RF MEMS Switches: High-Frequency Performance and Hot-Switching Reliability

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Exploring the hot-switching reliability of MEMS switches using different types of input signals.

Abstract

This article describes the S-parameter performance of on-board RF MEMS switches from DC to 4 GHz. It also explores the hot-switching reliability of MEMS switches using different types of input signals. Finally, it evaluates a possibility for improving the reliability of MEMS switches using an external circuit.

I. Introduction

Micro-electro-mechanical systems (MEMS) technology is an evolving technology that allows device fabrication using components at a submillimeter scale (1 to 100 micrometers). A wide variety of MEMS devices is available, including sensors, actuators and switches.

An RF MEMS switch is a specific type of MEMS-based device that can provide switching capability at RF (radio frequency) or even microwave frequencies. MEMS switches offer several advantages that make them an attractive alternative to conventional devices like mechanical relays and solid-state devices (PIN or FET switches): low insertion loss, high isolation, low power consumption, extreme linearity and the ability to be integrated with other electronics [1].

While the advantages are numerous, the long-term reliability of MEMS switches is relatively weak, especially when switching in the presence of input signals (hot-switching). In this paper we investigate RF MEMS switch performance and reliability issues by focusing on an off-the-shelf, ohmic-contact-based, single-pole-double-throw (SPDT) MEMS switch that is currently available.

A comparison of MEMS relays (MMR) and other solid-state devices and electro-mechanical relays (EMR) is shown in Table 1 [2].

II. On-Board RF MEMS Switch Performance

Our intent is to simulate actual use cases of an off-the-shelf, surface-mounted RF MEMS switch in a typical printed circuit board (PCB) application. We fabricated an evaluation PCB for mounting the RF MEMS switch so we could measure board-level performance like S-parameters from DC to 4 GHz.

Figure 1 shows the layout of the evaluation board. We used SMA connectors for connecting from PCB transmission lines to measuring equipment.

We used a network analyzer to make the S-parameter measurements. Below are the definitions of the network analyzer measurements we made on the evaluation board with an RF MEMS switch:

Insertion loss – S21 measurement from the common port (pole of the MEMS switch) of the board to either port A or B (throw of the switch).

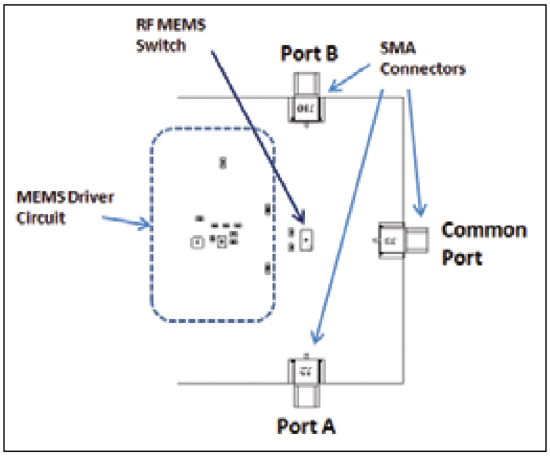

Figure 1 • MEMS evaluation board.

Characteristic	MMR	GaAs FET	PIN diode	EMR PCB	EMR SMA
Size	Small	Very small	Small	Medium	Large
Resistance	0.5 Ω	1-5 Ω	1-5 Ω	0.1 Ω	0.5 Ω
Switching power	2 W CW	0.5 W CW	5 W CW	10 W CW	35 W CW
Breakdown voltage	Low	Low	Varies	High	High
Speed	0.5-200 µs	10-100 ns	10-100 ns	0.8-10 ms	1-40 ms
Life cycle	100 million+	Billion	Billion	0.5-5 million	0.1-2 million
Frequency	Up to 70 GHz	Up to 4 GHz	Up to 20 GHz	Up to 5 GHz	Up to 40 GHz
In. loss max (dB)	0.25	0.5	0.5	0.4	0.1
Isolation min (dB)	40	30	30	40	80
3rd order harmonics	Very good	Poor	Poor	Good	Very good
Power consumption	Very low	Low	Low	Medium	High
Integration capability	Very good	Very good	Very good	Average	Difficult
Cost – SPDT type	$8 to $20	$0.5 to $4.50	$0.9 to $8	$0.85 to $12	$38 to $90

Table 1 • Comparison of MEMS relays with existing switches.

Return loss – S11 measurement at any port of the board with other ports terminated with a 50 Ω load.

Isolation – S21 measurement from the common port to either port A or port B while the switch position is intentionally set to the opposite port.

The measurement results with the analyzer are presented in Table 2 (a) to (c).

Frequency	S21 (dB)
10 MHz	-0.1
30 MHz	-0.1
300 MHz	-0.1
4 GHz	-0.7

Table 2(a) • Insertion loss of on-board MEMS switch.

Frequency	S11 (dB)
10 MHz	-43.2
30 MHz	-44.2
300 MHz	-48.2
4 GHz	-17

Table 2(b) • Return loss of on-board MEMS switch.

The on-board performance data indicates that RF MEMS switches indeed have very good high-frequency performance in terms of low insertion loss, good matching and excellent isolation.

III. Hot-Switching Reliability of RF MEMS Switches

RF MEMS switch reliability is a major concern because of the relatively new technology of the devices. Adoption of the technology is lower compared to other established components like solid-state devices and electromechanical relays, so there is not much data across industries to show the long-term behavior across the entire lifetime of the applications.

Frequency	S21 (dB)
10 MHz	-100
30 MHz	-90
300 MHz	-96
4 GHz	-43

Table 2(c) • Isolation of on-board MEMS switch.

One way MEMS switches fail is through "stiction," where a switch contact is unable to be moved to another intended position when biasing voltage is applied.

When you apply very low or no input signal during switching cycles (cold-switching), MEMS switches can last as long as specified by the manufacturer. However, when you apply significant input power to the switch during switching cycles (hot-switching), contact stiction can occur much earlier than the lifetime specified on the manufacturer's data sheet. The failure is caused by "microwelding" of the contacts during the switching transition from one position to another [3].

We evaluated the hot-switching reliability of RF MEMS switches using the same evaluation board we used for studying switch performance.

Figure 2 shows the setup of the hot-switching measurement. Input signals are continuously applied to the MEMS switch while biasing voltages are used for device switching. You can use an oscilloscope or spectrum analyzer to continuously monitor the output signal to detect any switch failures. We ran the measurement continuously until the switch failed and recorded the number of switch cycles until failure.

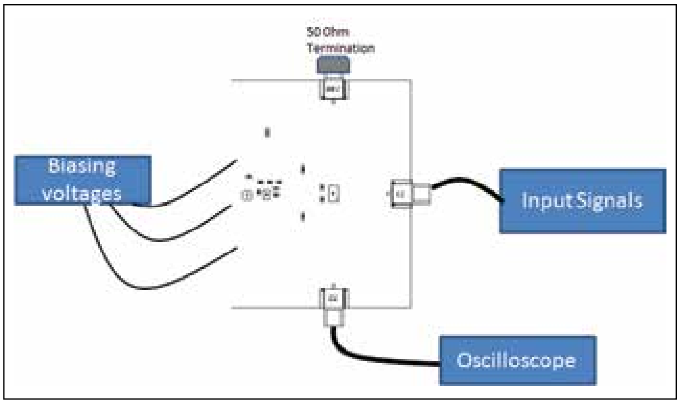

Figure 2 • Hot-switching setup.

We applied three types of signals to study the hot-switching behavior of the RF MEMS switch under different signal conditions:

(1) DC voltage at 20 V

(2) Continuous RF (2 GHz) at +30 dBm

(3) DC pulses: Peak voltage = 26 V, pulse width = 6.5 ns, pulse frequency = 50 kHz

We used three samples for each type of input signal. Tables 3 (a), (b) and (c) show the number of switch cycles it took to reach failure when high-power input signals were applied for hot-switching.

	Failure cycle
Sample 1	1,801
Sample 2	4,180
Sample 3	5,750

Table 3(a). Hot switching with DC voltage.

	Failure cycle
Sample 1	484,775
Sample 2	1,346,358
Sample 3	964,161

Table 3(b). Hot switching with continuous RF.

	Failure cycle
Sample 1	3,114,338
Sample 2	150,722
Sample 3	3,333,143

Table 3(c). Hot switching with DC pulses.

The results show that hot-switching with DC voltage has the worst reliability. This can be explained by looking at the duration of input signal voltage applied during the switching transition period. For a DC signal, the voltage is applied constantly for the whole switching transition period, and it yields the highest probability of microwelding. For signals like RF signals or pulses, the duration of peak voltage applied during switching transition is shorter than the voltage duration for DC signals, so there are fewer occurrences of microwelding. More microwelding will cause more contact damages and shorten the life of the MEMS switches.

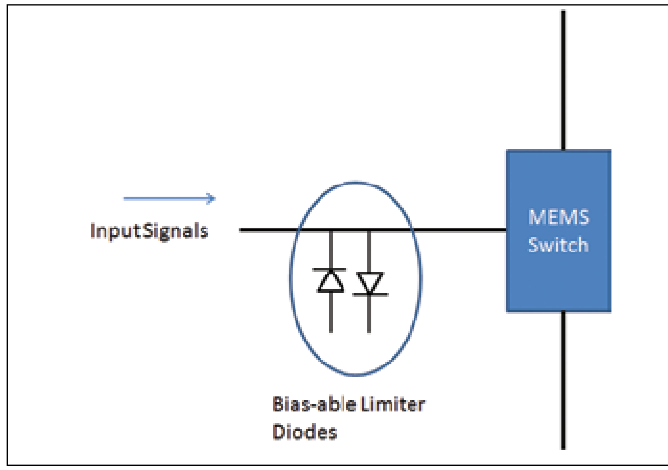

Figure 3 • Limiter diodes circuit for MEMS switches.

IV. How to Improve Hot-Switching Reliability

As we discussed in Section III, the hot-switching failure of RF MEMS switches is caused by "microwelding" of the contacts during the switching transition. There is no risk of microwelding after the switching transition completes.

Therefore, microwelding could be eliminated or reduced if there is a circuit to block or limit the input signals during the switching transition period.

Figure 3 shows a proposed circuit for this purpose. A bias-able limiter diode circuit is added to the common port of the RF MEMS switch. When there is no switching needed, the limiter diodes are reversed biased at high voltages like +/- 20 V, such that input signals are not distorted by the diodes. During switching transitions, the limiter diodes are biased at 0 V so input signals are clipped to the forward voltages of the diodes. After switching is settled, the biasing voltages for the diodes revert to +/- 20 V.

We fabricated an evaluation board based on the diode circuitry shown in Figure 3 for on-board evaluation of the RF MEMS switch. We made network analyzer measurements to study the S-parameter performance of the new circuit. Figure 4 (a) to (c) shows the respective board-level performance of the added circuit.

We repeated the hot-switching experiment with DC pulses to observe the improvement on RF MEMS reliability. Table 4 shows the results.

From the board-level S-parameter results, the addition of a limiter diode circuit will cause degradation of

Without limiter diode circuit	With limiter diode circuit
150 thousand to 3 million cycles before failure	Up to 7.8 million cycles and no failure yet

Table 4 • RF MEMS reliability comparison.

insertion loss and return loss compared to an RF MEMS circuit without it. However, clipping of the input signals via limiter diodes during switching transitions does significantly improve the hot-switching reliability of RF MEMS switches.

V. Conclusion

We measured and analyzed the RF performance and hot-switching reliability of an RF MEMS switch mounted on a PCB. We added an external circuit to improve the hot-switching reliability of the MEMS switch. However, there are trade-offs for the addition of the external circuit in terms of insertion loss and return loss. You can use the information in this paper to determine the suitability of RF MEMS switches in your application from the perspectives of high-frequency performance, as well as hot-switching life cycles under different signal conditions.

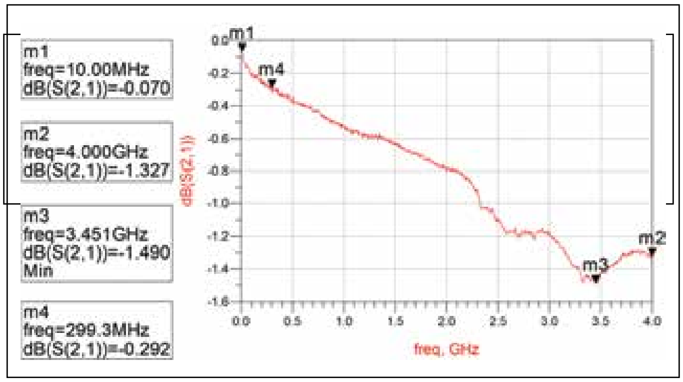

Figure 4(a) • Insertion loss of new circuit.

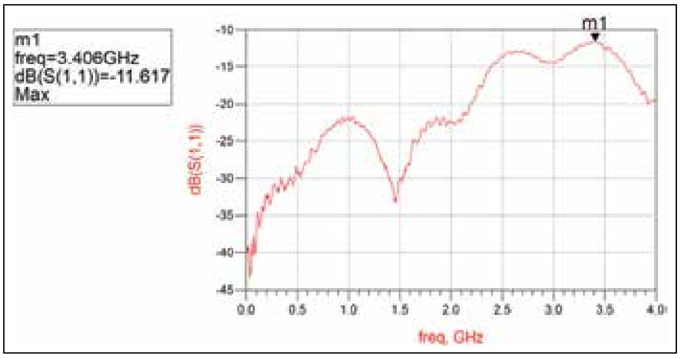

Figure 4(b) • Return loss of new circuit.

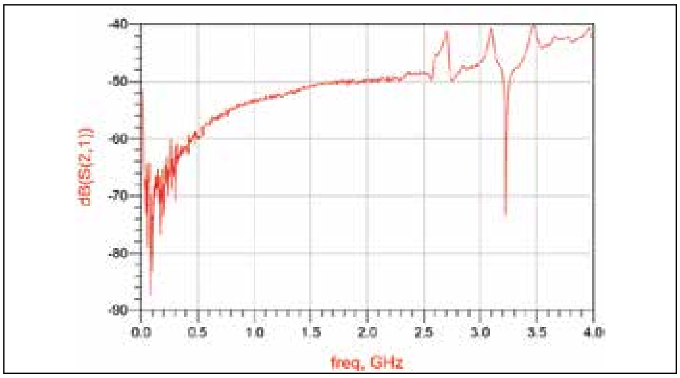

Figure 4(c) • Isolation of new circuit.

References:

[1] John Maciel, "RF MEMS Switches are Reliable: A Comprehensive Technology Overview," MEMS Journal, http://www.memsjournal.com/2010/07/rf-mems-switches-are-reliable-a-comprehensive-technology-overview.html

[2] T. Campbell, "MEMS Switch Technology Approaches the 'Ideal Switch,'" Applied Microwave & Wireless, Vol. 13, No. 5.

[3] G. M. Rebeiz and J. B. Muldavin, "RF MEMS Switches and Switch Circuits," IEEE Microwave Magazine, Dec 2001

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Wen-Jau Tai serves as an R&D Hardware Engineer at the Microwave & Communications Division of Agilent Technologies.