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A Reconfigurable Microstrip Patch antenna with Various Patches

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Abstract: A reconfigurable Microstrip Patch Antenna of various shapes surrounded by two fork shaped patches and one rectangular patch has been designed using Ansoft HFSS software. The different shapes of the central patch are Rectangular (horizontal or vertical) or Square or circular or elliptical are used. The three outer patches are connected to the central rectangular patch through PIN diodes. By changing the state of the diodes, frequency reconfigurability has been obtained. The FR4 epoxy dielectric material of 1.6mm height with relative permittivity 4.4, loss tangent of 0.02 has been used as substrate. The antenna is probe feeded. Based on the condition of the diodes i.e. either OFF or ON, the antenna resonating frequencies are varying from 2.0 GHz to 10 GHz., the bandwidths are varying from 50 MHz to 600 MHz and return loss is changing from 11 dB down to 50 dB down. Peak Directivity, Gain and radiation efficiency are also determined for all the cases. The proposed antenna is suitable for WLAN, ISM band, Search and Rescue (SAR) and UWB applications.

Keywords: Rectangular horizontal patch, Rectangular vertical patch, Square patch, Circular patch, Elliptical patch.

I. INTRODUCTION

Now a days frequency reconfigurable microstrip multiband patch antennas are widely used in various wireless services. Compared to broadband antennas, reconfigurable antennas should be able to alter their operating frequencies, impedance bandwidth, and polarization and radiation pattern independently to accommodate changing operating requirements. These reconfigurable antennas are low weight, low cost, low fabrication cost and it uses the electromagnetic spectrum very efficiently [1]-[9].

The stubs and parasitic elements acts as perturbation agent and it has various effects on resonating frequency, bandwidth and various parameters that included in the antenna design. These various effects depend up on the shape, size that is attached [10]-[12]. Proper positioning of stubs is used to increase the gain and also excite more resonating bands. Here stubs are placed at symmetrical locations around the patches of Rectangular (vertical, horizontal), circular, square and elliptical [13]-[16]. The antenna designs presented in this paper has two fork shaped and one rectangular strip shaped connected with the central patch through pin diodes [17]. The ON and OFF shapes of the diodes has resulted in the frequency reconfigurability and multiband response of the antenna.

II. ANTENNA DESIGNS

The antenna consists of patches of different sizes surrounded by three outer patches. Two fork shaped patches of equal size are connected symmetrically at the opposite sides of the central patch and one rectangular strip shaped patch is connected to the third edge of the central patch. The two arms of the fork shaped patches have an angle of 45 degrees between them. Three PIN diodes D1, D2 and D3 are placed between central and the outer patch. For simulation purposes the ON and OFF states of the diodes having different combinations are realized by presence or absence of a conductor strip of a 2mm width. The patch antenna designs with and without the conductor strips representing the ideal ON and OFF states of the diodes are shown in Figure.1 respectively.

The dimensions of the central patch (W2, L2) have been obtained by using standard mathematical expressions for antenna designing and then further optimized to achieve the desired results [18]-[19]. The FR4 epoxy of 1.6mm height with relative permittivity 4.4, loss tangent of 0.02 has been used as substrate dielectric material. The ground is considered as infinite and is placed on other side of the substrate of size 40mm by 40mm. The antenna is coaxial feeded and the feed point of the antenna is located at 2.4mm apart from the center of the central patch along the negative x-axis[15].

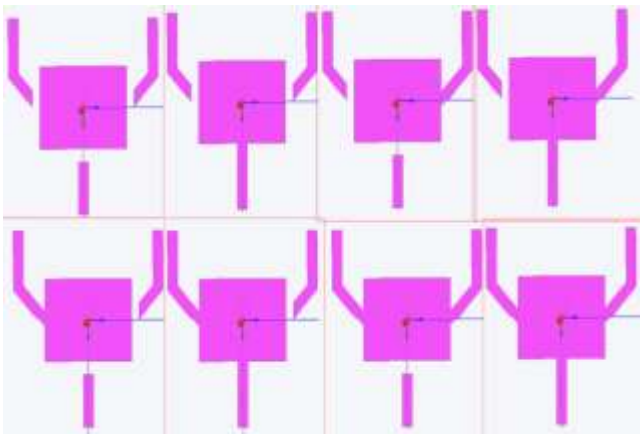


Figure1. Different states of diodes of reconfigurable antenna

III. STUDY OF PARAMETERS OF PROPOSED ANTENNA DESIGNS

In this section different parameters like return loss, Band width, Peak gain and directivity etc. of the antenna have been observed by varying the shape of the central patch keeping the forks and rectangular shaped strip constant [1]. The dimensions of antenna for different shapes are given in Table 1. The multiband response for each antenna is obtained by changing the state of the diode.

Table1. Dimensions of patch antenna

Parameter	Dimention (mm)
L1	8.7
Rectangular Horizontal L2	13.2
Rectangular Vertical L2	9.7
Square L2	13.2
Circular L2	14.2
Eliptical L2	9.94
L3	8.5
W1	4.18
Rectangular Horizontal W2	17
Rectangular Vertical W2	13.5
Square W2	13.2
Circular W2	14.2
Eliptical W2	14.2
W3	2
D1/D2/D3	2

A. STUDY OF CENTRAL RECTANGULAR HORIZONTAL PATCH

Here we have considered the central patch as rectangular horizontal patch as shown in Figure. 2. The number of resonating frequencies are less for small size of the patch. For different states of three diodes the return losses are calculated and plotted in Figure. 3. The various parameters of the antenna are tabulated in Table 2. The resonating frequencies are ranges from 2.4GHz to 9.6GHz. The maximum and minimum bandwidth is 570 MHz and 40 MHz at 9.28GHz and at 2.43GHz respectively.

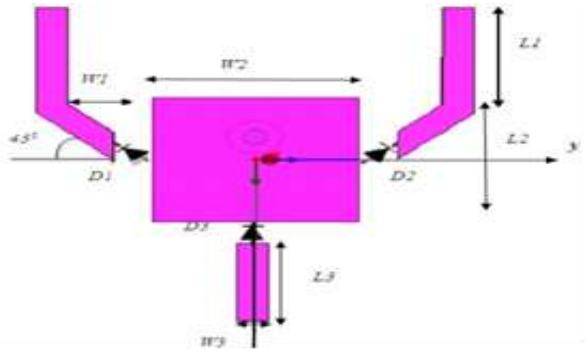


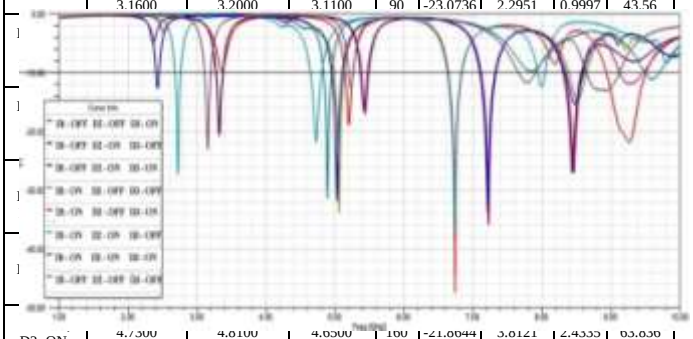
Figure2. Rectangular horizontal patch antenna.

Maximum and minimum return losses are -11.0624dB and -47.3308 dB at 6.74GHz and at 9.61GHz. More gain is obtained at large resonating frequencies. If antenna gain is increasing then the radiation efficiency is also increasing. At 4.87GHz and 8GHz maximum radiation efficiency of 68% is obtained.

Figure3. Return loss plot for Rectangular horizontal patch antenna by varying the states of diode

Table2. Results for Rectangular horizontal Patch antenna

Rectangular Horizontal Patch	Resonating Frequency (GHz)	Higher cut off Frequency (GHz)	Lower cut off Frequency (GHz)	Band width (MHz)	Return Loss (dB)	Peak Directivity	Peak Gain	Radiation Efficiency (%)
D1=ON, D2=ON, D3=ON	5.20	5.26	5.15	110	-18.9194	3.763	1.9289	51.26
	6.7400	6.8400	6.6400	200	-47.3308	3.5329	1.8338	51.906
	9.2800	9.5000	8.9300	570	-21.7127	7.6319	4.12	53.983
D1=OFF, D2=OFF, D3=OFF	4.8700	4.9500	4.8400	110	-31.3533	4.4985	3.0882	68.651
	9.6100	9.7100	9.4900	220	-11.0624	7.0464	3.7374	53.04
D1=OFF, D2=OFF, D3=ON	5.2300	5.2700	5.2000	70	-12.6035	5.0883	2.1906	43.052
	7.7900	7.9000	7.6700	230	-11.6118	6.4467	4.2825	66.429
	8.9400	8.6500	9.1200	470	-12.9503	5.1955	2.1047	40.511
	3.1600	3.2000	3.1100	90	-23.0736	2.2951	0.9997	43.56
D2=ON, D3=OFF	4.7300	4.8100	4.6500	160	-21.8644	3.8121	2.4335	63.836
	6.7300	6.8400	7.9400	110	-37.5042	3.5253	1.8514	52.517
	8.0000	8.0600	7.9400	120	-12.4731	5.8049	3.9764	68.501



B. STUDY OF CENTRAL RECTANGULAR VERTICAL PATCH

The Rectangular vertical central patch is shown in Figure. 4. The return loss plot is shown in Figure. 5. The various parameters of the antenna are tabulated in Table 3. Rectangular

vertical patch antenna resonating frequencies ranges from 2.66GHz to 9.6GHz. At resonating frequency of 9.6GHz nearly 280MHz bandwidth and minimum bandwidth of 60MHz obtained at 5.42GHz. Minimum return loss of -43.9394 is obtained at 5.41GHz and maximum return loss of -14.3291 at 9.12GHz. As the antenna gain increases radiation efficiency also increases. At 9.12GHz maximum radiation efficiency of 65% is obtained.

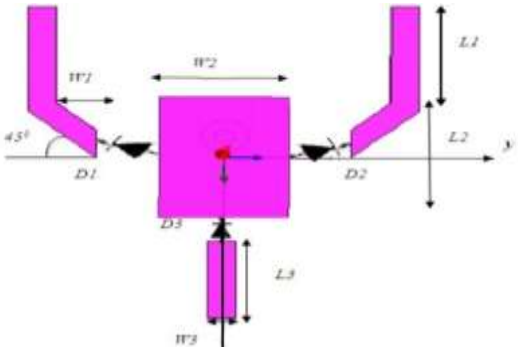


Figure4. Rectangular vertical patch antenna.

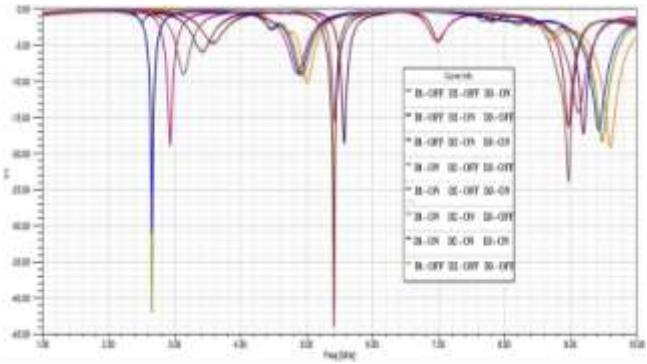


Figure5. Return loss plot for Rectangular vertical patch antenna by varying the states of diode

Table3. Results for Rectangular vertical Patch antenna

Rectangular Vertical Patch	Resonating Frequency (GHz)	Higher cut off Frequency (GHz)	Lower cut off Frequency (GHz)	Bandwidth (MHz)	Return Loss	Peak Directivity	Peak Gain	Radiation Efficiency (%)
D1=ON, D2=ON, D3=ON	5.4100	5.4700	5.3500	120	-43.9394	4.4203	1.6423	37.154
	8.9600	9.0300	8.8900	140	-16.2392	6.1169	3.3288	54.42
D1=OFF, D2=OFF, D3=OFF	9.6000	9.7400	9.4600	280	-19.2022	7.6667	4.8943	63.839
D1=OFF, D2=OFF, D3=ON	5.4200	5.4500	5.3900	60	-15.6225	3.3462	0.57655	17.23
	8.9700	9.0500	8.8300	220	-23.7574	6.0506	3.3693	55.686
D1=OFF, D2=ON, D3=OFF	2.6600	2.7000	2.6200	80	-30.9630	1.5795	0.37849	23.962
	9.4200	9.5400	9.3100	230	-16.7404	6.5735	4.2462	64.595
D1=OFF, D2=ON, D3=ON	5.5700	5.6100	5.5200	90	-18.6097	4.5507	1.2962	28.483
	9.1900	9.2600	9.1200	140	-17.3443	6.7421	3.0565	45.334
D1=ON, D2=OFF, D3=OFF	2.6600	2.7000	2.6200	80	-41.9701	1.6282	0.4011	24.635
	9.4800	9.6000	9.3600	240	-18.3628	6.634	4.2474	64.025
D1=ON, D2=OFF, D3=ON	5.5700	5.6200	5.5300	90	-16.4610	4.442	1.2945	29.141
	9.2300	9.3000	9.1600	140	-19.9954	6.9592	3.0278	43.508
D1=ON, D2=ON, D3=OFF	2.9300	2.9800	2.8900	90	-18.9148	1.8828	0.47152	25.043
	9.1200	9.2100	9.0100	200	-14.3219	6.4095	4.2191	65.825

C. Study of Central Square Patch

The square central patch antenna is shown in Figure. 6. The return loss plot is shown in Figure. 7. The various parameters of the antenna are tabulated in Table 4. The resonating frequencies range from 2.55GHz to 9.78GHz. Both the narrow bands and wide bands are obtained. At resonating frequency of 9.36GHz a maximum bandwidth of 450MHz is obtained and minimum bandwidth of 70MHz is obtained for 2.55GHZ and 2.56GHz resonating frequencies. Minimum return loss of -40.30 is obtained at 9.78GHz and maximum return loss of -11.35 is obtained at 9.74GHz. Maximum peak directivity and peak gain is obtained at 9.78GHz.

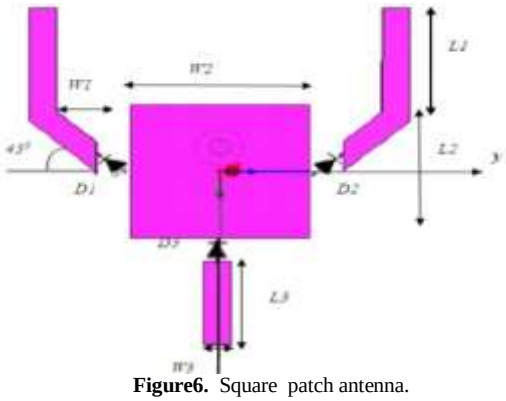


Figure6. Square patch antenna.

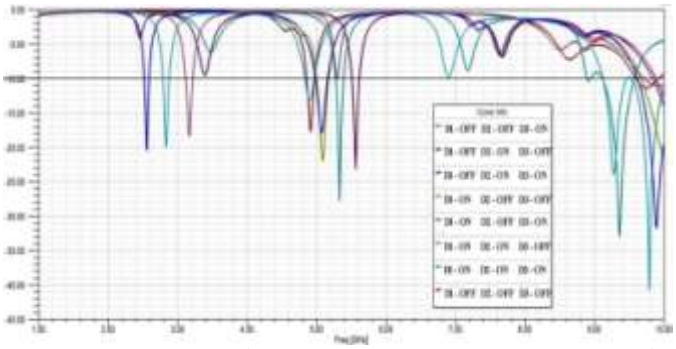


Figure7. Return loss plot for Square patch antenna by varying the states of diode

Table4. Results for Square Patch antenna

Square patch antenna	Resonating Frequency (GHz)	Higher cut off Frequency (GHz)	Lower Cut off Frequency (GHz)	Bandwidth (MHz)	Return Loss	Peak Directivity	Peak Gain	Radiation Efficiency (%)
D1=OFF,	4.9100	4.9700	4.8600	100	-17.7301	4.4976	2.9604	65.823
D2=OFF, D3=OFF	9.7400	9.9200	9.5900	330	-11.3472	4.4108	3.2961	74.73
D1=ON, D2=ON, D3=ON	5.3300	5.3900	5.2700	120	-27.7491	4.0089	1.7609	43.924
	9.3600	9.5700	9.1200	450	-32.9272	5.3405	2.5011	46.832
D1=OFF, D2=OFF, D3=ON	3.1700	3.2200	3.1100	110	-18.4039	2.328	0.99623	42.794
D1=OFF,	2.5600	2.5900	2.5200	70	-20.4438	1.4481	0.40992	27.961
D2=ON, D3=OFF	5.0700	5.1600	4.9800	180	-17.9063	4.342	2.6428	60.860
D1=OFF, D2=ON, D3=ON	5.5600	5.6100	5.5100	100	-22.1763	4.1326	1.4718	35.615
D1=ON, D2=OFF, D3=OFF	2.5500	2.5900	2.5200	70	-20.1376	1.4459	0.4035	27.906
	5.0900	5.1700	5.0000	170	-21.9517	4.2629	2.5296	59.34
D1=ON, D2=OFF, D3=ON	5.5600	5.6100	5.5100	100	-23.1841	4.112	1.4397	35.012
D1=ON, D2=ON, D3=OFF	2.8300	2.8800	2.7900	90	-19.8720	1.5815	0.4142	26.193
	4.9200	4.9600	4.8400	120	-12.6740	3.8023	2.2743	39.815
	9.2800	9.4500	9.1300	320	-23.9283	6.4156	4.6236	72.068
	9.7800	10.000	9.5600	440	-40.7030	8.5989	5.5416	64.445

D. STUDY OF CENTRAL CIRCULAR PATCH

The circular center patch antenna is shown in Figure. 8. By changing the states of the diodes the antenna has more significant effect on resonating frequencies at 2GHz to 3GHz and 5GHz to 7GHz. The return loss plot is shown in Figure. 9. The various parameters of the antenna are tabulated in Table 5.

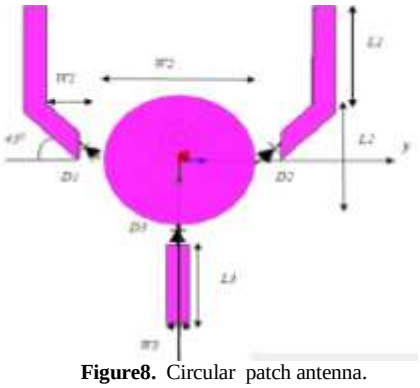


Figure8. Circular patch antenna.

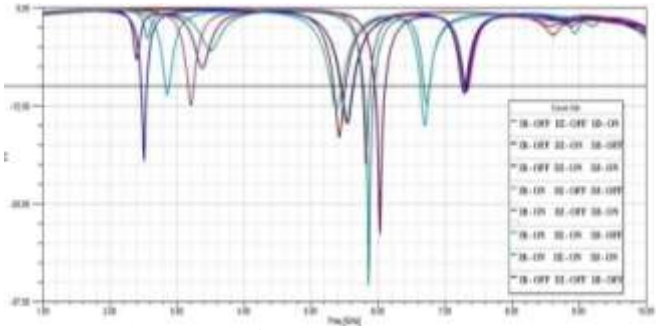


Figure9. Return loss plot for Circular patch antenna by varying the states of diode

Table5. Results for Circular Patch antenna

Circular Patch Antenna	Resonating Frequency (GHz)	Higher cut off Frequency (GHz)	Lower Cut off Frequency (GHz)	Bandwidth (MHz)	Return Loss	Peak Directivity	Peak Gain	Radiation Efficiency (%)
D1=OFF, D2=OFF D3=OFF	5.4200	5.5100	5.3400	170	-16.4661	3.9648	1.7946	45.263
D1=ON, D2=ON, D3=ON	5.8600	5.9400	5.7900	150	-35.3705	4.2583	2.3549	55.302
	6.7200	6.7700	6.6900	80	-12.1916	4.1831	1.9745	47.203
D1=OFF, D2=OFF, D3=ON	5.8200	5.8800	5.7600	120	-19.9815	4.6022	2.0174	43.836
	3.2100	3.2500	3.1700	80	-12.4625	2.2724	0.9366	41.217
D1=OFF, D2=ON, D3=OFF	2.5100	2.5500	2.4700	80	-19.4227	1.3399	0.3783	28.238
	5.5400	5.6400	5.4500	190	-14.6884	3.3886	1.9097	56.356
	7.2900	7.3200	7.2500	70	-10.9238	3.8954	2.0148	51.721
D1=OFF, D2=ON, D3=ON	6.0300	6.1100	5.9500	160	-28.7133	4.4221	2.2433	50.728
D1=ON, D2=OFF, D3=OFF	2.5100	2.5500	2.4700	80	-19.5483	1.3493	0.3809	28.233
	5.5300	5.6200	5.4406	180	-14.6409	3.4078	1.9476	57.151
	7.2800	7.3000	7.2500	50	-10.7569	3.8951	2.0272	52.045
D1=ON, D2=OFF, D3=ON	6.0300	6.1100	5.9600	150	-28.9005	4.4413	2.2566	50.81
	7.3300	7.3500	7.3000	50	-10.6237	3.6134	1.9072	52.782
D1=ON, D2=ON, D3=OFF	2.8600	2.8900	2.8300	60	-11.1588	1.6274	0.4392	26.992
	5.3800	5.4600	5.3100	150	-12.9996	3.9461	2.5353	64.248
	6.7000	6.7700	6.6400	130	-15.0831	4.6687	2.3781	50.936

Circular patch antenna resonating frequency ranges from 2.51GHz to 7.33GHz. Both the narrow bands and the wide bands are obtained. At resonating frequency of 5.54GHz nearly 190MHz bandwidth is obtained and minimum bandwidth of 50MHz is obtained at resonating frequency of 7.33GHz and 7.28GHz. Minimum return loss of -35.3705 is obtained at 5.86GHz and maximum return loss of -10.6237 is obtained at 7.33GHz. We have obtained the maximum radiation efficiency at 5.38GHz.

E. STUDY OF CENTRAL ELLIPTICAL PATCH

The elliptical center patch antenna is shown in Figure. 10. The return loss plot is shown in Figure.11.The various parameters of the antenna are tabulated in Table 6. Elliptical patch antenna resonating frequencies ranges from 2.33GHz to 9.55GHz.

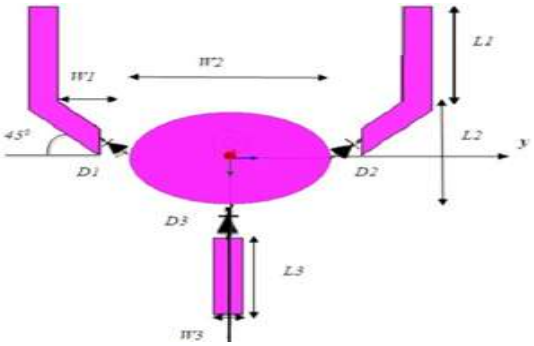


Figure10. Elliptical patch antenna

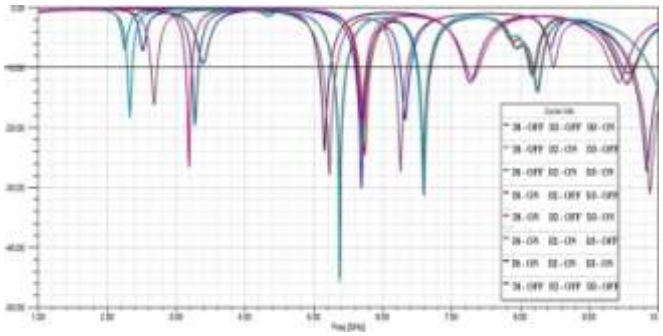


Figure11. Return loss plot for Elliptical patch antenna by varying the states of diode

Table6. Results for Elliptical Patch antenna

Elliptical Patch antenna	Resonating Frequency (GHz)	Higher cut off Frequency (GHz)	Lower cut off Frequency (GHz)	Bandwidth (MHz)	Return Loss	Peak Directivity	Peak Gain	Radiation Efficiency (%)
D1=OFF, D2=OFF, D3=OFF	5.1600	5.2400	5.0800	160	-23.9979	4.6258	3.0088	65.045
	7.2800	7.3600	7.1900	170	-12.4543	7.4961	4.2408	56.574
D1=ON, D2=ON, D3=ON	5.6900	6.3300	5.7900	540	-30.1215	3.9902	2.4678	61.847
	6.33 00	6.4100	6.2500	160	-18.6425	2.6284	1.431	54.43
D1=OFF, D2=OFF, D3=ON	3.1900	3.2300	3.1400	90	-26.6259	2.2005	0.9280	42.175
	5.6900	5.7600	5.6200	140	-18.7534	4.0188	2.1107	52.521
	7.3200	7.3900	7.2200	170	-11.8819	6.5187	3.8199	58.599
	9.4400	9.5300	9.3200	210	-12.2828	4.4068	2.4944	56.605
D1=OFF, D2=ON, D3=OFF	2.3300	2.3600	2.2900	70	-18.1136	1.0582	0.3820	36.107
	5.3700	5.4700	5.2700	200	-46.7448	3.692	2.092	60.303
	6.5900	6.6900	6.5000	190	-31.0124	2.8456	1.6069	56.47
	8.2400	8.3000	8.1700	130	-13.9978	5.2274	2.6645	50.97
D1=OFF, D2=ON, D3=ON	3.2700	3.3200	3.2300	90	-19.5720	2.2005	0.8640	39.266
	5.7100	5.7900	5.6300	160	-22.8039	3.9699	2.2744	57.291
	6.6000	6.6800	6.5100	170	-22.8237	3.0487	1.6757	54.964
	8.1700	8.2100	8.1200	90	-11.3537	1.50014	2.644	52.865
	9.5500	9.6600	9.4100	250	-12.2992	6.0725	3.4249	56.4
D1=ON, D2=OFF, D3=OFF	2.3300	2.3600	2.3000	60	-18.2475	1.0531	0.3798	36.067
	5.3800	5.4800	5.2800	200	-44.9061	3.3901	2.0803	61.362
	6.6000	6.7000	6.5000	200	-31.3281	2.819	1.5895	56.385
	8.2500	8.3200	8.1800	140	-14.1284	5.0682	2.5328	49.975
D1=ON, D2=OFF, D3=ON	3.2800	3.3300	3.2300	100	-19.4428	2.1955	0.8555	38.966
	5.7400	5.8200	5.6600	160	-24.6290	3.9659	2.2947	57.86
	6.5900	6.6800	6.5000	180	-24.8526	3.1697	1.7457	55.076
	8.1900	8.2200	8.1500	70	-11.3084	4.9607	2.5863	52.135
	9.5500	9.6700	9.4200	250	-12.7289	6.0345	3.4252	56.759
D1=ON, D2=ON, D3=OFF	2.6800	2.7300	2.6400	90	-16.2379	0.88196	0.2894	32.817
	6.2600	6.3600	6.1700	190	-27.4238	2.7543	1.5631	56.752
	5.2300	5.3300	5.1300	200	-27.9151	4.1344	2.802	67.773

bandwidth of 60MHz is obtained. Minimum return loss of -46.7448 is obtained at 5.37GHz and maximum return loss of -11.3084 is obtained at 8.19GHz. We have obtained the maximum radiation efficiency at 5.23GHz. As the size of the central patch increases the return loss is decreasing. By changing the state of diode it shows significant effect on resonating frequency at 2GHz to 3GHz and 5GHz to 7GHz and shows less effect on other resonating frequency.

IV. RESULTS AND DISCUSSION ON FREQUENCY RECONFIGURABLE ANTENNA

As per the results, the frequency reconfigurability has been observed. We have obtained the best results for Rectangular (horizontal) and elliptical patch antennas. We have obtained minimum return loss of -47.3308 at resonating frequency 6.74GHz of bandwidth 200MHz and maximum return loss of -11.0624 at resonating frequency of 9.61GHz of bandwidth 220MHz for Rectangular (horizontal) patch antenna. We also obtained minimum return loss of -46.7448at resonating frequency of 5.37GHz of bandwidth 200MHz and maximum return loss of -11.3084 at resonating frequency 8.19GHz of bandwidth 70MHz for elliptical patch antenna. Further it is observed that the return loss is decreasing for increasing the size of the central patch.

V. CONCLUSION AND FUTURE SCOPE

A low cost and compact size frequency reconfigurable antenna design has been proposed in this paper. We have obtained the large number of resonating frequencies at C band as well as in X band which are suitable for ISM, WLAN and SART (Search and Rescue Transponder).Since the substrate used in this antenna is FR4 epoxy which is having a higher loss factor, the gain obtained is low. The gain and bandwidth of the antenna may be increased by using suitable substrate material. We can design the formulas to vary the size of the patch and to obtain particular band of frequencies. The switches are assumed to be ideal and in actual antenna fabrication PIN diodes or MEMS switches can be used. A suitable bias circuit is needed for the switching elements.

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