International Journal of Electrical Sciences & Engineering (IJESE)
Online ISSN: 2455 6068; Volume 1, Issue 1; January 2016 pp. 68-73

Design of Reconfigurable Rectangular Patch Antenna using PIN Diode

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***Abstract*: In this paper, frequency reconfigurable rectangular antenna is presented. The proposed antenna consists of a Microstrip patch antenna. In this design it makes use of two patches with different dimension in order to tune for multiple frequencies. The antenna design make use of micro strip feeding technique, PIN diode is used for switching between the patches to tune for different frequencies. The antenna is capable to reconfigure up to two different frequencies i. e. , 9. 2GHz and 6. 2GHz when no PIN diode is connected. When a single PIN diode is connected it will generate a frequency of only 6. 2GHz and when two PIN diodes are connected it will reconfigure itself to generate two different frequencies i. e. , 2. 2GHz and 3. 5GHz. This antenna is simulated and measured results are used to demonstrate the performance of the antenna.**

***Keywords:* Reconfigurability, Feeding Technique, Microstrip Antenna and Rectangular Patch**

1. INTRODUCTION

With rapid development of wireless communication especially in depth research on MIMO techniques Reconfigurable antennas gaining great attention. Different characteristics (such as resonant frequency, radiation patterns, polarization, etc) of these novel antennas can be reconfigurable through the change of the structures. . 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 [1]. Frequency reconfigurable antenna has the reconfiguration of the resonant frequency by the change of the structure, while the radiation patterns and polarization remain unchanged. So, frequency reconfigurable antenna can be applied among a very wide arrangement of frequency band or among multiple frequency bands.

Depletion of available frequency resources has been one of the major problems in wireless communication systems. To solve this, cognitive radio is considered to be a promising solution [5]. In the cognitive radio system, antenna characteristics are required to be as equivalent as possible at any selected frequency band. Various types of effective reconfigurable antennas were proposed [6]. Microstrip patch antennas have found extensive application in wireless communication system owing to their advantages such as low profile, conformability, low-cost fabrication and ease of integration with feed networks[3]. Electrical reconfiguration techniques are based on the use of switches to connect and disconnect antenna parts as well as to redistribute the antenna currents. Radio frequencymicro-electromechanical systems (RF-MEMS) have been proposed for integration into reconfigurable antennas since 1998[7]. P-i-n diodes or varactors have appeared to be a faster and a more compact alternative to RF-MEMS. The switching speed of a p-i-n diode is in the range of 1–100 nsec[8].

Several methods are used to feed microstrip antennas. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a Microstrip line[4]. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the Microstrip line and the radiating patch. The four most popular feed techniques used are the Microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

In this design we used contacting feed such as Microstrip Line Feed. In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. However as the thickness of the dielectric substrate being used, increases the surface waves and also spurious feed radiation, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation. This method is advantageous due to its simple planar structure. In this paper, a reconfigurable rectangular patch antenna using PIN diodes is presented to provide multiple-frequency operation for various applications. Switches can be modeled at different levels of complexity, depending on the required accuracy and available computational resources. At the basic level, the switch can be modeled simply by a metal tab; switching between the ON and OFF states is then just a matter of simulating the model with and without that piece of metal.

2. ANTENNA DESIGN CALCULATION

Step 1: Calculation of Width (W)

The width of the Microstrip patch antenna is given as:

$$W = \frac{c}{2 f_o \sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

Where, c is velocity of light, f_0 is Resonant Frequency & ε_r is Relative Dielectric Constant, of course other widths may be chosen but for widths smaller than those selected according to the width equation [3], radiator efficiency is lower while for larger widths, the efficiency are greater but for higher modes may result, causing field distortion.

Step 2: Calculating the Length (L)

Effective dielectric constant (ε_{eff})

Once Width is known, the calculation of the length which involves several computations; the first would be the effective dielectric constant [2]. The dielectric constant of the substrate is much greater than the unity; the effective value ε_{eff} will be closer to the value of the actual dielectric constant ε_r of the substrate. The effective dielectric constant is also a function of frequency. As the frequency of operation increases the effective dielectric constant approaches the value of the dielectric constant of the substrate is given by:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Effective length (L_{eff})
The effective length: This can be found by

$$L = \frac{c}{2 f_o \sqrt{\varepsilon_{re}}}$$

Length Extension (ΔL)
Because of fringing effects, electrically the micro strip antenna looks larger than its actual physical dimensions. For the principle E – plane (x-y plane), where the dimensions of the path along its length have been extended on each by a distance ΔL, which is a function of the effective dielectric constant and the width-to-height ratio (W/h). The length extension is:

$$\Delta L = 0.412\, h \frac{(\varepsilon_{re} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{re} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

Calculation of actual length of patch (L)

Because of inherent narrow bandwidth of the resonant element, the length is a critical parameter and the above equations are used to obtain an accurate value for the patch length L. The actual length is obtained by:

$$L_{eff} = L + 2\Delta L$$

Feed Point Location

After selecting the patch dimensions L and W for a given substrate, the next task is to determine the feed point (x, y) so as to obtain a good impedance match between the generators Impedance and the input impedance of the patch element. It is observed that the change in feed location gives rise to a change in the input impedance and hence provides a simple method for impedance matching.

$$Z_{in} \approx jX_f + \frac{R}{1 + j2Q(f/f_0 - 1)}$$

From the above equation we see that if the feed is located at $x = x_f$ and $0 \le y_f \le W$, the input resistance at resonance for the dominant TM_{10} mode can be expressed as:

$$R_{in} = R_r \cos^2(\pi x_f / L) \qquad R_r \ge R_{in}$$

Where x_f is the inset distance from the radiating edge and R_r is the radiation resistance at resonance when the patch is fed at a radiating edge [5]. The inset distance x_f is selected such that R_{in} is equal to the feed line impedance, usually taken to be 50Ω. Although the feed point can be selected anywhere along the patch width, it is better to choose $y_f = W/2$ if $W \ge L$ so that TM_{0n} (n odd) modes are not excited along with the TM_{10} mode. Determination of the exact feed point requires an iterative solution. Below equation provides a useful guideline for the purpose. Kara has suggested an expression for x_f that does not need calculation of radiation resistance. It is approximately given by

$$x_f = \frac{L}{2\sqrt{\epsilon_{re}(L)}}$$

3. ANTENNA DESIGN

The basic structure of the proposed antenna, shown in Fig. 1, consists of three layers. The lower layer, which constitutes the ground plane, covers the partial rectangular shaped substrate with a side of 42×46mm. The middle is the substrate, which is made of Teflon, has a dielectric constant ϵ_r=2. 1 and height 1. 5 mm. The upper layer consists of two rectangular patches. The rectangular patches have dimensions 33×16. 8 mm and 33×17. 5 mm that covers a portion of the substrate. The patch is fed by a Microstrip line with 50Ω input impedance.

The three essential parameters for the design of a rectangular Microstrip Patch Antenna:

1. Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. The Antenna was designed for radar communications, satellite uplink, Mobile Broadband Wireless Access and WiMAX. Hence the antenna designed must be able to operate in these frequency ranges. The resonant frequencies selected for our design are 6. 2 and 9. 2 GHz.

2. Dielectric constant of the substrate (ε_r): The dielectric material selected for our design is Teflon which has a dielectric constant of 2. 2. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.

3. Height of dielectric substrate (h): For the micro strip patch antenna to be used in wireless application, it is essential that the antenna should be compact. Hence, the height of the dielectric substrate is selected as 1. 5mm.

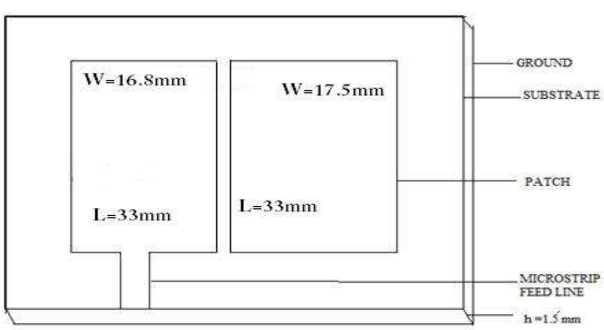

Fig. 1. The proposed geometry of patch antenna

Simulations were performed using HFSS. Convergence was tested for a number of times. Once convergence was obtained simulations were conducted in order to obtain sweep frequency response. Initially we started with one patch with no PIN diodes, then went with both the patch operating with input to the second patch are through only one PIN diode, then finally checked with two PIN diodes, however it was observed that in order to achieve proper impedance patch position and dimensions need to be adjusted accordingly.

The proposed antenna is designed to operate at two different frequencies with single patch with no diode ON at the first stage, then when both the patches are connected together using one PIN diode with specification of PIN diode are Resistance-1. 2Ohms, Inductance-0. 6nH and Capacitance-0. 3pF produces one frequency that's second stage, Finally in last stage when two PIN diode are used it produces still two more frequencies. In this antenna microstrip feed is used with the length of 13mm and width of 1. 5mm, the gap between the two patches is 0. 7mm.

The designed antenna is as shown figure 2, Blue color indicates substrate (S), dark blue color indicates patch (P1) and (P2), red indicate feed (F), pink indicates PIN diodes (D1 and D2) and white indicates feed port (Fp). In the design feed is given to patch P1.

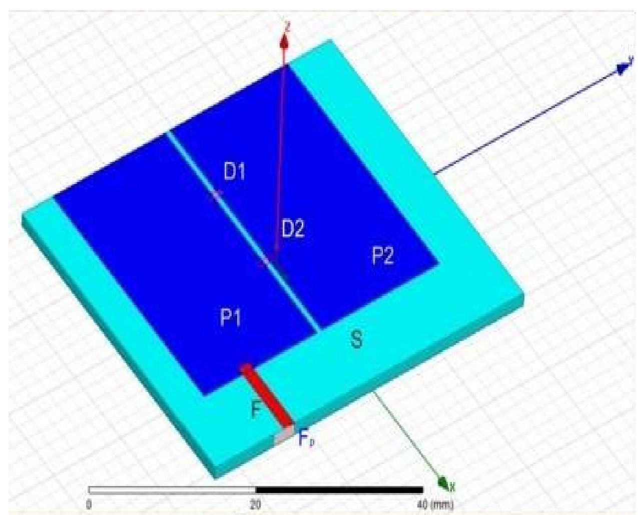

Fig. 2. The designed microstrip rectangular patch antenna.

4. DESIGN ANALYSIS

There are three stages of operation each one is discussed below:

***Stage 1*:** In this case when both PIN diodes D1 and D2 are OFF, only patch P1 is radiating and patch P2 is not operating or radiating, is as shown in the figure 3.

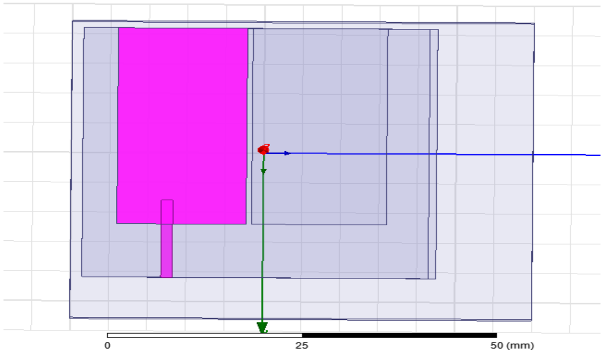

Fig. 3. Patch P1 is radiating.

Stage 2**:** In this case when PIN diode D1 is ON and D2 is OFF, now both patch P1 and P2 is radiating, the current flow from patch P1 to P2 is through diode D1, is as shown in the figure 4.

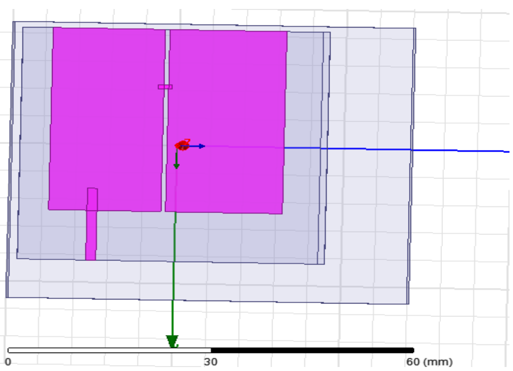

Fig. 4. Patches P1 and P2 are radiating connected using a single PIN diode D1.

Stage 3: In this case when both PIN diode D1 and D2 are ON, now both the patches P1 and P2 are radiating, the current flow from patch P1 to P2 is through both diodes D1 and D2, is as shown in the figure 5.

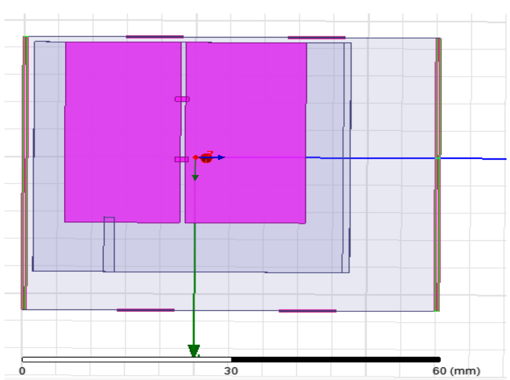

Fig. 5. Patches P1 and P2 are radiating connected using two PIN Diodes D1 and D2.

5. RESULTS AND OBSERVATION

We observe what happens in each case discussed in above stages,

Stage 1: In this case we can observe that the antenna can produce two frequencies such as 9. 2GHz and 6. 2 GHz which are used for radar communication and satellite uplink communication is as shown in figure 6(a) with a gain of -26. 02 and -16. 33 dB. For these two frequencies we can observe the voltage standing wave ratio as 1. 10 and 1. 37 which is within the acceptable range in practically (ideally should be 1) is as shown in figure 6(b).

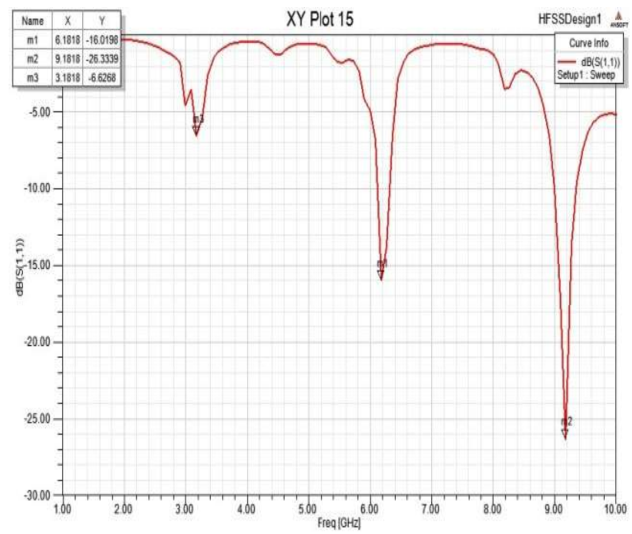

Fig. 6(a). Plot of frequency v/s gain(dB)

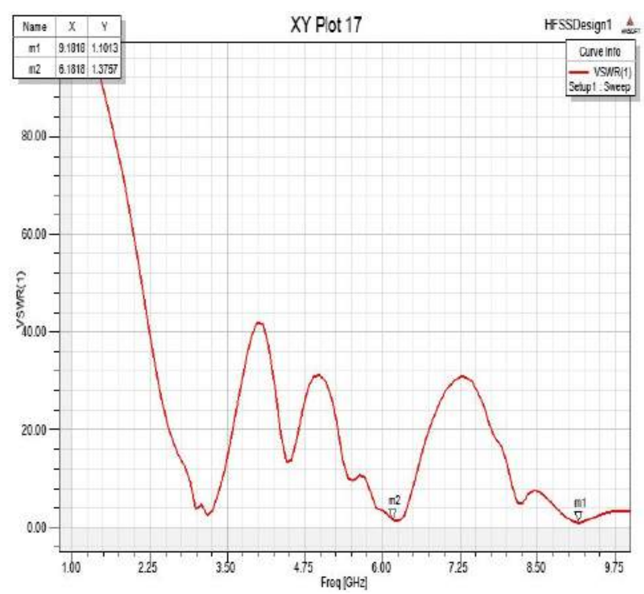

Fig. 6(b). Plot of frequency v/s VSWR.

Stage 2: In this case we can observe that the antenna can produce frequency of 6. 2 GHz which is used for satellite uplink communication is as shown in figure 7(a) but in this the gain grows to -24. 22 dB from 16dB compare to previous stage. For this frequency we can observe the voltage standing wave ratio of 1. 07. Which is within the acceptable range in practically (ideally should be 1) is as shown in figure 7(b).

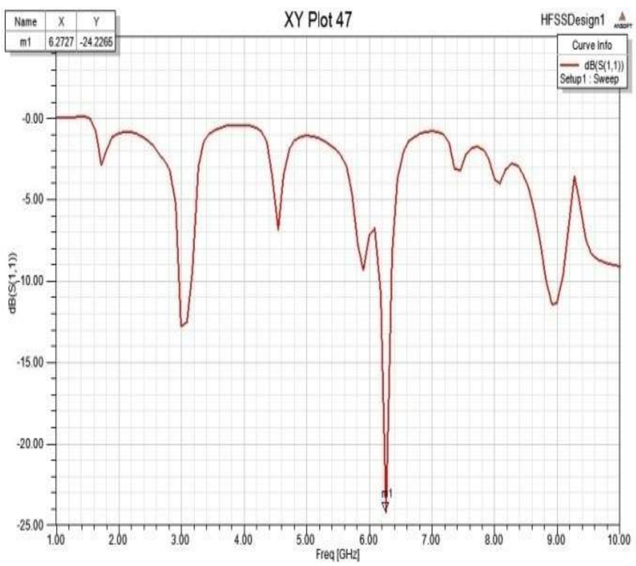

Fig.. 7(a): Plot of frequency v/s gain (dB).

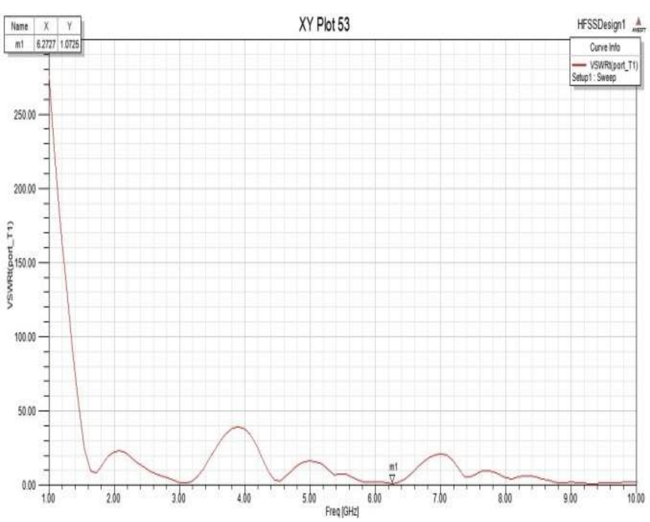

Fig. 7(b). Plot of frequency v/s VSWR.

Stage 3: In this case we can observe that the antenna can produce two frequencies such as 3. 5GHz and 2. 2 GHz which are used for WiMAXand Mobile Broadband Wireless Access (MBWA) is as shown in figure 8(a) with a gain of -15. 66 and -8. 71 dB. For these two frequencies we can observe the voltage standing wave ratio as 1. 39 and 2. 36, which is within the acceptable range in practically (ideally should be 1) is as shown in figure 8(b).

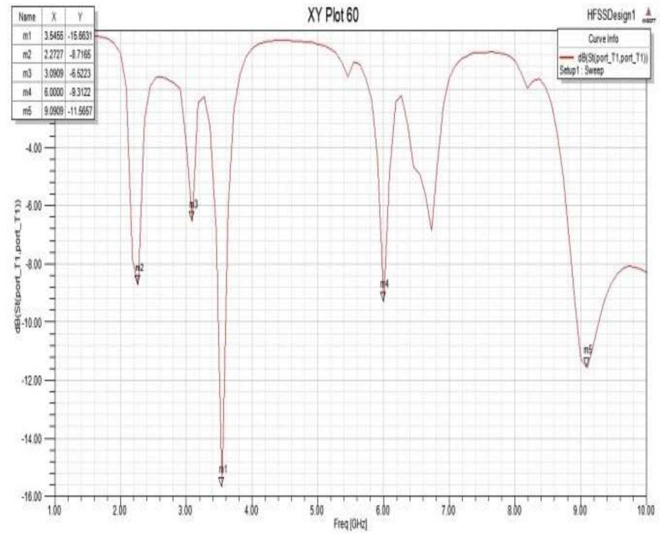

Fig. 8(a): Plot of frequency v/s gain(dB).

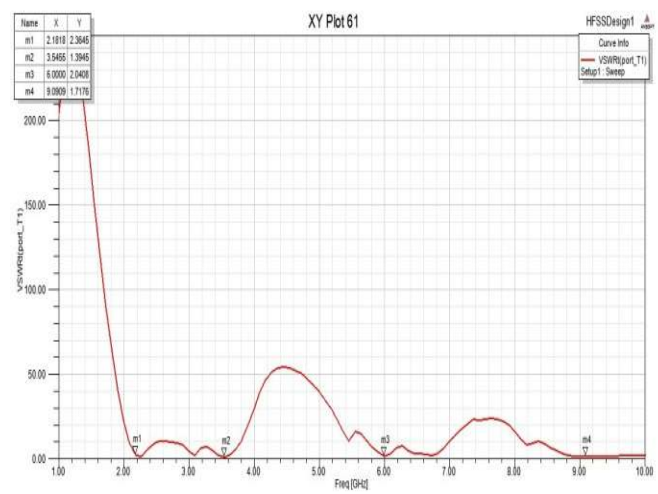

Fig. 8(b): Plot of frequency v/s VSWR.

From all the above results we can observe that the frequency will be maximum when all the PIN diode is OFF and with the more gain, as we connect one PIN diode between the patches the frequency slightly decrease and when we connect second PIN diode (as both PIN diodes are connected) the frequency still reduces. Finally we can say that once PIN diode is connected we can reconfigure the antenna for different frequency applications from highest frequencies to lowest.

6. CONCLUSIONS

In this paper the aim is to design a Reconfigurable rectangular patch antenna and to study the responses of the same. The antenna has been designed with two different patch dimensions, taking into consideration like patch dimensions, selection of the substrate, feeding technique and also the Operating frequency to design the antenna. The antenna is designed to operate in four different frequencies using PIN diode to switch between the patch in order to reconfigure the frequencies. By using PIN diode for switching we get three stages of operation and we studied all the three stages of design and also we observed their gain and VSWR with respect to the frequency in all the three stages in detail.

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