

Printed Crossed Dipoles Antenna with Switchable Sense of Circular Polarization

Ivana Radnović, Aleksandar Nešić

Abstract—The paper proposes printed circularly polarized antenna with polarization reconfigurability i.e. the possibility of switching the sense of circular polarization. The antenna consists of a pair of crossed dipoles above the reflector plate – capacitive and inductive, fed by a symmetrical microstrip line, and an identical additional inductive dipole. Inductive dipoles are alternately connected to the capacitive dipole by use of PIN diodes thus changing the physical structure of the antenna which results in switching the polarization sense between LHCP and RHCP. Biasing state of diodes is externally controlled by switching board located under the reflector plate.

Simulated gain in both polarization states is around 7 dBi; axial ratio (AR) is less than 3 dB in the operational range of 7% around the central frequency; reflection coefficient S_{11} is less than -10 dB in 10% of the bandwidth. Antenna is designed for the frequency range around 6 GHz.

All simulations and optimizations have been carried out using WIPL-D program package. Analysis of obtained results proves the validity of the proposed concept.

Keywords—Printed antennas; crossed dipoles; circular polarization; polarization reconfigurability.

I. INTRODUCTION

Reconfigurable antennas have recently become very attractive in antenna research field due to their ability to adjust to new operating scenarios i.e. to change their fundamental radiation characteristics through electrical, mechanical or other means. Thus, reconfigurable antennas should be able to alter their operating frequencies, impedance bandwidths, polarizations, and radiation patterns to adapt to new system requirements [1].

Antennas for polarization diversity attract considerable attention because they can offer different polarizations and maintain communication quality with a single antenna. Polarization reconfigurable antenna reduces unfavorable fading caused by multipath propagation and has a potential to improve performances of wireless or satellite communication system. Besides, it can replace a number of required antennas. The main goal in achieving polarization reconfigurability is to accomplish it without significant changes of antenna radiation characteristics in all polarization states. Many microstrip antennas with circular polarization diversity have been reported and discussed in the literature lately [2-6].

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Although they show good results and have advantages such as low profile, light weight and ease of fabrication, the main disadvantage of most of them are very narrow impedance and axial ratio bandwidths.

Here we propose polarization reconfigurable printed antenna with fixed operating frequency. The antenna consists of a pair of orthogonally crossed dipoles whose impedances fulfill the condition for generating circular polarization [7]. Four PIN diodes, which are commonly used switching devices, are incorporated into the antenna structure. Depending on their switching state, polarization excited by the antenna can be reconfigured between left-hand (LHCP) and right-hand (RHCP).

II. CONCEPT AND DESIGN

Proposed antenna concept is based on two printed parallel fed crossed dipoles with equal real parts of impedances and the phase difference of 90° between them in order to obtain circular polarization without the use of a phase shifter [8]. One arm of each dipole is printed on one side of the dielectric substrate and the other arm on its opposite side. The halves of dipoles on the same side of the dielectric are connected in the center of the structure forming the L-shaped element. Small plate in the center is then extended to a 50Ω symmetrical microstrip line terminated with a *bal-un* [9] and a coaxial SMA connector. Printed antenna structure is placed on the polyurethane foam distancer from the reflector plate, Fig. 1, whose height equals one quarter of wavelength at the central frequency. Relative dielectric constant (ϵ_r) of the polyurethane foam is 1.03, thus its influence on the antenna characteristics can be neglected.

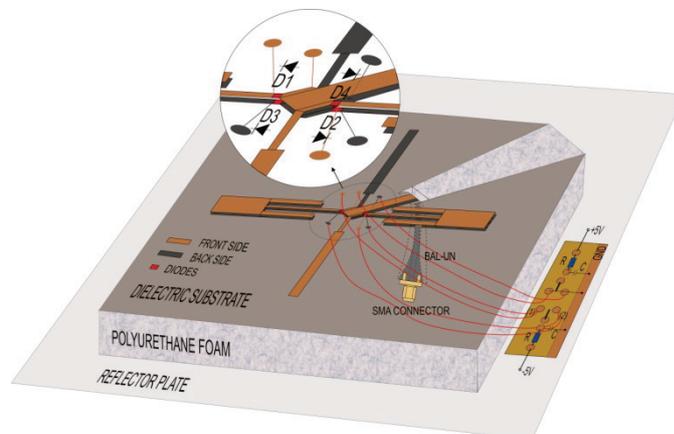


Fig. 1. Sketch of the antenna structure above the reflector plate

As the sense of circular polarization depends directly on the current path in the antenna, its configuration has to change in a way to alter the current flow in order to achieve polarization reconfigurability. One method is to modify physical structure of the antenna for the desired sense of polarization. This is accomplished by introducing an additional inductive dipole printed as a mirror image of the original dipole, with respect to the xy -plane. Depending on which inductive dipole arm (left or right) is connected with the capacitive dipole arm printed on the same side of the dielectric material, corresponding polarization is generated. Four PIN diodes are located between the arms of two inductive dipoles as indicated in Fig. 1. When diodes D1 and D2 are in ON state while D3 and D4 are in OFF state, electrical field vector rotates in anti-clockwise direction e.g. the left-hand polarization (LHCP) is obtained. The opposite situation (D1, D2 in OFF state and D3, D4 in ON state) switches the antenna configuration and enables exciting right-hand circular polarization (RHCP). Diodes used in the simulation (Skyworks Silicon Mesa Beam-Lead PIN diode DSM8100-000, [10]) are represented by their equivalent electrical circuits in forward (RL series circuit) and reverse biasing (RC shunt circuit). To provide good isolation loss shunt capacitor should have very low value, which is 0.025 pF in this case. For activating and deactivating the diodes, a switching board is mounted under the reflector plate supplying with ± 5 V voltage. It also includes a biasing circuit with DC blocking capacitors of 1 nF and 250 Ω resistors so to obtain forward bias current of 10 mA for each conducting diode. Anodes and cathodes of the diodes are connected with small copper areas through very thin (0.1 mm) printed lines. The anodes are connected to the ground while the cathodes D1-D2 and D3-D4 are alternately supplied with negative DC voltage, Fig. 2. Copper wires are soldered to the contacts on the switching board and led to corresponding terminals of each diode, Fig. 1.

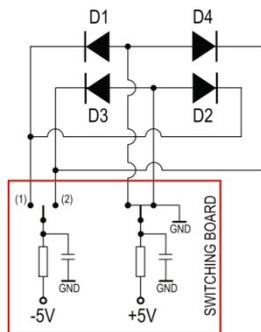


Fig. 2. Circuit diagram of the diodes biasing

Dipoles are optimized on a thin substrate ($\epsilon_r=2.17$, $h=0.127$ mm) at the distance of $0.25\lambda_0$ (at f_c) from the reflector plate using WIPL-D program package [11]. The goal of the optimization was to obtain complex-conjugated impedances: $Z_1=(50-j50)\Omega$ (capacitive dipole) and $Z_2=(50+j50)\Omega$ (inductive dipole) at the central frequency of 6 GHz, Fig. 3. In this way circular polarization of the antenna is achieved. Since the crossed dipoles are connected in parallel the impedance at the antenna feed point theoretically equals $(50+j0)\Omega$.

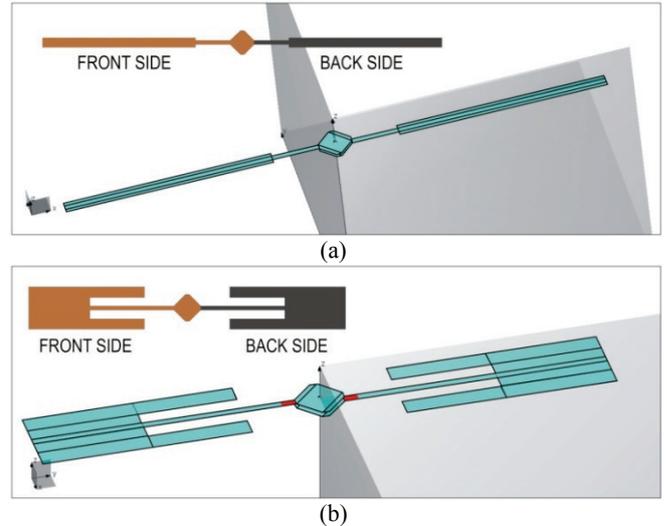


Fig. 3. Top view and WIPL-D models of (a) capacitive and (b) inductive printed dipoles (red areas denote places for diodes placement)

To prove the switching concept, in the first step inductive dipole is optimized assuming ideal switches between dipole arms and the plate in the center of the antenna structure. The ideal switch is represented by copper strip in ON state while the absence of a strip denotes OFF state. After that, ideal switches are replaced with actual PIN diodes. In Fig. 4 and Fig. 5, showing the S_{11} and AR characteristics of the antenna, discrepancies between these two cases are noticeable.

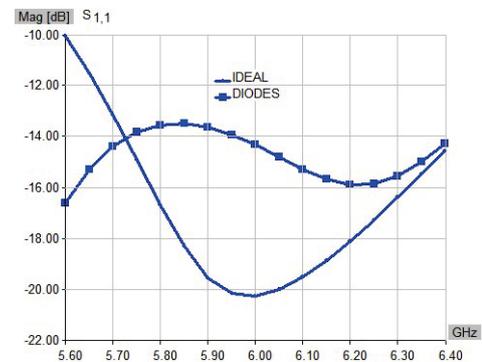


Fig. 4. Simulated reflection coefficient S_{11} of the proposed antenna in cases with ideal switches and actual PIN diode switches

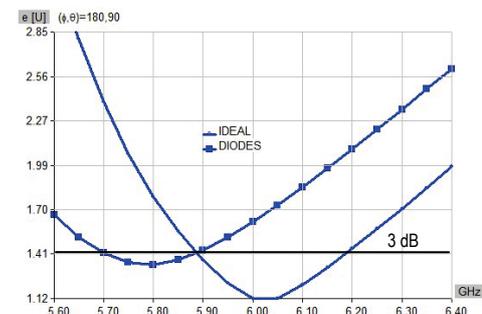


Fig. 5. Simulated axial ratio of the proposed antenna in cases with ideal switches and actual PIN diode switches

Therefore, to obtain accurate simulation results, additional optimization which includes actual PIN diode switches had to be carried out.

III. SIMULATED RESULTS

Simulated impedances of both inductive and capacitive dipole are given in Fig. 6, while the impedance of their parallel connection in the center of the antenna structure is presented in Fig. 7.

As the antenna feeding is performed through symmetrical microstrip line, its length has to be optimized to ensure ideal matching at the feed point. Furthermore, since the feed line is located between two arms belonging to capacitive and inductive dipole and is relatively close to them, original antenna model has to undergo some modifications in order to prevent possible degradation of the antenna radiation characteristics. This modification is shown in Fig.1 where two incisions are made in the dielectric substrate around the feed line and the loosened part is bent and threaded through the hole in the polyurethane foam distancer.

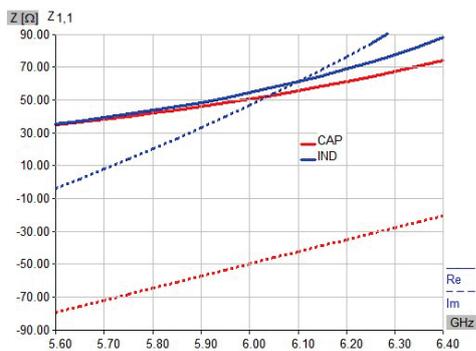


Fig. 6. Simulated real and imaginary parts of the capacitive and inductive dipole with actual PIN diode switches

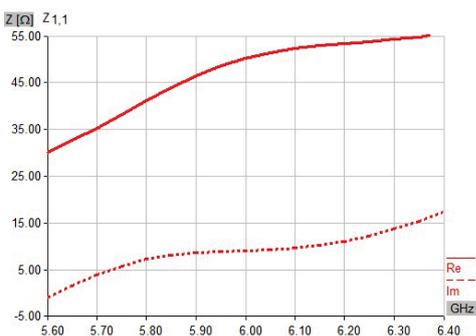


Fig. 7. Simulated real and imaginary part of the impedance in the center of the antenna structure with actual PIN diode switches

Fig. 8 shows simulated reflection coefficient S_{11} at the end of the bent feed line in both LHCP and RHCP cases together with the same parameter observed in the center of the antenna (LHCP case). It can be seen that reflection coefficient has slightly worsened at lower frequencies in case with feed line comparing to the case with no feed line, but it's still below -10 dB in 10% of bandwidth around the central frequency with a tendency of improving toward higher frequencies.

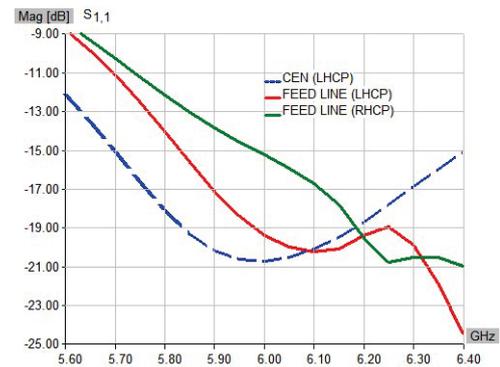


Fig. 8. Simulated reflection coefficients in the center of the antenna structure and at the end of the feed line in both polarizations

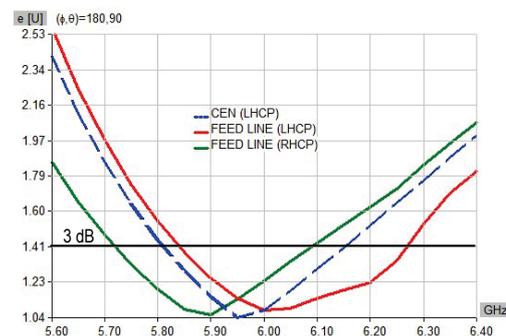


Fig. 9. Simulated axial ratio (AR) in the center of the antenna structure and at the end of the feed line

Diagrams of the axial ratio (AR) in Fig. 9, when feeding is performed in the antenna center, and at the end of the feed line with optimized length, for both polarizations, show that the AR bandwidth ($AR < 3$ dB) has been broadened from 5.8% (no feed line/LHCP) to 7.1% (feed line/LHCP) and 6.2% (feed line/RHCP).

Simulated gain of the antenna versus frequency ranges from 6.4 dBi to 7.3 dBi and is presented in Fig. 10.

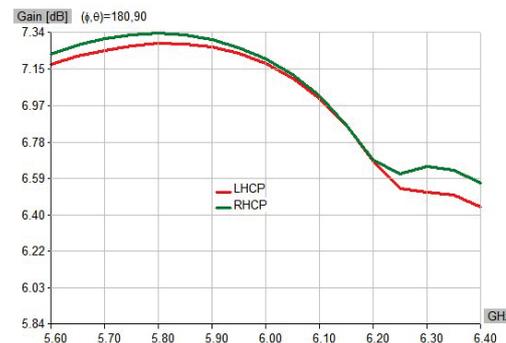


Fig. 10. Simulated gain vs. frequency for both antenna polarizations

Radiation patterns in E- and H-planes for both polarizations have been analyzed and plotted. The diagrams at the central frequency are presented in Fig. 11 and Fig. 12.

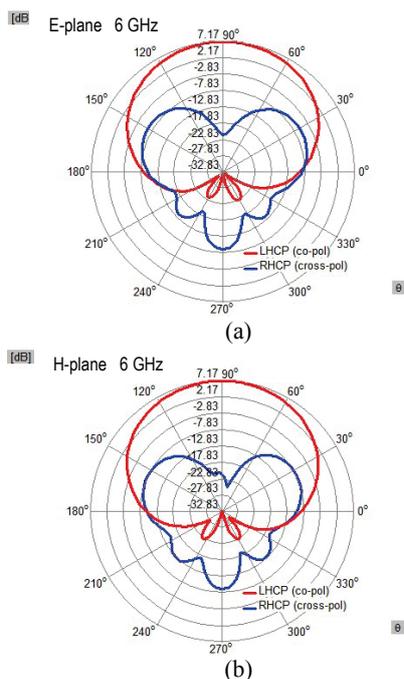


Fig. 11. Simulated radiation pattern in (a) E- and (b) H-plane of the antenna when LHCP is switched ON

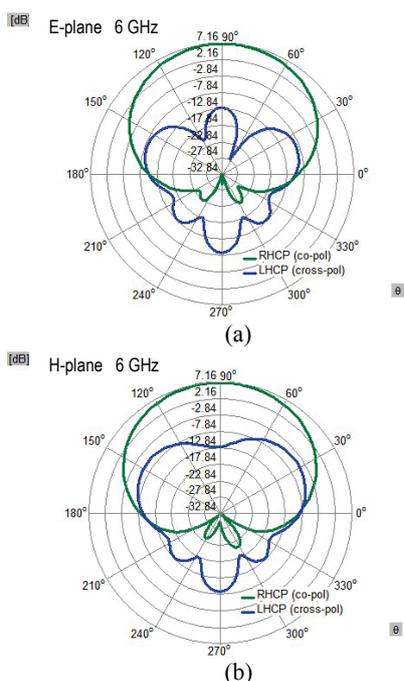


Fig. 12. Simulated radiation pattern in (a) E- and (b) H-plane of the antenna when RHCP is switched ON

Radiation characteristics in both LHCP and RHCP cases (when they represent co-polarization) are almost identical which was expected considering the physical symmetry of the antenna structure. Also, E- and H- plane patterns are symmetrical in both polarization states while cross-polarization levels remain below -15 dB in respect to the co-polarization levels.

IV. CONCLUSION

Concept and design of the printed crossed dipoles antenna with reconfigurability of circular polarization is proposed. Switching between LHCP and RHCP is accomplished by use of four PIN diodes which, depending on their switching state, alternately connect one or the other inductive dipole with a capacitive dipole and in this way change the physical structure and the current path in the antenna. To prove the switching concept simulations are carried out first with ideal switches and then with real diodes. Obtained results show good impedance matching (10% around f_c) and axial ratio bandwidth (6-7%) in both polarization states that are hardly attainable with conventional microstrip antennas (patches). Isolation between co- and cross-polarization in both cases is better than 15 dB within the 3 dB beamwidth which is about 90° . Proposed antenna is suitable for applications in mobile satellite as well as in wireless communications.

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