWITCH

The designed switch is called "Toggle switch" (Fig. 1). It consists of a cantilever, which is fixed by a torsion spring to the ground of the coplanar transmission line. The torsion spring is built of silicone nitride, which isolates the cantilever against RF ground. Thin electrodes under the cantilever allow electrostatic switching using a push pull concept. As in this case, no DC potential is needed on the signal line for switching, the cantilever can contact directly (without a dielectric between), the inner conductor of the coplanar line. An air-bridge connecting both ground metallisations of the coplanar line acts as a mechanical limit for the cantilever in open position. A flexible metal band creates the contact on the other side of the cantilever [5]. This allows in closed position a transmission starting at DC and yields ideal isolation for DC in the open position of the switch. Due to this, a large bandwidth of operation can be achieved, which is a great advantage compared to the well-known Shunt-Air-Bridge switches [3] where only a capacitive shunt connection can be achieved. The seris capacitance here limits the lowest frequency range of usage, if certain isolation must be obtained.

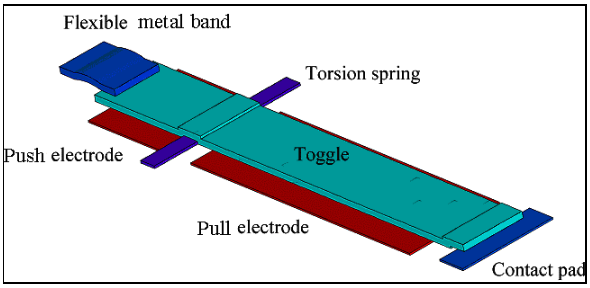
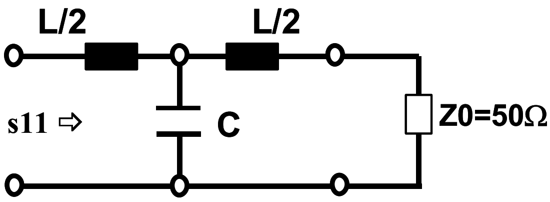


Fig. 1: Schematic view on the Toggle switch

SWITCH DESIGN AND OPTIMISATION

The Toggle-Switch is used in a 50 Ω coplanar line environment on a silicone substrate (centre conductor width 144 µm, gap 78 µm) where the Toggle is used as open circuit in the centre conductor. In closed position, the signal is routed via the direct metal contact to the cantilever and via the flexible metal band to the centre conductor of the coplanar line.

Due to the small distance of about 3µm to the grounded DC switching electrodes, the cantilever has a parasitic capacitance, which must be compensated for good RF performance. A broadband compensation of the capacitance is achieved by using a LC matching network.



(Figure 2).

Fig. 2: L/C matching network

It has been investigated, which maximum parasitic capacitance can be compensated while achieving a good match up to 30 GHz. The matching at the feeding port (S_{11}), depending of the inductance L and the capacitance C to be compensated is shown in Figure 3.

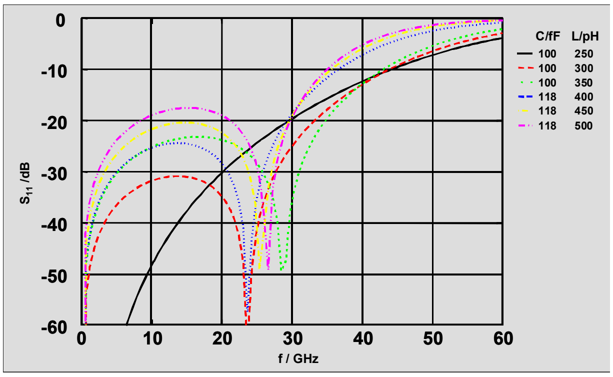


Fig. 3: Return loss at feeding port dependent of switch capacitance and inductive compensation

It is seen that a capacitance of approximately 100 fF can be compensated by a total inductance of 350 pH up to a frequency of 34.5 GHz. Frequency scaled, the actual capacitance of 118 fF is compensated with L=450 pH achieving a match of 20 dB at 30 GHz. A higher compensating inductance will decrease the performance in the lower frequency range.

Using this as starting values the 3D FDTD field simulator EMPIRE™ [6] has been used to simulate and optimise the Toggle-Switch. A compensation line with a width of 32µm and a length of 120 µm on the left side of the switch and a line with the width of 32 µm and a length of 100 µm on the right side were found as optimal implementation of the compensating inductors.

The magnitude of the electric field above the substrate at 20 GHz for the closed state of the switch is shown in figure 4. The field strength is indicated by colour and height. A difference of 60 dB is between the maximum amplitude (red colour) and the minimum amplitude (blue colour). The highest field amplitudes are below the cantilever as there is only a distance of 3µm to the grounded DC electrodes.

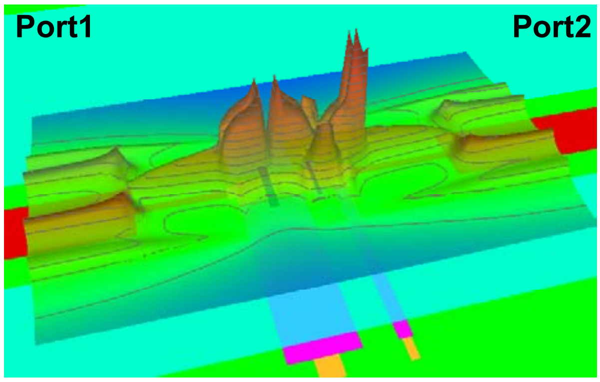


Fig.4: Magnitude of the electric field above the substrate @ 20 GHz in closed position of the switch

In open position of the switch (see figure 5) are the highest field values at the end of the open ended inductive line. The distance between the contact pad and the cantilever is simulated with 3 µm. The fields transmitted to port 2 are strongly attenuated.

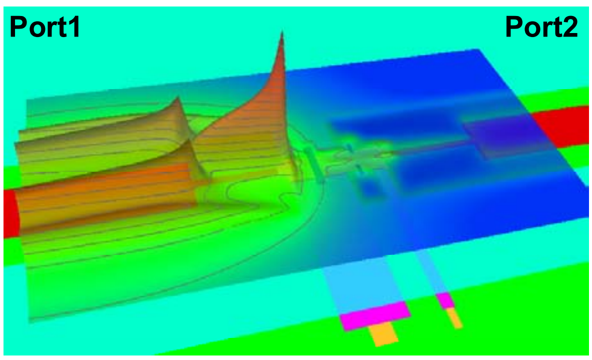


Fig.5: Magnitude of the electric field above the substrate @ 20 GHz in open position of the switch

The Toggle-Switch has been fabricated on high-resistivity silicon wafers (> 4000 Ωcm) with a wafer thickness of 525 µm. In measurements the DC and RF performance has been investigated. Two Keithley Voltage/Current sources have been used to apply the DC voltages for switching. A voltage of 10 V was needed to close the switch. Due to the high residual stress in the cantilever material the contact opens by reducing the DC voltages to 0V, and the cantilever jumps back to the original position. The RF measurements have been done with a Wiltron 360B network analyzer and an OSLT calibration for a frequency range from 40 MHz up to 40 GHz.

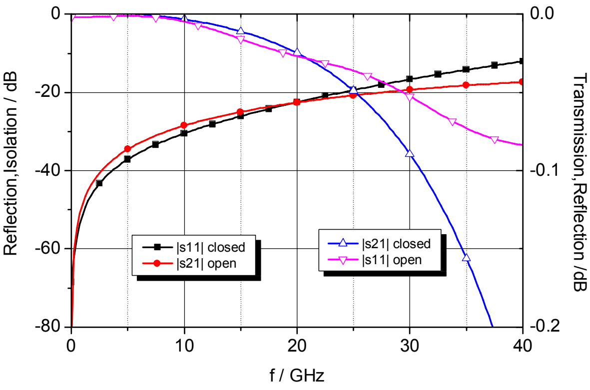


Fig.6: Simulation results of the Toggle-Switch in open and closed position.

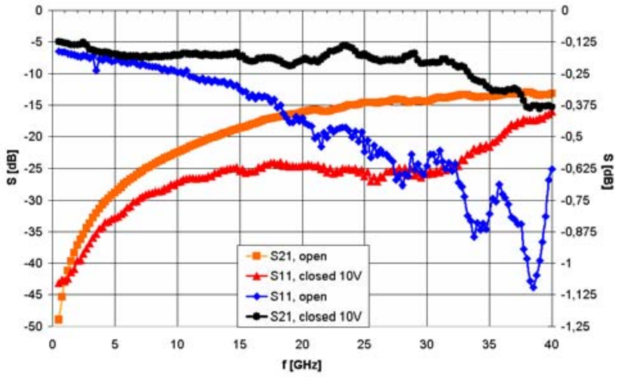


Fig.7: Measurement results of the Toggle-Switch in open and closed position.

Figure 6 shows the simulation results of the compensated switch in open and closed position and figure 7 shows the corresponding measurement results. The simulation and measurement results show a good agreement. The return loss of the closed switch is in the measurement and simulation up to 40 GHz below –15 dB. The insertion loss of the closed switch is in the measurements up to 40 GHz below 0.4 dB while the simulation, where the metal losses have been neglected, shows an insertion loss below 0.25 dB.

If the switch is in the open position an isolation of at least 15 dB at 30 GHz was measured (Fig. 10). Up to 10 GHz the isolation is better than 23 dB. The simulation predicted higher values for the isolation (about 19 dB at 30 GHz), which results from a lower capacitance of the simulated switch compared to the measured switch. The capacitance of the measured switch in open position is higher because the distance between the cantilever and the coplanar line is not as large as simulated (3 µm). This different capacitance and the neglection of the metal losses in the simulation are the reason for the different values in the return loss (0.6dB @ 30 GHz measured and 0.1 dB at 30 GHz simulated).

SPDT SWITCH

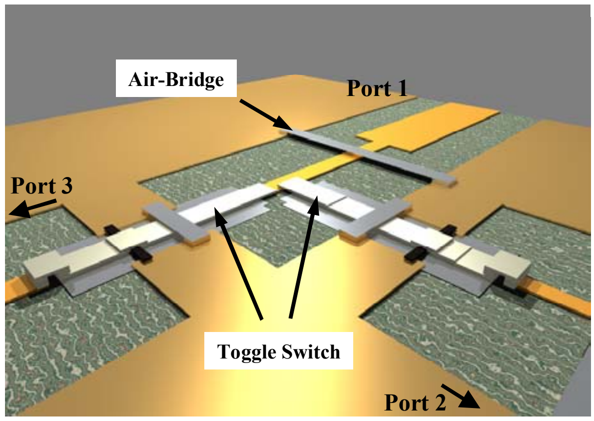


Fig. 8: 3D view of the Empire simulation model of the two toggle switches inside the SPDT switch.

A SPDT switch has been designed based on the SPST 'Toggle-Switch'. Figure 8 shows a 3D view of the inner SPDT structure with two toggle switches, which can route the signal to the two different output ports. One toggle switch is turned by 90°. Both toggle switches have fixed connections with a flexible metal band to the two output ports and can be connected, if they are switched to closed position, to the input signal from port 1. A standard air bridge is additionally needed to suppress unwanted modes if the signal is routed around the corner. Standard capacitive shunt switches have been used at the two output ports to increase the isolation to the non-switched ports. They increase the isolation especially for high frequencies where the coupling to the cantilever, which has a distance of 3µm in open position of the switch, becomes too strong.

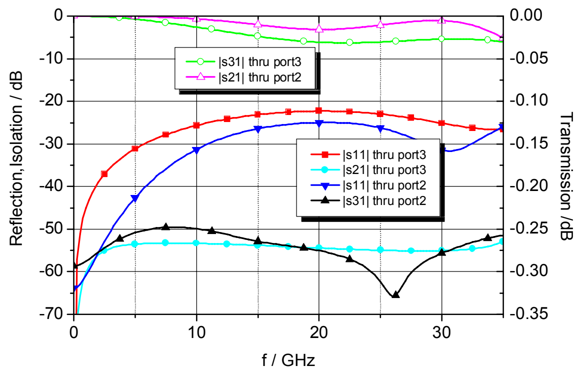


Fig. 9: Simulation results of the SPDT switch for both switching states.

The simulation results of the SPDT are shown in Fig. 9. It can be seen that the return loss is for both switch states up to 35 GHz better than 22 dB. The insertion loss with neglect of substrate and metal losses is for both switch states below 0.05 dB. This shows, that there is negligible radiation of the SPDT switch in the whole frequency range. The isolation to the non switched port is in both states better than 50 dB.

CONCLUSION

A new RF MEMS switch type for power application is presented for SPST and SPDT switching. Both devices offer the potential for building a new generation of low loss high-linearity microwave circuits for a variety of radar and communication applications.

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