MICROSTRIP ANTENNA PATTERN RECONFIGURATION USING ON-CHIP PARASITIC ELEMENTS

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Abstract:

In this paper, a design of pattern reconfigurable microstrip patch antenna and its simulation using CST-MW simulator is presented. The designed antenna is also fabricated and tested. The design consists of microstrip patch printed on FR-4 substrate with a coaxial line feeding on the back of the antenna which is the active element. Two on-chip parasitic elements (OCPE) also are printed on FR-4 substrate, each of which connected through a via hole to the ground. The proposed design has the advantage of movable parasitic chip elements with the same motherboard to control the reconfigurable pattern direction as well as operating frequency. It is also have the advantages of parasitic elements rotation to fit reception/transmission required steering angle. The results obtained show that the steering angle of the main beam in the H-plane depends upon the dimension of the parasitic element substrate as well as the type of the patch antenna. The presented antenna is suitable for different application, including Wifi and WiMax systems.

Keywords

reconfigurable; microstrip; parasitic elements; pattern steering

1. Introduction

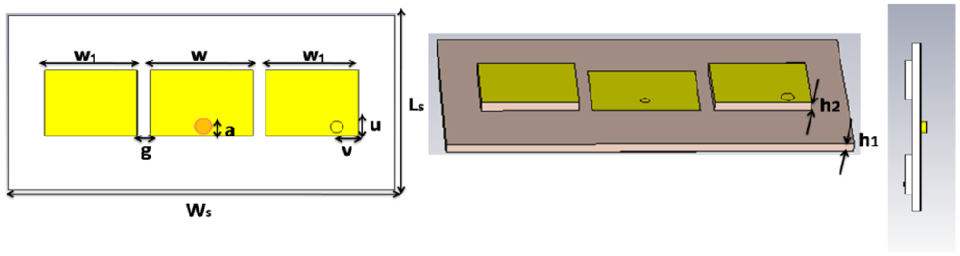
Over the past ten years, many antennas have been proven to be a very effective and sensitive part a communication system. Interference, energy waste, noisy environment and shadowing are the most serious problems that result in performance degradation of wireless communication systems. The solution to these problems is to direct the pattern to a desired user. This can be carried out using pattern reconfiguration (steering pattern) antenna techniques. This can effectively save energy and also overcome reception of unwanted signals. Antenna reconfiguration is classified into three categories, namely frequency, pattern and polarization reconfiguration. The first type is based upon controlling the frequency of radiating element within a specific margin without changing other radiating characteristics. One method or realizing frequency reconfiguration is by using Micro Electro Mechanical System Switch MEMS switches to switch between three types of antennas combined in one body to select different frequency bands (0.824–0.894 GHz, 1.75–2.48 GHz, 3.3–3.6 GHz) [1].Another approach is based upon using planar inverted F-antenna and a

DOI: 10.5121/jant.2015.1105

monopole antenna embedded in the same space [2]. The second type is to control the polarization type of radiating element without changing its orientation. This is done by using pin diodes to switch between two slots in the ground plane [3], or using them to switch between cross slots designed in the patch to select either circular or linear polarization [4]. The last type is to change the antenna radiation pattern either by changing the steering angle or by changing patterns between end fire and broad side types. Other techniques have been devised to realize pattern reconfigurable antenna. One of these techniques is based upon using two parasitic elements along with an active element and switch between one of them using pin/varactor diodes [5-7]. Another technique relies upon using the same RF switches to switch between two types of antennas to steer the main beam to certain angles [8]. The main beam can also be steered using another approach by varying the permittivity of the substrate using applied DC volt [9].Other types of reconfigurable antennas can be implemented to control the antenna characteristics including frequency/pattern and/or polarization by reconfiguring slot depth in each part of the ring [10] or to short annular slot antenna in a preselected position to reconfigure its pattern [11].This may use in different application in wireless systems such as WiMax application as done by [12].In this paper, a modified version of the microstrip patch antenna given [5] is presented. The modification is carried out by replacing the parasitic elements by parasitic chips with a short circuit switch (via hole). This provides a switchable and movable parasitic chip that result in steering far field pattern toward certain direction. The proposed antenna has been simulated using CST-MW package. It has also physically implemented and tested. Satisfactory results have been obtained in both cases. The paper is arranged as follows the proposed design is described and presented in section 2. Results discussions and experiment verification are given in section 3, and finally a conclusion is in section 4.

2. Antenna Design and Operation

The microstrip patch antenna that has been designed in [5] is modified by introducing two on-chip parasitic elements on the sides of an active patch instead of putting them on the same substrate with the active element. The design consists of an active element which is connected to the "subminiature version A" (SMA) cable from the back of the antenna. In addition, there are two parasitic elements located longitudinally on both sides of the active element. The new proposed design allows the removal, rotation or insertion of elements in order to fit operational conditions. The proposed antenna with the active patch and the two parasitic patches are shown in figure1. The central element is the active patch which has the dimensions W=16 mm, L=11.3 mm and it is fed through an SMA probe from the back of the antenna, which is located on a FR-4 substrate of dimensions 30.0x60.0 mm^2 with thickness 1.6 mm. Feeding location "a" is chosen to optimized desired input impedance.



(a) (b) (c)

Figure 1: Physical structure of the antenna in x-y plane (a) Front view (b) 3-D view and (c) Side view

The two parasitic elements which have the dimensionW1= 0.9W mm, L1= 0.97 L mm are set on a substrate FR-4 substrate with a thickness of 1.6 mm and copper pins used as switches. The pins exist in the parasitic elements located on the lower left hand corner of the left element or on the lower right hand corner of the right element. These switches have three modes, namely director-reflector (DR) mode, reflector- director (RD) mode and reflector- reflector (RR) mode. The DR mode exists when pin in right element is shorted (the right element is reflector, left element is director). The RD mode exists when pin in left element is shorted (the right element is director, left element is reflector), The RR mode exists when pins in left, right element are shorted (the right, left elements are reflectors). Coupling between active and parasitic elements, controls the radiation pattern. The physical dimensions of the proposed antenna are given in Table 1. It is worth noting that the dimension selected are the same as those of the antenna given in [5] in order to make it easier to comparison.

Table 1:Dimension of designed antenna in (mm)

Parameters	Description	Dimension
Ws	Substrate width	60
Ls	Substrate length	30
W1	Parasitic element width	0.9W
L1	Parasitic element length	0.97L
W	Active element width	16
L	Active element length	11
g	Spacing between active and parasitic	2
u	Copper pins location	3.4
v	Copper pins location	1.48
a	Feed point	2.85
h_1	Motherboard substrate thickness	1.6
h_2	Mother chip substrate thickness	1.6

3. Results Discussion and experimental verification

The proposed microstrip antenna has been simulated using CST software package when different types of substrate have been used. Table 2 gives a summary of the results if using different substrate with different values of relative permittivity (ε_r) at the same height as the motherboard which is 1.6mm. The optimum physical dimension of this antenna is shown in the first row, which gives the better efficiency and doesn’t shift the resonance frequency because of using the same material substrate as the mother board. This results in reducing the losses that may occur when using different material substrates.

Table 2: Effect of parasitic elements dielectric constant εr on antenna parameters in dB, Frequency in GHz, BW in MHz

ε_r	Gain	Efficiency (%)	Tilt angle	SLL	F	BW	S_{11}
4.3	**5.9**	**74**	**28°**	**-8.7**	**5.8**	**264**	**-11.8**
2.5	5.7	72.4	3°	-12.5	5.74	295	-15.3
2.2	5.7	72.2	5°	-12.4	5.74	302	-16.2
6.5	4.2	66.4	39°	-1.9	5.83	241	-17.8
7.4	3.9	51.6	51°	-11.6	5.86	234	-33.6
8.6	5.2	70.2	-35°	-2.7	5.76	227	-16.6
10	5.3	71.3	-33°	-3.2	5.72	230	-15.9

As could be noticed from Table 2, the tilt angle of the far field pattern is highly affected by the material relative permittivity and it is little bit shifted when using material with small relative permittivity while it is largely changed when using high ones. Side lobe levels also increase as the material relative permittivity increases. This is because of high losses in case of high relative permittivity materials. The reflection coefficient curves for dielectric materials with different relative permittivity are shown in Figure 2, It is observed from Figure 2 and table 2 that increasing value of the parasitic relative permittivity, increases main lobe tilt angle and decreases bandwidth and gain. It is clear that as the dielectric permittivity increases the return loss increases hence very small amount of power is forward to radiating element and hence radiating characteristics can be degraded. The best result occurs when we choose parasitic elements substrate to be of the same material as that of mother board (Fr4=4.3). This reduces the dielectric losses that may occur when choosing different materials with different relative permittivity. It is also noticed from the curve that, as the value of parasitic element material relative permittivity exceeds that of the relative permittivity of mother board, the resonance frequency shifted by 100 MHz.

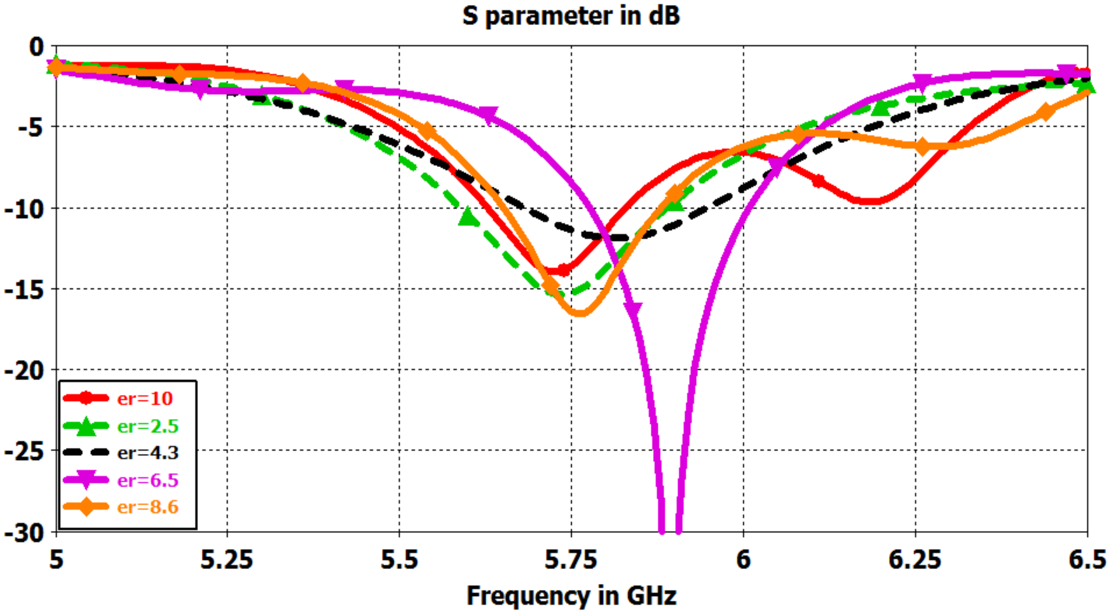


Figure 2: Reflection coefficient in decibels

Table 3 gives a summary of the results of using different substrate heights (h_2). The optimum physical dimension of this antenna is shown in the first row which gives reasonable compromise between different parameters. Figure 3 illustrates the relation between the return loss (s_{11}) and the frequency for different values of the substrate heights (h_2).It is noticed that as the thickness of parasitic substrate decreases, the losses due to surface waves decrease and this result in decreasing side lobe level. On the other hand, increasing the thickness results in better notch depth (s_{11}). From these results, it is clear that the optimum design is to put the parasitic elements on the FR-4 substrate having ($\varepsilon r=4.3$) with thickness $h_2=1.6$.

Table 3: Effect of height parasitic elements substrate on antenna parameters in dB, Frequency in GHz, BW in MHz

h_2	Gain	Efficiency (%)	Tilt angle	SLL	F	BW	S_{11}
1.6	**5.9**	**74**	**28°**	**-8.7**	**5.8**	**264**	**-11.8**
0.5	6.1	71.5	29°	-8.8	5.83	293	-12.3
1	6.1	73.6	29°	-9.2	5.82	270	-12
2	5.9	73.3	27°	-8.4	5.82	264	-12.1
3	5.7	72.4	25°	-7.4	5.81	268	-12.3
5	5.6	71	22°	-6.3	5.82	280	-13.3
10	5.1	66.7	15°	-3.9	5.81	309	-17.2

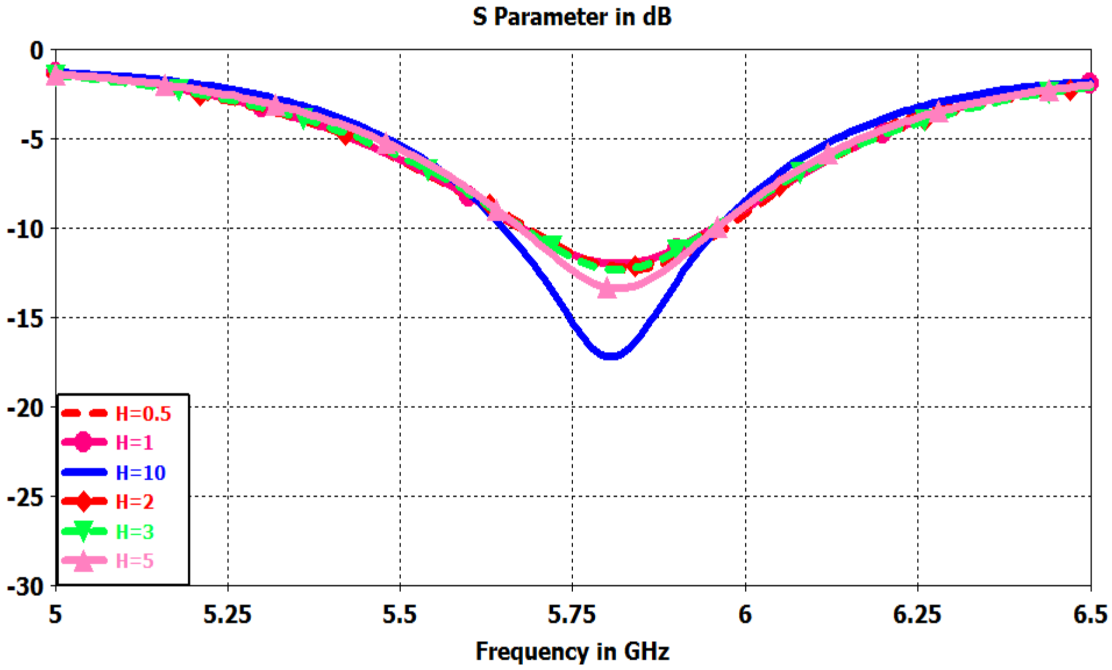
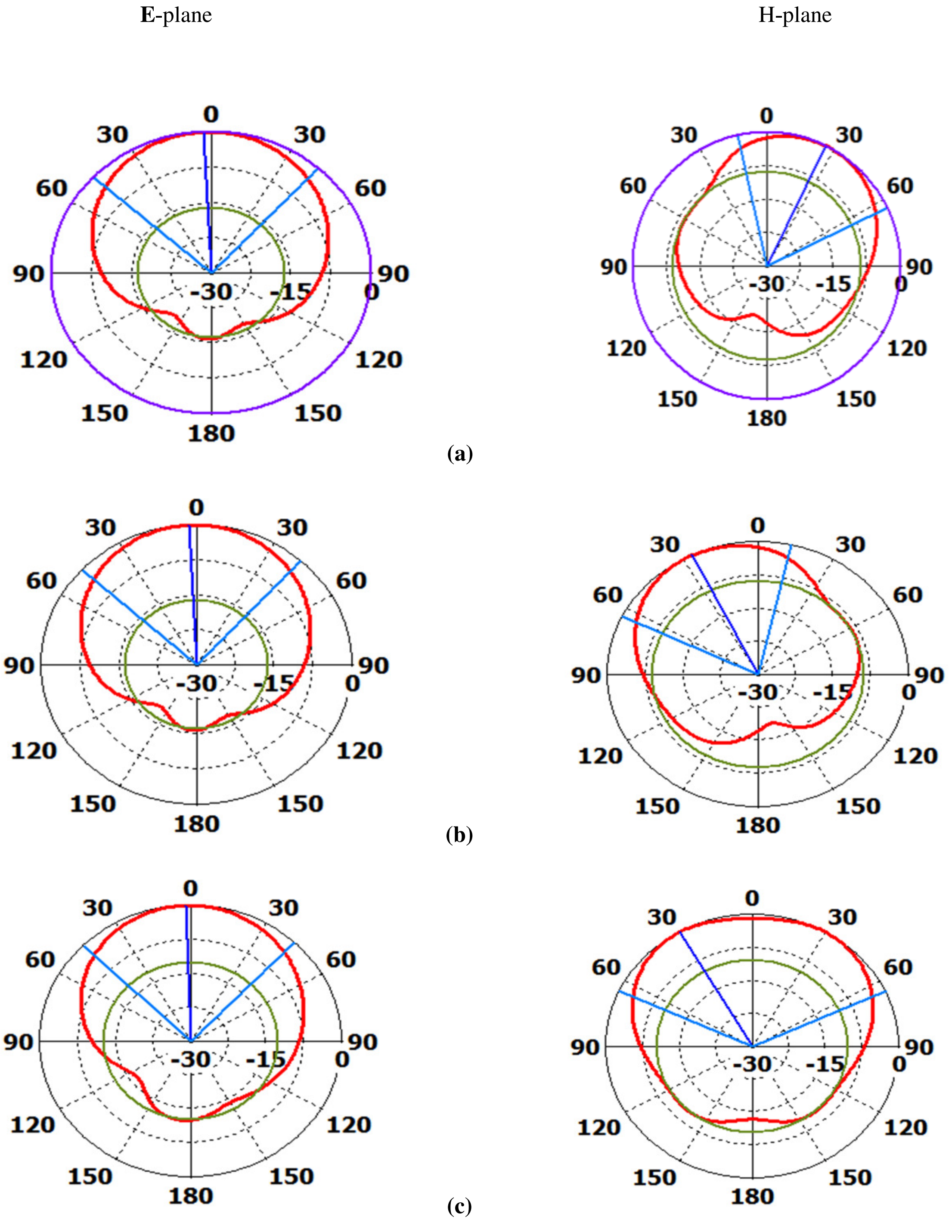


Figure 3: Reflection coefficient in decibels

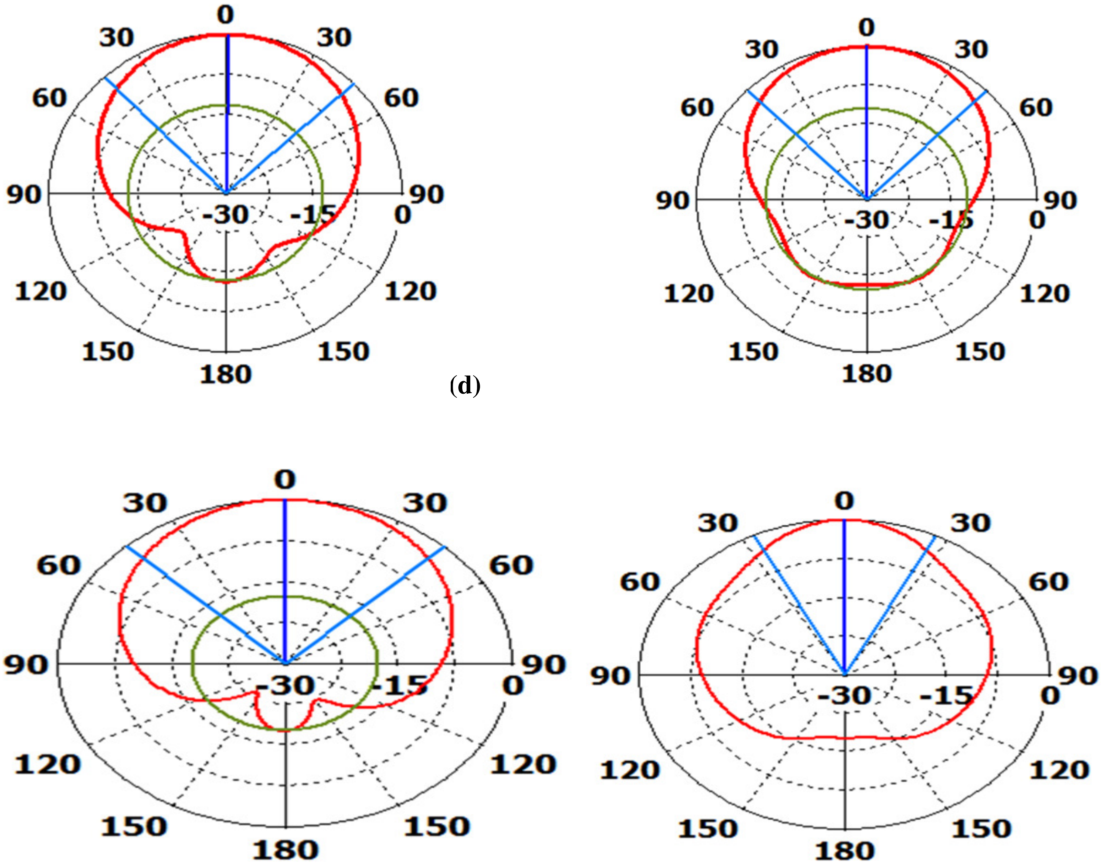
Figure 4 illustrates the E-plane and H-plane far field patterns of the proposed patch at different case of switch positions. In figure 4 (a), the position of the switch on the right parasitic element allows it to act as a reflector (DR mode), the pattern steering angle is deflects toward 28° in H-plane with no tilt in E-plane. In figure 4 (b) the H-plane pattern deflects to the opposite direction -28° because the position of the switch changes to left element which allows it to act as a reflector. In figure 4 (c) the switch is positioned at the two elements together in this case, these are no tilt angles in the pattern. Same result is obtained in figure 4(d) where no parasitic element around the active patch. Figure 4 (e) illustrates the case of two parasitic elements without switches hence the beam doesn’t deflect.



(a)

(b)

(c)



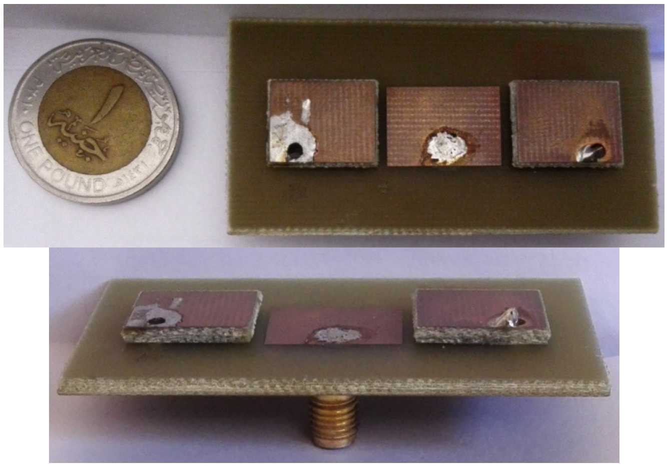
(d)

(e)

Figure 4: Simulated radiation patterns in E and H- planes at different cases of switch positions.

(a) E-plane and H-plane farfield for DR mode
(c)E-plane and H-plane farfield for RR mode
(b) E-plane and H-plane farfield for RD mode
(d)E-plane and H-plane farfield for patch alone
(e)E-plane and H-plane farfield for DD mode

A photograph of the manufactured reconfigurable antenna is shown in Figure 5(a),(b)designed 5.8GHz antenna front and side view respectively are shown.

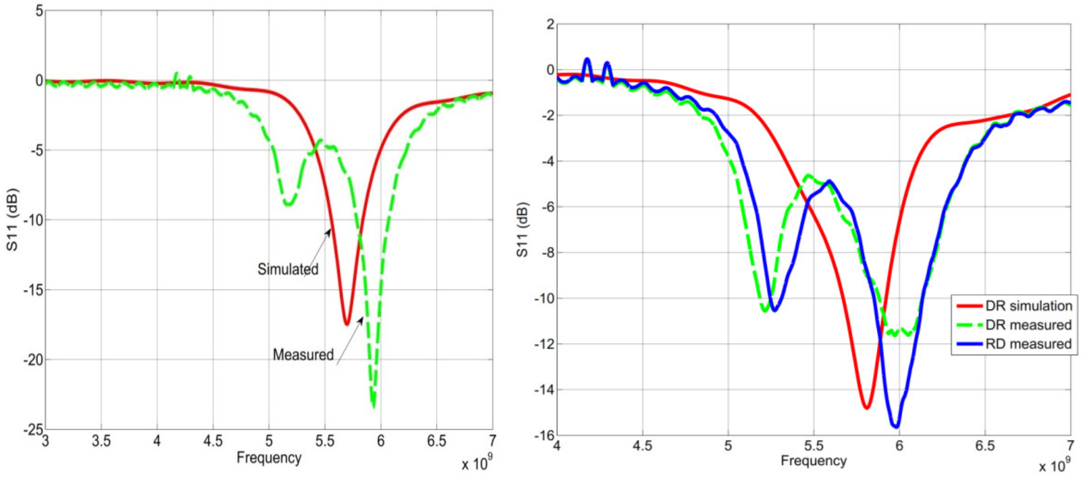


(a) **(b)**

Figure 5: Fabricated antenna (a) front view of antenna, (b) side view

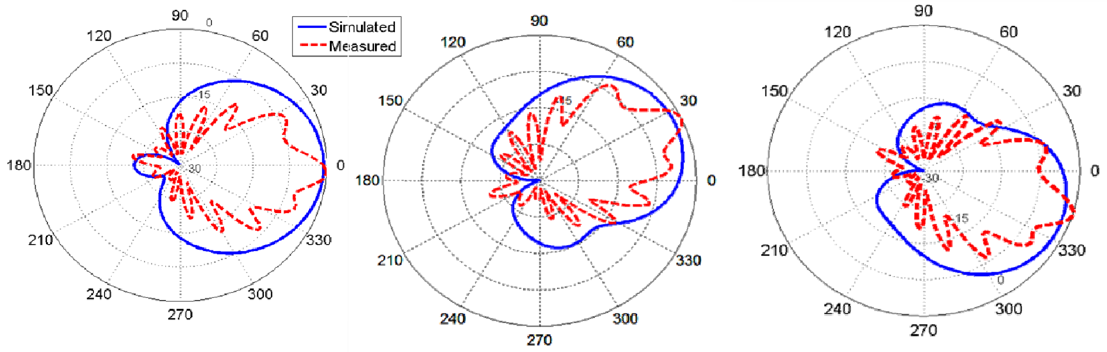
Figure 6(a) shows the comparison between simulated and measured $S_{11}$for active element only without parasitic elements. It is noticed that the resonance frequency is little bit shifted but it still within the operating band (5.5-5.8GHz), Figure 6(b) shows the simulated and measured S_{11} that for the case of existing parasitic elements with different switching modes. It is noticed that there exist a drift in the measured result; this is due to connector and soldering effect. Figure 7 shows the simulated and measured radiation patterns for the designed antenna at various switching modes.

It is clear that the main beam direction is the same for both simulated and measured results.



(a) **(b)**

Fig.6 (a) simulated and measured |**S_{11}**| for active element,(b)S11 measured results for various switching modes.



(a) (b) (c)

Figure 7: Radiation pattern for simulated and measured results at various switching case: (a) pattern at active element (b) pattern at DR case and (c) pattern at RD case

The designed antenna has the ability to rotate the parasitic elements around switches exist; the rotation could be either clockwise or counter clockwise as shown in Figure 8. This allows more flexibility in the design to meet different application needs. This is a major advantage over existing similar antennas. However, Due to geometry restrictions the rotation angle will be limited to certain values.

Table 4 gives the result of a simulated design in which the parasitic elements have been rotated counter clockwise with different restricted angles.

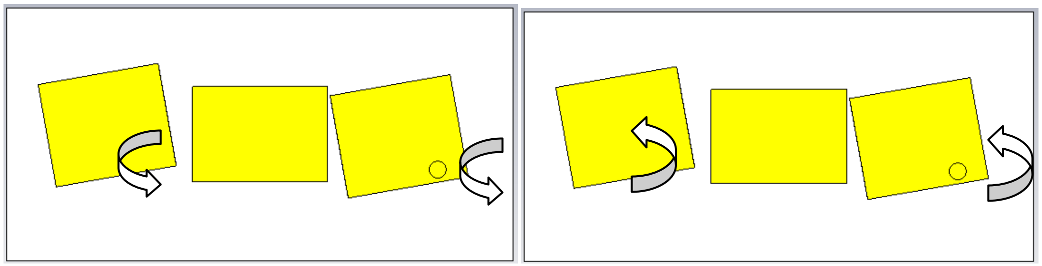


Figure 8: rotated parasitic elements clockwise and counter clockwise direction

Table 4: parametric study in changing the rotation angle for parasitic elements and the corresponding tilt angle

Rotation angle	S11	Bw	F	Tilt angle	SLL	Gain	Eff.
0°	-11.8	264	5.8	28°	-8.7	5.9	74
5°	-12.5	261	5.84	30°	-8.1	5.9	73.1
10°	-18.6	232	5.84	43°	-	4.3	62.8
13°	-13.8	270	5.84	32°	-6.8	5.6	72
60°	-31.2	232	5.82	40	-1	3.5	53
90°	-20.8	308	5.75	-22	-9	4	64.3

It is clear from this table that the tilt angle is affected by the rotation of the parasitic elements. But the parameters are in general not much affected.

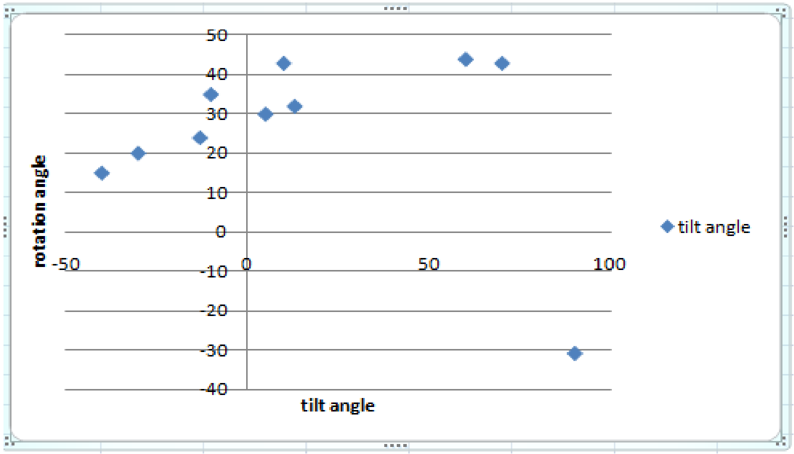


Figure 9: rotation angle versus pattern tilt angle

Figure 9 shows the relation between parasitic element orientation and the beam tilt angle. It is clear that the relation is non-continuous. This means that an optimization process should be adopted to select the suitable rotation angle to give the required beam tilt angle.

Table 5**:** comparison between pervious and proposed work

H[mm]	Gain[dB]	Eff.[%]	Tilt angle	SLL	F[GHz]	Bw[MHz]	S11[dB]
previous work[5]	5.1	62.1	34°	-5.3	5.81	249	14.8
proposed	5.9	74	28°	-8.7	5.8	264	-11.8
Rotated elements	4.3	62.8	43°	-7	5.84	232	-18.6

Table 5 gives a comparison between the simulated results of the patch with rotated parasitic elements (γ=10°), and the patch with non-rotated parasitic elements (γ=0°) and the patch in ref [5]. It is clear that the highest tilt angles are obtained with the rotated patches. The result is also illustrated in the simulated farfield patters of the three cases in figure 7.

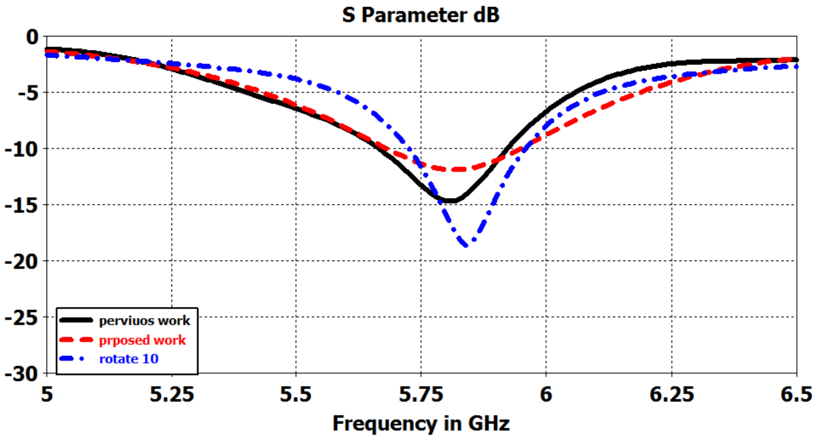


Figure 10: Reflection coefficient for pervious and proposed work

Figure 10 shows the reflection coefficient difference between previous and proposed design. It shows that proposed design has wider bandwidth at the same resonance frequency and the rotated parasitic elements give deeper notch ever.

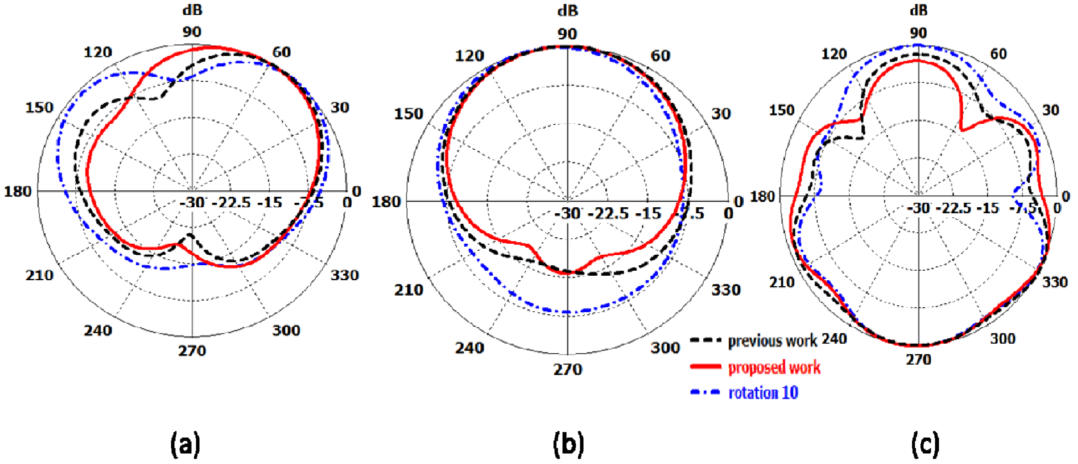


Figure 11. Simulated far field patterns for pervious and proposed work: (a) H-plane (φ =0°),(b) X-Y plane (θ=90°) and (c)E-plane(φ=90°)

Figure11 (a) illustrate H-plane radiation pattern in the patch given in [5], and the purposed design and rotated parasitic elements by 10°.It is noticed that side lobe level is reduces in proposed work and the tilt angle deflects toward 28° instead of 34° as the parasitic elements rotated by 10° it will give better tilt angle to 43° which is 79% better than [5] . Figure11 (b) illustrate X-Y plane (θ=90°) in which the main beam tilt angle decreased and also beam width while side lobe level decreases. Figure11(c) illustrate E-plane (φ=90°) in which the main beam tilt angle doesn't changes anymore and beam width become more directive.

4. Conclusion

Pattern reconfigurable microstrip antenna with on chip parasitic elements has been proposed and designed. It has been demonstrated that flexible pattern reconfigurable antenna can be achieved with better gain of 5.6 dB and bandwidth of 309MHz. The proposed design is characterized by physical removal or placement of parasitic elements so as to fit system requirements or environmental changes. The compact size of the antenna and its characteristics makes it appropriate for WiMax and Wifi application.

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