Microwave Review
December 2024, Vol. 30, No. 2, pp. 36-40
DOI: 10.18485/mtts_mr.2024.30.2.4

Linearly Polarized High Gain Antennas with Dynamic Polarization Control

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Abstract – **A reconfigurable microstrip antenna featuring linear polarization (LP) adaptability was developed by manipulating DC biasing in two p-i-n diodes. The design, modelling, and fabrication processes were meticulously executed to ensure optimal performance and compatibility with emerging communication standards supporting horizontal-linear polarization (H-LP) and vertical linear-polarization (V-LP). The antenna exhibits a 10dB bandwidth of 6.4% and 5.28%, showcasing versatility across a similar resonating frequency of 2.65 GHz. At 2.65 GHz, it achieves a maximum realized gain of 8.23 dBi, 9.19dBi with more than 80% efficiency. With its compact form factor and reconfigurable nature, the antenna contributes to advancing modern infrastructure, facilitating efficient and reliable wireless connectivity for various applications. The design is fabricated and measured to match the simulated result.**

Keywords – **Linear polarization, Horizontal linear polarization (H-LP), Vertical linear polarization (V-LP), p-i-n diode, Pattern reconfigurable.**

I. Introduction

Antenna polarization stands as a cornerstone within a wireless communication system, elaborating the orientation of the electric field produced by an antenna's radiating elements. This alignment dictates the propagation of electromagnetic waves in free space, impacting the overall signal efficiency and dependability of transmission and reception. Antennas demonstrate a spectrum of polarization states, encompassing linear, circular, and elliptical polarizations, each having distinctive benefits and practical uses [1]. LP, characterized by vibrations confined to a single plane, emerges as a prevalent technique in real-world applications. Understanding the principles of antenna polarization is essential for optimizing antenna performance and mitigating signal interference, making it indispensable in contemporary modern wireless communication technology. Vertical and horizontal polarization are two primary forms of LP commonly employed in wireless communication systems [2]. Vertical polarization involves orienting the antenna's radiating elements parallel to the earth's surface, facilitating efficient signal propagation over long distances and through obstacles such as buildings and foliage.

Article history: Received March 04, 2024; Accepted April 24, 2024

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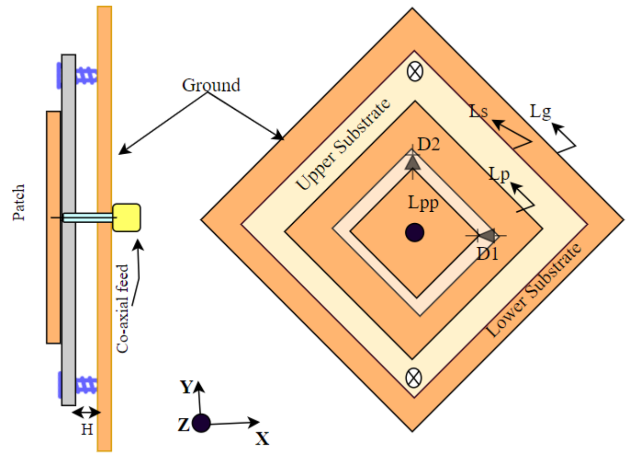
Conversely, horizontal polarization entails aligning the antenna elements perpendicular to the earth's surface, offering robustness against multipath fading and enhancing signal coverage in urban environments. LP is achieved in [3] by selectively exciting one of the antenna's feed ports, resulting in either vertical or horizontal orientation of the electric field. By controlling the excitation, the antenna radiates with the desired LP, enhancing its versatility in wireless communication. Additionally, circular polarization is attained by exciting both feed ports with a phase difference. This approach enables efficient polarization reconfiguration, catering to diverse communication needs.



(a) (b)

Fig.1. Proposed antenna: (a) cross-section view, (b) top view: (Lg=155 mm, Ls= 89.25 mm, Lp= 43.65 mm, Lpp= 18.6 mm, H= 3.5 mm, D1 and D2 are diodes)

A quadruple diversity antenna is proposed in [4] with both linear (vertical and horizontal) and circular (right-handed and left-handed) polarizations is introduced, featuring a reconfigurable coupler to enable real-time polarization diversity. Electrical switches within the antenna's feeding network facilitate polarization reconfiguration across four operational modes and two circular polarization modes. In [5], LP in the microstrip antenna is achieved by selectively routing power to both pairs of antenna feeds using commercially available RF MEMS SPDT switches. When power is directed to one pair of feeds, it results in vertical polarization, while directing power to either feed generates horizontal polarization. This approach allows for dynamic control of polarization diversity, enabling multifunctionality in wireless and satellite communication systems.

This research introduces a microstrip antenna capable of seamlessly transitioning between horizontal and vertical polarization orientations at a fixed resonating frequency, achieving complete polarization reconfiguration. The design employs the strategic placement of two p-i-n diodes within the slot, facilitating two distinct polarization diversity configurations. By precisely controlling the switching mechanism embedded in the slot, the antenna dynamically alters its polarization between H-LP and V-LP polarisation clearly mentioned in Table 1. The excitation of the antenna is achieved through a coaxial feed mechanism. Through meticulous design, fabrication, and experimental validation of both the antenna prototype and the accompanying feed network, the efficacy of the proposed approach is demonstrated for distinct wireless application antenna may be used [6]-[8].

II. Antenna Design

For circular microstrip antenna, inspired from prior work [12], Equations (1) and (2) govern the design, where (1) calculates the radius (r) and (2) determines parameter F crucial for (1).

$$r = \frac{F}{\left[1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right]^{1/2}}, \quad (1)$$

where,

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}. \quad (2)$$

But design equation for a square microstrip antenna, denoted by equation (3)

$$L = \frac{c}{2f_r\sqrt{\varepsilon_r}}, \quad (3)$$

determines the side length L of the square patch based on the resonant frequency f_r and the relative permittivity ε_r of the substrate material, where c represents the speed of light in free space. If any truncations can be introduced on the sides of the square patch to induce specific polarization diversity.

Here in the proposed antenna combines a coaxial feed square patch antenna designed on RT-Duroid 5870 with a relative permittivity of 2.33 and thickness of 1.6 mm. A square slot is etched out from the upper square patch. Two p-i-n diodes are adjusted in the slot [13],[15] of the upper patch, and the position of the p-i-n diode is carefully adjusted during the optimization process [9]-[11].

The ground plane is adjusted H mm below the substrate. To provide the mechanical strength of the upper substrate, the outer etched portion of the substrate is extended, and at the corner of the upper substrate, two plastic screws are installed so that the functionality of the antenna doesn't get affected [14]. Figure 1(a) and (b) demonstrate the cross-section and upper view of the proposed antenna. The proposed antenna is fabricated in the fabrication lab and thereby tested with the help of 'N5230A PNA-L network analyser' with the help of 'aplab 7612 dual dc power supply' for providing the supply to the diode. Figure 2(a) and (c) provide information about the setup model of the antenna, whereas 2(b) demonstrates the fabricated structure.

Fig. 2. (a) Proposed antenna, (b) fabricated, (c) setup model for the measurement

TABLE 1
Depicts conditions for H-LP and V-LP

Sl. no.	D1	D2	LP type
I	on	off	V-LP
II	off	on	H-LP

III. P-I-N Diode

The p-i-n diode, particularly the Bar-20-02L, offers superior reconfigurability as an RF switch due to its unique characteristics [16-20]. The diode functions as a self-protection resistor in its on-state, effectively managing the supplied current. The equivalent circuit for both on and off states is illustrated in Fig 3. The data sheet [21] specifies a resistance value of 5 ohms (R0) for the on-state, indicating its capability to handle current flow efficiently. Conversely, in the off-state under reverse bias conditions, the resistance (R1) is significantly higher at one kilohm, indicating minimal current flow [17-18]. The direction of both diodes is kept opposite, which assists one diode in coming into a conducting state at an instant. The disparity in resistance values of modes of diodes demonstrates the ability to swiftly transition between conducting and non-conducting states, making it an ideal choice for reconfigurable RF switching applications.

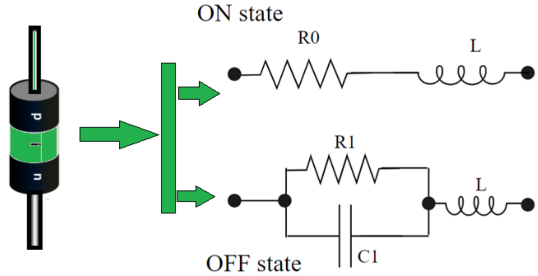


Fig. 3. Equivalent circuit of p-i-n diode as a switch for on and off state

IV. Simulation and Experimental Results

This section of the paper deals with the simulated and measured results of the polarisation diversity antenna. The arrangement of the p-i-n diode is implemented on the two adjacent corners of the square patch, almost optimized at 90 degrees with each other. This will help alter the surface current distribution of the radiating patch of the proposed antenna. The surface current distribution of the antenna demonstrating the LP switching, especially H-LP and V-LP, is shown in Figure 4(a) and (b), respectively.

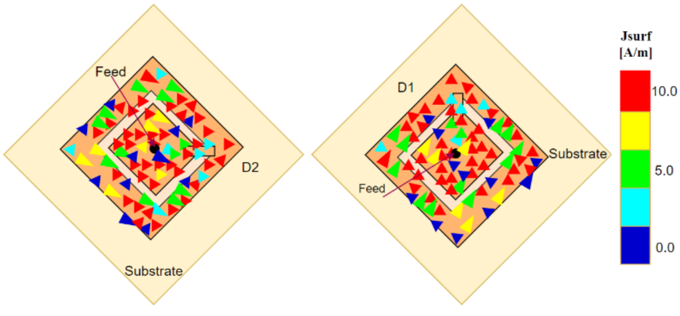


Fig. 4. Surface current distribution of the antenna for: (a) H-LP, (b) V-LP

The proposed design of the antenna is simulated, and the measured reflection coefficient of the antenna is demonstrated in Fig 5. The H-LP and V-LP polarisation antenna resonated at an almost similar frequency of 2.65 GHz. The VSWR is clearly shown in fig 6. Keeping the resonating frequency fixed is a challenging task for the LP is a challenging task which is tried to achieve by the tedious optimization process of the shorting point of the p-i-n diode. The 10db percentage impedance bandwidth of the antenna is 6.4% and 5.28% for both H-LP and V-LP from 2.57 GHz to 2.74 GHz and 2.58 GHz to 2.72 GHz respectively.

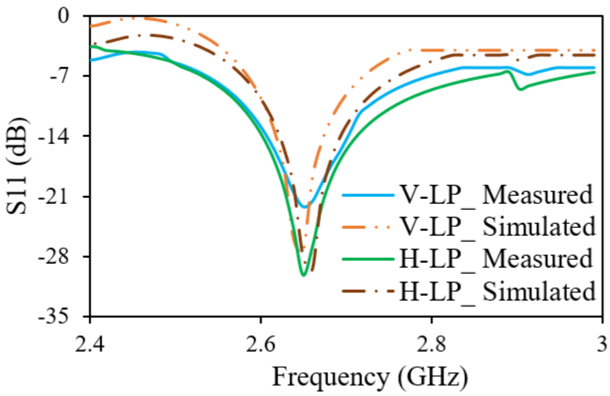


Fig. 5. Measured and simulated reflection coefficient of proposed antenna H-LP and V-LP

Fig 7 presents a detailed analysis of the frequency versus gain characteristics of the proposed antenna design. The simulated gain exhibits remarkable performance, peaking at 8.23 dBi and 9.16 dBi precisely at the anticipated resonating frequencies. The measured gain closely mirrors these simulated values, indicating robust performance for H-LP and V-LP, respectively. Some minor deviations in the measured outcomes are evident. These variations can be seen due to factors including the inherent tolerances within the substrate material, intricacies in etching processes, soldering intricacies, the intricacies of biasing circuits, and fluctuations in the copper thickness of the ground plane. Despite these slight disparities, the overall alignment between simulated and measured gains underscores the effectiveness of the proposed antenna design.

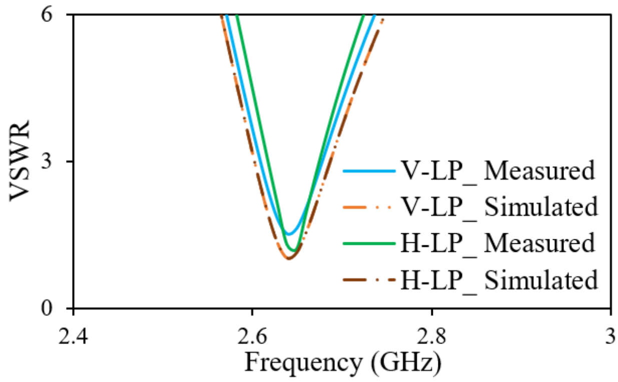


Fig. 6. Measured and simulated VSWR of proposed antenna for both H-LP and V-LP

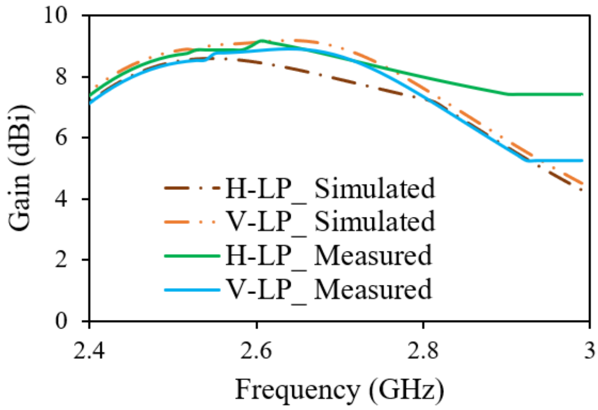


Fig. 7. Maximum gain of both H-LP and V-LP for the proposed pattern reconfigurable antenna

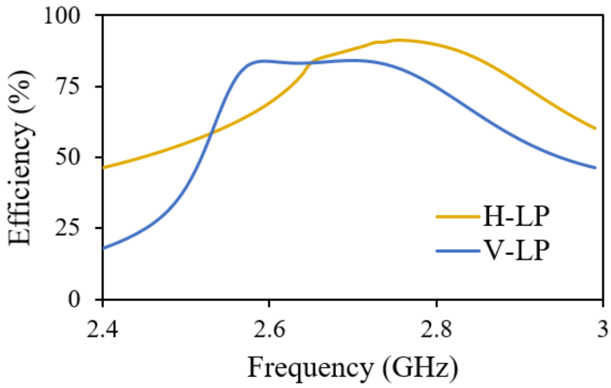


Fig. 8. Maximum Efficiency of H-LP and V-LP reconfigurable antenna

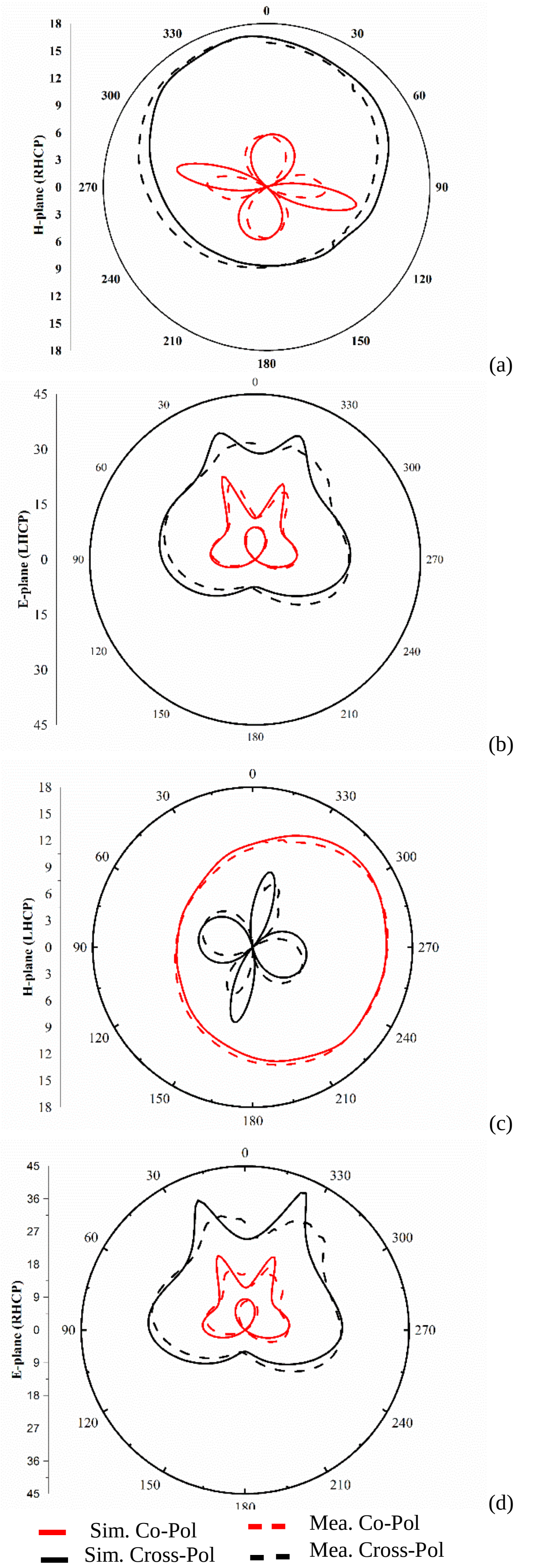


Fig. 9. Simulated and measured radiation patterns of the antenna

The antenna's performance, depicted in Fig. 8, demonstrates an efficiency surpassing 80% within the suggested bandwidth of the proposed antenna. This indicates a high level of effectiveness in converting input power into radiated energy, making it an attractive choice for trustable communication or broadcasting applications requiring robust signal propagation & reception.

Figure 9 presents the radiation patterns of the proposed antenna structure, analysed through full-wave simulations and measurements. The configurations, namely H-LP (Horizontal-Linearly Polarized) and V-LP (Vertical-Linearly Polarized), are illustrated at their resonance frequencies, typically occurring at 2.65 GHz.

The simulation was conducted using HFSS-R3 2019 software, enabling the evaluation of the antenna's co-polarization and cross-polarization characteristics. Co-polarization refers to the alignment of the electric field with the antenna's main axis, while cross-polarization represents the perpendicular alignment, and the minimum difference between both is maintained. By comparing simulated and measured radiation patterns along with antenna's performance the accuracy of the model is verified. These analyses are crucial ensuring their effectiveness in practical applications. Table 2 provides the comparative analysis of the proposed structure with several state of art work.

TABLE 2

PERFORMANCE COMPARISON OF PROPOSED ANTENNA WITH STATE OF ART WORK

Ref	Antenna type	Polarization	Diode no.	Gain (max)
[22]	Square M.S.A	VP to HP	8	3 dBi
[23]	Square M.S.A	VP to HP	6	6.3 dBi
[24]	Square M.S.A	VP to HP	7	8 dBi
[25]	square split-ring antenna	VP to HP	5.95	2 dBi
[26]	M.S.A	VP to HP	7.8	8 dBi
[27]	Square M.S.A	VP to HP	4	6.2 dBi
Proposed work	Square M.S.A	VP to HP	2	9.19 dBi

V. CONCLUSIONS

Design and development of LP reconfigurable antenna switching from H-LP and V-LP has been done. By adjusting the p-i-n diode biasing, it can resonate at a similar frequency of 2.65 GHz, achieving bandwidth of 6.4% and 2.28% with maximum gain of 8.23 dBi and 9.16 dBi with more than 80% efficiency in both cases. The reconfigurable microstrip antenna enables diverse applications, including telecommunications, satellite communication, aviation, military, remote sensing, automotive connectivity, healthcare, industrial automation, consumer electronics, and research and development.

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