Mobile Communication using Radio Frequency MEMS Switches

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Abstract: Radio Frequency MEMS (micro-electromechanical systems) have been keyed out as technology areas that hold the potential to provide a major impact on existing system architectures in wireless sensors and mobile communications. Switched capacitors based on radio frequency microelectromechanical systems (RF MEMS) can enable a breakthrough in radio technology. This paper describes these technologies should bring down weight, cost, size, and power dissipation by a few orders of magnitude. Their switching principle is founded along the mechanical movement of the dentures of a parallel plate capacitor using the electrostatic force. The resulting conflict in capacitance is used to switch an RF signal by MEMS. In this paper mainly discusses the device physics and application of these Microsystems of MEMS switches for Mobile communications.

Keywords: *MEMS Switch.*

I. INTRODUCTION

Radio frequency (RF) microelectromechanical (MEMS) switches and filters are extensively used for telecommunication in the last few years due to their high performance compared to the other microelectronics switches available in the present electronic world. The first widely used mechanically moving electrical switch was the telegraph key, which is On May 24, 1844. High performance, Schematic switches is replaced by RF MEMS switch in mobile communication technology. MEMS devices are proliferating in mobile devices. As smart phones and wireless communication devices continue to force the sales of MEMS devices for consumer electronics, most of the focus so far has been on inertial sensors – MEMS and gyroscopesaccelerometers. Additionally, EMS based microphones and a pressure sensor sees continually increasing adoption. Radio frequency microelectromechanical technologies, in another way it have not been incorporated in any smart phones and wireless communicationdevice in high volume until very recently. MEMS technology is now rapidly emerging as an enabling technology to yield a new generation of high-performance RFMEMS passives to replace these off-chip passives in wireless communication systems.Because of using low resistivity substrates, it cannot simply bring down the substrate loss, but also be a good solution for the integration of MEMS with IC. The mechanical relay has been re-born at the GE Global Research Center where a group of researchers are advancing MEMS (Micro-Electro-Mechanical Systems) Technology to create ultra-small switches that could have an ultra-large impact on system design that will drive mobile devices of the future. These metal switches, which are no larger than the width of a human hair, can master the flow of electricity of an arreay of electrical systems- from high-power devices that use kilowatts of power, of an ordinary light bulb.

MEMS are nowadays used in a wide range of everyday life applications, but also in space, instrumentation, RF applications... Their broadest use is in the sensor area andwireless communicational area. There exist MEMS sensors to measure vibrations, temperature, light, movement (1,2 and 3 axis), linear and rotational acceleration. They are integrated in ink jet printers, video games, cell phones, alarms, cars, etc. In the medical field, they are used as biosensors, pressure sensors, in studies related to drug delivery and other kinds of physical sensors. In the automotive area they are integrated in intelligent airbags and used in vibration detection and in many other applications. In telecommunications they are used all along the transmission line. MEMS are used in the implementation of tunable lasers, tunable filters, optical switches, dynamic gain equalizers, attenuators, etc.

Definition-RF MEMS Switches:

Switches are vital for all automated systems. Some parameters have to be taken into account for better swiching capability:

- **Available bandwidth:** Bandwidth is determined by the operating frequency range. Upper frequency is limited by resistances and parasite reactances.
- **Transition time:** time required to raise from 10% to 90 % of the final signal in an on-to-off direction or vice-versa.
- **RF Power handling:** indcates power efficiency of the switch from one direction to the other.
- **Switching tansients:** they are decaying voltages at the output due to change in control voltage.
- **Impedance matching:** good input and output matching is required to avoid the signal reflexion.
- **Series resistance:** the connection of the switch to the transmission path can offer some series resistance.
- **Switching rate:** time required for the switch to respond after change in control voltage.
- **Actuation voltage:** control voltage for operating the switch.

- **Life cycle:** the time within the switch operates properly.
- **Intercept points:** determines the linearity of the rf signals.
- **Insertion loss:** It is determined by the transmitivity of the switching device.

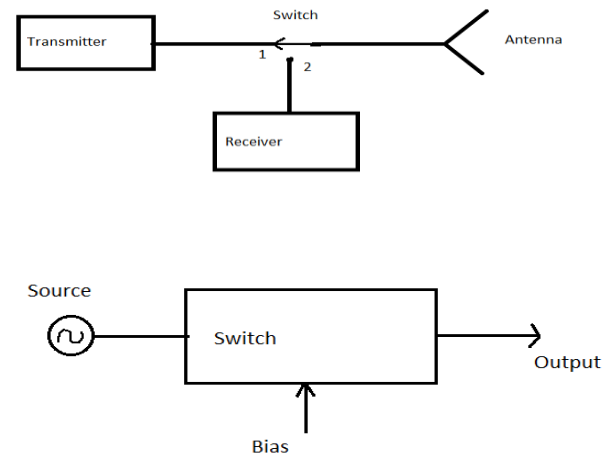


Fig.1 RF MEMS Switches

There are two types of RF MEMS Switches:

i. The Cantilever Structure MEMS switch
ii. The Bridge Structure MEMS switch

They both operate under the principles of electrostatic force between the upper and lower electrodes.

$$\boxed{F=\frac{CV^2}{2d}}$$

Benefits of MEMS:

- High Performance
- Low Cost
- Integration
- Miniaturization
- Low Power

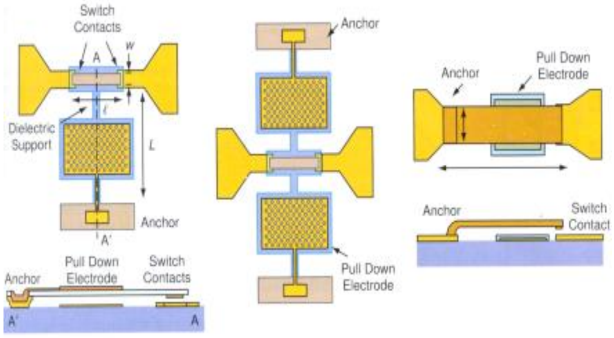


Fig.2.RF MEMS switches examples Cantilever MEMS Switch

A. Basic Structure Of MEMS Switch (SPDT)

OMRON's MEMS switch has a SPDT（Single Pole Double Throw） contact configuration. Two MEMS chips that have a SPST (Single Pole Single Throw） contact configuration are installed on the ceramic package using the flip chip bonding method as shown Fig.3.

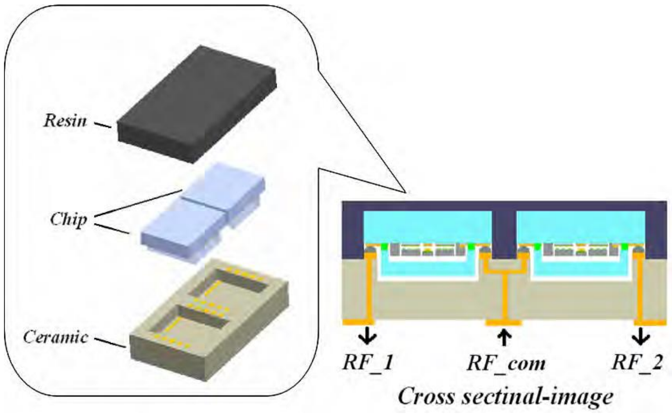
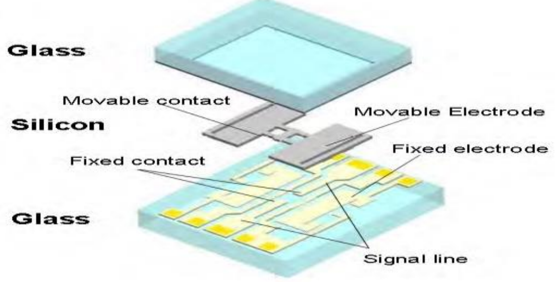


Fig.3: SPDT Package Structure

B. Basic Structure of MEMS Switch (bare CHIP)

The basic structure of MEMS switch consists of three layers which are Glass-Silicon- Glass, as shown Fig.4. It has a SPST contact configuration, "1a", normally open type. The top glass part is used for protecting the actuator and hermetic sealing. The middle silicon section contains the actuator and movable electrode.

A capacitor is built up between the fixed electrode and movable electrode. The signal line and fixed electrode are made on a glass base. When applying the voltage between Fixed Electrode and Movable Electrode, an electrostatic force is generated and it pulls in the Movable Electrode (actuator). When the driving voltage becomes OFF, the electrostatic force will disappear, and then the actuator will go back to the original position because of a self-restoring force. The signal line and the movable contact consist of pure metal wiring, and serve as a mechanical switch which can handle DC to High Frequency signals.



When applying the voltage, electrostatic force "F" is generated,

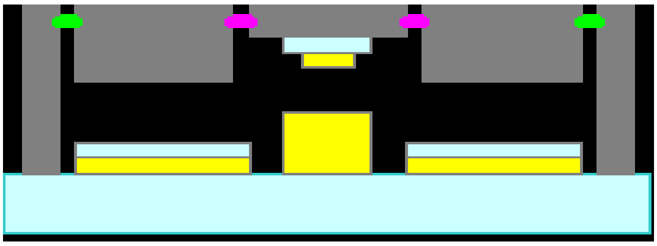


Fig.4: Internal Structure of MEMS Switch (CHIP)

MEMS switches are dominating over existing semiconductor devices such as PIN Diodes, Field-effect-transistors because of their minuscule size, less power consumption, low insertion loss and high OFF-state isolation.More than a century later, the transistor was discovered, which is currently, with a production volume exceeding the 1018 devices per year, [1] without doubt the most widely spread electrical switch. One more advantage of an RF MEMS switch is fabrication process is compatible with CMOS technology so these switches can easily interface with the ease of the circuitry. The success of the transistor is mainly a result of its small dimensions, high switching speed and extremely low production costs.

II. OVERVIEW OF MEMS SWICTH

These MEMS switches can provide low power consumption, lower insertion loss, higher isolation, and excellent linearity as shown in Table 2 in a side-by-side comparison to GaAs and SOI technologies. The T/R switch had traditionally been the focal spot of many RF MEMS developers because of the highly compelling benefits of space and power savings. The slowed rate of introduction of RF MEMS switches and the cost-competi- tive nature of T/R switching has caused the securities industry to proceed beyond the price range of RF MEMS. In the electronics and high-technology manufactures, the MEMS switch was considered as a hopeful entry into the optical switching market, which significantly slowed in the yr 2000. The collapse of this main market driver caused MEMS switch development to stall. Only the continual growth of the mobile phone market along with the developing problems of multiband/Multimode phones has spurred a renewed interest in MEMS for switching and other capacities.

In detail, RF MEMS switch devices re- semble a mechanical relay, but the geometries are typically in the submillimeter or hundreds of micrometers in size. The plates of size make these devices attractive because they make it possible to have switched solutions that can ideally take up 1 mm2 or less of blank. In summation, the switches can be modified to make a sort of micro applications such as delay lines and switched capacitor networks. In theory, RF MEMS technology is capable of surpassing the performance of high-speed semiconductors with devices that can route and control well up to 50 GHz signals. The realness is that there are many components that have determined the viability of RF MEMS in mobile telephone applications. Such factors include fabric-cation processes, packaging (hermetic isolation and parasitics), control voltages, long-term switching life cycles (contact point section), switching speed, RoHS compliance (reflow temperatures), and manufacturing costs. An RF MEMS switch is not much different than an optical MEMS switch, merely because of the power-handling requirements of RF, slightly different design techniques have to be used to confine and concentrate the impact of current and the resultant heat on the contact points of the substitution. A typical shift is made up with a cantilever (a suspended beam anchored at one spot) and is actuated either electrostatically or electromagnetically. A contact head rests at the “floating” end of each cantilever and is comprised of conducting metals not typically utilized in semiconductor manufacturing. Easy mechanics problems and solutions.

In conclusion, the availability, cost and performance of RF MEMS switches for mobile phones will continue to improve. First, applications have evolved to such a degree as to mandate an alternative to semiconduc- tor solutions. Second, novel fabrication and packaging techniques will enable the mass yield of the devices and accelerate their market acceptance. The fabrication techniques that have evolved to support low-cost solu- tions complete a virtuous cycle of product definition where volume drives price and cost drives applications.

III. WORKING OF MOVING SWITCHES

To ease the production of RF MEMS switches in an existing fan, we have chosen to base the technology on the NXP industrialized PASSITM process. This production process is committed to integrating capacitors and inductors on silicon. We have adapted this process to enable the output of RF MEMS switches. The gap g below the aluminum top electrode is created after deposition of the top electrode, by etching the “sacrificial” layer between the top electrode and the dielectric layer. This results in a released top electrode structure that can be affected by the electrostatic force.

A scanning electron microscope (SEM) picture of such a switch. The top electrode is connected by eight springs to four anchor points. It is separated from the bottom electrode by a gap with thickness g and by a silicon nitride dielectric with thickness dial. The holes in the top electrode facilitate etching of the sacrificial layer and cut the gas damping, thus resulting in faster switching.

However, there are some important aspects in which the “old-fashioned” mechanical switch performs better than the modern transistor. For instance, its energy losses are lower because currents only run through low-resistant metals. These advantages can be of critical importance for RF switches that are placed near to the antenna of a mobile telephone.Because RF powers are comparatively high (~4W), it is significant to minimize losses to preserve battery power.To forbid the mixing of frequencies, it is likewise indispensable to apply extremely linear devices.At NXP Semiconductors, work is in progress to combine the advantages of mechanically moving electrical switches with the miniaturization and low production prices of semiconductors. Such switches produced on a semiconductor substrate are called RF MEMS switches.

IV. CHANGES HAVE EVEN OCCURRED IN EXISTING HIGH VOLUME MEMS AREAS

Significant architectural changes have been observed in inertial sensors, with the current strong adoption of IMU combo sensors. Likewise, a new opportunity has appeared with a camera module's dedicated OIS gyroscope. A trend has appeared involving integration of a third MEMS microphone to provide HD voice recording (i.e. In the iPhone 5), in addition to the dual microphone architecture described in the last report. This trend is a market booster.Strong adoption of LTE in high-end platforms will boost the duplexer market for the next three years.

V. DIFFERENT TYPES OF FORCES

For an accurate description of the motion of the top electrode of the RF MEMS switch, a thorough discernment of the dominant forces on this plate is essential. The four dominant forces in RF MEMS switches are:

1. Contact forces F_c
2. Electrostatic force F_e
3. Air damping forces F_d
4. Mechanical spring forces F_{spring}

This enables us to measure the static and dynamic motion of the switch and can be applied to develop compact models of the switch [2] that can be implemented in circuit design software. Time-dependent capacitance measurements are used to study the dynamics of the switch. [2,3,4] For a more precise computation of the alternating motion and the mechanical deformations in two or three dimensions, finite element models are used that solve the governing partial differential equations for an arbitrary construction. [5]

VI. SWITCHING ACTION OF MEMS

The top electrode of the switch can be pulled downward by the electrostatic force that is generated when an actuation voltage is applied between the top and bottom electrodes. By gradually increasing this potential and after decreasing it, the switch will close and candid. Closing and opening voltages are different because the electrostatic force depends both on the voltage and on the distance between the electrodes. At high voltages, the top electrode touches the dielectric layer and a balance exist between electrostatic, spring and contact forces. At low voltages, the electrostatic forces are balanced by spring forces. . A corresponding reduction in the RF impedance will occur that enables the application of RF MEMS in switchable RF networks. In actual performance, the device will switch from an open (low actuation voltage) to a closed country (high actuation voltage), inducing a change from a downcast to a high capacitive state

VII. RELIABILITY

One of the largest challenges that one faces when using mechanical switches in mobile phones is to obtain a sufficiently high reliability. For certain applications the switch has to remain within specified limits for as much as 10 years. There are three primary mechanisms for failure of the switch: charge injection in the dielectric layer which can result in a modification of the electrostatic forces, irreversible (plastic) deformation of the springs as a outcome of mechanical stresses; and degradation of the switch as a result of moisture between the electrodes. Because it is practically infeasible to test each switch for 10 years, deterministic reliability models that predict acceleration factors based on physics of failure are needed. These models can supply an appraisal of the life of a shift from a short experiment.

VIII. APPLICATION OF MEMS SWITCHES

Switches near the antenna of mobile phones require very low energy losses and a high linearity. RF MEMS switches typically have a resistance of only 0.2 W. At a power level of 1 watt, they generate very small spurious signals of less than a nanowatt, as a result of their high linearity. These linear, low-resistance switches can enable significant improvements in the design of mobile phones. As outlined in the introduction above, the implementations of complex networks based on RF MEMS technology are still rather difficult to find on the market for multiple reasons. First, despite the fact that the manufacturing costs of RF MEMS devices and networks are, in general, lower if compared to advanced CMOS processes, bringing them from the prototype level to a market product demand high initial investments. Secondly, reliability and performance stability are significant issues when developing a new solution in RF MEMS technology. Indeed, the presence of movable and deformable micro-membranes makes each RF MEMS device or network prone to failure and degradation mechanisms; this is usually not a problem when dealing with their counterparts in standard semiconductor technology. The most relevant failure and degradation mechanisms affecting RF MEMS devices are contaminated, wearing, fracture, delamination, micro welding, charge entrapment, electromigration, and so on. Most of these problems can be mitigated by acting at three different levels, namely, at design level, technology level, and operation level.

IX. CONCLUSIONS

RF MEMS switches combine the low resistance and high linearity of mechanical switches with the miniaturization and low-cost production of semiconductor devices. Finally, RF MEMS switches like for instance SPDTs (single pole double throws) have seen the most success in the marketplace. The diligence of these switches requires a thoroughgoing discernment of a full orbit of novel physical phenomena at microscopic dimensions and their consequence on the dynamics, manufacturability and lifetime of the replacement. The more complex, integrated networks based on RF MEMS technologies are promising, but still mostly in development mode. However, these new classes of RF MEMS devices and integrated systems are likely to see a new wave of commercialization in the near future. The application of RF MEMS switches in reconfigurable and adaptive RF products promises an increase in efficiency and sensitivity, and a decrease in size and cost of future mobile phones.

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