A Switchable Polarization Slotted WLAN Antenna with DGS for IOT and Medical Applications

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Abstract: This work a 20 X 35 X 0.8 mm$^3$ rectangular polarization reconfigurable antenna with four slots made at the corners of the patch. These four slots give the appropriate extra modes for circular polarization. Switching between LP and CP can be achieved using a PIN diode which is inserted across an L-shaped slit in the plane of the ground. The designed antenna is optimized and analyzed through simulations. The axial ratio (< 3 dB) bandwidth and impedance bandwidth (< -10 dB) are overlapped from 5.15 to 6.25 GHz (19.3%). The prototype antenna is tested for both states of the diode (forward and reverse bias). The working band covers the wireless local area network (IEEE 802.11a) band (5150 – 5350 MHz, 5725 – 5825 MHz) and HIPERLAN band (5450 – 5725 MHz) and a favorable compromise between simulated and tested outcomes. The omnidirectional radiation diagrams of the antenna are suitable for wireless portable medical devices.

1. Introduction
Recently, Antennas with reconfigurable polarization are gained much attention because of their inherent advantages to alleviate fading losses in a multipath environment, hence the quality of signal transmission is improved. The advantages are more noteworthy by using the reconfigurable antenna with different polarization at the end of the broadcast and/or at the receiving end of an indoor communication system [1], [2]. In literature a huge number of frequency reconfigurable antennas are proposed, very few polarization reconfigurable antennas are also suggested. Reconfigurability is achieved by inserting different types of switches like Varactor diode, PIN diode, MEM's switches, etc. [13]-[24]. A single feed square patch antenna with a rectangular rim shaped slit was proposed in [3]. Eight diodes are integrated in the slits to achieve frequency and polarization reconfigurability. This antenna provides a bandwidth of 12% at 5.2 GHz and 30% at 5.8GHz. A microstrip patch antenna with a compact U-modelled slit is proposed. In the first configuration, a PIN diode is inserted across the slit to shift between linear and circular polarization. In the second configuration, a couple of PIN diodes are placed across the arms of the U-shaped slit to shift between right- and left-hand Circular Polarization (RHCP&LHCP) from 5725 to 5850MHz for WLAN applications [4]. In [5], [6] monopole and loop antennas are designed with the performance of wideband but those are having a high profile and complicated structure. Consequently, a large number of diodes (sixty-four diodes in [5] and forty-eight diodes in [6]) and lumped elements are required.

The unique construction of a microstrip patch reconfigurable circular polarization antenna with two orthogonal slits is discussed in [7]. A pair of slits are integrated with a microstrip patch and loaded with a pair of PIN diodes to open and close the slits. The proposed antenna radiates either left- or right-hand circular polarization (LHCP or RHCP) by alter the state of the diodes off or on. In [8], To
switch vertical to horizontal polarization a slotted patch antenna was proposed with CPW-to-slot line transition feed. Polarization reconfigurability is gained by adjusting the state of a pair of PIN diodes. In [9], A dual feed square patch with slots at the opposite corners is presented. A pair of PIN diodes are located in the slits and controlled to get linear polarization (LP) (horizontal and vertical), circular polarization (CP) (right-hand and left-hand). The size of the antenna is 50 mm X 50 mm due to the dual feeds. In [10] a single feed monopole polarization reconfigurable antenna is designed with a size 20 × 35 mm². It consists of a narrow L-model slit in the plane of the ground. By altering the condition of a pair of PIN diodes dual orthogonal polarization (Vertical and Horizontal) is achieved. It operates over 5-6.4GHz. In [7]-[10] by controlling the pin diodes we can achieve either linear (vertical and horizontal) or circular polarization (LHCP and RHCP) only.

A Shorted annular patch with partially reflected surface fed by Wilkinson power separator system is constructed for WLAN applications in [11]. All branches of the power partition system embedded with tetrad PIN diodes are controlled to alter its electric field orientation among LP and CP (RHCP and LHCP). The impedance and axial ratio bandwidths are 4680 to 5330 MHz. A 2 × 2 array antenna is modeled with a dual-mode substrate integrated waveguide (SIW) cavity. Two pairs of slits are inserted on the plane of the SIW cavity. The LP, LHCP, and RHCP are achieved by changing the radiation phases with the proper selection of the input port [12]. A massive number of diodes may also raise system intricacy and restrict the scope of practical attention. However, frequency and polarization reconfiguration must require changing band as well as polarization.

In this communication, a simple quadrilateral slotted patch antenna with a DGS (Defected ground surface) is designed. Reconfigurable polarization is gained by switching the PIN diode. The -10 dB bandwidth of antenna cover the bands WLAN (IEEE 802.11a) Systems (5150 - 5350 MHz (indoor), 5725-5825 MHz (outdoor)) and HIPERLAN/2 (5470-5725 MHz). CP can be achieved with four slots on the patch which provide two orthogonal modes with quadrature phase. Section II presents the antenna structure and parametric analysis to get optimized design parameters. In section III experimental and simulated results are discussed in detail and it is followed by conclusions in Section IV.

2. Antenna Geometry

2.1. Antenna Structure

A rectangular wideband slot antenna with polarization reconfigurability is shown in figure 1. The rectangular patch antenna 20 × 35 mm² was placed on a 0.8 mm height Fire resistant-4 substrate with relative permittivity 4.4 and 0.02 of loss tangent. The ground plane dimension is 20 × 20.5 mm². The L-modeled opening is made in the ground plane. The structure of the designed antenna and dimensions are shown in Figure 1.

After optimization, the height of the L-model slit on the ground is chosen as 2 mm. The 9 × 11.5 mm² rectangular patch fed with 50 Ω microstrip line which is 2 mm wide and 20.5 mm long. Four rectangular slots in the corners are created on patch with dimensions 3 × 1 mm². A PIN diode is employed to get the diversity characteristics which is mounted across the L-modeled slit in the ground. The position of the diode is determined by the parametric analysis for good Axial Ratio (AR) bandwidth. The prototype antenna is shown in Figure 2(a) and (b). Ansoft HFSS 3-D full-wave EM simulator is used for the simulation.
Table 1. The proposed polarized reconfigurable antenna dimensions

| Parameters | Ls  | Ws  | L1  | L2  | W1  | W2  | W  | L  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Value (mm) | 1   | 3   | 9   | 22  | 11  | 2   | 20  | 35  |

| Parameters | Lg  | W4  | L4  | L5  | L6  | W3  | L3  | h  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Value (mm) | 20.5| 4.5 | 16  | 3.5 | 2.9 | 6.5 | 20.5| 2  |

Figure 1. Structure of the designed antenna (a) Front view (b) Back view

Figure 2. Photographs of the prototype antenna (a) Front view (b) Back view

2.2. Parametric Study
The effect of leg length (W4) and the height (h) on the impedance bandwidth (defined as “a return loss below -10 dB”) of the antenna are carried out by doing parametric analysis. The ground plane is optimized for better return loss ($S_{11}$). Figure 3 presents a parametric study on the leg length (W4) of the L-shaped slot. The operating bandwidth of the proposed antenna is decreased from 33.3% to 7.3%, which is in reverse proportionate to the size of the leg. After a parametric study, we can observe that at $W_4=4.5$ mm the impedance bandwidth is 33% with good return loss -26 dB so in this proposed antenna $W_4=4.5$ mm.
Table 2. The impedance bandwidth of the designed antenna for different length of slot

| Length of the leg (W4) in mm | Band (GHz) | Impedance Bandwidth (%) |
|-----------------------------|-----------|-------------------------|
| 7                           | 5.3-5.7   | 7.3                     |
| 6.5                         | 5.2-5.8   | 10.9                    |
| 6                           | 5.2-5.9   | 12.6                    |
| 5.5                         | 5.1-6.1   | 17.9                    |
| 5                           | 5-6.5     | 26                      |
| 4.5                         | 5-7       | 33.3                    |

Figure 3. Parametric study of length of the leg (W4) in an L-molded slit

Figure 4 demonstrates the impact of the L-modeled slit height (h) on the reflection coefficient $S_{11}$. It is observed from the parametric study the impedance bandwidth is approximately the same but the operating frequency is shifted from 4.2 to 7GHz concerning the height of the slot. When the slot is 2mm above the ground the reflection coefficient is less than -10dB from 5.1-7GHz with impedance bandwidth 31.4% and maximum return loss is -24dB, So h value is taken as 2 mm to cover the bands IEEE 802.11a WLAN (5150–5350 MHz, 5725–5825 MHz) and HIPERLAN/2 (5450 – 5725 MHz).

The basis of this method is that the effective current path of the antenna can be increased by loading the slots on the rectangular patch. By altering the lengths of the slots, the principal resonant mode of microstrip patch (TM$_{11}$ mode) can be separated into two adjacent degenerate resonant modes which are having 90° phase difference with equal amplitudes; So, CP radiation can be attained without using 90° hybrid coupler. Figure 5 presents the direction of the current across four slots.

Small disturbances of regular patch shapes are appropriate for stimulating two orthogonal modes with a ±90° phase difference. To achieve the CP radiation, the circumference of the openings must satisfy a certain relationship and the exact value needs to be optimized by performing some numerical simulations for the desired resonant frequency. The size of the slit is usually chosen to be a half or quarter-wavelength. These slits can take various models. The dimensions of each slot are $L_s=1$ mm, $W_s=3$ mm. To get resonance at the desired frequency, the breadth $W_1$ of the rectangular patch is chosen such that

$$W_1 = \frac{c}{4f_0 \sqrt{\varepsilon_{\text{eff}}}} \quad (1)$$

$$L_4 + W_4 \approx \frac{\lambda_0}{2} = \frac{c}{2f_0 \sqrt{\varepsilon_{\text{eff}}}} \quad (2)$$
Figure 4. Effect of the height of the L-model slit on the resonant frequency of the antenna

Figure 5. Effective Current Path of the Antenna

The most commonly used switching component is the PIN diode for radiofrequency and microwave products. In this design, a PIN diode is preferred as a switching element to gain diversity characteristics. Datasheet of PIN diode BAR 6402 V is used to draw the simplified circuit models. In the simulations, the PIN diode is replaced with a simplified circuit model to get accurate results. The simplified circuit model for both forward and reverse biased cases is presented in Figure 6. It is a series LR circuit when the diode is forward biased. In the case of reverse-biased parallel RC, the circuit is connected to L in series. The value of Inductance L is 0.45 nH and resistance R\_ON is 1.5Ω. In diode OFF state value of capacitance C=0.25 pF and R\_OFF=2.5 KΩ.
Figure 6. The simplified circuit model of PIN diode for the case (a) forward biased and (b) reverse biased.

3. Experimental Results
Experimental results are matched with simulated outcomes as exhibited in Figure 7. The resonating frequency of the antenna is shifted from 5100MHz to 5600MHz resonates at 5100MHz and 5600MHz for PIN diode ON and OFF cases respectively. The experimental and simulated -10dB impedance bandwidth for the PIN Diode ON configuration is from 4.3 to 6.1 GHz (35%) and 4.5 to 6.1 GHz (30%) are shown in figure 7. On other hand, when the diode is in the OFF state the measured and simulated return loss($S_{11}$) bandwidth is 4.8 to 7 GHz (37.3%) and 5 to 7 GHz (33.3%). In both cases, the proposed antenna covers the bands HIPERLAN (5450–5725 MHz) and IEEE 802.11a WLAN (5150–5350 MHz, 5725–5825 MHz).

Figure 7. Comparison between measured and simulated $S_{11}$ for diode OFF and ON configurations.
Figure 8. Frequency vs axial ratios plot

The polarization state of the antenna is circular (RHCP) when the PIN diode is OFF. The measured and simulated AR for the CP antenna is displayed in Figure 8. The 3-dB axial ratio bandwidth is 1100 MHz, from 5.15 to 6.25 GHz (19.3%) the axial ratio is below 3 dB. When the diode ON it is linearly polarized (VP) with an axial ratio 50 dB. Figure 9 shows the antenna surface currents for diode ON and OFF states.

Table 3. Polarization of the designed antenna at different states of the diode

| PIN Diode State   | Polarization |
|-------------------|--------------|
| Forward Biased    | Linear (VP)  |
| Reversed Biased   | RHCP         |

Figure 9. Surface current distributions at 5.8 GHz (a) Diode ON (b) Diode OFF
Figure 10. Radiation Patterns (a) Diode ON (b) Diode OFF

The evaluated and simulated emission characteristics of the designed antenna in LP and CP at 5800MHz are presented in Figure 10. It is remarked that a decent omnidirectional pattern is achieved in both linear and circular polarizations. The gain of the designed antenna at different frequencies is plotted in Figure 11, the maximum peak gain of 2.5 dB. From Figure 12, it is detected that the radiation efficiency is between 85 % to 93 % in the operating band.
A slotted wideband antenna is designed for WLAN Applications. The diode is mounted across the slit in the plane of ground to minimizing the influence on radiation characteristics. It can provide linear and right-hand circular polarization using a single PIN diode. The antenna has an AR bandwidth of 19.3% for RHCP. The peak gain is 2.5 dB at 5.5GHz. The prototype of the antenna is fabricated and tested for linear and circular polarization cases. All the simulated and experimental outcomes showing that the designed antenna is suitable for portable medical devices.

4. Conclusion

References

[1] P. Y. Qin, Y. J. Guo, and C. Ding, “Dual-Band Polarization Reconfigurable Antenna for WLAN Systems,” IEEE Trans. Antennas Propag., vol. 61, no. 11, pp.5706-5713, Nov. 2013.

[2] Anantha Bharathi, MeruguLakshminarayana and P.V.D. Somasekhar Rao, A quad-polarization and frequency reconfigurable square ring slot loaded microstrip patch antenna for WLAN applications, AEU - International Journal of Electronics and Communications, Volume 78, August 2017, Pages 15-23.

[3] A. Bharathi, M. Lakshminarayana, P.V.D. Somasekhar Rao. A Novel Single Feed Frequency and Polarization Reconfigurable Microstrip Patch Antenna. International Journal of Electronics and Communication (AEU), Volume 72, February 2017, Pages 8-16.
[4] P. Y. Qin, A. R. Weily, Y. J. Guo, and C. H. Liang, “Polarization reconfigurable U-Slot patch antenna,” IEEE Trans. Antennas Propag., vol. 58, no.10, pp. 3383–3388, Oct. 2010.

[5] W. Li, S. Gao, Y. Cai et al., “Polarization-reconfigurable circularly polarized planar antenna using switchable polarizer,” IEEE Transactions on Antennas and Propagation, vol. 65, no. 9, pp. 4470–4477, 2017.

[6] Boli and Quan Xue, “Polarization Reconfigurable Omnidirectional Antenna Combining Dipole and Radiators”, IEEE Antenna And Wireless Propagation Letters, Vol-12, 2013.

[7] F. Yang and Y. Rahmat-Samii, A reconfigurable patch antenna using switchable slots for circular polarization diversity, IEEE Microwave. Wireless Compon Lett 12 (2002), 96-98.

[8] Y. Li, Z. Zhang, W. Chen, and Z. Feng, “Polarization reconfigurable slot antenna with a novel compact CPW-to-Slotline transition for WLAN application,” IEEE Antennas Wireless Propag. Lett., vol. 9, pp. 252–255, Apr. 2010.

[9] X.X. Yang, B. Gong, G. Tan, and Z. Lu, “Reconfigurable patch antennas with four-polarization states agility using dual feed port,” Prog Electromagn Res B Vol. 54, 285-301, 2013.

[10] M.H. Amini, H.R. Hassani, S. Mohammad Ali, “A Single feed reconfigurable polarization printed monopole antenna,” 6th Europian Conf. on Antennas and Prop. (EUCAP), pp. 1-4, 2012.

[11] Lu-Yang Ji, Pei-Yuan Qin, Y. Jay Guo, Can Ding, Guang Fu, and Shu-Xi Gong, “A Wideband Polarization Reconfigurable Antenna with Partially Reflective Surface,” IEEE Transactions on Antennas And Propagation, Vol. 64, No. 10, pp. 4534-4538, October 2016.

[12] Zhang-Cheng Hao, Kui-Kui Fan, and Honghui Wang, “A Planar Polarization-Reconfigurable Antenna,” IEEE Transactions on Antennas and Propagation, Vol. 65, No. 4, pp. 1624-1632, April 2017

[13] Rajiya S.K., Monika M., Madhav B.T.P. ( 2018 ) , ‘Circular slotted reconfigurable antenna for wireless medical band and X-band satellite communication applications’, Indian Journal of Public Health Research and Development, 9 (6),PP. 296-300

[14] Prasad B.S., Rao P.M., Madhav B.T.P. ( 2018 ) , ‘Trapezoidal notch band frequency and polarization reconfigurable antenna for medical and wireless communication applications’, Indian Journal of Public Health Research and Development, 9 (6),PP. 324-328

[15] Siva Prasad B., Mallikarjunna Rao P., Madhav B.T.P. ( 2018 ) , ‘Coplanar wave guide fed fork shaped frequency reconfigurable antenna for LTE, WI-FI and WLAN applications’, International Journal of Engineering and Technology(UAE), 7 (1.1 Special Issue 1),PP. 366-370

[16] Sureshkumar K., Chandra Vamsi G., Chandu L., Nikhil B., Chetan Sai K. ( 2018 ) , ‘Implementation of meander line based reconfigurable CPW-fed antenna’, Journal of Advanced Research in Dynamical and Control Systems, 10 (2),PP. 579-583

[17] Rao K.S., Kumar P.A., Gulu K., Sailaja B.V.S., Vineetha K.V., Baishnab K.L., Sravani K.G. ( 2018 ) , ‘Design and simulation of fixed–flexure type RF MEMS switch for reconfigurable antenna’, Microsystem Technologies, PP. 1-8

[18] Venkateswara Rao M., Madhav B.T.P., Anilkumar T., PrudhviNadh B. ( 2018 ) , ‘Metamaterial inspired quad band circularly polarized antenna for WLAN/ISM/Bluetooth/WiMAX and satellite communication applications’, AEU - International Journal of Electronics and Communications, 97, PP. 229-241

[19] Nadh B.P., Madhav B.T.P., Kumar M.S., Rao M.V., Anilkumar T. ( 2018 ) , ‘Asymmetric ground structured circularly polarized antenna for ISM and WLAN band applications’, Progress In Electromagnetics Research M, 76 (1),PP. 167-175

[20] Sheik A.R., Krishna K.S.R., Madhav B.T.P. ( 2018 ) , ‘Circularly polarized defected ground broadband antennas for wireless communication applications’, Lecture Notes in Electrical Engineering, 434,PP. 419-427

[21] Madhav B.T.P., Khan H., Sri Harsha B., Sai Kumar P., Lavanya M., Veena K., Venkateshwara Rao M. ( 2018 ) , ‘X-Slotted circularly polarized antenna with parasitic patches’, International Journal of Engineering and Technology(UAE), 7 (1.1),PP. 534-538

[22] Murthy K.S.R., Umakantham K., Murthy K.S.N., Madhav B.T.P. ( 2018 ) , ‘Polarization and frequency reconfigurable antenna for dual band ISM medical and Wi-Fi applications’, International Journal of Engineering and Technology(UAE), 7 (3.27 Special Issue 27), PP. 651-654.

[23] Sowjanya B., Saijea G.V., Krishna M., Krishna M., Bhagavan A. ( 2018 ) , ‘A novel planar dual polarized millimetre wave antenna for ku band applications’, International Journal of Engineering and Technology(UAE), 7,PP. 859-862.

[24] Ramakrishna T.V., Madhav B.T.P., Amulya D., Sumitra S., Kumar A.S., Rohit M., Anilkumar T. ( 2018 ) , ‘Design of CPW fed f-shaped circularly polarized antenna for amateur radio vehicular communications’, International Journal of Engineering and Technology(UAE), 7,PP. 360-365.