A Review Paper on Design of Distributed RF MEMS Phase shifter for Aerospace Communication.

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Abstract- **This paper deals with the RF (Radio Frequency) MEMS (Micro-Electro-Mechanical-System) phase shifter characteristics and importance in the wireless communication system. Also explains the different types of RF Phase shifters using different devices like PIN Diodes and Field-Effect-Transistors. It also helps to explain different types of analysis to check the performance of RF phase shifter graphically to show how Pull-in voltage affects on the tip deflection of the switch.**

Keywords- **RF-MEMS, Young's modulus, Pull-down voltage, isolation, insertion loss, electrostatic charge. FET, CPW plane.**

I.INTRODUCTION

MEMS technology demonstrated versatile applications in biology, life science, aerospace, and telecommunication for their unique and superior characteristics. Particularly recent and dynamic developments of personal communication devices have brought the signal frequency up to millimetre and microwave range. RF phase shifter is a two port network with the provision that the phase difference between output signal and input signal can be controlled by a control signal, usually a dc bias [3].The recent developments in the field of RF MEMS technology has proved to be strongly beneficial since the RF MEMS based devices such as switches, varactors, inductors, tunable filters, pressure and temperature sensors call for substantial dc power reduction for telecommunication, space based and radar systems.In general , the ferrite phase shifters have low insertion loss and can handle significantly higher powers, but are complex in nature and have a high fabrication cost. While semiconductor phase shifters using PIN diodes or FET are less expensive and smaller in size than ferrites, their application was limited because of high insertion loss. That's why other types of phase shifters using micromechanical system (MEMS) bridges can be used to overcome the above limitations

Phase shifters with low insertion loss, low drive power, continuous tenability and low production cost are the key to development of lightweight antennas. There are two basic designs of phase shifters i.e. the analog and digital approach. The analog phase shifters results in a continuously variable phase shift, from 0° to 360° and is built using varactor diodes. Digital phase shifters provide a discrete set of phase delays and are usually built using switches. There are two requirements for phase shifters: (1)constant phase versus frequency and (2)linear phase versus frequency. The constant phase designs are used for signal processing in radar application and high precision instrumentation systems, and they are best constructed using switched networks or loaded line techniques. The linear phase designs are pre-dominantly used in true time delay phased arrays and be best constructed using switched delay lines [1]. In this paper we mainly concentrates on design of RF phase shifting unit cell by using periodic placement of MEMS shunt switches on co planner transmission waveguide. Which is known as distributed MEMS transmission line (DMTL)[2]. RF switch suffer from some limitations such as limited speed of operation, higher actuation voltage and certain associated reliability issuesbuckling of the beam, stiction. These limitations can be overcome by process of miniaturization.

RF MEMS phase shifter structure:

MEMS switches and components demonstrated exceptional performance at RF and millimetre wave frequencies, including low insertion loss, high isolation and low drive power.The MEMS switch can be configured to generate phase shift by switching between twodifferent signal paths, as shown in Figure 1. or can be used as a distributed capacitiveswitch, in which the switch changes the effective capacitance of the transmission line.Combining MEMS technology in a unique design with new dielectric tunable materialscan result in lightweight, low-cost large-phased array antennas with significantly reducedproduction cost. The advantage of using dielectric tunable material is that it can give acontinuous change in phase.

Therefore, the PIN diode phase shifters can generate phase shift by switching the signal between two different path lengths l_o and l_o+l as shown in figure 1. The phase shift corresponds to the additional path delay βl, where β is the propagation constant of a medium[3].

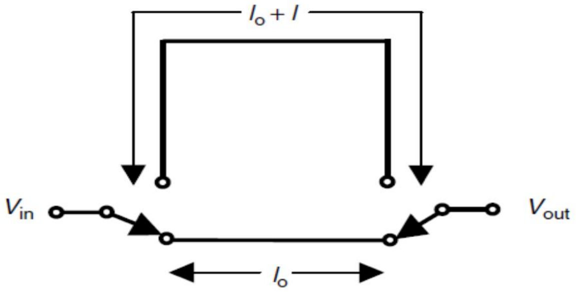

Figure 1.Schematic representation of MEMS switch (PIN diode) as a switched line phase shifter.

*1) Switched delay line phase shifters:*The types of MEMS switches canbe categorized as a resistive series switch (metal–metal) or a capacitive shunt switch(metal–insulator–metal), the capacitive shunt switch is usually used for high-frequencyapplications because of its lower actuation voltage and faster switching speed comparedwith series switches. These phase shifters in general consists of 180◦, 90◦, 45◦, 22.5◦, 11.25◦ phase shiftersin a cascaded arrangement. The switches are configured in different lines which can beselectively controlled for the propagation of RF signals. The difference between the pathlengths is determined by the phase shift.

*2) Polymer based MEMS phase shifters:*The MEMS phase shifters have low loss performance because of the bridge structure,which effectively prevents leakage current. However, in spite of these advantages, thereduction of actuation voltage is still a key issue for MEMS structures. Since a MEMSbridge with a height of at least 3μm is typically required to reduce the parasitic capacitanceof the bridges, it results in an actuation voltage of around 100V with conventionalmetal bridges. The actuation voltage can be reduced by decreasing the bridge height oradopting bridge materials with a relatively low elastic modulus such as polymer.

*3) Distributed RF MEMS phase shifters:*The capacitive shunt switch consists of a thin metal bridge suspended over the centreelectrode of a co-planar waveguide (CPW), which moves with a biased dc voltage.

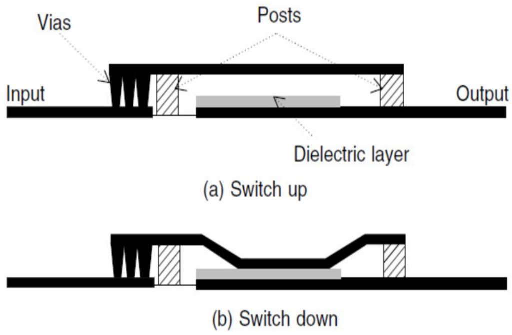

Figure 2. Schematic diagram of switch in the (a) up state and (b) down state

A thin dielectric layer such as silicon nitride is deposited on the bottom electrode to reducestiction and provide isolation between the metal bridge and bottom electrode. Figure2. presents a schematic diagram of a bridge switch. When the bottom electrode is dc biasedwith respect to the metal bridge, the attractive electrostatic force pulls the metal membranedown toward the bottom electrode, as shown in Figure 2.

II. SYSTEM DEVELOPMENT OF UNIT CELL:

CPW(Co planner waveguide) lines, made of gold, are fabricated on a high resistivity(10kΩ-cm) Si-substrate.Four goldbridges are connected tothe CPW ground planes, by means of fixedAnchors. Figure 3 and figure 4 depict the cross-sectional view andtop-view of the unit cell. Length *'l'*, width *'w'*and thickness 't' of the miniaturized bridgeare the main key to design phase shifter. A Si3N4 insulatoracts as an isolator in between the CPW centralline and the MEMS bridges. The dimensions havebeen chosen in such a way so as

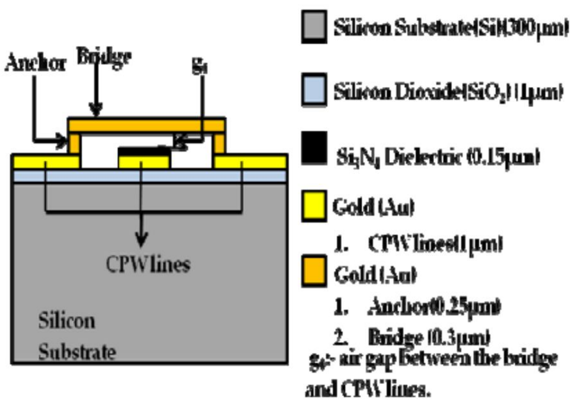

Figure 3. Development of phase shifter unit cell.

to result in a characteristic impedance of 70 ohms, when the transmission line is in unloaded state.

However, when the bias voltage is increased, the system becomes unstable and the bridge collapses suddenly when the deflection reaches one third of the gap height. This voltage, which results in the point of instability, is called the pull-down voltage. The applied bias voltage between the MEMS bridges and bottom electrodes changes the height of the MEMS bridges, which in turn varies the distributed MEMS capacitance. This results in a change in the loaded transmission line impedance and phase velocity, which in turn causes phase shift.

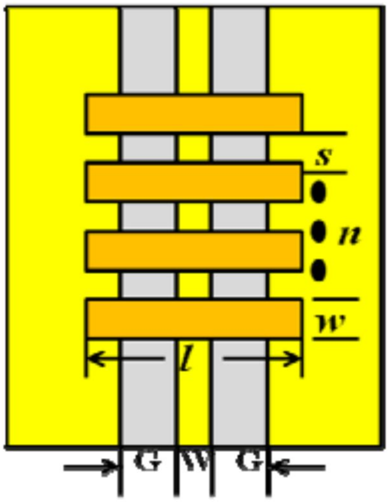

Figure 4. Top view of unit cell structure.

III. ANALYSIS AND EQUATIONS:

2) Static analysis: It helps to calculate the value of actuation voltage in volts, required to realise the down state. It is a plot of displacement vs. voltage applied to a switchwhen it is being subjected to an externallyapplied electrostatic actuation. Thus pull-down voltage can be obtained by governing mathematical equation,

$$V_p = \left(\frac{8k}{27\,\epsilon_0\,Ww}{g_0}^3\right)^{-1/2} \qquad \ldots..1$$

$$k = \frac{32Et^3w}{L^3} + \frac{8\sigma(1-v)tw}{L} \qquad \ldots..2$$

Where, *V*=actuation voltage required,
k = spring constant of the beam
*ε*0= permittivity of free space= 8.854×10-12F/m,
W=width of the central conductor in the CPWbased transmission line,
w=width of the miniaturized beam,
*g*0= height of the air gap in between the CPWcentral line and the MEMS bridge,
E= Young's Modulus of gold= 75G Pa,
t= thickness of the MEMS bridge,
l= length of the MEMS bridge.

The actuation voltage can be reduced by decreasing the bridge height or adoptingbridge materials with a relatively low elastic modulus such as polymer. However, it is notadvisable to decrease the height of the MEMS bridges to reduce the actuation voltagesbecause the narrow height makes fabrication difficult and there is a need to keep thebridge height as large as possible to increase the fabrication yield. General graph of the applied voltage Vs. Z-displacement is shown in figure 5. Normally pull-down voltage should be less than 50 volts. This graph shows that the actuation voltage is 12.16V.

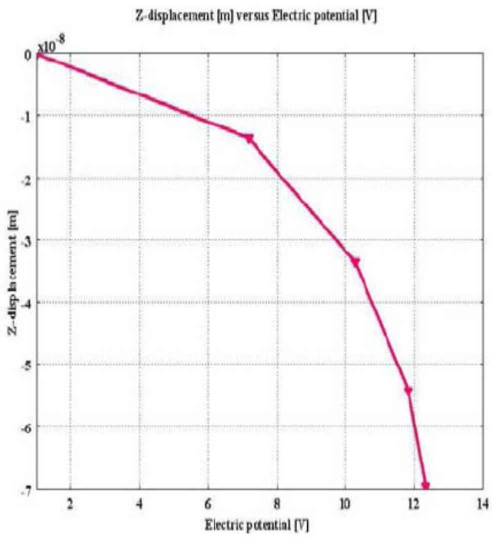

Figure 5. Electric potential Vs. Z-displacement.

2) Modal analysis: It helps to calculate the value of natural frequencies of vibration of the beam. Modal analysis is the study of the dynamicproperties of structures under vibrationalexcitation. The Eigen values are used todetermine the natural frequencies or Eigen frequencies of vibration, and the eigenvectors determine the shapes of these vibrational modes.Modal Analysis aids in computing the values of these mechanical resonant frequencies ofvibration of the beam[2]. The simplified governing equations are,

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad \ldots\ldots.3$$

$$m = 0.35(lwt)\rho \qquad \ldots\ldots 4$$

Where, *f*0=natural frequency of vibration (in Hz),
k=spring constant of the beam (eqn. 2),
m=mass of the beam (in kg),
l= length of the beam,
w= width of the beam,
t= thickness of the beam,
ρ= density of gold19,320kg/m3

Thus at different frequencies we can get different mode of vibration of beam by using modal analysis. We can use the software like COMSOL, Coventor-ware etc.

3) Transient analysis: It helps to calculate the value of switching time (in nsec)required by the miniaturized beam toundergo full up and down statetransition once.Transient Analysis is also known as the dynamicresponse of a system. It is the curve ofdisplacement (nm) vs. time (nsec) so as to obtainthe required switching time of operation. It follows a non-linearequation called D' Alembert's principle [1] asthe primary governing equation given by,

$$m\frac{d^2y}{dx^2} + b\frac{dx}{dt} + kx = F_e = \frac{\epsilon_0\, AV_s^2}{2(g_0 - x)^2} \qquad \ldots 5$$

$$b = \left(\frac{3}{2\pi}\right)\left(\frac{\mu A^2}{g_0^3}\right) \qquad \ldots\ldots 6$$

Where, *m*=mass of the beam (refer to eqn. (4)),
k=spring constant of the beam (refer toeqn. (2)),
Vs = 1.25Vp,
A = Area of the contact surface (W*w*),
E = Young's Modulus of gold = 75GPa,
ρ = density of gold =19,320 kg/m3,
μ = Coefficient of viscosity = 1.218×10-5Pa-s.
x=displacement of the beam.

Thus we can get the Displacement(nm) Vs Time(nsec) graph using transient analysis. the general graph of this analysis can be shown as[2],

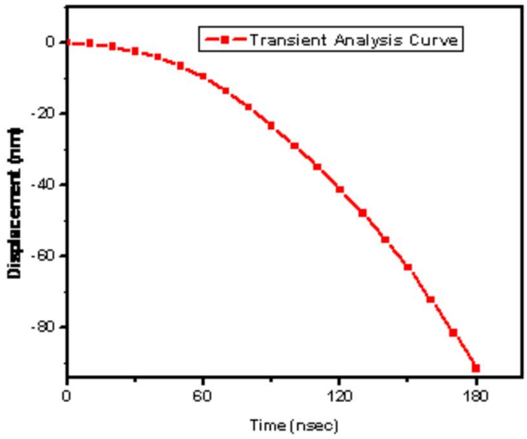

Figure 6.Displacement(nm) Vs Time(nsec).

4) Phase shift of the DMTL: The phase shift per unit length is found from the change in the phase constantand is given by [1],

$$\Delta\phi = \beta_1 - \beta_2 = \frac{wZ_0\sqrt{\varepsilon_{eff}}}{c}\left(\frac{1}{Z_{ld}} - \frac{1}{Z_{lu}}\right) \qquad \ldots.7$$

Where, ε_{eff} = Effective dielectric constant of the unloaded line,
Zlu= up-state loaded-line impedance values,
Zld= down-state loaded-line impedance values.

The phaseshift is determined by the impedance change of the DMTL, which also determinesthe reflection coefficient of the phase shifter. Typically, a maximum reflection coefficient of -15 dB is required because the DMTL is to be cascadedin 45º, 90º , and 180º sections to result in an N-bit phase shifter. Eq. 7 also show that phase shift is directly dependent on $\sqrt{\varepsilon_{eff}}$, and therefore, a DMTL on a silicon substrate results in more phase shift per unit length than a DMTL on a quartz substrate.

IV. CONCLUSION

In this paper we have seen the different types of RF MEMS phase shifters. Further how the RF MEMS phase shifter is superior to other existing phase shifters in comparison with stiction, Size, required power, insertion loss. Also seen how applied voltage effects the actuator deflection and different analysis i.e. static, modal, transient analysis with different types of equations.The key to the development of low-cost, lightweight phased array antennas and radar systemsis the low insertion loss, low drive power and low production cost of phase shifters. Thus the structure with severalMEMS bridges can act as a phase shifter when the applied bias voltage is less than thepull-down voltage.

ACKNOWLEDGEMENT

I would like to give Thanks to my Departmental staff for their assistance and thanks to all my friends and especially to my parents for encouraging me for this work whenever needs.

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