RF MEMS Switches Enabled H-Shaped Beam Reconfigurable Antenna

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Abstract ─ This work presents a novel RF MEMS-based pattern reconfigurable antenna capable of steering beam in three different directions. The proposed H-shaped microstrip antenna is based on the basic structure of a dipole antenna and forms an 'H' shape by combining two dipoles in reverse fashion. The proposed antenna provides pattern reconfigurability at a single resonant frequency of 1.8 GHz, that lies in L-band. The optimized simple structure of the proposed antenna allows easy incorporation of single pole single throw (SPST-RSMW101) RF MEMS switches. The antenna is simulated using electromagnetic (EM) simulators (HFSS and IE3D). The proposed antenna is fabricated on RT Duroid substrate with 2.2 dielectric constant, and 1.75 mm thickness. The ON and OFF state of RF MEMS switches enables three different scenarios of operation with peak gains of 6.25 dBi, 6.28 dBi, and 4.01 dBi respectively. For validation of pattern reconfigurability the antenna is tested using time domain antenna measurement system and found to have a good agreement with the simulated results.

Index Terms ─ Beam steering, low profile, microstrip, reconfigurable antenna, RF MEMS switches.

I. INTRODUCTION

Recent advances in modern multi-directional radar systems and wireless applications demand high performance reconfigurable antennas. Reconfigurability in antennas can be achieved in frequency of operation, pattern, polarization and combinations of them [1]. Among the reconfigurability techniques, pattern reconfiguration devises the antenna beam in different axial directions for the same operating frequency. This ensures the pattern reconfigurability using the same antenna. The beam steering antennas are widely used in satellite, telemedicine, and radar communications [2-4].

Reconfigurability in antennas can be achieved by use of RF tunable components like radio frequency microelectromechanical system (RF MEMS) switches [1, 5, 6], Varactor diodes [7], and PIN diodes [8-10]. The RF MEMS have been proposed for incorporation into reconfigurable antennas for the last 2 decades. Since then many designs are reported [11-14] due to its profound advantages like electromechanical isolation and minimal power consumption, in comparison to conventional semiconductor devices.

The beam steering antennas can be classified into two broad categories: firstly, single antenna element configuration [15] and secondly the adaptive array antenna system [16, 17]. The size of a single antenna configuration is smaller in comparison to the array configuration. However, the gain achieved with the array configuration is higher than single antenna system [15].

In [18], radiation pattern reconfigurable antenna based on square spiral-microstrip is presented. The antenna is capable to reconfigure the radiation patterns between end-fire and broadside with the help of two Radant single-pole single throw RF MEMS switches. Another MEMS based reconfigurable Vee antenna was presented in [11], that steered the radiation beam in different directions at 3 GHz and 17.5 GHz.

In [12], two pattern reconfigurable antennas based on four RF MEMS switches is presented, operating at 6 GHz and 10 GHz. The gain of both the antennas reported is in the range of 3-6 dBi. The antenna composition is based on rectangular spiral microstrip along with the RF MEMS monolithically integrated and packaged in the same substrate. The physical length of the rectangular spiral is varied by activating the switches and thus achieving reconfigurability in radiation pattern for the same antenna. The authors in [19] presented an E-shaped frequency reconfigurable antenna operating at 1.9 GHz and 2.4 GHz with 30.3% bandwidth. The bandwidth was

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increased by introducing slots that forms the E-shape of the final structure.

In this paper, a new beam steering H-shaped antenna is presented. RF-MEMS switches are used to change the physical arm length of the H-shaped antenna to achieve the reconfigurability in its radiation pattern. The proposed antenna is able to steer the beam in two different directions in the elevation plane. The simulation results are carried out by using two artificial switches (S_1 and S_2), while the RF-MEMS are placed instead in fabrication. The proposed H-shaped pattern reconfigurable antenna is compact in size and has good agreement in its simulation and measured results.

II. DESCRIPTION OF THE ANTENNA

The composition of antenna is based on basic dipole antenna structure. However, two radiating elements opposite to each other are incorporated for different axial direction coverage. The geometry of the antenna is shown in Fig. 1. The right dipole and left dipole forms an H-shape and are activated using two RF MEMS switches (S_1 and S_2). The proposed pattern reconfigurable antenna operates at 1.8 GHz that lies in L-band. The design specifications of the proposed H-shaped pattern reconfigurable antenna are summarized in Table 1.

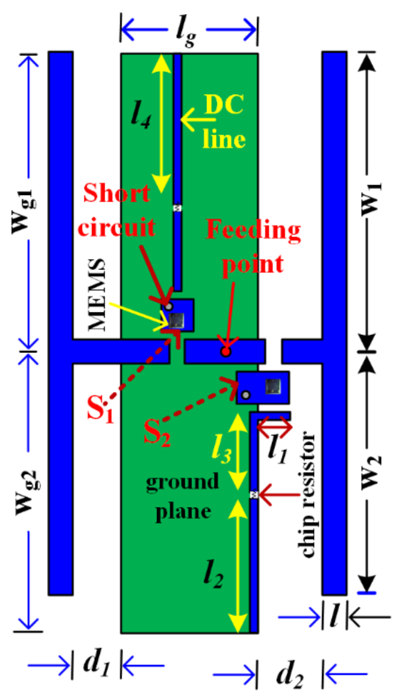


Fig. 1. The geometry of the proposed H-shaped antenna with MEMS.

The simulation of the proposed antenna is carried by Ansoft HFSS and Zeeland IE3D. The proposed antenna is fabricated on RT Duroid-5880 substrate with a dielectric constant of 2.2, loss tangent of 0.0009 and thickness of 1.57 mm. The width of the microstrip line is calculated using the Line Gauge of EM software IE3D. The resonant frequency of the proposed antenna depends on the total length of the microstrip line. The total length of the antenna (l_{tot}) can be calculated as:

$$l_{tot} = w_1 + w_2 \,. \tag{1}$$

In order to get accurate dimensions and accurate response of the proposed antenna, the ratio between w_1 and w_2 should be roughly 1.23. Keeping the ratio between w_1 and w_2 constant to about 1.23 and the width of the strip line (l) constant, the equation for the resonant frequency (f_0) of the antennas can be derived using the same procedure explained in [20, 21] as:

$$f_0 = \frac{c}{1.67 \times l_{tot}\sqrt{\varepsilon_e}}\,, \tag{2}$$

where ε_e is the effective dielectric constant, and c is the speed of light in free space.

Table 1: Proposed antenna parameters

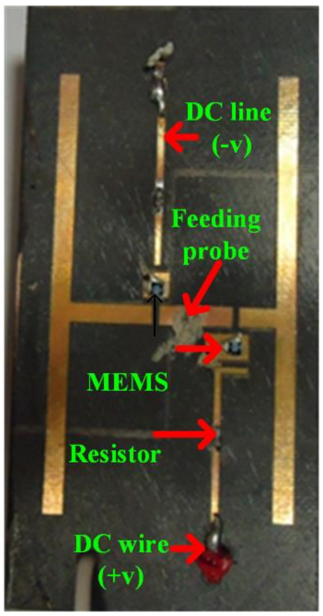
Parameters	Value (mm)	Parameters	Value (mm)
l	3	d_1	6
w_1	37.25	d_2	8
w_2	30.25	l_1	4
l_g	17	l_2	10
w_{g1}	37	l_3	16.7
w_{g2}	35	l_4	18.7

The antenna consists of an optimized ground plane with dimensions of 17×72 mm². The H-shaped patch has dimensions of 37×67.5 mm², where the width of each side of the H-shaped patch is 3 mm. The overall dimensions of the proposed antenna including the ground plane are 37×72 mm².

Two Radant MEMS single pole single through (SPST) RF MEMS switches are used for integration with the H-shaped antenna. The RF MEMS switches are highlighted in the fabricated version of proposed antenna as shown in Fig. 2. The RF MEMS switches (SPST-RMSW101) has a frequency range up to 12 GHz.

Figure 3 shows the close-up photograph of the RF-MEMS switch placement. One RF MEMS switch is placed on the rectangular patch with dimensions of 6.5×4 mm², while the other switch is placed on a square patch of 4×4 mm² size. The DC lines of 1 mm width each, as shown in Fig. 2, are used to apply the DC voltage. The switches are activated by applying DC voltage of 90 volts, while the Gate, source and drain are connected to the antenna arms with three bonding wires as shown in Fig. 3. Each RF MEMS switch is also connected to the ground to activate it. In addition, a 220 kΩ chip resistor is placed in each DC line to limit the current flow for the RF MEMS switches.

The operation of the antennas is therefore based ON and OFF state of the switches (S1 and S2). Thus the RF MEMS switches are placed in such a way that the left arm, right arm or both arms of the H-shape antenna can be activated or de-activated accordingly. This enables the antenna to steer its beam in 3 different directions. In case 1 switch 1 is ON and switch 2 is OFF, in case 2 switch 1 is OFF and switch 2 is ON, and in case 3 both switches are ON.



(a)

(b)

Fig. 2. The photograph of the fabricated H-shaped patch reconfigurable antenna with two artificial switches: (a) front side and (b) back side.

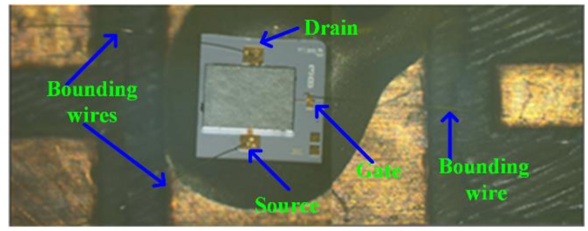


Fig. 3. The photograph of the RF MEMS switch placement.

III. SIMULATED AND MEASURED RESULTS

The H-shaped antenna was simulated using HFSS and IE3D for all the three cases. The fabricated antenna was also tested for all the three cases using Anritsu vector network analyzer 37369C. Figures 4-6 show the comparison of simulated and measured return loss (dB) for all the three cases, i.e. case 1 (ON-OFF), case 2 (OFF-ON), case 3 (ON-ON).

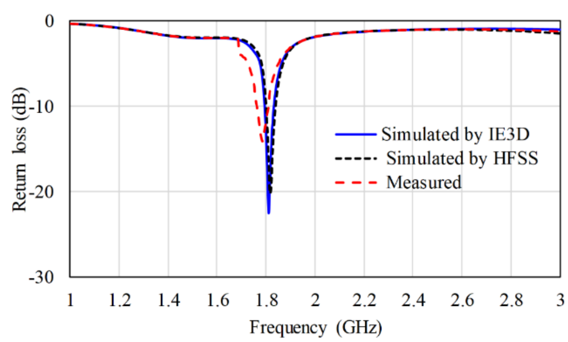


Fig. 4. Simulated and measured return loss for case 1 (ON-OFF).

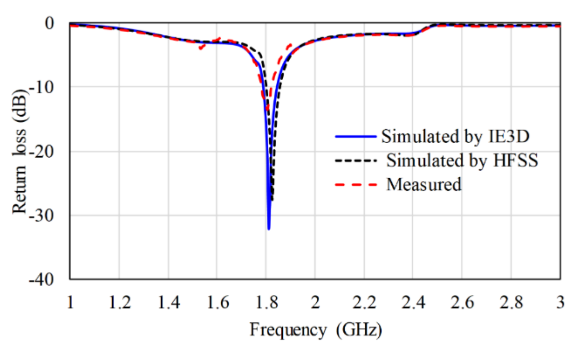


Fig. 5. Simulated and measured return loss for case 2 (OFF-ON).

As evident from Fig. 4, Fig. 5 and Fig. 6, a good agreement can be found in simulated and measured results. For all the three different cases the proposed H-shaped antenna has an operating frequency of 1.8 GHz with good matching. The characteristics of the H-shaped microstrip antenna such as gain, maximum beam direction, and maximum electric current for all the three cases using IE3D and HFSS are listed in Table 2 and Table 3 respectively.

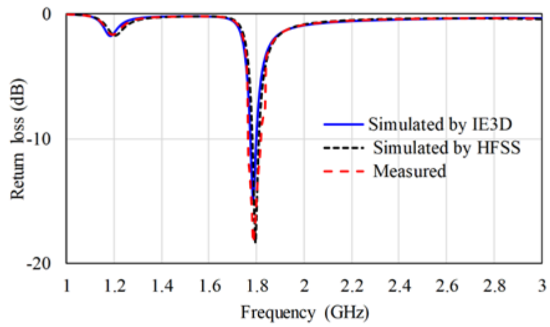


Fig. 6. Simulated and measured return loss for case 3 (ON-ON).

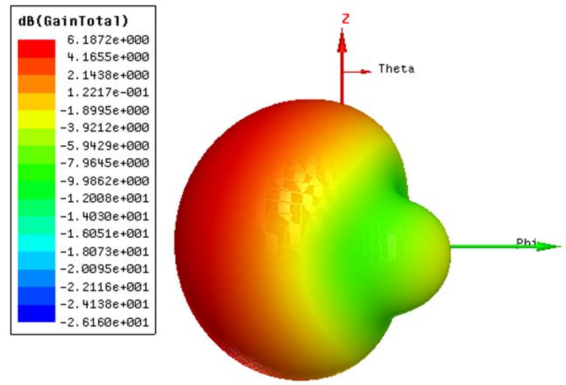
Table 2: Simulated characteristics of proposed antenna using IE3D simulator

Antenna State		Case 1	Case 2	Case 3
State of Artificial Switches	s_1	ON	OFF	ON
	s_2	OFF	ON	ON
Max. Beam Direction (degree)		-70	75	10
		0	0	90
Gain (dBi)		5.45	5.49	3.3

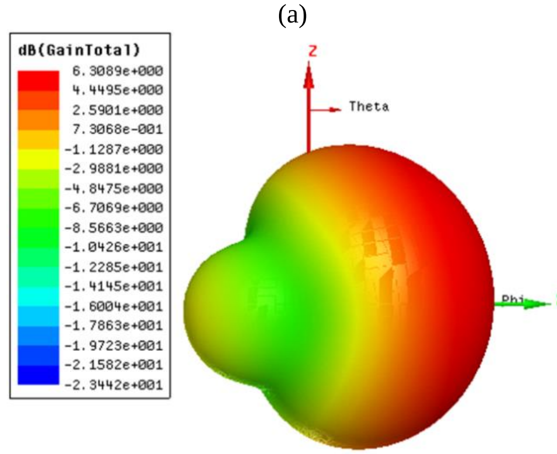
Table 3: Characteristics of H-shaped antenna in three cases by HFSS simulator

Antenna State		Case 1	Case 2	Case 3
State of Artificial Switches	s_1	ON	OFF	ON
	s_2	OFF	ON	ON
Max. Beam Direction (degree)		-75	80	10
		0	0	90
Gain (dBi)		6.25	6.28	4.01

Figure 7 illustrates the simulated 3D radiation patterns of the three cases of proposed antenna at 1.8 GHz using HFSS. A time domain antenna measurement system GEOZONDAS-AMS [22] is used to measure the radiation patterns for the proposed antenna. Figure 8 shows the normalized 2D simulated and measured radiation patterns of the proposed antenna on xz-plane are presented for case 1 (ON-OFF state), case 2 (OFF-ON state), and case 3 (ON-ON state) respectively. As seen in Fig. 8, the beam is steered in three different directions for the three cases. In case 1, the beam is directed at 270˚, while in case 2 the beam steers 180 degree apart from case 1, i.e., the maximum beam direction is at 90˚. However, for case 3, a multiplicative beam of case 1 and case 2 is observed with slightly reduced gain of 4 dB. The surface current distributions on the antenna arms for the three cases is presented in Fig. 9. The current distributions were carried out in IE3D simulator at 1.8 GHz.



(a)



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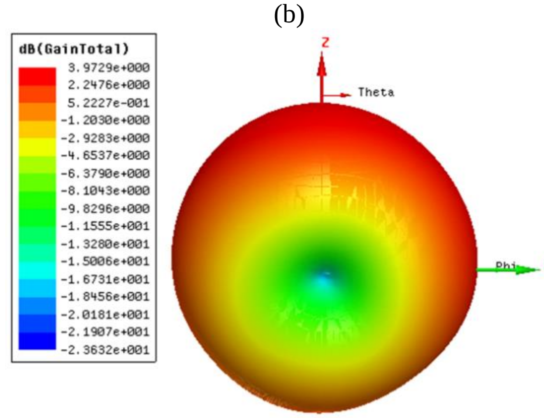
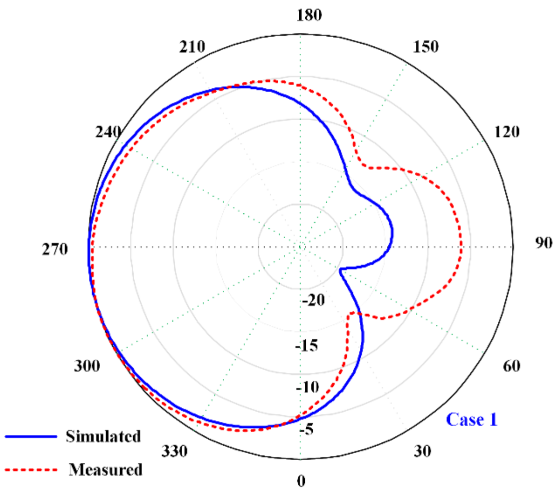


(c)

Fig. 7. The simulated 3D radiation patterns of the proposed antenna at 1.8GHz.



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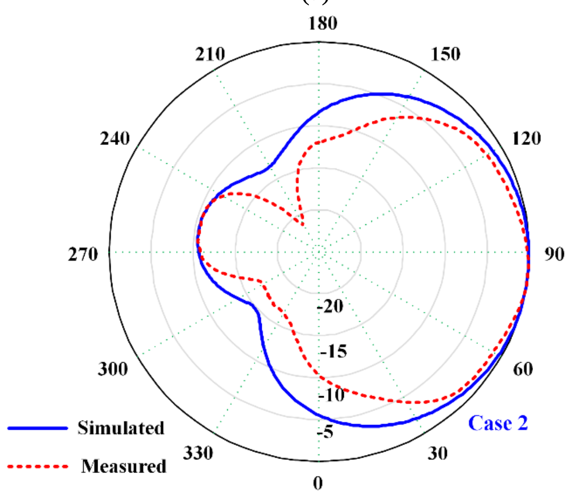

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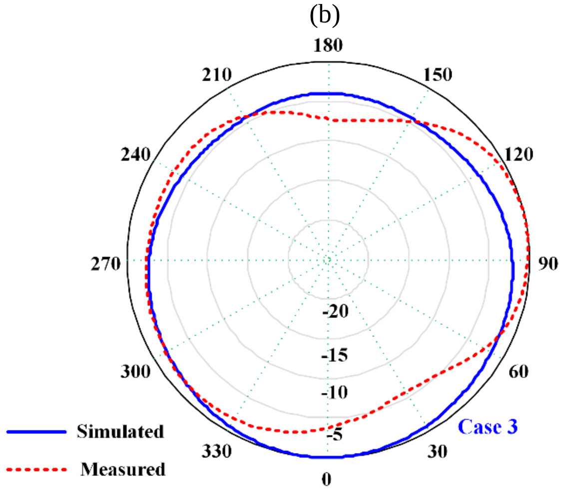
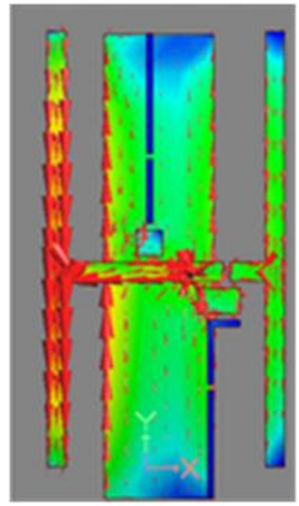
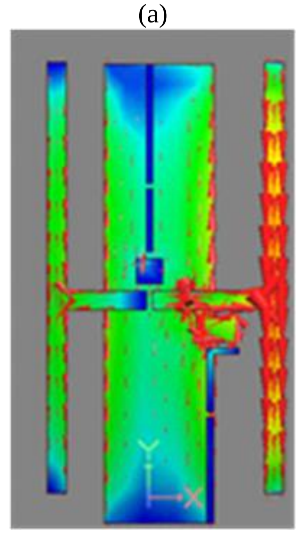


(c)

Fig. 8. The simulated and measured 2D normalized radiation patterns of the proposed antenna at 1.8GHz for: (a) case 1, (b) case 2, and (c) case 3 respectively.



(a)



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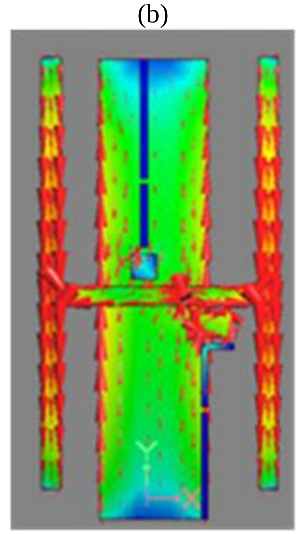

(c)

Fig. 9. Surface current distributions for: (a) case 1, (b) case 2, and (c) case 3 respectively.

The proposed reconfigurable antenna has more switchable directions than all MEMS reconfigurable antennas mentioned in Table 4. Additionally, our antenna has better gain among all the antennas listed in Table 4.

Table 4: Comparison Chart of reconfigurable antennas

Reference	No. of Beam Switchable Directions	Gain in All Directions (dBi)
[18]	2	NA
[11]	2	NA
[12]	2	3 ~ 6
Our proposed antenna	3	Case 1: 6.25 Case 2: 6.28 Case 3: 4.01

IV. CONCLUSION

A novel pattern reconfigurable H-shaped microstrip antenna has been designed, simulated, fabricated and tested. Two commercially available RF MEMS switches are utilized to steer the beam in three distinct directions. The proposed antenna has a simple structure, low profile, and has low manufacturing cost. The frequency of the proposed microstrip antenna is 1.8GHz with peak gains of 6.25 dBi, 6.28 dBi, and 4.01 dBi for case 1, case 2, and case 3 respectively. The different states of the MEMS switches make it possible to steer the beam in different prescribed directions without affecting the resonant frequency. This concept of reconfigurable antenna pattern is quite attractive as on antenna device can be utilized to steer the pattern in different desirable directions. The measured return loss and radiation patterns of the fabricated antenna shows a close agreement with the simulated results. Thus making the proposed antenna suitable for incorporation in pattern reconfigurable systems.

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