Optimization of A Beam Reconfigurable Antenna using PIN Diodes

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Abstract

In this article, two types of the beam reconfigurable antenna are designed and their performances are analyzed. The operation mechanisms of the antennas and their optimization processes using PIN diodes are introduced. Both of them are designed to operate over DCS 1800 and PCS 1900 frequency bands. The electrical shapes of the proposed antennas are symmetric about vertical center axis. The proposed antennas alternate their beam directions with essentially no input impedance difference. The equivalent linear circuit models of the PIN diode are illustrated, corresponding to on and off states. The simulated and measured results show that the proposed antennas can clearly change their radiation patterns by controlling the switching state.

Keywords : Antennas Reconfigurable antenna Radiation pattern

1. Introduction

In recent wireless communication applications, antennas may be required to have diverse radiation patterns. Combining several single antenna elements in an array can be a feasible solution to this requirement [1]. The radiation patterns of the array can be changed by modifying the so called array factor [2]. However, in an antenna array, mutual coupling effect between antenna elements can limit the performance of pattern diversity [3]. The element spacing can be increased to reduce coupling. However, it can allow unwanted grating lobes to occur and may exceed the practical aperture size limitations, resulting in being unsuitable in some applications.

One effective structure to overcome this limit is a reconfigurable antenna. In this article, two types of radiation pattern-reconfigurable antenna that can symmetrically change their beam directions are proposed. The proposed antennas are designed to operate over DCS 1800 and PCS 1900 bands. The electrical shapes of both types consist of a monopole-loaded loop and an open wire, which serves as a director or reflector for both cases. Optimization processes of both antennas using PIN diodes are then carried out. For optimization, equivalent linear circuit models of the PIN diodes are used. Depending on the switching state, both the two antennas can choose one between two symmetric radiation patterns with essentially no input impedance difference. The simulated and measured results are in good agreement, representing clear pattern reconfigurability.

2. Antenna Structure

Figure 1(a) shows the fundamental structure of the proposed antennas. Two switches are present on the top and bottom ends of the loop (four in total), being thrown on the same side. Thus, for both switching states, the electrical shape of the antenna flips about the center axis. In this case, the open wire changes the antenna directivity. Note that the electrical shape of the antenna does not essentially change in both switching states. Therefore, the input impedance remains constant irrespective of the switching state, which may be critically required in a beam reconfigurable antenna.

Figure 1(b) presents the two types of proposed antennas. The first type's vertical center conductor exceeds the length of the loop. This leads to the open wire to serve as a director [4]. In the case of the second type, the lengths of the loop edge of both sides are extended, which enables the open wire to operate as a reflector. Commonly for both types, the lower half of the antenna is replaced with a ground for both the radio frequency (RF) and DC signals using the image theory. This reduces the size of the antenna structure, removing the need for a balun. The antenna is printed on a 0.8 mm-thick FR-4 (ε_r = 4.6) substrate, and the copper-clad portion of the printed circuit board is 30 mm × 44 mm. As switching elements, PIN diodes are used. Since the PIN diodes are not ideal switching devices, the equivalent linear circuit models are developed. Then, the sizes of the proposed antennas are respectively optimized. The PIN diode used in this article is Microsemi MPP4203 [5]. Figure 2 (a) shows the equivalent linear circuit model of the PIN diode for on and off states. The model is obtained empirically by modifying the parameters from the datasheet.

3. Optimization

Based on the equivalent linear circuit model shown in Figure 2 (a), a series of simulations are performed using Ansoft HFSS software. Figure 2 (b) shows the schematic connection diagrams of the PIN diodes in the proposed antennas. The lines depict the electrical paths, and V_c and v_s are the DC switch control voltage and the RF signal, respectively. The DC control voltage is acquired using a 1.5 V battery. By changing the direction of the battery, V_c can be either +1.5 V or -1.5 V. In order to keep the DC signal from flowing into the RF measurement system, the RF signal v_s is connected through a DC block, which is omitted in the figure.

3.1 Type 1 (Director-type Antenna)

Figures 3 show the gains and bandwidths of the director-type antenna as functions of the antenna width and the monopole length-to-loop length ratio ($R = L_{monopole}/L_{loop}$). In all simulations, the sizes of the antenna are determined such that the antenna is matched to a 50 Ω feed line at 1.9 GHz. In the Figure 3 (a), the gain increases as the antenna width or 1/R decreases. Likewise, as shown in the Figure 3 (b), the bandwidth represents the similar tendency with the gain. In this paper, the size of the antenna is chosen to have the highest gain-bandwidth product value, while showing a front-to-back ratio of more than 6 dB. Consequently, the antenna width is determined to be 14 mm with an R of 2.2, with 1.01 dB, 251 MHz (1.735~1.986 GHz), and 7.23 dB being the gain, bandwidth, and front-to-back ratio, respectively.

3.2 Type 2 (Reflector-type Antenna)

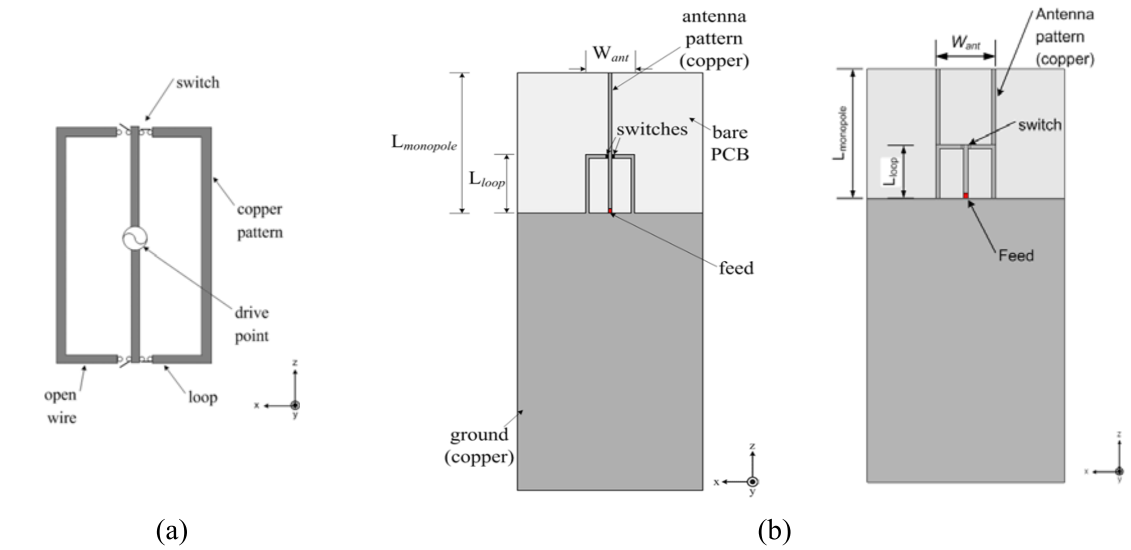
Figures 4 show the gains and bandwidths of the reflector-type antenna as functions of the antenna width and R. In the Figure 4 (a), the gain increases as the antenna width or 1/R decrease. On the other hand, the bandwidth increases as the antenna width and R increase. In this paper, the size of the antenna is chosen to have the highest gain-bandwidth product value. Consequently, the antenna width is decided to be 19.5 mm with an R of 2.6, with 0.903 dB, 234 MHz (1.825~2.059 GHz), and more than 10 dB being the gain, bandwidth, and front-to-back ratio, respectively.

4. Simulation and Measurement

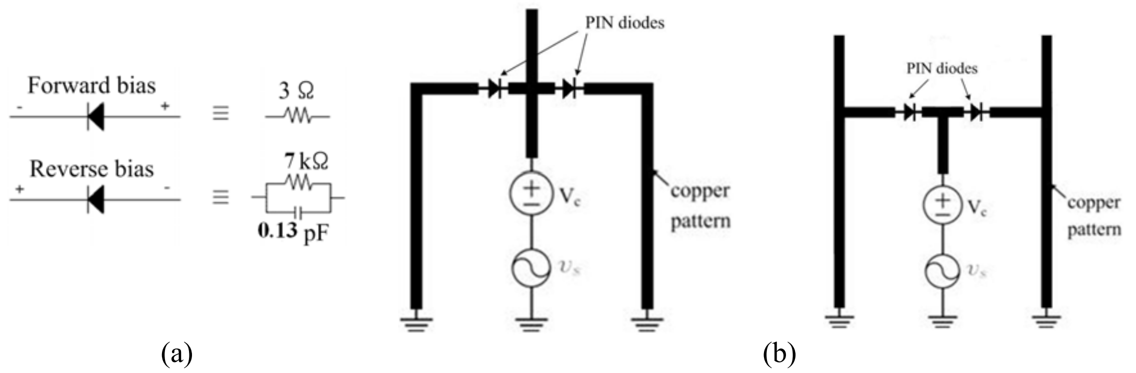
Figure 5 (a) shows the simulated and measured return losses of the optimized director-type antenna for the PIN diodes over a frequency range of 1.5 to 2.5 GHz. In a forward bias condition, the left switch is opened, corresponding to a beam directive in $\phi = 0^o$. The measured 6 dB bandwidths are 289 MHz (1.721~2.01 GHz) and 244 MHz (1.755~1.999 GHz) for forward and reverse bias conditions, respectively. Figure 5 (b) and (c) show the θ–polarized gain patterns of the optimized director-type antenna for the PIN diodes observed at 1.9 GHz. The measured antenna gains are -0.23 dB and -0.07 dB for forward and reverse bias conditions, respectively. Measured gains are approximately 1 dB less than the simulated gain. This is believed to be due to the losses in the biasing devices and measurement error. The measured front-to-back ratios are 7.68 dB and 5.27 dB for forward and reverse bias conditions, respectively.

Figure 6 (a) shows the simulated and measured return losses of the optimized reflector-type antenna for the PIN diodes over a frequency range of 1.5 to 2.5 GHz. In a forward bias condition, the left switch is opened, leading to a beam directive in $\phi = 90^o$. The measured 6 dB bandwidths are

168 MHz (1.855~2.023 GHz) and 185 MHz (1.833~2.019 GHz) for forward and reverse bias conditions, respectively. Figure 6 (b) and (c) show the θ–polarized gain patterns are 0.29 dB and -0.35 dB for forward and reverse bias conditions, respectively. Moreover, the measured front-to-back ratios are 8.44 dB and 6.34 dB for forward and reverse bias conditions, respectively. All the measured gain patterns show a front-to-back ratio of more than 5 dB, indicating apparent radiation pattern-reconfigurability.



Figures 1: Proposed antenna structures (a) Fundamental structure of the proposed antennas and (b) Two types of the proposed antennas, director-type and reflector-type.

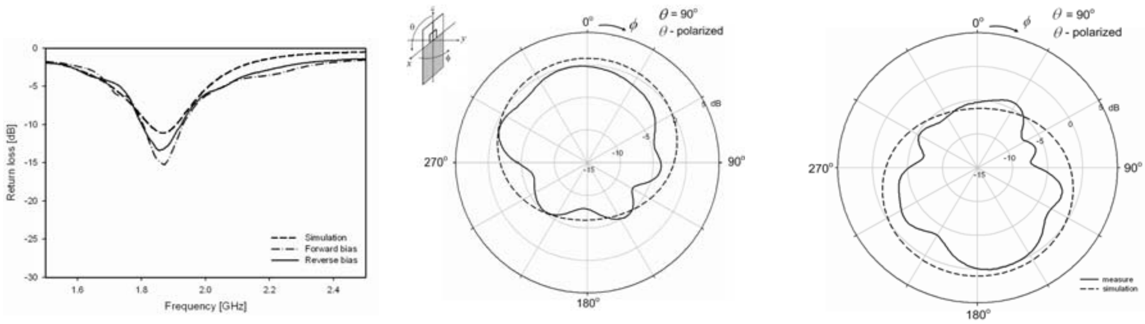


Figures 2: (a) Equivalent linear circuit model of the PIN diode (b) Connection diagrams of the PIN diodes in the two types of proposed antennas.

Figures 3: Variations of the director-type antenna: (a) Gain, (b) Bandwidths for the antenna width and the monopole length-to-loop length ratio.

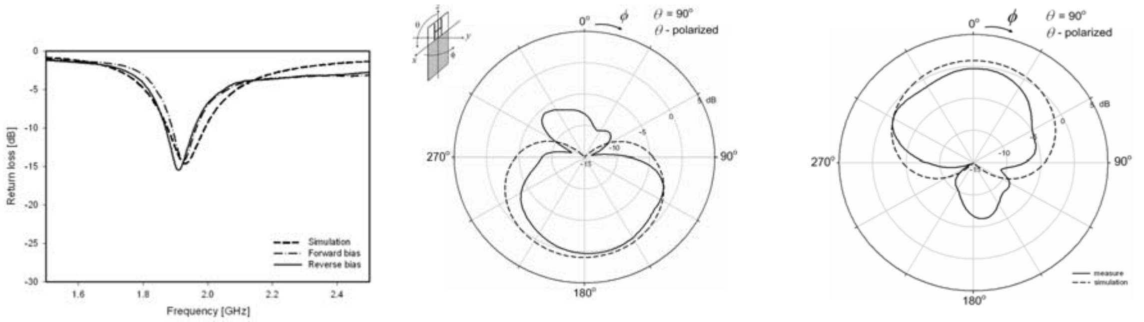
(a) (b)

Figures 4: Variations of the reflector-type antenna: (a) Gain, (b)Bandwidths for the antenna width and the monopole length-to-loop length ratio.



(a) (b) (c)

Figures 5: Simulated and measured results of the proposed director-type antenna. (a) Return losses, (b) θ-polarized gain patterns (forward bias), and (c) θ-polarized gain patterns (reverse bias).



(a) (b) (c)

Figures 6: Simulated and measured results of the proposed reflector-type antenna. (a) Return losses, (b) θ- polarized gain patterns (forward bias), and (c) θ-polarized gain patterns (reverse bias).

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Acknowledgments

This work was supported by Defense Acquisition Program Administration and Agency for Defense Development under the contact UD100005ID.