

# A Frequency and Polarization Agile Disc Monopole Wearable Antenna for Medical Applications

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**Abstract.** *A combined frequency and polarization reconfigurable textile based wearable disc monopole antenna is proposed in this paper. The antenna consists of a disc monopole as the radiator and four PIN diodes for realizing the agility property. By varying the different switching combination of the PIN diodes, frequency reconfigurability is achieved between the GSM and ISM band. Two circular polarization states, right hand circular polarization (RHCP) and left hand circular polarization (LHCP) are also realized in each operating frequency band. The upper band polarization state is controlled by an L shaped stub introduced in the ground plane whereas the lower band polarization agility depends on the length of the parasitic arc placed around the main radiator. The antenna is fabricated and its performance is measured to validate the proposed design.*

## Keywords

Wearable antenna, frequency reconfigurable antenna, polarization reconfigurable antenna, disc monopole, medical applications

## 1. Introduction

Body-centric wireless communication system has attracted significant interest during the past several decades. In supporting to this increasing interest, the IEEE 802.15 group has been established to standardize applications intended for off-body, on-body or in-body communication. Antenna system having multiple capabilities and functions with small occupied volume is the general demand of any modern wireless communication system. Due to the capability of providing more functionalities over the conventional antennas, reconfigurable antennas become the popular resolution for various communication requirements. A reconfigurable antenna can interpolate one or more of its characteristics like frequency, polarization and/or pattern with the help of different microwave circuit elements like RF varactor diodes [1], MEMS [2] and PIN diodes [3], [4] in order to execute specific demand. A frequency reconfig-

urable antenna for bluetooth, WiMAX, and WLAN applications has been proposed in [5] that can adjust its operating band according to the requirement. Polarization reconfigurability also has been reported in [6–10]. By using PIN diodes on the inset of the etched “U” shaped slot line on the patch antenna [6], switching between the polarization states has been achieved. The ground plane of the coplanar waveguide fed monopole antenna as proposed in [7] has been modified by introducing an L-shaped stub on the either side of the monopole along with PIN diode to achieve polarization reconfigurability. Using the technique of loading a pair of identical meandering perturbation slots symmetrically below the conventional annular ring slot antenna [8], polarization agility has been realized. Three polarization states LHCP, RHCP, and LP have been achieved using two pin diodes in a simple circular metal ring antenna with a modified ground plane [9]. A quad-polarization reconfigurable omnidirectional monopole antenna has been presented using two  $\lambda_g/2$  phase shifters and simultaneous feeding techniques [10].

In [11], a single aperture fed dual band patch antenna is proposed that allows switching among horizontal, vertical, and 45° linear polarizations. The center of each edge of the patch is connected to ground via a PIN diode for polarization agility. The frequency ratios of the two modes are adjusted by inserting four shorting posts into the patch. The works proposed in [5–11] are either frequency reconfigurable or polarization reconfigurable. However, the design [1] represents a combined frequency and polarization reconfigurable antenna where initially, three different polarization states are achieved utilizing different combination of the PIN diodes. The frequency of each polarization state is then tuned independently by using the varactor diodes. The polarization agility realized in [1] is the different states of linear polarization though the circular polarization reconfigurability is much more preferable for the modern communication system.

Nowadays, reconfigurable antennas in wearable technology are highly demanding for various applications. Several groups have achieved either the frequency reconfigurability [12], [13] and or the pattern reconfigurability [14], [15] in wearable technology. In [12], two GaAs hy-

perabrupt varactor diodes are placed between the parasitic patch and the radiator which play the key role in achieving continuous frequency reconfigurability. The conductive fabric radiator along with lumped elements is completely encapsulated within flexible polydimethylsiloxane (PDMS) layers to ensure physical robustness of the antenna even under severe deformation and washing. Textile based wearable antennas provide more flexibility with nominal weight. Its performance is also highly comparable with rigid substrate based antennas. A frequency reconfigurable Denim material based textile antenna has been reported in [13] that operates in ISM and WLAN band. PIN diode is used to tune the antenna between these two operating bands with simple biasing circuitry. Another approach has been reported in [16] that realizes two different types of polarization in a frequency reconfigurable antenna. Using the edge truncation technique of the rectangular patch, the circular polarization feature has been realized in the lower band (1.575 GHz) whereas linear polarization is achieved in the upper frequency band (2.45 GHz).

It is obvious that a frequency and polarization reconfigurable antenna offers more flexibility and diversity than a conventional frequency or polarization reconfigurable antenna. Such antennas can bring significant benefits to WBAN. Moreover, a CP antenna offers an improved effectiveness in receiving the communication signal and has an exceptional ability of reducing multipath fading. Hence, realizing a frequency reconfigurable antenna along with circular polarization agility can be a new domain of research. To exploit the advantages of a multi reconfigurable antenna in wearable domain, a combined frequency and polarization reconfigurable textile based wearable disc monopole antenna is proposed in this work. Using different switching diode combinations, the frequency reconfigurability has been achieved and for each frequency band, the LHCP, RHCP is independently realized. The presented reconfigurable antenna is fully fabricated using denim material to enable ease of integration with clothing and to ensure users comfort. The simulated and measured performances of the antenna have been presented in the following sections.

## 2. Antenna Design and Working Principle

### 2.1 Antenna Design

Initially, a simple disc monopole antenna has been designed for the ISM band (2.45 GHz). Henceforth, a C shaped parasitic arc has been appended with the disc monopole by PIN diode to generate another resonance frequency at lower band. The GSM band (0.92 GHz) operation is then well optimized by introducing two slots in the parasitic arc. The ISM band CP characteristic has achieved by introducing an L stub with PIN diode in the ground plane. As well as GSM band CP operation is realized by

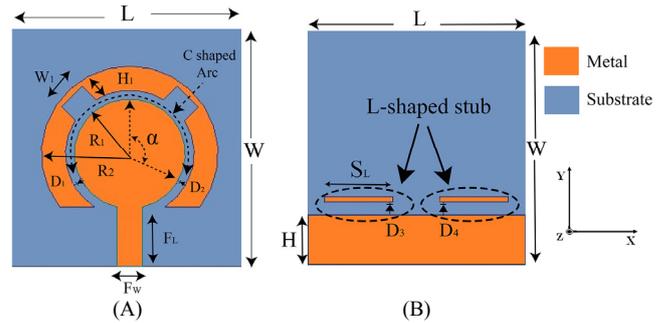


Fig. 1. Schematics of the proposed antenna: (A) Front view, (B) back view.

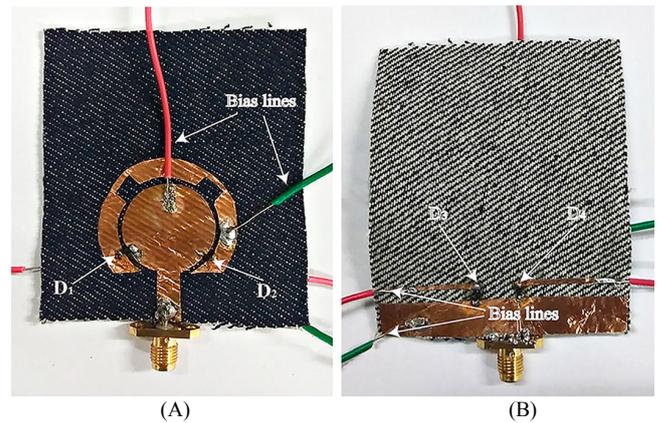


Fig. 2. Fabricated antenna prototype: (A) Top view, (B) bottom view.

position optimization of the diodes  $D_1$  and  $D_2$ . The geometry of the antenna is shown in Fig. 1 and the corresponding detailed dimension is given in Tab. 1. The proposed antenna is fabricated on jeans substrate having dielectric constant of 1.7, thickness of 1 mm and loss tangent of 0.025 as shown in Fig. 2. An adhesive copper tape of thickness 0.05 mm is used here as radiating element and ground plane of the disc monopole. The antenna is fed by a 50  $\Omega$  microstrip transmission line. For switching mechanism, four PIN diodes (BAP64-03) are used. According to the PIN diode datasheet [17], the diode represents a resistance of 1.5  $\Omega$  for the ON state and a capacitance of 0.1 pF for the OFF state. All the simulation has been performed by using High-Frequency Structure Simulator (HFSS).

### 2.2 Working Principle

It is obvious that the dimension of the antenna determines its resonant frequency. By using different combinations of PIN diodes, an antenna's physical property can be changed and hence frequency reconfigurability is established. In this work, to achieve the frequency agility, the effective electrical length of the disc monopole has been altered. Integrating four PIN diodes ( $D_1, D_2, D_3, D_4$ ), the radiating structure is modified and consequently two frequency bands (GSM and ISM) with different CP configuration are obtained. The different combination of the four diodes and their consequences is shown in Tab. 2. When

| Symbol     | L  | W  | S <sub>L</sub> | H   | W <sub>1</sub> | H <sub>1</sub> | R <sub>1</sub> | R <sub>2</sub> | F <sub>L</sub> | F <sub>W</sub> | α    |
|------------|----|----|----------------|-----|----------------|----------------|----------------|----------------|----------------|----------------|------|
| Value (mm) | 60 | 70 | 24.6           | 8.5 | 5.8            | 3.8            | 11             | 17.5           | 12             | 5              | 102° |

Tab. 1. Dimensions of the proposed antenna.

| State | D <sub>1</sub> | D <sub>2</sub> | D <sub>3</sub> | D <sub>4</sub> | Band | Polarization |
|-------|----------------|----------------|----------------|----------------|------|--------------|
| I     | ON             | OFF            | OFF            | OFF            | GSM  | LHCP         |
| II    | OFF            | ON             | OFF            | OFF            | GSM  | RHCP         |
| III   | OFF            | OFF            | ON             | OFF            | ISM  | LHCP         |
| IV    | OFF            | OFF            | OFF            | ON             | ISM  | RHCP         |

Tab. 2. States of diodes and corresponding operation modes.

D<sub>1</sub> or D<sub>2</sub> is ON and D<sub>3</sub> & D<sub>4</sub> are OFF, the disc monopole along with the parasitic arc acts as the radiator and the GSM band (880–960 MHz) operation is obtained. When D<sub>1</sub> is ON and D<sub>2</sub> is OFF (state I), as the current flows from the inner circular monopole to the outer circular parasitic, a C shaped arc path is formed which helps the antenna to work in LHCP mode in GSM band. The total length of the C shaped arc is chosen λ/4. Inversely, RHCP in the same GSM band is achieved when D<sub>1</sub> is OFF and D<sub>2</sub> is ON (state II). When D<sub>1</sub> and D<sub>2</sub> both are OFF, the circular patch is disconnected from the parasitic arc and hence its dimension is reduced. Thus the ISM band (2.4–2.48 GHz) operation is realized. The ISM band CP configuration is achieved by the different switching combinations of D<sub>3</sub> and D<sub>4</sub> diodes. When D<sub>3</sub> is ON and D<sub>4</sub> is OFF (state III), an L shaped stub is created in the ground plane. The orthogonal arm of the stub ensures a 90-degree phase difference between the two current components and hence the LHCP is achieved in ISM band. Similarly, RHCP is realized by the inverse combination of D<sub>3</sub> and D<sub>4</sub> (state IV).

To illustrate the CP operation mechanism of the proposed antenna, the current distribution and the direction of the dominant current (J<sub>s</sub>) for different phase values on the radiator at 0.92 GHz for state I is shown in Fig. 3. At 0° and 90°, the dominant surface current are in the +y and +x direction respectively. The surface current for 180° and 270° are in -y and -x direction correspondingly. Thus, the predominant surface current in the azimuth plane rotates clockwise, which is accountable for left-hand circular polarization (LHCP) along the +z direction in the GSM band. The current distribution in the ground plane at 2.5 GHz for the state III is shown in Fig. 4. The dominant current in this case is in -x direction at 0° phase, while at 90° phase, the current turns towards the +y direction. It is also observed that the current direction at 180° and 270° are opposite in phase as that of in 0° and 90° respectively, which indicates a left handed CP (LHCP) is achieved in ISM band. In addition, RHCP could be obtained in both ISM and GSM

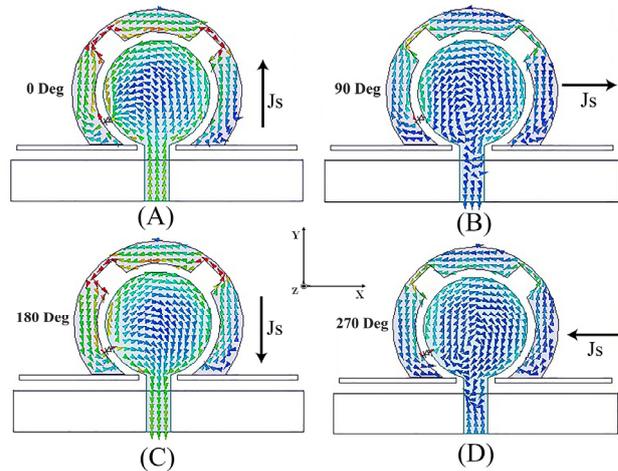


Fig. 3. Simulated surface current distribution on the proposed antenna for State I at 0.92 GHz: (A) 0°, (B) 90°, (C) 180°, (D) 270°.

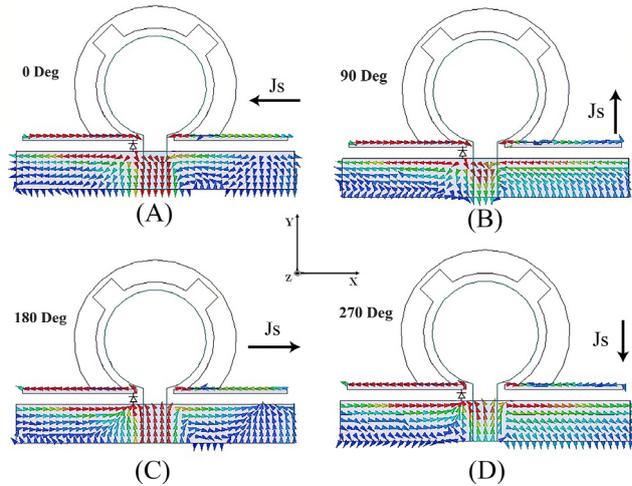


Fig. 4. Simulated surface current distribution on the proposed antenna for State III at 2.5 GHz: (A) 0°, (B) 90°, (C) 180°, (D) 270°.

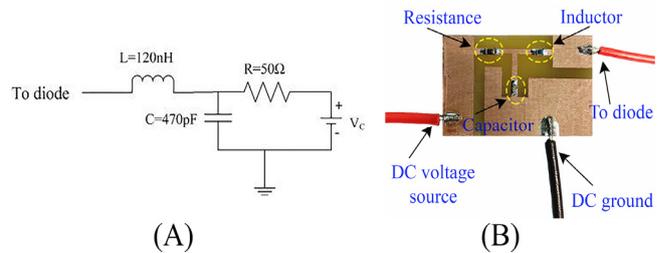


Fig. 5. Biasing circuit: (A) Schematic diagram. (B) Fabricated prototype.

band by inverting the PIN diode combinations as described in state II and state IV.

### 3. Antenna Performance

The return loss, axial ratio and radiation patterns of the proposed antenna have been simulated and measured for all of its operating frequencies. The PIN diode (BAP64-03) which is being used here as switching component, needs proper biasing circuit for optimized performance. The schematic diagram of the biasing circuitry and its fabricated prototype is shown in Fig. 5. The biasing circuitry consists of a 120 nH inductor for RF choking and a 470 pF capacitor for dc blocking. The RF choke and DC blocking capacitor minimizes the mutual effect of the RF signal and DC bias signal. To limit the biasing current a resistance of 50 Ω is also used. The bias tee has also been used for RF source protection.

#### 3.1 Input Reflection Coefficients

The return loss of the proposed antenna has been simulated and measured for the different states of the four PIN diodes. Figures 6 and 7 show the variation of simulated and measured input reflection coefficient with frequency under different combination of PIN diodes (state I–IV). Due to the symmetrical structure, for opposite combination of the diodes, the reflection coefficient profile for state II and

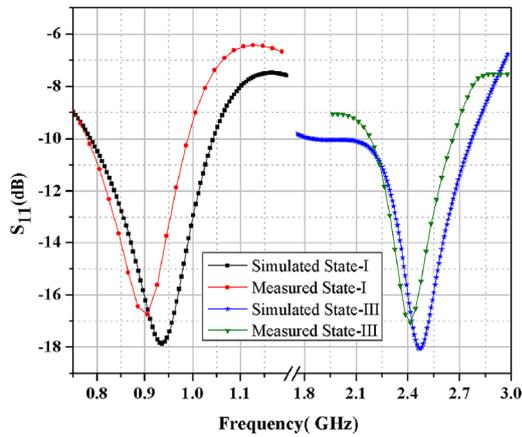


Fig. 6. Measured and simulated reflection coefficient for State I and State III.

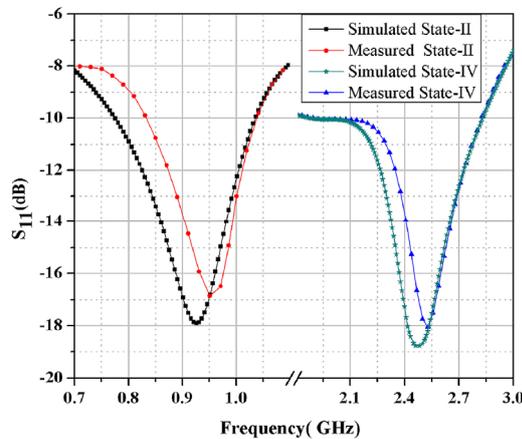


Fig. 7. Measured and simulated reflection coefficient of the proposed antenna for State II and State IV.

IV are almost same as state I and III respectively. The simulated and measured impedance bandwidth of the antenna for different states (state I–IV) has been shown in Tab. 3. An excellent agreement is observed between simulated and measured reflection coefficient of the antenna with a little shift in frequency band that is endorsed to fabrication tolerance. The adhesive at the back of the copper tape may also affect its performance.

#### 3.2 Axial Ratio

Figures 8 and 9 show the simulated and measured axial ratio of the different operational states of the antenna. The corresponding 3 dB axial ratio bandwidths have been shown in Tab. 4.

| Configuration      |                         | State I   | State II  | State III | State IV  |
|--------------------|-------------------------|-----------|-----------|-----------|-----------|
| Simulated $S_{11}$ | Resonance frequency GHz | 0.92      | 0.92      | 2.47      | 2.47      |
|                    | Impedance bandwidth GHz | 0.78–1.04 | 0.76–1.04 | 1.96–2.78 | 2.09–2.84 |
|                    | % bandwidth             | 28        | 30.4      | 33.4      | 30.4      |
| Measured $S_{11}$  | Resonance frequency GHz | 0.897     | 0.95      | 2.41      | 2.54      |
|                    | Impedance bandwidth GHz | 0.78–0.99 | 0.83–1.04 | 2.18–2.65 | 2.10–2.83 |
|                    | % bandwidth             | 23.3      | 22.1      | 19.1      | 28.7      |

Tab. 3. Simulated and measured reflection coefficient of different states.

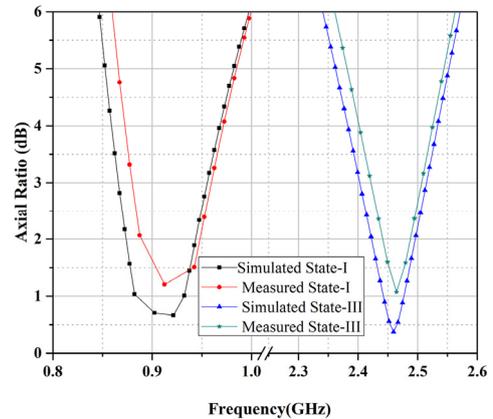


Fig. 8. Measured and simulated axial ratio of the proposed antenna for State I and III.

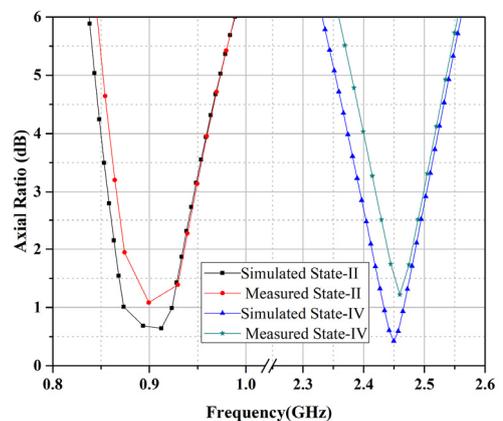


Fig. 9. Measured and simulated axial ratio of the proposed antenna for State II and IV.

| Configuration |                           | State I   | State II  | State III | State IV  |
|---------------|---------------------------|-----------|-----------|-----------|-----------|
| Simulated AR  | Axial Ratio bandwidth GHz | 0.86–0.95 | 0.85–0.94 | 2.39–2.50 | 2.40–2.51 |
|               | % bandwidth               | 9.57      | 10        | 4.5       | 4.48      |
| Measured AR   | Axial Ratio bandwidth GHz | 0.87–0.96 | 0.86–0.94 | 2.41–2.50 | 2.41–2.49 |
|               | % bandwidth               | 10        | 8.9       | 3.6       | 3.2       |

Tab. 4. Simulated and measured axial ratio of different states.

### 3.3 Far-Field Radiation Patterns

The LHCP and RHCP radiation patterns of the reconfigurable monopole at 0.92 GHz and 2.5 GHz of xz-plane and yz-plane are shown in Fig. 10 and Fig. 11, respectively. It is clearly shown that the LHCP and RHCP are achieved for both ISM and GSM band. The simulated maximum gain of the proposed antenna for ISM and GSM band is 1.28 dBi and 1.10 dBi, respectively. The corresponding measured gains are 1.09 dBi and 0.98 dBi which are in good agreement with the simulation. The simulated radiation efficiency of the ISM and GSM and are 84% and 86% whereas the measured values are 80% and 85%, respectively.

A comparison between the performances of the proposed reconfigurable antenna to similar published works is provided in Tab. 5. As observed in [5], [7] all the antennas were fabricated on rigid material with either frequency or polarization agility. The use of rigid substrate restricts their application in wearable technology as it may become uncomfortable to users. Other two antennas in [12] and [13] were implemented on flexible substrate, performing only

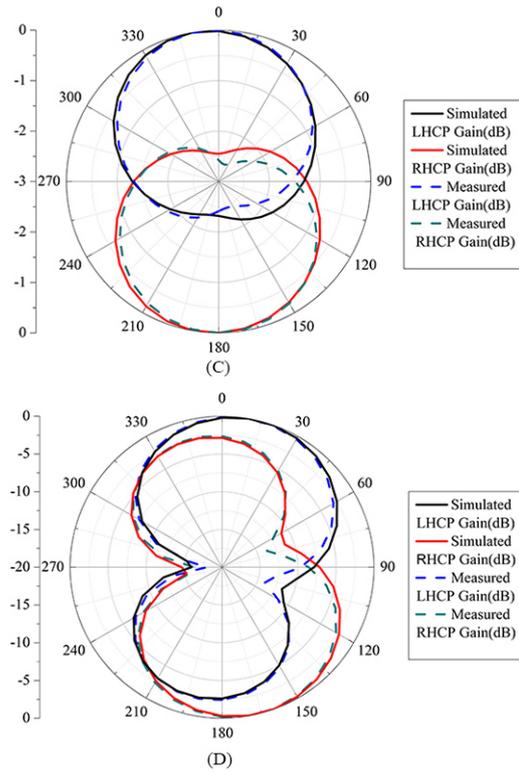
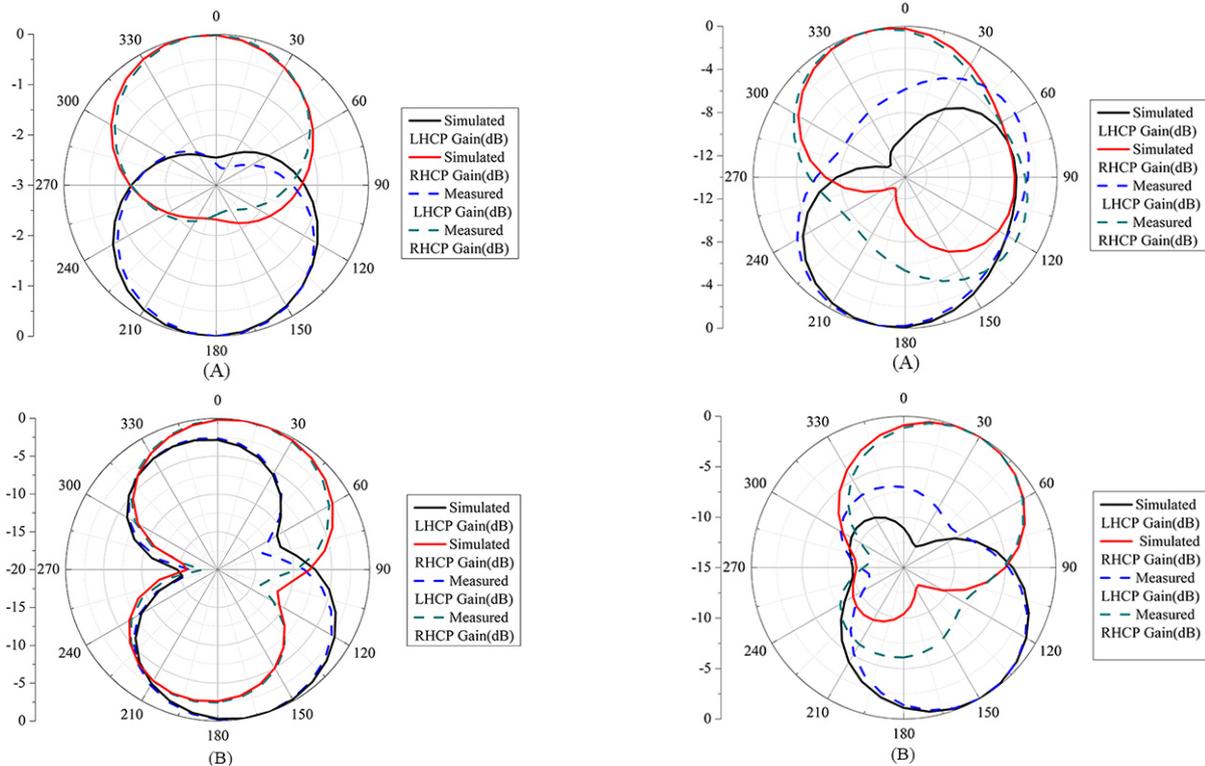
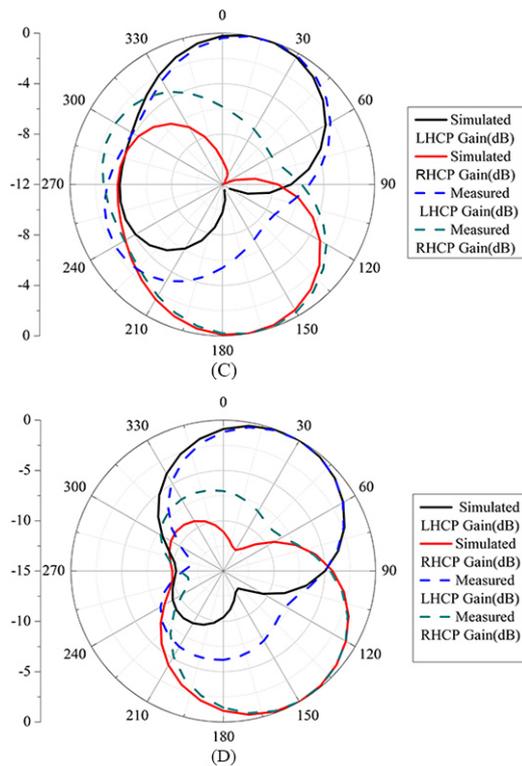


Fig. 10. Radiation patterns at 0.92 GHz: (A) xz-plane cut of State I, (B) yz-plane cut of State I, (C) xz-plane cut of State II, (D) yz-plane cut of State II.

frequency reconfiguration. The flexible antenna proposed in [16] is capable to perform frequency reconfiguration between two frequency bands and LHCP configuration is achieved only in the lower frequency band. Thus, the previously reported wearable antennas generally do not have polarization reconfigurability in every reconfigurable fre-





**Fig. 11.** Radiation patterns at 2.5 GHz: (A) xz-plane cut of State III, (B) yz-plane cut of State III, (C) xz-plane cut of State IV, (D) yz-plane cut of State IV.

| Ref.            | Flexibility | Material used                           | Frequency reconfiguration (GHz) | Polarization reconfiguration           | Max %ARBW |
|-----------------|-------------|---|---------------------------------|--|-----------|
| 5               | No          | Substrate with dielectric constant 2.65 | 2.32–2.59<br>3.04–3.96<br>4.7–6 | No                                     | NA        |
| 7               | No          | FR4                                     | No                              | LHCP, RHCP, LP                         | 13.62     |
| 9               | No          | Arlon CuClad 233                        | No                              | LHCP, RHCP, LP                         | 69.6      |
| 10              | No          | Rogers 5880                             | No                              | HP, VP, LHCP, RHCP                     | 28.6      |
| 12              | Yes         | Polydimethyl siloxane (PDMS)            | 2.2–2.65                        | No                                     | NA        |
| 13              | Yes         | Denim                                   | 2.38–2.52<br>5.17–5.33          | No                                     | NA        |
| 16              | Yes         | Felt                                    | 1.57–2.64                       | LP, LHCP                               | 1.26      |
| <b>Our work</b> | <b>Yes</b>  | <b>Jeans</b>                            | <b>0.78–1.04<br/>2.18–2.65</b>  | <b>LHCP, RHCP(each frequency band)</b> | <b>10</b> |

**Tab. 5.** Comparison of the proposed configuration with previous work.

frequency band. In this present work, the proposed antenna can reconfigure itself at two frequency bands with CP reconfigurability at each band.

### 4. Conclusion

A simple low-cost, flexible disc monopole antenna with frequency and polarization reconfiguration is pro-

posed herein which is also capable of integration with clothing. It offers LHCP and RHCP configuration at both the GSM and ISM band by selecting the different state of PIN diodes. The proposed design has the potential to improve biomedical communication systems that require multiple frequencies with the CP agility.

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