OHMIC RF MEMS SWITCHES

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This contribution deals with capacitively actuated Ohmic switches in series single pole single throw (SPST) configuration for DC up to 4 GHz signal frequency (<0.5 dB insertion loss, 35 dB isolation) and in shunt switch SPST configuration for a frequency range from DC up to 80 GHz (<1.2 dB insertion loss, 18 dB isolation at 60 GHz).

В данном докладе рассматриваются емкостные омические переключатели с последовательной однополюсной конфигурацией для коммутации электрических цепей от постоянного тока до частоты сигнала 4 ГГц (вносимые потери <0,5 дБ, изоляция 35 дБ) и переключатели с параллельной однополюсной конфигурацией для диапазона частоты от постоянного тока до 80 ГГц (вносимые потери <1,2 дБ, изоляция 18 дБ при 60 ГГц).

Introduction

Switches are deemed to be key components among the RF MEMS, and are used for manifold applications e.g. TX/RX selection, reconfiguration of filters, of phase shifters or of antennas. Capacitive switches have been presented by numerous authors [1, 2, and 3] and show excellent life time. One of the main concerns is dielectric charging which may lead to undesired shift of the actuation voltage. The contrast of S21 in the through state and in the isolation state is determined by the capacitance ratio of both states, and the performance is limited at low signal frequencies. In contrast to capacitive switches, Ohmic switches cover frequencies from DC to a certain high frequency limit. Higher self-actuation resistivity and basically no actuation voltage shift due to charging because of no need of dielectric materials in addition to the DC handling capability are the main benefits. However, achieving a sufficiently high reliability of the contact function in particular is challenging.

The most demanding specifications are low insertion loss (<0.5 dB), high isolation (> 30 dB), fast response time (<50 µs), low actuation voltage (< 10 V), low actuation power consumption, and long life time (> 1 Billion switch cycles). A certain minimum contact force and a certain force to open the contacts are necessary in order to achieve reliable function, low contact resistance, and high speed switching. This is basically in contrast to low actuation voltage and low power consumption.

This paper shows the design, fabrication sequence and measurement results of a capacitively actuated Ohmic RF MEMS switch with in plane actuation by a relatively large electrostatic actuator. In a further section, reliability issues are addressed. It is shown that the special design of these switch devices enhances the contact force and the opening force dynamically and that no charging occurs over 1 Billion switch cycles.

Design

The switch design is based on separate areas for the actuator and for the signal that has to be handled. Two different concepts for signal interconnection between the contacts and the terminals of the devices were followed. In case of the lower frequency series type switch device that is capable to handle signals of frequencies up to 4 GHz, via holes in the glass cover are used. In case of the mm-wave shunt type switch device for signal frequencies up to 75 GHz, a lateral feed through of coplanar strip lines on top of the silicon part has been chosen. Fig. 1 depicts a cross sectional view of the chip including glass cover, electrical vias and solder ball (4 GHz version). The movable part of the silicon chip is fabricated by deep reactive ion etching and isotropic release etching from the crystalline silicon for both switch types. The thickness of the movable part is 50 µm. The chip bond frame is coated by oxide and nitride isolation and by aluminum, which form the electric lines and act as chemically reducing material for anodic wafer bonding of the upper glass part.

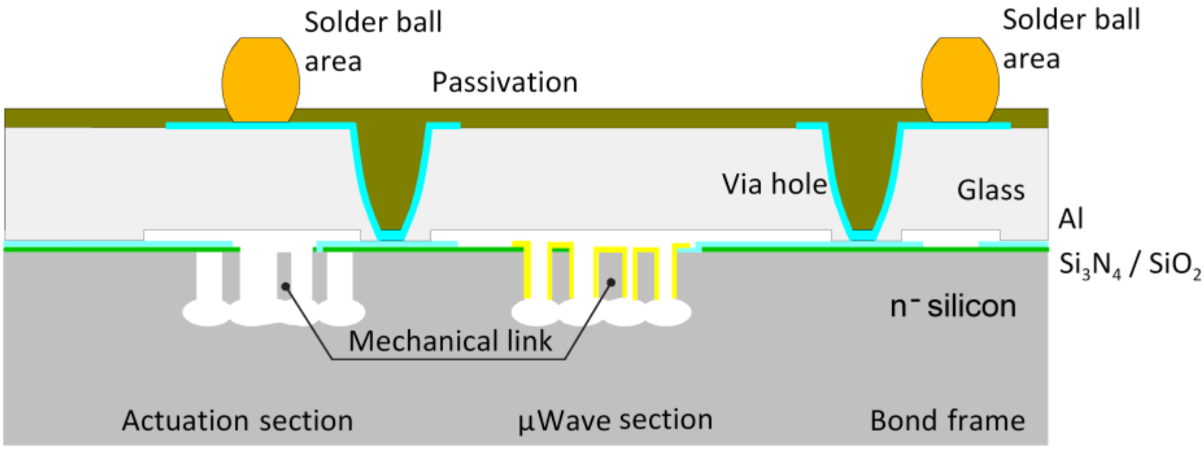


Fig. 1. Cross section view of the 4 GHz RF series switch

The actuation system consists of comb drives including comb drive rods, movable electrode fingers and fixed electrode fingers, a push rod, restoring springs, and a mechanism for gap reduction. Electrostatic forces from a large area electrostatic comb drive activate a push rod and press the contact tips towards the counter parts. The electrodes consist of silicon. Since there is no additional dielectric material applied on the electrodes, dielectric charging is not expected.

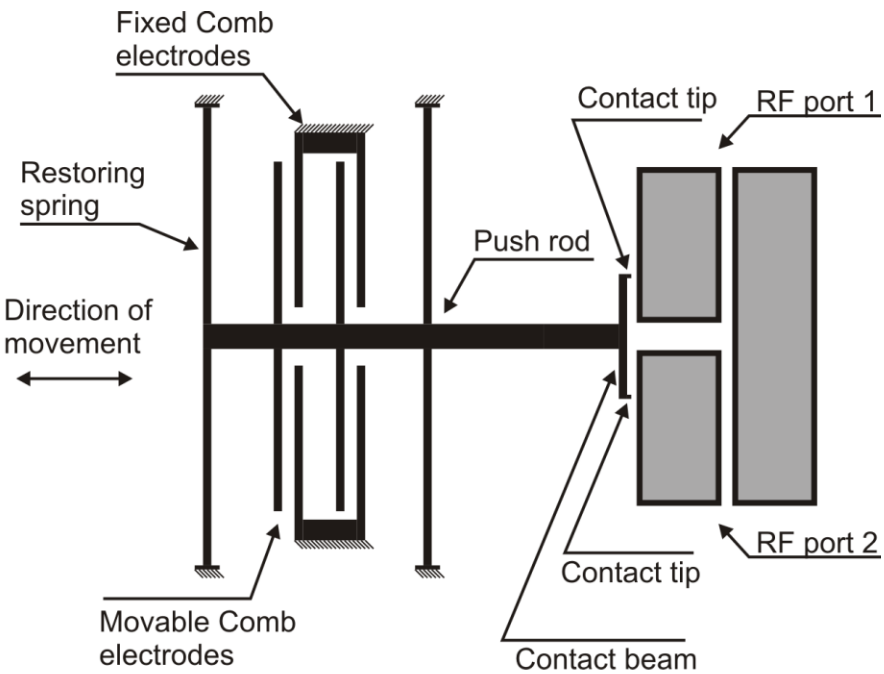


Fig. 2. Schematic drawing of the series switch

The concept of the series type switch is based on a double series switch (Fig. 2). The contact tips are connected to the push rod by contact beams in order to compensate the differences in the contact gap between both contacts within a chip. If one contact is closed earlier than the other, the elasticity of the contact beams allow for further travel of the push rod to close the other contact subsequently. The contact beams are electrically isolated from RF ground and from RF signal in the open state.

The series switch concept is susceptible for capacitive coupling and therefore not suited for frequencies much higher than 10 GHz. The shunt-type switches are better suited for millimeter wave signals. The concept that is followed for the 75 GHz switch, is based on a coplanar strip line design. The signal line is interrupted for providing space for the shunt contact and for the push rod, and a flexible signal line part, that is called contact beam in Fig. 3, is applied. The contact beam is bended by the actuation force. The very narrow width provides high elasticity, and therefore low force counteracting the actuation. The contact bar is electrically and mechanically connected to the signal line on its both ends. At lower frequencies and DC, the inductance of the contact beam is not critical. It is critical at high GHz frequencies. Therefore, a significant part of the signal line is arranged in parallel to the contact beam in order to form an additional capacitive coupling for high frequency signals. Thus, an additional current path is created, which reduces the inductive influences of the long contact beam.

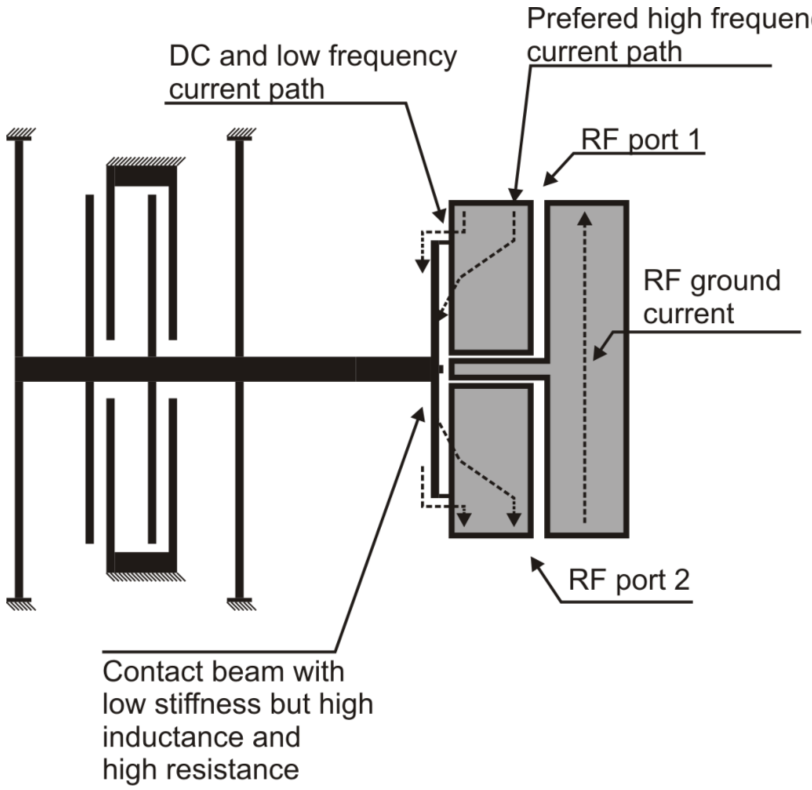


Fig. 3. Schematic drawing of the shunt switch

Fabrication of Samples

The fabrication sequence is summarized within Fig. 4. It starts with deposition and patterning of isolation layers and of wiring for micro wave signal section and for actuation section. An anisotropic high aspect reactive ion etching of the silicon electrodes, of the restoring springs, and of other movable parts is applied. Subsequently, an isotropic release etching follows in order to separate the movable structure from the substrate. After removing of the masking layers, metal is deposited in the contact area by sputtering using a shadow mask.

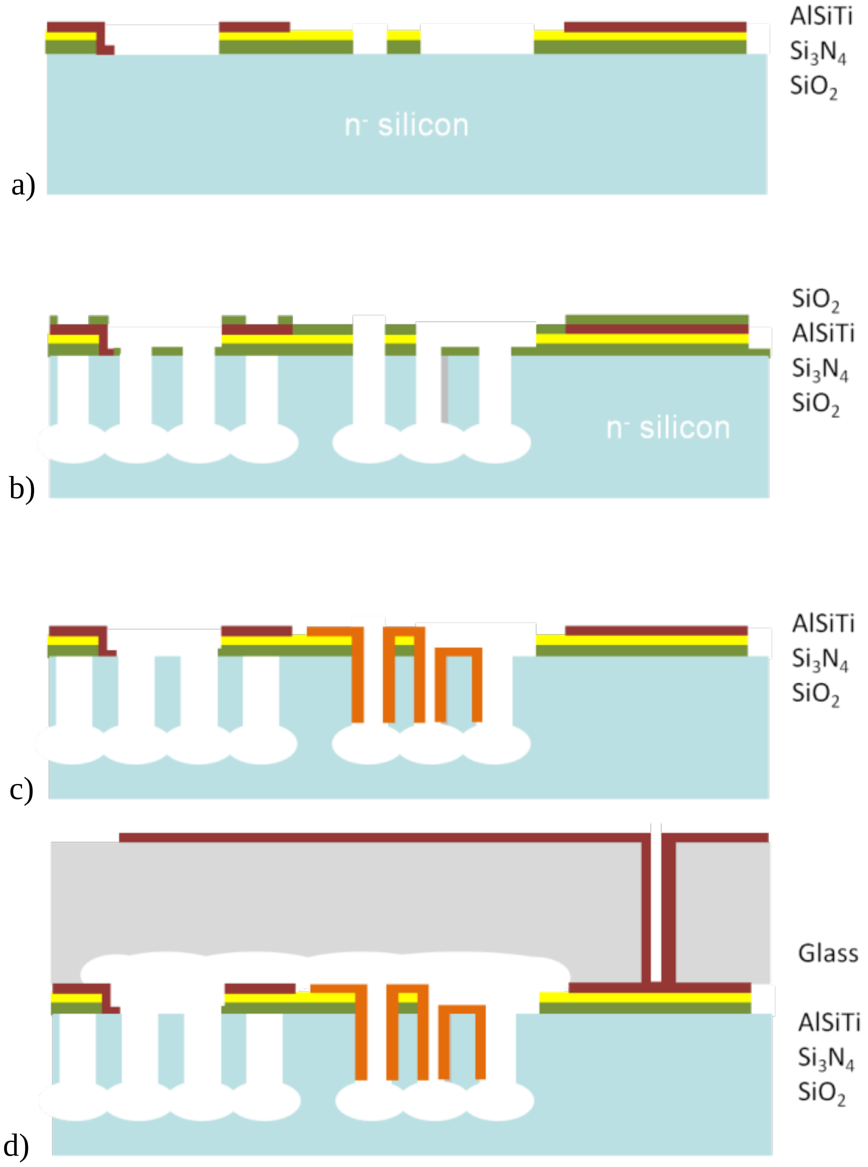


Fig. 4. Illustration of the fabrication sequence by cross sectional views, glass cap with via through holes

As stated in Ref. [5], contamination of the contact surface by residuals from the technology sequence and by the content of the ambient air significantly contributes to enlarged contact resistance, decreased reliability, and shortened life time. Cleaning procedures are implemented in some cases[5]. There, the contact metal is sputter deposited through a shadow mask that does not make further patterning of the contact metal necessary in case of this switch. Contamination by residuals of the photo resist can not be introduced following this fabrication sequence. Finally, the devices are hermetically sealed by wafer bonding in vacuum.

Test Results

Test results within Fig. 5 shows that the switch devices have a switching speed of 10 µs at an actuation voltage of 5 Volt.

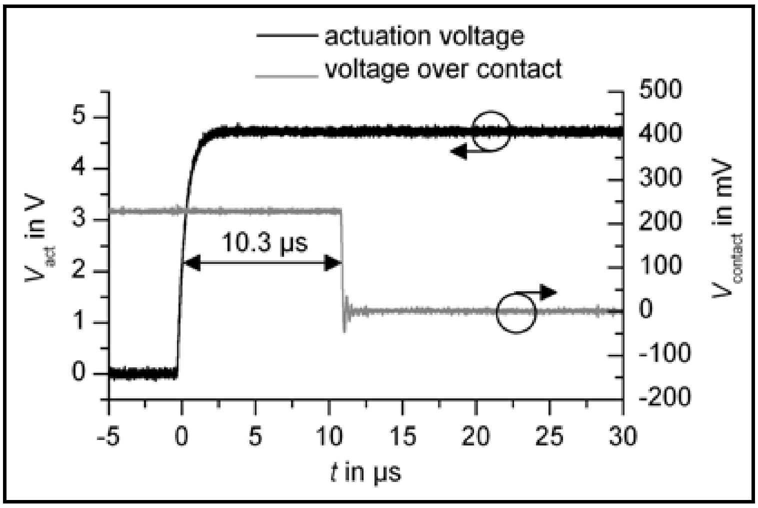
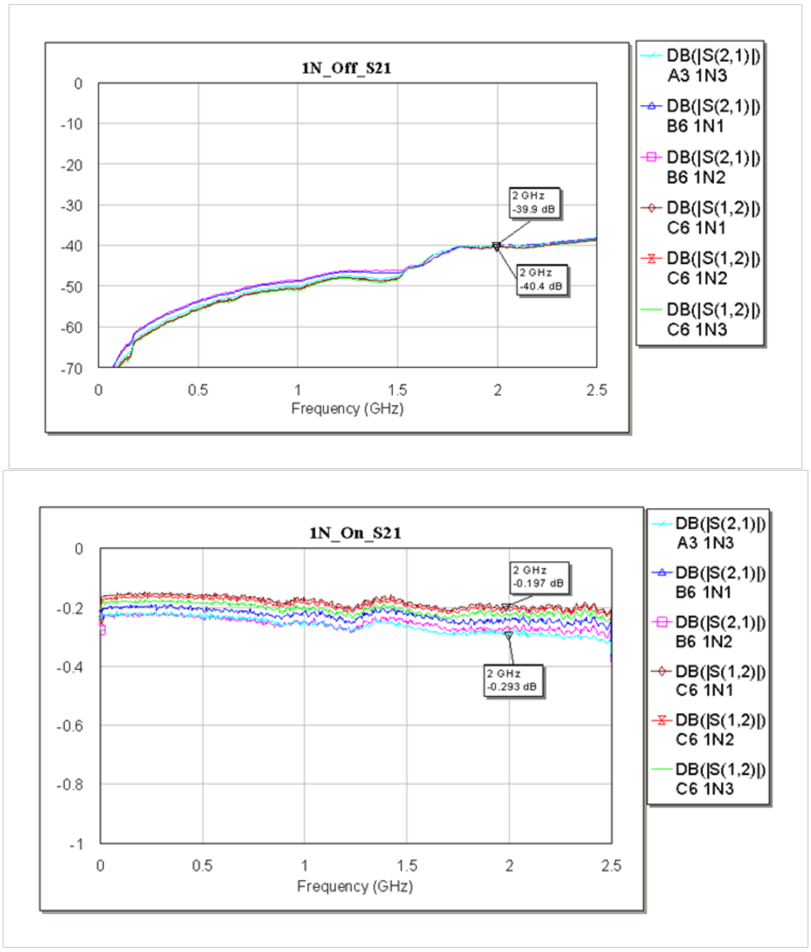


Fig. 5. Voltage over the contacts and actuation voltage showing the switch on time

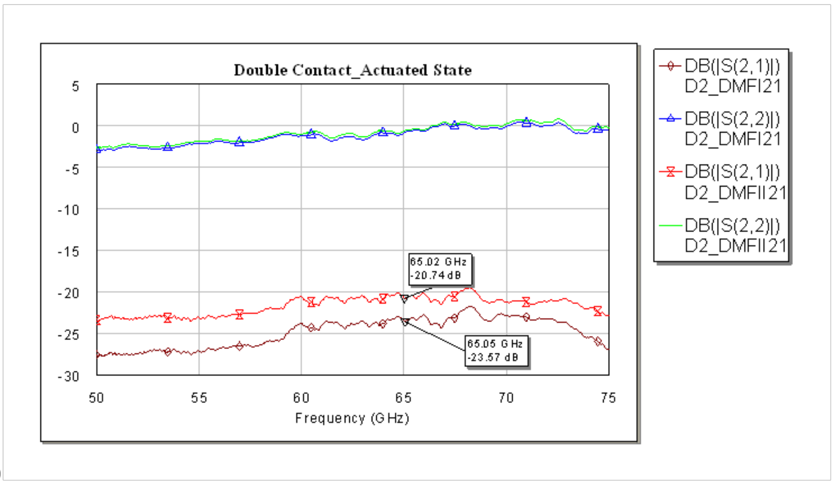
The spectral ranges of the specific devices are free of resonances up to 4 GHz and up to 75 GHz respectively. The insertion loss and the isolation of the 4 GHz switch is -0.5 dB and -35 dB respectively (Fig. 6). In case of the 75 GHz device, an insertion loss of -1.2 dB and an isolation of -20 dB were measured (Fig. 7).

a)



b)

Fig. 6. S21 in the open state a) and in the closed state of the 4 GHz series switch



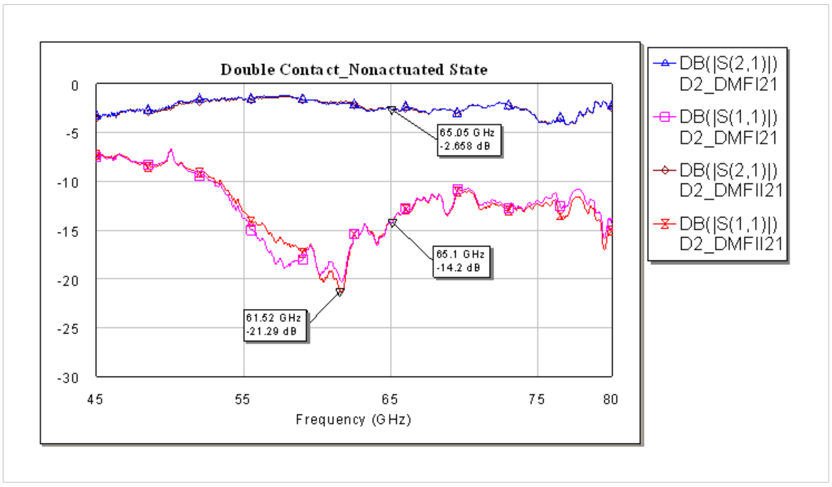


Fig. 7. S21 in the open state a) and in the closed state of the 75 GHz shunt switch

Charging of dielectric materials is one of the major reliability concerns of electrostatically actuated switches. In order to experimentally investigate this phenomenon on the switch types described here, the data from life time test was analyzed. In case of driving with voltages of a single polarity (Fig. 8), charging of the actuator would lead to non-symmetric change of the pull-in voltage and of the release voltage, respectively. It would originate from trapped charges that contribute to or counteract the applied voltage dependent on the voltage polarization.

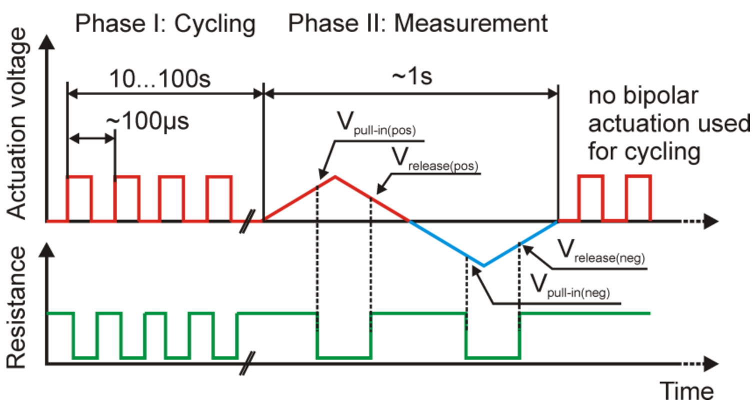


Fig. 8. Actuation voltage and contact resistance during the life time test

Actuation by negative voltages would be differently influenced compared to actuation with positive voltage, and the negative and positive pull-in voltages and the release voltages would differ from each corresponding other. The difference between the positive and negative pull-in voltages and release voltages remain constant for the described switch types (Fig. 9). This indicates that no charging has been registered.

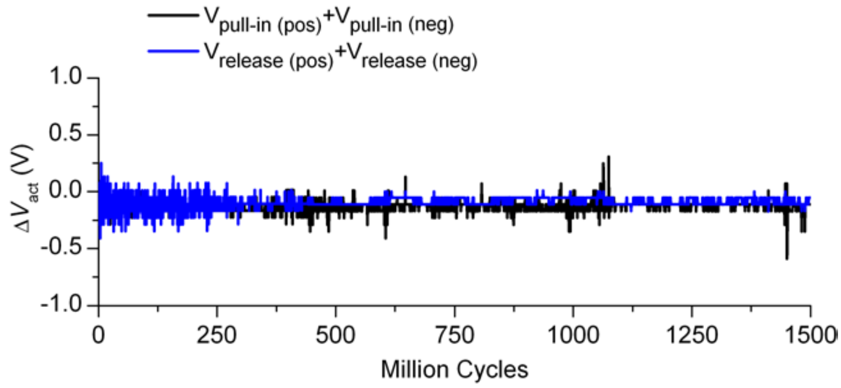


Fig. 9. Difference of positive and negative pull-in voltage and of positive and negative release voltage

The intermodulation distortion of the 4 GHz switch is better than 73 dB (IP3) measured by a signal at 1000 MHz and 997 MHz with 18 dBm (Fig. 10).

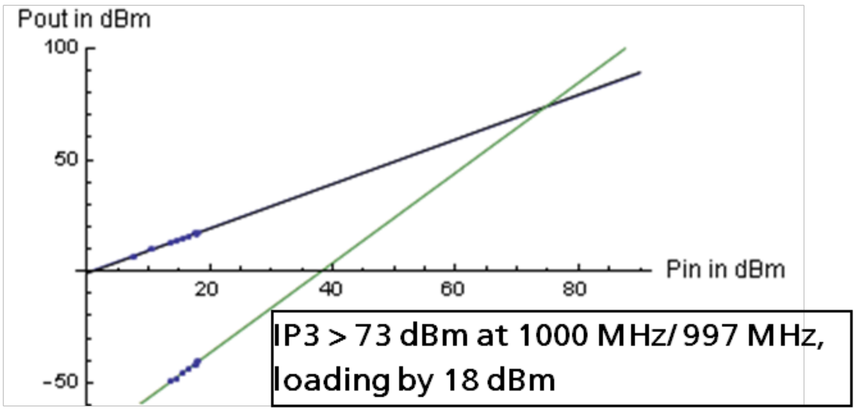


Fig. 10. Results of the IP3 measurement with data point and extrapolation lines

Summary

Two types of electrostatically actuated switches with Ohmic contacts were presented in this paper. A high force electrode system is applied. The special design of the mechanical system including an elastic part between the contact and the driving electrodes makes it possible to enhance the contact closing force and the force for contact separation. A static contact force of more than 100 µN and a dynamic force enhancement by electrode over travel with more than 250 µN were achieved. The switch devices are hermetically sealed by wafer level packaging. A defined vacuum pressure leads to optimized response time and no contact ringing. It has been shown by a long term life time test that the electrostatic drive system is free of charging.

References

1. Kaynak, et al., "BiCMOS embedded RF-MEMS switch for above 90 GHz applications using backside integration technique", IEDM Technical Digest 2010, 100-104 (2010).
2. Muldavin, J. Bozler, C. O., Rabe, S., Wyatt, P. W., Keast, C. L., "Wafer-Scale Packaged RF Microelectromechanical Switches", IEEE Trans. on Microwave Theory and Techniques 56 (2), 522-529 (2008).
3. Yamamoto, Y., Sogo, T., Obata, S. Miyagi, T., Hiura, S., "Millimeter-Wave MEMS capacitive switch in vacuum-sealed in-line wafer level package", Microwave Conference APMC 2009 Asia Pacific, 198-201 (2009).
4. Akiba, A. et al., "A fast and low actuation voltage MEMS switch for mm-wave and its integration", IEDM Technical Digest 2010, 828-831 (2010).
5. Ma, Q., Tran, Q., Chou, T., Heck, J., Bar, H., Kant, R., Rao, V., "Metal contact reliability of RF MEMS switches", Proc. SPIE 6463, (2007).