Loss Analysis of Wideband RF MEMS Shunt Capacitive Switch in T and Π-Match Configurations

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Abstract **─** A wide bandwidth coplanar-waveguide (CPW) based RF MEMS capacitive shunt switch with π-matched & T-matched having high impedance transmission lines is designed and simulated for broadband (18-40 GHz) application. The effects of variation in membrane width (50 & 70 μm) of the switch and high-impedance transmission line length (300 – 600 μm) between the switch structures on scattering parameters are studied. The variation in beam width has very little effect on return loss of the switch in up-state. The reduction in high-impedance transmission line length yields marginal improvement in return loss. In the down-state configuration, the return loss showed negligible change with the variation in beam width and high-impedance transmission line length. The isolation is found improved with the increase in beam width and high-impedance transmission line length in whole frequency range. Simulating the technical performance demonstrates the greater improvement in RF characteristics of the switch particularly in return loss in up-state position. In order to validate the obtained result, Artificial Neural Network (ANN) has been trained using ADS result. Comparison shows good agreement between ADS and ANN results.

Index Term- High impedance short transmission line, matched section, return loss and isolation, RF MEMS, shunt switch, wideband.

I. INTRODUCTION

Design of RF MEMS switches is one of the interesting areas that facilitate the researcher with great potential to improve the performance of communication circuit and systems. At microwave frequencies, the rapid development and use of micro electromechanical systems (MEMS) have proved tremendous advancement due to their high linearity and low losses [1] as well as low power consumption [2]. Among the various components of MEMS technology, MEMS switches are the basic building blocks replacing the conventional p-i-n diode and GaAs FET switches [3] at high frequency applications. Low cost MEMS switches are considered as prime category in MEMS technology due to their extremely low insertion loss (0.1dB) [4] and very high isolation upto 100 GHz, near zero power consumption (10-200 nJ/switching cycles) good isolation [5], lower insertion loss and low power consumption [3] properties. The analysis of MEMS switches from microwave to millimeter wave frequencies have revealed superior performance than the diode based switches which offer poor performance in terms of losses [6], tuning linearity and intermodulation distortion. The excellent linearity [7] due to the mechanical passive nature [8] of the device and wide bandwidth operation of MEMS switches makes it ideal for different wireless applications, reconfigurable antennas, filters and tuners, low loss phase shifters and high Q passive devices and resonators [5]. RF MEMS switches that are able to handle up to 20W and operating cycle of 10^{12} [1] have found applications in RADAR system, network analyzer, satellite communication system and in base stations [5].

MEMS switches are the devices which operate by the use of mechanical movement to achieve short or open circuit in RF circuits. The required force for mechanical movement can be obtained by different actuation mechanisms like electrostatic and magneto static [5]. MEMS switches can be designed in different configurations based on signal path (series or shunt), the actuation mechanism (electrostatic, thermal or magneto static), the type of contact (ohmic or capacitive) and the type of structure (cantilever or bridge) [9]. Extensive studies on various kinds of series and shunt

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MEMS switches are available in literature [10, 11]. The practical first capacitive shunt switch was presented by Raytheon based on fixed- fixed metal beam structure [11]. Later on, lot of research works have been carried out on capacitive shunt RF MEMS (CSRM) switches to achieve better performance [12].

In a CSRM switch, a thin metal membrane bridge is suspended over the center conductor [13] and fixed on the ground conductor of CPW [14]. This switch performance depends on isolation which in turn depends on capacitance ratio (C_{max}/C_{min}). The MEMS switches performs excellently for 10-100 GHz frequency range applications with a typical isolation of -17 dB at 10 GHz and -35 to -40 dB at 30-40 GHz for a capacitance of 4 pF [7]. In these wide frequency range, Ka-band (18 – 40 GHz) can be the band of choice for many radio communication applications due to its increasing capacity availability and its applicability for broadband services. This band can encompass a new type of architecture, new transmission and bandwidth management to provide higher quality, better performance and faster speed [15].

The conventional RF parameters which characterizing the MEMS switches are: 1) The insertion loss in ON-state; 2) The isolation (i.e., 1/|S21|) in OFF-state; and 3) The return loss (i.e., 1/|S11|) in both states. Much effort has to be taken to improve these parameters to achieve higher isolation in OFF-state and low insertion and return losses in ON-state. Matching is necessary for the best possible energy transfer from stage to stage. The impedance of the devices (generally 50 Ω internal impedance) connected in system must be matched in order to reduce the reflection and the related losses. Interstage matching has to be made between two complex impedances, which make the design still more difficult, especially if matching must be accomplished over a wide frequency band. In RF MEMS switches, either T-match or π-match configuration is used. In T-match configuration, the series inductors provide a good match at the design frequency. Whereas in π-match configuration, a short section of high impedance line is used between two shunt switches results in an impedance match. The π-match provides an excellent match in the upstate position over a wide bandwidth and wide isolation bandwidth compared to T-match. The double shunt capacitance ground the high frequency signal two times faster as compared to the T-match and improves the isolation [16-17].

In this paper, we analyze the RF design of coplanar waveguide based MEMS shunt switch in T and π-match configuration for Ka band applications. In T-match the capacitor is eliminated by using a distributed inductance of two short high impedance transmission lines (HITLs) and the π-matched consists of two bridges separated by a high-impedance transmission line. Scattering parameters of the T and π-matched shunt switch is studied as a function of:

1) Width of the switch membranes. 2) High impedance transmission line length.

The organization of the paper is as follows. Section two of this paper discusses the theory of capacitive shunt RF MEMS switch with its selection criteria and the proposed two types of matching network parameters. The electromagnetic simulation analysis of capacitive shunt switch in terms of insertion loss and isolation performance is discussed in Section 3. Section 4 presents applications of MEMS switch along the findings of our work.

II. CSRM SWITCH

A. Selection of switch

As mentioned in Section I, there are several types of MEMS switches based on different design parameters. The major criteria for switch selection are its application and frequency of operation. Out of two types of switches based on contact, the shunt is preferred over series due to minimal parasitic involved and capable of handling more RF power. Shunt switches have the benefit of ease of fabrication and fewer parasitic due to continuous transmission line [9]. The capacitive MEMS switch has excellent performance up to 40 GHz [18] and life time in excess of 1 million cycles [19] under low power conditions.

B. Theory of capacitive shunt RF MEMS switch

The capacitive shunt RF MEMS (CSRM) switch taken for analysis is based on a fixed - fixed beam [20] design and is shown in Fig. 1 (a). The MEMS Bridge with the gap of ‘g’ from the center conductor is connected to the CPW ground plane and the bridge is grounded.

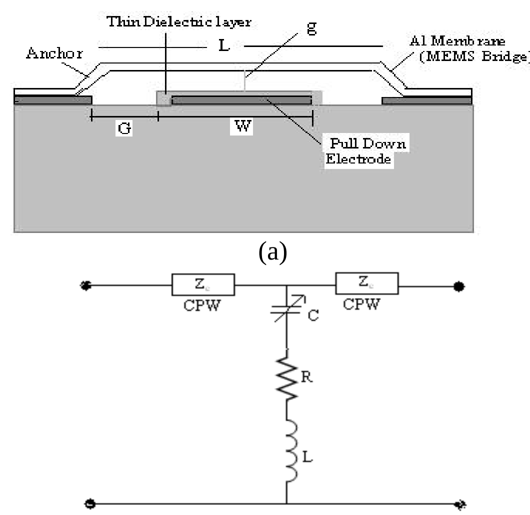

Fig. 1. Capacitive shunt RF MEMS switch: (a) cross section view, and (b) equivalent circuit.

The center pull down electrode provides both the electrostatic actuation [22] and RF capacitance between the transmission line and ground. When the switch is down (OFF) state actuated, the capacitance to the ground provides good results in excellent short circuit and high isolation at microwave frequencies. The lumped element equivalent circuit model of CSRM switch is shown in Fig. 1 (b).

C. RFMEMS shunt switch in π-match configuration

The model of the single RF MEMS membrane switch can be used to design the high-isolation, low insertion-loss π-matched shunt switch [21]. The π-matched switch consists of two single MEMS shunt switches separated by a short length 'd' of high-impedance transmission line as shown in Fig. 2.

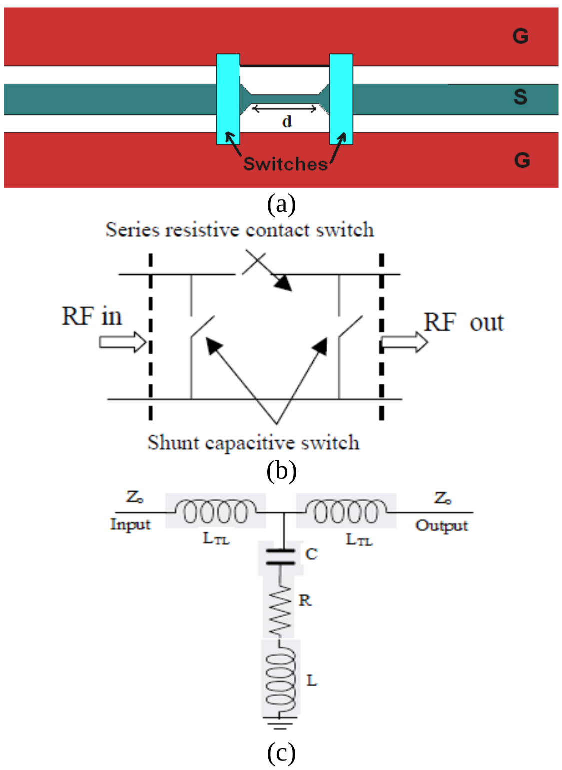

Fig. 2. (a) Schematic of RFMEMS shunt switch in π-match and its equivalent circuit in (b) π-match and (c) T-match.

The RF characteristic parameters of this switch are analyzed in terms of return loss, insertion loss and isolation. In our paper for getting broadband RF MEMS switch, we analyze the frequency response of the switch at different length of the midsection high impedance transmission line.

D. RFMEMS shunt switch in T-match configuration

The RF characteristics of a capacitive shunt switch depend on the capacitor of the switch in its up-state position. For lowering the actuation voltage, the gap-height should be decreased which leads to an increase in the up-state capacitor [22, 23]. This deteriorates the RF characteristics of the switch. In this paper, the up-state position of the switch with two short high-impedance transmission lines (HITLs) having inductance 'L_{TL}' is characterized by the C, L and R components. The capacitance 'C' is the more dominating component at high frequency in this model which causes the mismatch between input and output of the switch. We therefore match the circuit by using two additional short HITLs incorporating two inductors (L_{TL}) at the input and output of the switch which forms the T-matching circuit as shown in Fig. 2 (c). Though RF MEMS switches are 3D structures, they can also be seen as 2.5D structure due to their high aspect ratio. RF performance of the switch in terms of insertion and return loss is studied using ADS Momentum EM software. The characteristic impedance of CPW plays a major role which is determined by ground/substrate/ground (G/W/G) [24] dimension. In CPW line, the signal and two ground lines are on the same plane. In this proposal, the CPW line with dimensions G/W/G = 60 μm/100 μm/60 μm (50 Ω) was designed and two values (50 μm and 70 μm) has been chosen for width of the membrane bridge.

E. Artificial neural network

ANNs are biologically inspired computer programs to simulate the way in which the human brain process information. Each neuron has weighted inputs, simulation function, transfer function and output. The weighted sum of inputs constitutes the activation function of the neurons. The activation signal is passed through a transfer function which introduces non-linearity and produces the output. The neural network architecture used in this paper called MultiLayer Perceptron Neural Network has use the back propagation [24] learning algorithms used in this work are based on multilayer correction learning algorithm called back propagation.

III. RESULTS AND DISCUSSION

Simulated scattering parameters of the π-matched & T-matched with HITLs switch structure are discussed in this section. Figures 3 (a) & (b) show the return loss (S11) and isolation (S21) for the up-state position for the switch for π section and T section with HITL length from 300 to 600 μm for the width of the membrane bridge of W=50 μm and 70 μm. The up-state S11 parameters of π section are found to vary between – 5 dB to – 35 dB in the 18 – 40 GHz frequency range. The return loss of T section with HITL varies from -0.7 with highest minimum loss of -1.4 dB only. But for the same frequency range from 18 to 40 GHz, the π section gives the minimum return loss in the range from -4 dB to -32 dB.

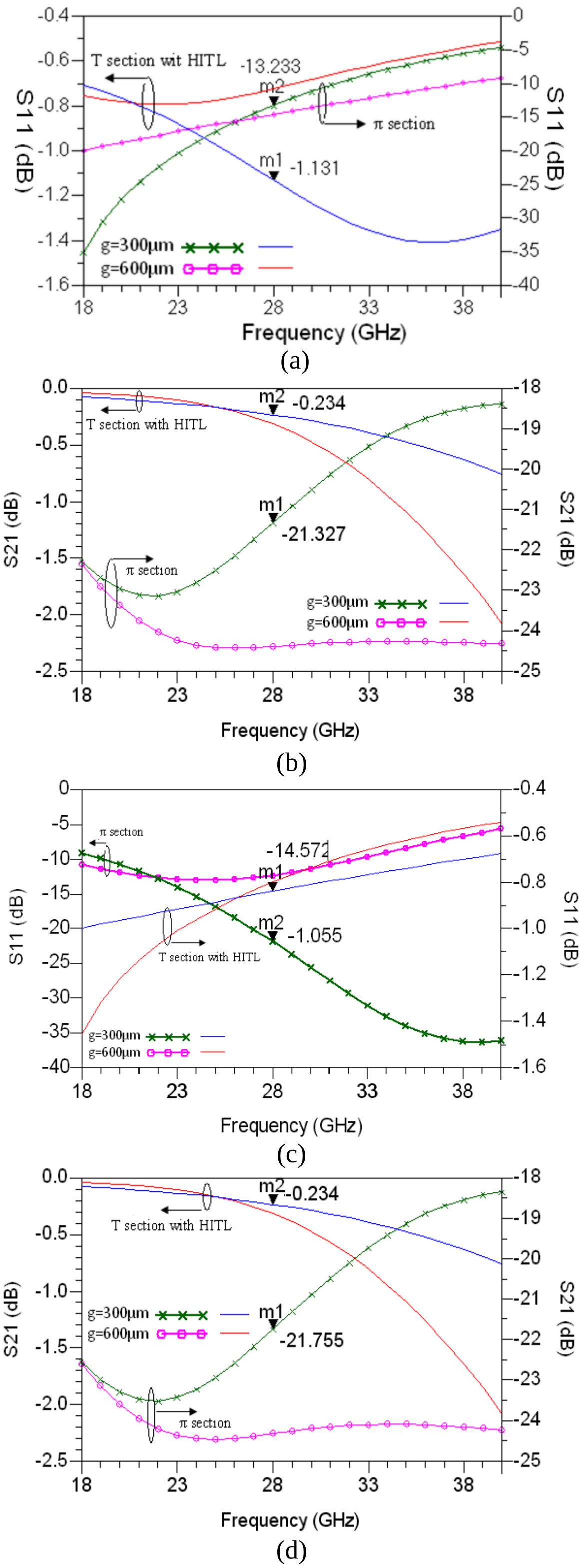

Fig. 3. UP-state insertion loss (S11) and isolation (S21) for π section and T section with HITL length from 300 to 600 µm and width of the membrane bridge (W) of (a) & (b) W=50 µm and (c) & (d) W=70 µm

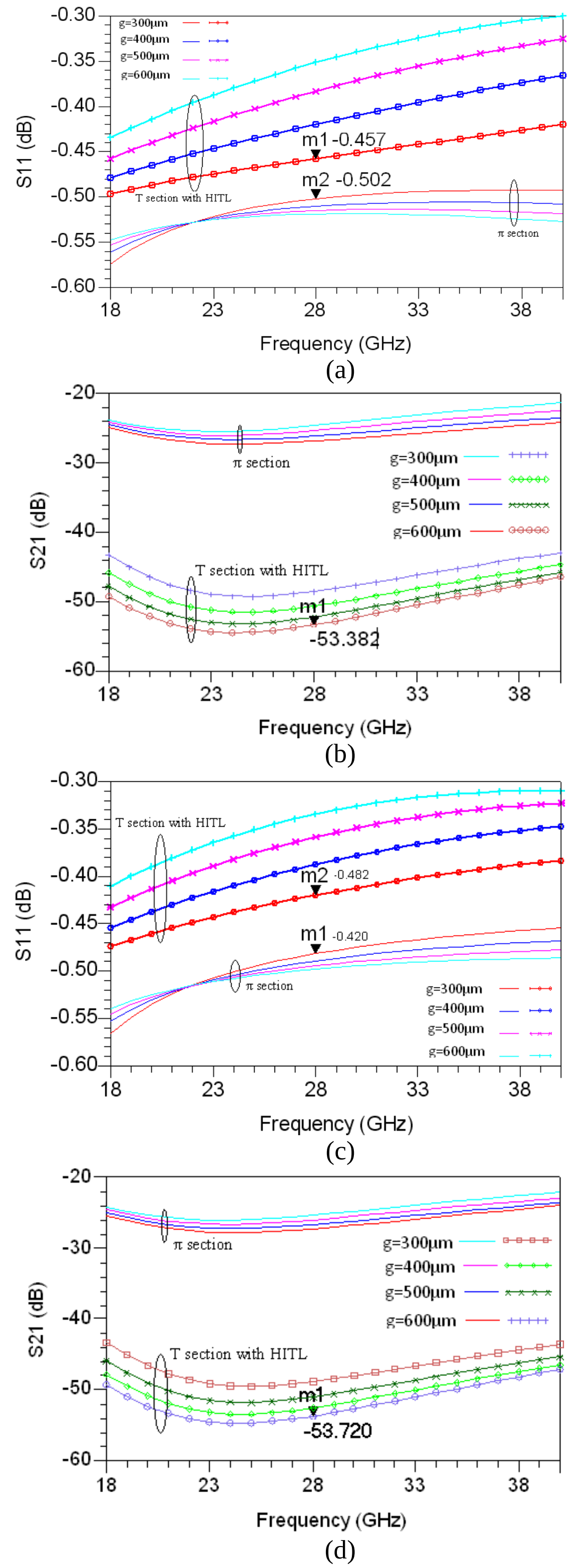

Fig. 4. Down-state insertion loss (S11) and isolation (S21) for π section and T section with HITL length from 300 to 600 µm and width of the membrane bridge (W) of (a) & (b) W=50 µm and (c) & (d) W=70 µm

This shows that the π section performs well compared to T section in terms of their losses. Figures 3 (c) and (d) give the return loss with the width of the membrane bridge of 70 µm. This graph explains that there is no much difference in the loss performance with respect to the width of the membrane bridge.

Figure 4 gives the return loss and isolation performance of switch in π section and T section with HITL length from 300 to 600 µm and width of the membrane bridge of W=50 µm & 70 µm in down-state configuration. In Fig. 4 (a), return loss (S11) for W=50 µm is found to be varied from -0.5 to -0.3 dB for T section with HITL and this is reduced from -0.58 to -0.51 for π section. However, the S11 parameters do not show any noticeable change with the width of the switch as well as with high-impedance transmission line lengths. For the isolation performance as in Fig. 4 (b), the better performance of π section (isolation from -26 dB to -22 dB) can be noticed compare to T section with HITL (isolation from -54 dB to -44 dB). Though there is no much variation in isolation for ‘g’ values, we have achieved nearly 30 dB reduction in isolation for π-section. The isolation values seem to be decreasing with the increase in the high-impedance transmission line lengths, while it increases with increase in the beam width. As the beam width increases, the downstate capacitance increases, which results in better isolation as shown in Fig. 4 (d). As can be seen from the figures, the RF losses performance of the down-state position for the CSRM switch gives better results in the frequency greater than 25 GHz. Therefore, the switch provides desirable RF characteristics (S11 and S21) for the Ka frequency band applications.

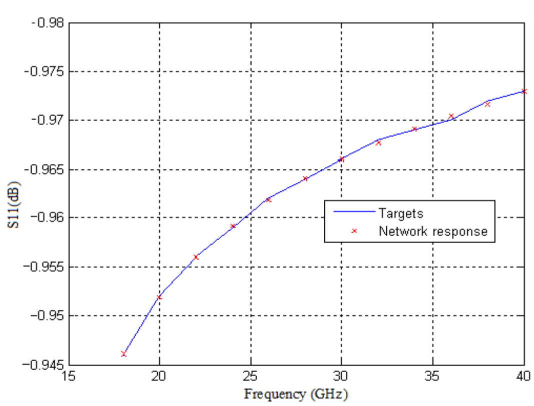

Fig. 5. Comparison of ADS and ANN trained values for insertion loss of CSRM with π section and T section.

In order to validate the obtained result, the neural network has been trained with the insertion loss ADS result obtained for down state insertion loss with W=50 µm and d=400 µm for π match configuration as shown in Fig. 5. After many trails, network having two hidden layers have been selected with dimensions of 4x14x10x2. This means that the numbers of neurons were 4 for input layer, 14 and 12 for first and second hidden layers respectively and 2 for output layer respectively. The better agreement between the results from ADS and ANN shows that the proposed matching networks are optimized by simulation.

IV. CONCLUSION

This paper presents parametric analyses of scattering parameters of the π-matched and T-section with high impedance transmission lines for capacitive shunt RF MEMS switch for broad band (Ka-band) application. The variation in beam width has very little effect on up-state scattering parameters; whereas, the reduction in high-impedance transmission line length showed the marginal improvement in return loss. In the down-state configuration, there is no much change in return loss for the beam width of the switch and high impedance transmission line lengths. The isolation is found to be improved with the increase in beam width and high-impedance transmission line length. The achieved scattering parameters shows that the CSRM switch with proposed matching networks are best suited for high frequency band (25 - 40 GHz) which support for Ka band applications like satellites communications uplink in either the 27.5 GHz and 31 GHz bands, high-resolution, close-range targeting radars, aboard military airplanes, vehicle speed detection by law enforcement and for downlink of scientific data collected by the space telescope.

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