Design of a Frequency Reconfigurable MIMO Patch Antenna for UWB and Notched UWB Characteristics

Harshal Nigam, Monika Mathur
Department of Electronics and Communication Engineering, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur-302017 (INDIA)
***Email*-hrshlnigam@gmail.com**
Received 15.02.2019 received in revised form 14.09.2019, accepted 17.09.2019

Abstract: In this paper, a frequency reconfigurable microstrip patch antenna having a partial ground plane and U-slot on the patch has been designed. The antenna is made reconfigurable by switching the different diodes placed on the U-slot of antenna. The antenna works for the entire UWB (3.1-10.7 GHz) when the diodes are at a particular state with minimum attenuation of around -23 dB at a frequency of about 9.4 GHz that can be used for RADAR applications. This antenna can be switched to different notched UWB based on different states of diode. The frequency band of 5-5.9 GHz has been notched thus removing the interference from WLAN band. The antenna has been designed for MIMO applications, here two antennas have been used and it is observed that both are working independently of each other on the designated frequency band. The antennas are having high isolation and a very low value of correlation coefficient.

Keywords: Microstrip patch Antenna (MSA), Multiple Input Multiple Output (MIMO), Partial Ground, Ultra Wide Band (UWB).

1. INTRODUCTION

Reconfigurable antennas have now become a great requirement in today's era of wireless communications as they can be reconfigured to have different characteristics based on the switching of a single antenna. UWB is a wide band ranging from 3.1 to 10.6 GHz by FCC [1] this is a very wide bandwidth and high data rates are obtained but generally UWB is used for short range indoor wireless communications only. UWB generally covers many small frequency bands that may produce interference so UWB is notched for certain bandwidths and the antenna does not work in that range. Frequency reconfigurable antennas are those which can work on multiple bands based on the switching technique employed in the antenna, so to create a notch bandwidth in an antenna a frequency reconfigurable antenna is used that works on full UWB and also on notched UWB at different states of the switch present in the antenna. There are many other techniques available in literature to create band notched antennas [2]-[4] but here the band notched characteristics are generated by embedding slot on the patch. The antennas can be made frequency reconfigurable by techniques such as RF-MEMS [5], varactor diodes [6-7] or using PIN diodes [8-9].MIMO antennas have now become the most important requirement for achieving high data rate wireless communications, where the data goes through multiple antennas at the same time thus increasing the data transmitted per unit time. The condition to design MIMO antennas is that the two antennas should work independently of each other with a very low mutual coupling between them and a very low value of correlation coefficient with high diversity gain. Mutual coupling can be reduced by many techniques as in literature using meander slot [10] or defected ground structures [11]

In this paper, first of all a single antenna was designed with a rectangular patch and partial ground plane to generate full UWB characteristics, after that a two antenna MIMO system was designed in which the two antennas were orthogonal to each other so as to reduce mutual coupling, after that the antennas were made reconfigurable by cutting a U slot on the patch with diodes inserted between them, based on different switching states of diode different working frequency bands for the antenna can be generated.

2. SINGLE ANTENNA DESIGN AND ANALYSIS

Authors have designed the patch antenna on FR4 substrate with a dielectric constant of 4.4 and thickness of 1.6 mm. As it can be seen from Fig. 1 the front view of antenna are having a patch and microstrip line feeding and also the back view as shown in Fig. 2 having a partial ground plane. The antenna was simulated and the S11 graph is observed as in Fig. 3 which shows that the S11 is less than -10 dB for the entire UWB (3.1-10.6 GHz) with a minimum attenuation frequency of 9.4 GHz.

The dimensions in Fig. 1 are as follows L1=30 mm, W1=40 mm, L2=10.5 mm, W2=9 mm, L3=12 mm, W3=2.9 mm. The dimensions for partial ground were found by optimizing values of L and W to get the best UWB results as L=10 mm and W=20 mm.

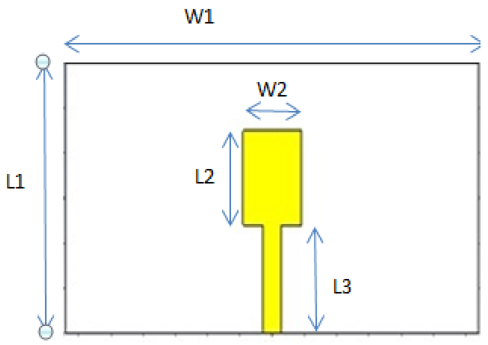

Figure 1: Front view of Antenna

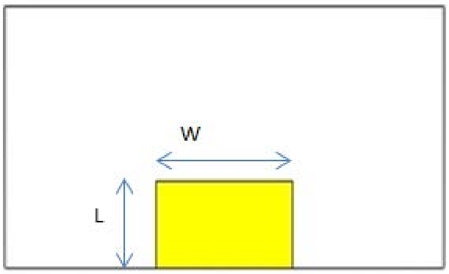

Figure 2: Back view of Antenna

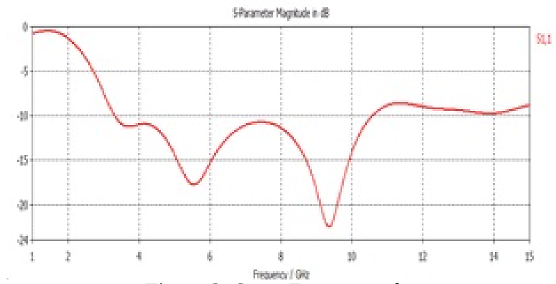

Figure 3: S_{11} vs Frequency plot

3. MIMO ANTENNA DESIGN AND ANALYSIS

Now, a 2 antenna MIMO system is designed using polarization diversity where one antenna is rotated at 90 degrees with respect to other to reduce the mutual coupling between the antennas as it can be seen in Fig. 4 that the above designed single antenna is duplicated orthogonally to design a MIMO antenna with two ports P1 and P2 and distance (d) between two antennas is around 12mm. The antennas have to be designed for a 2X2 MIMO system so two antennas are used that should have a very low mutual coupling between them. The mutual coupling between the two antennas is given by S21 and S12 results for this system as in Fig. 5 and observed that it is less than -20 dB, thus a reduced mutual coupling between the two antennas is obtained, also the correlation coefficient (ρ) and diversity gain (DG) has been calculated as given by equations (i) and (ii) [12] respectively and their plots with frequency as in Fig. 6 and Fig. 7 respectively. It can be observed from the figures that the correlation coefficient is nearly zero for the entire UWB as the values of S parameters are very low and so the diversity gain comes out to be nearly 10 dB for this band from equation (ii) thus the antennas are very less correlated with a high value of diversity gain.

$$\rho = \frac{\left|S11^{*}S12 + S21^{*}S22\right|^{2}}{\left(1-|S11|^{2}-|S21|^{2}\right)\left(1-|S22|^{2}-|S12|^{2}\right)} \quad \text{(i)}$$

$$DG(dB) = 10 * \sqrt{1-(0.99 * \rho)^{2}} \quad \text{(ii)}$$

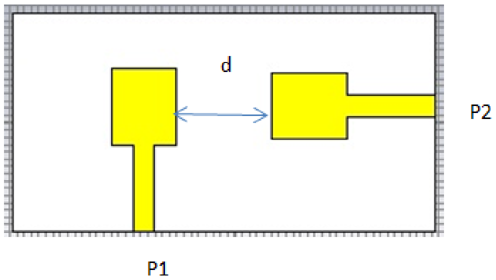

Figure 4: Two port MIMO Antenna System

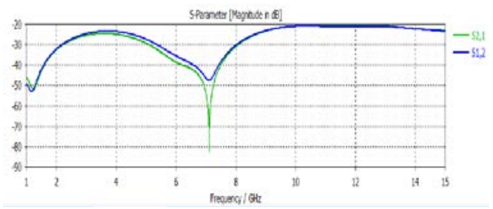

Figure 5: S_{21} and S_{12} plots with frequency

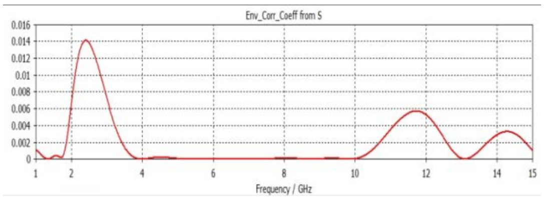

Figure 6: Correlation Coefficient plot with frequency

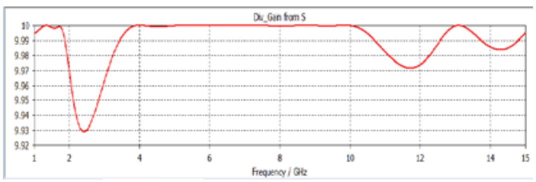

Figure 7: Diversity gain plot with frequency

4. RECONFIGURABLE MIMO ANTENNA DESIGN AND ANALYSIS

A U-slot has to be cut on patch antenna to create a notch frequency as it lengthens the current path which creates an additional resonance. The length of the slot is half wavelength of notch frequency to be calculated as from equation (iii) [13]

$$L = \frac{c}{2f\sqrt{e}} \qquad \text{(iii)}$$

Parametric analysis is applied to calculate width of the slot as in Fig. 8 and Fig. 9 respectively. The best calculated value to notch the 5-6 GHz band is ‘l1=0.5 mm’

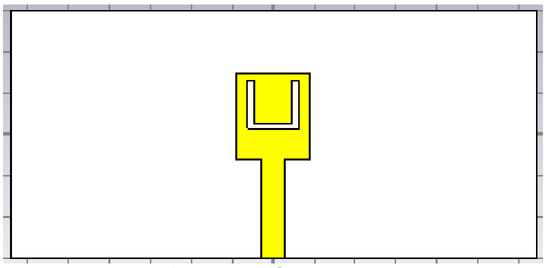

Figure 8: U-slot on antenna

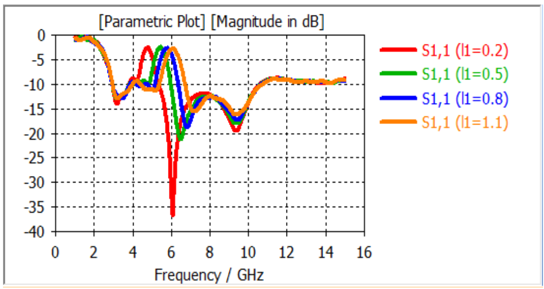

Figure 9: Variation of width of slot

Now, diodes are inserted between the slots as in Fig. 10. The diodes D1, D2, D3 (DSM8100-000 from Skyworks) are same in both the antennas when if the diode D1 is referred as ON, both D1 diodes in both the antennas are ON and if OFF both are OFF, same thing applies to other diodes also. The bias circuit for PIN diode is as shown in Fig. 11. The capacitors block the DC and inductors block AC, Thus RF and DC are separated. The diode can be forward bias or reverse bias depending on polarity of DC at the DC bias terminals. DC bias lines need to be inserted in the structure of antenna, to isolate the bias, some lumped elements in antenna are placed that causes a change in radiation pattern of antenna [14].

The diode is modeled in CST microwave studio, the equivalent circuit of diode in ON and OFF states is as shown in Fig. 12 where Rs=3 ohm Ls=0.15 nH in ON state and Rp=15 Kohms CT=32 fF and Ls=0.15 nH in OFF state.

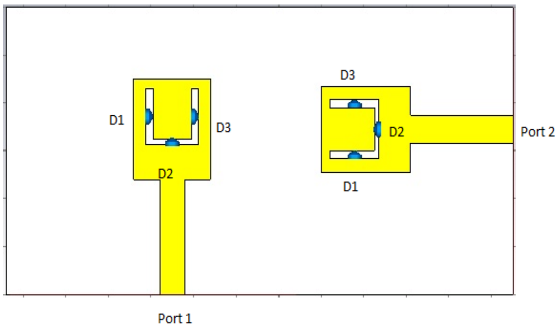

Figure 10: MIMO Antennas with U-slot and diodes

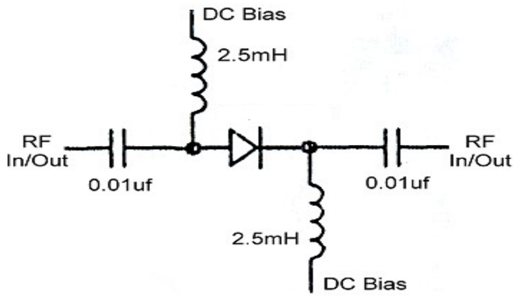

Figure 11: Biasing circuit for diode

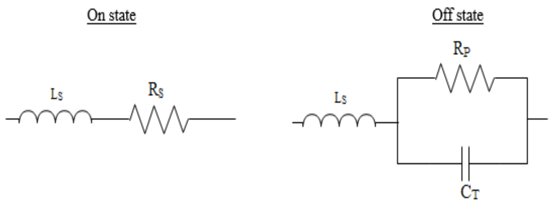

Figure 12: Circuit model of PIN diode in ON and OFF states

Now the different states of antenna are observed as in Table 1, Sxx denotes S_{11} or S_{22} and Sxy denotes S_{21} or S_{12}, it can be seen that for all the cases Sxy is less than -20 dB, thus mutual coupling between the antennas is reduced and depending on Sxx the antenna can work for both full UWB and different notched UWB as seen in table. Some S parameter graphs are shown in Fig. 13 (a)-(d) for S_{11}, S_{22} , S_{21} , S_{12} for the diodes state in full UWB working of antenna and in Fig. 14 (a)-(d) for S_{11}, S_{22} , S_{21} , S_{12} for the diodes state in notched UWB working of antenna where WLAN band 5-5.9 GHz has been notched. In Fig. 13 (a) and (b) S_{11} and S_{22} plots are shown that shows that both antennas are working on full UWB independent of each other as the value of S_{11} and S_{22} is less than -10 dB for the entire UWB in both the antennas. In Fig. 13 (c) and (d) graphs of S_{21} and S_{12} are shown that shows a reduced mutual coupling less than -20 dB between the two antennas.

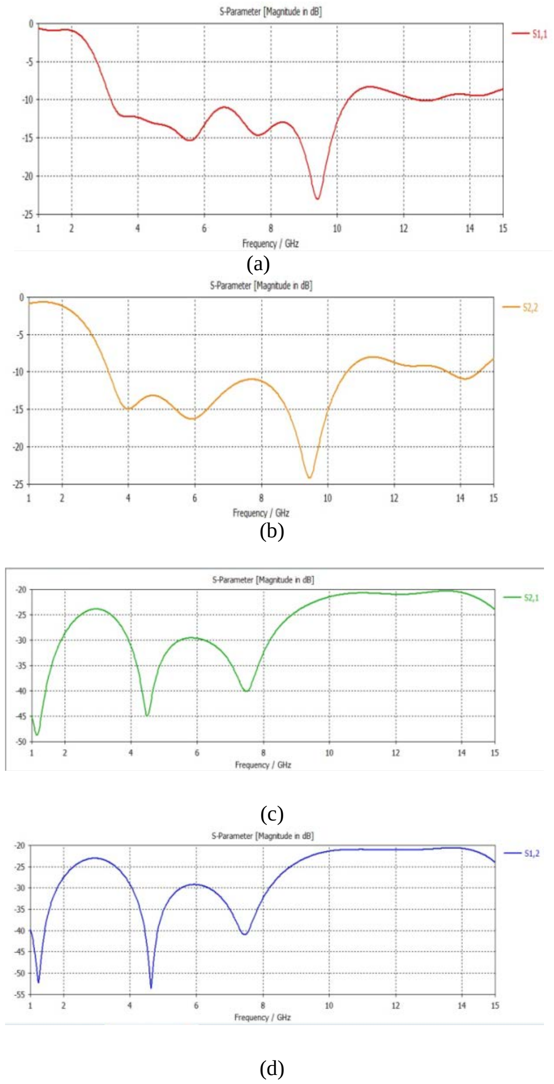

Figure 13: S_{11}, S_{22} , S_{21} , S_{12} plots for full UWB

Similarly in Fig. 14 (a)-(d) it can be observed from S_{11} and S_{22} that both antennas are working on Notched UWB with WLAN band notched and S_{21}, S_{12} graphs show a reduced value of mutual coupling between the two antennas. The combined graph for S_{11} is shown in Fig. 15 for S_{11} UWB (all diodes ON) and S_{11} notch WLAN band (all diodes OFF) cases. The polar plot of Gain for UWB and notched UWB antenna is also shown in Fig. 16 and Fig. 17 respectively at a frequency of 9.4 GHz that can be used for RADAR applications.

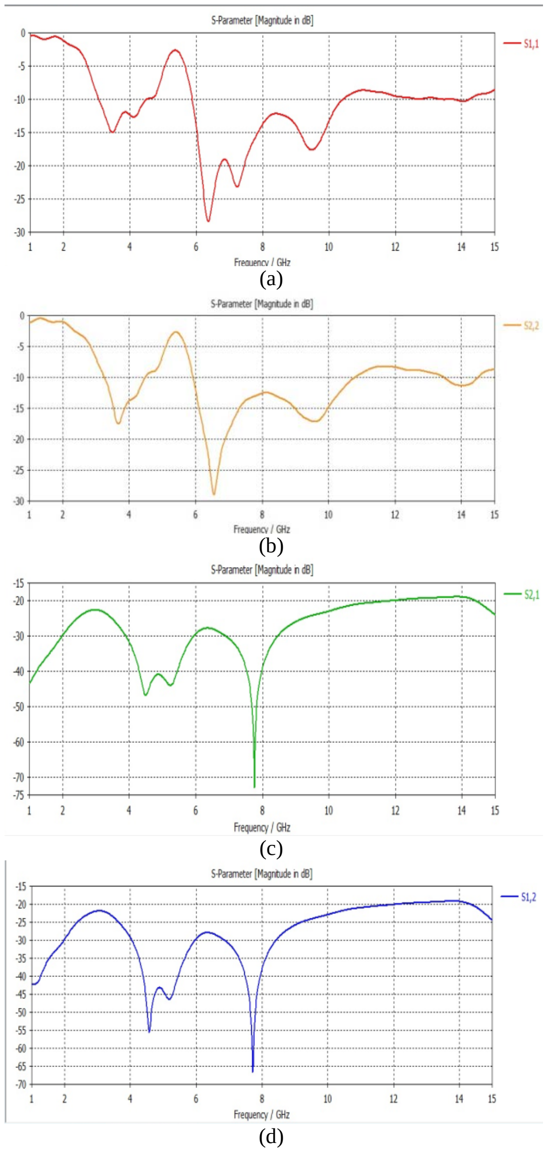

Figure 14: S_{11}, S_{22} , S_{21} , S_{12} plots for Notched UWB

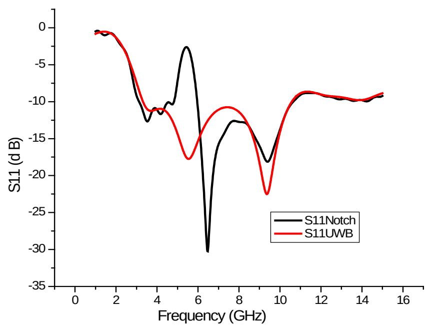

Figure 15: Combined S_{11} for UWB and Notched UWB

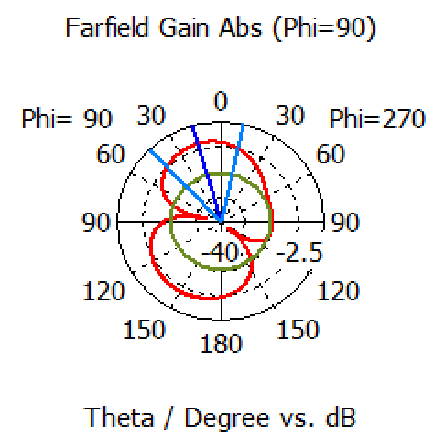

Figure 16: Polar plot for Notched UWB Antenna

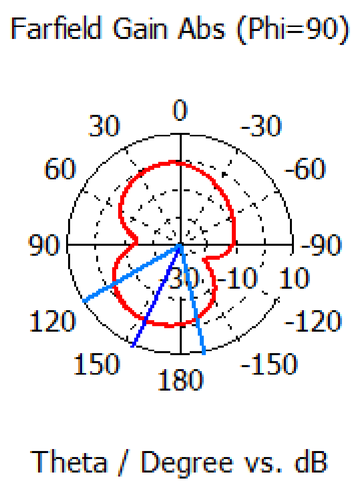

Figure 17: Polar plot for Full UWB Antenna

5. CONCLUSION

Thus, a MIMO frequency reconfigurable antenna has been designed that can be reconfigured to full UWB and notched UWB depending on the switching of diode, it can be observed that the antennas are working independently of each other with a low value of mutual coupling and correlation coefficient between them and with a high value of diversity gain. A MIMO antenna will provide high bandwidth and high data rate as compared to a single antenna transmission. The resonating frequency for UWB antenna is found at around 9.4 GHz for full UWB as in table that can be used for RADAR applications also different notched bands are observed as Notched WLAN band, this antenna can be used at the receiver side to attenuate the WLAN band thus reducing the interference from WLAN band to UWB also it can notch the S and C bands from the UWB as seen in table thus reducing their interference also from the UWB. UWB is a very large band and it suffers interference from many narrow bands that are currently allocated various applications as WLAN, WiMAX therefore an unwanted interference occurs from such bands so nowadays many systems require band notched antenna to remove such interference as here the notching of WLAN band and S and C band is done likewise other narrow bands can also be notched.

Table 1: Different states of Diode and Antenna frequency bands

S.N	State of the Diodes			Results for Sxx and Sxy	Working band of the antenna
	D1	D2	D3		
1	OFF	ON	ON	Sxx<-10 dB for 3.1 GHz to 10.6 GHz, Sxy<-20 dB	Full UWB
2	ON	OFF	OFF	Sxx<-10 dB for 3.1 GHz to 10.6 GHz with band notched 5.8 GHz to 7 GHz, Sxy<-20 dB	Notched UWB
3	OFF	OFF	ON	Sxx<-10 dB for 3.1 GHz to 10.6 GHz with band notched 5.8 GHz to 7 GHz, Sxy<-20 dB	Notched UWB
4	OFF	ON	OFF	Sxx<-10 dB for 3.1 GHz to 10.6 GHz, Sxy<-20 dB	Full UWB
5	ON	OFF	ON	Sxx<-10 dB for around 3 GHz to 6 GHz, Sxy<-20 dB	S and C band
6	OFF	OFF	OFF	Sxx<-10 dB for 3.1 GHz to 10.6 GHz with band notched 5 GHz to 6 GHz, Sxy<-20 dB	Notched WLAN Band
7	ON	ON	ON	Sxx<-10 dB for 3.1 GHz to 10.6 GHz, Sxy<-20 dB	Full UWB
8	ON	ON	OFF	Sxx<-10 dB for 3.1 GHz to 10.6 GHz, Sxy<-20 dB	Full UWB

ACKNOWLEDGEMENT

We are highly grateful to the management of SKIT Jaipur for providing us resources and a platform to carry out our research work.

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