

Design of Frequency Reconfigurable Micro-Strip Patch Antenna for Wireless Applications

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ABSTRACT: This research presents innovative design of a compact reconfigurable microstrip patch antenna system using different rectangular rings. Switching between different frequency band is achieved using six RF-MEMS switches. The antenna is capable to reconfigure up to three different frequency bands. Empirical relations relating to the design for rectangular rings for desired frequency band are included in the Paper. The proposed microstrip patch antenna structure is fed by micro strip line feed. The antenna is designed to operate at 2.4 GHz, 3.5 GHz and 4.8 GHz. The proposed antenna provides triple bands in which the bandwidth of 367MHz for 2.45 GHz, 799MHz for 3.5 GHz and a bandwidth of 3.47 GHz for 4.8 GHz has been obtained. The design and functional simulation of the proposed antenna structure is performed by using HFSS-v13. Simulated and measured results are used to demonstrate the performance of the antenna. The proposed reconfigurable antenna is low profile, compact and small in size. There is good agreement between the measurement and simulation results of this research provides ample justification for compatibility and application of the structure for many wireless communications such as WLAN, WI-MAX, UMTS.

KEYWORDS: Reconfigurability, Reconfigurable Antenna, MEMS switch, UMTS(Universal Mobile Telecommunication service), WI-MAX, Wireless Local Area Network(WLAN).

I. INTRODUCTION

The reconfigurable antenna is an attractive design alternative to the fixed antenna as it can offer controllable radiating properties such as resonance for wireless communications systems. This added degree of control could allow for future-proofing a system to changing standards, compensating for production defects, or tuning in the field to match a sensitive wireless environment. Tuning is typically achieved through a varactor diode or tuned resistance [1]. Reconfigurable antennas have recently received significant attention for their applications in communications, electronic surveillance and countermeasures. In reconfigurable antennas, changing the shape of radiating element is achieved by switching.

Future cognitive communication systems will require antennas capable of operating over multiple wireless standards. Multiband Antennas are very desirable for current wireless applications as they can cover multiple frequencies using a single antenna. However, fixed multiband antenna usually requires complicated filters with inflexible requirements to improve their out-of-band noise rejection [2]. The filter usually bulky and can add complexity to any communication systems. As a solution to these disadvantages, a reconfigurable antenna can achieve a better out-of band noise rejection. Reconfigurable antenna is an antenna that capable to reconfigure its characteristics such as frequency, pattern, bandwidth, and polarization to adapt to the environment. The reconfiguration is not limited to a single characteristic but can be a combination of different characteristics depending on the application. Reconfigurable antennas can be classified into three different categories. The first category is based on frequency re-configurability. The aim is to tune the operating frequency of the antenna and to have a single multifunctional antenna in a small terminal for many applications. Recently, frequency reconfiguration has attracted significant attention due to the introduction of future wireless communication concept such as cognitive radio which employs wideband sensing and reconfigurable narrowband communication [3].

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The second category is based on pattern re-configurability, where the frequency band remains unchanged while the radiation pattern changes based on system requirements.

The third category is based on polarization re-configurability, where the polarization is switched from linear to circular and from left hand (LHCP) to right hand (RHCP) circular. There are different kinds of switching technologies that can be used to achieve re-configurability, such as optical switches, PIN diodes, FETs, and radio frequency micro-electromechanical system (RF-MEMS) switches [4]. RF-MEMS antenna systems were first introduced in 1998 by E. R. Brown [5] and since then have been studied by several research groups. However, the integration of RF-MEMS with the antenna has not been fully demonstrated.

In this paper a novel design of frequency reconfigurable antenna is presented. RF-MEMS switches are used for switching. By changing the state of the switches, an electrical reconfiguration of the aperture can be obtained. It is also possible to use PIN diodes as switching element but we preferred MEMS switch for their significant better RF characteristics than conventional PIN diodes or FET switches up to approximately 40 GHz, regarding insertion loss, isolation, power consumption and linearity [6].

The antenna geometry and a brief discussion about the antenna re-configurability are presented in section II. Section III presents simulated results showing results of proposed reconfigurable antenna. Finally, the conclusion remark will be given in section IV.

II. ANTENNA ANALYSIS AND PERFORMANCE

A. Antenna geometry

The triple band base antenna is described in this section. The design starts with a micro-strip patch antenna where Figure 1 demonstrates the geometry of the designed patch antenna with partial conducting ground plane. The antenna comprised of rectangular rings which contribute to the three resonance frequency of the proposed antenna. The optimal design of the proposed antenna has small overall dimension of $46 \times 38 \times 0.5 \text{mm}^3$. FR4 epoxy substrate with a permittivity of $\epsilon_r = 4.4$ and substrate thickness of $h = 0.5 \text{mm}$ is used for the antenna design.

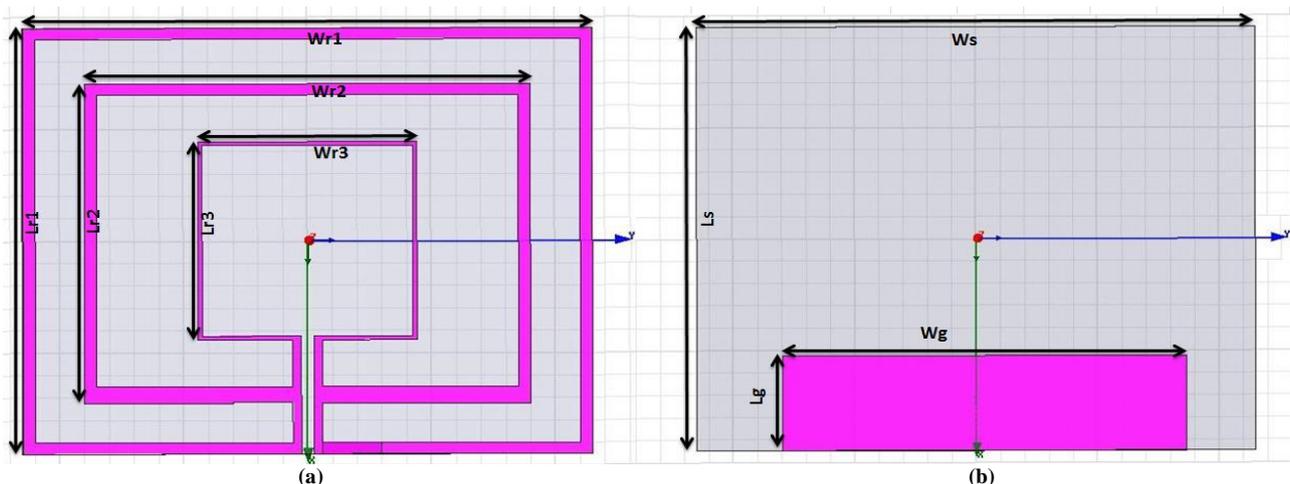


Figure 1 Geometry of triple band base antenna (a) Top-View (b) Bottom View

The dimensions and feed point location for proposed antenna have been optimized so as to get the best possible impedance match to the antenna. The dimension of the antenna is tabulated in Table 1.

Table 1: Dimension of the designed frequency reconfigurable antenna.

Parameter	Dimension(mm)	Parameter	Dimension(mm)
W_{r1}	46	t_1	1
W_{r2}	36	t_2	1
W_{r3}	17	t_3	0.34

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W _s	46	L _s	38
W _g	33.28	L _g	8.5
w ₁	4.82	L _{r1}	38
w ₂	4.82	L _{r2}	28.5
w ₃	3.5	L _{r3}	17.68

The analysis of the proposed compact reconfigurable antenna structure is based on transmission line modal analysis [7]. Figure 2 depicts the geometry of the proposed reconfigurable antenna with MEMS switches where the hatched area is metallization. A micro-strip feed-line, rectangular rings and six switch land pattern located on the top side. The bottom side metallization are a partial ground.

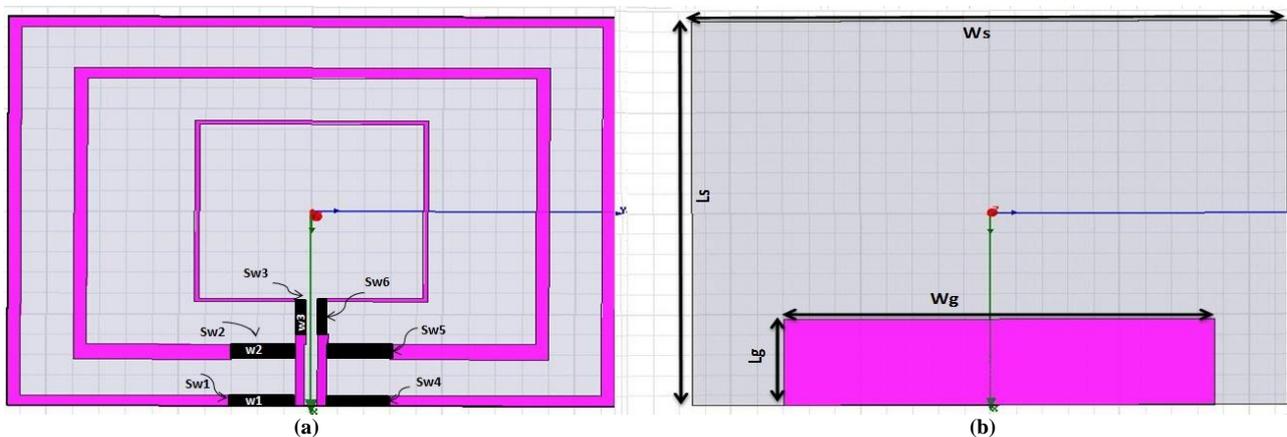


Figure 2 Geometry of proposed re-configurable antenna

DESIGNING EQUATIONS

Patch Dimensions: The width (W) and length (L) of the patch is given by the following formula-

$$W = \frac{c}{2fo \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

$$L = L_{eff} - 2\Delta L \quad (2)$$

$$Lg = 6h + L(3)$$

$$Wg = 6h + W \quad (4)$$

$$L_{eff} = \frac{c}{2 \times fo \times \sqrt{\epsilon_{eff}}} \quad (5)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\left(1 + 12 \frac{h}{W}\right)^2} \right] \quad (6)$$

$$\Delta L = 0.412 h \frac{(\epsilon_{eff} + 0.3)}{(\epsilon_{eff} - 0.258)} \times \left(\frac{W/h + 0.264}{W/h + 0.8} \right) \quad (7)$$

Where,

h = substrate thickness
L = length of patch
L_{eff} = effective length
W = width of patch
c = speed of light

fo = resonant frequency
ε_r = relative permittivity
ε_{reff} = effective permittivity
L_g = Length of ground plane
W_g = Width of ground plane

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B. FREQUENCY RECONFIGURATION USING MEMS SWITCHES

In order to achieve tuning and frequency reconfiguration, we have inserted narrow slots which act as open circuit stubs. The switches are located such that turning them ON allows only certain resonant frequencies. This final design is as shown in the fig. 2. Table 2 tabulates the switch configurations and resonant frequency of the proposed antenna.

Table 2: Switches and their respective frequency tuning

Switch Configuration	Bandwidth
Configuration I - (All ON)	I Band f_1 - 2.34GHz II Band f_2 - 3.76GHz III Band f_3 - 4.80GHz
Configuration II - (S1, S4 ON)	2.37 GHz
Configuration III - (S2, S5 ON)	3.54 GHz
Configuration IV - (S3, S6 ON)	4.74 GHz

In this paper, the proposed antenna is investigated by means of HFSS which is based on the finite element method (FEM). In this paper, the six MEMS switches are simulated by micro-strip lines. During the simulation and measurement, the presence of a metal bridge represents ON state and the absence of a metal bridge represents OFF state [8].

III. SIMULATION RESULTS AND DISCUSSION

The analysis of proposed antenna using RF-MEMS switch is done using the simulation performed on ANSYS HFSS EM simulator for the frequency range of 1 to 6 GHz. The re-configurability of the antenna is analysed in terms of return loss and radiation pattern.

- (1) Figure 3 shows the return loss (S_{11}) for proposed reconfigurable antenna for frequency ranging from 1 to 6 GHz when all switches are ON i.e. switch configuration I.

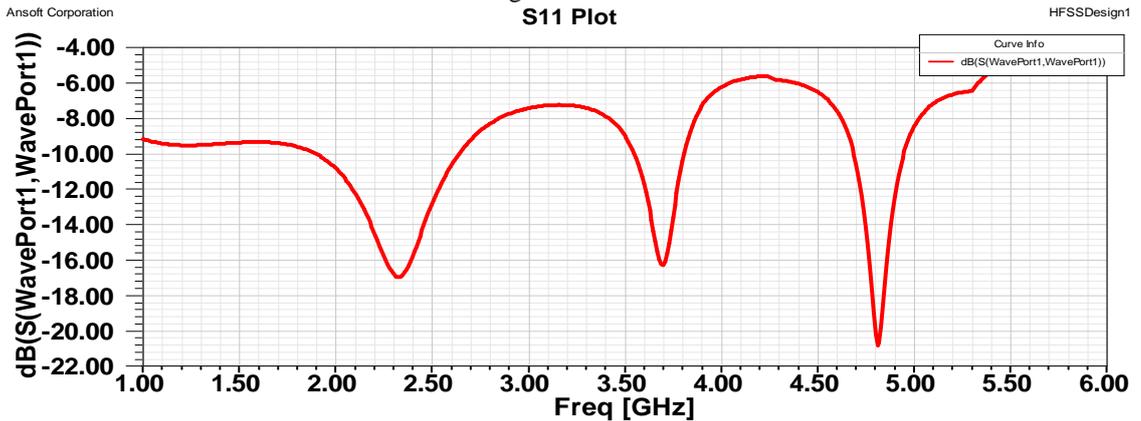


Figure 3 Graph of simulated return losses Vs. frequency of triple band base Antenna structure

From the plot of simulated return losses Vs. frequency of Antenna it is seen that the return loss of the antenna obtained is -17 dB at the resonance frequency of 2.34 GHz. Another resonance is obtained at the frequency of 3.76 GHz having return loss -16.31 dB and -20.85 dB at 4.8GHz shown in figure3. The simulated results show that the antenna covers a 32.05 % bandwidth (1.9 ~ 2.65 GHz) at f_1 , an 9.03 % bandwidth (3.5 ~ 3.82 GHz) at f_2 , and a 6.32 % bandwidth (4.65 ~ 4.95 GHz) at f_3 , thus allowing WLAN/Wi-MAX service.

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- (2) The graph depicted below in Figure (4) shows the RL characteristics corresponding to switch configuration II as stated in table 2. By altering the state of switches, the rectangle in radiator could be broken or completed. When the switch S1 & S4 is on, the complete outermost rectangular ring acts as a monopatch antenna and a narrowband centred on 2.37 GHz is obtained.

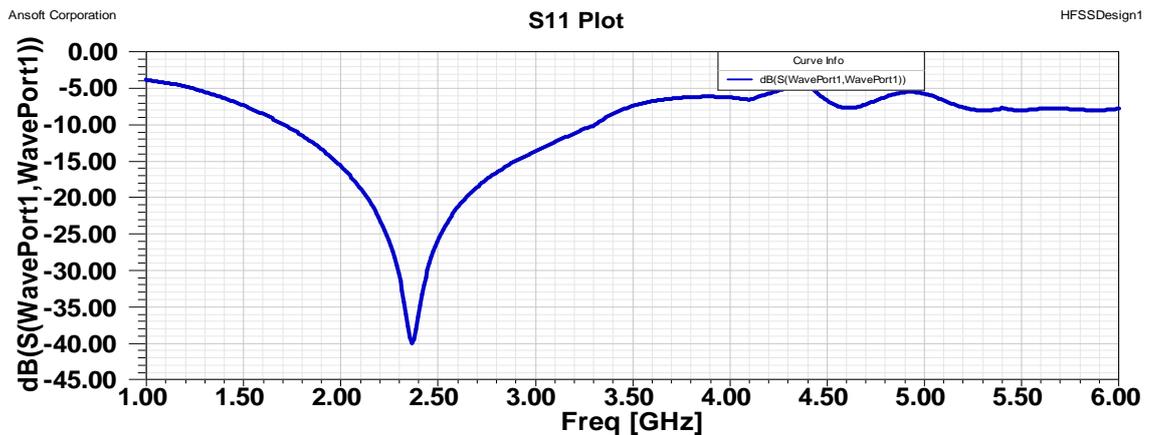


Figure 4. RL Vs. frequency curve for switch configuration II

From the plot of simulated return losses Vs frequency of Antenna it is seen that the return loss of the antenna obtained is -39.987 dB at the resonance frequency of 2.37 GHz.

- (3) The graph depicted below in Figure (6) shows the RL characteristics corresponding to switch configuration III. It is seen that for switch configuration III proposed antenna shows resonance at frequency 3.54 GHz covering 5.367% bandwidth for Wi-max application.

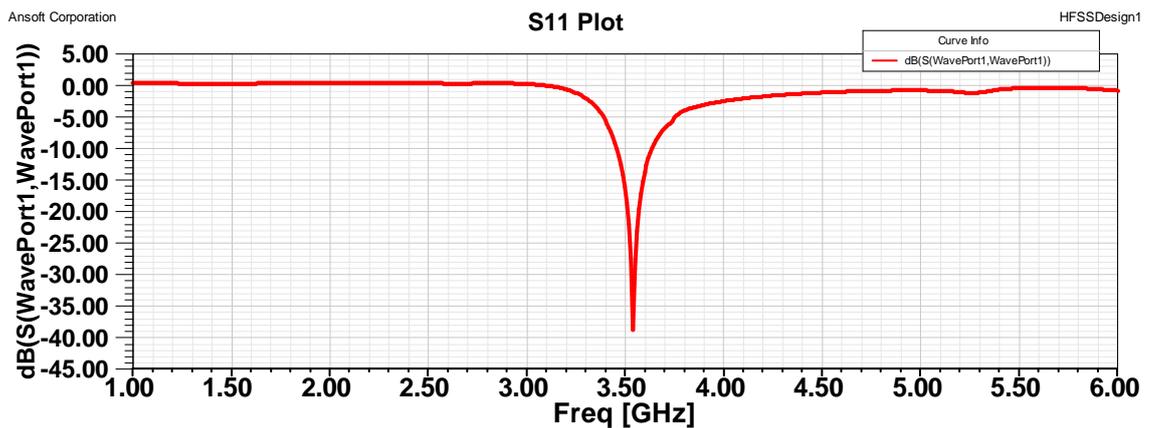


Figure 5. RL Vs frequency curve for switch configuration III

- (4) The graph depicted below in Figure (6) shows RL curves corresponding to switch configuration IV. From the plot of simulated return losses Vs frequency of Antenna in switch configuration IV it is seen that there exists a resonance at 4.8 GHz with fairly good return loss covering lower WLAN band (5.15-5.35). This reconfigured property of proposed antenna structure makes it suitable for wireless application.

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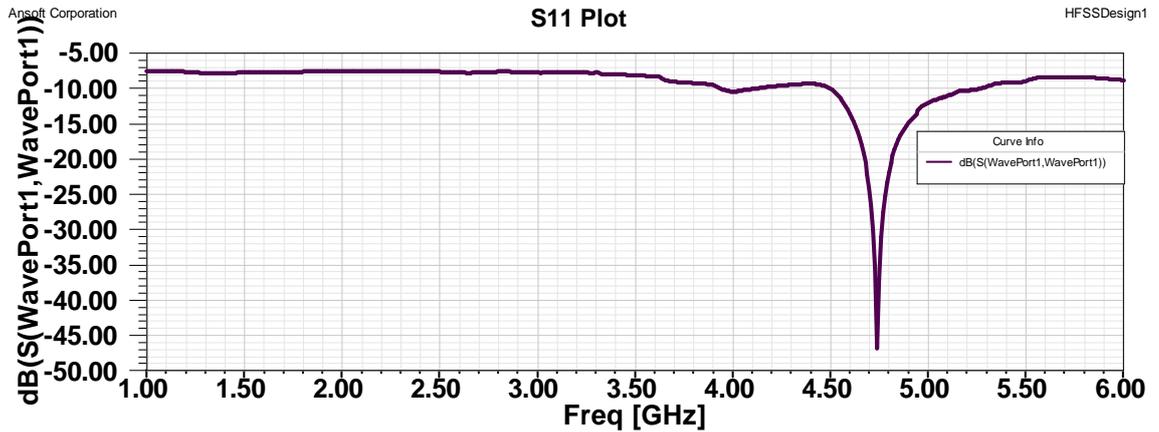


Figure 6. RL Vs frequency curve for switch configuration IV

- (5) In order to obtain a more detailed view about the operation of the proposed antenna, the surface current densities were also studied for different frequencies as depicted in figure 7.

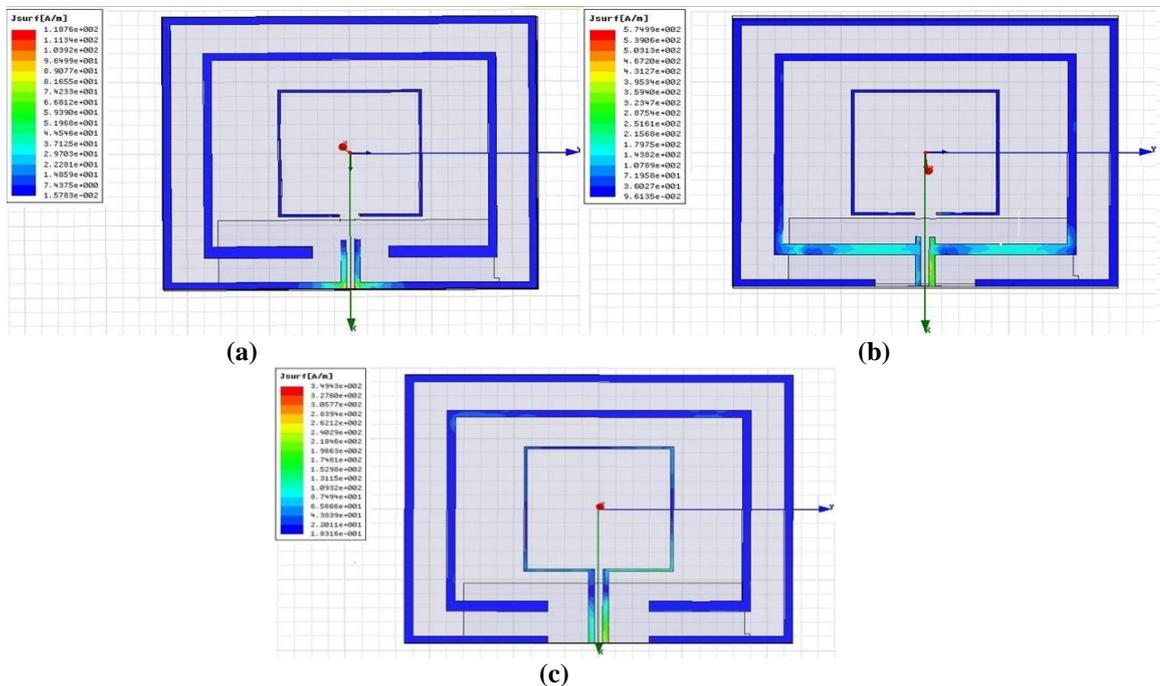


Figure.7. Current Distribution of Proposed Reconfigurable Antenna (a) At 2.4 GHz (b) At 3.5GHz (c) At 4.8GHz

It is clear from Fig.7 (a) that when the metal strip is absent, there is quite a large amount of current coupling towards the ring connected with feed-line through strips. A similar behaviour is observed in Fig.7 (b) and (c) when the antenna is operating with switch configuration III & IV respectively. This demonstrates that by introducing the metal strip to particular ring, the coupling from feed-line to another radiator rings is significantly reduced.

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- (6) The simulated radiation patterns at different resonant frequencies are illustrated in Figure 8. It shows that the antenna can give a nearly Omni-directional characteristic in the H -plane and quasi Omni-directional pattern in the E -plane

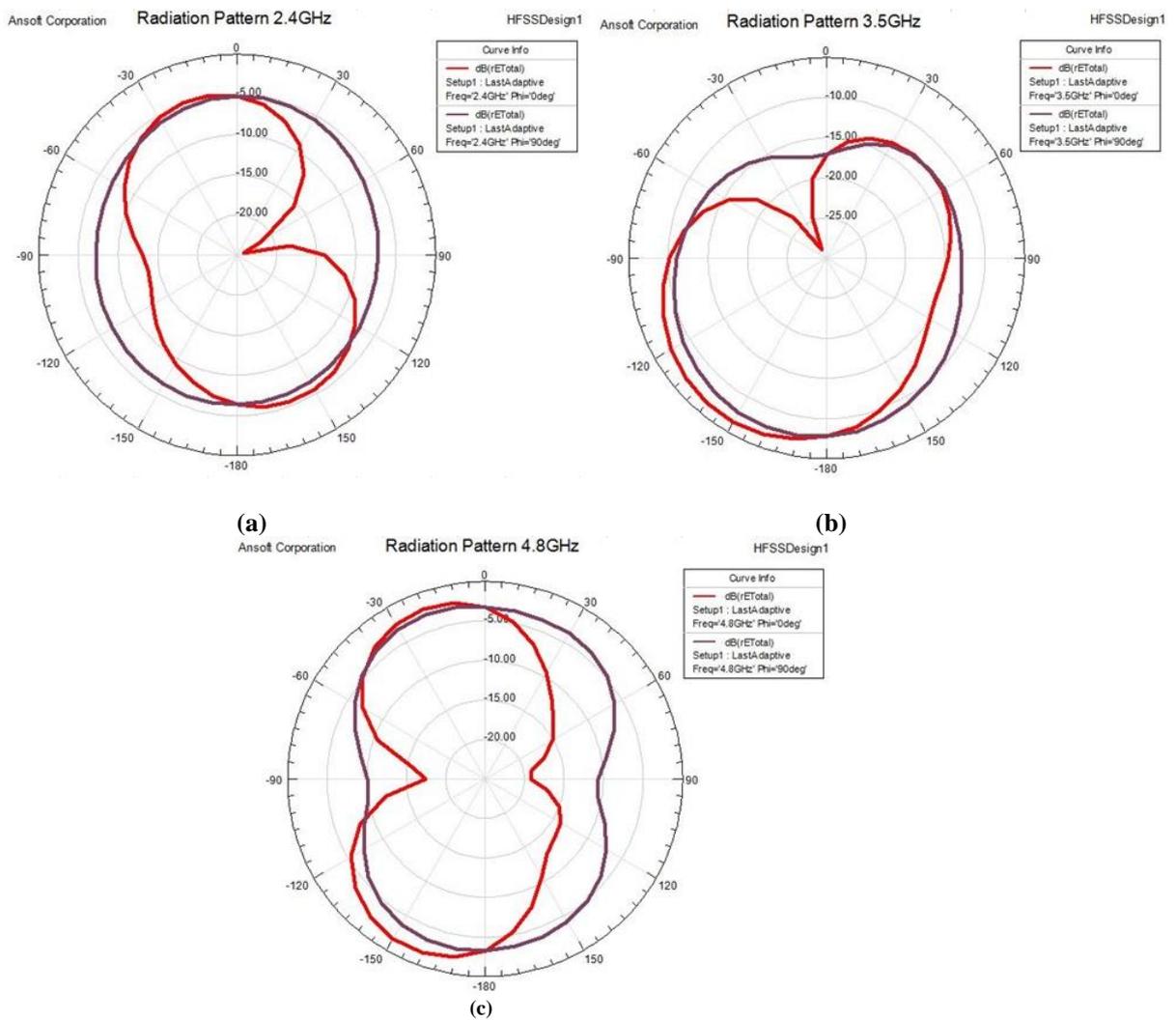


Figure7. Simulated radiation patterns (a) 2.4 GHz (b) 3.5GHz (c) 4.8GHz

IV. CONCLUSION

The use of rectangular micro-strip resonating elements integrated with RF-MEMS switches were implemented for reconfigurable micro-strip antenna for the frequency band ranging from 1 to 6 GHz. Simulations are performed on Ansys HFSS electromagnetic simulator. This reconfigurable antenna shows pattern re-configurability at 2.37 GHz, 3.54 GHz & 4.8 GHz depending upon the actuated switch configurations. The proposed antenna has measured antenna gain of 9.121 dBi with 86.8 % simulated radiation efficiency. Overall, the performance of the proposed antenna meets the desired requirements in terms of return loss. The proposed antenna covers the required frequency bands for WLAN/Wi-MAX/PCS-DCS/UMTS applications. This antenna can resonate in three frequencies simultaneously for WLAN and

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Wi-MAX applications. The proposed antenna provides the -10 dB bandwidth of 1600 MHz for 2.4 GHz, 190MHz for 3.5 GHz and a bandwidth of 800 MHz for 4.8 GHz. A prototype antenna is planned to be fabricated by the authors using low-cost FR4 Epoxy substrate for further work relating to this Paper.

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