JURNAL INFOTEL
Informatics - Telecommunication - Electronics
Website Jurnal : http://ejournal.st3telkom.ac.id/index.php/infotel
ISSN : 2085-3688; e-ISSN : 2460-0997

Double E-Shape Microstripe Antenna Design with Proximity Coupling Techniques

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Received 26 January 2021, Revised 28 August 2023, Accepted 23 October 2023

Abstract — The increasing public need for information supports technology to evolve into a more complex telecommunications network. One of the main components of the telecommunications network that is also evolving is the antenna. Microstrip antennas are the most popular type of antenna in the wireless world. Their small, efficient, and practical dimensions can produce polarization and radiation at the same level as large antenna dimensions. Therefore, this study designs and measures the proposed microstrip antenna in Double E with a proximity coupling technique in the S-Band frequency range. S-Band bandwidth is in broadband services' 2-4 GHz frequency range. The research methodology is to design by considering the antenna's dimensions according to its working frequency. Optimization is carried out on the feed slot and the position of the letter E on the patch antenna using Ansoft HFSS software to get maximum gain and bandwidth. From the results of the design and measurement of the antenna after fabrication, the operating frequency is 2.5 GHz, the return loss is -18,573 dB, the bandwidth is 144 MHz, the VSWR is 1.265, and the gain is 5.8 dB with the results of the omnidirectional radiation pattern being fulfilled as expected. Of course, this result fulfills the antenna requirements well in the 2-4 GHz frequency range.

Keywords –Antenna patch, Double E-shaped, S-Band, Proximity Coupling, VSWR, Bandwidth, Gain

I. INTRODUCTION

The development of wireless technology is multiplying along with the increasing number of applications in mobile communications, such as the internet, radar, GPS, and satellite communications. It cannot be separated from the function of the antenna to transmit and receive frequency signals. Every application of wireless communication technology must be supported by the specifications of the antenna equipment used in terms of shape, level of efficiency, and ease of manufacture. [1-2]

Various forms of microstrip antenna have been applied, such as rectangles, circles, triangles, and rings. The various forms have different functions depending on the working frequency and desired antenna parameters. One of the rectangular shape modifications is the E-shaped shape, which can produce circular polarization [1-2].

A literature study looks for theoretical references relevant to the cases or problems found. In research [3], the problem in previous research is to design an E-shaped microstrip antenna with circular polarization supplied by proximity coupled for Wireless Fidelity (Wi-Fi) applications at a frequency of 2.4 GHz. The result obtained is a circular polarization E-shaped antenna form that works at a frequency of 2.4 GHz with good simulation and measurement results.

Research [4] aims to design an E-shaped microstrip antenna for Multiband Applications equipped with inset probes at 5.7 GHz, 6.23 GHz, 6.9 GHz, and 7.5 GHz frequencies. Then research [5] aims to design a rectangular microstrip antenna for S-Band applications which is given an inset probe at a frequency of 2.4 GHz.

Further research [6] is designed an E-shaped microstrip antenna for 3 (three) working frequencies equipped with coaxial probes at 896 MHz, 1439 MHz, and 1719 MHz frequencies.

Research [7] designed a rectangular microstrip antenna supplied with proximity coupled at a frequency of 2.76 GHz.

II. BASED ON THE RESULTS OF SEVERAL SIMILAR RESEARCH REFERENCES, THIS STUDY PROPOSES TO DESIGN AND IMPLEMENT A DUAL E-SHAPED MICROSTRIP ANTENNA SUPPLIED WITH PROXIMITY COUPLED. THE HYPOTHESIS PROPOSED IS THAT GETTING A DOUBLE E-SHAPED ANTENNA AT 2-4 GHZ S-BAND FREQUENCY AIMS TO INCREASE THE GAIN FROM SEVERAL PREVIOUS STUDIES. FIRST, THE ANTENNA IS DESIGNED BY SOFTWARE SIMULATION, THEN CONTINUED WITH FABRICATION. ANTENNA DESIGN USING ANSOFT HFSS-15 SOFTWARE. PARAMETERS TESTED AFTER FABRICATION ARE VSWR, BANDWIDTH, RETURN LOSS, AND ANTENNA GAIN.METHOD

The double E-shaped microstrip antenna design uses the proximity coupling technique that works on the S-Band frequency. With the following specifications:

Table 1. Design antenna specifications

No.	Name	Parameter
1	Frequency	2 - 4 GHz
2	Return Loss	< -10
3	VSWR	⩽ 2
4	Gain	> 2 dB
5	Substrate	FR-4 Eproxy double layer
6	Dielectric Constant (εr)	4,4
7	Dielectric Layer Thickness (h)	1,6 mm
8	Loss Tangent	0,02

The characteristics of the substrate height used will also affect the antenna's performance, and the greater the desired frequency, the smaller the resulting antenna dimensions will be.

A. Patch Width

According to some researchers [8-11], the formula on the patch width is determined using equation (1).

$$W = \frac{C}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} = \frac{3\times 10^8}{2(2{,}4\times 10^9)\sqrt{\frac{4.4+1}{2}}} = 37\ mm$$

B. Patch Length

Determining the length of the patch, according to [11], for the first time to calculate the value of the effective dielectric constant using equation (2).

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{w}}}\right)$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2}\left(\frac{1}{\sqrt{1+12\frac{1.6}{37}}}\right) = 3.9633 \quad (2)$$

According to [12] states about the increase in patches is due to the fringing effect, so that the formula given can be seen in equation (3).

$$\Delta L = 0{,}412h\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w}{h}+0{,}264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{w}{h}+0{,}8\right)}$$

$$= 0.412(1.6)\left(\frac{(3{,}9633+0.3)\left(\frac{38}{1.6}+0{,}264\right)}{(3{,}9633-0.258)\left(\frac{38}{1.6}+0{,}8\right)}\right)$$

$$= 0{,}7419 \quad (3)$$

Then find the effective patch length using equation (4). [8] [11]

$$L_{eff} = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} = \frac{3\times 10^8}{2(2{,}4\times 10^9)\sqrt{3{,}9633}} = 30{,}13\ mm \quad (4)$$

So that the length of the patch can be seen in equation (5). [8] [11]

$$L = L_{eff} - 2\Delta L = 30{,}13 - 2(0{,}7419) = 28{,}64\ mm \quad (5)$$

C. Transmission Line

Antenna designed using microstrip line technique. Calculation of feed width can be seen in equation (6). [14-15]

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} = \frac{60\pi^2}{50\sqrt{4{,}4}} = 5{,}64 \quad (6)$$

Then the value of wf can be found using equation (7). [14-15]

$$W_f = \frac{2h}{\pi}\left\{B - 1 - ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left[ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\right]\right\}$$

$$= \frac{2 \times 1,6}{\pi}\left\{5,64 - 1 - ln(2(5,64) - 1) + \frac{4,4-1}{2(4,4)}\left[ln(5,64-1) + 0,39 - \frac{0,61}{4,4}\right]\right\}$$

$$W_f = 3,055\ mm$$

Checking the characteristics of the transmission line aims to compare the width of the supply line with the thickness of the substrate used.

$\frac{W_f}{h} = \frac{3,055}{1,6} = 1,9 > 1$, because $\frac{W_f}{h} > 1$, then the relative effective dielectric constant value can use Equation (8). [14-15]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\frac{h}{W_f}}}\right)$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2}\left(\frac{1}{\sqrt{1+12\frac{1.6}{3,055}}}\right) = 3.33 \quad (8)$$

Furthermore, the main length of the microstrip line with the impedance matching technique uses a $\frac{\lambda}{4}$ transformer, where λ_g is the dielectric wavelength which can be seen in Equation (9). [14-15]

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} = \frac{c}{f\sqrt{\varepsilon_{reff}}} = \frac{3 \times 10^8}{2,5 \times 10^9\sqrt{3,33}} = 0,066$$

Then the main length of the microstrip line uses Equation (10). [14-15] The results of the calculations are shown in table 2.

$$l_f = \frac{\lambda_g}{4} = \frac{0.066}{4} = 0,16\ mm \quad (10)$$

Table 2. The results of the specification antenna

Parameter	Size	Information
h_1	1,6	Substrate thickness 1
h_2	1,6	2
W	37	Patch width
L	28,64	Patch Length
W_f	3,055	Supply line width
L_f	16	Supply line length
W_1	5	Slot width 1
L_1	5	Slot length 1
W_2	5	Slot width 2
L_2	5	Slot length 2

III. RESULT

Figure 1 shows the results of the initial double E-shaped antenna design with the proximity coupling technique, which will be optimized until the desired frequency is obtained and according to the antenna parameters planned according to table 2.

In manufacturing the double E-shaped microstrip antenna with the proximity coupling technique, the FR-4 epoxy PCB is selected with a size of 1.6 mm. This material is chosen because it is easy to find on the market, connect, and light. The double E-shaped microstrip antenna design results with the proximity coupling technique can be seen in Fig. 2.

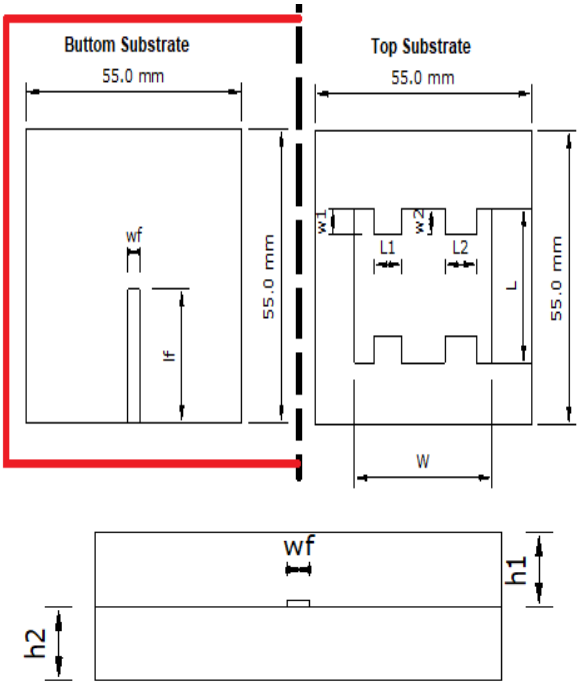

Fig. 1. Initial antenna design

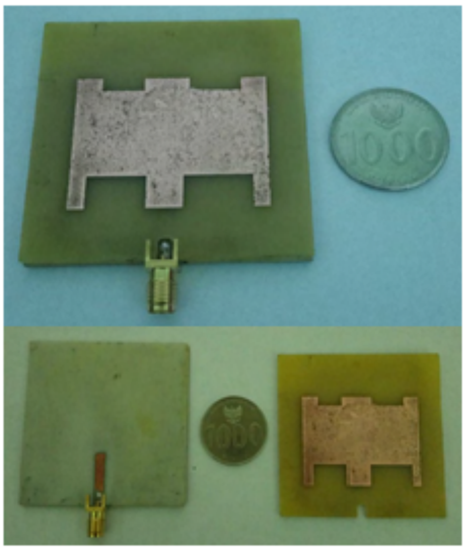

Fig. 2. Fabrication final antenna design

IV. DISCUSSION

A. Simulation

a) Rectangular Microstrip Antenna Design: Line Microstrip Technique

Table 3. shows the dimensions of the rectangular patch microstrip antenna. The input dimension values are simulated. The results can be seen in Fig. 3.

Table 3. Rectangular patch microstrip antenna input parameter

Parameter	Size (mm)	Information
W_{subs}	48	Substrate width
L_{subs}	40	Substrate length
h	1,6	Substrat thickness
W	26,5	Patch width
L	42	Patch Length
W_f	3	Supply line width
L_f	6,5	Supply line length

b) Designing Rectangular Microstrip Antenna: Proximity Coupling Technique

Table 4 shows the dimensions of the rectangular patch microstrip antenna using the proximity coupling technique. The input dimension values are simulated. Therefore, the results can be seen in Fig. 4.

Table 4. Input parameters of rectangular patch microstrip antenna with proximity coupling technique

Parameter	Size (mm)	Information
W_{subs}	55	Substrate width
L_{subs}	55	Substrate length
h	1,6	Substrat thickness
W	25,5	Patch width
L	32	Patch Length
W_f	3	Supply line width
L_f	17	Supply line length

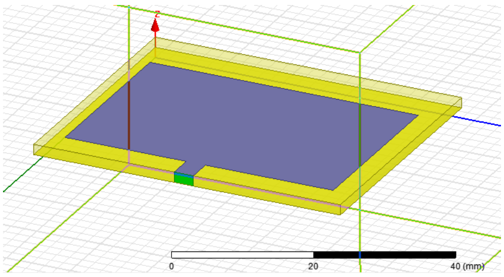

Fig. 3. Rectangular patch microstrip antenna design using microstrip line technique

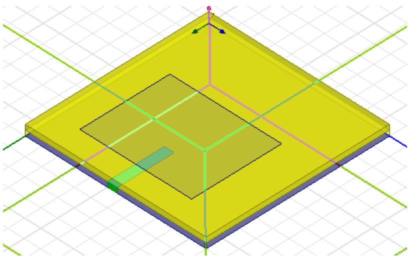

Fig. 4. Rectangular patch microstrip antenna design using proximity coupling technique

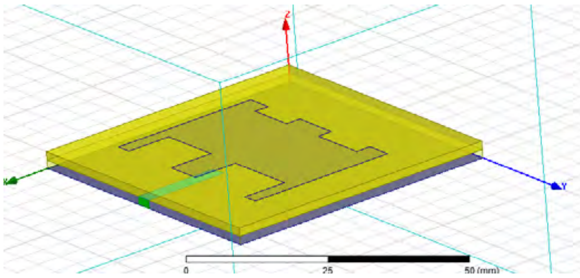

Fig. 5. Double E-shaped microstrip antenna design with proximity coupling technique

c) Designing Double E-Shaped Microstrip Antenna: Proximity Coupling Technique

Table 5 shows the dimensions of the double E-shaped microstrip antenna using the proximity coupling technique. The input dimension values are simulated. The results can be seen in Fig. 5. Fig. 5. shows the optimal optimization results after optimizing the E-shaped gap.

Table 5. E-shaped double microstrip antenna input parameters with proximity coupling technique

Parameter	Size (mm)	Information
$W_{subs}1$	55	Substrate width 1
$L_{subs}1$	55	Substrate length 1
h1	1,6	Substrat thickness 1
$W_{subs}2$	55	Substrate width 2
$L_{subs}2$	55	Substrate length 2
h2	1,6	Substrat thickness 2
W	39	Patch width
L	30	Patch Length
W_f	3	Supply line width
L_f	17	Supply line length
$W_{rec}1$	12	Gap width 1
$L_{rec}1$	9	Gap length 1
$W_{rec}2$	14	Gap width 2
$L_{rec}2$	9	Gap length 2
$W_{rec}3$	9	Gap width 3
$L_{rec}3$	3	Gap length 3
$W_{rec}4$	11	Gap width 4
$L_{rec}4$	3	Gap length 4

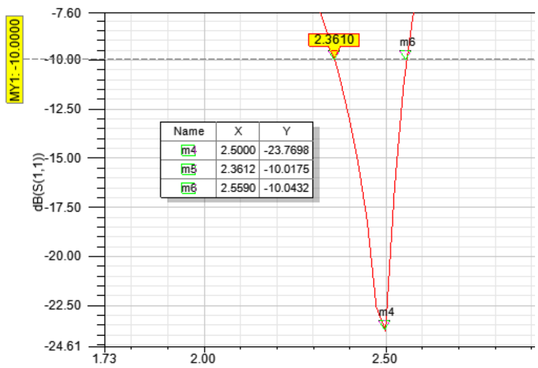

Fig. 6. Simulation results of return loss double E-shaped microstrip antenna

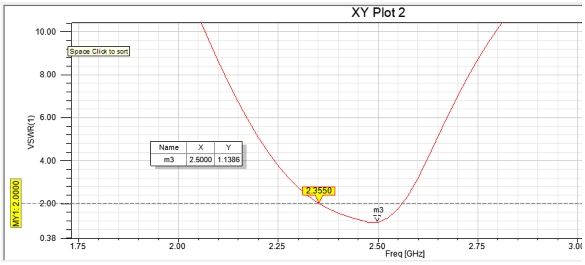

Fig. 7. VSWR simulation results for double E-shaped microstrip antenna

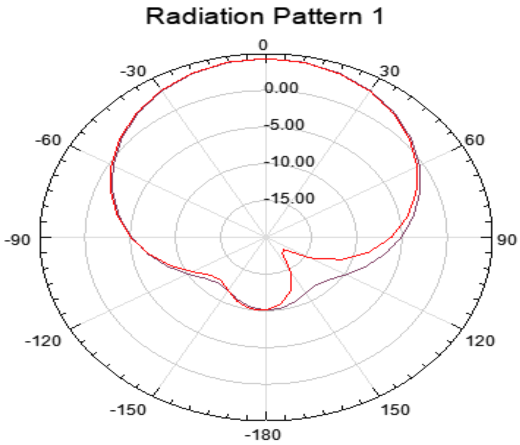

Fig. 8. The simulation results of the double E-shaped microstrip antenna radiation pattern

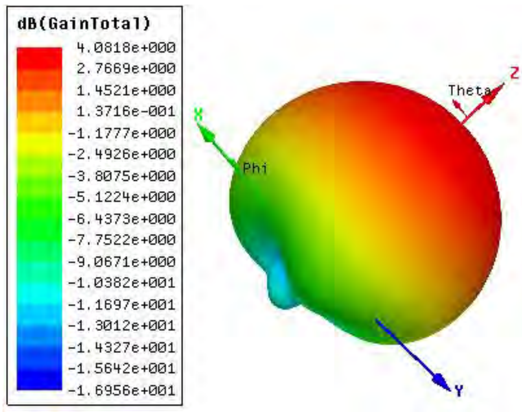

Fig. 9. The simulation results of the double E-shaped microstrip antenna gain

Fig. 6. shows the simulation results of the operating frequency after E-shaped optimization of 2.5 GHz. The return loss result is -23.7698 dB. By design, the return loss value of this antenna has met the criteria. Then the simulation results also show that the bandwidth value of the double E-shaped microstrip antenna using the proximity coupling technique is 197.8 MHz.

Fig. 7. Shows the VSWR simulation results for the 2.5 GHz working frequency of 1.1386. These results show that the value is feasible because the required VSWR value is <2.

Fig. 8. shows the result of the radiation pattern for a double E-shaped microstrip antenna using the proximity coupling technique. The polarization shape of this antenna is round and circular, so it can be analyzed that the double E-shaped microstrip antenna using the proximity coupling technique, has the form of an omnidirectional radiation pattern.

B. *Fig. 9. shows the simulation results of a gain of 4.0818 dB. These results can be analyzed in that a gap in the patch affects the bandwidth and working frequency of the double E-shaped microstrip antenna using the proximity coupling technique. Giving a gap in the width of the antenna (W) will disturb the working frequency and bandwidth but will not significantly affect the gain.Measurement*

Measurements at BRIN Bandung. The measurement scenarios to test the antenna fabrication results are:

1. First, carried out in the BRIN laboratory. Measurements measure return loss, VSWR, and bandwidth using an Anritsu MS46322A 40GHz Network Analyzer and 50-ohm coaxial cable.

2. Second, carried out in the anechoic chamber. Measurements made in the anechoic chamber are radiation pattern and gain.

Fig. 10. shows the results of the antenna return loss measurement with the Network Analyzer. The upper left has a description showing the return loss value of the antenna obtained. The results of the return loss measurement are shown in Table 6.

Table 6 shows the results of the return loss measurement on the double E-shaped microstrip antenna with the proximity coupling technique of -18.753 dB at a frequency of 2.53 GHz. These results show that the return loss value obtained follows the desired specifications, namely <-10 dB, which means that the conditions match.

Table 6. Results of measurement of return loss

Frequency (GHz)	Return loss measurement results (dB)
2.475	-10.07
2.53	-18.753
2.475	-10.05

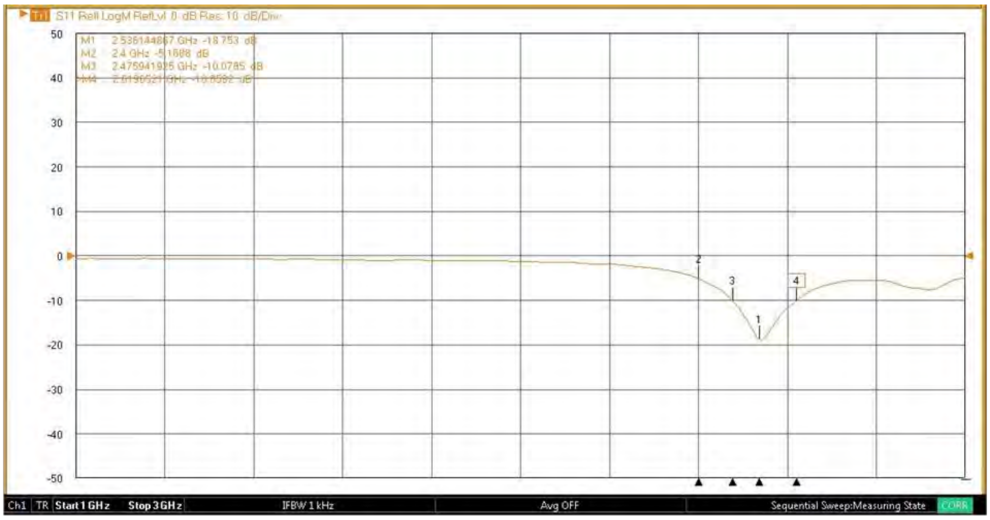

Fig. 10. The results of the return loss measurement of the double E-shaped microstrip antenna

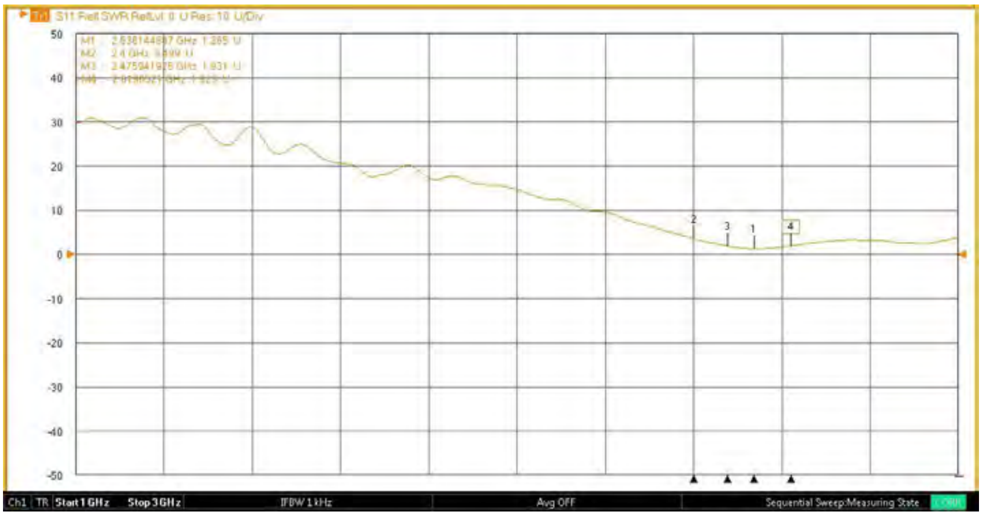

Fig. 11. VSWR measurement results for double E-shaped microstrip antenna

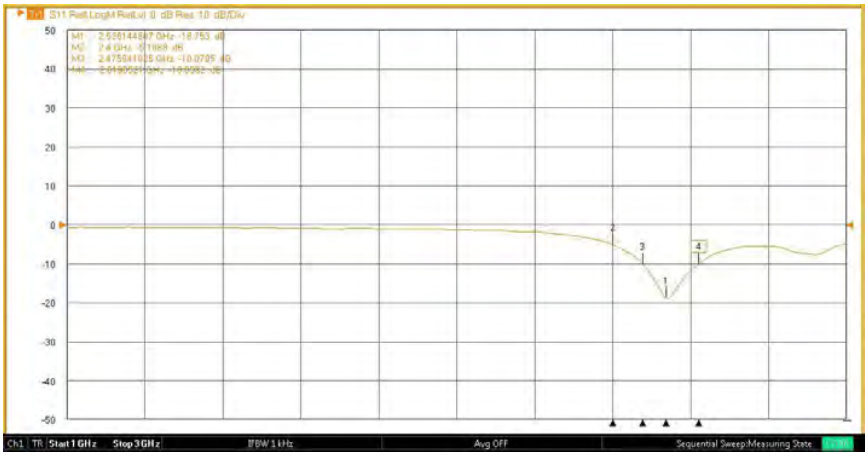

Fig. 12. The measurement results of the double E-shaped microstrip antenna bandwidth

The next step is to measure the VSWR value. Fig. 11. shows the VSWR measurement results. Table 7 shows the recorded VSWR measurement results. So it can be analyzed that the VSWR on the double E-shaped microstrip antenna with the proximity coupling technique is 1.265 at a frequency of 2.53 GHz. These results can be declared feasible and following the specifications, namely ⩽ 2 dB, which means that no reflection waves return and the channel.

Fig. 12. shows that at -10 dB, the frequency value is in the frequency range of 2.475 GHz to 2.619 GHz, so the bandwidth value obtained is 144 MHz.

Table 7. VSWR measurement results

Frequency (GHz)	VSWR measurement results
2.475	1.931
2.53	1.265
2.475	1.923

Subsequent measurements were carried out in the anechoic chamber using measuring instruments, including a signal generator, spectrum analyzer, horn antenna, microstrip antenna, coaxial cable, and tripod. The radiation pattern measurement vertically connects the horn antenna with the signal generator that functions as a transmitter. Then the signal generator is adjusted to a frequency of 2.5 GHz. The receiver's position has been installed with a double E-shaped microstrip antenna connected to the spectrum analyzer. Furthermore, the shape of the radiation pattern was obtained by measuring the signal level on the spectrum analyzer by rotating it every 10°. Table 8 is a collection of the results of the signal level measurement for each angle rotation. From the measured table data, the radiation pattern results are shown in Fig. 13. Fig. 13. It can see that the double E-shaped microstrip antenna with the proximity coupling technique has an omnidirectional radiation pattern, meaning that it is an antenna that radiates in all directions.

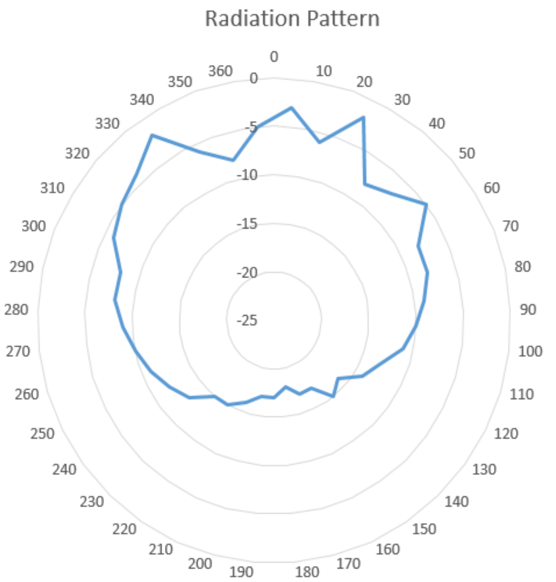

Fig. 13. The results of the measurement of the radiation pattern of the double E-shaped microstrip antenna

Table 8. Antenna signal level concerning angle rotation

Angle	Level polarization	Angle	Level polarization
0	-33	190	-47
10	-33	200	-44
20	-34	210	-48
30	-35	220	-42
40	-35	230	-43
50	-37	240	-45
60	-38	250	-42
70	-39	260	-42
80	-40	270	-41
90	-41	280	-40
100	-42	290	-39
110	-42	300	-37
120	-44	310	-36
130	-45	320	-34
140	-46	330	-35
150	-48	340	-33
160	-44	350	-33
170	-42	360	-32
180	-45		

The antenna gain can determine by positioning the double E-shaped microstrip antenna as a transmitter antenna connected to the signal generator. The reference antenna position connects to the spectrum analyzer within 1 meter. The microstrip antenna gained measurement results obtained are -32.4 dB with the horn antenna gain of 9.2 dBi. From the measurement results, the gain can calculate using the formula :

$$Ga\ (dBi) = -32.4 - (-29) + 9.2$$

$$Ga\ (dBi) = 5.8\ dB$$

C. *Comparison of Simulation and Measurement Results*

The next step is to compare the measurement results of the fabricated antenna with the simulation results. These results aim to determine whether the measurement results are better than the simulation results or vice versa, shown in Table 9.

Table 9 shows differences between the measurement results and the simulation, and the different factors have been analyzed, including:

1. The frequency shift can be analyzed in that the FR4 Epoxy substrate material does not match its dielectric constant as used during the simulation.

2. Factors affecting the frequency shift can also be caused by the position of the stacked two substrates that do not fit the size at the fabrication time. However, this shift can still tolerate because it is within the same frequency range.

3. The discrepancy between the size obtained from the simulation and the fabrication result.

4. Laboratory room conditions are not sterile enough, so there is still wave interference from other waves.

5. Inadequacy of measuring instrument readings because the value of the measuring instrument varies.

V. CONCLUSION

Several conclusions obtain after the design, simulation, realization, and measurement of the Dual E-shaped microstrip antenna using the proximity coupling technique. The operating frequency of the fabricated antenna is 2.53 GHz. The return loss value is -18,573 and still meets the requirements of <-10 dB. The wide bandwidth of 144 MHz. Not as comprehensive as planned, but broadband compliant. The VSWR value is 1.265. Of course, this value meets the requirements for an ideal antenna VSWR range. The gain of the fabricated antenna is 5.8 dB. This result is better than planned. The radiation pattern formed is omnidirectional.

The effect of the gap formed on the double E-shaped gives an increase in the value of return loss and bandwidth. Therefore, the supply proximity coupling technique is proven to increase the gain value of the fabricated antenna.

Based on the conclusions of this research, the authors provide suggestions for readers, namely:

1. To get better antenna results, further research suggests combining the array technique and the E-shaped shape or using a dielectric material with a better permittivity value.

2. Further research can also carries out using other feeding techniques to obtain differences in antenna performance.

ACKNOWLEDGMENT

The first special thanks to Mercu Buana University, which has supported domestic collaborative research, and the second to the National Research and Innovation Agency, Mr. Agus Dendi Rochendi, for his assistance and cooperation during this research. Hopefully, there will always be papers with Lembaga Ilmu Pengetahuan Indonesia in future research.

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