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## Reconfigurable RF MEMS Switch with Improved Switching Speeds using Push Pull Configuration

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### Abstract

The recent advancements in Radio frequency (RF) are brought forward using Micro-machining technology, for being small sized and better performances. There is more scope of improvement as it was most recent field of interdisciplinary field. Among the phase shifters using the MEMS technology are growing its importance when compared conventional shifters by overcoming most of the limitations. But switching speed is always a concern when a mechanical actuating element is present that compromises the overall performance of the devices. As DMTL base Shifter most rely on the RF MEMS switches, the speed of switch is governing to overall performance of the phase shifter. In this paper push pull base RF MEMS switch was mechanical altered with triangular cantilevers to improve switching speed. This would find better applications in Reconfigurable DMTL's that operated at wide band applications. The resonant frequency improvement was carried where 13% of switching was improvement for the device.

### Keywords

*MEMS; DMTL; Phase Shifters; RF MEMS Switch; Switching Time.*

### Introduction

The Micro-electro Mechanical systems (MEMS) technology, which leverages existing Integrated circuit fabrication technology was prominent in different disciplines of engineering and application this is due to being most advantageous in miniature of devices, cost reductions and less power budgets with unaltered performances. The main advantage the MEMS as come up with since the fabrication is most relied on the Silicon material which generic material for IC process and this silicon has the desired mechanical properties for making microstructures [1]. Due to this MEMS as been positioned on apex of all application fields which includes sensor's, actuators that includes accelerometers, inkjet micro-fluidic nozzles and pressure sensors which are huge replacement for conventional counterparts [2,3,4,5]. Among such fields of applications Radio Frequency (RF) is such MEMS has its extensive devices that from RF switch to diode and millimetre wave devices. Most among the devices the passive devices of RF are extensively brought to market using MEMS base technology. Among the RF Passive components, the most significant device is phase shifter with its prominence in wireless communications. This phase shifter is considered to be a two port network which provides the phase difference between the input wave and output, that is controlled by the signal. As it finds the applications in phase array antenna used for various communication needs phase shifters that has less loss, cost and power parameters with size minimised. With advent of L and S band phase shifter's using solid-state devices have unsuitable to wide band applications due limited band width, high insertion loss and constant resolution of phase shift over the band. With the use of MEMS RF design's these challenges are efficiently meet using true time delay (TTD) [6,7]. Using the phase shifters are categorised into two categories switch line and Distributed MEMS transmission Line shifter (DMTL). This DMTL shifter's are designed with loading of the RF MEMS switches. Along such RF MEMS switches are having high potential to be set into applications of Wireless communications and Sensor networks. When such switch design are considered, their respective performance are evaluated by the insertion loss, high isolation and linearity. The MEMS base RF switch over the decades as improved and shown superior performances when compared with GaAs FET and PIN diodes[8-10]. These switches are actuated using piezoelectric, electrostatic thermoelastic and electromagnetic forces and among all the electrostatic actuation was foremost important for its simple structure and can be applied for reconfigurable design most effectively. But when such switches fit into applications as all always ensured with low insertion loss, wide band and better resolution. But in most of the application the mechanically turning of switch speed was not applied. There are various works reported with lower actuation voltage of 10V and actuator moving with 10 micro sec [11]. In order to achieve switch fast response of the switch the spring constant is to be reduced and this was done by scaling down the dimensions of device and material changes. But this lowering the spring constant effectively reduces the mechanical restoring force causing the lower response time due different electrode states. In case of reconfigurable designs this even more complicated. In this paper we have concentrated in increasing the switching speed of the actuator of RF MEMS switch that was used DMTL phase shifter by replacing the Phase shifter design using triangular cantilever's DMTL Phase Shifter.

### DMTL Phase Shifter

DMTL phase shifters are designed with the MEMS switch that loaded across the transmission lines and these are considered as the replacement for the solid state switches. As the RF Switch was the important aspect in DMTL phase shifter with having the attributes of low loss transmission and sideband applications. In parallel facing the challenges like fabrication, parasitic capacitances etc. In most of the cases the design that was adopted is cantilever or beam which is further more concerned about the mechanical stability that alters the performance of the device. This even more vulnerable with change in material and higher operating frequencies. So there is need to design the structure that mechanical stability is intact and further the performance that in terms of speed was increased. As the shift in phase of the incoming wave depends upon the wavelength and length of line along with impedance loading is factor to achieve it. This loading was achieved by the serial loading of switch's on the transmission line [13]. They are few DMTL where the distributed capacitances and inductors are used to improve the performance Investigation

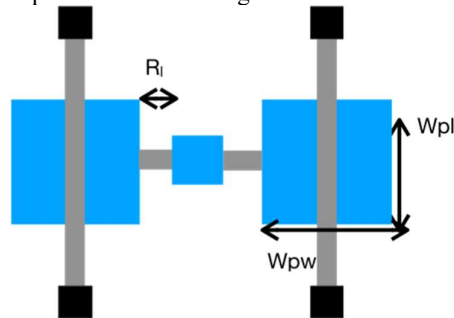


Fig. 1: Reconfigurable DMTL Phase Shifter

### RF MEMS Switch

These switches are actuated with electrostatic force of actuation which is explained with a parallel plate capacitance where one of the plate is moving. The moving plate is mechanically actuating element which is designed using cantilever or beam structures at micro scale and ground plane being the transmission line (waveguide). In such device where slow behaviour of the wave ( $V_p \ll c$ ) is observed. Such device is configured to be Distributed MEMS transmission Line Phase shifter (DMTL) [p,13]. In these devices the capacitance effect was changed as the mechanical actuator deflects with push and pull up functionality of the device. This deflection of the actuating element is control by the controlling voltage thus changing the capacitance and achieving the phase difference. As this was referred as the up state and downstate of the MEMS switch, where each switch is referred as the bridge. As to achieve the required phase difference, these bridges are arranged in series. So as this RF switch plays a vital role is design of DMTL phase shifter, so improvement of the RF MEMS switch is considered as the crucial aspect of bringing forward the better DMTL shifters. Initially these DMTL phase shifter are reported in 1999 and later improved with 18-40GHz []. And later with improvising the single pole multi throw switches, digital approach of the DMTL was brought into existence. Among the most of the reported DMTL, silicon is considered to be the base material and silicon di-oxide as dielectric for minimising the loss less transmission at higher frequencies. But later with improvement of micro machining process technology the material constraints are removed and applied with copper, aluminium etc. As the mechanical actuation are involved the actuating element is subjected to stress and strain and this further develops with added load. For material choices, properties like elasticity and Young's Modulus are governing factors that decide maximum performance of the device under long term operational hours. In most of the devices the mechanical stability are eliminated and tuning of the RF switch speed are done using actuation voltages rather than the mechanical running aspects. This switching speed's are modelled using charge and discharge cycles and this in case of MEMS base RF switches resonant frequency of cantilever beam is vital factor. Along with this pull down voltage of the switch is also related. This paper has come up with increase in switching speed of the RF MEMS switch devices, replacing the rectangular cantilever with triangular cantilever. As the triangular cantilevers are more sensitive and resonant frequency of them is in higher node. The overall frequency of the device is improved and thus switching speed can be enhanced [13]. The switching speed of the device is given by the eq.1 which is mentioned below.

$$t_s = (3.67 * V_p) / V_s \omega \quad (1)$$

Where  $V_s$  is referred as source voltage and is considered to be 1.4 times of the actuation voltage in DMTL. By substituting this eq.1, can modified as eq.2

$$T_s = 2.62 / \omega \quad (2)$$

When the eq.2 was modified in consideration to the spring constant and mass this resonant frequency this can be further simplified as eq.3

$$t_s = 2.67 \sqrt{m/K} \quad (3)$$

From the eq.3 it can be stated that switching time was dependent upon the mass and spring constant. In this paper the reconfigurable DMTL design was incorporated with the design of triangular cantilever structure, so that the sensitivity resonant frequency was improved by changing the spring constant. This was further compared with traditional rectangular cantilevers.

#### Reconfigurable DMTL

The RF switch that was proposed in the paper is based upon the push pull configuration which works on the electrostatic actuator which contributes to change in capacitance, provides the phase difference as impedance change. With optimization of push-pull configuration and considering the operating frequency from 18-40 GHz range, the maximum achievable shift was around 11 degrees. The moving plate of the pull stages are fixed and push stages are left free [14]. When the push and pull configuration are applied the centre plate move away and close to the centre plate, thus by changing the parasitic capacitance which is shown in eq.4

$$\Delta\phi = \frac{wZ_0\sqrt{\epsilon_{eff}}}{c} \left( \frac{1}{Z_1} - \frac{1}{Z_2} \right) \quad (4)$$

Where the  $Z_1$  and  $Z_2$  are impedances

#### Modeling RF MEMS Switch

The modeling of the RF MEMS reconfigurable DMTL as to approached with the design of switch that was implemented using push pull configuration. As this configuration consists of mechanical actuating element, the device characterisation and optimization are crucial in extracting the required parameters and performance. Along with that as discuss in Section I, the speed of the switch that involves the mechanical element is crucial, when compared with the GaAs devices are limited. In such scenarios the device which involves reconfigurable in nature and where the mechanical actuating element is complex. The mechanical tuning of the device to achieve the required performance is vital step. In this paper is endorsed with approach of improving the speed of the switch by improving the resonant frequency. In this analysis was approached using Finite element modeling where there is a comparison drawn between the rectangular and triangular base devices.

Aluminium and gold base devices. In each of the case the dimensions are made same and unaltered except. The device is area is around 580 micro \* 580 micron effect area. The dimensions are considered in such way to operate the DMTL in wide band application. The simulations are approached with the parametric and material sweep analysis to optimise the device for the total energy stored due to the actuation voltage applied was 16V. The resonant frequency with rectangular base device was around is around 40.974 KHz and whereas the triangular base device was 57.2KHz. The resonant frequency of the device was improved with device was improved by 17.2 KHz. With the help of the equation 3 the switching times can be approximated to be around 45.8u sec of triangular when compared with the 63.9u sec of rectangular device. This was merely around the 13% improvement in switching speed of the device. Such a device when tune dimensional stability and electrostatic tuning can yield better switching time and in this paper we have concentrated on the mechanical aspect of improving the switching speed's.

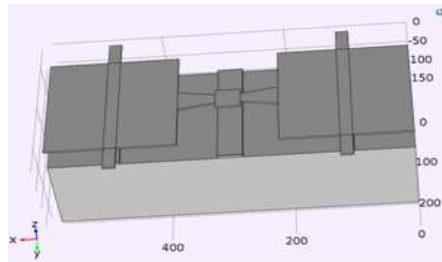


Fig. 2: Triangular Base RF MEMS Switch with Push-pull Configuration

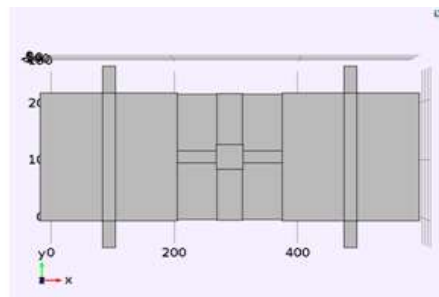
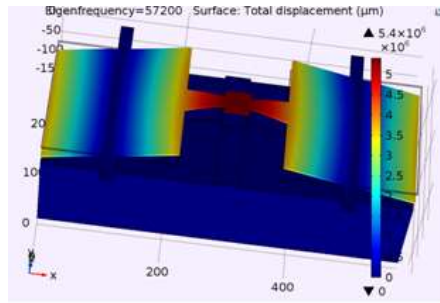
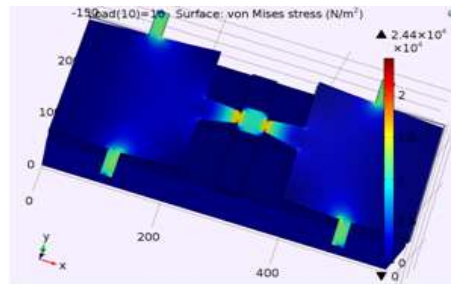


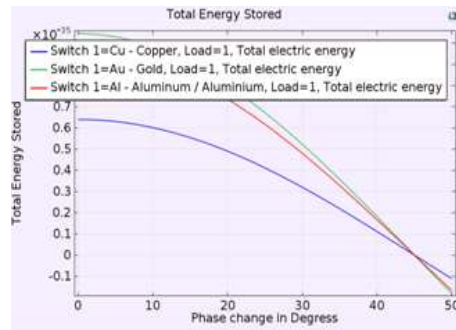
Fig. 3: Rectangular Base RF MEMS Switch with Push-pull Configuration



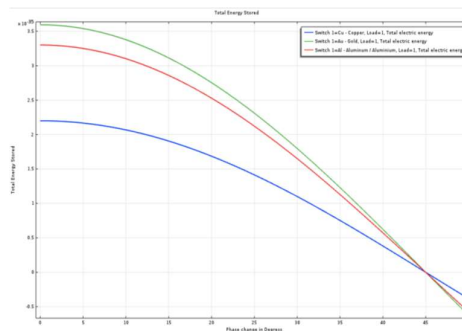
**Fig. 4: Principle Eigen Frequency Mode of Triangular RF MEMS Switch- Mechanical Actuating Element with Push Configuration and Frequency was 57200Hz.**



**Fig. 5: Surface Stress of the Device under Push Configuration**



**Fig. 6: Total Energy of Triangular Base Device with Three Different Materials**



**Fig. 7: Total Energy Stored of Rectangular Devices with Three Different Materials.**

**Table 1: Dimension of Device**

S. No.	Dimensions of the Device		
		Symbol	Dimension
1	Length of the plate	Wpl	170 um
2	Width of the plate	Wow	170 um
3	Length of rectangular cantilever	Rl	60um
4	Width of rectangular cantilever		20um
5	Center plate dimensions		40*40um
6	Anchor length		220um
7	Anchor width		20um
8	Total device thickness		2um

### Conclusion

The switching speeds of the RF devices are crucial in deciding the entire speed of the devices in most the applications of Wireless communication and this depends upon the basic components of RF regime. This work emphasised on such RF MEMS switches where it is intended to improve the speed and performance of the DMTL base phase shifter's. As DMTL consists of RF MEMS switch, the improvement of switching time will yield fast responses of overall device. For this mechanical tuning of the device was preferred by replacing the rectangular cantilever to that triangular where 13% switching time was achieved. For such a device the adaptation of Stress region or slit base would be further more improvement might the future scope of the work.

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