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# Design and Analysis of Vee Dipole Based Reconfigurable Planar Antenna

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**Abstract**—This paper presents the design and analysis of a planar pattern reconfigurable antenna for WLAN applications. The proposed design makes use of four Vee dipoles placed around a center input probe. The directional beam generated can be reconfigured to any one of the four directions in the azimuth plane ($xy$ plane). The antenna pattern can be controlled by means of switches provided to connect the Vee dipoles to the input port. The design and analysis of the parameters show the scalability of the design to adapt to any frequency of choice. To validate the concept, an antenna is designed for the WLAN frequency of 5.3 GHz, and a prototype is fabricated. The measured results match closely to that of simulated results. The gain provided by the antenna is noted as 7.5 dBi. The planar structure and simple design of the antenna enable this antenna to be useful for modern pattern reconfigurable communication systems.

## 1. INTRODUCTION

Reconfigurable antennas have attracted considerable attention in the past decade due to their ability to provide superior system performance to the systems using conventional omnidirectional antennas. Channel capacity increment, lesser co-channel interference, lower multipath fading, as well as advantages in terms of added wireless security and reduced power consumption make reconfigurable antennas a better option for modern communication systems. A switched beam antenna array can find application in location-aware indoor applications [1], body wearable applications [2], automotive wireless communication [3], WLAN and WiMax applications[4], wireless power reception and data telemetry [5]. Several methodologies for reconfiguring the antenna pattern are found in the literature [6]. Of these, the most popular one is to have electrically controlled switching of beam patterns so that the pattern can be reconfigured remotely [7, 8]. In view of the ease of integration and low cost, planar antennas are preferred for many applications. Various structures for antenna are studied extensively in the past. Printed dipoles because of their low profile are a good choice to design antenna with multiple elements. A three-element Yagi-Uda array based on V-dipole is discussed in [9], and a crossed dipole antenna is reported in [10], but these designs are not reconfigurable. Planar dipole theory based antennas with reconfigurable patterns are realized using PIN diodes in [11, 12]. The aforementioned antenna implementations are mostly limited to pattern angle variations around the boresight. A radiation pattern reconfigurable antenna with four beams in the azimuth is presented in [13]. However, the vertical structure causes packaging and integration concerns. Thus for applications where azimuth beam switching is convenient for integration, there is still scope for further improvement in terms of size and performance.

In this paper, a completely planar antenna that is designed based on Vee dipoles is presented. The radiation pattern of the proposed antenna can be directed to either 0°, 90°, 180° or 270° in the azimuth ($xy$) plane by changing the state of the switches. The truth table of pattern configurations that can be

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**Table 1.** Four beam configurations.

| Config | SW1 | SW2 | SW3 | SW4 | Beam Direction ($\varphi$) |
|---|---|---|---|---|---|
| 1 | ON | OFF | OFF | OFF | 90° |
| 2 | OFF | ON | OFF | OFF | 0° |
| 3 | OFF | OFF | ON | OFF | 270° |
| 4 | OFF | OFF | OFF | ON | 180° |

achieved by the antenna are shown in Table 1. This pattern reconfigurable antenna can find application in sophisticated adhoc and sectoral wireless communication systems.

## 2. ANTENNA DESIGN

The proposed antenna consists of four Vee dipoles arranged at equal distance around the center input probe. The arms of the dipoles are printed on either sides of the substrate. A single 50 Ω SMA connector is connected from the rear side of the substrate. The SMA connector pad is then split into four parallel strip feedlines. Each of these feedlines is in turn connected to the Vee dipole through a switch. The switch positions along with the dipole arrangement are shown in the Figure 1. These switches can be realized using a PIN diode which can be turned ON or OFF depending on the voltage applied across the diode, thus making it an electrically controllable antenna through remote operation.

The input impedance of a single dipole is dependent on the included angle of the Vee [14]. The impedance variation of a single Vee dipole with respect to the included angle ($2\theta$) is plotted in Figure 2 and from the plot it has been noted that the angle can be chosen to have particular impedance at the input of the dipole. Also, for a specific arm length, there is an optimum angle ($2\theta_0$) for which the antenna provides maximum directivity [15]. This is characterized by the single dipole arrangement and is shown in Figure 3.

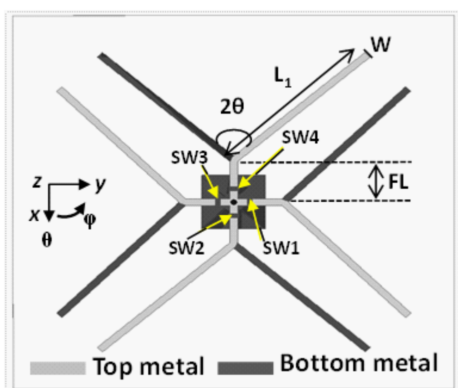



**Figure 1.** Layout of the reconfigurable antenna.

A substrate having a thickness of 0.8 mm and relative permittivity of 4.4 is used for the design of the antenna. The length of the dipole arm is chosen to satisfy a full wavelength at the desired centre frequency (5.3 GHz). The angle of the dipole is chosen as 94°. The lengths of the parallel strips are initially chosen as a quarterwave length and later optimized to compensate for the coupling between the four dipoles. The change of input impedance according to the variation in the length of parallel (FL) strips is given in Figure 4. The length $FL$ is chosen to be 5 mm based on the value that is closest to the centre of the smith chart. A gap of 1 mm is provided on the top metal trace of the parallel strip feedlines to incorporate PIN diodes.

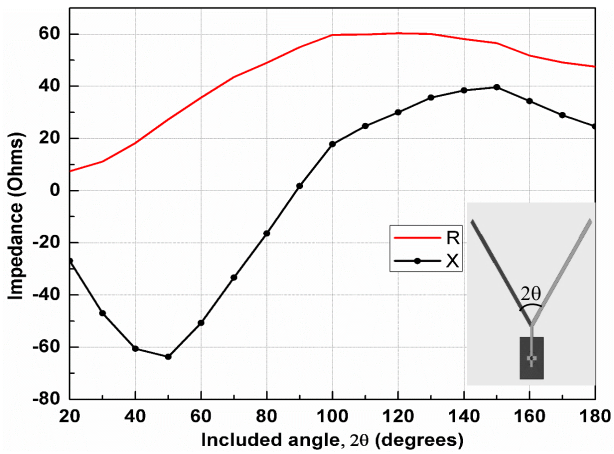



**Figure 2.** Impedance variation with included angle.

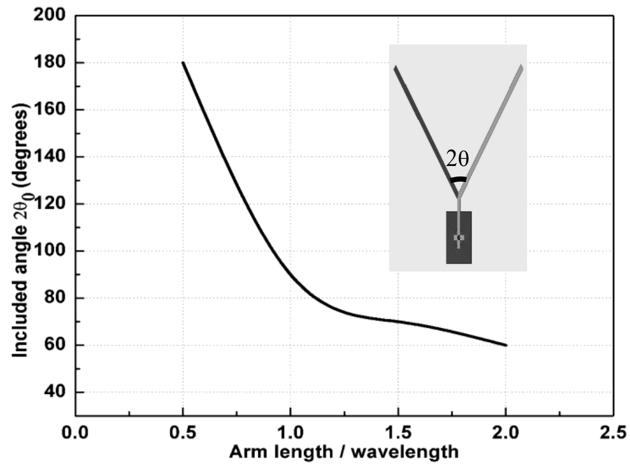



**Figure 3.** Included angle to obtain the maximum directivity for various length ratios.

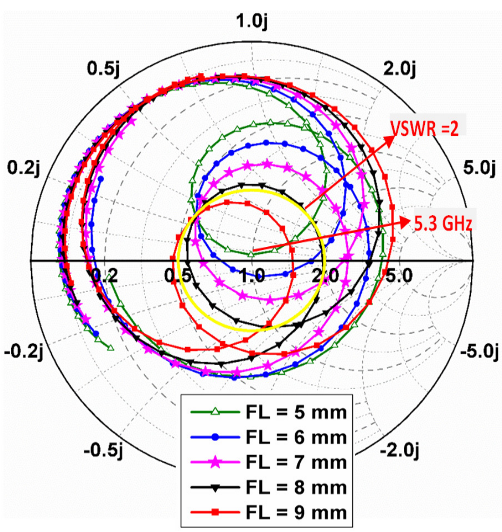



**Figure 4.** Parametric analysis of length of parallel strips.

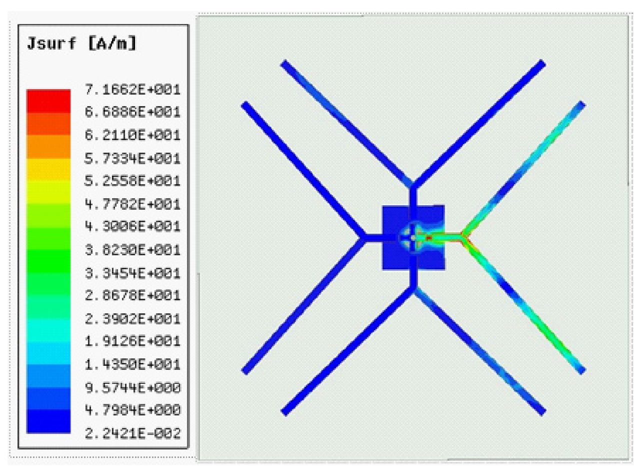


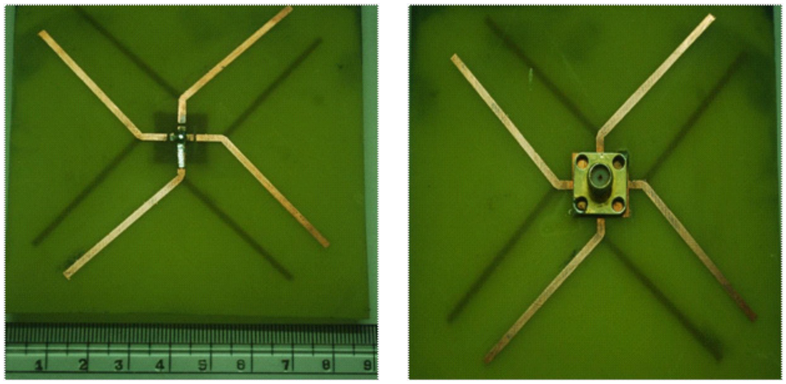

**Figure 5.** Simulated current density at the resonant frequency.

The software, ANSYS HFSS 17.1 is used to simulate the design of antenna. The final optimized dimensions of the antenna are $L_1 = 32$ mm, $W = 1.53$ mm, and $FL = 5$ mm. The current density of the antenna at the centre frequency obtained during simulation is shown in Figure 5.

## 3. RESULTS AND DISCUSSION

Based on the design values, the prototype of the pattern reconfigurable antenna is fabricated, and photographs of the antenna are shown in Figure 6. The overall size of the antenna is 90 mm × 90 mm. The return loss for the antenna is shown in Figure 7. The resonant frequency of the fabricated antenna is noted as 5.49 GHz. The deviation of the measured return loss from that of simulated result can be attributed to the fabrication errors as well as the conductive metal strips used in place of switches. The pattern reconfigurable feature of the antenna is validated as per Table 1, and the switching patterns obtained are plotted in Figure 8.

The normalized radiation patterns obtained during simulation (5.3 GHz) and measurement




(a) (b)

**Figure 6.** Photographs of the fabricated antenna, (a) front view, (b) rear view.

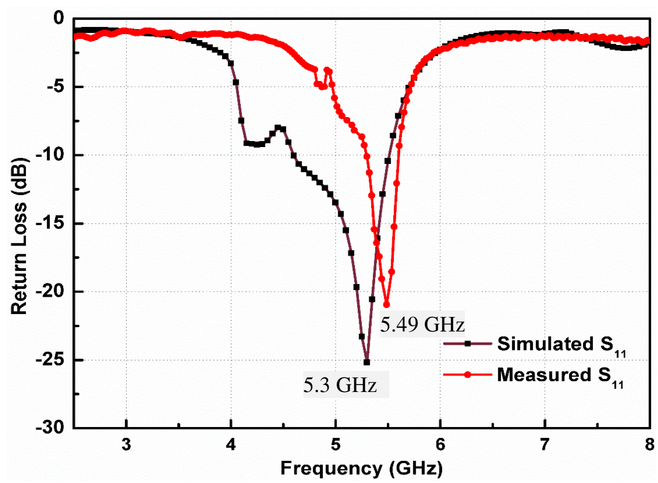



**Figure 7.** Return loss of the antenna.

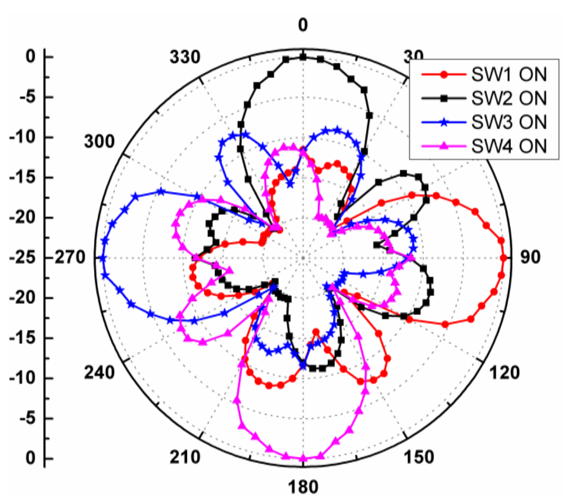



**Figure 8.** Measured radiation pattern for different switch combinations.

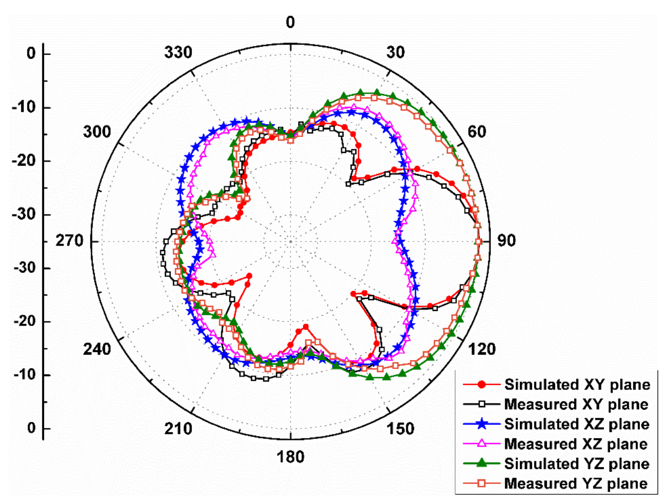


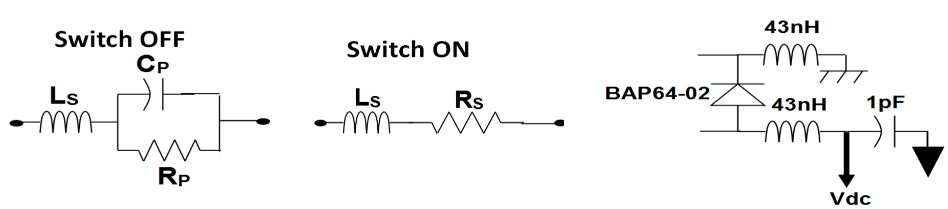

**Figure 9.** Measured and simulated radiation patterns.

(5.49 GHz) are compared in Figure 9, and it shows only minor variations in the results. The cross polarization can be reduced by isolating the dipole arms on the rear side and also by incorporating four more switches on the rear parallel strips. The measured peak gain of the antenna is 7.5 dBi as compared to the value of 8.02 dBi for simulation. The simulated directivity is 8.7 dBi, and efficiency is 92%. The 3 dB beamwidth of the antenna is measured the same as that of simulation, with a value of 30°. Comparison of the proposed antenna with some of the already reported reconfigurable antennas is given in Table 2. It is noted that [7] and [12] offer size advantage over the proposed antenna, but limited by radiation beam direction around the boresight and comparatively lower gain.

**Table 2.** Comparison of proposed antenna with already reported antennas.

| Ref. | Freq (GHz) | No. of switches | Size | Gain (dBi) |
|---|---|---|---|---|
| [7] | 5.8 | 2 | $1.47\lambda_0 \times 0.62\lambda_0 \times 0.03\lambda_0$ | 4.9, 6.5 |
| [8] | 2.4–2.5 | 12 | $0.8\lambda_0 \times 0.74\lambda_0 \times 0.1\lambda_0$ | 6.5 |
| [11] | 5.2 | 12 | $1.9\lambda_0 \times 1.21\lambda_0 \times 0.02\lambda_0$ | 7.6–10 |
| [12] | 2.4 | 4 | $0.8\lambda_0 \times 0.8\lambda_0 \times 0.05\lambda_0$ | 5 |
| [13] | 2.5 | 4 | $1.0\lambda_0 \times 1.0\lambda_0 \times 0.25\lambda_0$ | 5.08 |
| [16] | 3.1–10.6 | 4 | $2.47\lambda_0 \times 1.1\lambda_0 \times 0.03\lambda_0$ | – |
| **This Work** | **5.49** | **4** | $1.65\lambda_0 \times 1.65\lambda_0 \times 0.01\lambda_0$ | 7.5 |

The switching scheme for the measurement used conducting strips which can be replaced by PIN diodes to implement an electrically reconfigurable antenna. To validate the use of PIN diode for the switching scheme, simulation is carried out by incorporating the equivalent circuit model of PIN diode BAP64-02. Figure 10(a) shows the equivalent circuits for the switch OFF and ON conditions. The equivalent circuit is modeled in HFSS by a series connection of two RLC boundaries with values of $L_S = 0.6\,\mathrm{nH}$, $R_S = 2\,\Omega$, and $C_P = 0.23\,\mathrm{pF}$. The results of the simulation show a frequency shift in the resonant frequency and feed line length, and $FL$ is re-optimized to obtain the centre frequency of 5.25 GHz. The bias circuitry proposed for the PIN diode is given in Figure 10(b). The use of SMT components enables the placement of bias circuitry within the limited space available.




(a) (b)

**Figure 10.** PIN diode. (a) Equivalent circuit. (b) Bias circuitry.

## 4. CONCLUSION

A pattern reconfigurable antenna based on printed Vee dipoles is presented in this paper. The antenna is designed to have the centre frequency at 5.3 GHz. The peak gain obtained by the antenna is noted as 7.5 dBi. The measured radiation pattern with the four combinations of switches validates the pattern reconfigurability achieved with this antenna. The conductive strips used in the analysis can be replaced by PIN diodes to enable the antenna to be electrically controllable for remote operation. This antenna with highly planar and simple design methodology can be easily integrated into any pattern reconfigurable communication system.

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