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Design And Analysis Of Antenna Microstrip Patch Pi Slot Array Four Elements With Proximity Coupling Method For Multi Wide Band Characteristics

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ARTICLEINFO	ABSTRACT

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This research has described the design and realization of a pi-slot patch microstrip antenna array four elements who optimized by using proximity coupling method for multi wideband which is tested on frequency of 1-10 Ghz. The proximity coupling method is used to widen the bandwidth and increase the return loss value of the antenna. Based on the measurement results, it is known that the antenna designed has met the requirements of multi wide band because it has six operating frequencies with the best return loss value -30.44 dB VSWR ≤2 at a frequency 5.388 Ghz with bandwidth 90 Mhz. And for the widest bandwidth 202 Mhz at a frequency 8.560-8.762 Ghz with return loss -12,19 dB VSWR ≤2

1. Introduction

Nowadays, wireless telecommunications networks inovation was develop not only in terms of technical specifications but also in applications. The development in this technology such as 4G, 5G to 6G cellular broadband [1], IoT [2] , LoRa [3], and Open RAN [4]. This many inovation in wireless telecommunications network is directly proportional with the growth of users in this technology. The increase of user made a new problem regarding the lack of frequency spectrum capacity, because the frequency spectrum is a limited natural resource and its uses are regulated by law. One solution for this issue is widening the bandwidth by using Ultra Wideband (UWB) technology. UWB able to provide new radio services that can coexist with existing radio systems, have low interference, and super wide bandwidth making it have very high data transfer rates. [5]

Based on this phenomenon, this research was conducted to obtain the characteristics of an antenna with a wide bandwidth (wideband) and able to work on several frequencies at once (multiband).

Several previous studies have produced antenna designs with multiband and at the same time wideband characteristics, such as; research [6] conducted an optimization of the multiband microstrip antenna design using the PSO algorithm; Research [7] conducted trials on designing a rectifier antenna with wideband characteristics; Research [8] has designed a monopole antenna with multiband characteristics using CPW technique for GSM/WLAN/WiMAX applications. Research [9] designed a multiband antenna that can be integrated into smartwatch devices. This sample of research shows that studies on the concept of multiband and wideband antennas are still very needed at this time and for future.

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From the various antenna design studies that have been referred previously, it found that one of the popular antennas types being developed today is microstrip antenna. Microstrip means a thin electrical conductor that is separated from ground by an insulating layer or gap filled with air. Microstrip antenna means an antenna that in the manufacturing process uses a microstrip device. The basic form of a microstrip antenna consists of three layers, a patch at the top which functions as a radiator, a dielectric substrate at the patch, and a ground plane at the base of the antenna. Patches are generally made by copper, silver, a mixture of silver with palladium or gold. Patches are usually square, rectangular, circle, triangle, or elliptical. [10]

In this study, an experiment design and manufacture of microstrip antennas using pi-Slot patch will be carried out in an array of four elements. This Pi-Slot patch design is referred to previous studies, the research of Rakesh Kumar and Tripathi Rajesh Khanna who designed a pi-slot microstrip patch antenna capable of producing dual band characteristics [11], research by Ambros and Iskandar which was able to produce multiband characteristics with a two-element pi-slot array patch design [12], research by Er. Nitin Agarwal who tested the pi patch design and succeeded in obtaining a bandwidth of 200 MHz [13], research by Amit A. Deshmukh who tested the design of a pi patch microstrip antenna and succeeded in obtaining three-frequency multiband characteristics [14], research by Sayantan Mazumder who tested the pi patch design and obtained multiband characteristics [15], as well as research from Vinay Sharma who tested the pi slot patch design and succeeded in obtaining an antenna capable of working at a frequency of 5.2 GHz (WLAN) [16]. In this study, a fork-shaped feed line was tested with a pi-slot patch in an array of four elements and combined with the proximity coupling technique.

This research was carried out up to the manufacturing stage to prove whether the prototype of this pi-slot patch can properly produce multi-wide band characteristics at the time of measurement with VNA. Hopefully the results have a wider bandwidth than previous studies (> 100 MHz), get multiband characteristics with more than four operating frequencies, and at least one operating frequency is in accordance with the standart of working frequency in current wireless applications.

2. Research Methods

This research can be categorized as an experiment, because in the antenna design, we try adding patch antenna variable and compared with previous research with less patch to see the changes of parameters occurred. However, literature studies based on journal and book references must still be carried out first so that the experiments still have a strong theoretical basis.

The antenna is designed using Fr4 substrate material which has a relative dielectric constant (ε_r) 4.4 , has a thickness 1.6 mm, and use copper as a material for feeders and patches. The substrate Fr4 was chosen because this type is easy to obtain, the price is affordable and many previous studies have been using this substrate. The stages of this research process can be seen in Figure 1 below :

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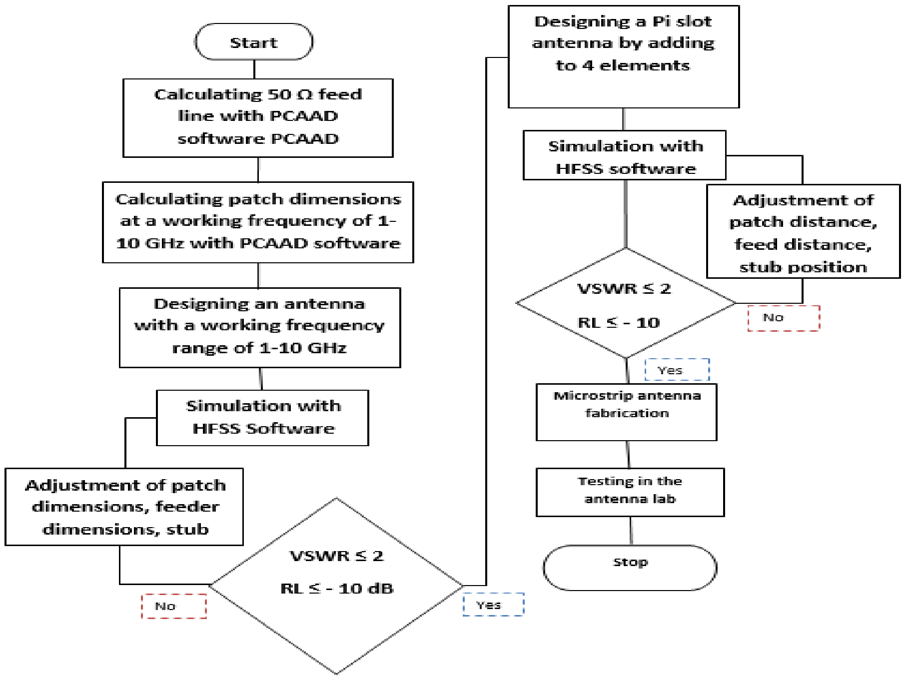

Fig 1. Antenna Design Flowchart

3. Result and Analysis

3.1 Antenna Design Stage

In designing this antenna, the first thing to do is to determine the dimensions of antenna. In this study we provide three antenna simulation designs with each design having a different number of elements, but the dimensions of patches elements, slots and feeders have the same size. We do this so after that we can see the impact of increasing elements with the results of return loss and VSWR. We also can be seen the effect of changing the distance of tunning stub with antenna bandwidth.

a. Antenna Dimension Calculation

First of all, we calculate the width of antenna feeder. PCAAD simulator software was used referring to previous studies [13]. In the simulation it was found that for a dielectric constant 4.4 (Fr4 epoxy) and the impedance characteristic 50 Ω, the appropriate feeder width is 0.304 cm.

After got the feeder width, we continue to calculate the dimensions of patch antenna. To find the length and width of antenna patch, we also use the PCAAD software simulator. In the simulation results was found that for a center frequency of 2.298 Ghz (tested frequency range 1-10 Ghz), a dielectric constant 4.4 (Fr 4 epoxy), 0.3 cm feed line (rounded from 0.304) found the patch length is 3.3 cm and the patch width is 2.6 cm.

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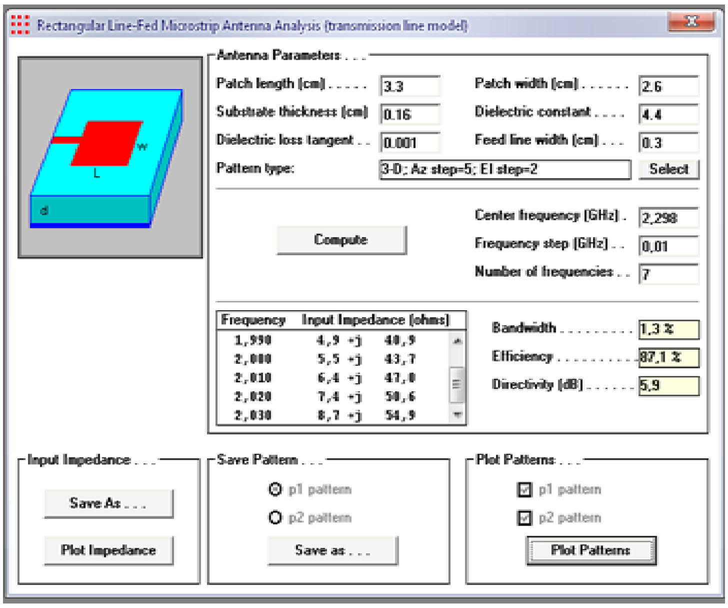
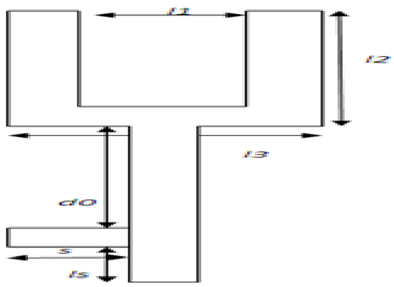


Fig 2. Simulation of Patch Dimensions with PCAAD

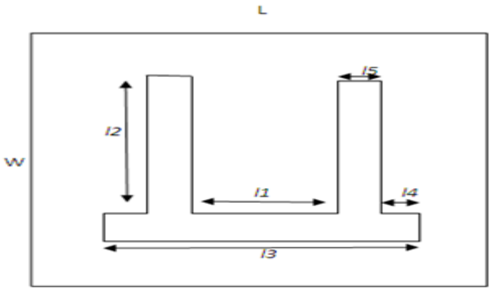
b. Fixed Dimension Design

At this stage the feeder size and the patch size who found by PCAAD simulation before will be inputted into HFSS 3D antenna design software. When all size found by PCAAD before are inputted into the single element HFSS antenna design, the results of antenna simulation don't meet the criteria for multiband antenna because just only one frequency has a return loss < -10dB and VSWR < 2 in frequency test 1-10 GHz. So that to meet the criteria of multiband antenna in HFSS simulation, the siza who found by PCAAD before are changing repeatedly, until got at least two frequencies with return loss < -10dB and VSWR < 2. After repeated simulation with HFSS, finally we found the single element antenna with multiband characteristics. The dimensions of antenna that have been found will be used as a fixed size for further experiments with array techniques. The dimensions size of the fixed antenna can be seen in figure 4 a and 4 b



(d0=1,9 cm, ls=0,8, s= 0,5, l1= 1cm, 12= 1 cm, l3= 1,6 cm)

Fig 3. Feed line geometry



(l1= 0.6cm, l2= 1.6 cm, l3= 1.8cm, l4= 0.2cm, l5= 0.4cm, W= 3cm, L= 3cm)

Fig 4. Pi-slot Patch Geometry

3.2 Four Element Antenna Design

The size of patch, slot, and feeder as shown in Figures 4a and 4b will be used in HFSS simulation for four elements. This simulation experiment will be combined the proximity coupling method [17] and the array technique [18]. The upper layer of substrate is used for patches and slots, and the lower layer of substrate is used for feeding and earthing. In the simulation process, after got the multiband characteristic, we try to obtained the result of return loss, VSWR and bandwidth with tuning the stub(s) [19]. The picture of four elements antenna design can show in figure 5 below :

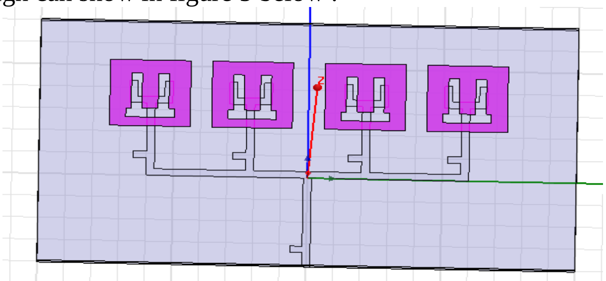


Fig 5. Four Elements Antenna Design with HFSS Software

After try multiple simulation design process, we found the best simulation result for four elements antenna are four operating frequencies that work <-10 dB, and VSWR <2. The first is frequency 2.70 GHz - 3.07 GHz with a return loss value of -14.76 dB (bandwidth = 0.37 GHz). The second is frequency 4.24 GHz – 4.35 GHz (bandwidth = 0.19 GHz) with a return loss -29.19dB. The third is frequency 4.71 GHz – 4.85 GHz (bandwidth = 0.14 GHz) with a return loss -22.94dB. The fourth is frequency 8.04 GHz – 8.45 GHz (bandwidth = 0.41 GHz) with a return loss -18.72dB. The return loss graph for the four element antenna simulation can be seen in Figure 6 below:

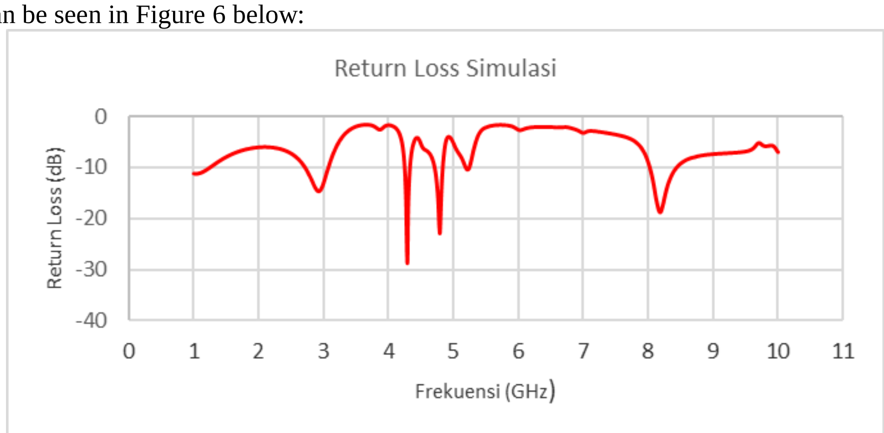


Fig 6. Return Loss Graph of Simulation Results

From the figure 6 we can see that there are two operating frequencies that have a wide bandwidth and the other two operating frequencies have a narrow bandwidth. But, the operating frequency that has a narrow

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bandwidth has a much better return loss value than the wide bandwidth. Meanwhile, the VSWR graph results of the four-element simulation can be seen in Figure 7 below:

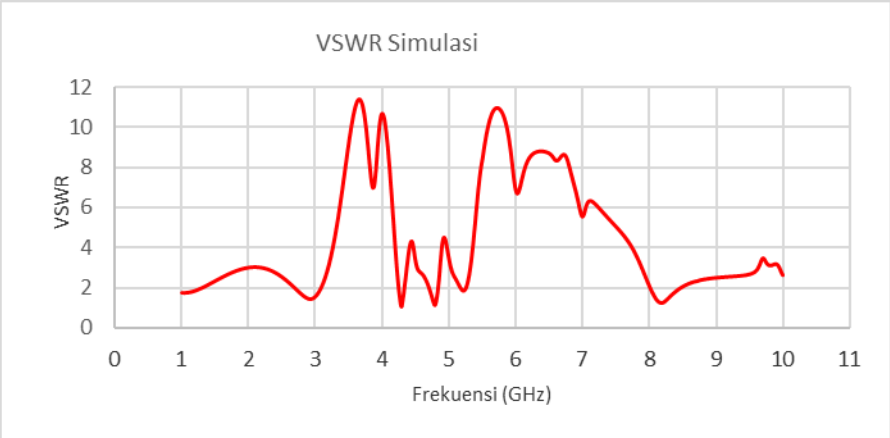

Fig 7. VSWR Graph of Simulation Result

From the VSWR graph in figure 7, we can see that the best VSWR value for four elements simulation is 1.07 which is at frequency 4.30 GHz and the lowest VSWR value is 1.46 which is at 2.92 GHz frequency.

3.3 Antenna Measurements

The size of antenna four elements design that already simulated before will be printed on real FR4 substrate first to be measurements in antenna laboratory by using WILTRON model 37347A Vector Network Analyzer which can work in 40 MHz – 20 GHz frequency range. Before starting the measurement, the VNA instrument is calibrated first to match the tested frequency range 1GHz – 10 GHz. The antenna measurement process can be seen in figure 8.

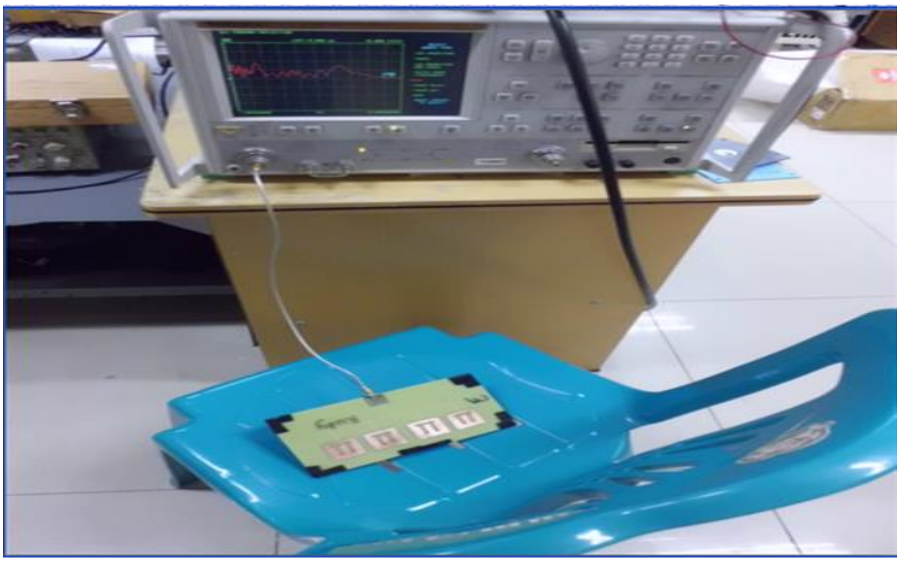

Fig 8. Antenna Measurement Process

The parameters of measurement are return loss and VSWR. VSWR (Voltage Standing Wave Ratio) is the ratio of maximum standing wave amplitude to the minimum. The magnitude of the VSWR value varies from 1 to ~ (infinity). The higher the VSWR, the greater the discrepancy. Ideally the VSWR value is 1, but in theory used a VSWR tolerance of 2. Return Loss is the ratio of the power reflected by the antenna to the power fed into antenna from transmission line. A good antenna has a return loss lower than –10 dB. [20] In this study, the antenna design chosen for manufacturing and measuring is a four-element design.

a. Return Loss Measurement

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Measurement result of the antenna return loss based on -10dB parameter produces six operating frequencies, there are 1.67GHz – 1.68 GHz (bandwidth = 0.01 GHz) with a return loss -13.72 dB, a frequency of 3.4075 GHz - 3.475 GHz (bandwidth = 0.0675 GHz) with a return loss -17, 09 dB, frequency 3.970 GHz - 3.992 GHz (bandwidth = 0.022 GHz) with return loss -11.71 dB, frequency 4.802GHz – 4.870 GHz (bandwidth = 0.068 GHz) with return loss -17.49 dB, frequency 5.342 GHz - 5.442GHz (bandwidth 0.10 GHz) with a return loss of -30.44, and a frequency of 8.560GHz - 8.762 GHz (bandwidth 0.202 GHz). The graph of return loss measurement result can be seen in Figure 9 below:

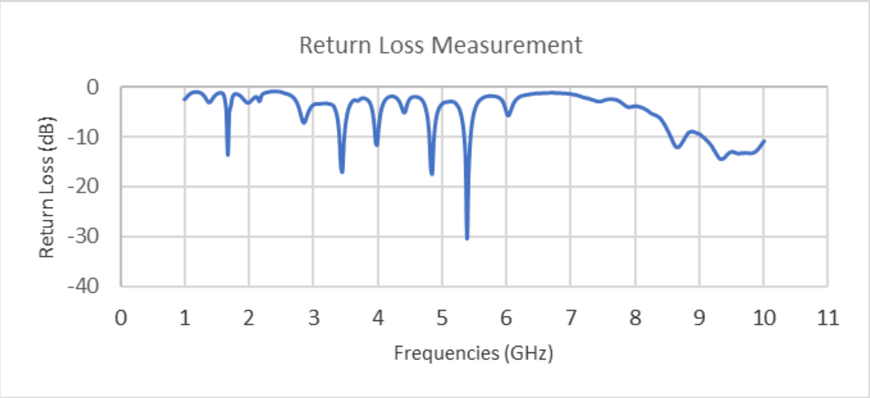

Fig 9. Return Loss Measurement Result

b. VSWR Measurement Result

The VSWR measurement results also obtained six operating frequencies that have VSWR ≤ 2, the frequency is 1.675 GHz – 1.676 GHz, frequency 3.407 Ghz – 3.4750 GHz, frequency 3.970 GHz – 3.992 GHz, frequency 4.8250 GHz – 4.870 GHz, frequency 5.365 GHz - 5.455 GHz and frequency 8,560 GHz – 10 GHz. The graph of the VSWR measurement results can be seen in Figure 10 below:

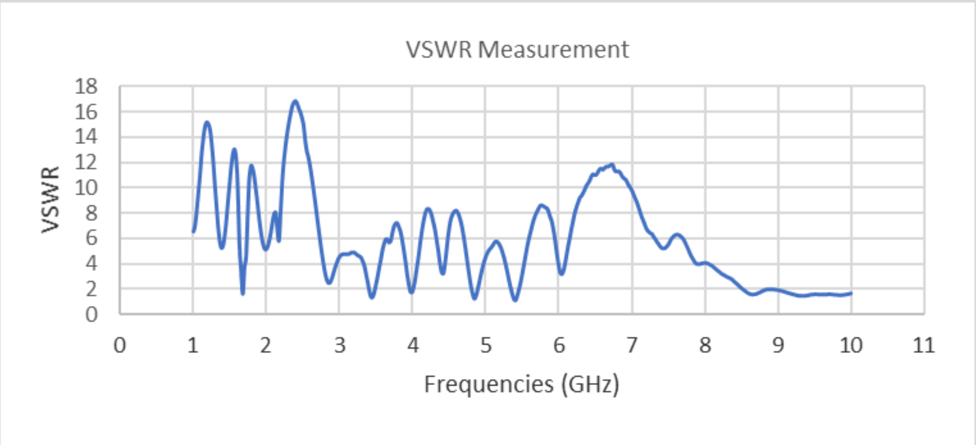

Fig 10. VSWR Measurement Graph

c. Input Impedance Result

In this study, the input impedance of the four-element antenna was not measured using the WILTRON VNA tool so that the impedance analysis was made based on the simulation results on the HFSS software. The simulation results in Figure 16 show that at several frequencies in the antenna design, the input impedance requirement is 50. As a sample impedance 50.013368 at a frequency of 2.7 GHz, 50.467706 at a frequency of 4.15 GHz, 50.476840 at a frequency of 4.79 GHz, 50.408017 at a frequency of 4.99 GHz, 51.228151 at a frequency of 5.3 GHz, and 50.035507 at 6.19 GHz.

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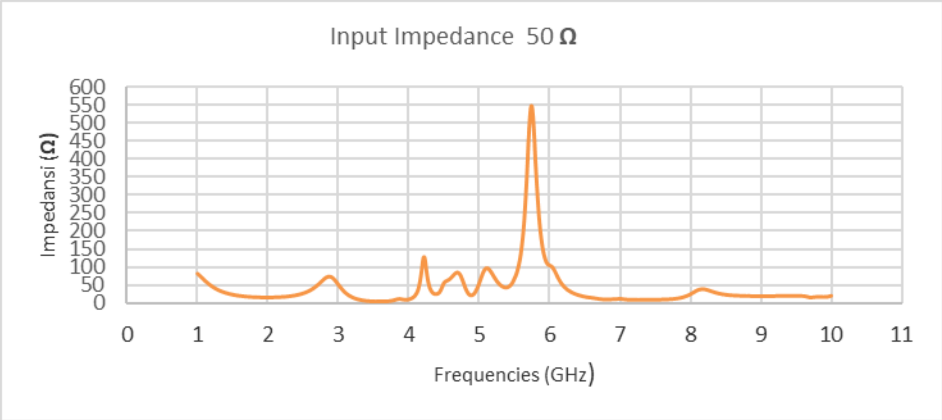

Fig 11. Input Impedance 50 Ω Graph

3.4 Analysis

Based on the graphs of measurement results in Figures 9 and 10, it can be seen that there has been a very significant frequency shift and even a discrepancy in operating frequencies at the lower and upper frequencies. This is reinforced by the finding that the simulation results with HFSS software only produce four operating frequency bands, whereas when the same dimensions antenna are used for fabrication and measurements, the results on the VNA are six operating frequencies. Measurement results with VNA have also shown that the fabricated antenna can be categorized as a microstrip antenna with multiwideband characteristics. This is because the antenna has a bandwidth of 100MHz for measurement of return loss at operating frequency 5,342 GHz - 5,442GHz (bandwidth 0.10 GHz) and at operating frequency 8,560 GHz - 8.762 GHz (bandwidth 0.202 GHz). The wideband characteristic (≥ 100 MHz) is also found in the VSWR measurement at the operating frequency of 8,560 – 10 GHz (1,430 GHz).

In this study we also found the increase of antenna elements with array technique will be impact to return loss and operation bandwidth. That will seen in table 1 below:

Table 2

Changes in the number of slots on return loss

No	Slot	*Best Return loss* (dB)	*Lowest Return loss* (dB)	Information
1	1	-15,53	-12,13	Consists of 2 operating bandwidth
2	2	-22,79	-11,35	Consists of 3 operating bandwidth
3	4	-29,11	-14,85	Consists of 4 operating bandwidth

From this table we can said that in general, the performance of antenna will increase with the increase in number of elements designed by using array technique. Another finding in this research about the impact of change the stub distance (d0) to the widening of bandwidth in the four element antenna design.

Table 2

Changes in d0 to bandwidth

No	Stub distance d0 (cm)	*Widest Bandwidth (GHz)*	*Narrowest Bandwidth (GHz)*	Information
1	3	0,10	0,05	Consists of 3 operating bandwidth
2	3,2	0,14	0,03	Consists of 3 operating bandwidth
3	3,4	0,45	0,12	Consists of 3 operating bandwidth

From table 2 above, we can see that changes in the stub distance d0 in the four-element antenna design have an effect on changes in the width of the antenna bandwidth. The maximum bandwidth is generated at d0 = 3.4 cm, namely the widest bandwidth = 0.45 GHz and the narrowest bandwidth = 0.12 GHz with four operating bands. If d0 = 3.2 cm, there is a reduction in the width of the bandwidth, either in the widest or narrowest bandwidth, namely the widest = 0.14 GHz and the narrowest = 0.03 GHz. If d0 3 cm there is also a reduction in the width of the bandwidth at the widest bandwidth, which is 0.10 GHz for the widest bandwidth and 0.5 GHz for the narrowest bandwidth. However, there is no change for the number of operating bands if the distance of d0 is 3.2 cm and 3 cm, which is fixed in the three operating bands.

4. Conclusion

Based on simulation experiments, the results of measuring antenna parameters with VNA, and the comparison data of antenna dimensions, several conclusions can be drawn:

a. Based on the obtained of return loss and VSWR parameters, this research has succeeded in designing and realizing a prototype of a four-element pi-slot microstrip patch antenna using proximity coupling method with multi wideband characteristics.
b. Proximity coupling method can produce wide bandwidth on microstrip antenna
c. An increase in the number of elements with array technique will impact to increasing number of operating bands of the antenna
d. Changes in stub position will impact in bandwidth.
e. The measurement results did not find ultra-wideband (UWB) characteristics in the operating frequency range of 1-10 Ghz, but found one frequency that worked at 5.3 GHz with a bandwidth of 100 Mhz, return loss -30,437 and VSWR 1.19 which could be used for WLAN 802.11a applications.

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