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Reconfigurable Inverted Circular Patch Antenna for Wireless Applications

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Abstract

This paper presents a frequency reconfigurable inverted circular patch antenna with U-slot. The incorporation of U-slot in the circular patch provides a wide impedance bandwidth than conventional patch antenna. By introducing shorts at appropriate position on U-slot and on feed, antenna can be made resonant at two frequency bands (1.80GHz-1.98GHz) and (2.10GHz-2.68GHz) in two modes. The proposed antenna not only avoid the interference problem faced in fixed dual band antenna but at the same time provides a good gain of nearly 8 dB in both mode of operation. The prototype of optimized antenna is fabricated and experimental results are in close agreement with the simulated one. This antenna can be used for different wireless application like Personal Communication System (PCS) and Bluetooth/WLAN.

Keywords: *Aperture coupling, Inverted circular patch antenna, Multiband, Reconfigurable antenna*

1. Introduction

With the growth of wireless industry, the demand for miniaturization in antenna size has gained popularity in recent past. A number of approaches have been proposed by researchers to reduce the size of antenna. One approach that has evolved in the recent past is the usage of multiband antennas. These antennas use multiple frequency bands to support two or more applications (*e.g.,* PCS and WLAN/Bluetooth). Therefore in-place of using individual antenna for each wireless application; one antenna could easily perform the same task. These antennas though effective in terms of cost and has low profile but suffer from serious drawback of interference.

To resolve this issue reconfiguration concept has been proposed in literature as they provide selectivity in frequency, polarization, bandwidth and gain. Hence for different wireless application like PCS (1.85GHz-1.99GHz), WLAN (2.4 GHz-2.483GHz), Bluetooth (2.4 GHz-2.5GHz) need of low profile, low cost and high gain reconfigurable antenna is in demand. Reconfiguration in antenna performance is usually achieved by incorporating pin diode, FET, transistor switches, variable capacitors, varactor diodes or MEMS switches in design of the antenna. A number of papers are available in literature that discusses the usage of reconfiguration concept in dual band antennas for wireless application [8-14] as follows:

An electronically tuneable dual band slot antenna has been proposed in [8-9]. The two resonant frequencies are due to the λ/2 and λ modes, which impose some complications to obtain similar radiation patterns at both bands. Also, the maximum realized gain at the lower band is 0.6 dBi and the higher band is 2 dBi.

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In [10], a reconfigurable multiband Planar Inverted-F Antenna (PIFA) for wireless application was presented. This antenna works at 900, 1800, 1900 and 2400 MHz with gain values of -3.9, -1.98, -1.98 and -1.75 dBi respectively.

In [11], a dual-band reconfigurable antenna using varactor and inductor was proposed. This antenna has tuning range from 2100-2900 MHz.

In [12], a coplanar waveguide fed microstrip slot antenna was presented. This antenna operates at two frequency ranges with almost same radiation pattern with maximum gain of nearly 2dB in both the modes of operation. In [13], a frequency reconfigurable square ring slot antenna for operation in GSM and WLAN frequency bands was presented. The gain of antenna was not taken into consideration as one of the performance metric while designing the antenna.

A varactor tuned dual band slot antenna with was proposed in [14].This antenna has similar radiation pattern with low cross-polarization and .5dB and 1.8dB gain in two mode of operation. In [18], areconfigurable fractal antenna for multiband application is presented. It works in four modes and can be used for different wireless applications.

In all of the above proposals the gain that is an essential parameter for antenna is either not considered or not good in all the reconfiguration modes. Therefore this paper presents a high gain frequency reconfigurable inverted circular patch antenna. The Proposed antenna operates at two frequency bands i.e. (1.8GHz-1.98GHz), when switches are on and (2.10GHz-2.68GHz), when switches are off. Both the simulation and experimental results of return loss, gain and radiation pattern are presented.

The rest of the paper is organized as follows. In Section II, design and optimization of antenna is explained. In Section III, frequency reconfiguration procedure, simulation and measured results of the proposed antenna in two modes is presented and discussed. Finally, the paper is concluded in Section IV, followed by references.

2. Antenna Design

The proposed reconfigurable inverted circular patch antenna consists of two substrate layer separated by air gap. The substrate material used is low cost Arlon 25N with Relative permittivity (ε_r) = 3.38, Thickness (h) =1.52mm and loss tangent (δ) =0.0025. The upper layer consists of a circular patch of Radius (a) = 28mm with U-shape slot as shown in Figure 1. Lower layer consists of Microstrip line which is used to feed the antenna using aperture coupling as shown in Figure 2 and Figure 3.

Circular patch radius is first calculated mathematically [1-2] for resonant frequency (f_r) =1.6 GHz as given below.

$$f_r = \frac{8.794}{a_e\sqrt{\varepsilon_r}}$$

$$a_e = a\left[1 + \frac{2h}{\pi\varepsilon_r a}\left\{ln\left(\frac{a}{2h}\right) + (1.41\varepsilon_r + 1.77) + \frac{h}{a}(.268\varepsilon_r + 1.65)\right\}\right]^{1/2}$$

$a_e$is the effective radius and
ais physical radius of circular patch.

Due to fringing fields [2] at the periphery of the patch conductor, a circular patch with physical radius a has an effective radius a_e such that a_e>a. Circular patch antenna having the aperture coupling is designed in Zealand IE3D software.

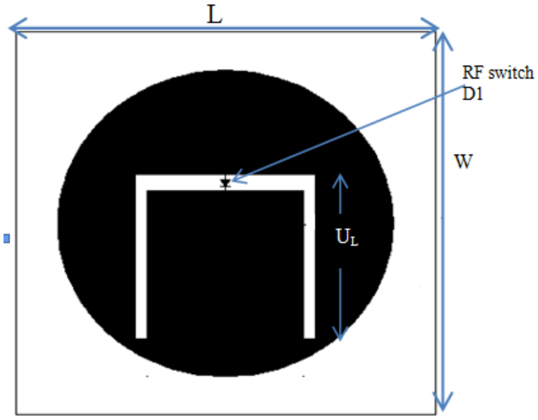

Figure 1. Bottom Surface of Top Layer of Antenna

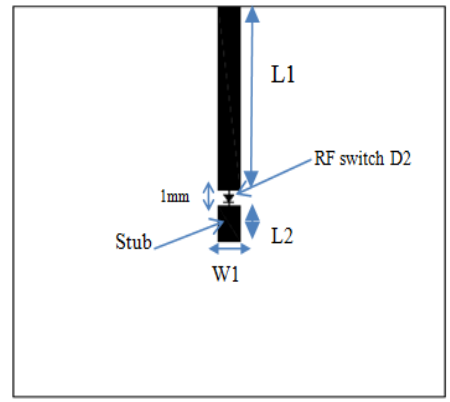

Figure 2. Bottom Surface of Bottom Layer of Antenna

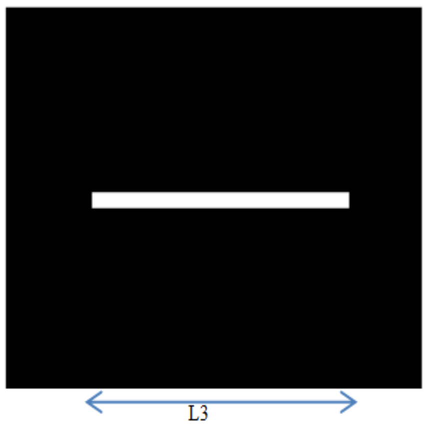

Figure 3. Top Surface of Bottom Layer of Antenna

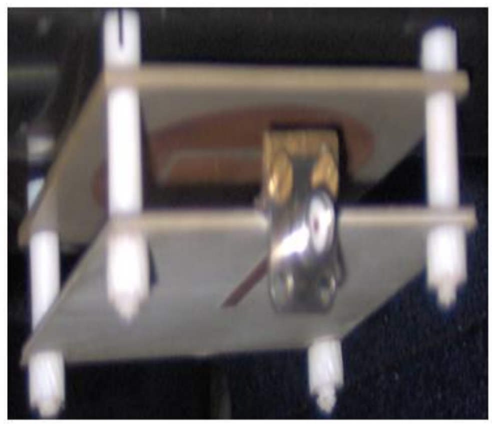

Figure 4. Photograph of Fabricated Antenna

By using thick air substrate and with proper slot loading good impedance bandwidth and high gain can be achieved [6] [15].Air gap introduced between two layer of antenna has an effect of lowering the effective permittivity of patch antenna, thus resonant frequency get shifted to upper side and impedance bandwidth gets improved. U-slot is etched in circular patch antenna to further increase the bandwidth [16-17]. Air gap between two layers, position, length and width of U-slot is optimized using IE3D software so that antenna resonates nearly at 2.4GHz with wide impedance bandwidth and good gain.

Two switches are used to make the antenna reconfigurable as shown in Figure 1 and Figure 2. The critical design parameter of the inverted circular patch antenna is shown in Table 1. The optimized antenna prototype is built as shown in Figure 4.

Table 1. Critical Antenna Design Parameters

Antenna Parameter	Dimension(mm)	Antenna Parameter	Dimension(mm)
Radius of circular patch	28	L1	40.2
L	70	L2	1.8
W	70	L3	42.1
Air gap between two layers	10	W1	3.616
Length of U-slot(U_L)	30	Width of U-slot	2

3. Results and Discussion

The antenna is simulated and analyzed using Zealand IE3d software. This proposed antenna works in two modes, U-slot mode and L-slot mode. Relationship between the operation modes and the states of switches is shown in Table 2.

Table 2. Relationship between Various Modes and Switch Positions

Mode	Switch Position
U-slot Mode	D1=off , D2=off
L-slot Mode	D1=on , D2=on

For modeling of RF switch, a common way is that when switch is on, it is represented by metal tape ($1\times1mm^2$) and when switch is off, no metal tape is used. In simulation and measurement this modeling is used to get the results.

U-slot Mode: - In this mode diode D1 and D2 are in off position. Simulated and measured return loss of antenna is shown in Figure 5. The experimental return loss of fabricated antenna is taken using HP8720B network analyzer. Simulated and measured gain of antenna is shown in Figure 6. Gain and radiation pattern of fabricated antenna is measured in anechoic chamber. A calibrated horn antenna is used to measure the gain of this antenna. Simulated radiation pattern of antenna in U-slot mode at 2.05 GHz and 2.5 GHz is shown in Figure 7 and Figure 8 respectively. Measured radiation pattern is shown in Figure 9 and Figure 10. Following points can be concluded for this mode.

- The proposed antenna resonates at 2.3 GHz in this mode and covers the frequency band of 2.10 GHz-2.68 GHz as shown in Figure 5.
- The circular patch has U-slot which provides the wide impedance bandwidth of 24.2%.
- From Figure 5, it clear that measured return loss is in good agreement with simulated one.
- Simulated and Measured gain of antenna in U-slot mode is approximately 8dB.

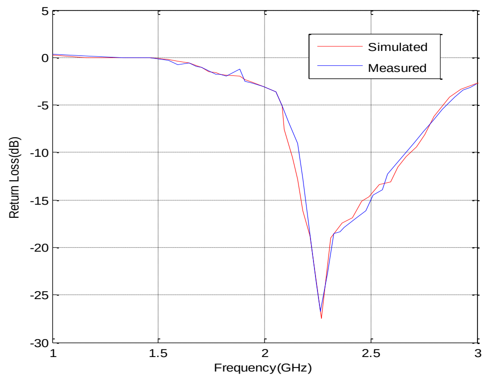

Figure 5. Return Loss of U-slot Mode

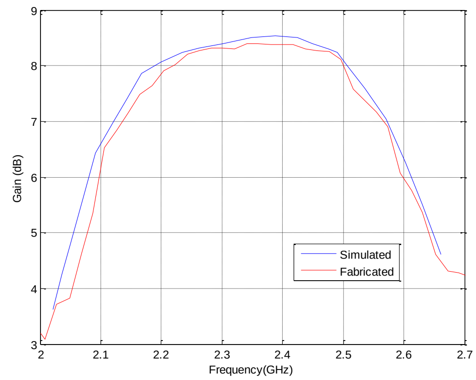

Figure 6. Gain of U-slot Mode

- Due aperture coupling back lobe appears in radiation pattern, but it is 16-20dB down to the main lobe.
- Experimental results in Figure 9 and Figure 10 shows more back lobe level in comparison to simulated results due to finite ground plane effect and losses.

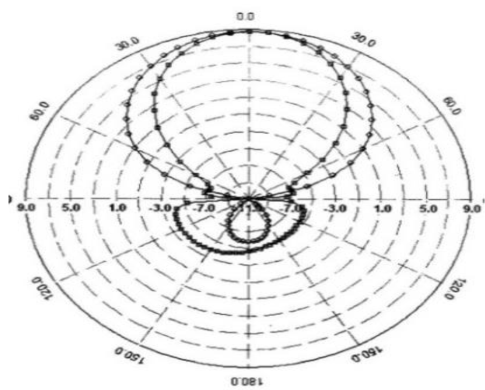

Figure 7. Simulated Radiation Pattern of U-slot Mode at 2.05 GHz for φ = 0^0 and φ = 90^0

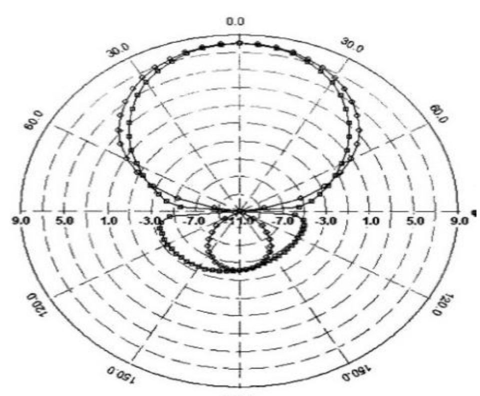

Figure 8. Simulated Radiation Pattern of U-Slot Mode at 2.5 GHzfor φ = 0^0 and φ = 90^0

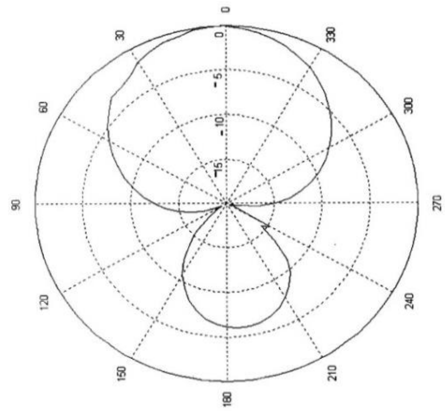

Figure 9. Measured Radiation Pattern of U-Slot Mode at 2.05GHzfor φ = 0^0

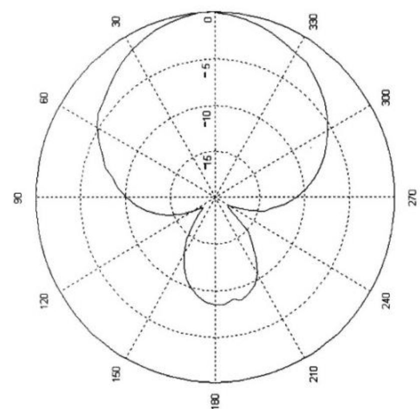

Figure 10. Measured Radiation Pattern of U-Slot Mode at 2.5 GHz for φ = 0^0

L-SLOT MODE: -When both the switch D1 and D2 are in on position, antenna works in L-slot mode. Simulation is done by leaving a copper gap of 1mm at the middle of U-slot. Current flow through this copper gap at the center of U-slot and it seems that circular patch antenna has two L-slot. Due to change in current distribution resonant frequency gets changed. For proper matching in L-slot mode length of microstrip line is changed using diode D2.

Simulated and experimental return loss of antenna is shown in Figure 11. For testing a copper strip of $1\times 1mm^2$ is connected at center of u-slot to convert it into L-slot and copper strip of $1\times 1mm^2$ is also connected to feed to connect it to the stub. Gain of antenna is shown in Figure 12. Simulated and measured radiation pattern of antenna in L-slot mode is shown in Figure 13 and Figure 14 respectively. Following points can be concluded for this mode.

- In this mode antenna resonates at frequency of 1.88 GHz and covers the frequency band of 1.80 GHz-1.98GHz.
- Measured return loss as shown in Figure 11 is in close agreement with simulated one.
- In L-slot mode antenna has impedance bandwidth of 9.5%.
- At resonant frequency antenna has gain of 7.8dB as shown in Figure 12.

- Back lobe appears in radiation pattern due to aperture coupling, but it is 16-20dB down to the main lobe. In Experimental results back lobe level is more as compared to simulated results due to finite ground plane effect.

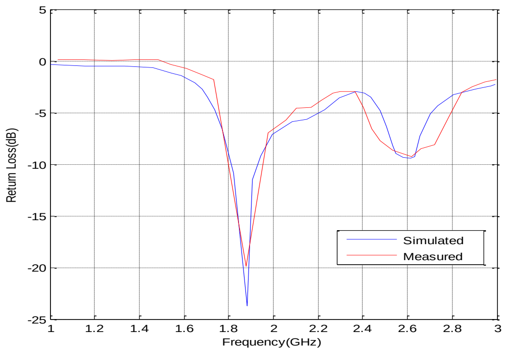

Figure 11. Return Loss of Antenna in L-Slot Mode

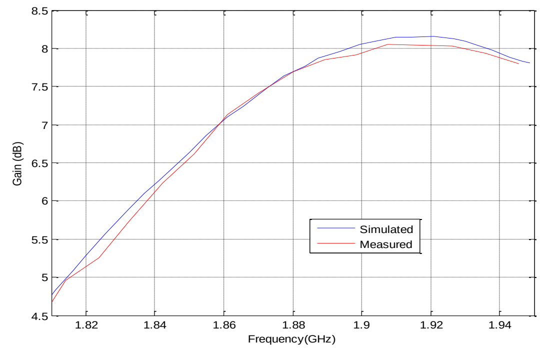

Figure 12. Gain of Antenna in L-Slot Mode

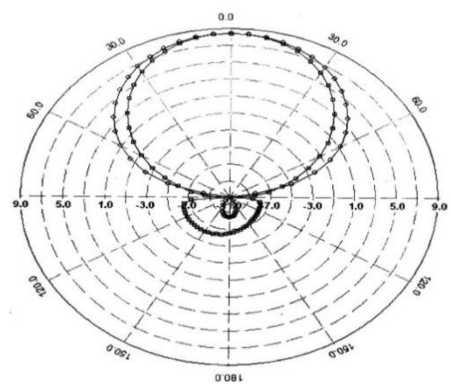

Figure 13. Simulated Radiation Pattern of Antenna in L-Slot Mode at 1.88 GHzφ = 0⁰ & φ = 90⁰

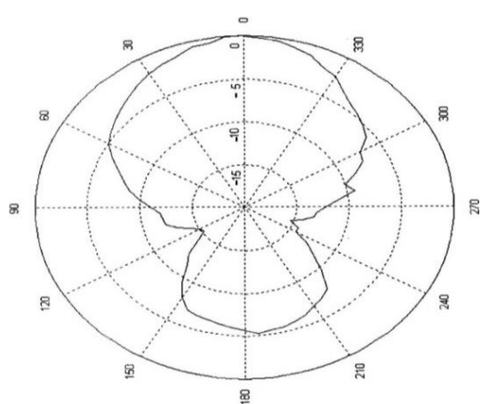

Figure 14. Measured Radiation Pattern of Antenna in L-Slot Mode at 1.88 GHz for φ = 0⁰

Radiation pattern and gain of antenna in both the modes are approximately same, only frequency bands changes as antennas switches from one mode to another, which is desired characteristic of reconfigurable antenna.

4. Conclusion

A high gain frequency reconfigurable inverted circular patch antenna fed by microstrip line using aperture coupling is presented. Frequency reconfiguration is achieved by changing the current distribution in circular patch. Antenna operates in two modes and cover the frequency bands (1.80GHz-1.98GHz) and (2.10GHz-2.68GHz). The proposed antenna has a good gain of approximately 8 dB in both the modes and covers a wide impedance bandwidth of 24.2% in U-slot mode and 9.5% in L-slot mode. Back lobe appears in radiation pattern of antenna due to aperture coupling which can be further reduced by using a reflector. In U-slot mode antenna can be used for Bluetooth and WLAN application and in L-slot mode it can be used for PCS application.

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