Reconfigurable Microstrip Patch Antenna With Polarization Switching in Three Switchable Frequency Bands

RAJESH KUMAR SINGH1, (Student Member, IEEE), ANANJAN BASU2, (Member, IEEE), AND SHIBAN KISHEN KOUL2, (Life Fellow, IEEE)

1Bharti School of Telecommunication Technology and Management, Indian Institute of Technology Delhi, New Delhi 110016, India
2Centre for Applied Research in Electronics, Indian Institute of Technology Delhi, New Delhi 110016, India

Corresponding author: Rajesh Kumar Singh (rajeshsingh.iitd@gmail.com)

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ABSTRACT In this paper, a polarization switchable reconfigurable microstrip patch antenna is designed first, it is extended further to get polarization switching in three switchable frequency bands by using corner connection/disconnection and additional patch connection/disconnection techniques. Three switchable operating bands are obtained with centre frequencies of 5.1 GHz (first band), 5.45 GHz (second band), and 6.3 GHz (third band) using 5 p-i-n diodes. Proposed structure is capable of being switched between left-hand circular polarization (LHCP), right-hand circular polarization (RHCP), and linear polarization (LP) in all three switchable frequency bands. A proximity coupled triangular tapered feed is used to feed the structure to get wide impedance and axial ratio bandwidths. Detailed analysis is carried out to observe the effects of various design parameters on the performance of the circuit. This also gives insight into the behavior of the circuit in terms of resonance frequency which would be useful to translate the structure at different frequency bands for various applications. Measured performance of the antenna agrees well with the simulations. The prototyped antenna has an acceptable reflection coefficient and axial ratio (AR below 3dB) in each operating band. Polarization and frequency diversities of the proposed design could enhance the reliability of modern wireless systems.

INDEX TERMS Microstrip patch antenna, p-i-n diode, proximity coupling, reconfigurable antenna, tapered microstrip line.

I. INTRODUCTION Reconfigurable antennas are very popular in modern and future wireless communication systems, such as LTE and 5G. Reconfigurability can be achieved from antennas in many ways, such as polarization, frequency, radiation pattern or combined of these. Reconfigurable antennas with polarization switching are used to double the system capacity and reduce multipath fading. Due to reflections from objects or any other obstacles, polarization of the receiving signal may change its direction and reduces the amplitude; circularly polarized antennas are insensitive to the orientation of receiving and transmitting antenna. These antennas are best suited in such cases and reduce the polarization loss and enhance the signal strength. Microstrip based circularly polarized antennas offers advantage of being simple, light weight and low loss, therefore research activities related to the circularly polarized microstrip antennas have been continuously reported in the literature. Various designs of circularly polarized antenna have been reported earlier with single or dual feed mechanism. Antenna with single feed mechanism has simple circuitry compared to that with the dual feed. Usually, a single feed microstrip patch antenna (MPA) radiates linear polarization (LP). Circular polarization (CP) can be obtained from the microstrip patch antenna by perturbing its shape by inserting slot or slits, [1], [2], truncating its corner, [3]–[5], or other mechanisms. In [3] and [4], CP was obtained by truncating two diagonally placed corners, but it could also be
achieved by truncating only one corner of the patch [5], [6]. This method offers simplicity and reduces the number of switches in the structure to get the same characteristics that obtained with the diagonal corner truncation. Another method to obtain CP is to load the microstrip patch antenna through a stub that perturbs the fields and generates two orthogonal modes with equal amplitude and 90° phase difference. Reported antennas in [7]–[15] had capability to switch its polarization among LP or CP (left-hand or right-hand CP) in a single operating band by using various techniques. However, modern wireless systems require antenna to be operated in more than one frequency band. Compared to the dual polarized antennas, polarization reconfigurable antennas are more advantageous due to their compact structure and reduced manufacturing complexity and effective use of electromagnetic spectrum. In 5G technology, it requires more than one frequency band for interband carrier aggregation where a device transmits or receives information on various channels simultaneously in separate bands. Furthermore, large bandwidth is required for each band to accommodate more channels. Dual-band polarization reconfigurable antennas had been reported but these antennas have fixed band of operation, there was no freedom to switch the operating band independently [14], [15]. Few reported antennas have capabilities to switch among RHCP or LHCP in two different frequency bands but these reports had no freedom to switch the polarization among RHCP or LHCP in the same frequency band [17]. Polarization diversity is extensively used in modern wireless systems, it is highly demanded that multifunction reconfigurable antennas must be switched in between polarization and radiation beam [13], [18], [19], or polarization and frequency. Few structures have been investigated earlier with functions to switch between polarization and radiation pattern in more than one frequency bands [29]. Frequency and polarization switching in a discrete manner using p-i-n diodes or in a continuous manner using varactor diodes had been presented [20]–[30]. Continuous frequency switching with polarization agility had been obtained by several authors, although these antennas cover the whole operating bands (bandwidth is wide) but the axial ratio bandwidth in a single switched band is not enough, new wireless technologies require polarization diversity with a wide axial ratio bandwidth in a single operating band.

The aim of this work is to propose a planar and compact reconfigurable antenna, which can have freedom to switch independently both polarization and frequency in more than one frequency bands with wide axial ratio bandwidth within the switchable band. By using such multifunction antennas, modern wireless systems could be benefitted by getting the polarization diversity in different frequency bands with a good axial ratio bandwidth so that more number of channels could be accommodated in these operating bands. In this paper, a polarization reconfigurable microstrip patch antenna switched in three different states (LHCP, RHCP, and LP) in a single frequency band is investigated first, then it is extended further to achieve polarization reconfigurability in three switchable frequency bands. Final structure is a combination of three different techniques (stub loaded, corner connection/disconnection, and additional patch connection/disconnection) to obtain CP. Finally, developed structure has a freedom to switch independently in three different frequency bands with polarization agility among all these frequency bands.

The reported paper is organized as follows. Section II discusses the design of a polarization switchable single-band antenna by connecting or disconnecting the tapered stubs at the patch corners. Section III explains the concept of switching in more than one frequency bands and gives the design guidelines by analyzing the effects of various parameters on the design. This section also describes the measured performance of the proposed antenna, makes a comparison with that obtained with full wave electromagnetic simulator, and lists a fair comparison between the proposed and previously reported work. Section IV concludes the paper by discussing the advantages of the proposed solution.

II. POLARIZATION SWITCHABLE SINGLE-BAND ANTENNA

A. ANTENNA CONFIGURATION

Configuration of a single-band polarization switchable antenna is shown in Figure 1(a). The design of an antenna consists of a nearly square patch; two small stubs are connected or disconnected at the corners of the patch with two MA4SPS402 p-i-n diode switches. Conventional patch antenna is designed at 5.2 GHz by using design equations given in [31]. Antenna is fed by a quarter wave transformer. Biasing circuit consists of RF choke (thin microstrip line), DC block lumped capacitors of 100 pF, bias pads, dc wires and power supply. Design parameters are listed in Table 1. Here, circular polarization (CP) is achieved by loading one of the stubs to the patch radiator. Loaded stub perturbs the radiated fields and generates two orthogonal modes. Amplitudes and phases of these two modes can be adjusted by choosing proper dimension of the stub.
TABLE 1. Design parameters of a single-band polarization switchable antenna.

| Parameters | Values (mm) | Parameters | Values (mm) |
|------------|-------------|------------|-------------|
| Lg         | 50.00       | Wg         | 50.00       |
| Lh         | 11.30       | Wh         | 00.20       |
| Lp         | 18.50       | Wp         | 18.35       |
| Lr         | 02.10       | Wt         | 00.60       |
| Lr         | 11.40       | Wf         | 00.70       |
| Wf         | 02.40       | W2         | 02.00       |

B. SIMULATED AND MEASURED RESULTS

Full wave electromagnetic software (CST microwave studio) is used to design and simulate the complete structure [32]. After optimizing the dimensions of the stub, antenna is designed on N9000 Neltec substrate with dielectric constant of 2.2. Thickness of the substrate is 0.762 mm and loss tangent is 0.0006. Photograph of the fabricated design is shown in Figure 1(b). Keysight DC supply is used to bias the p-i-n diodes by means of dc wires. RF chokes made from thin microstrip line are used in the circuit to block RF signal from flowing into DC supply. P-i-n diode used in the circuit turns ON by supplying 0.8 V. Here, 0.85 V is applied across the p-i-n diodes; it allows 10 mA current to flow. At 10 mA current, p-i-n diode presents a series resistance of 5Ω as shown in Figure 1(b). S-parameters of a p-i-n diode are measured separately by designing a 50Ω microstrip lines (make a cut in the microstrip line and place a p-i-n diode in between the path) and biasing circuit. S-parameters of a p-i-n diode used in the design are plotted in Figure 2. Figure 2(a) shows the OFF state of a diode while Fig. 2(b) shows the ON state. When forward bias (Vdc = 0.85 V) is given to the circuit, D1 turns ON and D2 turns OFF, consequently antenna radiates LHCP. In the second case, if reverse biased (Vdc = −0.85 V) is applied, D1 turns OFF and D2 turns ON, RHCP is generated. In the third case, if both the diodes are OFF, consequently antenna radiates linear polarized wave. Polarization can be seen from the current distributions on the patch surface with different time instants. Surface current distributions are plotted in Figures 3 and 4 for LHCP and RHCP mode at different time instants (ωt = 0°, 90°, 180° and 270°) for LHCP and RHCP mode, respectively. From Figure 3, it is clear that surface current rotates anticlockwise with time and follows left-handed rule, LHCP generates from the structure while in Figure 4, it reverses the direction and generates RHCP. Reflection coefficients were measured using vector network analyzer. Measured and simulated reflection coefficients are plotted in Figure 5. Measured −10dB impedance bandwidth (IMBW) for LHCP, LP and RHCP are 70 MHz (5151-5221 MHz), 72 MHz (5159-5231 MHz), and 74 MHz (5158-5232 MHz), respectively while simulated values are 122 MHz (5154-5276 MHz), 60 MHz (5178-5238 MHz), and 124 MHz (5156-5280 MHz), respectively. Radiation patterns are measured in an anechoic chamber with Agilent signal analyzer and Anritsu MG3694B microwave signal generator. Proposed antenna is used as a receiver put on a table (it rotates horizontally) and illuminated by a linearly polarized
wideband ridged horn antenna (model 3115) with known gain used as a transmitter. The distance (200 cm) between the transmitting and receiving antenna is fixed to satisfy the far-field condition. Measured radiation patterns are plotted in Figure 6. In case of LHCP and RHCP mode, proposed antenna receives almost equal power in co- and cross-polarization because it is independent from the alignment of the transmitting (horn antenna in our case) and receiving (proposed antenna) antenna. For LP mode, cross-pol level is 18 dB down from the co-pol in the beam width of 50° in the broadside as shown in Figure 6. The measured axial ratio beam width (with AR < 3 dB) for LHCP is from -105° to 42° while simulated is from -65° to +105°.

Measured 3 dB axial ratio beam width for RHCP is from -72° to +87°, while simulated is from -66° to +105°. ARBW is plotted for LHCP and RHCP as shown in Figure 7. Measured ARBW for LHCP is 64 MHz (5144-5208 MHz) while simulated is 36 MHz (5173-5209 MHz). Measured ARBW for RHCP is 60 MHz (5145-5205 MHz), while simulated is from 33 MHz (5176-5209 MHz). Measured realized gain of the proposed antenna is plotted in Figure 8. The variations in the measured realized gain within the operating band are less than 0.6 dB. The simulated and measured values of a single-band antenna are listed in Table 2. Next, the concept is extended to develop a polarization reconfigurable antenna in three switchable frequency bands.

### III. POLARIZATION RECONFIGURABILITY IN THREE SWITCHABLE FREQUENCY BANDS

The proposed single-band antenna design is extended further and a polarization reconfigurable antenna in three different frequency bands is developed. Enhancement in the impedance and axial ratio bandwidth are also aimed to use this design for modern wireless communications applications where more bandwidths are required. The microstrip patch antenna has narrow impedance bandwidth. Impedance bandwidth of microstrip antennas could be enhanced by using various techniques [34]–[37]. Impedance bandwidth can be
enhanced by increasing the thickness of the dielectric substrate but it limits up to 4-5%. Another way of increasing the bandwidth is stacking the patch elements with slight difference in the dimensions to get two nearer resonances [34]. Impedance bandwidth has also been enhanced by using proximity coupled feed to the patch radiator [35]. In proximity feeding, the feed line is sandwiched in between the patch and ground plane. The radiating patch is on the top of the substrate and ground plane is on the bottom. The design of feed line also plays an important role in enhancing the bandwidth up to some extent. Impedance bandwidth can also be improved by tapering the feed line. Several methods have been proposed to taper the feed line such as triangular, exponential, continuous, stepped, etc., [34], [38]. In this design, triangular tapering is proposed to feed the radiating patch which improves the matching in broad frequency range and hence enhances the bandwidth of the circuit. Corner truncation is a popular technique to get LHCP or RHCP from a patch radiator. In [6], circular polarization was achieved by truncating only one corner of the patch. Again, to switch the polarization between LHCP or RHCP, two switches are placed near the truncated corners to connect/disconnect small conductor to/from the microstrip patch, respectively. By doing this, another resonance (f2) occurs which is different from that obtained with loaded stubs. To get another resonance (f3) from the circuit, an additional patch or stub is attached to the main patch as shown in Figure 9(a). When, an additional patch is positioned close to the main patch, reference frequency (f1, 5.2 GHz) of the main patch is shifted downwards because of the coupling capacitance between both patches (main patch and additional patch). Due to this coupling, capacitance is increased and hence frequency is reduced. When an additional patch is attached to the main patch, resonance frequency depends on various parameters those are discussed in this section. A detailed analysis on stub parameters is made because there is a range of frequencies that can be obtained by varying the parameters of an additional patch. All four critical parameters are included in this analysis those affects the resonance that is generated after adding an additional patch. Those parameters are, additional patch length (Lstub), additional patch width (Wstub), gap between the main patch and additional patch (g), and switch position (P) as shown in Figure 9(a).

First, the length of an additional patch is varied, while other parameters remain constant. Initially, the gap between the main and additional patch (g) is 0.4 mm, and width of the additional patch (Wstub) is 16.7 mm (same as the width of the main patch, Wp). Simulation is done for various values of length, out of which, reflection coefficients are plotted here for five different values. From Figure 10, it is observed that reflection coefficient, which is a function of frequency, doesn’t show significant changes in its value and resonance peak by varying the length. Slight shift in the frequency is observed because of the small change in the effective length of surface current on an additional patch.

The change in resonance frequency is more by varying ‘Wstub’. As width of the additional patch increases, surface current increases. Also, by varying the width, the direction of surface current flow changes. On the basis of the flow of surface current, resonance occurs at below or upper to the reference frequency. This phenomenon is explained in details in [33]. Simulated reflection coefficients by varying the width of the additional patch are shown in Figure 11. Third parameter varied in this parametric study is the gap between the main and additional patch. Gap is varied from
0.4 mm to 18 mm, while other parameters remain constant. From Figure 12, when \( g = 0.4 \) mm, the resonance is at higher frequency compared to the reference frequency. At \( g = 14 \) mm, frequency becomes equal to the reference frequency, because the surface current on the additional patch doesn’t impact on the overall effective length of antenna. Further increase in the gap, and at \( g = 18 \) mm, frequency is decreased and now it is below the reference frequency. Initially, surface current decreases with an increase in the gap, further increment in the length, surface current change its direction and adds in phase with the surface current on the main patch, as a result effective surface current increases and hence, the resonance frequency decreases. In all the above parametric variation, position of the switch was fixed and it was at the centre of the radiating edge of the microstrip patch antenna. Now, at different positions of the switch, reflection coefficient is plotted in the Figure 13. Centre of the switch is at \( P = 0 \) mm. By changing the position of the switch, dual-band or tri-band behaviour can be obtained from the circuit; this is because of the asymmetry of the structure. Here, switch is placed in the centre to achieve RHCP or LHCP with same impedance matching and good axial ratio in both CP senses. After studying the design parameters effect, antenna is designed on the N9000 neltec substrate. To improve axial ratio further, two corners of an additional patch are chamfered; axial ratio is slightly improved at 6.3 GHz because the surface current flowing on the additional patch shows impact at around 6.3 GHz (third operating band) and make the phase difference between two orthogonal modes close to 90°. Antenna is then fabricated. The photograph of the fabricated structure is shown in Figure 9(b). The process used in the fabrication of both structures is photolithography. For the second antenna (as shown in Figure 9), two dielectric substrates with same thickness (0.787 mm each) are used. For the upper substrate, reconfigurable structure with patches and biasing lines are etched by removing the copper from the bottom of the upper substrate. For the lower substrate, microstrip tapered feed is etched on one side and ground plane is on the other side. For grounding, a small hole made in both the substrate layers, thin copper wire is inserted and soldered at top (DC pad is made) and bottom (ground plane) of the substrates. Both substrate layers stick to each other by using a very thin layer of silicone paste (the dielectric constant of the silicone paste is around 2, it doesn’t affect the performance of the antenna which has a dielectric constant close to 2). Four Teflon screws are attached at the corners of the antenna for fixing the substrate layers avoiding the formation of air bubbles between the substrates. In the simulation, Teflon screws have been taken into account, these screws are far away from the radiator so these screws do not affect the performance of the antenna. There is a slight deviation observed between the simulated and measured results; this is due to misalignment of the feed to the structures and minute air gap between the two dielectric substrates near the coaxial connector.

Dimensions of the polarization reconfigurable antenna with switchable frequency bands are given in Table 3. Proposed antenna incorporated five MA4SPS552 p-i-n diodes as shown in Figure 9. MA4SPS552 p-i-n diode has low series resistance \( (R_s = 2 \) ohm) in the ON-state, and low capacitance \( (C_{off} = 0.07pF) \) in the OFF- state. Other parasitics are negligible and ignored in the simulations. Centre frequencies of obtained bands are 5.1, 5.45 and 6.3 GHz. Polarization switching between LHCP, LP and RHCP in the first band (center frequency, 5.1 GHz) is obtained by connecting small tapered stub at the corners of the patch as explained in Section II. Polarization switching in the second band is obtained by truncating patch corners, small square conductor is connected or disconnected by using p-i-n diodes. Third band is obtained by connecting a parasitic patch to the main patch. In order to get polarizations switching in the first band, diode D5 is in the OFF-state. To get LHCP, diodes D1, D3 and D4 are ON while others are OFF. When diodes D2, D3 and D4 are ON while others are OFF, it generates RHCP. To get LP, diodes D1, D2, D3, and D4 are turned ON. To get polarization switching in the second band, diodes D1 and D2 are in the OFF-state, tapered stubs get disconnected from the circuit. To get LHCP, diode D4 is ON while for getting RHCP, diode D3 is ON.
**TABLE 3.** Dimensions of the proposed polarization reconfigurable antenna in three switchable bands.

| Parameters | Values (mm) | Parameters | Values (mm) |
|------------|-------------|------------|-------------|
| a          | 02.75       | Lstab      | 03.12       |
| b          | 00.75       | W1         | 02.20       |
| g          | 00.40       | W2         | 07.00       |
| l1         | 23.50       | Wg         | 58.00       |
| l2         | 58.00       | Wp         | 16.70       |
| Lp         | 16.90       |            |             |

When D3 and D4 are ON, linearly polarized wave is generated. To get polarization switching in the third band, diodes D1 and D2 are OFF; again the tapered stubs are disconnected from the circuit. Two CP senses (LHCP or RHCP) are generated either by turning diodes D4, D5 ON or D3, D5 ON.

Two LP states are obtained by turning diodes D3, D4, D5 ON (LP is generated at centre frequency of 6.1 GHz) or D5 ON while other diode are OFF (LP is generated at centre frequency of 6.5 GHz). Surface current distributions at 5.45 and 6.3 GHz at different time instants are plotted in Figures 14-17 for LHCP and RHCP mode, respectively. Reflection coefficients against frequencies are plotted in Figure 18. As observed, some discrepancies are observed in the measured results. In most cases, resonances are shifted upwards; this is due to the formation of air bubbles near the coaxial connector as shown in Figure 9(b). Due to the presence of air in between the substrates, it reduces the effective dielectric constant that results in upward shift in the resonance frequencies. It can be improved by properly connecting two substrates using some robust techniques. Measured and simulated normalized radiation patterns at 5.1, 5.45 and 6.3 GHz are plotted in Figures 19-21 for LHCP and RHCP mode, respectively.
6.3 GHz are plotted in Figure 19. All measurements of radiation patterns were done using linearly polarized horn antenna. For linear polarization, cross-pol level is below 18 dB from co-pol level in all the three switchable bands. Measured and simulated axial ratios are plotted in Figure 20(a), (b) and (c). Axial ratios are less than 3 dB within the operating band. Measured and simulated gains are plotted in Figure 20(d). Realized gain is reduced in the third operating band and it is due to increase in the backward radiation. The summary of the proposed structure is listed in Table 4.
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**TABLE 4. Results of the proposed reconfigurable antenna in three switchable bands.**

| Polarization state | -10 dB Impedance BW (MHz) | 3dB ARBW (MHz) | Peak Gain (dBi) |
|--------------------|--------------------------|----------------|----------------|
|                    | Simulated                | Measured       | Simulated      | Measured      | Simulated    | Measured    |
| LHCP, first band   | 4928-5281                | 5030-5410      | (7.45%)        | 5054-5168     | 5043-5171    | (2.5%)       | 7.35         | 6.5         |
| LP, first band      | -                        | 4914-5070      | (3.15%)        | -             | -            | -            | 6.3          | 6.5         |
| RHCP, first band    | 4926-5280                | 5040-5469      | (8.41%)        | 5050-5159     | 5049-5182    | (2.6%)       | 7.35         | 6.65        |
| LHCP, second band  | 5264-5592                | 5390-5591      | (3.68%)        | 5361-5483     | 5312-5514    | (3.7%)       | 7.9          | 7.5         |
| LP, second band     | -                        | 5210-5341      | (2.47%)        | -             | -            | -            | 6.55         | 6.0         |
| RHCP, second band  | 5256-5592                | 5391-5600      | (3.83%)        | 5368-5490     | 5328-5521    | (3.54%)      | 7.9          | 7.42        |
| LHCP, third band   | 6129-6400                | 6138-6357      | (3.63%)        | 6311-6333     | 6292-6351    | (0.93%)      | 4.1          | 3.9         |
| LP, third band      | 6004-6178                | 6002-6210      | (3.40%)        | -             | -            | -            | 4.6          | 4.5         |
| RHCP, third band   | 6402-6570                | 6402-6570      | (2.58%)        | -             | -            | -            | 4.7          | 4.6         |

**TABLE 5. Comparison with earlier reported reconfigurable structures.**

| Polarization switching and frequency states | Axial ratio bandwidth (LHCP/RHCP) in the switching/tuning band | Peak Gain (dBi) | Total Size (mm³) | Switches used | Switching |
|--------------------------------------------|---------------------------------------------------------------|----------------|-----------------|--------------|----------|
| [10] LHCP and RHCP at 2.38 and 2.46 GHz     | 1.01%                                                        | >5 at 2.38 and 2.46 GHz | 85.8×60×3.0 | 4 p-i-n diodes | Discrete |
| [11] LHCP, RHCP, LP at 5.8 GHz and +45° at 5.2 GHz | <1%                                                          | 2.5 at 5.2 GHz, 3.0 at 5.8 GHz | 60×50×1.6 | 6 pairs of p-i-n diodes | Discrete |
| [15] Horizontal, vertical, 45° LP at 2.4 and 5.8 GHz | <1%* (Dual operating band)                                   | 8.0 at 2.4 GHz, 7.3 at 5.8 GHz | 100×100×4.75 | 4 p-i-n diodes | Discrete |
| [16] LHCP and RHCP at 1.9 and 2.4 GHz       | 0.5%, 0.6%                                                   | 7.73 at 1.9 GHz, 6.06 at 2.4 GHz | 120×120×3.175 | 12 p-i-n diodes | Discrete |
| [22] LHCP, RHCP, and LP at 1.67, 1.77, and 1.91 GHz | 1.8%, 1.7%, 1.6% (three operating bands)                     | 4.5 for CP and 4 for LP | 110×100×22 | 8 varactor diodes | Continuous |
| [23] LHCP, RHCP and LP in the tuning range of 2.4-3.6 GHz | <1%*                                                        | <4.7            | 100×100×1.5 | 12 varactor diodes | Continuous |
| [24] LHCP and RHCP in the tuning range of 1.97-2.53 GHz | <1%*                                                        | <3              | Not given | 4 varactor diodes | Continuous |
| [25] LP in six different angles and at five frequencies (1, 1.25, 1.57, 2 and 2.75 GHz) | not given | -3.0 at 1.25 GHz, 3.0 at 1.57 GHz, 1.0 at 2.75 GHz | 80×80×3.17 | 24 p-i-n diodes | Discrete |
| [26] LHCP/RHCP at 2.45 and 5.3 GHz and LP at four different frequencies | 7% at 2.45 GHz and 4% at 5.3 GHz | 2.6 at 2.45 GHz and 3.1 at 5.3 GHz | 55×30×1.0 | 4 p-i-n diodes | Discrete |
| [27] LHCP/RHCP in the tuning range of 1.97-2.54 GHz | not given | From -2.65 to +3.1 in the operating band | 136×136×1.6 | 6 varactor diodes | Continuous |
| [28] LHCP/RHCP/LP in the range 1.82-2.25 GHz | <1%*                                                        | From 2.6 to 6.8 in the operating band | Circular radius of 55 mm | 8 varactor diodes | Continuous |
| [29] LHCP/RHCP/LP at 2.31 and 2.33 while LP at 2.29-2.38 GHz | <1%*                                                        | From 3.4 to 4.7 dB in the operating band | 130×130×1.57 | 48 p-i-n diodes | Discrete |
| [30] Two CP and one LP from 1.83-2.65 GHz   | <1%*                                                        | Gain variation <1.8dBi, peak gain is 7.8dBi | 120×120×3.175 | 16 p-i-n diodes | Discrete |

*Calculated from the given data.

Comparison of the proposed work with previously reported work is listed in Table 5. Reported dual-band polarization antennas had no freedom to operate independently in both operating bands [15]. Polarization switchable antennas in different operating bands can effectively use the electromagnetic spectrum instead of making it dual-band or tri-band.
Antennas reported in [22]–[24], [27], [28] have continuous tuning bands but these antennas have low axial ratio bandwidth in a single tuning band. Antenna investigated in [29], [30] had large volume and occupied more space in the system. Antenna reported in [30] has large gain and achieved more switching states, but antenna had large volume and incorporated 16 p-i-n diode switches in the circuit. In this paper, a simple, compact and planar structure (volume is less) is investigated. Proposed structure incorporates only 5 p-i-n diodes to get switching in three independently switchable bands with wide axial ratio bandwidths.

IV. CONCLUSION

Proposed stubs loaded polarization switchable single-band antenna and its extension to achieve polarization switching in three switchable frequency bands are investigated in this paper. Prototype of both designs are fabricated and measured. Proposed second prototype has LHCP, LP or RHCP characteristics in all three switchable bands. Proposed antenna operates in a single band at a time efficiently uses the available electromagnetic spectrum. A detailed analysis is made throughout the paper to understand the behavior of each parameter on the design. A good agreement was obtained between measured and simulated results. Proposed polarization switchable antenna in three switchable frequency bands has wide impedance- and axial ratio bandwidth. Proposed antenna is suitable for current and future wireless systems due to its independent switching function among frequency or polarization with wide impedance- and axial ratio bandwidth.

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RAJESH KUMAR SINGH (Student Member, IEEE) was born in March 1989. He received the B.Tech. degree in electronics and communication engineering from Gautam Buddha Technical University (GBTU), Lucknow, in 2010, and the M.Tech. degree in microwave electronics from Delhi University South Campus, Delhi, in 2013, and the Ph.D. degree in microwave engineering from the Indian Institute of Technology, Delhi, India, in 2018. His main research interests include reconfigurable planar antennas, microwave integrated circuits, and active integrated antennas. He was a recipient of the Young Scientist Award for the International Union of Radio Science (URSI) General Assembly and Scientific Symposium (GASS) 2020. From 2014 to 2016, he served as a Treasurer of the IEEE MTT-S Student Branch Chapter of Indian Institute of Technology Delhi, India. From 2016 to 2018, he served as a Chairman of the IEEE MTT-S Student Branch Chapter of Indian Institute of Technology Delhi.

ANANJAN BASU (Member, IEEE) was born in August 1969. He received the B.Tech. degree in electrical engineering and the M.Tech. degree in communication and radar engineering from the Indian Institute of Technology Delhi (IIT Delhi), in 1991 and 1993, respectively, and the Ph.D. degree in electrical engineering from the University of California at Los Angeles (UCLA), in 1998. He was with the Centre for Applied Research in Electronics, IIT Delhi, as an Assistant Professor, from 2000 to 2005, and an Associate Professor, from 2005 to 2012, where he has been a Professor, since 2012. His research interest includes microwave and millimeter-wave component design and characterization.

SHIBAN KISHEN KOUL (Life Fellow, IEEE) received the B.E. degree in electrical engineering from the Regional Engineering College, Tiruchirappalli, in 1977, and the M.Tech. and Ph.D. degrees in microwave engineering from the Indian Institute of Technology Delhi, India, in 1979 and 1983, respectively.

From 2009 to 2019, he was the past Chairman of M/S Astra Microwave Pvt. Ltd., a major private company involved in the Development of RF and Microwave systems in India. From 2012 to 2016, he was the Deputy Director (strategy & planning) of IIT Delhi. From 2015 to 2019, he was a Dr. P.P. Shenoy Astra Microwave Chair Professor with the Centre for Applied Research in Electronics where he was involved in teaching and research activities. He is currently an Emeritus Professor with the Indian Institute of Technology Delhi. He is also the Deputy Director (Strategy & Planning and International affairs) of the Indian Institute of Technology Jammu. He has delivered more than 275 invited technical talks at various international symposia and workshops. He has successfully completed 34 major sponsored projects, 52 consultancy projects, and 55 technology development projects. He is the author/coauthor of 452 research articles, nine state-of-the-art books, and three book chapters. He holds ten patents and six copyrights. His research interests include RF MEMS, high-frequency wireless communication, microwave engineering, microwave passive and active circuits, device modeling, millimeter-wave IC design, and reconfigurable microwave circuits, including antennas. He is currently a member of the IEEE MTT Society’s Technical Committees on RF MEMS (MTT-21), the India Initiative Team of the IEEE MTT-S, Membership Services Regional Co-Coordinator Region-10, the Sight Adhoc Committee MTT-S, and the MTT-S Speaker Bureau Lecturer. He is a Fellow of the Indian National Academy of Engineering (NAE) and the Institution of Electronics and Telecommunication Engineers (IETE). He was a recipient of the Gold Medal by the Institution of Electrical and Electronics Engineers Calcutta, in 1977, the S. K. Mitra Microwave Research Award, in 1986, from the IETE; the Best Research Paper, the Indian National Science Academy (INSA) Young Scientist Award, in 1986, the International Union of Radio Science (URSI) Young Scientist Award, in 1987, the top Invention Award of the National Research Development Council for his contributions to the indigenous development of ferrite phase shifter technology, in 1991, the VASVIK Award for the development of Ka-band components and phase shifters, in 1994, the Ram Lal Wadhwa Gold Medal from the Institution of Electronics and Communication Engineers (IETE), in 1995, the Academic Excellence Award from Indian Government for his pioneering contributions to phase control modules for Rajendra Radaar, in 1998, the Prof. Shri Prakash Bhasin Award in the field of Electronics and Information Technology, in 2009, the Teaching Excellence Award, from IIT Delhi, in 2012, the Award for contributions made to the growth of smart material technology by the ISSS, Bangalore, in 2012, the Vasvik Award for the contributions made to the area of Information, Communication Technology (ICT), in 2012, the M.N.Saha Memorial Award from the IETE for the Best Application Oriented Research Paper, in 2013, and the IEEE MTT Society Distinguished Educator Award, in 2014. He is the Chief Editor of the IETE Journal of Research and an Associate Editor of the International Journal of Microwave and Wireless Technologies (Cambridge University Press). From 2012 to 2014, he served as a Distinguished Microwave Lecturer of the IEEE MTT-S and a Distinguished Microwave Lecturer-Emeritus of the IEEE MTT-S, in 2015.