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On-Line Testing of Ohmic RF MEMS Switches for SiP Applications

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Outline

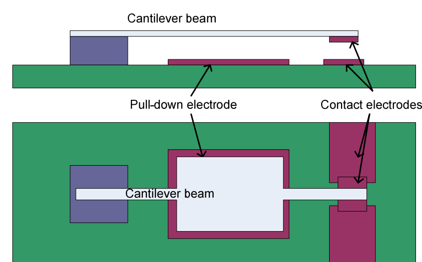
- Introduction
- Lifetime of an ohmic RF MEMS switch
- Analog boundary scan on SiP level
- On-line test method for ohmic RF MEMS switch
- Measurements and results
- Future directions
- Conclusions

Introduction

- RF MEMS switches are promising when compared to existing RF switches
  - Near-zero power consumption
  - Very high isolation
  - Very low insertion loss
- But there is also some disadvantages
  - Low speed
  - Power handling
  - Packaging
  - **Reliability**

RF MEMS switches

- RF MEMS switches can roughly be categorized by the switching method to capacitive and ohmic switches



- Ohmic switches are typically electrostatically actuated
  - Pull-down electrode pulls the cantilever down to enable contact between electrodes

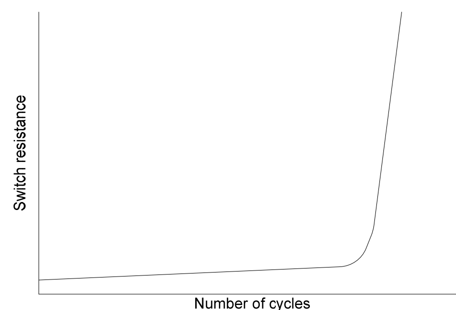
Life-time of an ohmic RF MEMS switch

- RF-power loss consists of three components: return loss, isolation loss and ohmic resistance
- Ohmic resistance consists of package wiring and switch resistance
  - Typically the nominal switch resistance is $\leq 1\Omega$
- The power loss is usually dominated by the switch resistance

$$Loss = 10\log_{10}\left(\frac{Z_0}{Z_0 + R_{sw}}\right)$$

Life-time of an ohmic RF MEMS switch

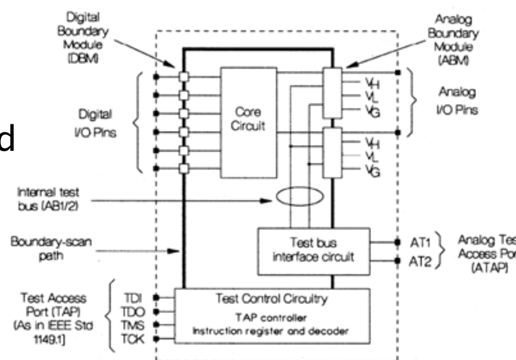
- The switch resistance increases as a function of switching cycles
  - Caused of the switch contact degradation



- The speed of resistance increase depends of the switching type
  - Cold switching can be tolerated several decades cycles more than hot switching

Analog boundary scan on SiP level

- IEEE Std 1149.4 “Standard for a Mixed-Signal Test Bus”
  - Bases on IEEE Std 1149.1
  - Defines testability structures for mixed-signal circuits
  - Standard will be updated in 2008
- Powerful test method but has not gained such popularity as 1149.1



Analog boundary scan on SiP level

- 1149.4 can be used as test access for SiP devices from production to field tests
- Implementing 1149 to SiP is a challenge due SiP adds a hierarchy layer to a board design
  - SiP is seen as a single IC on board while it can have multiple IC’s inside
  - Solution is presented for 1149.1*
- Extending the solution to 1149.4 only requires routing the analog test lines to required IC

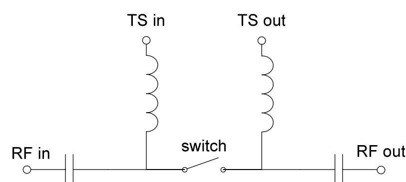
*F. de Jong, A. Biewenga, “SiP-TAP: JTAG for SiP”, International Test Conference 2006

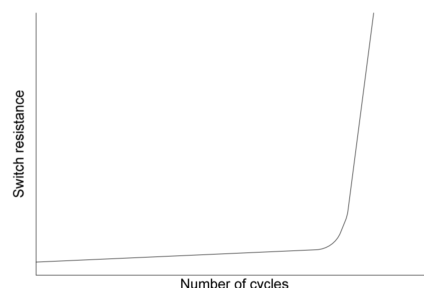
Analog boundary scan on SiP level

- 1149.4 creates an generic analog access which can be used for
  - Component testing
  - Health monitoring
  - Signal routing
  - etc
- Test access is reusable from manufacturing level to on-line field tests
  - Critical component monitoring
  - Power on self-test, etc
  - Requires test signal measurement and generation

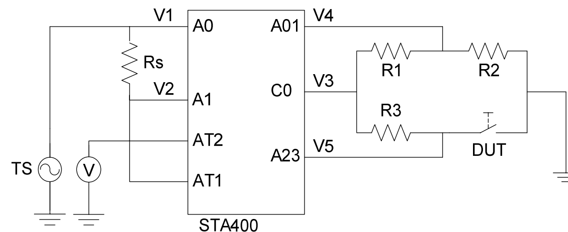
On-line test method for ohmic RF MEMS switch

- Test method is based on simple resistance measurements of the ohmic RF MEMS switch while it is on switch-on mode
- The resistance change reveals the aging of the component



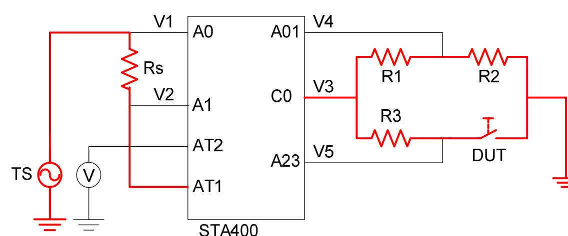


On-line test method for ohmic RF MEMS switch



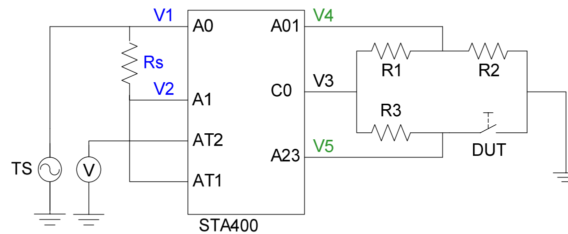
- 1149.4 environment was used for on-resistance measurements
- The small resistance measurement is based on Wheatstone bridge circuit
  - Successfully used in BGA junction monitoring

On-line test method for ohmic RF MEMS switch



- Resistances Rs and R1-R3 are known
- The test signal routed thru RS to pin AT1
- From AT1 the test signal is routed internally trough C0 to the bridge circuit
- The pin voltages are measured internally through AT2

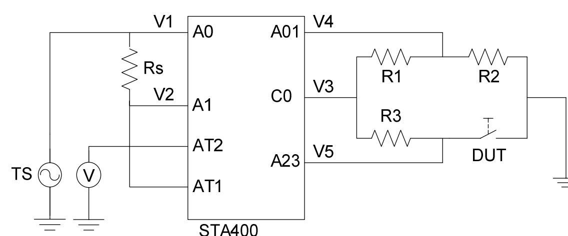
On-line test method for ohmic RF MEMS switch



- The test signal current I can be calculated from voltages in points V_1 and V_2 and from the resistance R_S
- The off balance voltage V_G can be calculated from the measured voltages V_4 and V_5

$$I = \frac{V_1 - V_2}{R_S} \qquad V_G = V_4 - V_5$$

On-line test method for ohmic RF MEMS switch

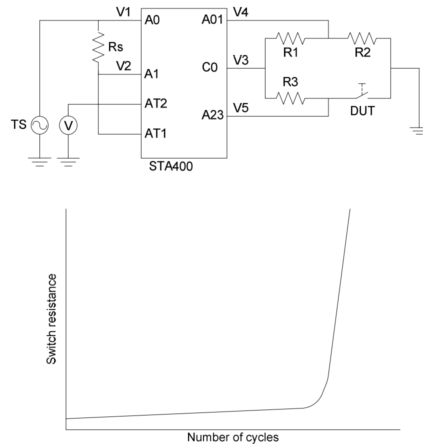


- Using calculated values V_G and I and previously known resistances R_1–R_3 we can calculate the switch on resistance R_{SW}

$$R_{SW} = \frac{R_2 R_3}{R_1 - \frac{V_G}{I}} + \frac{V_G}{I} \frac{R_1 + R_2 + R_3}{R_1 - \frac{V_G}{I}}$$

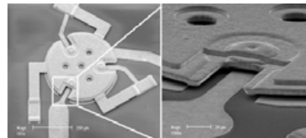
On-line test method for ohmic RF MEMS switch

- R_{SW} can be used to estimate the current condition of the switch
- Significant increase R_{SW} or crossing predefined boundary value indicates the end of switch life



Measurements and results

- Device Under Test
  - Commercial ohmic RF MEMS Single Pole Double-Throw switch (Teravicta)
  - Bandwidth DC to 7 GHz
  - Initial switch on-resistance 0.3 Ω
  - Requires 68 V actuating signal

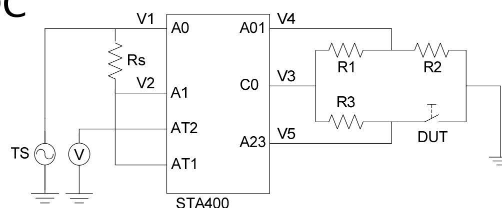


Measurements and results

- Measurement environment
  - Switch cycling was done with charge pump driven by a signal generator (HP 33120A)
  - Cycling monitored with a universal counter (HP 5316A)
  - Test signal for 1149.4 measurement by signal generator
  - 1149.4 environment controlled by BS controller (JTAG PM4705)
  - Overall measurement controlled by LabVIEW

Measurements and results

- The used switch actuation frequency 1 kHz
- Cold switching
- Test signal 1 mA DC
- Component values
  - RS = 1 kΩ
  - R1 = R2 = 10 kΩ
  - R3 = 0.3 Ω

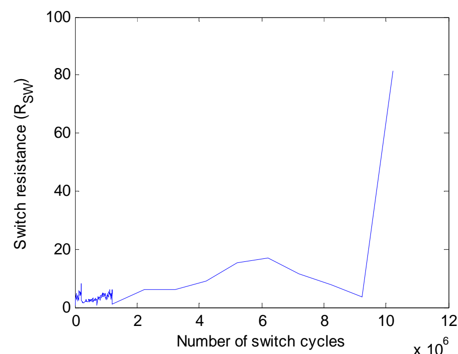


Measurements and results

- Before testing actual switches, measurement environment was validated with resistors
- Two MEMS switches were tested
  - 1st component was broken before measurements
  - 2nd component was broken without any early warning signs

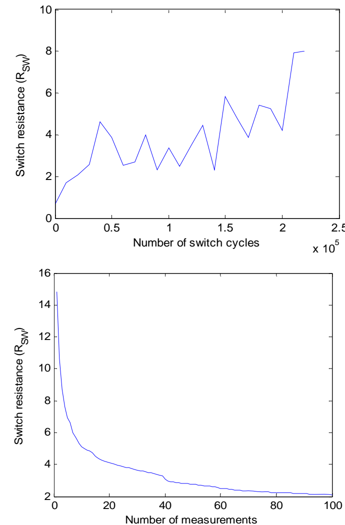
Measurements and results

- 1st ohmic RF MEMS switch
  - Was initially broken
  - Measurements done in three phases
    1. 220 000 cycles measured after 10 000
    2. 1 000 000 cycles, measured after 10 000
    3. 11 000 000 cycles, measured after 1 000 000



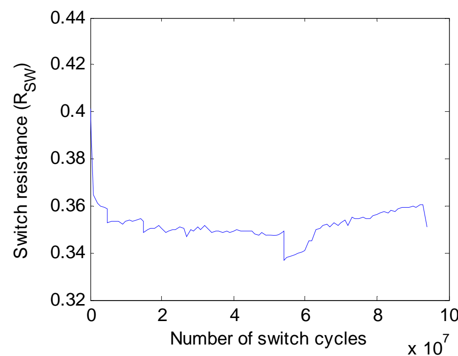
Measurements and results

- 1st ohmic RF MEMS switch
  - On first phase the resistance increased rapidly
  - On second phase the resistance was measured continuously 100 times after every 10 000 cycles
    - E.g. resistance decreased from 14.8 to 2.1 Ω
    - Measurement environment was ruled out to be the reason



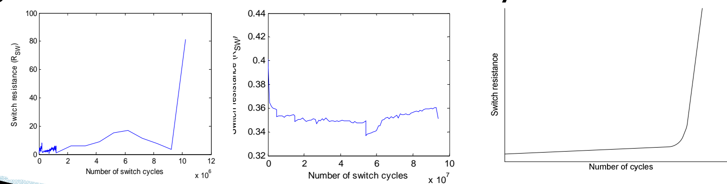
Measurements and results

- 2nd ohmic RF MEMS switch
  - Switch was cycled successfully nearly 100 million cycles
  - Measured after 1 million cycles
  - No signs before breaking
  - R_{SW} stable
    - Cycles 1mil – 94 mil variation ~4%



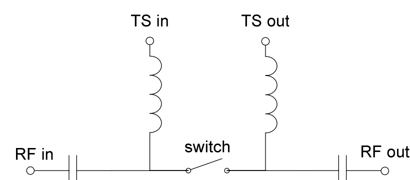
Measurements and results

- The measurements prove the effectiveness of the test method
- Previous studies have shown that switch resistance increases as function of switching number
- The on-line test method would be effective e.g. in systems with redundancy



Future directions

- The next phase is to redo measurements with new components
- Implement a test setup where live RF-signal is available
- Comparative measurements with RF and DC
- Problem: Is there any commercial components?



Conclusions

- 1149.4 is useful and one possible method for solving mixed-signal tests on SiP level
- 1149.4 architecture can be used for the whole life-time of the product
  - from production testing to on-line field testing and system monitoring
- The presented on-line test method estimates the condition of the ohmic RF MEMS switch through the on-resistance

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Thank you!

Any questions?

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