Analysis of Planar Inverted-F Antenna (PIFA) U-Shaped at 2.4-3.7 Ghz for 5G Communication

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ABSTRACT

The PIFA u-shaped design process is carried out by using math formulation and experimental methods with several reference of processors journal helps. For simulate it, it uses some software. Magus Antenna is one of them for designing purpose and for simulating and optimizing the Antenna is 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 is VSWR ≤ 1, reference impedance 50 Ω, and s-parameter below -20dB.

The results 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.

Keywords

5G Communications, Planar Inverted-F Antenna (PIFA), PIFA U-Shaped, Antenna parameters, VSWR, Line Impedance, Return Loss, Gain, Radiation Pattern.

1. INTRODUCTION

The PIFA antenna is an inverted-F planar antenna which 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. In several journals that 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, researcher design 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]

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]

2. PLANAR INVERTED F ANTENNA

PIFA designs tend to be low profile, light weight and efficient space filling structures, and as such, are particularly attractive for handset and terminal applications. Conventional PIFA designs have constrained bandwidth; however, it is possible to realize novel structures which are electronically tunable over most of the 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 approximately equation. This equation is a very rough approximation which does not cover all the parameters which significantly affect the resonance frequency of PIFA.

$$Fr = c/(4(Lp + Wp)\sqrt{\varepsilon r}) \quad (1)$$

Where:

fr is the resonance frequency at desired band.

Lp is the length of the radiating element.

Wp is the width of the radiating element.

εr is the dielectric constant of the substrate.

c is the speed of light.

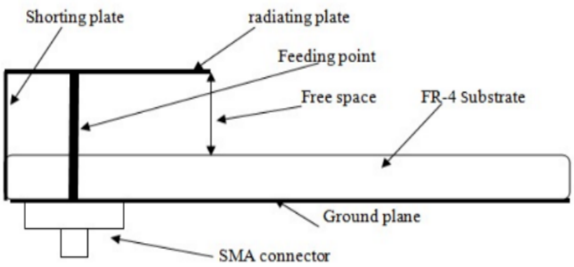

Figure 1. The geometry of the PIFA antenna proposed

The configuration of the PIFA is shown in Figure 1. The radiating plate has the dimensions of Wp×Lp (Figure 2.1) and 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]

3. 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]

$$W + L = \lambda/4 \qquad (2)$$

Where:

- W is the width of antenna patch.
- L is the length of antenna patch.
- λ is the wave length.

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 Figure 2.[10]

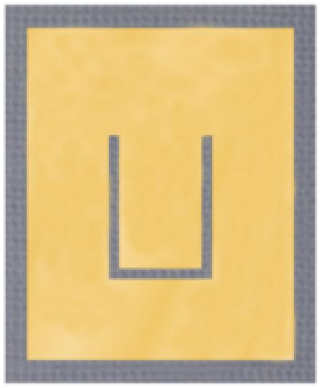

Figure 2 PIFA U-shaped

4. 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:

Figure 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.

5. SIMULATION PROCESS OF U-SHAPED PIFA

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	

Figure 4 CST Studio Suite 2020 parameter value list before optimization

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

6. SIMULATION RESULT OF U-SHAPED PIFA

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.

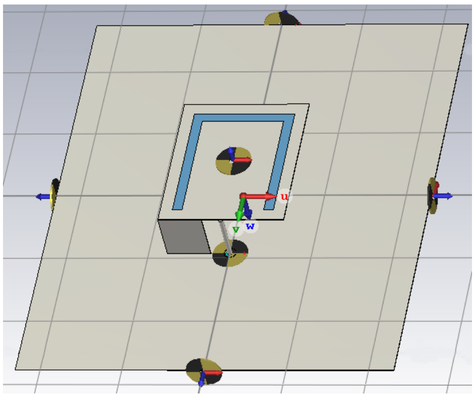

Figure 5 PIFA U-shaped before optimization

7. U-SHAPED PIFA OPTIMIZATION RESULTS

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:

Parameter List

Name	Expression	Value	Description
wavelength_centre	= c0/(frequency_minimum/2 + frequency_maximum/2)	94.2743578616352	
slot_width	= 1.2	1.2	Slot width
slot_offset	= 0	0	
shorting_strip_width	= 5.5	5.5	Width of shorting plate
plate_outer_width	= 15.5	15.5	Outer element width
plate_outer_length	= 18	18	Outer element length
plate_inner_width	= 10	10	Inner element width
plate_inner_length	= 14	14	Inner element length
plate_height	= 6	6	Plate height
metal_thickness	= wavelength_centre/1000	9.42743578616352e-02	
gnd_width	= plate_outer_width*3	46.5	
gnd_length	= plate_outer_length*3	54	
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	

Figure 6 CST Studio Suite 2020 parameter value list after optimization

7.1 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.

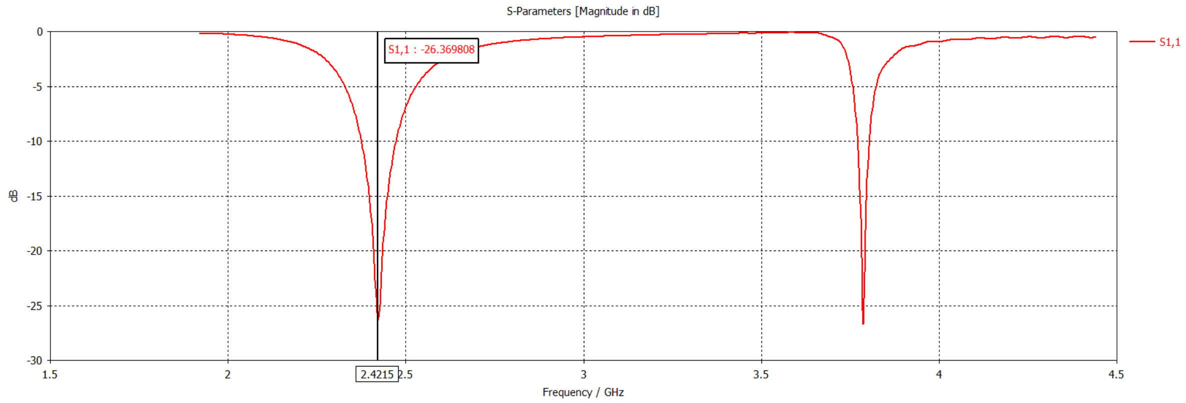

Figure 7 Return Loss slot 1 PIFA U-shaped after optimization

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

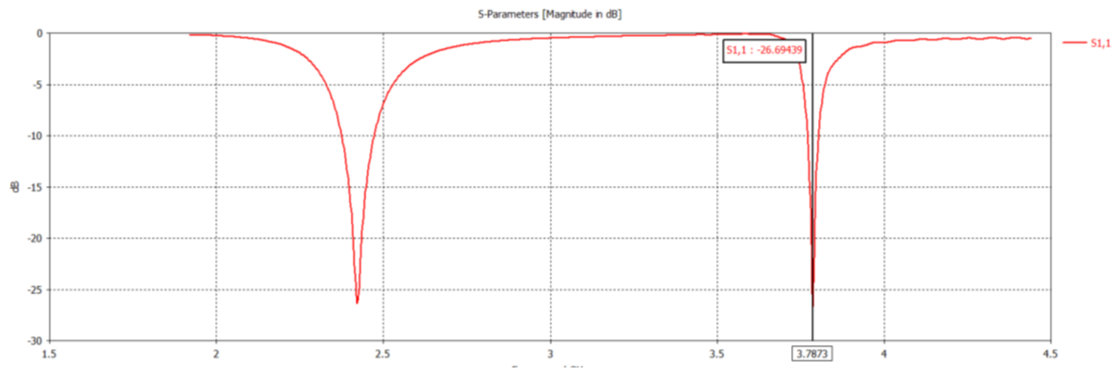

Figure 8 Return Loss slot 2 PIFA U-shaped after optimization

7.2 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

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

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.

7.3 PIFA U-shaped Line Impedance Value 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.

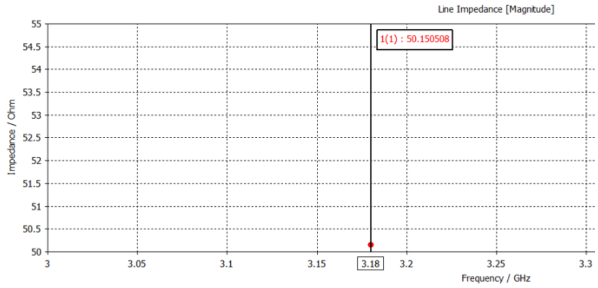

Figure 9 PIFA U-shaped Line Impedance after optimization

7.4 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.

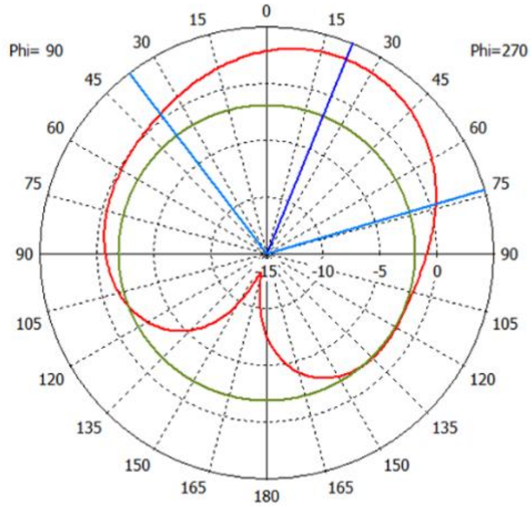

Figure 10 PIFA U-shaped gain after optimization at 2.4 GHz

Whereas in Figure 18 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.

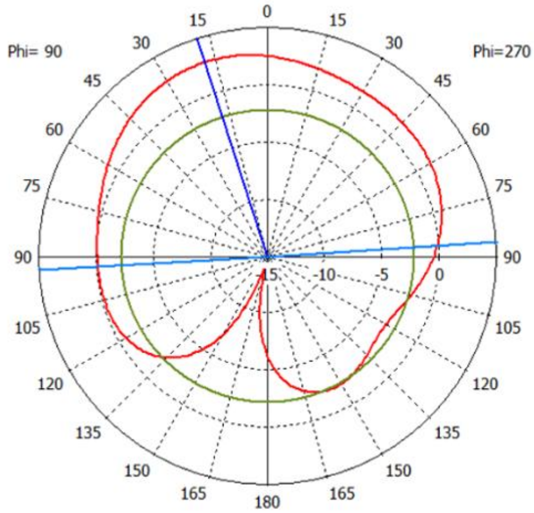

Figure 11 PIFA U-shaped gain after optimization at 3.7 GHz

8. 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 two tables, namely table 1 and table 2. Comparisons were made with two tables to simplify the reading process. Table 1 will present the parameter results in slot 1 PIFA U-shaped, while for slot 2 PIFA U-shaped will be presented in table 2.

Table 1 The Comparison Result of Slot 1

	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%

Table 2 The Comparison Result of Slot 2

	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%

Error percentage is the comparation percentage between before and after. Error percentage can be calculated by equation:

$$Error\ percentage = (|before - after\ |)/(|before|)\ X\ 100\% \quad (5)$$

For the gain of slot 2 can be calculated by:

$$Error\ percentage = (|after - before|)/(|after|)\ X\ 100\% \quad (6)$$

Because the after value is bigger than Simulation.

9. CONCLUSIONS

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 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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