Design of Multiband Microstrip Patch Antenna for Wireless Application

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Abstract— **This paper presents the design of a low-profile multiband patch antenna. The antenna can be used for various combinations of wireless applications such as Wi-Fi, WiMAX, 3G and UWB within a microwave L, S, C, and X frequency bands in Electromagnetic Spectrum. This work deals with the design of an antenna which can be used for most of the wireless applications. A frequency reconfigurable multiband microstrip patch antenna is designed with microstrip feeding technique. The reconfigurable antenna is designed with one square patch and U-shape slot is inserted inside the patch, in order to get multiband. Pin diode is used for various applications. By changing the status of the diode, the antenna can be designed for various frequencies. The antenna has been designed and simulated using Agilent Advanced Design System (ADS) EM simulator. This antenna gives low return loss at all operating frequencies.**

Keywords— **Multiple frequencies, Tunability, Pin diode, Patch antenna, Low profile, Vector Network Analyzer.**

I. Introduction

Compact and broadband antennas are highly desired nowadays for communication terminals as they occupy limited space and can interface with various communication standards. Modern mobile handsets are miniature in size, and they are required to operate at multiple-frequency bands in order to provide the enhanced and multifunctional performances. Further, due to the device convergence trend antenna structure, very limited space is available for the antenna structure. The design of an efficient wide band small size antenna, for recent wireless applications, is a major challenge. Microstrip patch antenna is a resonant element. Tunable multiband antennas are becoming popular for use in the multifunctional handsets due to their significant advantages in terms of weight, volume and performance. Tunable narrow-band antennas can be advantageous if small efficient antennas are required to cover a large frequency range.

Another new concept called compact reconfigurable antenna is introduced for mobile communication devices. The uniqueness of these antenna's designs are that they allow various groups of their operating frequency bands to be selected electronically. In particular, each group of frequency bands can be made to serve several different communication systems simultaneously. These systems may include various combinations of GSM, DCS, PCS, UMTS, Bluetooth, and Wireless Local-Area Network (WLAN). One advantage is that through the different operational modes, the total antenna volume can be reused, and therefore the overall antenna can be made compact. A reconfigurable antenna can reuse its entire volume at different operating bands so the physical size of the multiband antenna can be reduced. The concept is that each operating band resonates on the portion of or the entire antenna geometry such that there is almost no extra size required to create multiband characteristics. A frequency reconfigurable antenna is one of the effective solutions in minimizing antenna design. It allows several operating states to be switched in the same antenna pattern without any extra structure. By combining these states, the bandwidth can be increased by multiple times. So, there is a need to combine both tunability and reconfigurability to achieve large bandwidth and to reduce the size of an antenna. Using reconfigurability, multiple bands can be covered and using tunability, frequency tuning can be done in each band.

Tunability is basically tuning to different frequencies in a same band of frequencies and Reconfigurability is tuning to different defined bands of frequencies using same antenna volume. The proposed technique is to combine both Reconfigurability and Tunability for wireless applications in the frequency range of C and S band (2 to 8 GHz). It includes different wireless applications for the wireless devices such as Mobile phones, WLAN, Bluetooth, Wi-Fi, WiMAX. The incorporation of tunability and reconfigurability in single antenna may lead to compact size and low cost. Brushless dc (BLDC) motors have been desired for small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the control complexity for variable speed control and the high cost of the electric drive hold back the widespread use of brushless dc motor. Over the last decade, continuing technology development in power semiconductors, microprocessors/logic ICs, adjustable speed drivers (ASDs) control schemes and permanent-magnet brushless electric motor production have combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications.

A patch antenna (also known as a rectangular microstrip antenna) is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or patch of metal, mounted over a larger sheet of metal called aground plane. The assembly is usually contained inside a plastic random, which protects the antenna structure from damage. Patch antennas are simple to fabricate and easy to modify and customize. The two metal sheets together form a resonant piece of microstrip transmission line with a length of approximately one-half wavelength of the radio waves. The radiation mechanism arises from discontinuities at each truncated edge of the microstrip transmission line. The radiation at the edges causes the antenna to act slightly larger electrically than its physical dimensions, so in order for the antenna to be resonant, a length of microstrip transmission line slightly shorter than one-half a wavelength at the frequency is used. A patch antenna is usually constructed on a dielectric substrate, using the same materials and lithography processes used to make printed circuit boards.

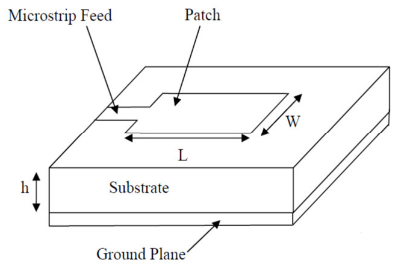

Figure 1: Geometry of microstrip Patch antenna

II. MATHEMATICAL MODEL

To design Microstrip patch antenna of following specifications:

Operating frequency is 2.7 GHz.
Substrate required is FR4.
Relative permittivity of FR4 is 4.34
Height of substrate is 1.5 mm.

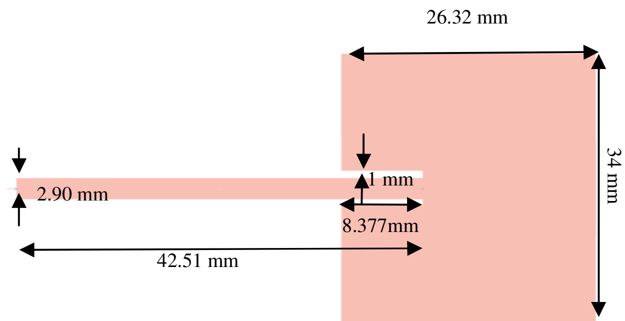

Figure 2: Designed microstrip patch antenna

The width 'W' of the microstrip patch antenna was computed with the following equation.

$$W=\frac{c}{2\times f_r}\times\sqrt{\frac{2}{\varepsilon_r+1}} = 34\text{ mm} \qquad (1)$$

Where 'c' is the speed of light 3x10^8 m/s, 'fr' is the operating frequency of 2.7 GHz and 'εr' is the dielectric permittivity of 4.34

The length of microstrip patch antenna is given by the following equations:.

$$\varepsilon\text{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\times\frac{h}{w}\right)^{-\frac{1}{2}} = 4.02 \qquad (2)$$

Where 'εreff' is the effective dielectric constant and 'h' is the thickness of the dielectric substrate.

$$\text{Leff (effective length)} = \frac{c}{2\times f_r\times\sqrt{\varepsilon_{reff}}} = 27.68\text{mm} \qquad (3)$$

$$\Delta L=0.412\times h\times\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\times\frac{\left(\frac{w}{h}+0.264\right)}{\left(\frac{w}{h}+0.8\right)}=0.68\text{mm} \qquad (4)$$

In the equation above 'ΔL' stands for length extension. Therefore, the actual length 'L' of the microstrip patch antenna is given by

$$L = \text{Leff} - 2\times\Delta L = 26.32\text{ mm} \qquad (5)$$

To compute the width 'w' of the feed for impedance 'Z0' of 50Ω the following equations were used

$$A=\frac{Z_0}{60}\times\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r+1}{\varepsilon_r+1}\times\left(0.23+\frac{0.11}{\varepsilon_r}\right) = 1.5214 \qquad (6)$$

$$B=\frac{377\times\pi}{2\times Z_0\times\sqrt{\varepsilon_r}} = 5.69 \qquad (7)$$

$$w=\frac{2\times h}{\pi}\left\{B-1-\ln(2\times B-1)+\frac{\varepsilon_r-1}{2\times\varepsilon_r}\times\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\} = 2.90\text{ mm} \qquad (8)$$

Using these dimension rectangular patch is designed on Agilent Advanced Design System software.

Figure 3, shows the simulation resonant frequency of 2.712 GHz with -32.052 dB return loss of Figure 2. Thus, this antenna can be used for WiMAX application.

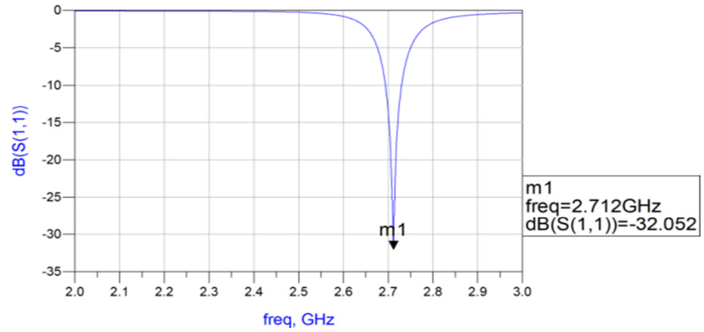

Figure 3: Frequency characteristic (S11 parameter) of designed microstrip patch antenna

III. PROPOSED MODEL

To have the antenna resonating at more than one frequency we go for multi banding. One of the easy and efficient methods of achieving multi banding is cutting slots in the patch. The length and position of the slots can be changed to obtain the microstrip patch antennas resonating at more than one frequency. In this way we can have the dual or triple band antennas.

Multiband antenna is designed just by placing U- shape slot in the middle of Figure.2. Hence all the dimensions of multiband antenna are same as simple microstrip patch antenna. Figure.4 shows the Reconfigurable multiband patch antenna.

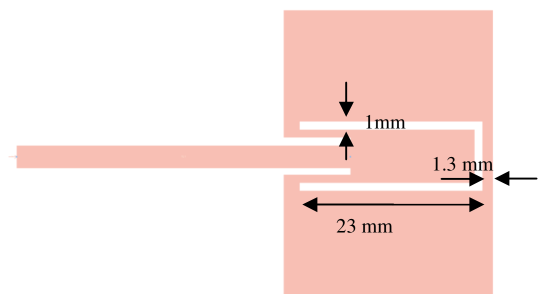

Figure 4: Reconfigurable multiband patch antenna when all diodes are in OFF condition

In Figure.4 no pin diodes are inserted inside the U-slot hence this is called OFF condition or ‘0’ status of pin diode. And if pin diode is inserted inside the U-slot then this is called ON condition or ‘1’ status of pin diode. In this way reconfigurability is achieved using pin diodes.

Simulation of multiband microstrip patch antenna when all diodes are in OFF condition is shown in Figure 5. Many frequencies are obtained in various bands such as S band (2 to 4 GHz), C band (4 to 8 GHz) and X band (8 to 12 GHz) by inserting the U-shape slot.

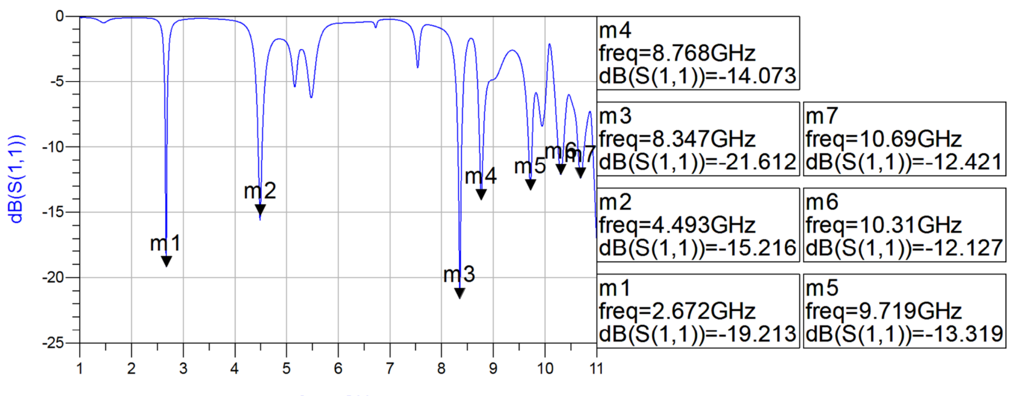

Figure 5: Frequency characteristic (S11 parameter) when all diodes are in OFF condition

Table 1 shows various frequencies with corresponding return loss using Advanced Design System (ADS) software.

TABLE 1: Resonant Frequencies and their Return Loss for reconfigurable multiband patch antenna when all diodes are in OFF condition

Frequency (GHz)	Return loss (dB)
2.672	-19.213
4.493	-15.216
8.347	-21.612
8.768	-14.073
9.719	-13.319
10.31	-12.127
10.69	-12.421

From Table 1 it is concluded that frequencies obtained comes under more than one band i.e. S band (2-4 GHz), C band (4-8 GHz) and X band (8-12 GHz) hence the design antenna is named as multiband antenna. This antenna can be used for WIMAX and UWB applications.

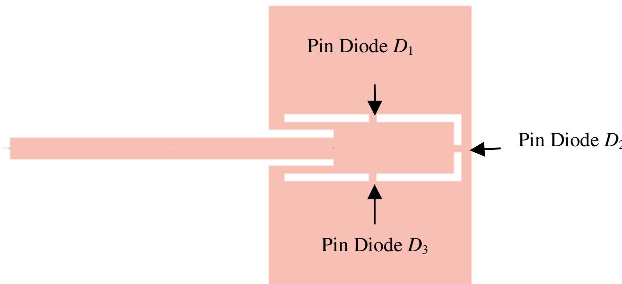

Figure 6: Reconfigurable multiband patch antenna when all diodes are in ON condition

In Figure.6 diodes D1, D2 and D3 are present hence it is called as ON-ON-ON /111condition. From the Figure.4 and Figure.6 it is clear that if pin diodes are present then it is called ON/1. And if pin diodes are absent then it is called OFF/0. Three pin diodes are used inside U-shape slot. Thus, there are 8 different possible combinations of pin diodes status like 000, 001, 010, 011, 100, 101, 110 and 111. By using these combinations different frequencies in different frequency bands are achieved. Because of presence of pin diodes flow of current over patch get changed and hence radiating frequency also changes.

In Figure.7 the simulation result of reconfigurable multiband microstrip patch antenna with three diodes is in ON condition. The ON status of pin diodes D1, D2 and D3 give frequencies which are obtained in L band (1-2 GHz), S band (2-4 GHz), C band (4-8 GHz) and X band (8-12 GHz) as shown in Table 2.

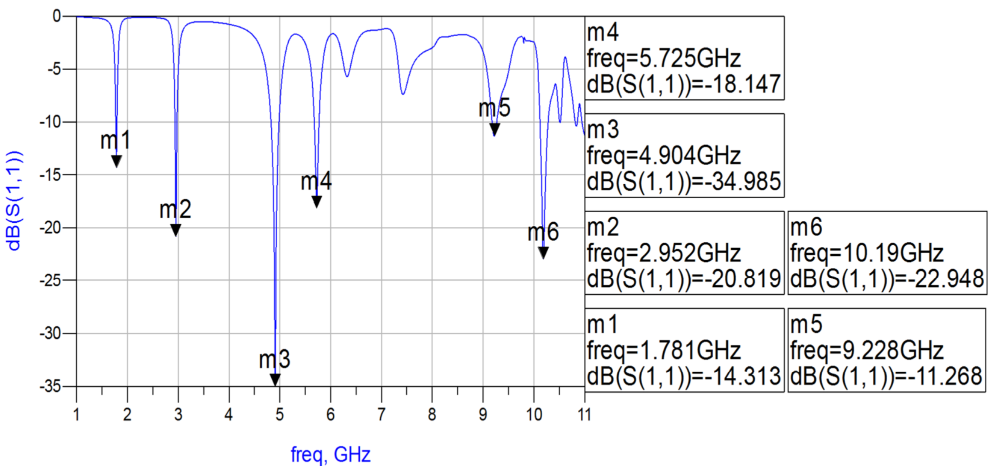

Figure 7: Frequency characteristic (S11 parameter) when three diodes are in ON condition

Table 2 shows simulated frequency with corresponding return loss using Advanced Design System (ADS) software.

TABLE 2: Resonant frequencies and their Return Loss for reconfigurable multiband patch antenna when three diodes are in ON condition

Frequency (GHz)	Return Loss (dB)
1.781	-14.313
2.952	-20.819
4.904	-34.985
5.725	-18.147
9.228	-11.228
10.19	-22.948

From Table 2 it is concluded that when three diodes are in ON condition, wireless applications like 3G, Wi-Fi, WIMAX and UWB can be achieved.

In Figure 8, diodes D2 and D3 are present hence it is called as OFF-ON-ON/011 condition i.e. when two diodes are in ON condition. These diodes are fixed in the middle of slot to get reconfigurability.

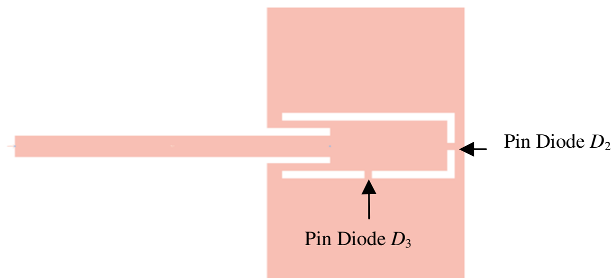

Figure 8: Reconfigurable multiband patch antenna when two diodes are in ON condition

In Figure 9, the simulation result of reconfigurable multiband microstrip patch antenna with two diodes is in ON condition. The ON status of pin diodes D2 and D3 give frequencies which are obtained in L band (1-2 GHz), S band (2-4 GHz), C band (4-8 GHz) and X band (8-12 GHz) as shown in Table 3.

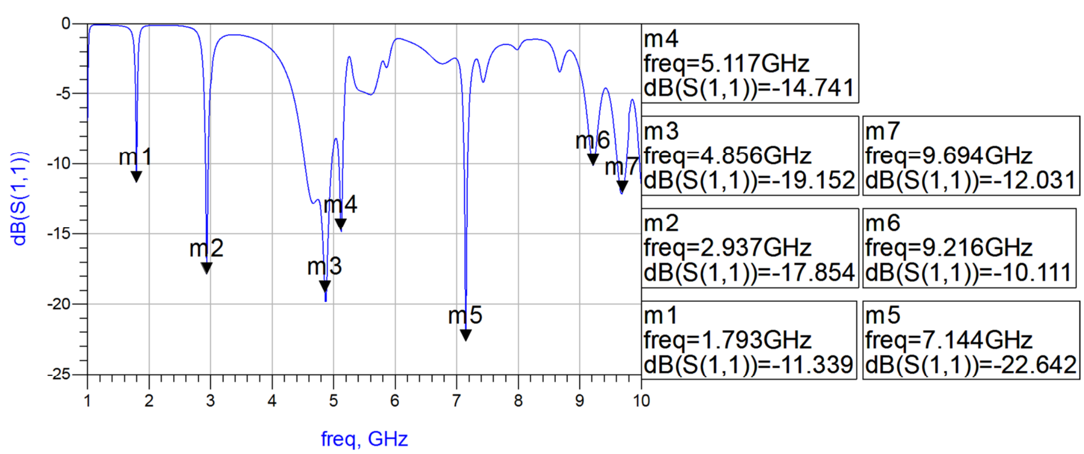

Figure 9: Frequency characteristic (S11 parameter) when two diodes (D2, D3) are in ON condition

Table 3 shows simulated frequency with corresponding return loss using Advanced Design System (ADS) software.

TABLE 3: Resonant frequencies and their return loss for reconfigurable multiband patch antenna when two diodes are in ON condition

Frequency (GHz)	Return Loss (dB)
1.793	-11.339
2.937	-17.854
4.856	-19.152
5.117	-14.741
7.144	-22.642
9.216	-10.111
9.694	-12.031

From Table 3 it is concluded that when two diodes are in ON condition, wireless applications like 3G, Wi-Fi, WIMAX and UWB can be obtained

In Figure.10, Reconfigurable multiband microstrip patch antenna with one diode is in ON condition. Here diode D1 is present hence it is called as ON-OFF-OFF/100 condition.

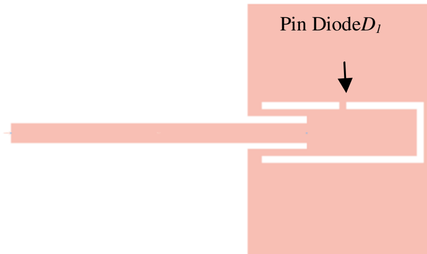

Figure 10: Reconfigurable multiband patch antenna when one diode is in ON condition

In Figure.11 Simulation of reconfigurable multiband Patch Antenna when one diode is in ON condition is given. The ON status of pin diode D1 gives frequencies which are obtained in S (2 to 4 GHz), C(4 to 8 GHz) and X(8 to 12 GHz) bands.

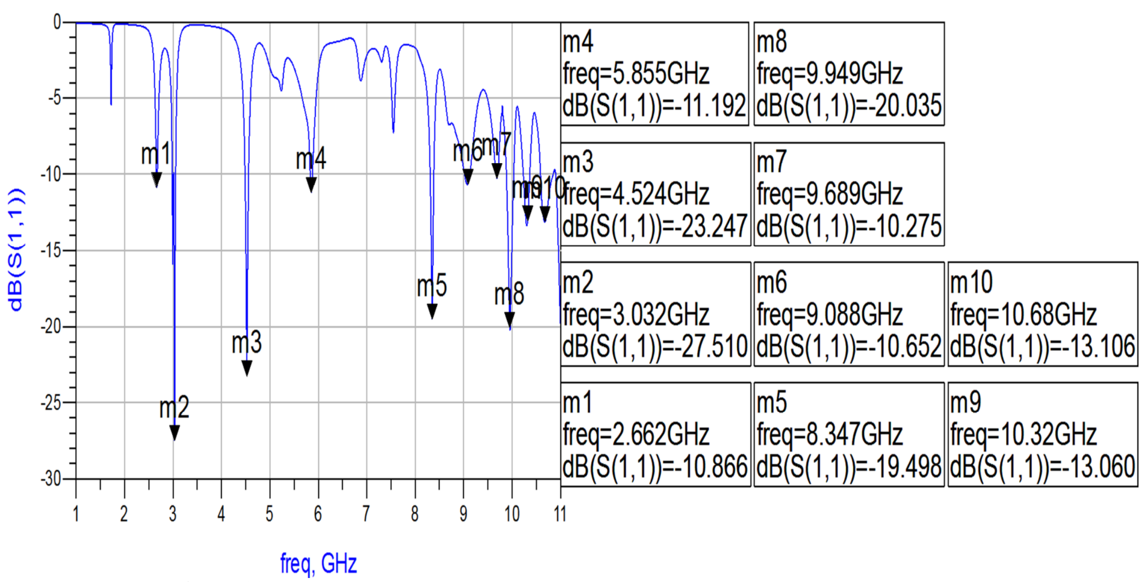

Figure 11: Frequency characteristic (S11 parameter) when one diode is in ON condition

Table 4 shows various frequencies with corresponding return loss using Advanced Design System (ADS) software.

TABLE 4: Resonant frequencies and their return loss for reconfigurable multiband patch antenna when one diode is in ON condition

Frequency (GHz)	Return Loss (dB)
2.662	-10.866
3.032	-27.510
4.524	-23.247
5.855	-11.192

8.347	-19.498
9.088	-10.652
9.689	-10.275
9.949	-20.035
10.32	-13.060
10.68	-13.106

From Table 4 it is concluded that when one pin diode is in ON condition, wireless applications like WiMAX and UWB can be obtained.

It is concluded that when slot is inserted inside the patch antenna, multiband can be obtained. And by placing PIN diode inside the slot reconfigurability can be achieved. Here, using only single patch antenna wireless applications like 3G, Wi-Fi, WiMAX and UWB are obtained.

IV.HARDWARE IMPLEMENTATION

Reconfigurable Multiband Patch antenna with two pin diodes (D2, D3) in ON condition in Figure.8 has been implemented as shown in Figure.12. It has been tested using Vector Network Analyzer (VNA) and measured results are shown in Figure.13.

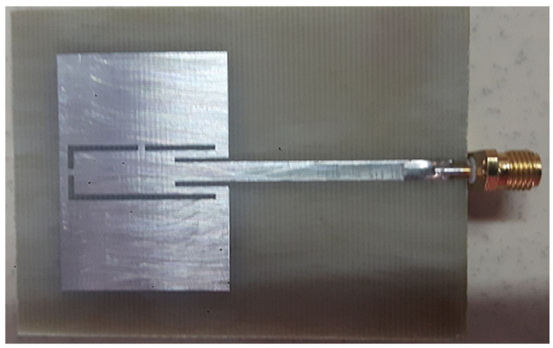

Figure 12: Implemented reconfigurable patch antenna when two diodes are in ON condition (011 COMBINATION)

V.RESULT

Measured result of 011 implemented reconfigurable patch antenna is shown in Figure 13.

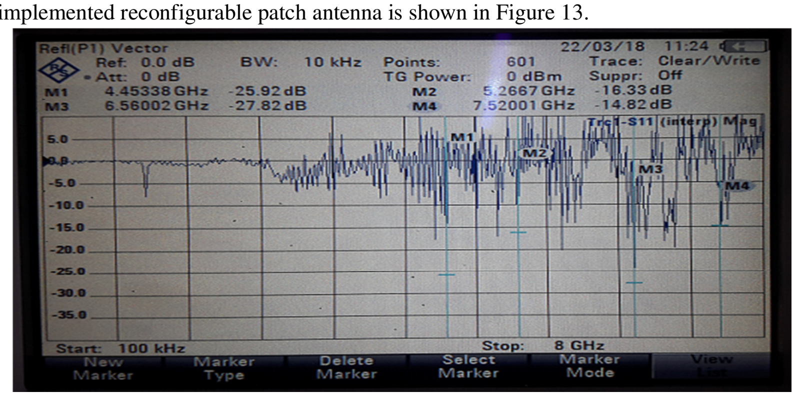

Figure 13: Measured result using VNA when two diodes are in ON condition

The 011 status of pin diodes of reconfigurable multiband patch antenna, gives frequencies with their return loss is shown in Table 5.

TABLE 5: Measured resonant frequencies and their return loss for implemented reconfigurable multiband patch antenna when two diodes are in ON condition

Frequency (GHz)	Return Loss (dB)
4.45	-25.92
5.26	-16.33

6.56	-27.82
7.52	-14.82

According to Table 5, 011 patch antenna can be used for Wi-Fi, WiMAX and UWB applications.

From Table 6, it is seen that there is a deviation between simulated and measured frequencies due to following reasons: Fr4 substrate is sensitive to frequency, cable losses while testing an antenna. Also from Table 6, it is clear that the major % error in simulated and implemented frequency is below 8%.

TABLE 6: Comparative study of simulation and implementation results of patch antennas

Sr. No .	**State of diode**	**Simulated frequency (GHz)**	**Implemented frequency(GHz)**	**% error in frequency**	**Simulated return loss (dB)**	**Implemented return loss (dB)**
1	011	4.856	4.45	8.3	-19.152	-25.92
		5.117	5.26	2.7	-14.741	-16.33
		7.144	7.52	5.3	-22.642	-14.82

Table 7 shows, all possible combination of states of pin diodes D1, D2 and D3. Depending upon the status of pin diodes, same patch antenna can be used for different wireless applications.

TABLE 7: Wireless applications depending upon pin diode status

SR. NO.	**State of Pin Diodes ('0': OFF, '1': ON)**			**Wireless Application**	**Frequency Obtain (GHz)**
	D_1	***D_2***	***D_3***		
1	0	0	0	Wi-Max	2.672
				UWB	4.493 , 8.347 , 8.768 , 9.719,10.31, 10.69
2	0	0	1	Wi-Max	2.65, 3
				UWB	4.5, 8.3
3	0	1	0	UWB	7.1, 9.8
4	0	1	1	3G	1.793
				UWB	2.937, 4.856, 7.144, 9.216, 9.694
				Wi-Max/Wi-Fi	5.117
5	1	0	0	Wi-Max	2.662, 5.855
				UWB	3.032, 4.524, 8.347, 9.088, 9.689,9.949, 10.32, 10.68
6	1	0	1	Wi-Max	2.65
				UWB	4.5, 7.5, 9.1, 9.5
7	1	1	0	Wi-Max/Wi-Fi	5.15
				UWB	3, 7.1
8	1	1	1	3G	1.781
				UWB	4.904, 2.952,9.228, 10.19
				Wi-Max/Wi-Fi	5.725

From Table 7 it is concluded that by turning pin diode ON and OFF, antenna structure provides band of frequencies for Wi-Fi, WiMAX, 3G applications. Thus for having applications WiMAX and UWB simultaneously, the status of D3 can be anything. But D1 and D2 should be OFF. Also for 3G application, D1 can have any state but D2 and D3 should be ON.

VI. CONCLUSION

Various methods for obtaining multiband have been introduced. A rectangular microstrip patch with microstrip line feed is designed. Also a U-shape slotted rectangular microstrip patch with microstrip line feed is designed to get multiband and reconfigurability is obtained using pin diodes. Multiband antenna design can be achieved by placing U-shape slot inside the rectangular microstrip patch antenna. By varying the status of pin diodes frequency reconfigurability can be done. Thus one can replace two or more antenna by single antenna. The proposed single reconfigurable multiband patch antenna can be used for various wireless applications like 3G, Wi-Fi, WiMAX and UWB etc.

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