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DUAL-BAND FREQUENCY RECONFIGURABLE 5G MICROSTRIP ANTENNA

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Abstract
Microstrip Antenna is an antenna widely developed and used in modern telecommunications equipment because of its advantages: simple shape, lightweight, easy to fabricate, and easy to integrate. Microstrip antenna is also used in 5G development which is expected to increase communication capacity and also be able to provide very large data rates. The frequency used in 5G is 28, 38, and 78 GHz. However, the 5G network with high frequency has a weakness: transmitted waves are vulnerable to weather because of their dense waveform. Therefore, the multiband is used to support different frequencies in one antenna. Furthermore, antenna reconfiguration is used to set the antenna to work on a different frequency and adjust different radiation patterns depending on the needs without changing the form of the antenna. This paper studies the antenna with RT Duroid 5880 as its substrate is reconfigured using PIN diodes placed between the main patch element and secondary patch element and simulated on CST software in 28 GHz and 38 GHz frequency with two conditions, ON and OFF. Simulation results show the OFF condition only works at 38 GHz with an S-parameter value of -31.215 dB. In comparison, in the ON condition, the antenna works on 28 GHz and 38 GHz frequencies with S-parameter -10.805 dB and -10.041 dB, respectively.

Keywords:
Microstrip Antenna;
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INTRODUCTION

The industrial transformation that is happening globally has led to many improvements in people's daily life, including communication technology. The 5G is the next-generation mobile communication technology that improved from Long Term Evolution (LTE) technology. 5G is expected to provide the user with improved services at ultra-high-speed data rates at low latency, support higher connectivity, and improve the bandwidth capacity [1]. Some tools are also used in 5G technologies, such as antenna.

There are various types of antennas, such as the Microstrip Antenna. Microstrip antenna is widely developed and used in modern telecommunications equipment because of many methods and techniques in the antenna design and applications [2] where the design needs of these antennas meet the application of the antenna which keeps shrinking in size [3], also microstrip antenna widely used because of its advantages, which are simple shape, lightweight, easy to fabricate, and easy to integrate and cheap [4]. Microstrip antenna consists of a substrate and thin metallic acting as patch radiating element and the ground placed on the substrate surface. Microstrip patch antenna can be designed in many shapes like circular, rectangular, and triangle [5].

There are many applications of the microstrip antenna. One of them is the 5G antenna which is still intensively developed. The frequency in the in the mm-wave range that are approved by WRC-15 are 24,25 – 27,5 GHz, 31,8 – 43,5 GHz, 45,5 – 50,2 GHz, 50,4 – 52,6 GHz, 66 – 76 GHz, and 81 – 86 GHz. These bands are usually used for local and personal communication [6].

The 5G network that uses high frequency has an emitting waveform that is sufficiently dense so that the transmitted wave is very vulnerable to weather [7]. Multiband supports using different frequencies to produce a good gain and radiation pattern. This multiband antenna can synchronize electromagnetic signals at all frequencies, supported primarily at the desired frequency [8]. Multiband antennas are also used because they can replace two or more antennas that are separated into one antenna only, reducing complexity of the antenna [9].

A single antenna can be reconfigured for multiple parameters [10]. Antenna reconfiguration is used to set the antenna to work at a particular frequency depending on needs. This multiband antenna can be configured by adding a switch to the antenna's patch element to determine the antenna's working frequency [11]. A reconfigurable frequency antenna can avoid interruption from different unused frequency bands, thus reducing the demand for filters and simplifying the antenna's shape [12]. This reconfigurable antenna is the best candidate for software-defined radio which can easily adapt to the surrounding environment and can change its function as intended [13]. Reconfiguration antenna can be done using several components, including RF PIN diodes, varactor diodes, and Radio Frequency Micro Electromechanical System (RF MEMS) switches [14]. The PIN diodes have the advantages of a low loss rate and low cost and are often implemented as a reconfigurable antenna. RF-MEMS are more used when power consumption is low and has wide impedance bandwidth, and a varactor diode adjusts the tuning frequency faster [15], [16].

There has been a lot of research on the design of reconfigurable antennas. For example, research [17] studied frequency reconfigurable microstrip antenna achieved by changing the state from the RF switch and using five PIN diodes placed on the patch antenna surface and then connected to the PIC microcontroller. This research giving some conditions with the results obtained also vary depending on the conditions determined earlier. The results work in the frequency range of 850 MHz to 3.3 GHz.

Another research [18] designed an antenna as a mobile PCB with 8 slots shaped like the letter T on the top of the PCB. A pair of PIN diodes are placed in the T slot for the antenna to work as a reconfigurable antenna that can change the frequency from 38 GHz to 28 GHz. This research designs an antenna that works on a particular frequency according to the state of the diode.

The paper [19], proposed two antenna designs working on two modes, single-band, and dual-band. The antenna is shaped like the number 9 (nine) and epsilon. The frequency in dual-band mode is 2.45 and 5.20 GHz while in single-band mode is 3.50 GHz.

Several studies proposed reconfigurable antenna design using PIN diode connected to the antenna to act as a switch with biasing line and Arduino as the reconfiguration setting. In the paper [20], the frequency works at 2.47 GHz, 3.8 GHz, and 5.36 GHz. The paper [21] proposes a MIMO design with the frequency working at 2.4 GHz and 2.6 GHz given different conditions. And paper [22] proposes antenna with L slot using two pin diode placed on the slot to change the working frequency from 4.75 GHz to 5.18 GHz based on the given condition.

The paper [23] presents an N-shaped frequency reconfigurable antenna. Two PIN diodes are used as an auto-switching unit with the help of an Arduino UNO microcontroller. The auto-switching unit is given different conditions to change every 5s delay. The result obtained varies from 1.2 GHz to 6.8 GHz.

This research mainly focused on reconfiguring the frequency of the microstrip antenna applied with a PIN diode acting as the switch between the two patch elements to enable different configurations. This reconfigurable frequency antenna works on 5G frequencies 28 GHz and 38 GHz. It will be given two conditions: ON and OFF. This paper is organized as follows: the antenna design with its Parameter will be discussed in the antenna design section, then the simulation and measurements results obtained will be described in the results and discussions section. Finally, this concludes all the results and analyses obtained.

METHOD

Antenna Design

The antenna design will use two rectangular-shaped patches as the radiating element.

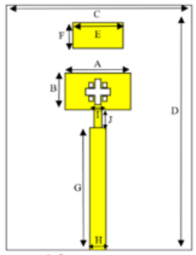


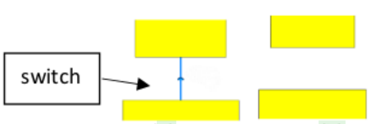
Figure 1. Proposed frequency reconfigurable 5G antenna

RT Duroid 5880 is used as the substrate with a dielectric constant (ε_r) 2.2. Substrate height (h) 0.254 mm, loss tangents (tan δ), and copper thickness = 0.035. Because of its dielectric constant, making RT Duroid is suitable for high-band application [24]. Plus mark (+) Slot with additional four small square-shaped slots in each corner placed on the main patch element to give a better result. The MA4AGBL912 PIN diode is used because it is suitable for high frequencies up to 40 GHz. The antenna parameters are listed in Table 1.

Table 1.The Parameter of the Frequency Reconfigurable Antenna

Dimension	Value (mm)
A	5.2
B	2.9
C	15
D	20
E	4
F	2
G	10
H	1.25
I	0.625
J	1.4

Simulation is done with two conditions which are ON and OFF. The lumped element is placed between the radiation patches and acts as a diode switch to determine the ON condition and in the OFF condition, the lumped element that has been placed between the radiation patches is removed as shown in Figure 2.



(a) (b)

Figure 2. (a) ON condition in simulation with lumped element between the two radiation patches, and (b) OFF condition in simulation without lumped element

The antenna design specification in this research is presented in table 2.

Table 2. The Design Specification of the Proposed Antenna

Parameter	Specification
Frequency	28 & 38 GHz/38 GHz
Return Loss	≤ 10 dB
Gain	≥ 8 dB
Bandwidth	≥ 350 MHz

The characterization of the antenna is done by adding a plus (+) shaped slot in the main radiation element. The slot parameters are shown in Table 3.

Table 3. Parameters of Characterization Slot

Parameters	Value (mm)
Length of the main (+) slot	2
Widht of the main (+) slot	0.5
Length of the additional square slot	0.36
Width of the additional square slot	0.4

The purpose of the slot is to shift the working frequency to obtain the desired frequency at 38 GHz in the main element without changing the shape and size to increase the antenna efficiency as well for novelty [25].

RESULTS AND DISCUSSION

The simulated result of the S parameter antenna resulted from the antenna on both condition configuration is shown in Figures 3.

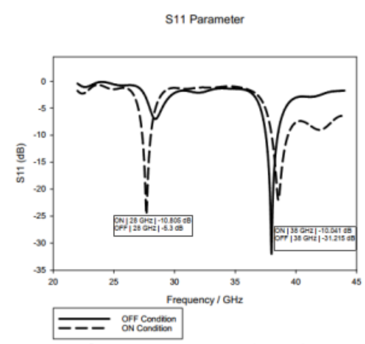


Figure 3. S11 Parameter of the frequency reconfigurable antenna ON and OFF condition

Figure 3 shows the S11 results in 28 GHz only works at ON condition with return loss value -10.805 dB that already satisfy the conditions of the minimum return loss value. In the OFF condition at 28 GHz, the frequency cannot work properly because the return loss value only at -5.3 dB which doesn't satisfy the minimum requirement. For 38 GHz frequency, both ON and OFF conditions can work properly given the return loss value is at -10.041 dB and -31.215 dB which is already meet the minimum requirement of -10 dB.

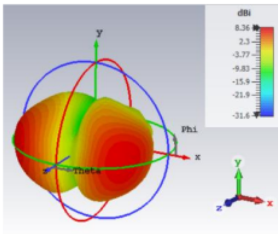
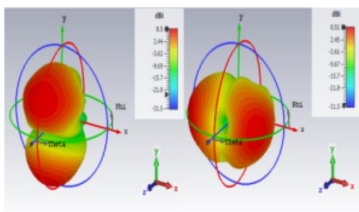


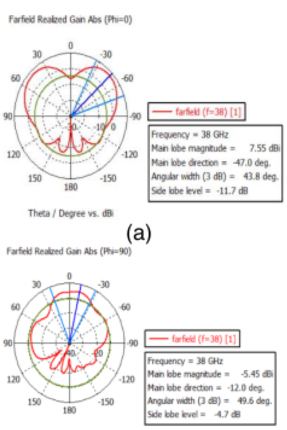
Figure 4. Simulated result of directivity gain frequency reconfigurable antenna OFF condition at 38 GHz



(a) (b)

Figure 5. Simulated result of directivity gain frequency reconfigurable antenna ON condition (a) 28 GHz (b) 38 GHz

Figure 4 and Figure 5 show the directivity gained from the simulation in each condition. For example, in figure 5, the obtained gain for 38 GHz at OFF condition is 8.36 dBi. The gain in ON conditions shown in figure 9 for the frequency 28 GHz and 38 GHz is 8.5 dBi and 8.51 dBi. This shows both conditions have high antenna gain for each working frequency.

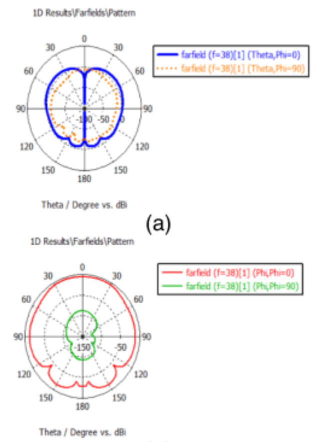


(a)

(b)

Figure 6. 2D radiation pattern of the 38 GHz frequency in the OFF condition (a) E-Plane (Phi=0) (b) H-Plane (Phi=90)

Figure 6 show the 2D radiation pattern for realized gain of 38 GHz in OFF condition in the E-Plane obtained while Phi=0 and H-Plane obtained when the Phi=90. The realized gain obtained in E-Plane and H-Plane is relatively high for 7.55 dBi and -5.45 dBi respectively.

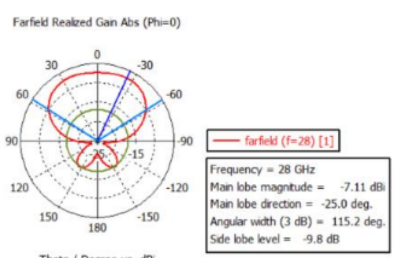


(a)

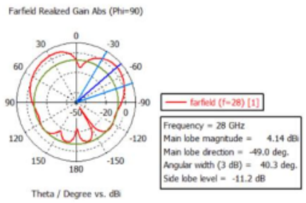
(b)

Figure 7. Co-polarization and cross-polarization of the (a) Theta and (b) Phi of the 38 GHz frequency in OFF condition

Figure 7 is the 2D graphics of the co-polarization and the cross-polarization of the antenna where there figure 7 (a) shows the co-polarization and cross-polarization of theta and figure 7 (b) shows the co-polarization and cross-polarization of phi. The co-polarization of theta is obtained when the phi=90 while cross-polarization of theta is obtained when phi=0. Meanwhile, for co-polarization of phi is obtained when phi=0 and cross polarization of phi is obtained when phi=90.



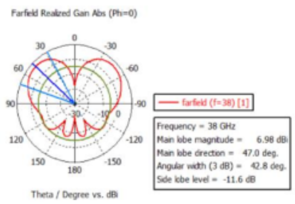
(a)



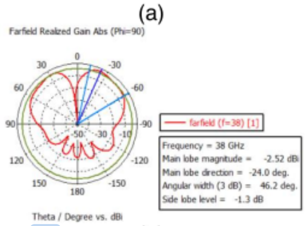
(b)

Figure 8. 2D radiation pattern of the 28 GHz frequency in the ON condition (a) E-Plane (Phi=0) (b) H-Plane (Phi=90)

Figure 8 shows the realized gain 2D radiation pattern for 28 GHz in ON condition for E-Plane -7.11 dB and H-Plane 4.14 dBi.



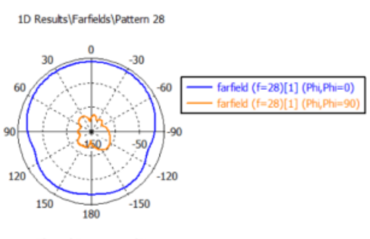
(a)



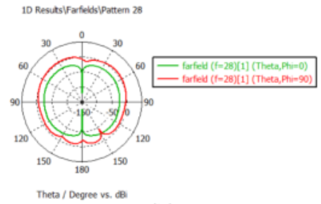
(b)

Figure 9. 2D radiation pattern of the 38 GHz frequency in the ON condition (a) E-Plane (Phi=0) (b) H-Plane (Phi=90)

Figure 9 shows the realized gain 2D radiation pattern for 38 GHz in ON condition for E-Plane 4.14 dBi and the realized gain in the H-Plane is small for only -2.52 dBi.

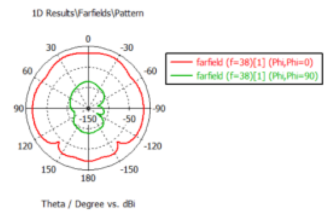


(a)

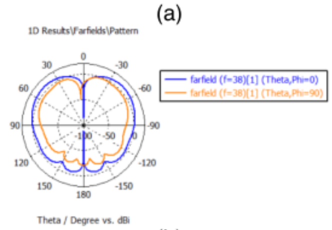


(b)

Figure 10. Co-polarization and-cross polarization of the (a) Phi and (b) Theta of the 28 GHz frequency in ON condition



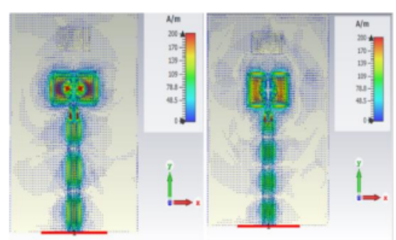
(a)



(b)

Figure 11. Co-polarization and cross-polarization of the (a) Phi and (b) Theta of the 38 GHz frequency in ON condition

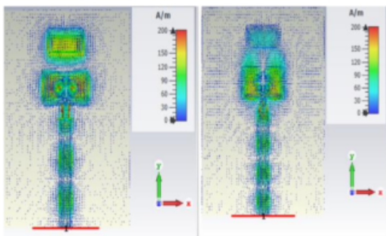
Figure 10 and 11 shows the graphics of the co-polarization and cross-polarization of the antenna in 28 GHz and 38 GHz in the ON condition. The figure 10 and 11 (a) shows the co-polarization and cross-polarization of Phi and figure 10 and 11 (b) shows the co-polarization and cross-polarization of Theta.



(a) (b)

Figure 12. Simulated current flow on reconfigurable antenna OFF condition (a) 28 GHz (b) 38 GHz

Figure 12 shows the simulated current flow on the reconfigurable antenna in the condition of the diode OFF, which only works at a frequency of 38 GHz. It shows that the current flow only enters the main radiating element with a current value of the maximum set in the measurement is 200 A/m. The average value of the incoming current is around 109 to 170 A/m, which implies that the surface current flows in this antenna quite well. While in the second radiating element, there is no incoming current, so at a frequency of 28 GHz cannot operate in the OFF condition



(a) (b)

Figure 13. Simulated current flow on reconfigurable antenna ON condition (a) 28 GHz (b) 38 GHz

Figure 13 shows the antenna current flow in the ON condition. At 28 GHz, the current flows into both radiating elements; thus, it can work well with the maximum value of 200 A/m. The value of the average current flowing on the surface of this antenna is around 90 to 150 A/m and this shows that the current can flow on the surface quite well. At 38 GHz, the current flow is entirely focused on the main radiating element, while the second radiating element has a relatively low current flow. This shows that in the ON condition, the antenna can work well to simultaneously transmit the frequencies of 28 GHz and 38 GHz.

The simulated results from the frequency reconfigurable antenna have shown that the proposed antenna design works appropriately with the different given condition, which is ON and OFF. Furthermore, applying the diode between the two patch elements results in different working frequencies.

The result comparison of the simulated frequency reconfigurable antenna can be shown in table 4 below.

Table 4. The result comparison of OFF and ON conditions of the simulated antenna

Parameter	OFF 28 GHz	OFF 38 GHz	ON 28 GHz	ON 38 GHz
S11(dB)	-5.3	-31.215	-10.805	-10.041
Gain (dBi)		8.36	8.5	8.51
Bandwidth (MHz)	0	36	228	198

Table 4 shows the comparison results for each condition which implies the antenna is working correctly with the diode to act as a switch controlling the ON and OFF condition. The simulation result between the ON and OFF conditions already satisfies the design specification for S11 and gain. However, the bandwidth does not satisfy the requirement for 5G.

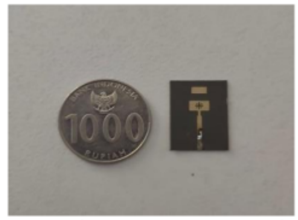


Figure 14. The fabricated proposed frequency reconfigurable antenna

The fabricated antenna in Figure 14 is compared with the Indonesian coin 1000 rupiah. The size of the antenna is tiny because of its high frequency. Therefore, the fabricated antenna is measured manually to see the antenna's performance before the antenna is applied with the switch and microcontroller. The test is done by applying the copper tape to connect the first and second patches to see the antenna's performance in ON conditions.

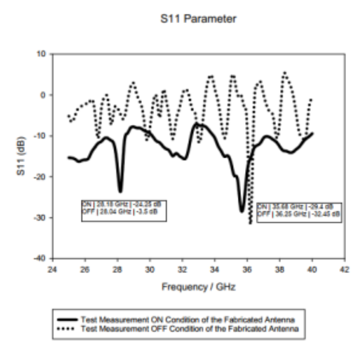


Figure 15. S11 Parameter of the test of the fabricated antenna in ON and OFF condition

The manual test of the fabricated antenna shown in figure 15 shows that the antenna can function as intended in both ON and OFF conditions. The working frequency in the ON condition is 28.18 GHz and 35.68 GHz, with an S11 of -24.25 dB and -29.4 dB, respectively. While in the OFF condition, the frequency 28 GHz only has a return loss value of -3.5 dB and the lowest return loss value at -32.45 dB on 36.25 GHz frequency. The comparison of the simulated and fabricated results is shown in Table 5.

Table 5. Result Comparison of the Simulated and Fabricated Antenna

	Simulated ON	Fabricated ON	Simulated OFF	Fabricated OFF
Frequency (GHz)	28/38	28.18/35.68	28/38	28.04/36.25
S11 (dB)	-10.805/ -10.041	-24.25/ -29.4	-5.3/ -31.215	-3.5/-32.45
Bandwidth (MHz)	228/198	1339/3409	0/35	0/316

As shown in table 5, the reconfigurable antenna can work adequately given the different conditions. In the ON condition, the working frequency is 28 and 38 GHz, while in the OFF condition, the working frequency is only 38 GHz. However, some frequencies in the fabricated antenna are shifted due to many factors, such as fabrication process, antenna soldering, and port feeding. The measurement process can also affect the antenna result. For example, the frequency shifted around 3 GHz and 2 GHz for the working frequency of 38 GHz resulting in ON conditions. As a result, the working frequency is 28 GHz and 35.68 GHz, and in OFF conditions, the working frequency shifted from 38 GHz to 36.25 GHz.

The comparison result of this research and other research are presented in table 6.

Table 6. Comparison Table with Other Research

Research	Frequency	S11	Gain
This Research	28 & 38 GHz/ 38 GHz	-10.805 & -10.041/ -31.215 dB	8.36 – 8.51 dBi
[13]	850 MHz – 3.3 GHz	-	-
[14]	28 GHz/ 38 GHz	-	-
[15]	1.2 GHz – 6.8 GHz	-	2.7 – 3.4 dBi

The comparison is based on the simulation result. The frequency used varies from 850 MHz to 38 GHz. The research [13] focused on changing frequency through various simulations resulting in frequencies ranging from 850 MHz to 3.3 GHz. These authors also focused on radiation patterns; thus, the S11 and gain are not presented. The research [14] has a similar working frequency to our paper; however, the working frequency is only at a single band; given the diode condition, the frequency works only at 28 GHz or 38 GHz. This paper also focused on beam steering resulting in S11 and gain being absent. Research [15] runs many simulations in different conditions resulting in the working frequency is ranged from 1.2 GHz to 6.8 GHz. The S11 Parameter is also not presented in this research. However, this research comparing gains obtained from its different states ranged from 2.7 to 3.4 dBi.

CONCLUSION

The frequency reconfigurable antenna with two radiating patch elements connected by a diode acting as a switch to control the given condition can affect the working frequency. In the ON condition, the current will flow into the second patch element, thus will activate both operating frequencies to make the antenna work as a dual-band in the 28 GHz and 38 GHz. In contrast, in the OFF condition, the current cannot flow into the second patch element resulting in only one working frequency from the main patch element at 38 GHz.

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