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HIGH GAIN LINEAR POLARIZATION SWITCHABLE PLANAR ARRAY ANTENNA

M. A. Hossain*, **E. Nishiyama, I. Toyoda, and M. Aikawa**

Department of Electrical and Electronic Engineering, Saga University, 1 Honjo-machi, Saga-shi, Saga 840-8502, Japan

Abstract—In this paper, a linear polarization switchable planar array antenna with enhanced gain and better crosspolarization is proposed. The proposed array antenna consists of a fed patch and four parasitic patches. Four switching diodes are loaded on the corners of the fed patch. The boundary condition of the fed patch is controlled by using the ON/OFF condition of the diodes, and the polarization angle of the array antenna can be orthogonally switched to $\pm 45^\circ$ with better than -22 dB of crosspolarization. The simulated gain of the array antenna is remarkably increased to 12 dBi by using four parasitic patches surrounding the fed patch. For matching the resonance frequency of the parasitic patches with the fed patch, a square slot is formed at the center of each parasitic patch. The characteristics of the proposed array antenna are investigated by the FDTD simulation method. The array antenna is fabricated and the experiment is carried out. Both the simulation and the experimental results of the proposed array antenna demonstrate the polarization switching functionality successfully with the enhanced gain in S-band.

1. INTRODUCTION

Recently, the planar antenna technologies have been advancing due to the increasing demands for various wireless applications in the ubiquitous society. The advantages of the planar antenna over the other antennas such as dipole, loop etc. are low cost, low profile and easy to integrate with active components [1, 2]. In these regards, reconfigurable planar antennas have attracted much more attention recently because of their versatility in various wireless systems in terms of frequency controllability and polarization diversity [3, 4].

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* Corresponding author: Md. Azad Hossain (azad@ceng.ec.saga-u.ac.jp).

This research is focused on the orthogonal polarization reconfigurability along with both the gain enhancement of the antenna and better crosspolarization. The main features of the proposed array antenna are, single feed excitation, four parasitic patches for gain enhancement and four switching diodes on the fed patch for $\pm 45°$ linear polarization switching. A square slot is introduced on each parasitic elements in order to improve the crosspolarization performance. The orthogonal transmission and reception of the conventional antennas are generally fixed. If the polarization switching is possible, the design flexibility of the wireless systems will be much more expanded [4]. There are many reports on the reconfigurable antennas with polarization agility [5–10]. The antennas with dual polarization characteristic have also been reported [11–13]. Moreover, the gain enhancement researches have also been reported [14–19]. Therefore, there are many reports for dual polarization or gain enhancement individually.

The authors have reported on the orthogonal linear polarization switching using the planar antenna [20, 21]. For the paper [20], there is a cross-slot on the patch element and the star coupled diodes are loaded at the center of the cross-slot. Using the ON/OFF condition of the diodes, the polarization angle can be switched to $\pm 45°$. And for the paper [21], four switching diodes are loaded on the corners of the fed patch and four parasitic patches are arranged around the fed patch. The fed patch is exited by the single feed point and the parasitic patches are exited by the electromagnetic coupling. The distinct advantage of the parasitic array structure compared with the conventional array antennas is the absence of feed circuit, i.e., the parasitic array antenna is very simple structure. For the paper [21], in order to match the resonant frequency of the fed patch and the parasitic patches, the size of the parasitic patches are increased. As a result, the simulated gain of the array antenna is remarkably increased to 12 dBi, but the crosspolarization was at the best -16 dB. The main reason is that, the corners of the parasitic patches become so closed to each other that it deteriorates the array crosspolarization performance. In this paper, in order to solve the issue of the crosspolarization, a square slot is introduced on each parasitic patches to keep the parasitic patches same size with the fed patch. The performance of the array antenna is analyzed by the variation of the slot size and the gap between the fed patch and the parasitic patches. The behaviors of the proposed antenna are analyzed by the Finite Difference Time Domain (FDTD) method. The series resistance of the forward biased diode and the junction capacitance of the reverse biased diodes have been taken into account for the simulation. The experimental results have a very good agreement with the simulation results. The proposed array

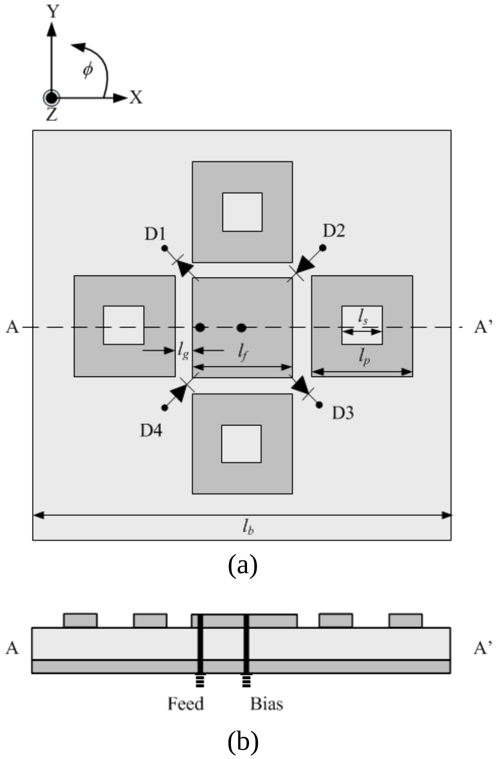

Figure 1. Structure of the proposed array antenna. (a) Top view. (b) Cross-section View.

antenna can be very useful for the polarimetric radar/sensors and as the polarization diversity antennas.

2. POLARIZATION SWITCHABLE ARRAY ANTENNA

2.1. Structure and Basic Behavior

The structure of the proposed array antenna is shown in Fig. 1. In order to enhance the gain, parasitic patch array structure is effectively applied. The antenna consists of a fed patch including four diodes at the corners and four parasitic patches. Both side length l_f, l_p of the fed patch and parasitic patches are 24 mm for the design frequency of 3.93 GHz. The ground plane size l_b is 100 mm. The four parasitic elements are arranged around the fed patch for gain enhancement. The parasitic patches are excited by mutual coupling with the fed patch. The gain and the radiation performance of the proposed array antenna depend strongly on the mutual coupling.

The basic behavior of the array antenna is shown in Fig. 2. When the positive bias voltage is applied to the fed patch, the diodes D1 and D3 become ON (short) state due to the forward bias condition and diodes D2 and D4 remain OFF (open) state due to the reverse bias condition. As a result, surface current of the array antenna is excited as shown in Fig. 2(a). And the polarization angle ϕ is tilted to $+45^\circ$. When a negative bias voltage is applied, the main polarization angle ϕ of -45° is obtained as shown in Fig. 2(b). Therefore, by changing the polarity of the bias voltage, the proposed array antenna can switch and radiate the orthogonal linear polarizations. The resonant frequency of the fed patch is lower than that of the parasitic elements mainly due to the capacitance of the OFF state diodes. In order to match the resonant frequency of the fed patch and the parasitic

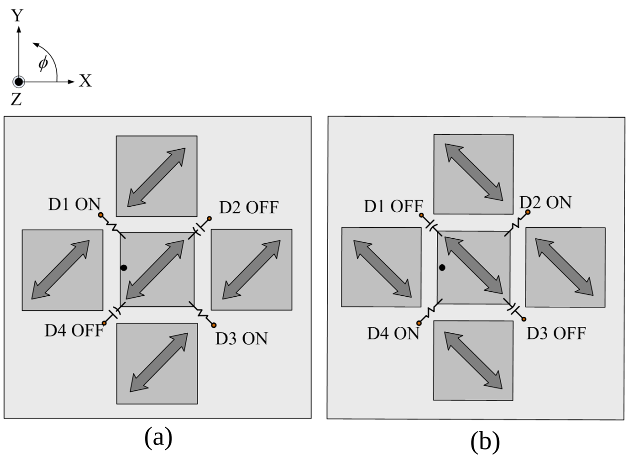

Figure 2. Basic behavior of the orthogonal linear polarizations. (a) Positive bias. (b) Negative bias.

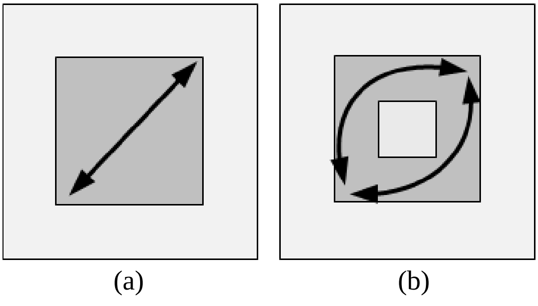

Figure 3. The current path of patch containing slot. (a) Without slot. (b) With slot.

patches, the parasitic patches were made larger in our previous work [21]. In this case, the corners of the parasitic patches comes very near to each other and there induces an electromagnetic coupling between the parasitic patches. For this reason, the experimental result for the crosspolarization was only −16 dB. In order to overcome this issue, a square slot is formed on each parasitic patch. The advantage of introducing slot on the patch element is the reduced resonance frequency without increasing the size of the parasitic patch elements [22], which can be understood by Fig. 3. The surface current path of structure (b) is longer than structure (a) due to the presence of the slot on the patch. Therefore the resonant frequency of (b) is lower than (a) for the same size patch.

2.2. Analysis of the Array Antenna

The FDTD method introduced by Yee [23] is used for the simulation for the array antenna. Berenger's perfectly matched layer (PML) with 10 cells is applied as the absorbing boundary condition. The space steps used in the FDTD simulation are $\Delta X = 0.4\,\mathrm{mm}$, $\Delta Y = 0.4\,\mathrm{mm}$ and $\Delta Z = 0.8\,\mathrm{mm}$ respectively. The time step is $\Delta t = 0.88\,\mathrm{ps}$ for the selected computational domain of $309\,\Delta\,X \times 309\,\Delta\,Y \times 41\,\Delta\,Z$. The silicon Schottky barrier diodes were used for fabricating the array antenna. For simulation, the diodes are replaced by series resistance R_s of $3\,\Omega$ for forward bias condition and junction capacitance C_j of 0.22 pF for reverse bias condition according to the data sheet provided by the manufacturer. The resonance condition and the whole performance of the proposed array antenna changes mainly with two factors; one is the gap l_g between the fed patch and the parasitic patches, which changes the mutual coupling. The second one is the square slot size l_s on the parasitic patches. In this paper, the characteristics of the array antenna vs both the gap l_g and slot size l_s are investigated.

First, the slot size is decided by analyzing the single parasitic element. In this case, the slot size l_s is achieved at 6.4 mm for the

Table 1. Characteristics of the array antenna vs the gap l_g, where l_s is 6.4 mm.

Gap (l_g) (mm)	Impedance matched freq. (GHz)	Gain (dBi)	Pol. Angle ϕ (deg.)
0.4	3.98	12.0	44
0.8	3.93	12.0	45
1.2	3.90	11.0	45
1.6	3.87	10.0	49

Table 2. Characteristics of the array antenna vs the slot size l_s, where l_g is 0.8 mm.

Slot size (l_s) (mm)	Impedance matched freq. (GHz)	Gain (dBi)	Pol. Angle (deg.)
4.8	4.00	12.3	48
5.6	3.96	12.2	47
6.4	3.93	12.0	45
7.2	3.90	7.2	45
8.0	3.87	5.5	40

resonant frequency of 3.93 GHz. After confirming the slot size l_s, the array antenna is investigated by variation of gap l_g as shown in Table 1. Moreover, after confirming the gap l_g, the array antenna is again analyzed by variation of the slot size l_s as of Table 2 in order to confirm the nearest optimized values of l_g and l_s. Table 1 shows the characteristics of the proposed array antenna for the variation of the gap l_g when slot size l_s is fixed to be 6.4 mm. Table 2 shows the characteristics of the array antenna for the variation of the slot size l_s when the gap l_g is fixed to be 0.8 mm. As shown in Table 1, it is found that the impedance matching frequency decreases with the increment of the gap l_g, and the polarization angle ϕ increases. The gain also decreases with the increment of the gap l_g. From Table 2, it is found that the impedance matching frequency decreases with the increment of the slot size l_s and the polarization angle ϕ decreases. The gain decreases with the increment of the slot size l_s. Therefore, considering the data such as Table 1 and Table 2, the slot size l_s and the gap l_g can be decided to be 6.4 mm and 0.8 mm, respectively as the nearest optimized value. By combining a genetic algorithm [24, 25] or a particle swarm optimizer [26–29] with the analysis software, the geometry of the structure can be optimized and exhibit the best behavior regarding the radiation characteristics.

A prototype of the fabricated array antenna using $l_s = 6.4$ mm and $l_g = 0.8$ mm is shown in Fig. 4. The teflon glass fiber substrate is used. The conductor plane is made of copper whose thickness is 0.018 mm. The relative dielectric constant ϵ_r of the substrate is 2.15 with the thickness of 0.8 mm and the $\tan\delta$ of 0.001. A single feed point is used to the fed patch using SMA connector. The bias port is connected to the center of the fed patch using SMA connector. Four silicon Schottky barrier diodes (MSS30-154 B10B) are loaded on the corners of the fed patch. Fig. 5 shows the measured $|S_{11}|$ characteristics of the array

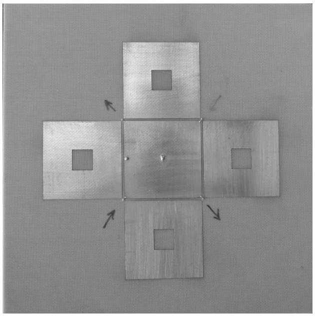

Figure 4. Photograph of the fabricated array antenna.

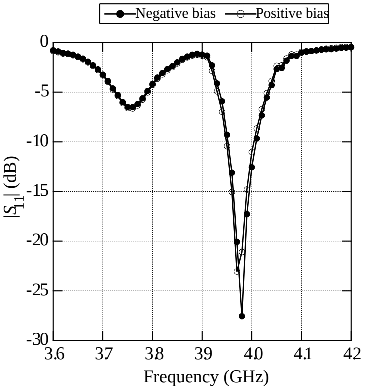

Figure 5. The measured $|S_{11}|$ characteristics of the array antenna.

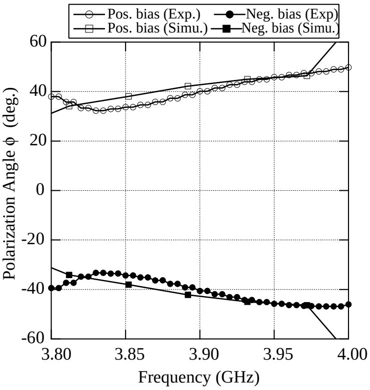

Figure 6. Polarization angle ϕ of the array antenna.

antenna. The array antenna impedance is matched from 3.95 GHz to 4.0 GHz. The simulated resonant frequency for the specified structure used for experiment is 3.93 GHz. The experimental results are almost same as the simulated results. The main reason for about 5 percent difference between the experiment and simulation is the fabrication error including additional copper wires inside the via-holes and solder volume which are neglected in the simulation.

The frequency characteristic of the polarization angle ϕ of the array antenna is shown in Fig. 6. The polarization angle ϕ for the experiment of the array antenna is $+45.8^\circ$ and -45.8° for positive and negative bias input at 3.95 GHz. For simulation, the polarization angle ϕ is $\pm 45.0^\circ$ at 3.93 GHz. Figs. 7 and 8 show the radiation pattern characteristics of the array antenna for E-plane and H-plane at 3.95 GHz, respectively. For both the positive and the negative bias

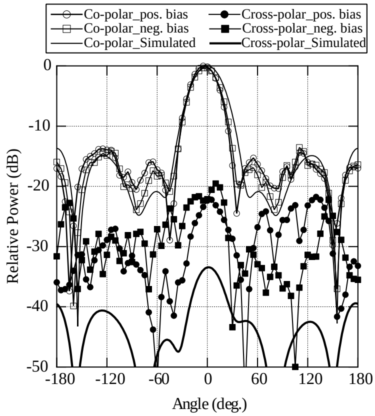

Figure 7. The radiation pattern of the array antenna for E-plane at 3.95 GHz.

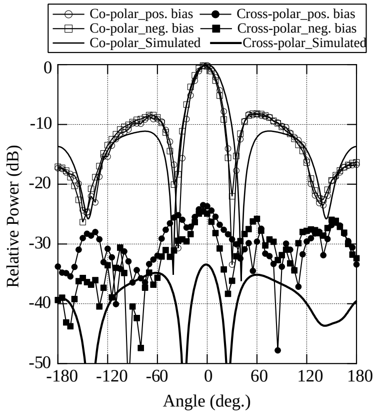

Figure 8. The radiation pattern of the array antenna for H-plane at 3.95 GHz.

voltages, the crosspolarization is better than -22 dB. This is a better cross-polarization performance for the array antenna as compared with our previous results [21]. However, the simulated crosspolarization is -33 dB for both E-plane and H-plane. The factors for the difference between the simulated and experimental crosspolarization are the fabrication and experimental errors such as via hole coupling, addition solder impedance and antenna parallax error.

In our previous results [21], the crosspolarization is obtained about -16 dB. As for the proposed array antenna, by loading a square slot on the parasitic patches, the parasitic patch size of the array antenna kept as the same size of the fed patch. As a result, the crosspolarization of -22 dB is successfully confirmed. Therefore, the proposed array antenna is realized with a better performance as compared with the previous array antenna [21].

3. CONCLUSIONS

In this paper, a novel orthogonal linear polarization switchable microstrip array antenna with better crosspolarization and high gain is proposed. The array antenna consists of a fed patch and four parasitic patches. Four switching diodes are loaded on the corners of the fed patch. A square slot is formed on each parasitic patch for matching the resonant frequency of the fed patch and the parasitic patches. As a result, crosspolarization performance is improved. The characteristics of the array antenna are simulated by the FDTD method and confirmed by the experimental investigation. The boundary condition of the fed patch can easily be controlled by the ON/OFF states of the diodes. Therefore, the linear polarization switching of the array antenna can be easily realized by the polarity of the bias voltage. The array antenna structure is very simple as no additional feed circuits for the parasitic patches are required. Excellent performances such as, exact orthogonal linear polarization switching and better than -22 dB of crosspolarization as compared with our previous work [21] are confirmed in S band. The gain of the array antenna is also successfully increased to be 12 dBi. Moreover, large scale array antenna can be realized by arranging the proposed array antennas as an array unit on a two layer structure. In this case, the array antenna gain can be more enhanced. The proposed array antenna can be used for the short range wireless data transmission which is our next research plan. In that research, the switching speed of the array antenna and other important experiments will be conducted. The proposed antenna is practically attractive for various kinds of wireless systems including sensor applications such as polarimetric radars and FM-CW radar systems etc.

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