A new design of MEMS coplanar waveguide phase shifter

Zhao-feng Wu, Ji-bin Liu*
National University of Defense Technology, Changsha 410073, China
Email: wuzhaofeng13@nudt.edu.cn

***Abstract*— This paper presents a new design of MEMS coplanar waveguide (CPW) bridge membrane to realize a small, low-loss and fewer-cell phase shifter. In the proposed structure, a symmetrical bridge membrane is added to a universal distributed MEMS phase shifter. These additional bridge membranes are placed under the CPW. By using these structure, it is possible to increase the phase shift of a unit. Furthermore, the phase shift could be increased by employing a discrete capacitance on both ends of the bridge. The structure is simulated at 10 GHz using CST software. According to simulation results for all phase states the insertion loss is 0.5 dB. The employment of the proposed structure can considerably decrease the number of cells. As a result, the size and loss can be reduced.**

***Keywords*—MEMS，phase shifter，coplanar waveguide**

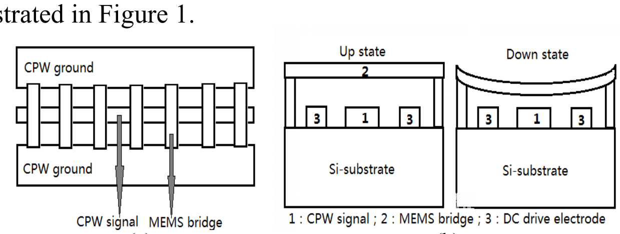
I. Introduction

MEMS (micro electro mechanical systems) phase shifter has the advantages of high quality factor, high isolation, low cost, low loss, easy to integrate and so on[1]. It is now a hot spot of research throughout the world[2]. Radio Frequency (RF) MEMS phase shifter can be divided into switch linear MEMS phase shifter, coupling MEMS phase shifter and distributed MEMS phase shifter according to the working principle. Among them, the switch line type MEMS phase shifter is simple in principle and easy to be realized, but it has the disadvantages of large insertion loss, large area and narrow bandwidth. The size of the coupled phase shifter is smaller than that of the switch line type phase shifter, and the utilization rate of the chip is high. The insertion loss of the coupling phase shifter increases with frequency. Meanwhile, due to the shorter length of the reflection ray, the process of the MEMS phase shifter switch becomes more complex, making it difficult. At present, the distributed MEMS phase shifter is that places bridge membrane above the CPW with same distance and controls the membrane height by the driving voltage, which changes the distribution of capacitance to realize the phase shift. However, in order to obtain good phase shift characteristics, a larger capacitance ratio is required. To increasing the capacitance ratio, many complex bridge structures have been studied, which have long transmission lines, therefore increasing loss.

Based on the distributed MEMS phase shifter designed by predecessors, the Symmetric Double bridge membrane method is first proposed in this paper. A same phase shift can be achieved with a shorter transmission line, smaller bridge membrane deformation and fewer cells. Compared with the universal distributed MEMS phase shifters which the bridge membrane only above the CPW, increase the phase shift of a unit and the size is reduced.

II. Design and Analysis

The distributed MEMS phase shifter periodically loads MEMS bridge membrane on high impedance microwave transmission line. Then, by adding certain DC drive voltage to change state (up state and down state) of the membrane, we get different MEMS bridge membrane capacitance, so as to achieve phase shifting. The MEMS distributed phase shifter is made up of many same MEMS bridges that span between two ground wires of CPW. Therefore, a cell of MEMS bridge membrane is the basic unit and the core of the design. The schematic diagram of the distributed MEMS phase shifter is illustrated in Figure 1.



(a) (b)

Fig.1. Schematic diagram of the distributed MEMS phase shifter (a) and working principle (b)

The basic idea of the MEMS distributed phase shifter is to load the movable bridge membrane with high capacitance ratio on the CPW periodically, thereby by changing the distributed capacitance between the signal line and the ground and making the coplanar waveguide transmission line a slow wave system it can achieve the purpose of phase retardation. The size of the phase shift is determined by the capacitance ratio of the MEMS unit switch and the capacitance of the transmission line.

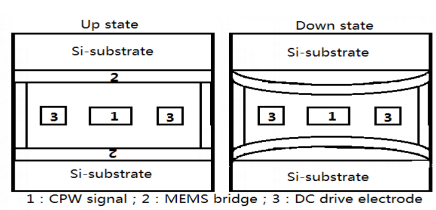
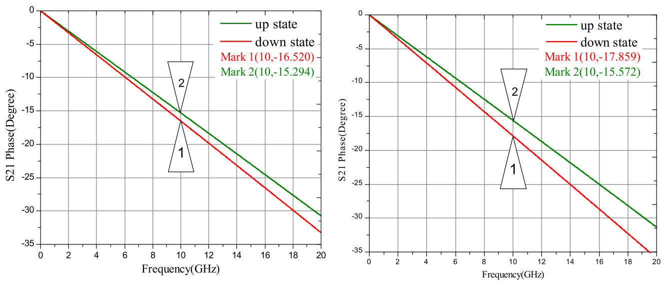


Fig.2. symmetric double bridge membrane

Now almost all of the MEMS CPW phase shifters are only loaded the movable bridge membrane periodically above the half space of the transmission line. On this basis, the symmetrical structure of the bridge membrane is loaded in the under the half space as shown in Figure 2. Thus, with the same bridge membrane structure, driving voltage and transmission line length, a larger capacitance ratio and phase shifting can be obtained.

III. Simulation and Result

All the simulations in this paper are based on the frequency domain calculation method of CST software. The excitation of the simulation is the waveguide port. The boundary condition is the open space. There is no particular reason for the simulation frequency and the phase shift results. It's just for simplicity that 10GHz is chosen as the observation frequency.

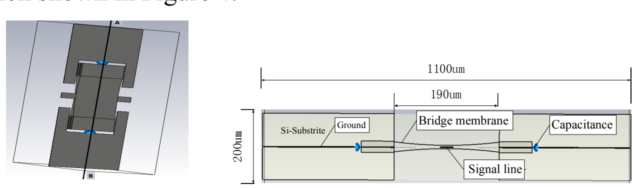


(a) (b)

Fig.3. Phase shift change of single side bridge membrane (a) and phase change of symmetrical double sides bridges at 10GHz (b).

From the above simulation results, the phase shift of the single-sided bridge membrane in the up and down state of 10GHz is 1.226 degrees, while the phase shift of the symmetrical double-sided bridge membrane is 2.287 degrees. The phase shift of the symmetric double-sided bridge membrane structure is approximately two times than that of the original one. Therefore, with the same bridge membrane structure, driving voltage and transmission line length, a larger capacitance ratio and a larger phase-shift volume can be obtained.

In order to reduce the difficulty of the process and obtain the determined capacitance ratio, in the article [3] a discrete capacitance is connected to the MEMS bridge. Referencing this design, two discrete capacitances are connected at both ends of the bridge membrane to increase the capacitance ratio, and further increase the phase shift of the same structure, which shown in Figure 4.



(a) (b)

Fig.4. (a) is the 3D structure (dielectric substrate is not displayed), and (b) is its cross-session view along line AB.

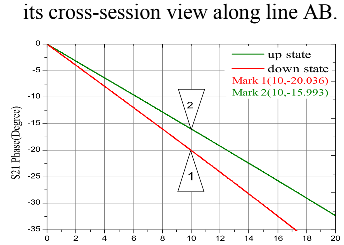
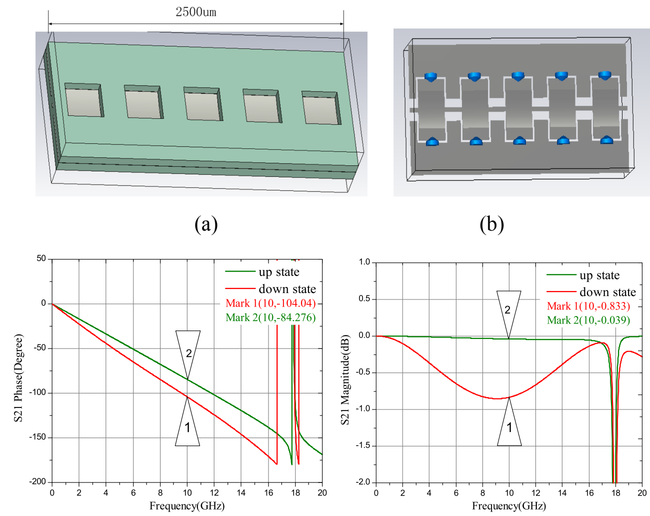


Fig.5. Phase shift change with discrete capacitance

The loaded discrete capacitor can increase the capacitance ratio and increase the phase shift. Fig. 5 is the simulation result of phase change after loading capacitance, and the phase shift is increased from 2.287 degrees to 4.043 degrees. This helps to further reduce the longitudinal size of the phase shifter.



(a) (b) (c) (d)

Fig.6. Multiple unit series diagrams and simulation results. (a) and (b) are the 3D structures with and without substrate, respectively. (c) and (d) are the results of phase change and insertion loss, respectively.

The five cells are connected in series to form a controllable phase shifter, which can obtain 19.764 degrees phase shift to the max. Insertion loss in the up state is 0.039dB, 0.833dB when all cells' bridge membranes are down.

Conclusion

The aim of this paper is to design a new structure of MEMS phase shifter, which has a shorter transmission line, smaller bridge membrane deformation and fewer cells. The simulation results show that the symmetric double bridge membrane structure proposed in this paper can achieve the purpose. With the same transmission line length, we can get nearly two times of the phase-shift. In this paper, the phase shift is further increased on the basis of the Symmetrical Double bridge membrane by loading discrete capacitance between the two ends of the bridge. It provides a feasible new idea and method for the design and optimization of MEMS phase shifter. However, this article has not discussed the opening voltage, as well as the optimization of the production process, still need further research and discussion.

References

[1] Dey Sukomal, Koul Shiban K., Poddar Ajay K., Rohde Ulrich L., "Reliable and Compact 3-and 4-Bit Phase Shifters Using MEMS SP4T and SP8T Switches," Journal of Microelectromechanical Systems, vol. 27, pp.113-124, Feb 2018.

[2] Chakraborty Amrita, Gupta Bhaskar. "Development of compact 180 degrees phase shifters based on MEMS technology," Sensors and Actuators A-physical, vol.247, pp.187-198, Aug. 2016.

[3] ZhangXiaosheng, "Research on chip-set X band five bit MEMS distributed phase shifter." University of Electronic Science and Technology of China. (in Chinese).