

A Review Paper on Enhancement of Radio Frequency MicroElectro Mechanical Systems

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Abstract—Radio Frequency Micro Electro Mechanical Systems (RF MEMS) refers to the design and fabrication of committed MEMS for RF circuits. RF MEMS is a multi-disciplinary area in which the components operate Micromechanical And / Or components are fabricated using micromachining and these components are used in RF systems. The regular microwave switches currently employed in the microwave industry are mechanical switches and semiconductor switches. Mechanical coaxial and waveguide switches offer benefits such as, low insertion loss, large off-state isolation and high power handling capabilities. Yet, they are bulky, heavy and slow. Semiconductor switches provide switching at a much faster speed and are smaller in size and weight, but are inferior in insertion loss, DC power consumption, isolation and power handling capabilities than their mechanical counterparts. MEMS switches promise to combine the advantageous properties of mechanical and semiconductor switches. There are nevertheless few issues in RF MEMS Switch like, Actuation Speed, Power handling capacity, Stiction and Actuation voltage etc. In this paper, the remedies to overcome the above specified issues are discussed.

Keywords—RF MEMS; Micromechanical; RF systems

I. INTRODUCTION

Micro Electro Mechanical Systems actuated by means of Radio Frequency has been developed to overcome the disadvantages and to combine the advantageous properties of the conventional mechanical and semiconductor switches. RF MEMS promise higher performance by providing sharp filters, stable frequency, reduced loss, higher isolation (reduced cross talk), reduced signal distortion and larger bandwidth. RF MEMS also offers lower power consumption and circuit and system miniaturization. RF MEMS are used for mobile applications, to improve the power efficiency, number of dropped calls and to increase web browsing speeds. Hence RF MEMS bring significant benefits to consumers and cell phone network operators. It can be also used for tunable antennas in Smart Phone. Today, RF MEMS Switch can be used in Radar Systems for Defense Applications, Satellite Communication System, Wireless Communication Systems and in Instrumentation Systems. RF MEMS Switch market is anticipated to touch a business of 350\$M from a current business of about 50\$M. Further research and development is indeed required in the field of RF MEMS to exceed the forecasted milestone expectations.

II. NEED FOR RF MEMS

MEMS switches combine the advantageous properties of mechanical and semiconductor switches. RF MEMS have advantages such as, Low insertion loss, High isolation, Lower power consumption, Excellent signal linearity, Better impedance match, Less dispersion, Miniaturization, Simple control circuits, High volume production possible, Very large bandwidth, Resistant to external environment. Table I and Fig 1 provide a comparison of RF MEMS Switches with the conventional switches.

TABLE I. COMPARISON OF VARIOUS PARAMETERS[2]

Parameter	RF MEMS	PIN	FET
Voltage(V)	20-80	±3-5	3-5
Current(mA)	0	3-20	0
Power consumption ^a (mW)	0.05-0.1	5-100	0.05-0.1
Switching time	1-300(μs)	1-100(ns)	1-100(ns)
C _{up} (Series)(fF)	1-6	40-80	70-140
R _s (series)(Ω)	0.5-2	2-4	4-6
Capacitance ratio ^b	40-500 ^b	10	n/a
Cutoff frequency(THz)	20-80	1-4	0.5-2
Isolation(1-10GHz)	Very high	High	Medium
Isolation(10-40GHz)	Very high	Medium	Low
Isolation(60-100GHz)	High	Medium	None
Loss(1-100GHz)(dB)	0.05-0.2	0.3-1.2	0.4-2.5
Power handling (W)	<1	<10	<10
Third-order intercept point(dBm)	+66- 80	+27- 45	+27 - 45

^a—Include voltageup converter or drive circuitry.

^b—Capacitive switch only. A ratio of 500 is achieved with high-ε_r.

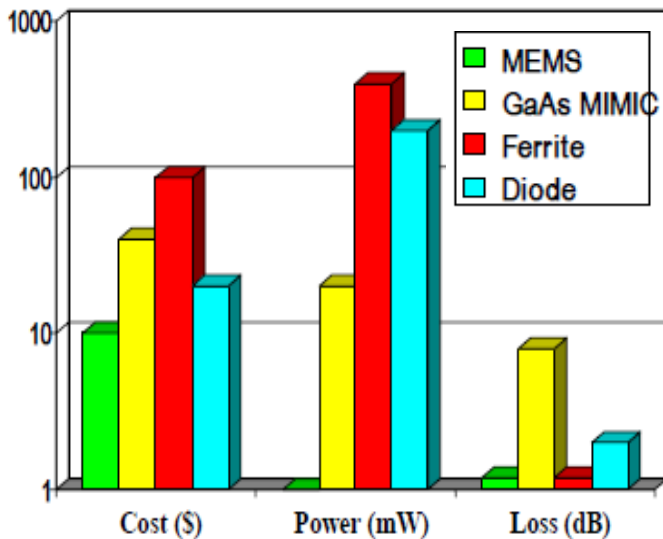


Fig.1 COMPARISON OF COST, POWER CONSUMPTION AND LOSS IN SWITCHES

III. RF MEMS CONFIGURATION [2]

Two distinctive parts of an RF MEMS switch are “The Actuation (Mechanical) Section” and “The Electrical Section”. Different types of Actuation Mechanisms are: Electrostatic, Magnetostatic, Piezoelectric, Thermal designs. And the Switch Movement could either be Vertical or Lateral. The Electrical Section comprises of the Circuit Configurations and the Contact Type. Type of Circuit Configuration could be: Series configuration, Shunt configuration. Contact Type: Metal-to-metal contact, Capacitive contact. Thus, one can build at least 32 (2 x 2 x 2 x 4) different type of MEMS switches by means of different actuation mechanisms, contact, and circuit implementations.

IV. SWITCH DESIGN [1]

The switch design begins with the selection of the actuation technique and the optimization of various parameters. The RF switch is much more than just a few series or shunt connections of diodes or monolithic microwave integrated circuits (MMICs). It is a vital part of any RF system. Proper selection of the right RF switch can formulate the difference between a marginal performance and meeting the intended design goals. By careful selection of the key parameters, an RF switch can be optimized to achieve the desired values for specific applications. In a simple electric circuit, the principal parts are a source of electrical energy, a load or an output device and a return path for the flow of current. If any of the above requirements is not fulfilled, current cannot flow in the circuit and the energy from the source cannot be delivered to the output device.

A. Design Parameters [1]

Different parameters to be considered in the design of RF switches are: Transition time, Switching rate, Switching transients, RF power handling, Matching with circuit, Bandwidth, Insertion loss, Isolation, Series resistance, Actuation voltage, Lifecycle, Resonant frequency, Interception and level of distortion, Phase and amplitude tracking.

Transition Time: The time required for the output RF signal to rise from 10% to 90% of its value for off - to-on transition.
Switching Rate: It represents the time for toggling from one state of the switch to another.

Switching Transients: These are the exponentially decaying voltage spikes at the input, output or both of an RF signal path, due to a change in the control voltage.

RF power handling: It is a measure of how efficiently a switch passes the RF signal.

Impedance Matching: The switching device should be matched at both input and output sides.

Available Bandwidth: The band of frequency of operation.

Insertion Loss: It is a measure of its efficiency for signal transmission.

Isolation: The isolation of switching systems is specified when there is no signal transmission.

Series Resistance: Any resistance offered by the switch which is connected in series, during signal transmission (on state) would lead to loss of signal level.

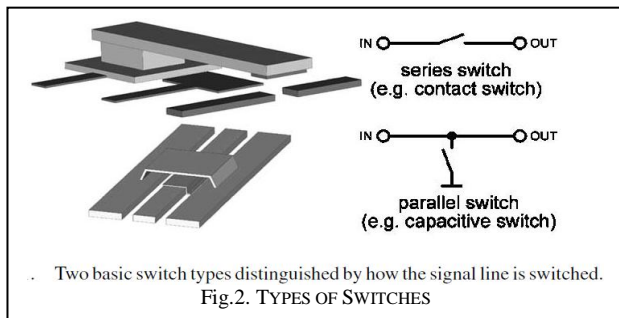
Actuation Voltage: All automated systems require a control signal for actuation. Depending on the scheme and its efficiency, these voltages vary considerably.

Life-cycle: In all schemes that involve moving parts, the lifetime may have to be considered.

Resonant Frequency: The moving parts in the mechanical switches have resonant frequencies that can be modeled in terms of their effective spring constants and resonating mass.

V. ACTUATION MECHANISMS FOR RF MEMS [1][2][4]

In an RF circuit, switching devices such as bipolar junction transistors (BJTs) or FETs can be replaced with MEMS switches or it is possible to use the MEMS device to redirect the RF signal between different transmission paths. However, in most of the RF circuits, the most important consideration should be its reactive elements and the induced inductive or capacitive elements because each has their own clear operational functions in an RF circuit. The actuating and control circuits should not load the circuit, and the Dc voltage must be isolated from the RF path. The actuation of the switch can be electrostatic, magnetic or electromagnetic: each of them has their own pros and cons. The advantage of electrostatic actuation is that there is no current consumption and its drawback is that it requires a higher actuation voltage, typically 5–100 (V). The advantage of electromagnetic actuation is the lower voltage, but, with considerably higher current consumption. Electrostatic switches offer the most promise as configuration switches, where low power consumption is the key aspect.



Switching has two types [4] - Series Contact Switches, Shunt Capacitive Switches. Ohmic and Capacitive coupling switches can be configured as series or shunt switches. Usually, Ohmic switches are used in serial mode. Whereas Capacitive switches are preferred as Shunt Switches. Series Switches are initially disconnected and get connected when the switch is actuated. Series Switch is Normally OFF Switch. Series Switches have good isolation characteristic from DC to RF signal, but insertion loss, control and reliability are the issues, because self welding may happen at the metal to metal contact area between membrane and transmission line.

Shunt Capacitive Switches - Many applications demand the lowest attainable insertion loss as well as low operating voltages. The high insertion loss from a switch increases the required power from the source and harmfully impacts the noise figure of the system. It is initially connected and gets disconnected when a required voltage is applied. Shunt Switch is Normally ON.

VI. RF MEMS ISSUES AND CONCERNS

Following are the issues, which undermine the potential RF MEMS switch applications: [4]

Higher actuation voltage (>10 V), Low RF power handling capability, Switching speed, Reliability uncertain, Lifetime uncertain, Problematic integration with RF Circuits, Special packaging is necessary.

A. Approaches For Low-Actuation Voltage Actuation Voltage Switches [1]

The high-voltage actuation of MEMS switches makes them far beyond the compatibility of standard IC technology because for applications in RF and microelectronics systems the voltages are needed to be around 5(V). The pull-down voltage of the system can be written as

$$V_p = \left(\frac{8K_s g_0^3}{27\epsilon_0} \right)^{1/2}$$

(1)

It is clear from (1), that to reduce the pull-in voltage three different courses of action are available: (a) increasing the area of actuation, (b) decreasing the gap between the switch and the bottom electrode, (c) by designing the structure with a low spring constant. Increasing the area would not be a practical solution because the compactness is the prevailing

issue and adoption of MEMS technology is to achieve the Miniaturization. In the second option, the return loss associated with the RF signal restricts the size of the gap. The most flexible road is the third one, in which the design of the spring does not considerably impact the size, weight or RF performance. It is proven that by designing switch structures with extremely compliant folded suspension springs and a big electrostatic area the actuation voltage can be reduced.

B. RF Power Handling Capacity

Traditional RF MEMS switches have intrinsic limitations dictated by RF power handling. Device failure occurs due to Self-Actuation, Stiction (adhesion), Electromigration, Microscopic bonding, and Electrical breakdown of the air. Various approaches to improve the RF power-handling capacity are: The addition of an electrode to pull the beam upward, Toggle the cantilever beam downward, An array of many switching elements, in order to increase isolation and reduce current density, An increase in the width and thickness of the beam, Increase in the contact force, The use of extraordinary contact materials, like a diamond film.

C. Switching Speed [2]

Switching speed for an electrostatic actuator is given by,

$$t_s \approx 3.67 \frac{V_{\text{pull-in}}}{2\pi V_{\text{act}} f_0}$$

(2)

Mechanical resonance frequency is given by,

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

(3)

The Switching Speed can be mitigated by using: Choice of appropriated structural material, Mechanical design considerations.

D. Reliability and Lifetime [7]

Ohmic switches tend to fail disastrously by stiction, whereas capacitive switches often degrade gradually through charging of their dielectric insulators.

E. Mitigation of Stiction

Use of push-pull mechanism, Selecting contact materials with less adhesion, Adding a thin dielectric layer to separate two conducting electrodes when actuated between the electrodes, Applying chemical surface treatment, Eliminating contamination with plasma cleaning, Increasing the equivalent spring constant by increasing the cantilever thickness and shortening the cantilever length. Mitigation of

dielectric charging, improved dielectric material, Reduced actuation voltage, Reduced dielectric contact area, Optimized control-voltage waveforms.

VII. RF MEMS APPLICATIONS

A. Radar Systems for Defense Applications

RF MEMS technology is used in radio detection and the ranging (radar) sensors. RF MEMS components for radars include attenuators, limiters, and phase shifters, transmit/receive switches and the tunable matching networks. Radar subsystems which benefit from RF MEMS technology include active electronically scanned arrays and passive electronically scanned arrays (lenses, reflect arrays, sub-arrays, and switched beam Formers).

B. Satellite Communication System

Applications of RF MEMS switch matrices in the satellite industry, where mass reduction and performance improvement is vital. RF MEMS enabled electronically scanned antennas for satellite communications.

C. Wireless Communication Systems

RF-MEMS components are primarily used as inductors, tunable capacitors, switches, in VCOs, and resonators. Popular MEMS switches for wireless applications include transmit/receive duplexers, band-mode selection, time delay for phased-array antennas, and the reconfigurable antennas. Steerable antennas for wireless LAN and ultra-wideband applications, tunable filters for communication systems.

D. Instrumentation Systems

In many cases, RF MEMS components would not only significantly reduce size, weight, and power consumption, but also promise superior performance when compared to that of current technologies. The benefits of MEMS technology become more marked for switch matrices because there is a large number of switching elements and, therefore, any size and mass reduction would have large overall impact.

VIII. CONCLUSION

The most broadly used switching elements at present in RF are FETs and PIN diode switches. The large insertion loss in the On State and poor isolation in the Off State is a problem for a large number of these semiconductor switches and efforts are being made to develop micromechanical switches for mechanically switching RF signals. The current developments in MEMS technology have made possible the design and fabrication of micromechanical switches as a new switching element in the RF circuits. MEMS-based switches achieve low insertion loss, negligible power consumption, good isolation and higher linearity by using electrostatic actuation mechanisms.

Electrostatic actuation is the favoured method because of the simple processing requirements for integration with IC technology.

The advantages of MEMS technology include fast response, low power consumption, integration with microelectronics and high off-to-on state resistance. Over the past couple of years, a significant increase in publication of MEMS switches has highlighted its development profile.

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