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TECHNICAL PAPER

Design and performance analysis of hybrid SPDT RF MEMS switch

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Abstract

This paper presents the design and simulation of Hybrid type RF MEMS switch for satellite communication application. The Hybrid switch beam is having non-uniform meanders and holes. The gold material is used as a beam and CPW. The gap between the beam and dielectric is 3 µm. The design is based on the shunt and series configuration consisting of 2 capacitive switches and 2 Ohmic switches. The performance analysis is done by using the HFSS tool. The individual Ohmic switch having 31 dB isolation and capacitive switch having 67 dB isolation. The proposed Hybrid switch having 87 dB isolation when both switches are in the OFF state. During ON state, the switch shows the low insertion loss of − 0.18 dB and return loss of − 63 dB at 16 GHz.

1 Introduction

In RF MEMS switches different types of switches are present like a Ohmic switch, Capacitive switch and hybrid switches. A variety of MEMS components such as resonators, phase shifters, RF MEMS switches, variable capacitors, oscillators, inductors etc. have been employed in 5G devices operating at millimetre wave frequencies. Among them RF MEMS switches plays a key role in devices such as reconfigurable antennas, phase shifters and filters etc. due to having the advantages of low power consumption, small size and low cost (Kumar et al. 2018).

Ohmic switches are often used in series-configuration. The proposed Ohmic SPDT switch is made up of silicon substrate and CPW transmission line. The material used for beam is gold it is on the dielectric layer. The Ohmic switch is having Meanders and perforations. High isolation at the low frequency used for space and defense applications. A dielectric is laid over the signal line to combat the unnecessary loss of signal and in this way, the flow of the electric signal is curbed, only the RF signal gets transmitted (Lakshmi Narayana et al. 2017a, b). A switch is proposed to improve high isolation by using hafnium oxide dielectric material at a frequency range of 10 GHz to 15 GHz (Yao et al. 1999). The novel SPST, SPDT switches are proposed for improving switch performance by using gold as beam material and the switch shows less insertion loss of 0.3 dB. (Jaiswal et al. 2018). RF MEMS switches possesses high performance characteristics when compared with traditional semiconductor switches like FETs and PIN diodes in many applications. The conventional switches have large leakage currents which weakens the RF characteristics of the device and can be overcome by proposing RF MEMS switches (Rebeiz 2003).

For parallel configuration, capacitive switches are frequently used. When deciding the operating frequency of the switch the difference is in coupling in parallel and series configuration. In the parallel configuration, the device will operate up to 200 GHz while in series configuration this capability falls to 20 GHz. Another benefit of capacitive switches the dielectric layer protects the switch, which enhances the switch's lifespan in a Small number of cycles. A simple low-cost method called four-mask process is used to fabricate RF MEMS switch having a gap of 1.5 µm and achieved pull in voltage of 9 V (Balaraman et al. 2002). A non-contact switch is proposed at pull in voltage of 25 V and also suffers from stiction problems A differential gap between electrodes for high isolation of the switch. It consists of two actuation beams rather than one beam and the 29% of pull in voltage is reduced using double vertical actuations (Park et al. 2009). The high performance of RF MEMS shunt such as high bandwidth,

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low insertion loss, and high isolation have made these switches well suitable for high performing microwave and millimeter wave circuits. Mafinejad et al. (2009) presents a RF MEMS shunt capacitive switch for Ka and V band application A novel H-shaped beam is proposed to reduce pull in voltage up to 7 V by using aluminium as a material and the switch shows less isolation of 20 dB at 12 GHz (Batmanov et al. 2006). Besides the advantages, RF MEMS switches suffers from high pull in voltage and slow switching time make them less reliable to integrate with VLSI circuits (Manivannan et al. 2014). Ravirala et al. (2017) presents Comparative study is done for zigzag, plus and three square shaped meander along with rectangular perforations on each structure. When the gap between the dielectric and the movable beam is 0.8 µm, the up state capacitance for HfO2 is 4.06fF and for Si3N4 is 3.80fF.

Hybrid switches are regularly used in both series and parallel configurations. The device switching between transmission and receiving is possible by hybrid SPDT RF MEMS Switch. The switch is having 2ohmic switches and 2 capacitive switches. Hybrid switches are mostly preferable for RF performance. Hybrid switches having high isolation performance. The size of the switch is reduced compared with the individual switches. When the numbers of switches are more than only the switch is having less size. At different frequencies, the capacitive switch is designed and compared to the shunt switch. The switch shows the insertion loss higher than 0.35 dB and return loss lower than 0.35 dB and isolation observed at 75.33 dB at a frequency of 8.2 GHz in Zahr et al. (2015). Use of a single series capacitive switch compared to the conventional approach of a capacitive and series combination, offers compact size, higher bandwidth and superior reliability (Bansal et al. 2014). At a frequency range of 26 GHz, high isolation has been achieved using series and shunt configuration switch (Kumar et al. 2018). In the SPDT 3-port switch, 15 dB isolation with an insertion loss of 1 dB is observed at upstate and 40 dB isolation with an insertion loss of 1 dB is observed at a pull in voltage of 35 V (Ketterl and Weller 2005). Generally the RF MEMS switches consist CPW as the transmission line. Various types of RF MEMS switches are available in the communication applications like series, shunt, capacitive type (Chan et al. 2003). A surface micromachining process, which is compatible with the conventional millimeter-wave integrated circuits (MMICs) fabrication technology, was adopted to fabricate the RF switch on GaAs substrates. Its S-parameter was taken using a HP8510C vector network analyzer and a Cascade Probe station (Zheng et al. 2005). Different types of simulations are done in series-shunt SPST switch at w-band frequency. The insertion and return losses are observed as 0.7 dB and 7 dB at an isolation of 10 dB (Sharma and Pandey 2018).

The design of the paper illustrates that, Sect. 2 discussed the proposed structure and working principle. In section-3 discussed the results of the S parameters for different conditions using HFSS tool. Finally the summary of the results are present in the conclusion section followed by references.

2 Proposed structure

The proposed switch is a Hybrid model, designed over the coplanar waveguide transmission line and mounted on a high dielectric thick substrate. An insulating layer is placed in between the transmission line and substrate to provide better isolation and prevents leakage currents. The beam is placed above the transmission line with the help of meanders having a small air gap present between beam and Coplanar Waveguide (CPW). These meanders are connected to the ground planes by providing anchors. The dielectric layer of thickness 0.1um made up of Si_3N_4 placed over the silicon substrate. The top view of proposed hybrid SPDT Switch is shown in Fig. 1. The dielectric layer over the signal line varied with silicon nitrate with a thickness of 0.2 µm. Table 1 presents the dimensions of the proposed switch components.

To decrease the size, the hybrid SPDT switch is proposed. The hybrid SPDT switch consists of both Ohmic and capacitive switches. In Ohmic SPDT switch size is small and it maintains limited frequency. The capacitive SPDT switch, size is large and it maintains high frequency. The hybrid SPDT switch has a small size and it maintains a certain frequency. Compare to Ohmic and capacitive switches the size of the hybrid switch is reduced. Basic block diagram of SPDT Switch as shown in Fig. 2.

Input is applied to the RF input signal, then the series beam must be actuated to complete the circuit connection and shunt beam in its original position providing a very low capacitance for signal transmission. Whereas the shunt beam is actuated in the OFF state of the device and deflects the bridge vertically downwards, which gives a high capacitance, while at the same time the series beam

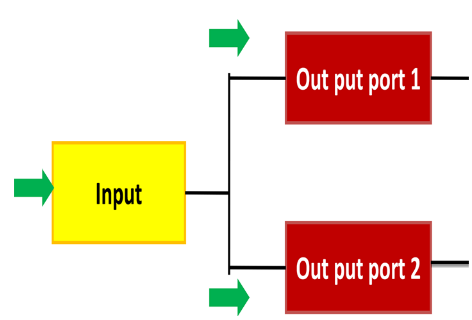

Fig. 1 Top view of hybrid SPDT RF MEMS switch

Table 1 Specifications of proposed capacitive SPDT switch

Sl no.	Component	Material	Length (μm)	Width (μm)	Thickness (μm)
1	Capacitive beam	Gold	150	300	1
2	Ohmic beam	Gold	250	300	1
3	Signal line	Gold	300	400	1
4	Holes	Gold	8	6	1
5	Dielectric layer	Silicon nitride	200	150	0.5

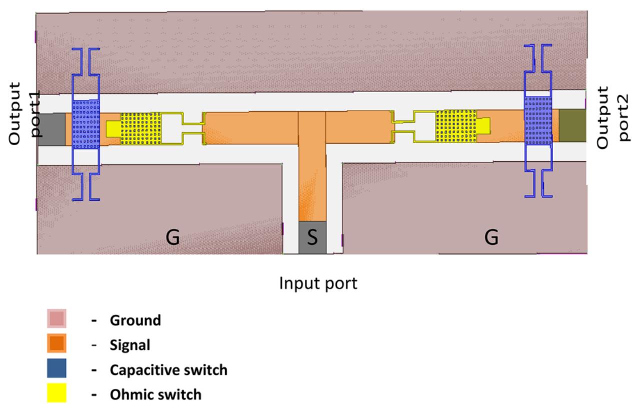

Fig. 2 Basic block diagram of SPDT switch

maintains its original position i.e., opening the circuit to block the RF signal resulting in high isolation. The Equivalent circuit of SPDT switch as shown in Fig. 3.

Ohmic switches are small in size but their frequency is very low. To improve the isolation at higher frequencies will prefer capacitive switches. The capacitive switch offeres high isolation rather than ohmic switches. But capacitive switch size is almost double compare to ohmic switch. To incerese isolation and decrese size hybrid switches are proposed. For this, capacitive switches are seriesed with Ohmic switch for high isolation. In this way size of switch also reduced. Frequency of the operation of the proposed switch can be shifted.

The most important part of the circuit is the distance between the MEMS Switches and the reactive junction, labeled d_s in the figure. When s1 is in an up-state position, the short t-line reaction in the s1 arm serves as a slight

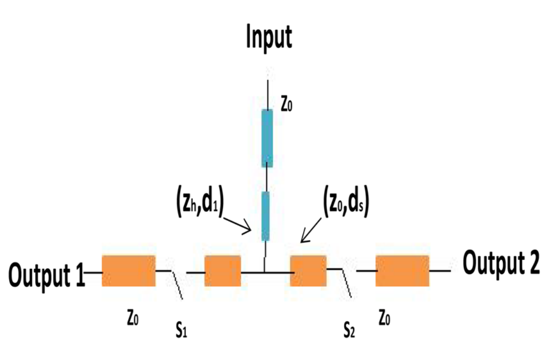

Fig. 3 Equivalent circuit of SPDT switch

capacitance and increases the input reflection coefficient of the SPDT switches. By adding short high impedance the input reflection coefficient can be increased.

3 Results and discussion

3.1 Electromagnetic analysis of proposed switch

Electromagnetic characteristics of the switch are studied by designing the proposed hybrid switch using HFSS tool and simulating over a 16 GHz frequency. The isolation of the output and input terminals and the study of S-parameters at upstate and downstate gives the RF performance characteristics of the proposed switch.

3.1.1 Ohmic switch

When voltage is applied, then the membrane will deform and the input RF signal is completely isolated. The amount of isolation for the RF can be measured using Isolation losses (S_{21}) In the Ohmic SPDT having 31 dB of isolation as shown in the Fig. 4.

3.1.2 Capacitive switch

Once the voltage is applied the membrane deforms and the RF signal is completely isolated. The RF losses can be calculated using isolation losses (S21) in the capacitive SPDT with 67 dB of isolation as shown in the Fig. 5.

3.1.3 Hybrid SPDT switch

The power losses of the switch can be explained with the s-parameters. The switch is analyzed by the isolation, return loss and insertion loss. RF performance is performed in the HFSS TOOL. In the hybrid, SPDT RF MEMS switch has four different cases.

3.1.3.1 Case 1 Isolation loss of the device occurs in 3 conditions when the shunt beam is on state and the series beam is off condition then isolation is observed as 81 dB in Fig. 6.

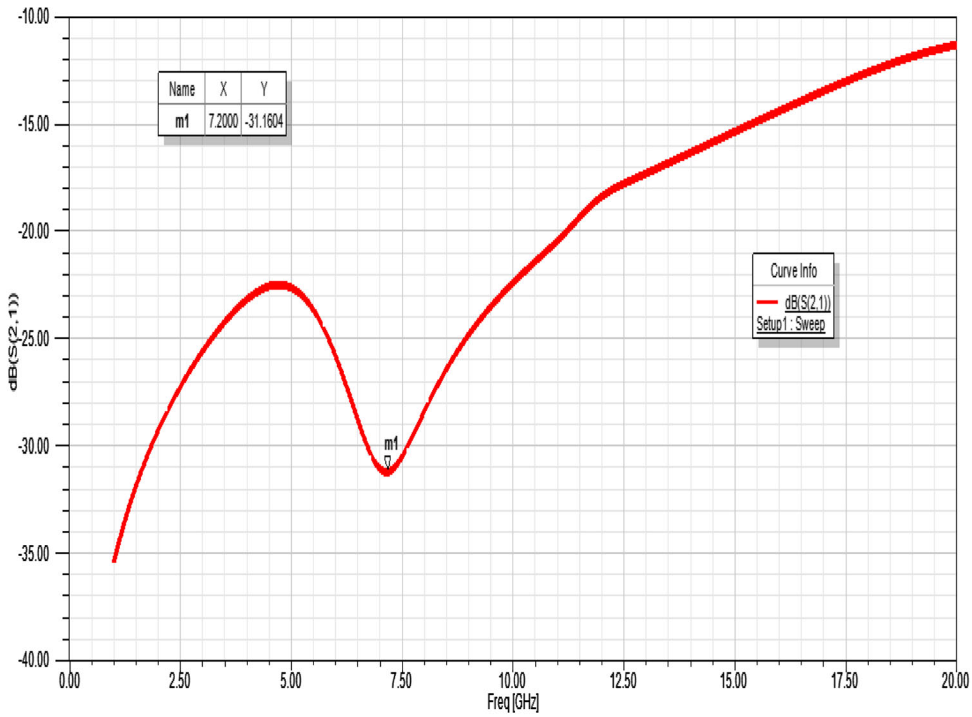

Fig. 4 Isolation of the Ohmic SPDT switch

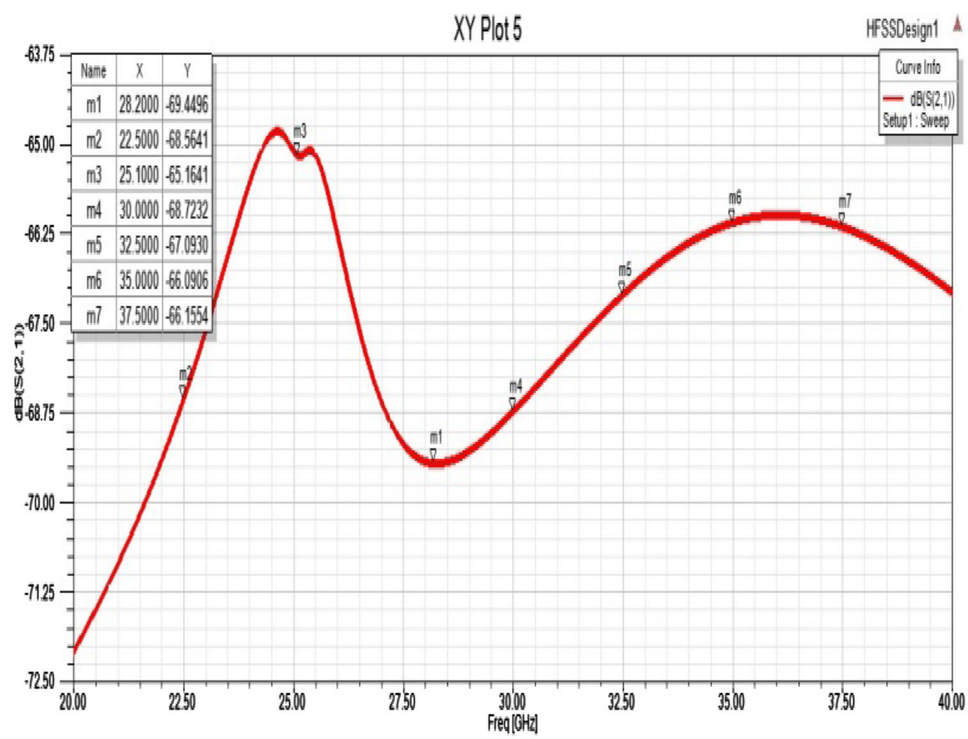

Fig. 5 Isolation of the capacitive SPDT switch

3.1.3.2 Case 2 When the shunt beam is OFF state and a series beam is ON state the hybrid switch observed isolation of 82 dB in Fig. 7.

3.1.3.3 Case 3 When both the switches are in OFF state i.e., the shunt beam is downstate and the series beam is upstate. The isolation of 87 dB is observed at 16 GHz shown in Fig. 8.

3.1.3.4 Case 4 Input is applied through the signal line then the RF signals perform insertion loss and return loss outputs when both shunt switches are in upstate and series

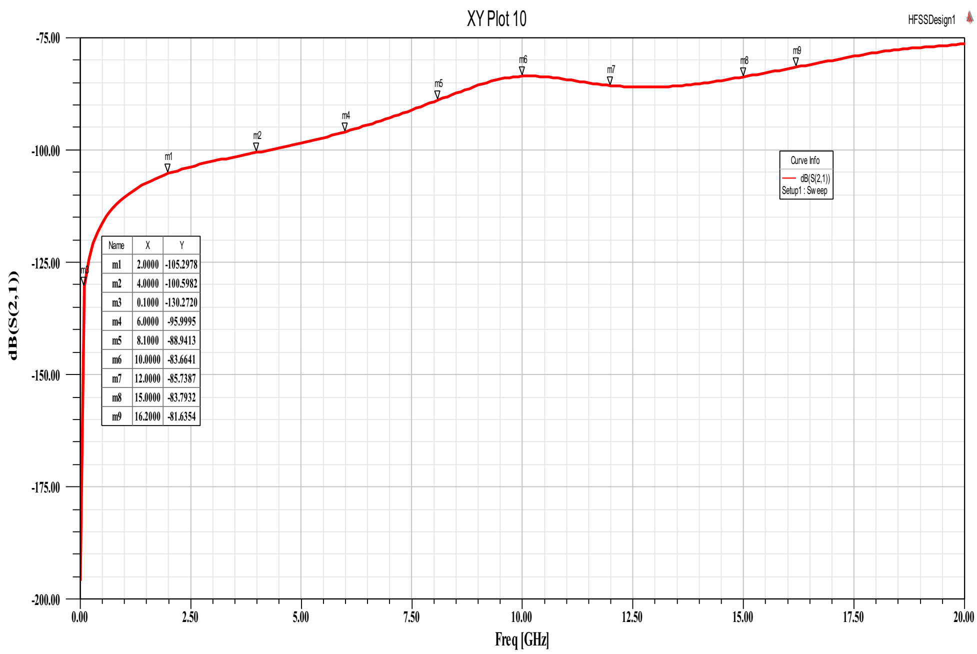

Fig. 6 ON, OFF state of hybrid SPDT switch

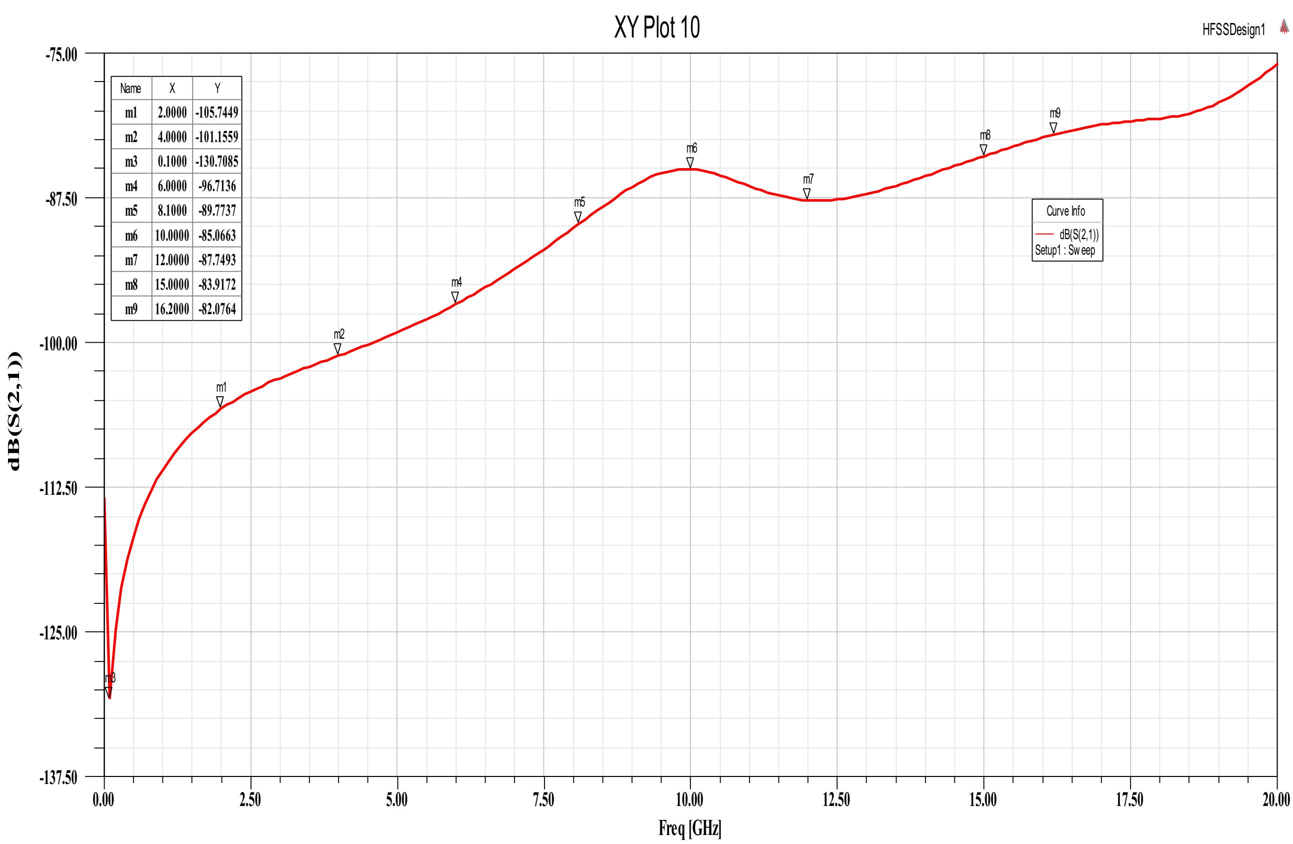

Fig. 7 OFF, ON state of the proposed hybrid SPDT switch

switches are in downstate. The return loss can be given as follows in Eq. (1). The return loss and insertion loss of hybrid switch are observed as 63.6 dB and 0.18 dB at 16 GHz as shown in Figs. 9 and 10.

$$S_{11} = \frac{-j\omega C_{up} Z_0}{2 + j\omega C_{up} Z_0} \quad (1)$$

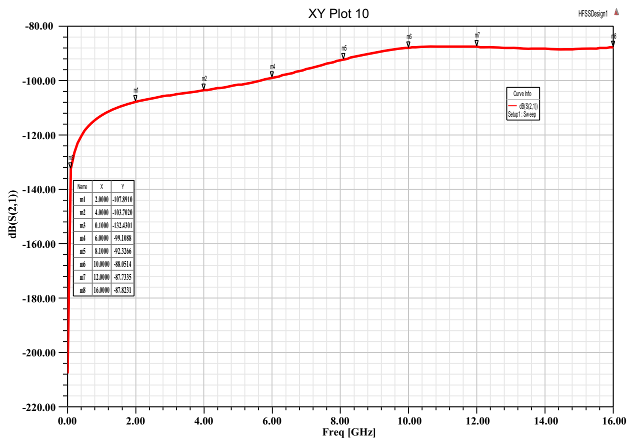

Fig. 8 OFF, OFF State of proposed hybrid SPDT switch

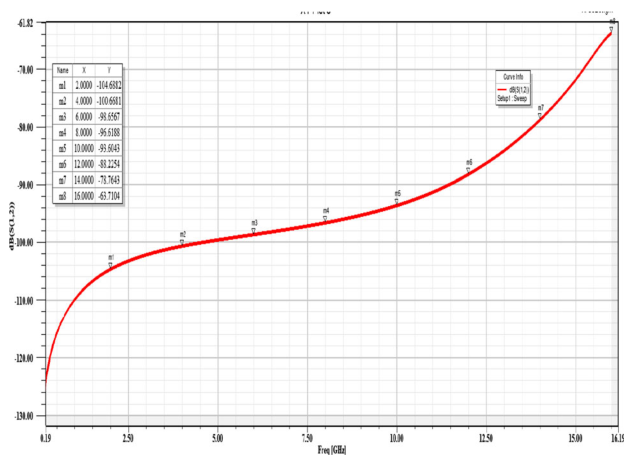

Fig. 9 Return loss of the proposed hybrid SPDT switch

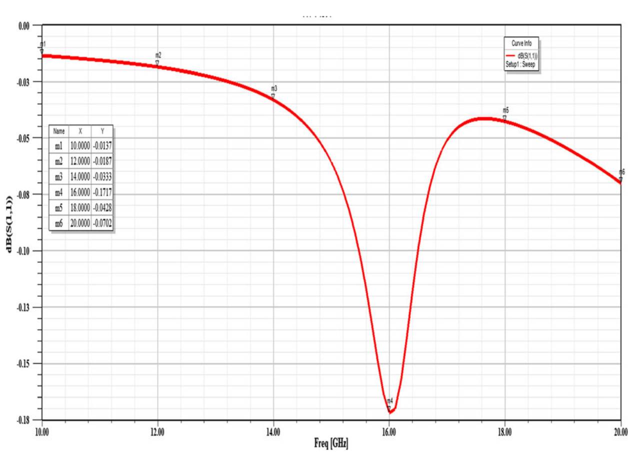

Fig. 10 Insertion loss of the proposed hybrid SPDT switch

While considering the insertion losses which occur due to material dispersion, the switch allows RF signal up to 16 GHz by having insertion loss less than 1 dB. The insertion loss can be given as follows in Eq. (2).

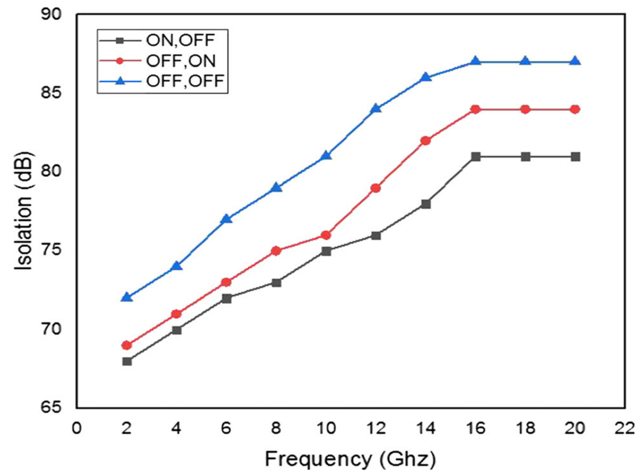

Fig. 11 Different states of proposed hybrid SPDT switch

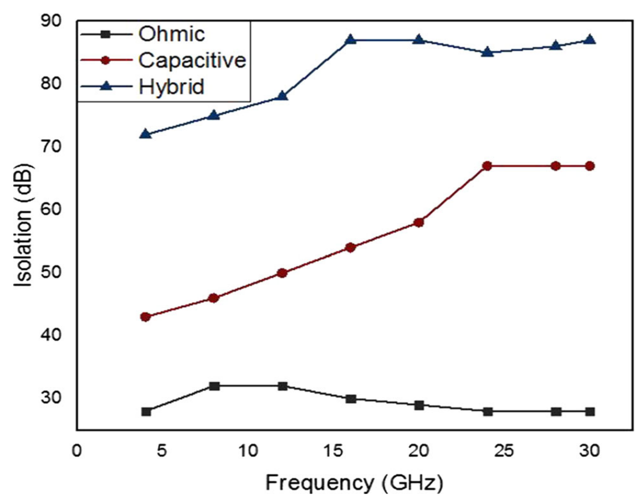

Fig. 12 Compare individual switches with hybrid switch

$$S_{12} = \frac{1}{1 + \frac{jwc_d z_0}{2}} \quad (2)$$

When the shunt switch is OFF state and a series switch is OFF state the hybrid switch observed high isolation of 87 dB and compare with the individual switches the hybrid switch having high isolation. The below Fig. 11 shows different conditions of the membrane and isolation of Ohmic, capacitive and hybrid switches. In Fig. 12 compare hybrid switch with individual switches.

During Off state the hybrid switch shows good quality of isolation as 87 dB at 16 GHz.

Hybrid switch has the highest isolation compare to individual switches (Table 2) shows comparison of the proposed hybrid switch with the literature work.

Table 2 Comparison of the proposed RF MEMS switch with literature works

Parameters	Singh and Pashaie (2014)	Kumar et al. (2018)	Proposed design
Frequency (GHz)	20	26	16
Isolation (dB)	60	82.4	87.2
Insertion loss (dB)	0.1	0.1	0.1
Return loss (dB)	50	59	63

4 Conclusion

In this paper, a novel Hybrid SPDT RF MEMS Switch is proposed and analyzed the RF performance. The performance parameters such as isolation return loss and insertion loss are analyzed. With different cases observe the isolation. In the Ohmic SPDT switch observe isolation at 32 GHz, in capacitive SPDT switch, observe isolation at 67 GHz and In hybrid SPDT switch OFF, OFF condition An good isolation of 87 dB is obtained at 16 GHz. An Insertion loss is − 63.6 dB and return loss is − 0.18 dB used for satellite applications.

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