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Design and Analysis of Reconfigurable Microstrip Patch Antenna

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Abstract: In this paper, frequency reconfigurable microstrip patch antenna is presented. In this design it makes use of three patches with different shapes 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 of resonating at a frequency of 6.2GHz, when no PIN diode is connected. When a PIN diode is connected between two patches it will generate a frequency of 5.6GHz and 2.2GHz. When all the three patches are connected it will reconfigure itself to generate a different frequency i.e., 3.4GHz. This antenna is simulated and measured results are used to demonstrate the performance of the antenna.

Keywords: Reconfigurability, PIN Diode, Microstrip Antenna, Circular Patch and HFSS.

I. INTRODUCTION

An antenna is said to be reconfigurable if it changes its characteristics such as frequency, radiation pattern and polarization to adapt to the environment. The reconfiguration is not limited to a single characteristic but can be a combination of different characteristics depending on the application. 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]. Moreover, frequency reconfigurable antennas have the potential to reduce the size of front end system and allow pre-filtering at the receiver. Thus, it can support many wireless applications in one single terminal system [2].

The design of an efficient wide band small size antenna, for recent wireless applications, is a major challenge. 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. So, Microstrip patch antennas are being used in this design. Switching components, such as PIN diodes, varactor diodes, and micro-electro-mechanical (MEMS) switches, are frequently adopted in the design of reconfigurable antennas to electronically change the operating frequency band, the radiation pattern, and/or the polarization [3]-[5]. Among these switching devices, PIN diodes are very reliable and compact because they have high switching speeds and low resistance and capacitance in the on and off states, respectively.

Microstrip patch antennas can be fed by a variety of methods. 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. 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.

II. 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 W is known, the next step is the calculation of the length which involves several other computations; the first would be the effective dielectric constant [3]. 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 [4]. 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: 2.

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

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. 3.

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

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

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

III. 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 32x24mm. The middle is the substrate, which is made of FR4_epoxy, has a dielectric constant ε_r ε_r=4.4 and height 1.5 mm. The upper layer consists of a circular patch etched out in a rectangular patch and a central E-shaped patch. 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:
Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. The Antenna was designed for radar communications, satellite uplink, one-point to multi-point systems. Hence the antenna designed must be able to operate in these frequency ranges. The resonant frequencies selected for our design are 6.2, 2.2 and 5.6 GHz.
Dielectric constant of the substrate (ε_r): The dielectric material selected for our design is FR4_epoxy which has a dielectric constant of 4.4. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
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.

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,

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however it was observed that in order to achieve proper impedance patch position and dimensions need to be adjusted accordingly.

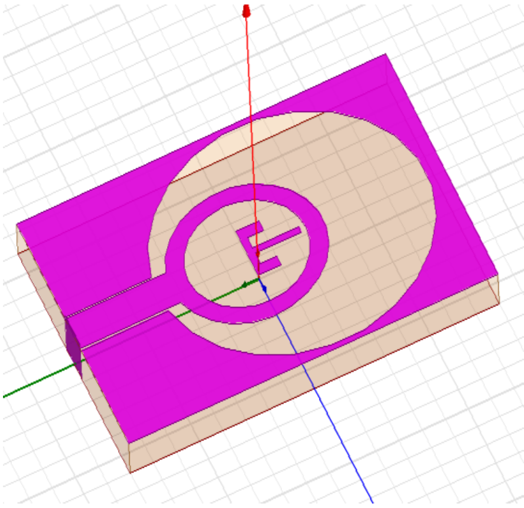

Figure 1: The proposed geometry of patch antenna.

The proposed antenna is designed to operate at a single frequency with single patch with no diode ON at the first stage, then when two patches are connected together using a PIN diode with specification of PIN diode are Resistance-1.2Ohms, Inductance-0.6nH and Capacitance-0.3pF produces another frequency that's second stage, Finally in last stage when two PIN diode are used to connect all the patches to get two different frequencies.

IV. 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 and P3 are not operating or radiating, is as shown in the figure 3.

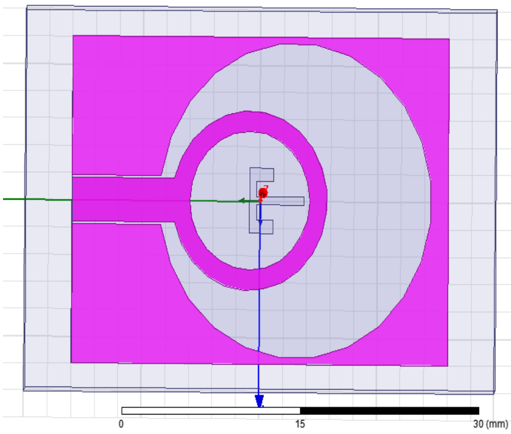

Figure 2: Patch P1 is radiating.

Stage 2: In this case when PIN diode D1 is ON and D2 is OFF, now the patches P1 and P2 is radiating, the current flow from patch P1 to P2 is through diode D1, is as shown in the figure 3.

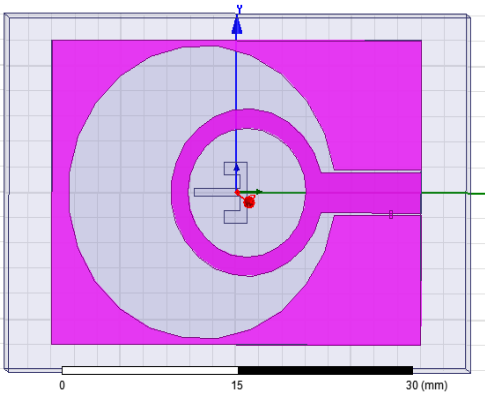

Figure 3: Patches P1 and P2 are radiating connected using a PIN diode D1.

Stage 3: In this case when both PIN diode D1 and D2 are ON, now all the patches P1, P2 and P3 are radiating, the current flow from patch P1 to P2 is through diode D1 and from patch P1 to P3 is through diode D2, is as shown in the figure 4.

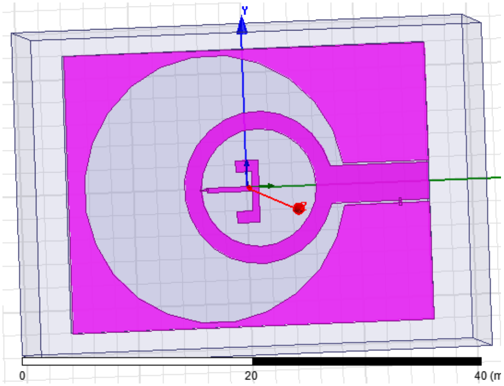

Figure 4: Patches P1, P2 and P3 are radiating connected using PIN Diodes D1 and D2.

V. RESULTS AND OBSERVATIONS

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

Stage 1: In this case we can observe that the antenna can produce a frequency of 6.2 GHz which is used for radar communication is as shown in figure 5(a) with a gain of -35.6 dB. For the above frequency we can observe the voltage standing wave ratio as 1.103 which is within the acceptable range in practically (ideally should be 1) is as shown in figure 5(b).

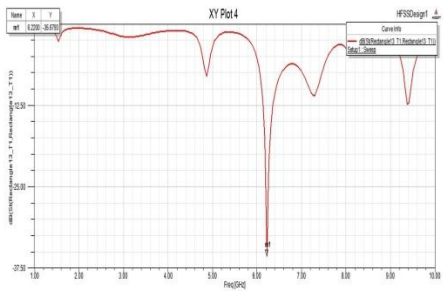

Figure 5(a): Plot of frequency v/s gain(dB)

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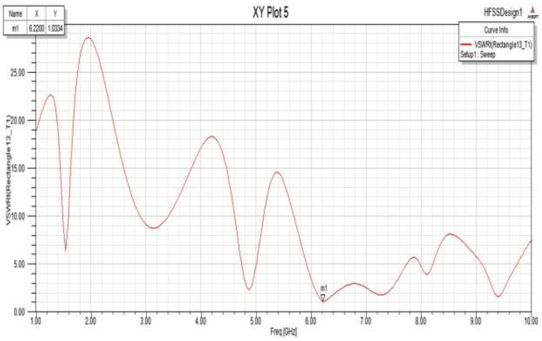

Figure 5(b): Plot of frequency v/s VSWR.

Stage 2: In this case we can observe that the antenna can produce a frequency of 2.2 GHz which is used for mobile communication is as shown in figure 6(a) which has a gain of -17 dB. For this frequency we can observe the voltage standing wave ratio of 1.3. Which is within the acceptable range in practically (ideally should be 1) is as shown in figure 6(b).

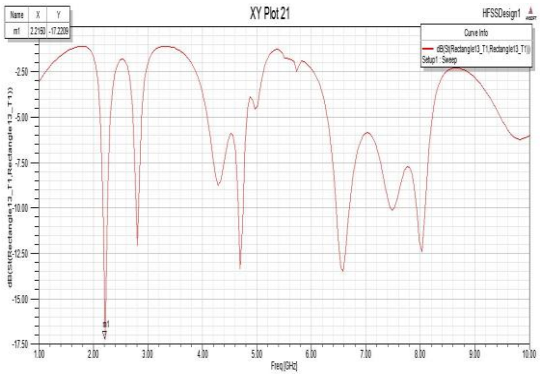

Figure 7(a): Plot of frequency v/s gain (dB).

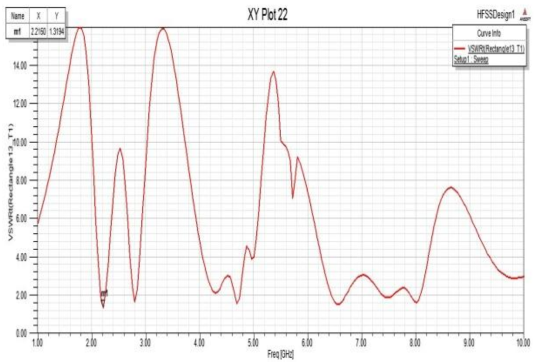

Figure 6(b): Plot of frequency v/s VSWR.

Stage 3: In this case we can observe that the antenna can produce two frequencies such as 3.4GHz and 5.6 GHz which are used for Mobile Broadband Wireless Access (MBWA) and satellite uplink communication is as shown in figure 7(a) with a gain of -16 and -20.8 dB. For these two frequencies we can observe the voltage standing wave ratio as 1.44 and 1.35, which is within the acceptable range in practically (ideally should be 1) is as shown in figure 8(b).

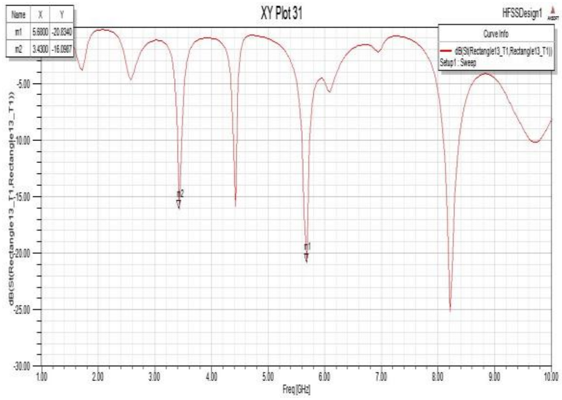

Figure 8(a): Plot of frequency v/s gain(dB).

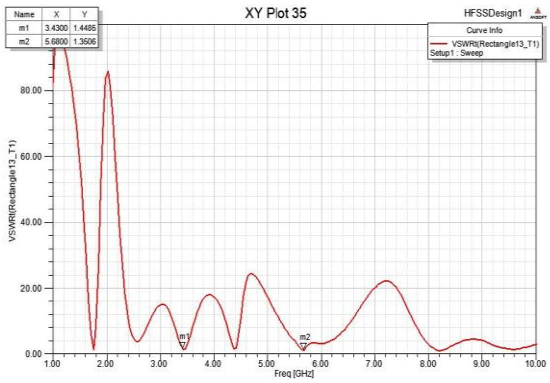

Figure 8(b): Plot of frequency v/s VSWR.

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.

VI. CONCLUSION

In this paper the aim is to design a Reconfigurable rectangular patch antenna and study the responses of the same. The antenna has been designed by considering like different patch dimensions, different substrate, different feeding technique and also the Operating frequency. The antenna is designed to operate at four different frequencies using PIN diode to switch between the patch in order to reconfigure the frequencies. We observed the gain, VSWR and frequencies for different dimensions of patch and substrate.

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