# DESIGN OF A RADIATION PATTERN RECONFIGURABLE ANTENNA FOR ELECTRONIC TOLL COLLECTION IN INTELLIGENT TRANSPORT SYSTEM

## THIẾT KẾ MỘT ANTEN TÁI CẤU HÌNH THEO ĐỒ THỊ BỨC XẠ ỨNG DỤNG CHO THU PHÍ ĐIỆN TỬ TRONG HỆ THỐNG GIAO THÔNG THÔNG MINH

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**Abstract:**

In this paper, we propose a radiation pattern reconfigurable microstrip dipole antenna for Electronic Toll Collection (ETC) in Intelligent Transport System (ITS). The antenna consists of five dipoles connected or disconnected by five pin diodes on the top side of substrate. Based on the switching state of the PIN diodes, the radiation pattern of the proposed antenna can be reconfigured into three modes. In these three modes, the antenna maintain a resonant frequency of 5.8 GHz. The antenna obtains a high gain thanks to a surface reflective structure integrated under the substrate of antenna. The proposed antenna is designed on FR4 substrate with the relative permittivity of 4.4, the thickness of 1.6 mm, and the loss tangent of 0.02 and it is simulated and optimized using combination of Computer Simulation Technology (CST) microwave and CST design software.

**Keyword:**

Pattern reconfigurable antenna, PIN diode, dipole element, ITS, ETC.

**Tóm tắt:**

Trong bài báo này, chúng tôi đề xuất một cấu trúc anten tái cấu hình theo tần số dựa trên anten dipole ứng dụng cho thu phí điện tử trong hệ thống giao thông thông minh. Anten bao gồm 5 dipole đặt trên mặt điện môi được nối hoặc ngắt với nhau bằng các PIN diode. Anten có thể được tái cấu hình để hoạt động theo 3 chế độ khác nhau tạo ra 3 đồ thị bức xạ có hướng khác nhau bằng cách điều khiển trạng thái của PIN diode. Ở cả 3 chế độ, anten đều hoạt động ở tần số 5.8 GHx. Hệ số tăng ích anten đạt được cao nhờ sử dụng cấu trúc mặt phản xạ được đặt dưới tấm điện môi. Anten đề xuất được thiết kế trên tấm điện môi FR4 với các thông số như sau: hằng số điện môi là 4.4, chiều dày lớp điện môi là 1.6 mm và hệ số suy hao là 0.02. Anten được môi phỏng và tối ưu trên phần mềm kết hợp CST microwave và CST design.

**Từ khóa:**

Anten tái cấu hình, tái cấu hình đồ thị bức xạ, PIN diode, ITS, ETC.

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## 1. INTRODUCTION

With the rapid development of wireless communication, pattern reconfigurable antenna has received a considerable amount of attention in recent years. Pattern reconfigurable antenna is known as an antenna that's radiation characteristic can adapt with changing system requirements or environmental conditions [1]. A pattern reconfigurable antenna can provide different radiation patterns, so it can replace a number of traditional single antennas in system [2]. Therefore, compared with traditional antennas, the advantages of reconfigurable antennas are multifunction, flexibility, and help to reduce cost and overall size of system [3]. Furthermore, because of adjustable radiation patterns, reconfigurable antenna can be directed toward the access point, so it can save power for transmission and reduce noise [4].

So far, there is a lot of researches on radiation pattern reconfigurable antennas with different techniques, in which PIN diode is used popularly. In [5], radiation pattern of a compact planar antenna can be switched from different directions using PIN diodes, whereas in [6], it can steered between bidirectional and unidirectional. In [7, 8], the proposed antennas can switch between omnidirectional pattern and directional pattern by controlling PIN diodes. Another radiation pattern reconfigurable antenna using PIN diode is proposed in [9] can select between two beam directions. However, the bandwidth of this antenna is narrow. A planar printed dipole antenna with reconfigurable pattern properties in [10] is able to archive two opposite directions by switching four PIN diodes. This antenna has high gain, but increase in the overall antenna dimensions.

In this paper, we propose a radiation pattern reconfigurable antenna based on printed dipole structure which can operate at 5.8 GHz band for Electric Toll Collection (ETC) in Intelligent Transport System (ITS). This antenna includes five elements connected or disconnected by PIN diodes. A conventional surface reflective structure is applied under the ground of the antenna for gain enhancement.

By switching these diodes, the antenna can operate at three configurations with beam-steering angles of $-60^\circ$, $0^\circ$ and $+60^\circ$ without change in resonant frequency. The bandwidths in any configurations achieve about 200MHz which is suitable for ETC applications. Overall dimension of the antenna is $40 \times 60 \times 13$ $mm^3$. The antenna archives gain above 5.37 dBi in three configurations.

The remainder of the paper is organized as follows. Section 2 describes the antenna design. Section 3 presents simulation and measurement results with some discussion. Finally, the conclusion of the paper is given in Section 4.

## 2. ANTENNA DESIGN

The structure of the proposed antenna is given in figure 1. The antenna includes the main radiation part and the reflector.

The main radiation part of the antenna looks like an array of five printed dipoles with each dipole placed on front side and back side of the substrate. These dipoles are fed via a central transmission line. The transmission line with two microstrip lines are designed on the opposite sides of a dielectric substrate. The reflector is a full copper surface which is used for gain enhencement. The antenna achieves the best simulated gain when the distance from the substrate to the copper is 13 mm. The substrate of antenna has the thickness h=1.6 mm, the relative permittivity $\varepsilon_r$=4.4 and the loss tangent $\delta$ = 0.02. The overall size of antenna is 40 mm × 60 mm × 13 mm.

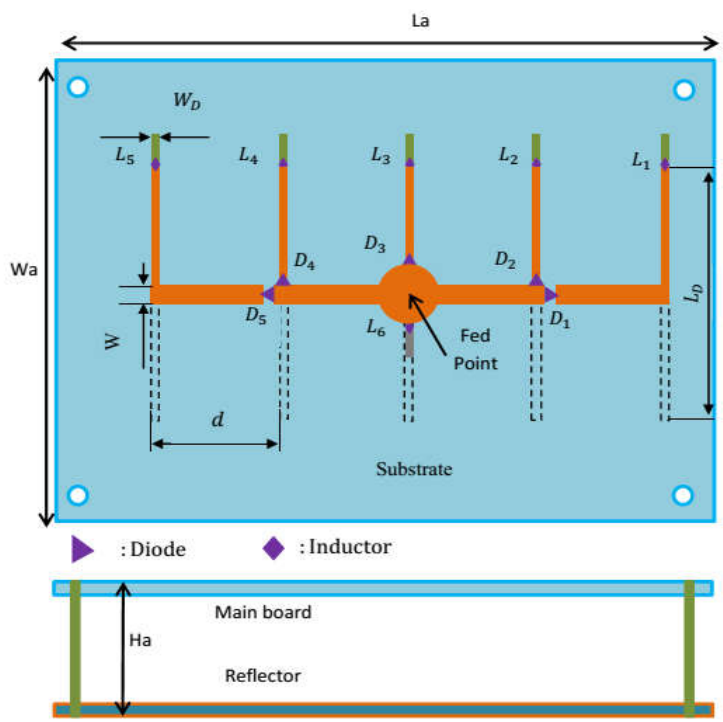



**Figure 1. Antenna structure: dark lines on the front side of the dielectric substrate, transparent ones on the back (front view and side view)**

The width of the transmission line is chosen to ensure the input impedance at fed point to be 50 Ω. Because the feeding line is on two side of the substrate, it is equivalent to two 25 Ω microstrip lines with the width of $W$ and the substrate thickness of $h/2$. We can calculate the width of transmission line from the equation (1) [11].

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_e}\left[\frac{W}{h}+1.393+0.667\ln\left(\frac{W}{h}+1.444\right)\right]} \quad (1)$$

where $Z_0$ is impedance of the transmission line (25 Ω), $\varepsilon_e$ is effective permittivity of transmission line given approximately by:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}} \qquad (2)$$

The length of a single dipole for a designed resonant frequency $f_r$ is:

$$L_D = \frac{c}{2 f_r \sqrt{\varepsilon_e}} \qquad (3)$$

where c is the speed of light in free-space.

Now, we compute the width $W_d$ of the dipole. We select the dipole characteristic impedance of 50 Ω to match to transmission line. To achieve the characteristic impedance $Z_{in}$ = 50 Ω, the radius of the cylindrical dipole is computed by the equation (4) [12]:

$$Z_{in} = 120\left[\ln\left(\frac{L_D}{a_D}\right) - 2.25\right] \qquad (4)$$

where $a_D$ is the radius of the cylindrical dipole, $L_D$ is the length of the dipole. For printed dipole, its width $W_d$ is calculated [13]:

$$W_d = \pi a_D \qquad (5)$$

Also, the distances between the elements are selected so that two operating dipoles are distanced $\lambda_e/2$ in each operating state, which is detailed below. .

Based on initial dimensions, the antenna is optimized again by CST simulation software. The dimensions of the proposed antenna are shown in table 1.

In oder to achive radiation parttern reconfiguation, PIN diode switchings are used. PIN diodes are controlled to ON or OFF to achieve different radiation patterns with the same frequency of 5.8 GHz at all states. Inductors are used to isolate AC current from the DC bias line system which is used to control PIN diodes. Five SMP1345 PIN diodes are used to obtain three operating states. These PIN diodes can operate within a frequency range from 10 MHz to 6 GHz and have equivalent circuit depicted in figure 2. The operations of the PIN diodes at three states are given in table 2. In each state, only two dipoles distanced $\lambda_e/4$ operate. It means that the distance of the two operating dipoles in three states is the same while the difference in phase excitation between the ones are different, which helps to adjust the total radiation field of the antenna. These phase differences in state S1, S2, S3 are 0, $\pi/2$; $-\pi/2$. The electrically equivalent shapes of the antenna at different configurations are given in figure 3.

**Table 1. Dimensions of the proposed antenna (mm)**

| Ld | Wd | W | D | Wa | La | Ha |
|---|---|---|---|---|---|---|
| 16.6 | 1 | 3 | 8.8 | 40 | 60 | 13 |

**Table 2. Operation of PIN diodes**

| State | D1 | D2 | D3 | D4 | D5 |
|---|---|---|---|---|---|
| S1 | OFF | ON | OFF | ON | OFF |
| S2 | ON | OFF | ON | OFF | OFF |
| S3 | OFF | OFF | ON | OFF | ON |

In the state S1, diode D2 and D4 are ON, the remaining diodes are OFF. Therefore, only element L2 and L4 are connected to transmission line. The antenna is in a symmetric topology. The phases of the waves which are fed to the two main radiating elements are the same, thus the main lobe is perpendicular to the antenna plane.

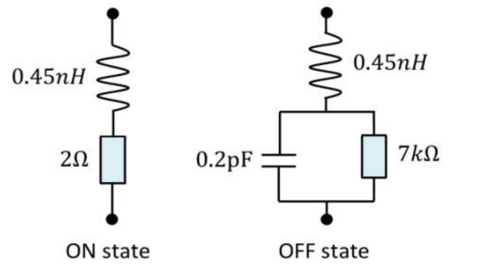
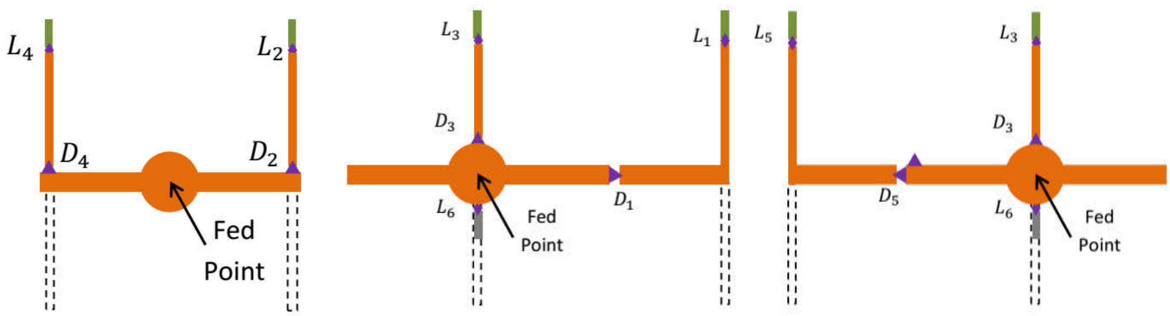



**Figure 2. Equivalent circuit of PIN diode SMP1345**

In the state S2, diode D1 and D3 are ON, the remaining are OFF, elements L1 and L3 are connected to the transmission line. The phase of the wave fed to element L3 is π/2 earlier than that to L1. Therefore the main lope is skewed towards the element L1.




(a) State 1 (b) State 2 (c) State 3

**Figure 3. Equivalent configurations in three states**

The state S3 is similar to the state S2 but the radiation pattern reconfigured to other direction. In this state, diode D1 and D3 are ON and the remaining are OFF. The operating elements are L1 and L5. The main lope is toward the element L5.

## 3. RESULTS AND DISCUSSION

This section presents the simulation and measurement results of S11 parameter as well as the simulation radiation pattern. The S11 parameter and the radiation properties of the proposed antenna are simulated by the combination of CST Microwave and CST design software.

Simulation results of S11 parameter are shown in figure 4. It can be seen clearly that all configurations produce the same resonance frequency of 5.8 GHz with -10 dB bandwidths about 200 MHz. This bandwidth is very suitable for ETC applications.

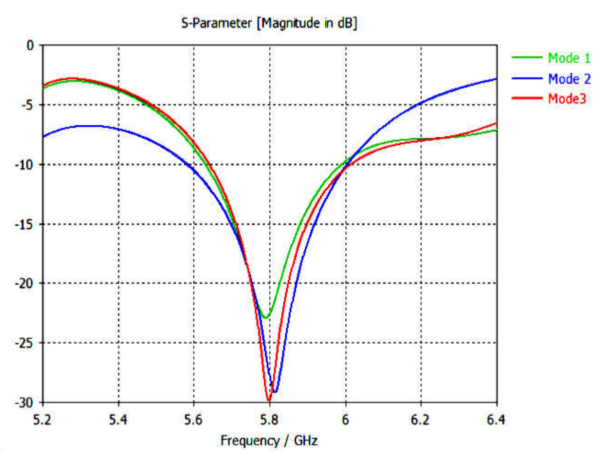



**Figure 4. Simulation results of S11 parameter in all states of the proposed antenna**

The simulation radiation patterns of the antenna with different configurations are plotted in figure 5 and figure 6. By switching diodes, the pattern characteristic is reconfigured between three different directions. The axis of the maximum gain is shifted at an angle of $60^o$ degrees when changing the configuration of the antenna. The simulation gains in state S1, S2, S3 are 5.37, 6.34, and 6.09 dBi respectively.

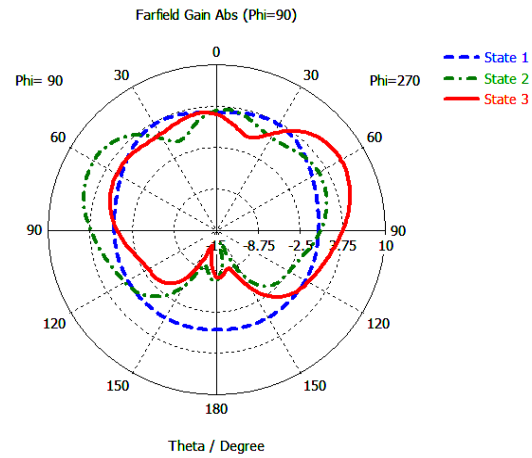
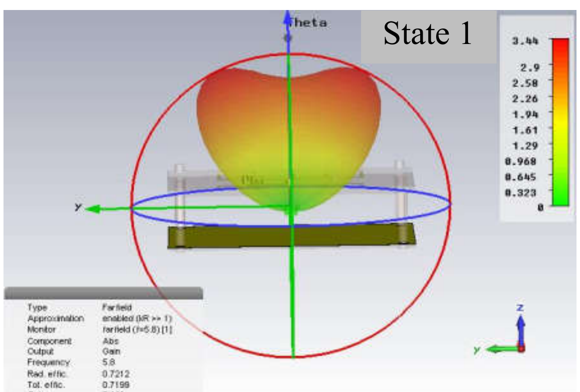
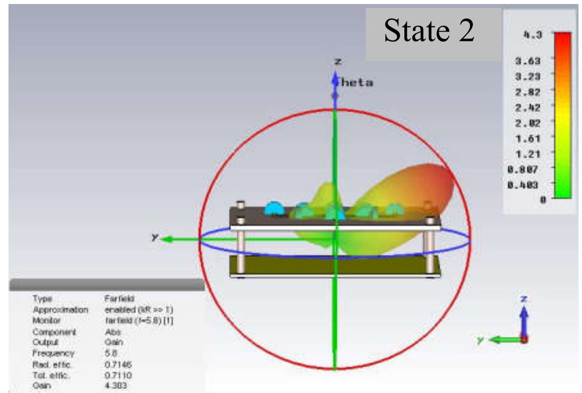



**Figure 5. Simulation results of 2D radiation pattern in all states of the antenna**



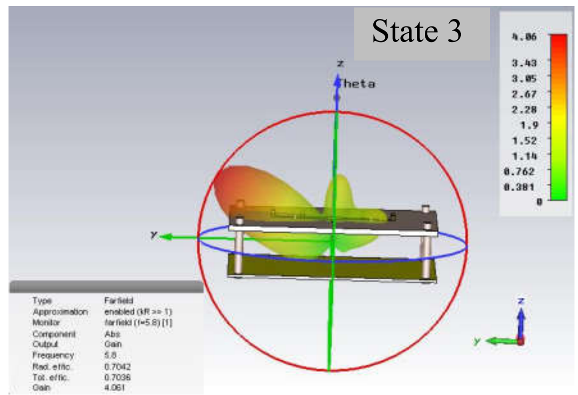




**Figure 6. Simulation results of 3D linear radiation pattern in all states of the proposed antenna**

Table 3 summarizes all simulation results of the proposed antenna, including the resonance frequency, the bandwidth, the beam-steering angles, the 3dB angular width as well as the maximum gain in each state.

**Table 3. Summary of simulation results in all states of the proposed antenna.**

| State | Resonance Frequency (GHz) | Bandwidth (MHz) | Beam-steering angles (degree) | Angular width (3dB) (degree) | Peak Gain (dBi) |
|---|---|---|---|---|---|
| S1 | 5.8 | 195 | 0 | 103 | 5.37 |
| S2 | 5.8 | 200 | 60 | 58.2 | 6.34 |
| S3 | 5.8 | 195 | -60 | 58.1 | 6.09 |

## 4. CONCLUSION

This paper presents a novel radiation pattern reconfigurable dipole antenna using PIN diode for Electric Toll

Collection in Intelligent Transport System. By switching diodes placed on radiation elements, the antenna archives three different radiation patterns while maintaining the resonance frequency of 5.8 GHz with the bandwidth about 200MHZ at three configurations which is very suitable for ETC application. The peak gain of antenna in three configurations is in turn 5.37, 6.34, and 6.09 dBi. The antenna is a suitable candidate for smart radio in the future. With this approach, we are able to design radiation pattern reconfigurable antenna operating in desired frequencies for difference applications. The proposed antenna is designed on FR4 and simulated and optimized by the combination of CST microwave and CST design software. Because of lack of anechoic chamber, the antenna radiation pattern has not been measured yet. In the future, we will do measurements in radiation pattern to confirm with the simulation results.

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