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Reconfiguration of Polarized Antennas for WLAN Applications

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Abstract: Wireless technology based on the IEEE 802.11 standard and in accordance with the KEMINFO 2019 regulations requires antennas that can adapt to changing environments. Microstrip antennas are a good solution to meet the current technological advancements because they have several advantages, such as a simple design, lightweight, easy manufacturing, and low cost. When designing a microstrip antenna, bandwidth parameters must be observed. The bandwidth of a microstrip antenna is narrow. In order to work properly, some simple techniques can be used to increase antenna bandwidth. This research proposes a reconfigurable microstrip antenna polarization using a U-slot at a frequency of (2.4– 2.485) GHz for WLAN applications. The proposed antenna reconfiguration utilizes two (2) switching mechanisms that can be turned on and off individually or simultaneously. The results of the simulation showed that Ant. 1 and Ant. 2 have a linear polarization (LP), Ant. 1 has a bandwidth of 85 MHz (2.399 – 2.484) GHz, and Ant.2 has a bandwidth of 87 MHz (2.398– 2.485) GHz, both with S-parameter values ≤-9.54 dB. Then, Ant. 3 has a right circular polarization with a bandwidth value of 124 MHz (2.397 – 2.484) GHz, and Ant. 4 has a left circular polarization with a bandwidth value of 87 MHz (2.398 – 2.485) GHz at the Axial Ratio (AR) limit of ≤ 3 dB.

Keywords: Circular Polarization; Linear Polarization; Microstrip Antenna; Reconfiguration; U-slot, WLAN

Introduction

Technology in the field of telecommunications is rapidly developing (Cakula et al., 2021; He et al., 2022; Kang et al., 2021; Supriya et al., 2015). This can be seen in the development of wireless communication, which allows the exchange of information even with long distances wirelessly (without wires). The public widely uses this technology to meet human needs (Ehsan et al., 2021; Sukmawati et al., 2022; Nafrianto, 2021).

WLAN stands for Wireless Local Area Network or a communication system connecting devices without cables to exchange information (Ehsan et al., 2021; Kumar et al., 2020; J. Yang et al., 2016). Compared to LAN, WLAN technology offers significant advantages because it can reach mobile users, while LAN networks are typically used for fixed users (Wahyuni, H. I, 2018). According to references (M. Yang et al., 2020), Wireless Local Area Network (WLAN) is one of the most important wireless networks, particularly with the increasing attention from the researchers due to its support for high-definition video services and real-time applications. Wireless Local Area Networks (WLANs) contributed for 43% of global IP traffic in 2017 and increased by as much as 51% in 2022. In June 1997, the IEEE introduced the 802.11 standard for WLANs with a working frequency of 2.4 GHz. In the end of 1999, the IEEE released an addition to the 802.11 standard for w/g/n for WLAN (Issac, 2009; Alam, 2018). Based on the regulation of the Ministry of Communication and Information Technology of the Republic of Indonesia in 2019, a frequency range of 2.4 GHz – 2.4835 GHz was designated for WLAN communication systems

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(Permenkominfo, 2019), with a central operating frequency of 2.44175 GHz.

In WLAN communication systems, the role of the antenna is an important element to function as a transmitter and receiver of electromagnetic waves containing information (Alam, 2018; Shanmugasundaram et al., 2018). Various types and designs of antennas have been developed for diverse applications (Boehmert et al., 2018; Wang et al., 2019). The antenna needs to be small-sized, high-performance, cost-effective, and be able to work optimally according to the frequency standards used. Microstrip antennas are one solution to meet current technological developments, as they offer several advantages, including simple shape, lightweight, easy to make, and low cost (Bansal, 2008).

Microstrip antennas have a narrow bandwidth (Surjati, 2010), but this limitation can be overcome by modifying the antenna using simple techniques that are proven to increase/widen the bandwidth. Several studies have been conducted to widen bandwidth with parasitic element method on square patches as demonstrated by Ref (Alam, 2018), which be able to increase bandwidth up to 35.17%. In Reference, the U-slot method is used to increase antenna bandwidth. From Reference research (wahyu Kirana, 2021), the use of slot "ꦩ" influences to increase the value of return loss by 42.63% and bandwidth by 5.17% (Madiawati et al., 2020; Ruliyanta et al., 2021; Sumpena et al., 2020). The method of adding dual U-slots (Sandi et al., 2020) can increase the bandwidth performance of microstrip antennas by 76%.

In addition, WLANs require antennas with the ability to adapt on the change of environments. Reconfigurable or reconfigured antennas have become very popular in recent years due to their dynamic nature. According to its function, the reconfigurable antenna parameters, namely: polarization, radiation pattern, and frequency (Jin et al., 2019), its polarization-reconfigurable antenna design also attracted significant attention because it reduced the effects of poor multipath damping and increased channel capacity. In order to enable good antenna reconfiguration capabilities, switching devices, such as PIN diodes or switches are used (Effendi et al., 2018; Li et al., 2018; Ojaroudi Parchin, et al, 2020; Sim et al., 2022) to apply other response dynamics, namely: varactor, microelectromechanical radiofrequency system (RF-MEMS), field effect transistor (FET), parasitic pixel layer, photoconductive element, mechanical actuator, metamaterial, ferrite, and crystalline liquid (Mohanta et al., 2019).

Several patch antenna studies have been proposed to achieve the expected antenna polarization. The patch antenna with controlled slot can achieve the polarization purpose of antenna reconfiguration. Table I shows a comparison of the results of the proposed polarization reconfigured antenna and the existing references. According to Ref (Sim et al., 2022), to achieve a reconfiguration between linear polarization (LP), left circular polarization (LHCP), and right circular polarization (RHCP),) by using two (2) PIN diodes are embedded between A filling channel of coplanar waveguide (CPW) and an open square patch. In Reference (Li et al., 2018), a prototype antenna is designed for WLAN applications, the antenna prototype is for WLAN applications with the antenna design consisting of four straight dipoles as conducting elements and six pairs of PIN diodes used to control the polarization of the antenna. By turning on or off these PIN diodes, the designed shape can achieve linear and circular polarization. (Effendi et al., 2018) stated that using an array antenna design consisting of eight (8) microstrip square patches configured in a planar circular array, it is proposed for wireless local area network (WLAN) applications with switchable polarization.

The characterization results show that the switch table polarization antenna array can be changed in eight (8) directions with a 45° step in the azimuth plane. The designed patch antenna array has eight (8) switches. As of Ref (Nafrianto, 2021;Surjati, 2010), the proposed antenna is suitable for WLAN applications as a transmitting or receiving antenna consisting of a circular main patch antenna with a rectangular slot Defected Ground Structure (DGS). In order to achieve linear polarization, left circular polarization (LHCP) and right circular polarization (RHCP), two (2) diode pins are installed in the rectangular slot. This paper on Ref (Niture et al., 2018) presents the results of polarization antenna reconfiguration for WLAN applications. The proposed antenna has a square ring slot equipped with a T-shaped microstrip feedline. Two diodes are connected to a diagonal slot at the top of the square ring and two more switches are added to the ground plane. Depending on the state of the diode (ON/OFF), this research can switch to different polarization states, namely horizontal and vertical linear polarization.

In this research, polarization reconfiguration antennas were designed with open circuit and close circuit condition switch techniques at frequencies of 2.4 GHz – 2.4835GHz. With the addition of the U-slot technique to this research, the circular patch is expected to increase bandwidth on microstrip antennas.

Method

This section describes the steps in the circular patch design for the proposed antenna polarization reconfiguration. This research used specifications from

WLAN criteria, which work at a frequency of 2.4 GHz – 2.483 GHz with a middle frequency of 2.441 GHz, and a limit of impedance bandwidth S-parameter ≤-9.54 dB, and circular polarization Axial Ratio (AR) ≤3 dB. The antenna design involved FR-4 substrate material with a dielectric constant (ε_r) of 4.3 and a thickness of 1.6 mm. In the irradiating element and ground plane, the antenna used copper material with a thickness of 0.035 mm.

Research design

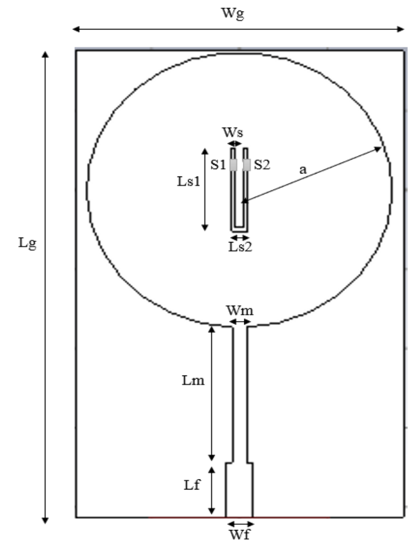

Figure 1. Scheme of antenna reconfiguration design

In the patch dimension design of the antenna, calculation are made using equations (1) and (2) (Bansal, 2008). After using Equations (1) to (6), the dimensions of the reconfigurable microstrip antenna can be obtained as shown in Figure 1 with the U-Slot and Table I. The reconfigurable microstrip antenna has full ground plane. There are 2 Switches, namely S1 and S2 contained in U-Slot to achieve polarization characteristics, then will be turned on individually or simultaneously. On-state is a channel on Switch will be disconnected, while in off-state, Switch channel will be connected.

Table 1. The Initial Dimensions of the antenna reconfiguration

Parameters	Dimension (mm)	Parameters	Dimension (mm)
a	15.7	Wm	0.7
Ls1	10.41	Lf	17
Ls2	0.933	Wf	2.87
Ws	0.461	Wg	40
Lm	12	Lg	35

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r}\left[ln\left(\frac{\pi F}{2h}\right)+1,7726\right]\right\}^{\frac{1}{2}}} \quad (1)$$

$$F = \frac{8,791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

Description:
ε_r = effective dielectric constant of the substrate (F/m)
f_r = working frequency
h = substrate height

This research used a feedline calculation technique where two microstrip channels involved with impedance values of 50 Ω and 70.70 Ω. The use of enumeration with different impedance values aims to obtain matching values on the impedance of the antenna to be designed. To obtain a matching impedance value, equation (3) can be used (Bansal, 2008).

$$Z_{in} = \frac{Z^2{}_{QWT}}{Z_L} \quad (3)$$

Calculating U-slots used can be through parameters C, D, and E with equations (3) to (5) (Sandi et al., 2020):

$$E = F = \frac{\lambda}{60} \quad (4)$$

$$\frac{c}{W} \geq 0.3 \quad (5)$$

$$D = \frac{c}{F_{low}\sqrt{\varepsilon_{eff}}} - 2(L + 2\Delta L - F) \quad (6)$$

In this research, the antenna design was reconfigured; there were four conditions with two (2) switches which can be seen in Figure 2. Ant. 1 has the conditions of S1 *on state*; S2 *on state*, then Ant. 2 has the condition of S1 *off state*; S2 *off state*, Ant. 3 has the condition of S1 *on state*; S2 *off state*, and Ant. 4 has the condition of S1 *off state*; S2 *on state.*

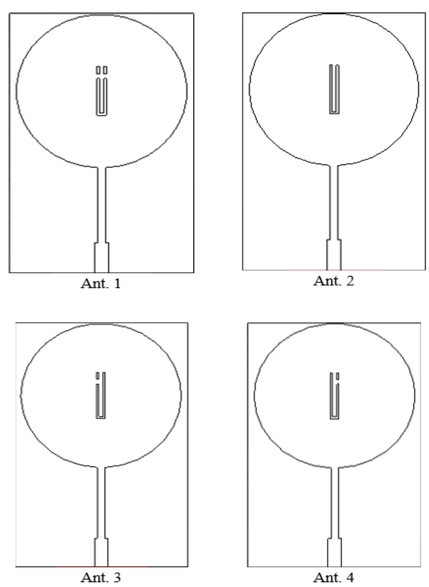

Figure 2. Scheme of antenna reconfiguration design

Design draft iterations

The antenna design was then simulated with CST Microwave Studio software. In order to obtain the best results according to the expected specifications on the S-parameter and Axial Ratio, iterations were produced by changing the reconfigured antenna's LS1, LS2, and Ws dimensions. Simulation results at the iteration stage of Ant. 1 can be seen in Figure 3.

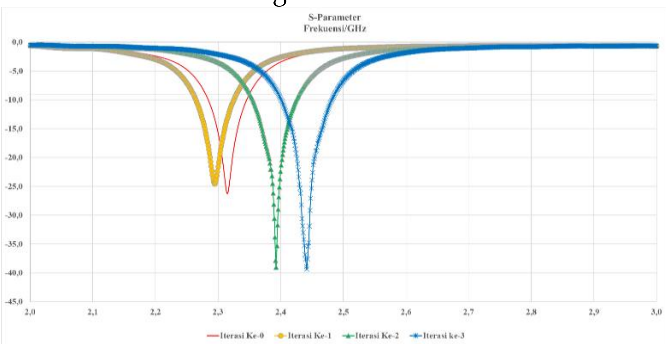

Figure 3. Simulation results of S-parameter iteration stage Ant. 1 antenna reconfiguration (S1 *on state*; S2 *on state)*

Figure 3 shows the results of the S-Parameter simulation from the stages of the Ant.1 iteration that have been carried out. Iteration 0 represents the result of the initial design using equations (1) to (6). The 64 MHz bandwidth results in the 2.283 GHz – 2.347 GHz frequency range with a middle frequency of 2.315 GHz, so the 1st iteration is required because the results do not match the expected specifications. The 1st iteration produces a bandwidth of 63 MHz in the frequency range of 2.263 GHz – 2.326 GHz. This indicates that it does not match the antenna specifications, so the 2nd iteration is carried out. The 2nd iteration shows a bandwidth value of 72 MHz in the frequency range of 2.354 GHz – 2.426 GHz and has a middle-frequency value of 2.393 GHz. This does not match the expected antenna specifications, thus the 3rd iteration was carried out. The 3rd iteration produces a bandwidth of 85 MHz in the frequency range of 2.399 GHz – 2.484 GHz with a middle-frequency value of 2.444 GHz. There is an increase in bandwidth after iteration. The initial bandwidth of 64 MHz has been increased to 85 MHz.

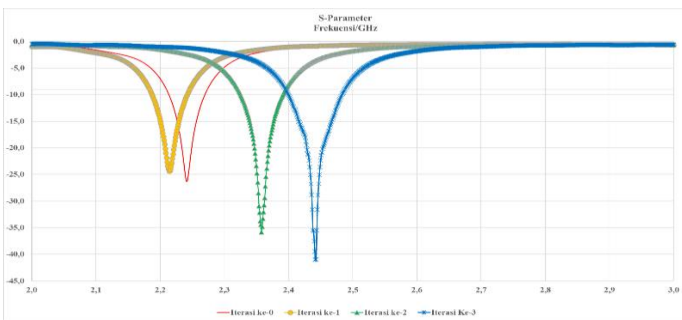

Figure 4. Simulation results of *S*-parameter stage iteration Ant. 2 antenna reconfiguration (S1 *off state*; S2 *off state)*

The results of the iteration stage on Ant. 2 can be seen in Figure 4. Iteration 0 from the initial design with a bandwidth value of 59 MHz frequency range 2.212 GHz to 2.271 GHz. These results did not match to the expected specifications so the 1st iteration was carried out. In the 1st iteration, bandwidth showed 57 MHz from the frequency range of 2.186 GHz to 2.243 GHz. This indicates that it does not conform to antenna specifications. The 2nd iteration was carried out with a bandwidth value of 69 MHz in the frequency range of 2.406 GHz to 2.463 GHz and has a middle-frequency value of 2.358 GHz. This does not match the expected antenna specifications so the 3rd iteration was carried out. In the 3rd iteration stage, it produced a bandwidth of 87 MHz in the frequency range of 2.398 GHz to 2.485 GHz with a middle-frequency value of 2.441 GHz. There was an increase in the previous bandwidth value of 59 MHz up to 87 MHz.

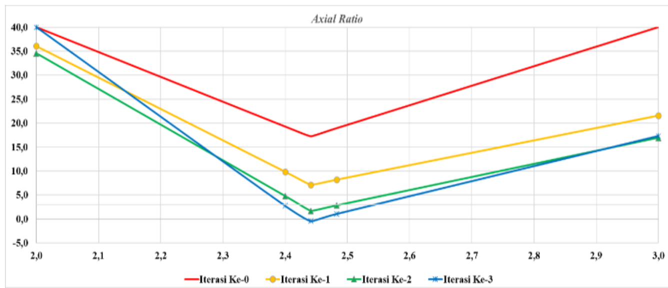

Figure 5. Results of the Axial Ratio simulation stage of the Ant. 3 iteration stage antenna reconfiguration (S1 *on state*; S2 *off state)*

Figure 5 shows the Axial Ratio results of the Ant iteration stage. 3. Iteration 0 results from the design do not produce bandwidth values. This is due to the Axial Ratio (AR) value of > 3 dB with an AR value of 17.29 dB at a frequency of 2.2441 GHz. These results did not match the expected specifications so the 1st iteration was carried out. The 1st iteration does not produce an Axial Ratio (AR) bandwidth value of > 3 dB, with a 2.441 GHz midfrequency bandwidth of 7.105 dB. The 2nd iteration stage was carried out with the result of a bandwidth value of 85 MHz in the frequency range of 2.41 GHz to 2.495 GHz. AR value of 1.689 dB at a frequency of 2.441 GHz. This did not match with the expected antenna specification. Thus the 3rd iteration was carried out. The 3rd iteration stage results in a bandwidth of 124 MHz in the frequency range of 2.397 GHz to 2.521 GHz with an AR value of -0.457 dB at a frequency of 2.441 GHz.

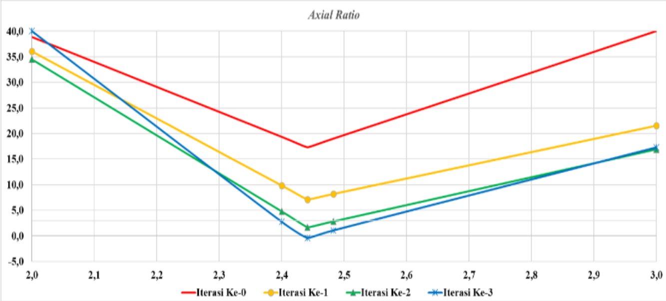

Figure 6. The results of the Axial Ratio simulation of the Ant iteration stage. 4 Antenna reconfiguration (S1 *off state*; S2 *on state)*

The simulation results of the Ant iteration stage. 4 can be seen in Figure 6. In iteration 0 and iteration 1 of the design, there is no bandwidth value. This is due to the Axial Ratio (AR) value of > 3 dB. The 0th iteration values the mid-frequency AR at 17.33 dB at 2.2441 GHz, while the 1st iteration is 7.114 dB at 2.441 GHz. The 2nd iteration was carried out because the 0th iteration and 1st iteration do not match the expected specifications. The bandwidth of the 2nd iteration is 120 MHz in the frequency range of 2.398 GHz to 2.518 GHz, with the resulting AR Value of 1.695 dB at a frequency of 2.441 GHz. This is already in accordance with the expected antenna specifications, but the antenna reconfiguration must follow the same parameters as Ant. 1, Ant. 2, and Ant. 3. The 3rd iteration produces a bandwidth of 128 MHz in the frequency range of 2.396 GHz to 2.5824 GHz with an AR value of -0.407 dB at a frequency of 2.441 GHz.

The expected result is the reconfiguration of Ant. 1, Ant. 2, Ant. 3, and Ant. 4 was obtained in the 3rd iteration. Changes in Ls1 dimension values from 10.41 mm to 11 mm, Ls2 dimensions from 0.933 mm to 8 mm, and Ws dimensions from 0.461 mm to 0.2 mm. The bandwidth value of the four antennas has increased.

Result and Discussion

Simulation results of linear polarized antenna reconfiguration

Ant. 1 and Ant. 2 simulation results indicate linear polarization.

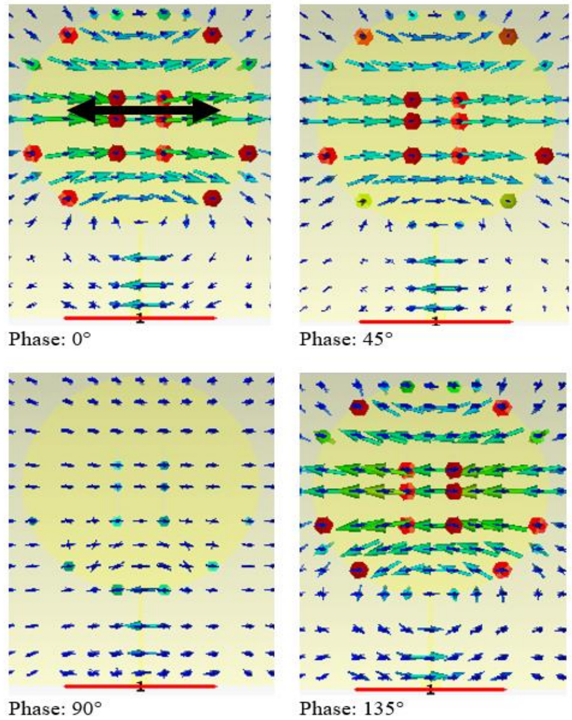

Figure 7. Simulation results of linear polarization of Ant. 1 (S1 *on state*; S2 *on state)*

In Figure 7, the *E-field* results show the polarization of Ant. 1. The polarization change is shown from phase 0° to the right, then phase 45° to the right then phase 90° shows rotation, and phase 135 ° shows to the left. This is the horizontal linear polarization or LP.

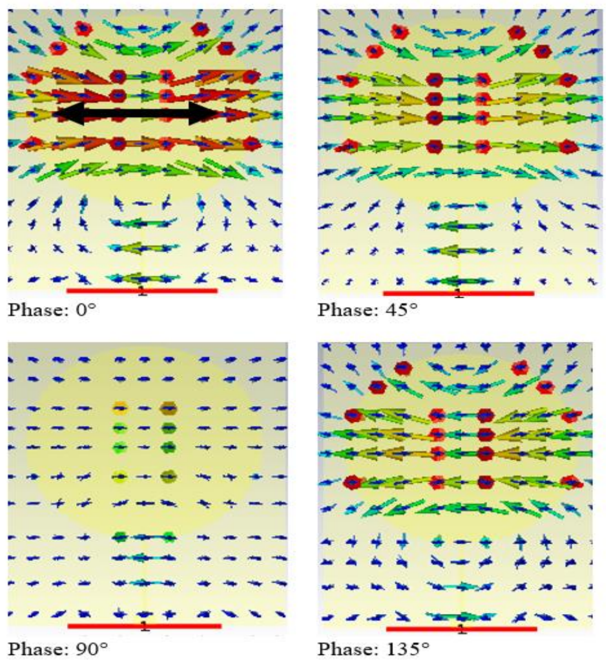

Figure 8. Simulation results of linear polarization of Ant. 2 (S1 *off state*; S2 *off state)*

The *E-field* results of Ant. 2 show linear polarization or LP. Phase 0° shows to the right, phase 45° to the right, then in phase 90° shows rotation, and phase 135° to the left.

Simulation results of circular polarization antenna reconfiguration

Circular polarization is the result of Ant's design simulations of 3 and 4.

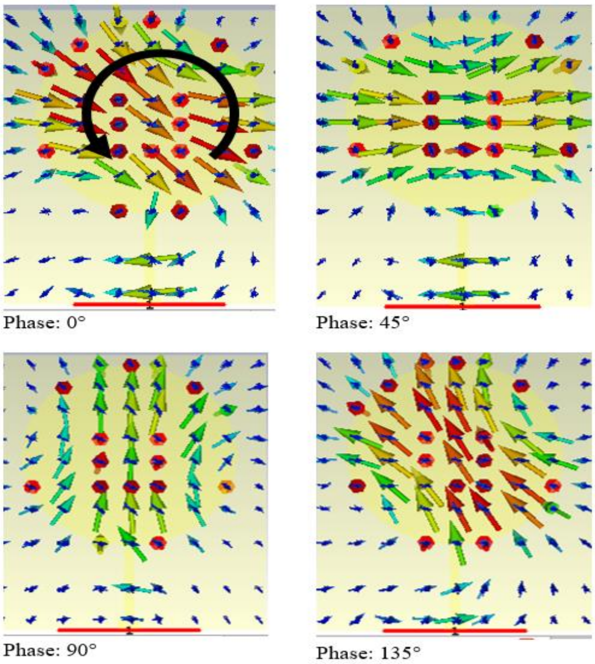

Figure 9. Results of RHCP polarization simulation from Ant. 3 (S1 *on state*; S2 *off state)*

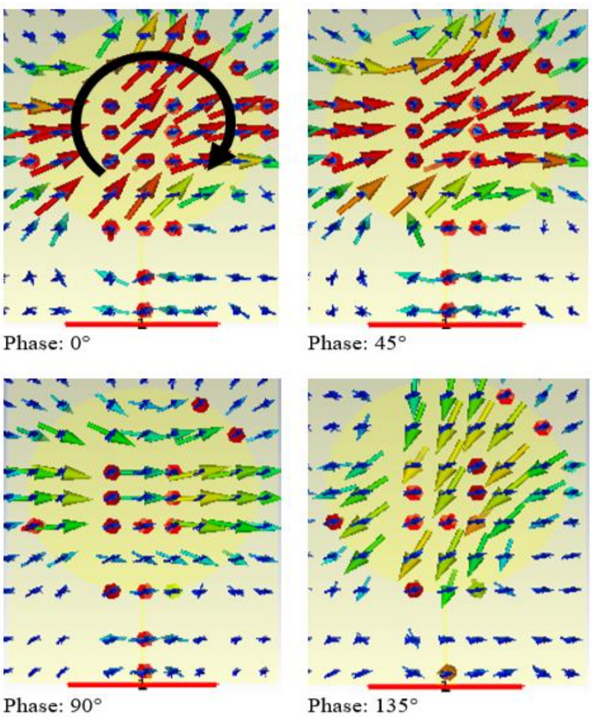

Figure 10. LHCP polarization simulation results from Ant. 3 (S1 *off state*; S2 *on state)*

Figure 9. shows the polarization of Ant. 3 where it shows the result of circular polarization to the right. It can be seen in phase 0° which shows the direction to the bottom right, then in phase 45° to the right, in phase 90° to point up and phase 135° to show the direction up to the left. This indicates the rotation of the electromagnetic flow to the right or right circular polarization (RHCP). Meanwhile, Figure 10 shows the opposite direction of Figure 9. Where in phase 0° to the top right then in phase 45° to the right, in phase 90° to the right and phase 135° shows the bottom left direction. This indicates the rotation of the electromagnetic flow to the left or left circular polarization (LHCP).

From the discussion that has been presented in points A and B above, Table I shows the characteristic results for four (4) different switching states.

Gain results and radiation patterns from antenna polarization reconfiguration

The gain parameter at the center frequency of the antenna linear polarization reconfiguration design with the addition of a U-slot has a value of 1.419 dBi in Ant.1, while Ant. 2 is 1.392 dBi. At the circular polarization of Ant. 3, it has a gain value of 0.2158 dBi, while in Ant.4 is 0.2047 dBi.

The four antennas at the center frequency produce the *unidirectional* radiation pattern, as shown in Figure 11 for Ant. 1 and Ant. 2, while Ant.3 and Ant. 4 are shown in Figure 12.

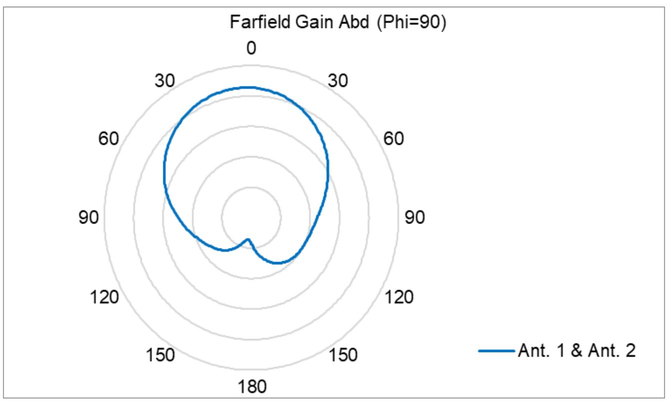

Figure 11. Radiation pattern results from Ant. 1 and Ant. 2

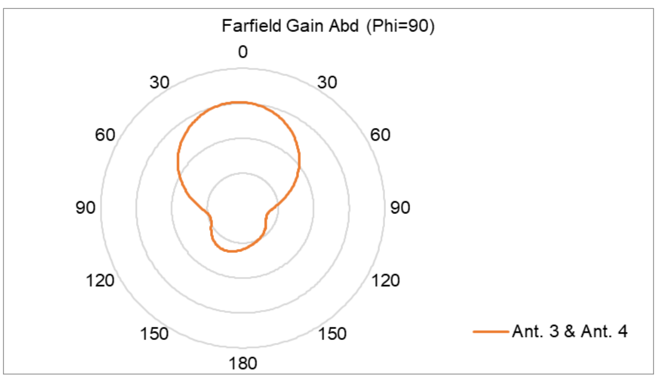

Figure 12. Radiation pattern results from Ant. 3 and Ant. 4

Conclusion

This research has designed antenna reconfiguration for the resulting polarization microstrip patches on Ant. 1 and Ant.2 linear polarization (LP). The bandwidth of Ant. 1 is 85 MHz (2.399 GHz – 2.484 GHz) and Ant. 2 is 87 MHz (2.398 GHz – 2.485 GHz). Ant. 3 has a right circular polarization (RHCP) with a bandwidth value of 124 MHz (2.397 GHz – 2.484 GHz), while Ant. 4 has a right circular polarization (LHCP) with a bandwidth of 87 MHz (2.398 GHz – 2.485 GHz). The addition of U-slots on the patch can increase bandwidth value. The results of this research can be applied to reconfigurable WLAN antennas.

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Author Contributions
Filda Ayu Afrida: methodology, software, formal analysis, investigation, resources, data curation, writing—original drafting, writing—review and editing, and visualization. Fitri Yuli Zulkifli: methodology, validation, formal analysis, resources, writing—original drafting, writing—review and editing, visualization, supervision, and acquisition of funding. Eko Tjipto Rahardjo: methodology, formal analysis of writing—preparation of original drafts, writing—review and editing, visualization, and supervision.

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Conflicts of Interest
The author declares that there is no conflict of interest in this research.

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