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Analysis of Planar Inverted-F Antenna (PIFA) U-Shaped At 2.4-3.7 GHz For 5G Communication

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ABSTRACT

Keywords
5G
PIFA
Return Loss
Gain
Radiation Pattern

PIFA u-shaped is one type of PIFA which is better than other types of PIFA. It has advantages in the form of easy production, simple antenna structure, low production costs, and low specific absorption rate where the antenna can be manipulated by adding pins to the feed to reduce the size of the antenna dimensions. PIFA U-Shaped has two frequency slots, that can work at two different working frequencies which are 2.4 GHz and 3.7 GHz. The PIFA u-shaped design process is carried out by using math formulation and experimental methods with several references of processors journal helps. To simulate it, it uses some software. Magus Antenna is one of them for designing purposes and for simulating and optimizing the Antenna using the CST Studio Suite 2020 software. The PIFA optimization process is carried out by changing the antenna dimension elements, to get the IEEE-defined standards, which are VSWR ≤ 1, reference impedance 50 Ω, and s-parameter below -20dB. The results were obtained in the form of slot 1 antenna that works at a frequency of 2.4 GHz and slot 2 at a frequency of 3.7 GHz. The results obtained are the value of slot 1 and slot 2. VSWR has a value of 1.10090581 and 1.09702511. The return loss is -26.369808 and -26.69439. The gain is worth 3.49 and 2.82. The antenna has a line impedance of 50.150508 Ω which has a tolerance of 0.150508 Ω

1. Introduction

The PIFA antenna is an inverted-F planar antenna that has several advantages, namely it has two slots, each of which can be used for two different frequency signals. [1] The frequency that can be delivered by PIFA is in the mid-band range. The government is still considering the frequencies to be used in 5G communication in Indonesia. On several news portals, it was reported that the frequencies to be used by 5G communications are 2.3 GHz, 700 MHz, 2.6 GH and 3.5 GHz. Therefore, the PIFA antenna is considered suitable for use in 5G communication because it can provide two frequency slots. The frequency taken is the middle frequency that will work in the mid-band, namely the 2.4 GHz and 3.7 GHz frequencies. PIFA has several types of slots, namely PIFA V-shaped, PIFA L-shaped, and PIFA U-shaped. Several journals discuss the three types of PIFA, they describe their advantages and disadvantages.[2] In reference journals, the majority of the results show that the U-shaped PIFA is superior to other PIFA types. Therefore, the researcher designed and analyze the U-shaped PIFA for 5G communication [3].

5G communication is a technology that has a much higher data rate than 4G. [4] The data speed offered by this technology is estimated to reach Gb/s which previously only reached tens of Mb/s. Every communication technology definitely requires an antenna as a transmitter and receiver [5].

An antenna is a tool for sending and receiving electromagnetic waves, depending on the usage and frequency usage. So, in designing the PIFA on 5G, it is necessary to know the 5G frequencies that will be applied in Indonesia first. The parameters of the antenna are VSWR, bandwidth, Return Loss, Line Impedance, and radiation pattern. These parameters are determined with the aim that the antenna can meet the criteria and can work on a 5G network [6].

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2. Method

2.1. Planar Inverted F Antenna

PIFA designs tend to be low profile, lightweight and efficient space-filling structures, and as such, are particularly attractive for the handset and terminal applications. Conventional PIFA designs have constrained bandwidth; however, it is possible to realize novel structures which are electronically tunable over most wireless communication bands. Tunable multi-functional handset modules employ the same basic design aims to provide favorable trade-offs in terms of volume, weight and performance. Many interesting PIFA, and more general tuned printed antennas, have been proposed. Various switching technologies, such as RF switches, MEMs switches, PIN diodes and varactor diodes have been used in reconfigurable antenna designs. The varactor diodes in particular seem to offer a rich possibility for future designs over a wide frequency range, due to their excellent DC voltage-controlled reactance property [7].

For the conventional PIFA antennas, each PIFA-patch element will be designed carefully based on the approximate equation. This equation is a very rough approximation that does not cover all the parameters which significantly affect the resonance frequency of PIFA.

$$F_r = \frac{c}{(4(L_p+W_p)\times\sqrt{\varepsilon r})} \quad (1)$$

Where: F_r : Resonance frequency at desired band;
L_p : Length of the radiating element;
W_p : Width of the radiating element;
εr : Dielectric constant of the substrate;
c : Speed of light.

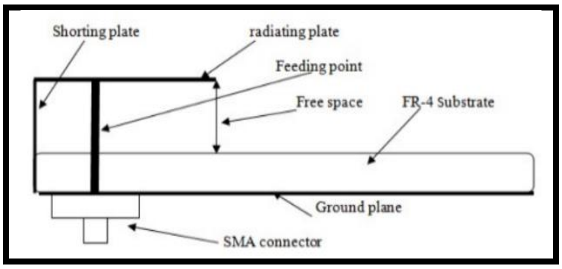

Fig. 1. The geometry of the PIFA antenna proposed

The configuration of the PIFA is shown in Fig. 1. The radiating plate has the dimensions of Wp×Lp (Figure 2.1) and the ground plane dimensions are Wg×Lg. There is an FR-4 substrate has a relative dielectric constant of 4.4 and it is between the rectangular ground plane and radiating plate. The antenna height is h=ha+hs and the space between the top plate and the substrate are also filled with air (free space). In practice, a substrate is generally just underneath the top plate, but this will make the top plate too heavy to be supported by the shorting and feeding plates. The shorting plate with the dimensions of Wsh×h is placed under the top corner of the top plate. The horizontal distance between shorting and feed plates is x. The distance between the coaxial cable and the right edge of the ground plane is Wp/2 and even for shorting plate. The PIFA antenna is fed by a coaxial cable through a subminiature version A (SMA) connector [8].

2.2. Planar Inverted F Antenna U-shaped

Generally, PIFA consists of ground plane, patch, probe or shorting pin which is the connector between patch and ground plane. PIFA can be configured to work at several frequencies, like dualband, triband, and quadband with adding extra slot in its patch. The addition of the slot can affect antenna characteristic, like frequency resonant.

To find the antenna dimensions, length and width, it is necessary to know in advance the parameters of the material to be used, namely dielectric height, dielectric constant, conductor thickness, and material losses. The antenna patch can be calculated using the equation [9].

$$W + L = {}^{\lambda}/_{4} \quad (2)$$

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Where: W = Width of antenna patch;
L = Length of antenna patch;
λ = Wave length.

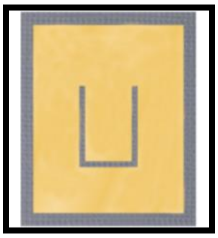


Fig. 2. PIFA U-shaped

The length and width of the slot on the PIFA with the U-shape are calculated in the same way as the L-shape, using equation (1). Example of U-Slot on PIFA is shown in Fig. 2. [10].

2.3. Design Process of U-shaped PIFA

The antenna design process is carried out in the Antenna Magus software. Antenna Magus is a useful software to accelerate the process of designing and modeling an antenna. This software increases efficiency by helping engineers by providing and informing about the choice of antenna elements, for good design. This software is also integrated with the CST Studio Suite 2020 software; therefore, this makes the design process easier [11]. From the software, the parameter obtained:

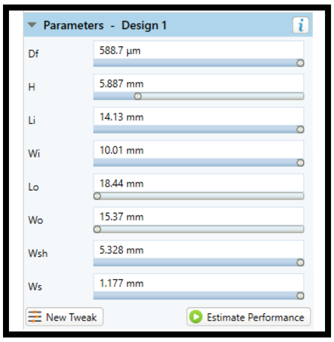
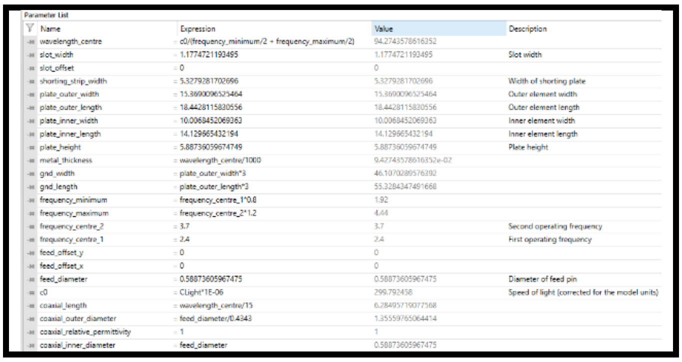


Fig. 3. Dimension parameters PIFA U-shaped in Antenna Magus

The antenna has several dimensions of X, Y, Z, such as: X=15.37 mm. Y=18.44 mm. Z=5.887mm. and Ss=1.568mm.

3. Results and Discussions

The results of the PIFA U-shaped simulation will be shown. The simulation results are the temporary results of the antenna before the antenna goes through the optimization process and get ideal results such as VSWR ≤ 1, reference impedance 50 Ω, s-parameter below -20dB, and working frequencies at 2.4 GHz and 3.7 GHz. From the software, the parameter obtained:



Parameter List

Name	Expression	Value	Description
wavelength_centre	= c0/(frequency_minimum/2 + frequency_maximum/2)	94.2743578616352	
slot_width	= 1.1774721193495	1.1774721193495	Slot width
slot_offset	= 0	0	
shorting_strip_width	= 5.3279281702696	5.3279281702696	Width of shorting plate
plate_outer_width	= 15.3690096525464	15.3690096525464	Outer element width
plate_outer_length	= 18.4428115830556	18.4428115830556	Outer element length
plate_inner_width	= 10.0068452069363	10.0068452069363	Inner element width
plate_inner_length	= 14.129665432194	14.129665432194	Inner element length
plate_height	= 5.88736059674749	5.88736059674749	Plate height
metal_thickness	= wavelength_centre/1000	9.42743578616352e-02	
gnd_width	= plate_outer_width*3	46.1070289576392	
gnd_length	= plate_outer_length*3	55.3284347491668	
frequency_minimum	= frequency_centre_1*0.8	1.92	
frequency_maximum	= frequency_centre_2*1.2	4.44	
frequency_centre_2	= 3.7	3.7	Second operating frequency
frequency_centre_1	= 2.4	2.4	First operating frequency
feed_offset_y	= 0	0	
feed_offset_x	= 0	0	
feed_diameter	= 0.58873605967475	0.58873605967475	Diameter of feed pin
c0	= CLight*1E-06	299.792458	Speed of light (corrected for the model units)
coaxial_length	= wavelength_centre/15	6.28495719077568	
coaxial_outer_diameter	= feed_diameter/0.4343	1.35559765064414	
coaxial_relative_permittivity	= 1	1	
coaxial_inner_diameter	= feed_diameter	0.58873605967475	

Fig. 4. CST Studio Suite 2020 parameter value list before optimization

After the result obtained, and do some optimization, the result changed to:

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3.1. Simulation Result of U-shaped PIFs

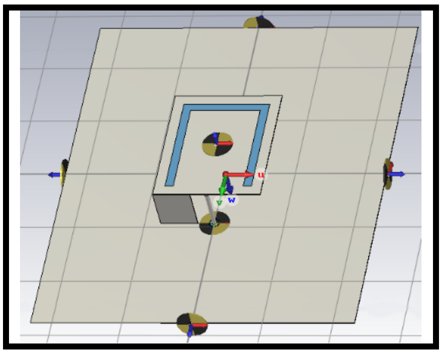
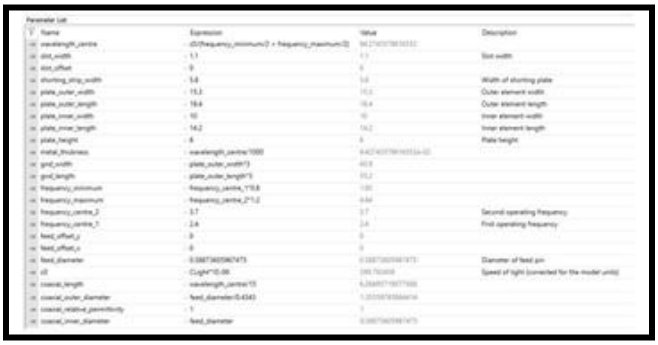


Fig. 5. PIFA U-shaped before optimization

Figure 5 is the simulation result in the CST Studio Suite 2020 software in the form of a PIFA U-shaped antenna displayed in 3D. The simulated antenna can be rotated and enlarged as desired.

3.2. U-shaped PIFA Optimization Results



Parameter List

Name	Expression	Value	Description
wavelength_centre	c0/(frequency_minimum/2 + frequency_maximum/2)	[illegible]	
slot_width	1.1	1.1	Slot width
slot_offset	0	0	
shorting_strip_width	5.6	5.6	Width of shorting plate
plate_outer_width	15.3	15.3	Outer element width
plate_outer_length	18.4	18.4	Outer element length
plate_inner_width	10	10	Inner element width
plate_inner_length	14.2	14.2	Inner element length
plate_height	6	6	Plate height
metal_thickness	wavelength_centre/1000	[illegible]	
gnd_width	plate_outer_width*3	45.9	
gnd_length	plate_outer_length*3	55.2	
frequency_minimum	frequency_centre_1*0.8	1.92	
frequency_maximum	frequency_centre_2*1.2	4.44	
frequency_centre_2	3.7	3.7	Second operating frequency
frequency_centre_1	2.4	2.4	First operating frequency
feed_offset_y	0	0	
feed_offset_x	0	0	
feed_diameter	0.58873605967473	[illegible]	Diameter of feed pin
c0	Clight*1E-06	299.792458	Speed of light (corrected for the model units)
coaxial_length	wavelength_centre/15	[illegible]	
coaxial_outer_diameter	feed_diameter/0.4343	[illegible]	
coaxial_relative_permittivity	1	1	
coaxial_inner_diameter	feed_diameter	[illegible]	

Fig. 6. CST Studio Suite 2020 parameter value list after optimization

After examining changes in antenna dimension elements, optimization of the U-shaped PIFA is simulated in the CST Studio Suite 2020 software. The antenna optimization process will be carried out in the same software. Antenna optimization is done by implementing the research results obtained in Section 4.2. The intended implementation is by using the method of matching and combining antenna dimensional elements so that the antenna parameters are in accordance with the IEEE setting. The antenna parameter set according to IEEE is a VSWR value ≤ 1, reference impedance 50 Ω, s-parameter below -20 dB. From the software, the parameter obtained:

3.2.1. PIFA U-shaped Return Loss Value After Optimization

Figure 7 and Figure 8 are the results of the S-parameter or PIFA U-shaped Return loss after going through the optimization process. The optimization process carried out in the process is to conduct research by changing the antenna dimension element coefficient. Figure 14 will display the return loss value in the first slot of the antenna, while Figure 15 will display the return loss value in the second slot of the antenna. The first PIFA U-shaped slot has a value of -26.369808 at 2.4215 GHz.

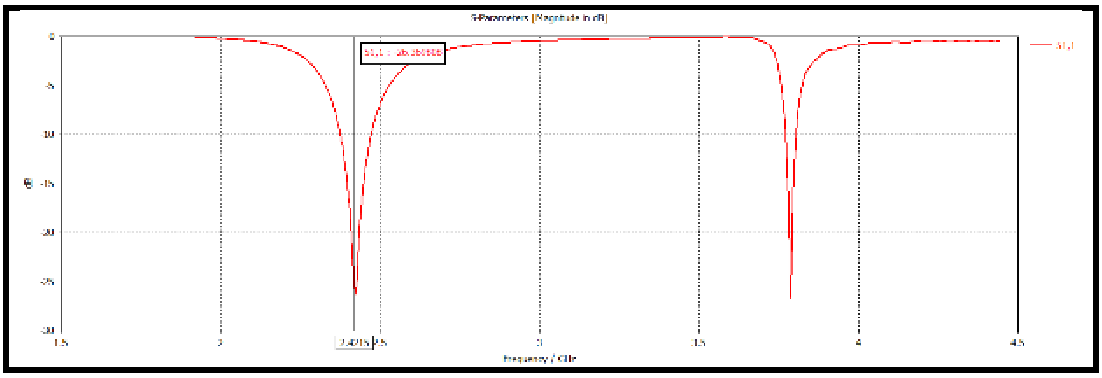


Fig. 7. Return Loss slot 1 PIFA U-shaped after optimization

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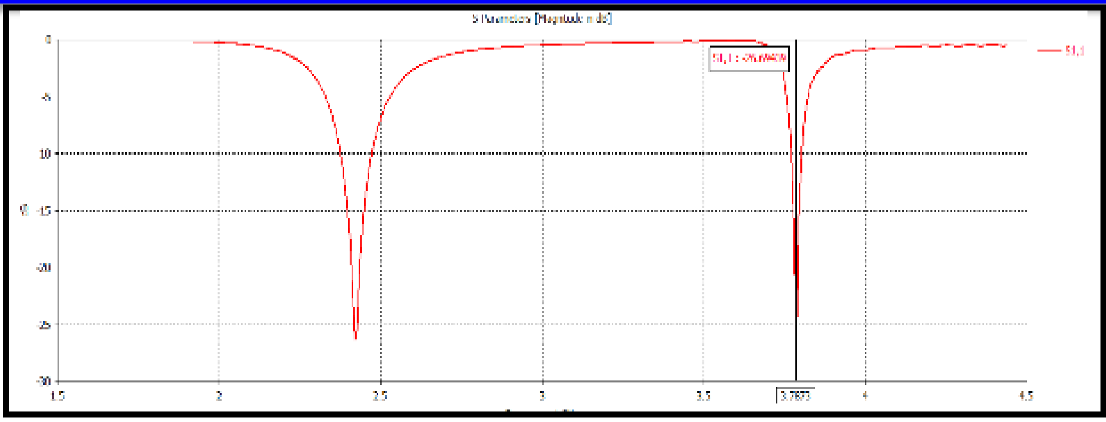

Fig. 8. Return Loss slot 2 PIFA U-shaped after optimization

The second slot PIFA U-shaped has a value of -26.69439 at 3.7873 GHz.

3.2.2. U-shaped PIFA VSWR Value After Optimization

To find the VSWR value, a formula is used as regarding the VSWR PIFA U-shaped value before optimization, where:

$$VSWR = \frac{1+10^{\frac{-RL}{20}}}{1-10^{\frac{-RL}{20}}} \quad (3)$$

Where RL is Return Loss, so we get VSWR for PIFA before optimization which is symbolized by VSWR1 for VSWR value in the first slot, and VSWR2 in the second slot.

$$VSWR = \frac{1+10^{\frac{26.369808}{20}}}{1-10^{\frac{26.369808}{20}}} = 1.10090581 \quad (4)$$

$$VSWR = \frac{1+10^{\frac{26.69439}{20}}}{1-10^{\frac{26.69439}{20}}} = 1.09702511 \quad (5)$$

3.2.3. PIFA U-shaped Line Impedance Value After Optimization

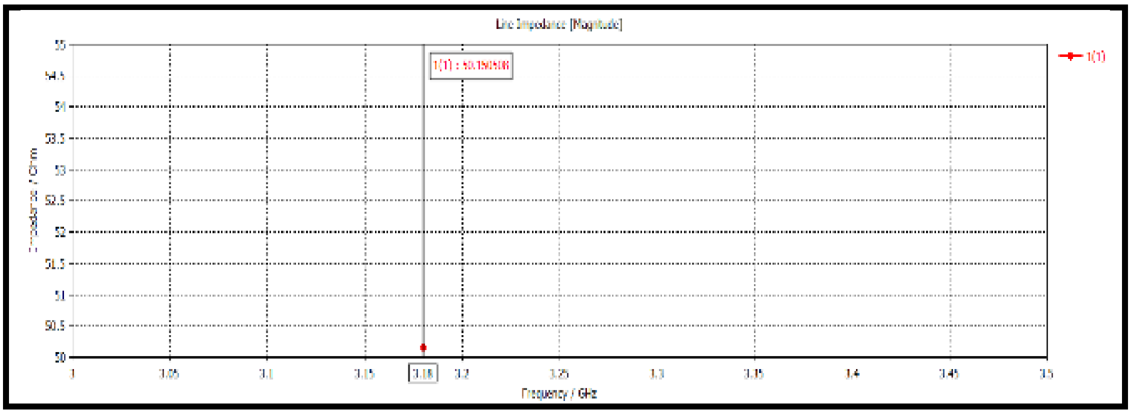

Fig. 9. PIFA U-shaped Line Impedance after optimization

Figure 14 is the Line Impedance PIFA U-shaped value which implementation will be connected to the coaxial transmission media. Coaxial is used because it has a commonly used impedance of 50 Ω. In this study, the value obtained was 50.150508 where the antenna has a tolerance of 0.150508.

3.2.4. U-shaped PIFA Gain Value After Optimization

As explained above, the U-shaped PIFA emission pattern is omnidirectional. In Figure 15 and Figure 16, the antenna gain results are shown in the form of a 2D image with the value in the form of the main lobe magnitude, which is 3.49 dBi at a frequency of 2.4 GHz. This result is the gain in slot 1 PIFA U-shaped.

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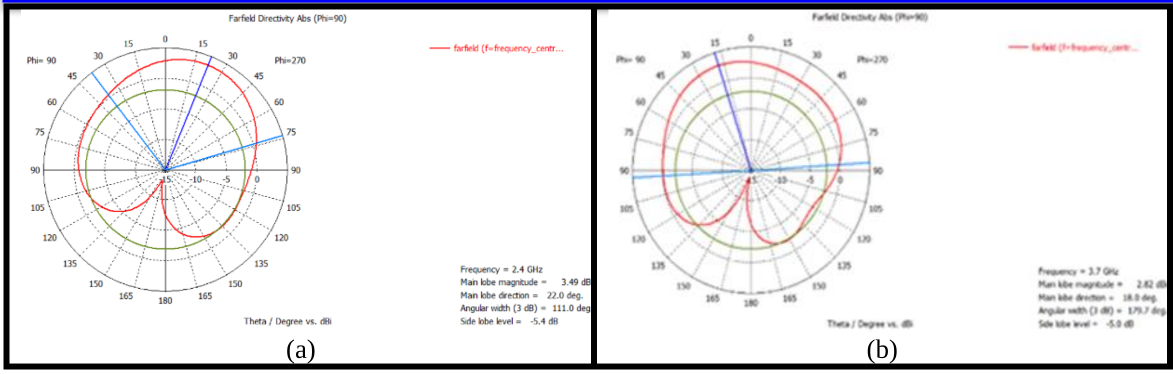
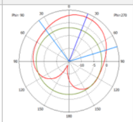
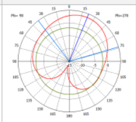


Fig. 10. (a) PIFA U-shaped gain after optimization at 2.4 GHz, (b) PIFA U-shaped gain after optimization at 3.7 GHz

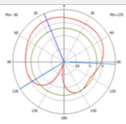
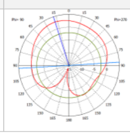
Whereas in Fig. 11. (b) it is explained that the research results are in the form of a gain in slot 2 PIFA U-shaped which gets a value of 2.82 dBi at a frequency of 3.7 GHz.

3.3. Comparison of PIFA U-shaped Before and After Optimization

The process of comparing the PIFA U-shaped results is done by comparing the antenna parameters before and after the optimization process. The comparison results will be displayed in Fig. 11. there are two tables. Comparisons were made with two tables to simplify the reading process. Fig. 11. (a) will present the parameter results in slot 1 PIFA U-shaped, while for slot 2 PIFA U-shaped will be presented in Fig. 11.(b).

	Parameters	Before	After	Error Percentage
1	**Return Loss**	-16.581745	-26.369808	59.02%
	at freq (GHz)	2.4164	2.4215	
2	**VSWR**	1.34802973	1.10090581	18.33%
	at freq (GHz)	2.4164	2.4215	
3	**Line Impedance (Ω)**	50.150508	50.150508	0
	Tolerance (Ω)	0.150508	0.150508	
4	**Gain (dBi)**	3.5	3.49	0.3%
5	**Radiation Pattern**			

(a)

	Parameters	Before	After	Error Percentage
1	**Return Loss**	-17.68195	-26.69439	50.97%
	at freq (GHz)	3.7848	3.7873	
2	**VSWR**	1.30040472	1.09702511	15.64%
	at freq (GHz)	3.7848	3.7873	
3	**Line Impedance (Ω)**	50.150508	50.150508	0
	Tolerance (Ω)	0.150508	0.150508	
4	**Gain (dBi)**	2.32	2.82	17.73%
5	**Radiation Pattern**			

(b)

Fig. 11. The Comparison Result of (a) Slot 1 and (b) Slot 2

Error percentage is the comparison percentage between before and after. Error percentage can be calculated by (5):

$$Error\ Precentage = \frac{(|Before - After|)}{(|Before|)} \times 100\% \qquad (6)$$

For the gain of slot 2 can be calculated by:

$$Error\ Precentage = \frac{(|After - Before|)}{(|After|)} \times 100\% \qquad (7)$$

Because the after value is bigger than Simulation.

4. Conclusion

Based on the previous four chapters, objectives, research methods, analysis, and research results, several points can be concluded, such as:

1. The research is focused on the design and simulation of a U-shaped PIFA antenna for 5G communication at 2.4 GHz and 3.7 GHz working frequencies;
2. There are several important aspects in the design, namely the dimensional elements of the antenna. This research discusses the effect of changes in antenna dimensional elements on changes in the

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results of antenna parameters. The antenna dimensions discussed include the diameter of feed pin, plate height, inner element length, inner element width, outer element length, outer element width, width of shorting plate, and slot width;

3. The research results are shown by describing the simulation results of the PIFA U-shaped after optimization to obtain antenna parameters. The results obtained are VSWR which is divided into slot 1 which gets a value of 1.10090581 and slot 2 which has a value of 1.09702511. The return loss value obtained in slot 1 is -26.369808, and slot 2 is -26.69439. The gain obtained in slot 1 is 3.49 dBi and in slot 2 is 2.82 dBi. PIFA U-shaped can work with coaxial transmission media with an antenna line impedance of 50.150508 Ω.

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