A simple semi-circular arc shaped frequency and polarization reconfigurable antenna

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Abstract A simple semi-circular shaped antenna having frequency as well as polarization reconfigurability is presented in this work. The proposed antenna has a size of 70.4 × 67.5 × 1.52 mm³. This antenna consists of three switches (S1, S2 and S3) which have been used to attain frequency reconfigurability and polarization reconfigurability in both LP (linear polarization) and CP (circular polarization). When switch S1 is OFF and any of switch S2/S3 is ON then we are obtaining frequency at Single Band (2.4 GHz). When Switch S1 is ON and any of the Switch S2/S3 is OFF then we are obtaining frequency at dual Band (2.4 GHz and 5.52 GHz). When all the switches S1, S2 and S3 are ON at the same time then we are obtaining frequency at Single Band (5.52 GHz). The simulated fractional bandwidth of the lower band centred at 2.4 GHz is observed to be 17.4% and for the upper band centred at 5.52 GHz is observed to be 5%. Proposed antenna gain greater than 2dBi is obtained for all five cases along with less than 2 VSWR with excellent radiation efficiency. The proposed reconfigurable antenna is suitable for Bluetooth and WLAN application.

Keywords: Frequency, Polarization, Reconfigurability, Switching element, Axial ratio.

1. Introduction

In today modern era with new development and technology upgrading as time passes by, there has been a huge increase in the demands of reconfigurable antennas around the globe. Mainly due to their properties which is an asset for all communications. Reconfigurable antennas have the ability to provide dynamic frequency patterns and polarisation in a single antenna [1]. Reconfigurable antennas have solved the major concern of all the health authorities around the globe by reversing the dangerous effect of electromagnetic radiation coming from wireless devices [2]. Reconfigurable antenna has also decreased the adverse effect of cochannel inheritance in jamming. Reconfigurable antennas are used for covering different wireless receivers which are spanned over wide frequency [3]. Over the past few eras various researches have taken place solely focusing on a single antenna property instead of multiple brand property which is a need of new era communication [4].

Reconfigurable antenna uses binary switching of some part at particular time to achieve the desired frequency [6]. Switching element like pin diode, varactor diodes and copper strips (square and rectangle shape strips) are used to achieve reconfigurability. Circularly polarized antennas have an upper edge over the linearly polarized antennas in various ways as it has the ability to alleviate the polarization mismatch and establish stable communication between receiving and transmitting ends respectively. Needs of the
modern world have been solved by the growing demands of reconfigurable antenna. Generally due to its small size and light weight as the needs of the market are directly linked to the reconfigurable antenna. In today’s modern era with the enhancement of new technology everyday there is a huge increase in the demands of single antenna in which the frequency and the pattern of the system can be changed independently which is a challenge for all the communication engineers around the globe [7]. The shifting range of the antennas is very less due to its complex structure and design [8]. The proposed antenna has a size of 30×28.4 mm and is elongated on a height of 0.508 mm. The proposed antenna has application in the field of WiMAX. The antenna works on the principle of frequency reconfigurability. The antenna design has a large structure which is unsuitable for the future generation trends as it has a large size (67.5×35.2×1.52), very less gain (2dBi) and only a single band at frequency 2.4 GHz with circular polarization and linear polarization at different states [10]. The proposed antenna has a patch structure with a stair-slotted ground. The antenna is elongated at a height of 1.62 mm and 28.6×27.5 mm wide. The slotted ground is responsible for linear as well as circular polarization.

The antenna is used in future generation communication technologies like WLAN [11]. The proposed work has a size of 0.5×0.83×0.03 mm. The antenna uses Pin Diodes to achieve reconfigurability and has application in the field of satellite communication [12]. The antenna uses four pin diodes for observation of frequency. The desired antenna is incapable of working in modern day world [13]. The complex technology like liquid crystal technique is used to observe the reconfigurability [14]. This antenna has a complex structure with the size of 100×100×1.6 which is proposed for use in the aircraft communication system. Reconfigurability is achieved using a single diode with a gain of 1.5dBi and 3dBi in different switching states [15]. The antenna has a wheel shaped structure with conical shaped radiation pattern with a gain of less than 0.6dBi [16]. The proposed antenna uses varactor diodes to achieve reconfigurability and this antenna has a gain of 0.25dBi [17]. The proposed antenna has circular monopolar patch efficiency varying from 45% to 85% as the frequency changes. The antenna uses 8 varactor diodes to achieve reconfigurability. The antenna has a thickness of 6.43 mm [18].

In this communication, a semi-circular shaped reconfigurable antenna is designed for Bluetooth, W-LAN applications and simulated in CST studio suite (v2020). The proposed antenna is an asset for new generation of wireless communication where frequency and polarization of system can be independently tuned. The proposed antenna can work either in single band or dual frequency band mode according to state of lumped switches. S1(Switch) is used to connect semi-circular patch with extended feed to achieve frequency reconfigurability while other two lumped switches (Switch2 and Switch 3) are connected at ground to achieve polarization reconfigurability at 2.4 GHz. Compared to other antennas [1]-[18], proposed antenna is simple in structure. Comparative study with existing literature is carried out in Table-3. It can be seen that the proposed antenna provides good impedance matching and stable radiation pattern with in the interested frequency range.

2. Antenna Design

The initial design idea of proposed antenna is based polarization reconfigurable microstrip antenna at 2.4 GHz in [10]. In new design extended microstrip feed length and inverted L stubs is connected to attain frequency and polarization reconfigurability. Proposed antenna is designed on a low-cost Taconic substrate with relative permittivity of 3.5 and loss tangent of 0.018. Figure 1 shows all dimensions of proposed antenna structure. Semi-circular patch is mounted on substate. The antenna is fed through 50-ohm strip line which is 4 mm wide and 39.75 mm long. The two stubs are separated from each other by a square of side 4 mm. The stubs are connected on ground by the help of switching elements by S2 and S3. The switching elements S2 and S3 are responsible for obtaining desired frequency.
A semi-circular patch is proposed by the help of a circular patch with outer radius 12.8 mm and inner radius 8.5 mm which is cantered at a distance of 17.5 mm above the centre is made. There is arc shaped slot between the feed line arc having a outer radius of 10 mm and inner radius 9 mm centred at a distance of 16 mm above the centre. The additional feed line of 4mm wide and 7.2 mm long is attached and diode S1 is connected between the additional feed and circular patch. The additional feed line is responsible for dual band at 2.4 GHz and 5.52 GHz. Two L-shaped vertical stubs are connected at the top of the semi-circular patch. All dimensions of proposed antenna are given in Table 1.
Table 1. Dimensions of proposed antenna in (mm)

| Parameters | Value | Parameter | Value | Parameters | Value | Parameter | Value |
|------------|-------|-----------|-------|------------|-------|-----------|-------|
| Wg         | 76.4  | Lp1       | 3.5   | Ls5        | 5     | Ld        | 4     |
| Lg         | 29.2  | Lp2       | 1     | Ls4        | 3     | R0        | 12.8  |
| Wf         | 4     | Ls1       | 9     | Ws4        | 3.6   | R1        | 8.5   |
| Lf         | 39.75 | Ls2       | 2     | Ws3        | 3     | r0        | 10    |
| Lf1        | 7.2   | Ws1       | 13    | Ls3        | 3     | r1        | 9     |
| Wp1        | 1     | h         | 2.2   | Ls6        | 11    |           |       |
| Wp2        | 9.5   | Ws5       | 1.4   | Wd         | 4     |           |       |

2.1 Design Flow of proposed antenna

The designing steps of proposed antenna consists of four stages. Figure 2 shows combine result of return loss (dB) of the proposed antenna for each stage. In stage 1, antenna 1 consists of simple circular patch attached to the feedline. In stage 2, antenna 2 has circular patch which is converted to a semi-circular patch to improve impedance matching. In stage 3, a semi-circular arc is mounted on the semi-circular patch and the extended feed is attached to the circular patch. In stage 4, two L-Shaped stubs of equal dimensions attached to the top of the circular patch. It can be seen that desired antenna 4 is the most optimized antenna in which all the desired parameters are met. The combine results of S11 (dB) are discussed in figure 2.
Parametric analysis of proposed antenna

Parametric analysis is conducted by simulations to examine effect of antenna parameters on $|S11|$ and axial ratio for design and optimization. Parametric results of proposed antenna are observed for variation in length of feed $L_f1$, width of semi-circular arc slot $r_0 - r_i$, length of L shaped stubs. These effects of parameters are described below:

2.2.1 Effect of feed length $L_f1$

The major changes in the result are observed by varying dimensions of the extended feed ($L_f1$) ranging from 5.4 mm to 7.2 mm as shown in figure 3. The optimized results are obtained at 7.2 mm. On decreasing the length of the extended feed below 7.2 mm, higher band is vanishing for 5.4 mm length.

2.2.2 Effect of width of semi-circular arc slot

On further analysis, by varying the width of the circular arc slot ranging from 0 mm to 2 mm quite optimized results are obtained at 1 mm as shown in figure 4. On increasing the width of semi-circular arc slot, the frequency of the lower band move to higher frequency side and the frequency...
of the higher band slightly moves to lower frequency. On decreasing the width of the semi-circular arc, higher band is vanishing in dual band.

![Figure 4](image.png)

**Figure 4** Effect of semi-circular arc slot

### 2.2.3 Effect of width of L-Shaped stubs

On varying the width of the L-Shaped stubs results in the variation of the axial ratio. As the width of the stubs decreases the axial ratio becomes stable. On decreasing the width, the axial ratio increases as shown in figure 5. The dimension variations of the width of L-Shaped stubs connected on the back of the antenna plays a vital role in decrement of the axial ratio below 3dB which is a necessity for the antenna proposed working in the field of Bluetooth application.

![Figure 5](image.png)

**Figure 5** Variation of Ws (mm) on Axial ratio(dB)

### 2.3 Results and Discussion

In this letter head, we have proposed a reconfigurable antenna. The proposed antenna has the ability to provide frequency reconfigurability and polarization in both LP and CP (RHCP and LHCP) at 2.4 GHz and 5.52 GHz which is suitable for wireless communications. The reconfigurability in antenna is achieved by help of switching elements. In proposed antenna, three Switches (S1, S2 and S3) have been used. The simulated S11(dB) of the proposed antenna either in state 3 or state 4 is dual band, having LP at 5.52 GHz,
RHCP/LHCP at 2.4GHz is shown in figure 6. The proposed antenna shows -10dB return loss offered at two frequencies with bandwidths at 2.4GHz (2238-2657 MHz) and 5.52 GHz (5402-5674) in figure 8.

In table 2, proposed antenna has been analysed in five different states. In State 1, S1 and S2 are OFF and only S3 is ON then we obtain single band at frequency 2.4 GHz in which we observe circular polarization (in both RHCP and LHCP). In State 2, S1 and S3 are OFF and only S2 is ON then we obtain single band at frequency 2.4 GHz in which we also observe circular polarization (in both RHCP and LHCP). In State 3, S1 and S3 are ON and S2 is OFF then we obtain dual band at frequency 2.4 GHz and 5.52 GHz in which we observe linear polarization as well as circular polarization (in both RHCP and LHCP) in figure 6. In State 4, S1 and S2 are ON and S3 is OFF then we obtain dual band at frequency 2.4 GHz and 5.52 GHz in which we observe linear polarization as well as circular polarization (in both RHCP and LHCP). In State 5, when all the switches are connected (i.e., S1, S2 and S3 are ON) then we obtain single band at frequency 5.52 GHz in which we observe linear polarization. The following states are shown in table 2.

| States | Pin Diodes | Resonant frequency (GHz) | Polarization | Applications |
|--------|------------|--------------------------|--------------|--------------|
| 1      | 0 0 1      | 2.4                      | CP (RHCP /LHCP) | Bluetooth     |
| 2      | 0 1 0      | 2.4                      | CP           | Bluetooth     |
| 3      | 1 0 1      | 2.4 and 5.52             | LP and CP    | Bluetooth, WLAN|
| 4      | 1 1 0      | 2.4 and 5.52             | LP and CP    | Bluetooth, WLAN|
| 5      | 1 1 1      | 5.52                     | LP           | WLAN          |

The combine simulated results of average gain and average radiation efficiency in all states are shown in figure 7. The antenna has realized gain that varies from 3.2 to 3.6 dBi and 4.5 to 5 dBi in intended frequency bands. The antenna has simulated gain of 3.2dBi at 2.4 GHz and 4.50 dBi at 5.52 GHz respectively as shown in figure 7. The simulated radiation efficiency is 93% at 2.4 GHz and 97% at 5.52 GHz respectively. Simulated VSWR of less than 2 and reference impedance of 49 ohm is constant in interested frequency bands. The simulated AR in figure 5 is observed below 3 so these results show presence of circular polarization in antenna. The 2D radiation patterns of proposed antenna are simulated and which are stable in intended frequency bands, as discussed in figure 9 and figure 10. In E-plane (phi =0°) is observed bidirectional and in H-plane (phi =90°) pattern is observed omnidirectional at 5.52 GHz. The radiation patterns for RHCP/LHCP in state 1 / state 2 are shown in Figure 10. at phi=0 in E-plane and phi=90 in H-plane for 2.4 GHz with a peak gain of 3.2dBi and 4.50dBi.
**Figure 6** Simulated result of S11 dB in state 3

**Figure 7** Combine simulated results of average gain and radiation efficiency

**Figure 8** Combine simulated result of S11(dB) in all states
Table 3- Comparison of proposed antenna with existing literatures

| References | Size (in mm³)     | No. of Switches | Gain (dBi) | Reconfiguration          |
|------------|-------------------|-----------------|------------|--------------------------|
| [10]       | 35.2×67.5×1.52    | 2 pin diodes    | 0.6, 0.9, 1.2 | Frequency (CP and LP)    |
| [15]       | 128.5×80×3.2      | 1 diode         | 1.5, 3     | Frequency                |
| [17]       | 100×100×1.6       | 1 Varactor diode| 0.25       | Frequency and Pattern    |
| [9]        | 70×55×1.57        | 2 pin diodes    | 1.4, 1.2, 2.7 | Frequency (RHCP and LHCP) |
| Proposed Work | 70.4×67.5×1.52 | 3 Pin diodes    | 3.2, 4.50  | Frequency and CP (RHCP/LHCP) |

Figure 9 radiation pattern of proposed antenna for state 5 in E-plane and H-plane at 5.52GHz

Figure 10. Radiation pattern of proposed antenna for state 1/state 2 in E-plane and H-plane at 2.4 GHz

Conclusion
A simple low-cost semi-circular shaped antenna has been proposed which has ability to provide frequency reconfigurability and polarization reconfigurability which is suitable for wireless communications. In this communication, three switches are connected to obtain reconfigurability. The proposed antenna has an efficiency greater than 90% and a good range of VSWR. The optimized gain at 2.4GHz is 3.2dBi and at 5.52 GHz is 4.50dBi. The proposed antenna provides efficient bandwidth which is suitable for wireless communications in Bluetooth and WLAN. The numerical variation of different parameters is realized to conclude that the proposed antenna is an efficient antenna in terms of performance as well as gain and radiation efficiency.
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