A Novel Reconfigurable MMIC Antenna with RF-MEMS Resonator for Radar Application at K and Ka Bands

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***Abstract*—This paper presents a new reconfigurable antenna based on coplanar waveguide (CPW). The design for reconfigurable antenna is based on monolithic microwave integrate circuit (MMIC). This scheme combines a CPW antenna and switchable resonator radio frequency micro-electro-mechanical system (RF-MEMS). The resonator RF-MEMS presents a meander inductor structure and tuning capacitor controlled by the applied DC voltage. This component can be used for the System on the Chip (SoC). Moreover, this device presents a compactness characteristic and the possibility to operate at high frequencies. The switch element allows changing the frequency band and the resonant frequency easily. The simulation results are shown between 10 and 40 GHz. The presented reconfigurable antenna can cover five bands: (26, 26.6) GHz, (26.4, 27.3) GHz, (27.3, 28) GHz, (29, 30.1) GHz and (30.13, 30.7) GHz. All simulation results were made by the High Frequency Structural Simulator (HFSS) software and validated by Computer Simulation Technology Microwave Studio (CST MWS).**

Keywords—RF-MEMS; CPW; Bandwidth; Meander; Resonator; Frequency reconfigurable antennas and MMIC

I. INTRODUCTION

Recently, the reconfigurable antennas, which are able to support different standards [1] becomes a very interesting topic for researchers. In the literature, a multiple reconfigurable frequency antenna designs have been published in wireless communication field [2].

In various applications, the reconfigurable single or array antennas use several switching technologies, such as, varactors [3], inductor [4], PIN diodes [5], FET transistor [6] and RF-MEMS.

In 1998, E. Brown is the first researcher witch used the RF-MEMS for reconfigurable antenna [7]. Lately, many potential researchers use the RF-MEMS for frequency reconfigurable antenna essentially at very important frequencies.

The micro-electromechanical systems (MEMS) present the mixture of mechanical and electronic elements integrated on a common substrate. A common feature in MEMS component is the presence of suspended membranes of different geometry (beams, cantilevers, bridges, etc.), which allows to obtain a unique and very complex functionality [8]. The RF-MEMS is used to replace the classical switch based on semiconductors to obtain the best RF performance [9].

Actually, The RF-MEMS switches present many advantages compared to the conventional semiconductor components, such as, low insertion losses, good linearity, low power consumption, very important cut-off frequency, small volume and low cost fabrication [10]. However, the RF-MEMS switches have some limitations, such as, their switching speed, usually limited to a few microseconds caused by the mechanical structure movement [11].

The RF-MEMS switches can be used in various domains in wireless communication, space, defence, security applications [12] and complex circuit.

In recent years, the radio frequency (RF) MEMS electrostatic actuators have been widely used in microwave communication system applications [13]. The majority of RF-MEMS are operated using an electrostatic force. This micro-electromechanical bridging element is employed to change the frequency.

In the literature, there are many recent reconfigurable antennas using different technologies; Such In [14], Prafulla et al have developed a reconfigurable Microstrip patch antenna using MEMS switch for Ku-band application, showing a good result in the gain and the frequency range; In [7], Bahram et al have used the SIW antenna technologies with the RF-MEMS switch in order to obtain the reconfigurable antenna by optimising the radiation pattern. In [15], Slot-ring patch antenna loaded with multi MEMS has been proposed and designed giving three different approaches (switchable antenna with RF-MEMS switches, wideband or multiband antenna integration with tunable filters, and array architectures). In [16], the CPW technology is combined with RF-MEMS cantilevers for the design of the reconfigurable UWB antenna.

The main problem with these papers is the hybrid structures (heterogeneous integration); only a few papers, such [15], have used the monolithic structure.

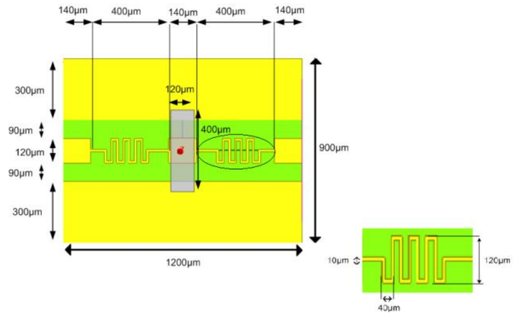
In this paper a novel structure design of monolithic reconfigurable antenna is presented and designed. The proposed structure of RF-MEMS resonator based on a bridge with two meander self. The presented paper falls into three parts: Section 1 presents a design of the proposed resonator

RF-MEMS giving the simulation results for the MEMS parameters, such as the return loss, the insertion loss at different states. In Section 2, a CPW multiband antenna is described. In Section 3, the application of reconfigurable CPW antenna with the insertion of the RF-MEMS resonator is designed and analysed. Section 4 describes CPW reconfigurable antenna based on RF-MEMS resonator and finally Section 5 concludes this paper.

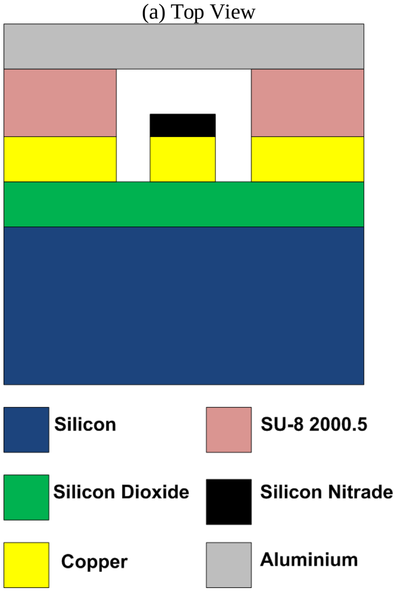
II. THE PROPOSED TUNABLE RF-MEMS RESONATOR

A. *Conception of the proposed resonator*

In the literature, there are tunable RF-MEMS, such as [17]-[18]; but their proposed structures are very complicated in order to have a simple configuration of a tunable RF-MEMS. We propose in [19] the structure of the Figure 1. This RF-MEMS resonator has a small dimension (1200x900x681) μm^3 and it is built with multilayer configuration as shown in Table 1. The base of the substrate is silicon (Si) with a thickness of 675 µm. The second layer is silicon dioxide (SiO_2). It is of the order of 2 µm and the line circuit CPW made of copper with thickness equal to 1 µm. The bridge is based on aluminium (Al) has a depth of 1µm. The bridge ends are attached to the base line of the CPW by a negative toner photoresist based on an epoxy polymer called SU-8 2000.5 with a thickness of 3 µm. The dielectric is fabricated with a Silicon Nitrade (Si_3N_4) with depth equal to 1µm.



(a) Top View



(b) Cross sectional view

Fig. 1. Design of resonator RF-MEMS

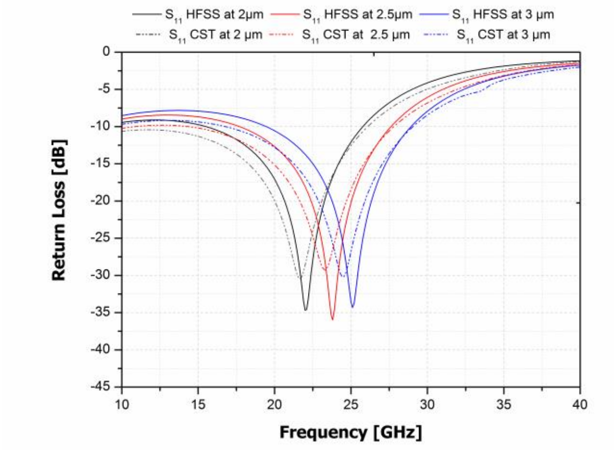
TABLE I. GEOMETRIC PARAMETRS OF THE RESONATOR RF-MEMS

	Material	**Design parameter**	**Value**
Substrate	Si	Length*Width*Thickness (μm^3)	1200*900*675
Buffer layer	SiO_2	Length*Width*Thickness (μm^3)	1200*900*1
Patch	Cu	CPW ligne (G/C/G) (µm)	90/120/90
		Meander RF line Length (µm)	400
		Meander RF line width (µm)	10
		Meander RF space (µm)	10
		Thickness of patch (µm)	1
Dielectric	Si_3N_4	Length*Width*Thickness (μm^3)	(140*120*0.5)
Epoxy	SU-8 2000.5	Length*Width*Thickness (μm^3)	(50*120*3)
Bridge	Al	Length*Width*Thickness (μm^3)	(400*120*1)
		Initial gap with RF line g_0 (µm)	3

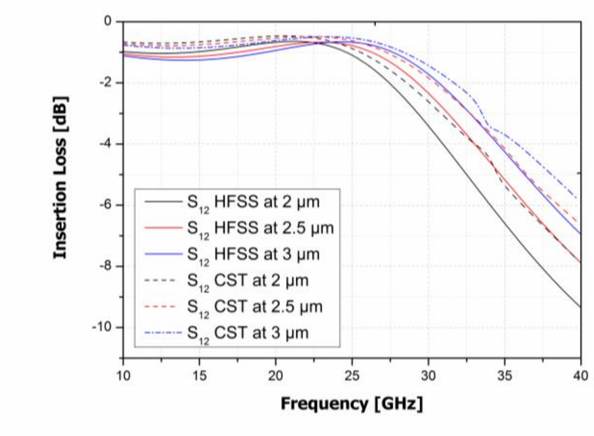
B. *Simulation results of the proposed resonator*

The proposed tunable resonator has been simulated by HFSS and CST MWS. Figure 2 presents the scattering parameters for different bridge positions made on a frequency band between 10 GHz and 40 GHz. The spacing g among bridge and CPW line varies between g=2µm at OFF state and g=3µm at ON state.

In Figures 2(a) and 2(b) shown as respectively the return loss (S_{11}) and the insertion loss (S_{12}) respectively for g=2, 2.5 and 3 µm are shown. Bridge to change these levels gives three resonance frequencies. The insertion loss S_{12} parameter presents almost constant value equal to -1 dB for all simulated spacing g factor when the S_{11} parameter is down to -10dB. There is a good correspondence between the simulation on HFSS and CST MWS.



(a) Return Loss parameters at 2, 2.5 and 3 µm



(b) Insertion Loss parameters at 2, 2.5 and 3 µm

Fig. 2. Scattering parameters at: (a) OFF state ,(b) g = 2, 2.5 and 3µm

The frequency range and the applied voltage is shown in Table 2. In this Schedule contains a comparison of the simulation result between HFSS and CST. The proposed bandwidth covers 3 bands.

TABLE II. RF-MEMS RESULTS

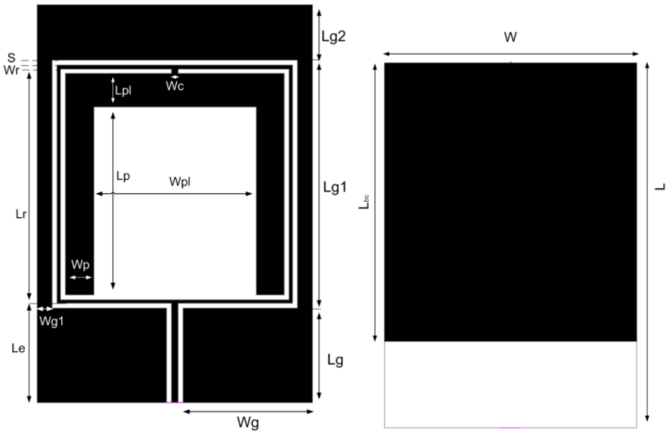
Space g(µm)	***Applied voltage (V)***	***Cover band***			
		Resonance Frequency (GHz)		Frequency range (GHz)	
		HFSS	CST	HFSS	CST
2	25V	21.9	21	15.6-25.7	10-26.1
2.5	19V	24	23.1	17.8-27.6	14.4-27.8
3	0V	25.1	24.6	19.5-29	16.8-29

III. CPW ANTENNA WITH ABSENCE OF RF-MEMS RESONATOR

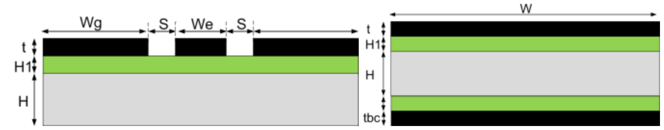
A. Geometry of the proposed antenna

Figure 3 shows the geometry of the proposed design multiband antennas. This antenna consists of CPW above IC antenna (4.9*7.1* 0.677) mm^3. The wafer is based on Silicon substrate with a thickness of 0.675 mm and Buffer layer based on SiO_2 equal to 1µm. L and W denote the length and width of the Wafer respectively, which are constant at 4.9 mm and 7.1 mm here.

The RF patch is modified in the shape of an inverted U with a ring resonator are printed and 50 Ohm CPW feed line ((S/We/S) = (90/120/90) µm) with a Length 1.6 mm on the same side of the substrate. The conductor-backed consists of rectangular for improving antenna efficiency [20]. In the Table 3 shows the dimensions of the proposed antenna.



(a) Top view configuration (b) Bottom view configuration



(c)Cross-sectional view at starting terminal (d) Cross-sectional view at finished terminal

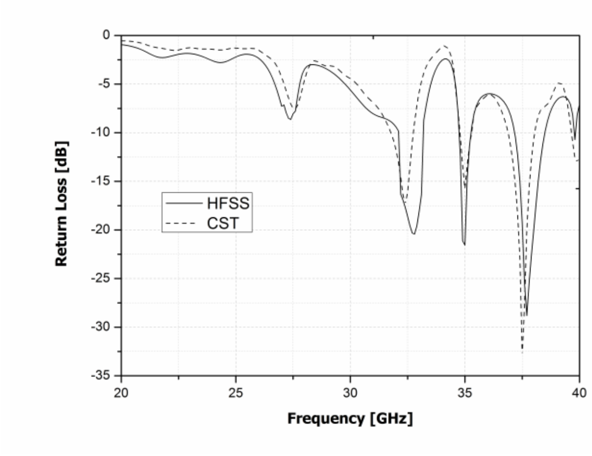
Fig. 3. Structure of proposed antennas

TABLE III. THE GEOMETRIC PARAMETERS OF THE CPW ANTENNA

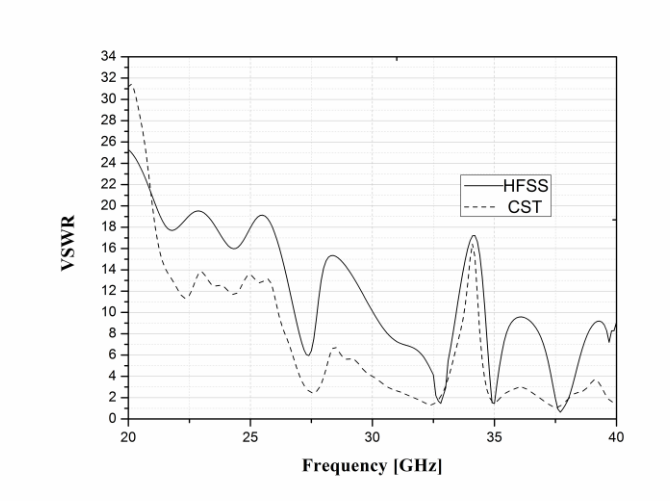
Index	**Value (mm)**	**Index**	**Value (mm)**	**Index**	**Value (mm)**
L	7.1	W	4.9	H1	0.675
H2	0.001	T	0.001	Tbc	0.001
L_{bc}	5.34	Lg	1.68	Lg1	4.41
Lg2	0.99	Wg	2.25	Wg1	0.26
Le	1.77	We	0.120	S	0.090
L_r	4.14	W_r	0.06	Wc	0.12
Lp	3.36	Lpl	0.59	Wp	0.5
Wpl	2.9				

B. Simulation results of the CB-CPW antenna

The simulation results of the proposed antenna are presented in Figure 4. The Figures 4(a) and (b) shows respectively the reflection coefficient and the voltage standing wave ratio (VSWR), the resonant frequencies at 32.8, 35.1 and 37.5 GHz and the simulation -10 dB impedance bandwidth of the proposed present their bands respectively [32-33], [34.8-35.3] and [37.2-38.44] GHz and VSWR (< 2) of their bands.

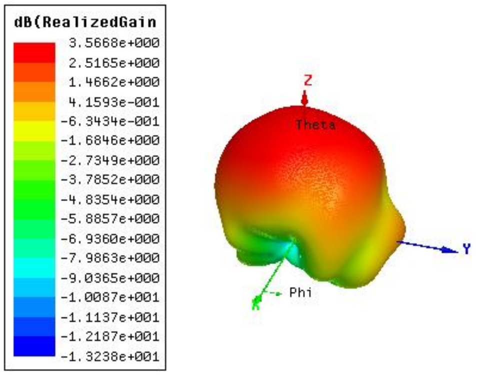


(a) Return Loss

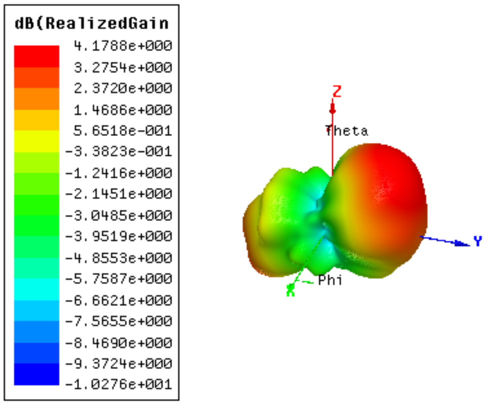


(b) VSWR

Fig. 4. Return Loss and VSWR of the proposed antennas



(a)



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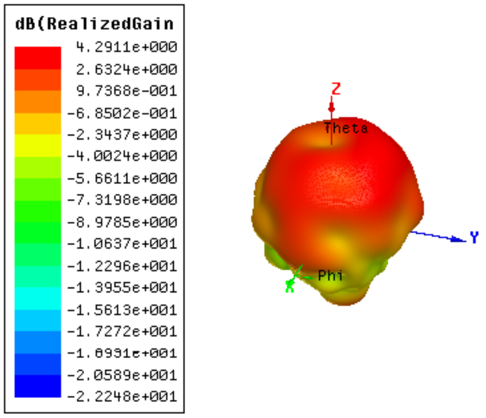


(c)

Fig. 5. Realised gain of the proposed antenna at different frequencies: (a) at 32.8 GHz, (b) at 35.1 GHz and (c) at 37.5 GHz

Figure 5 presents the realised gain in 3D polar at three resonance frequencies, 3.566, 4.178 and 4.29 dB, respectively.

IV. CPW RECONFIGURABLE ANTENNA BASED ON RF-MEMS RESONATOR

A. *Geometry of the proposed reconfigurable antenna*

The configuration of the proposed reconfigurable CPW antenna is shown in Figure 6. The study of the integration of complementary RF-MEMS with CPW on the same substrate: MMIC technology. The reconfigurability of this antenna depends on the switching condition of the resonator RF-MEMS.

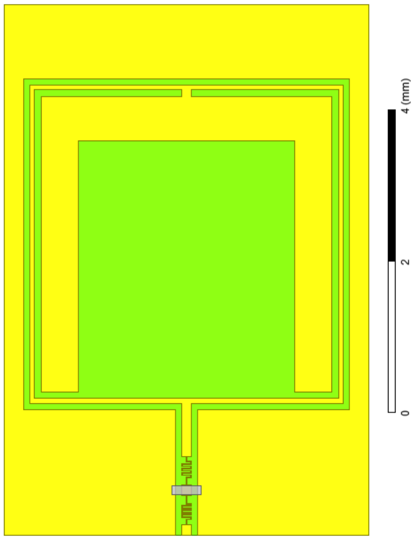


Fig. 6. Monolithic reconfigurable antenna based on RF-MEMS

B. Simulation results of the reconfigurableantenna

Figure 7 shows the reflection coefficient Simulation results, the resonant frequencies can be observed at three state of the bridge. for g = 2 µm has alone resonant frequency 26.3 GHz the return Loss is coming to be 15.1 dB, for g = 2.5 µm has two resonant frequencies: firstly at 27 GHz with a return loss of 23 dB and 29.8 GHz (18dB), and for g = 3 µm has two resonant frequencies 27.5 GHz (19.84 dB) and 30.6GHz (26.62 dB).

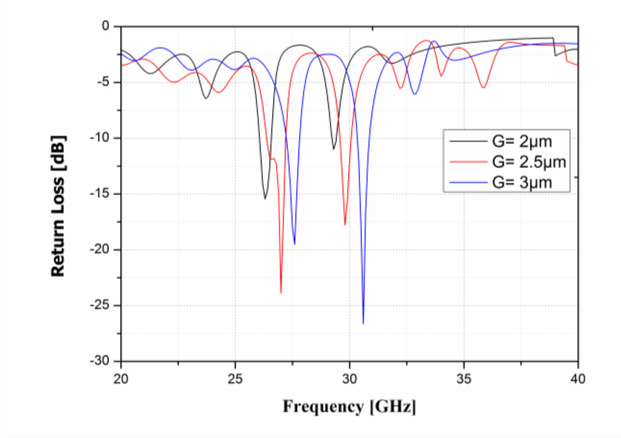
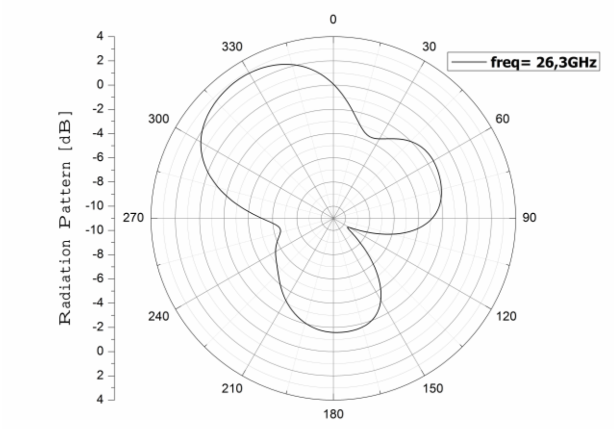
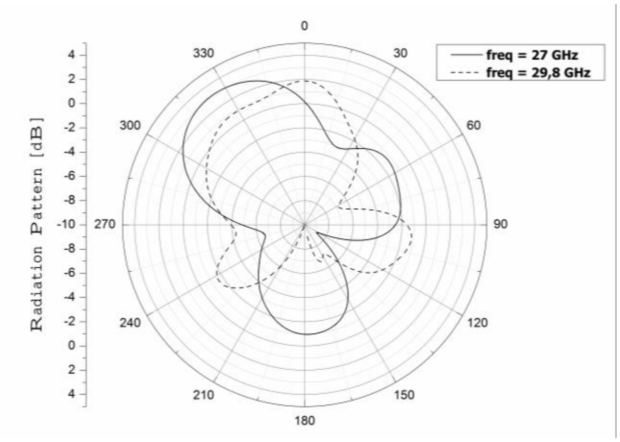


Fig. 7. Return loss of reconfigurable antenna at different at differents states

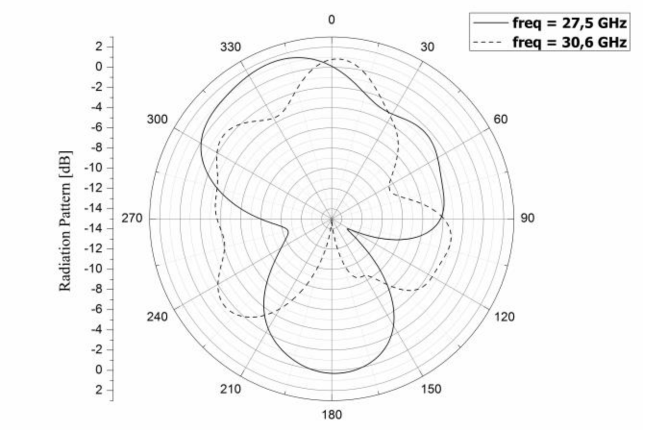
Figure 8 shows the radiation pattern at different resonance frequencies for three states when phi = 90°. Simulation results, the resonant frequencies can be observed at three state of bridge. Firstly, the three states bridge given three resonance frequencies and the main lobe at teta = 310°. Secondly, only for g= 2.5µm and g= 3µm given the resonance frequency and the main lobe at teta = 0°.



(a)



(b)



(c)

Fig. 8. Realised gain of the reconfigurable antenna at different states: (a) at 2µm, (b) at 2.5 µm and (c) at 3 µm

Table 4 summarises the results of the reconfigurable antenna in terms of resonance frequencies, frequency ranges, bandwidth (calculate by equation 1) and the gain.

$$BW\% = \frac{2(f_{\max} - f_{\min})}{(f_{\max} + f_{\min})} * 100 \tag{1}$$

TABLE IV. THE RECONFIGURABLE ANTENNA RESULTS

Parameters	***Values***				
Space g(µm)	2	2.5		3	
Applied voltage (V)	25	19		0	
Resonance Frequency (GHz)	26.3	27	29.8	27.5	30.6
RL (dB)	15.1	23	18	18.84	26.62
Frequency range (GHz)	26-26.6	26.4-27.3	29-30.1	27.3-28	30.13-30.7
BW(%)	2.281	3.333	3.691	2.545	1.863
Gain (dB)	3	3	2	2	1

V. CONCLUSION

This paper presents a new contribution design for reconfigurable antenna, the idea of this reconfigurable antenna is very simple, based on the association between the resonator RF-MEMS and CPW antenna. The resonator is based on meander inductors and variable capacities. The control of this capacity is depending of the applied voltage to the bridge membrane.

This sheet used for a new compact CPW antenna. The proposed antennas are a SRR and are added within the shape of inverted U shape to have the appearance multi-band feature which shows almost the same results as of CST, MWS and HFSS. The results of the resonant frequencies are 32.8, 35.1 and 37.5 GHz, respectively with the realised gain of 3.57, 4.18 and 4.29 dB, respectively.

The association of the proposed RF-MEMS and this antenna are the reconfigurability aspect at Ka band. For g = 2 µm has alone resonant frequency 26.3 GHz the return Loss is coming to be 15.1 dB and the realised gain equal to 3 dB, for g = 2.5 µm has two resonant frequencies 27 and 29.8 GHz with a return loss of 23 dB and 18dB, the realised gain 3 dB and 2 dB. For g = 3 µm has two resonant frequencies 27.5 and 30.6 GHz return loss (19.84 dB) and (26.62 dB) with realised gain 2 dB and 1 dB.

This resonator switcher can be used in different RF applications and in this paper this component is used in reconfigurable antenna.

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