CPW Dependent Loss Analysis of Capacitive Shunt RF MEMS Switch

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Abstract **─** CPW (CoPlanar Waveguide) plays major role in design of RF MEMS switch to improve the performance in terms of losses and required bandwidth of operation. This paper proposes the analyses of the mechanical characteristics on the electrical performance of the Capacitive Shunt RF MEMS (CSRM) switch based on various CPW structures and contact area roughness of the switch using electromagnetic 2.5D ADS simulator. The result of momentum method was analyzed up to the K-band frequency of 100 GHz. The result shows that the CSRM switch with two conductor CPW coupler has a maximum isolation of -46 dB with operating bandwidth up to 90 GHz at the resonant frequency of 50 GHz. 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 Terms **─** Artificial neural network, capacitive shunt switch, CPW, isolation loss, RF MEMS switch.

I. INTRODUCTION

Design of RF MEMS switches is one of the interesting research area that facilitates to design 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] in high frequency applications. Low cost MEMS switches are considered as prime category in MEMS technology due to their extremely low insertion loss (0.1 dB) [4] and very high isolation up to 100 GHz, near zero power consumption (10-200nJ/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 band width operation of MEMS switches make it ideal for several wireless applications, reconfigurable antennas, filters and tuners, low loss phase shifters and high Q passive devices and resonators [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 mechanisms for actuation like electrostatic and magneto static [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 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 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 work has 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 of coplanar waveguide (CPW) [13] and fixed on the ground conductor

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of CPW [14]. This configuration 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 4pF [7]. The electrical performance depends on the mechanical properties of structure, materials used for implementation and the method of fabrication [15]. The dependence of electrical performance of MEMS switches on mechanical properties can be studied by commercial simulation tools. Though RF MEMS switches are 3D structures, they can also be seen as 2.5D structure due to their high aspect ratio.

In this paper, the analyses of various losses of CSRM switch have been carried out using electromagnetic simulation for K-band (18-26.5 GHz) applications using 2.5D ADS–Momentum^{TM} full wave EM software. The isolation analysis, bandwidth and frequency of operation are concentrated by considering various configurations of CPW.

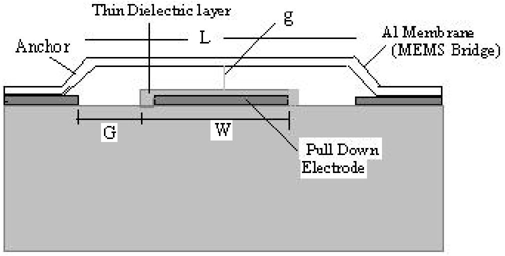
II. CAPACITIVE SHUNT RF MEMS SWITCH

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 continue t-line [9]. The capacitive MEMS switch has excellent performance up to 40 GHz [16] and life time in excess of 1 million cycles [17] under low power conditions.

B. Theory of capacitive shunt RF MEMS switch

The capacitive shunt MEMS switch taken for analysis is based on a fixed–fixed beam [18] 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. The center pull down electrode provides both the electrostatic actuation [5] 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).



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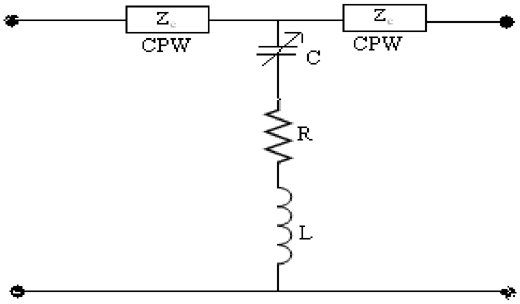

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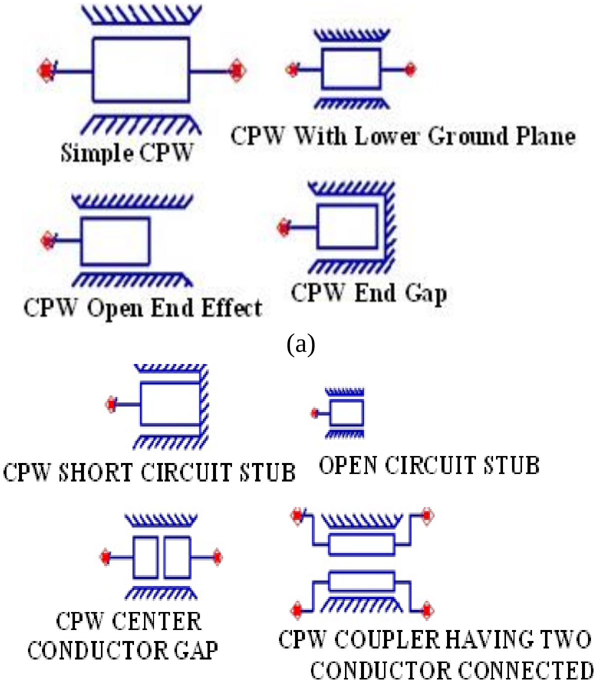
Fig. 1. Capacitive shunt RF MEMS switch: (a) cross section view and (b) equivalent circuit.

C. Structure of CPW

In the above mentioned lumped element model, the characteristic impedance (Z) of CPW plays a major role which is determined by G/W/G dimension. CPW is a planar transmission line (t-line) above which the shunt switch should be fabricated [5]. In this t-line, the signal and two ground lines are on the same plane [9]. There are various configuration of CPW like simple CPW, CPW with lower ground plane (CPWG), CPW with short open circuited stub (CPWSC), CPW with open circuited stub (CPWOC), CPW open end effect (CPWEF), CPW end gap (Cpwegp) and center conductor gap (Cpwcgp) and CPW coupler having two conductor connected (Cpwcpl2). The ADS symbols for the above mentioned CPWs are shown in Fig. 2.



(a)

(b)

Fig. 2. Different configurations of coplanar waveguide.

The ADS illustration of simple CPW configuration used in this work is shown in Fig. 3. In this figure, CPWSUB is the substrate required for all coplanar waveguide components with W and L are the center conductor width and length respectively and G is the gap between center conductors. The fitted values of this parameter for getting better loss performance of the considered switch are given in Table 1.

Table 1: Typical parameters of CPW used for ADS

Name	Description	Value
H	Substrate thickness	675µm
Er	Relative dielectric constant	11.8
Mur	Relative permeability	1
Cond	Conductor conductivity	4.1e7
T	Conductor thickness	1µm
TanD	Dielectric loss tangent	0.01
Rough	Conductor surface roughness	0µm
W	Center conductor width	120µm
G	Gap between center conductor and ground plane	90µm
L	Center conductor length	300µm

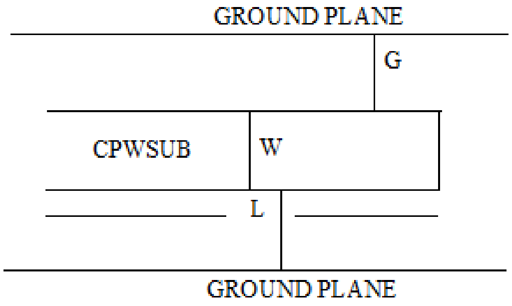


Fig. 3. Cross section of simple CPW.

D. Electromagnetic analysis of switch

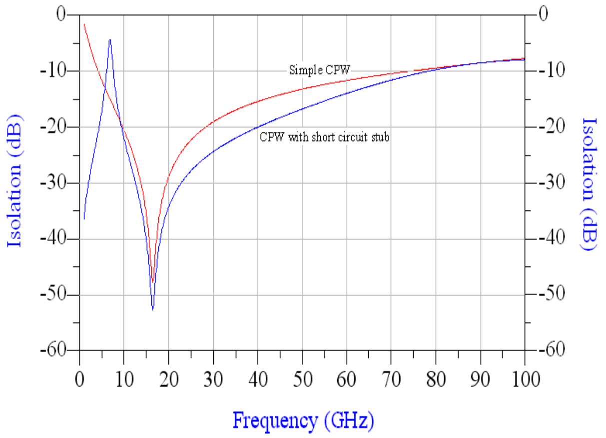
The EM modeling of CSRM switch is proposed with 2.5D full wave EM ADS-Momentum software. Using this EM tool, this paper proposes the electrical modeling of capacitive switch taking into account of electrical performance on the mechanical properties. In the simulation, the isolation parameters are extracted in the frequency range up to 100 GHz for different CPW structures. The parameters of the lumped model are optimized to obtain the value of S-parameter which is closer to ideal.

E. Artificial neural network

ANNs are biologically inspired computer programs to simulate the way in which the human brain process information. Neural models can be much faster than original detailed EM/physics models, more accurate than polynomial and empirical models, allow more dimensions than table lookup models and are easier to develop when a new device/technology is introduced [19]. The power of computation in neural network is determined from connections in a network. 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. Training a network consists of adjusting weights of the network using learning algorithms. During learning process, neural network adjusts the weights and thresholds so that the error between neural predicted output and sampled output is minimized. The learning algorithms used in this work are based on multilayer correction learning algorithm called back propagation [20]. During training process, the inter-unit connections are optimized until the error in prediction is minimized. Once the network is trained, new unseen input information is entered into the network to calculate the test output. The neural network architecture used in this paper is the MultiLayer Perceptron Neural Network (MLPNN), which is multilayer feed forward architecture composed of layers of computing nodes called neurons [21].

III. RESULTS AND DISCUSSION

Since the CPW has been used as the base for RF MEMS switches, we have taken various configuration of CPW to analyze the resonance frequency, bandwidth and isolation characteristics of capacitive shunt RF MEMS switch. Figure 4 shows the isolation of switch for different structures of CPW. It is clear that the resonance frequency obtained is above 15 GHz for all structures and the three structures (CPW coupler, CPW open end effect and CPW end gap) are able to work in two different resonant frequencies. The maximum operating frequency (90 GHz) can be obtained from CPW end gap and CPW open end effect structures with better isolation of nearly -75 dB.



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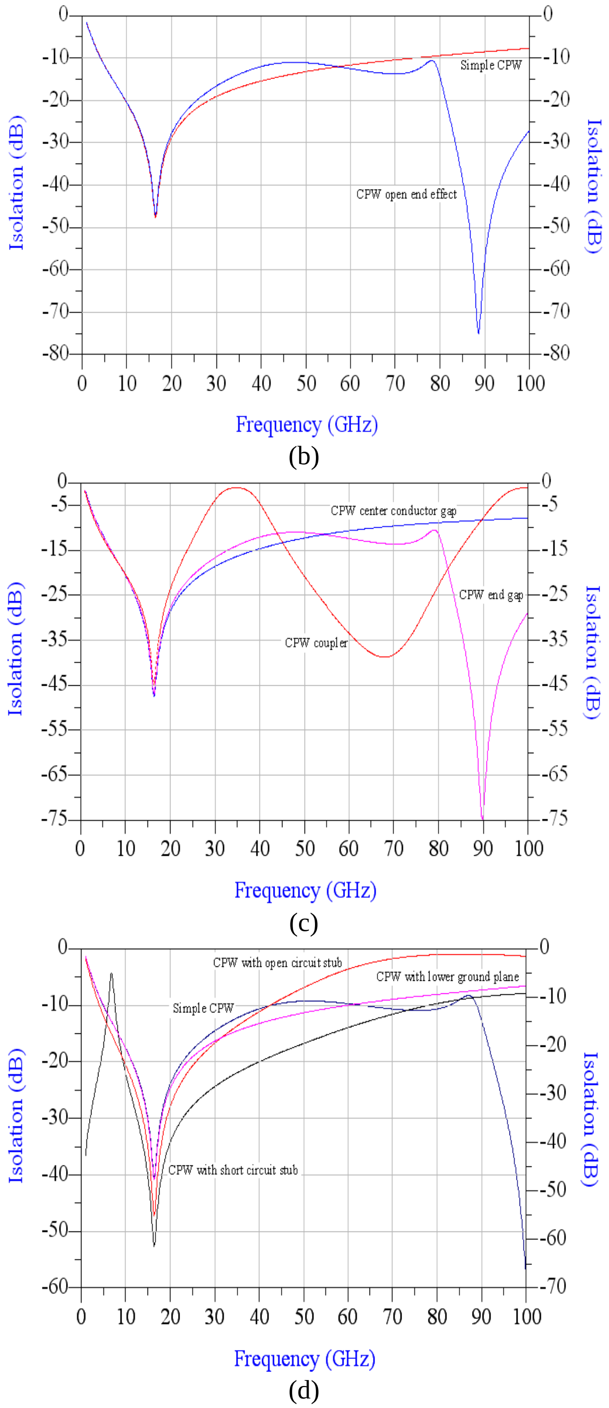


(b)

(c)

(d)

Fig. 4. Comparison result for isolation performance of CSRM switch with different CPW structures: (a) simple & short circuit stub, (b) simple and open end effect, (c) CPW center conductor gap, end gap and CPW coupler, and (d) CPW open, short circuit stub, lower ground plane and simple CPW.

Among all structures considered, the switch with CPW having lower ground plane differ in isolation loss characteristics by random variants of loss in operating frequency and maximum isolation of only -32 dB. All other switch structures can work with maximum isolation up to -45 dB at the resonance frequency of 15 GHz. The comparison of three parameters taken for analysis of CSRM switch for with various CPW structures is shown in Table 2. Since the resonant frequency of 15 GHz has been achieved in all CPW configuration of CSRM switch, these switches are much suitable for K-band satellite communications applications.

Table 2: Performance comparison of CSRM switch structures with simple CPW structure

CPW Type	Bandwidth Resonance (GHz)	Operating Frequency (GHz)	Isolation (dB)
SCPW	ENTIRE	16	-48
CPWG	ENTIRE	16	-41
CPWSC	5-80	16	-52
CPWOC	5-41	16	-48
CPWEF	5-90	16 & 88	-45 & -75
CPWEGP	5-90	16 & 90	-46 & -75
CPWCGP	5-70	16	-46
CPWCPL	5-25 & 45-90	16 & 68	-45 & -75

Based on the statistical obtained from comparison figures, it is obvious that the CSRM switch having CPW coupler with two conductors connected is having superior characteristics in terms of dual bandwidth with maximum operating bandwidth up to 90 GHz, higher isolation of -46 dB and resonant frequency of 67 GHz. The equivalent lumped circuit model of CSRM with simple CPW derived from ADS simulation is shown in Fig. 5. This switch topology is normally used in the integrated circuits where RF lines are DC grounded. In that condition, the membrane cannot be directly anchored to the CPW ground planes but a capacitive anchor is used for DC isolation.

The capacitive anchor of the membrane to the CPW ground planes has been considered as two shunt capacitors one for each anchor. The Fig. 6 (a) shows the comparison of isolation of the simple CPW CRSM switch with and without capacitive anchor. It is observed that the resonant frequency has been shifted to 30 GHz with the penalty of reduction in isolation loss of -7 dB with the addition of capacitive anchor for DC isolation when the switch is used for integrated circuits.

In the above lumped element model, the value of contact capacitance in the down state has the deviation in value which depends on the perfect roughness of the material between the membrane and the CPW center conductor. In order to validate the obtained result, the neural network comparison has been trained with the ADS result obtained for with and without capacitor anchor. After many trails, network (Fig. 6 (d)]) 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 MLP network was trained with input and hidden layers having the hyperbolic tangent sigmoid activation function and output layer having linear activation function as the learning algorithms. Figure 7 shows the comparison between ADS and neural network result for simple CPW with and without capacitive anchor. The better agreement between the results from ADS and ANN training clears that the fitted circuit values in the lumped element model are optimized by simulation.

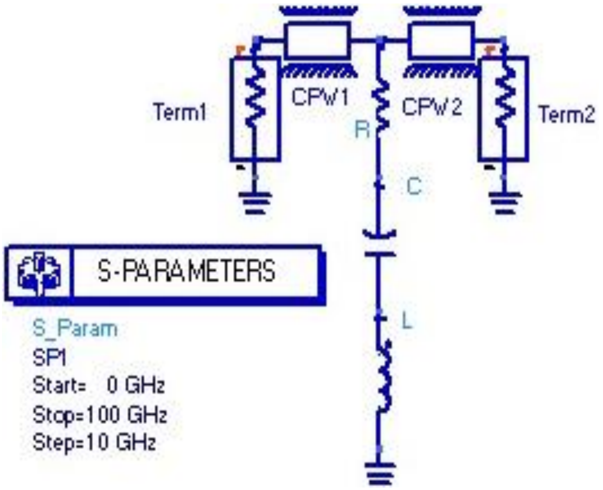
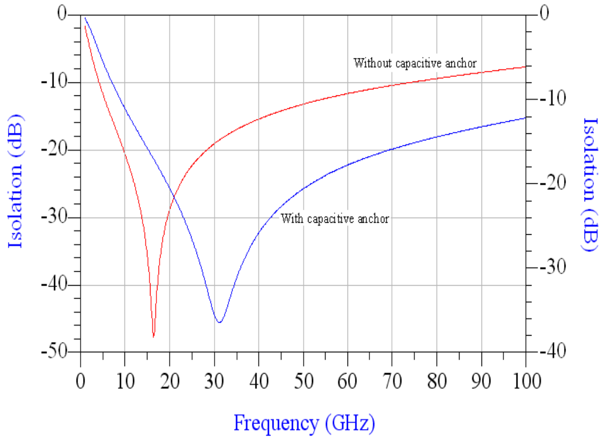


Fig. 5. ADS lumped element model of CSRM.



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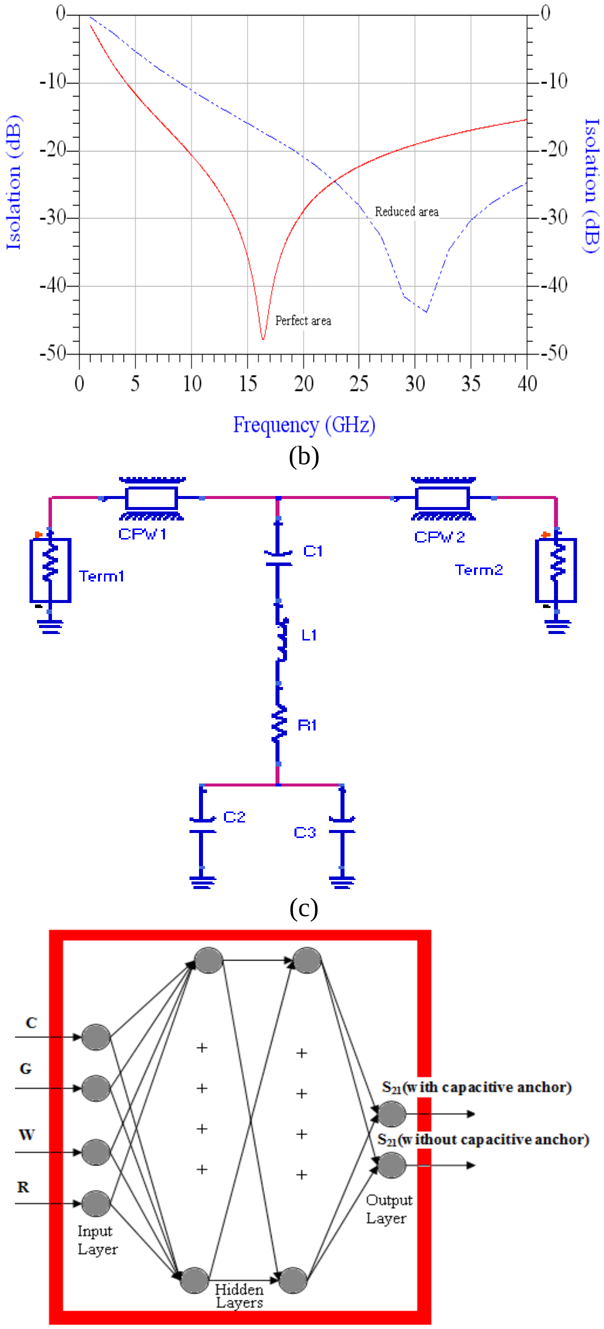

(b)

(c)

(d)

Fig. 6. Isolation performance comparison of CSRM: (a) with and without capacitive anchor, (b) with perfect and reduced contact area between membrane and center conductor, (c) lumped ADS circuit model of CSRM with shunt capacitor for DC isolation, and (d) ANN model.

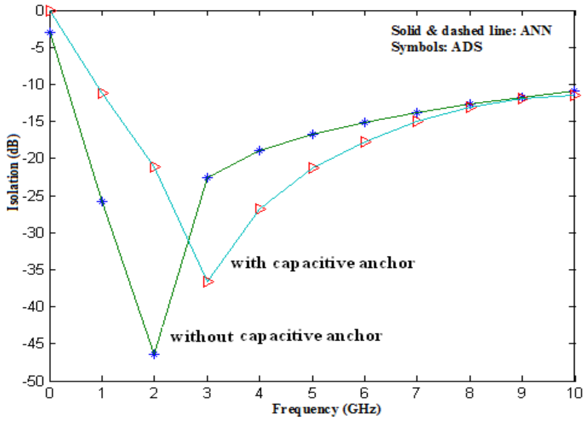

Fig. 7. Comparison of ADS and ANN trained values for isolation of CSRM switch with and without capacitive anchor.

VI. CONCLUSION

Different issues to analyze the mechanical properties on the electrical performance in terms of isolation and resonant frequency of capacitive shunt RF MEMS switch have been discussed for K-band satellite communication applications. The electromagnetic simulation results that the resonant frequency and the isolation performance of the proposed switch can be improved in two ways: by proper selection of CPW structures and the roughness of the contact between the membrane and CPW center conductor. From the analyses using different CPW structures, the better switching performance has been achieved from the switch with CPW coupler having two conductors connected. By reducing the contact area, the isolation increase of -4 dB and the resonant frequency up shift of about 15 GHz has been derived. The proposed switch performance can find applications with electronically scanned arrays (phase shifters), reconfigurable antennas and in tunable band-pass filters.

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